AGN X-ray Variability and relationship to optical and radio galaxy properties

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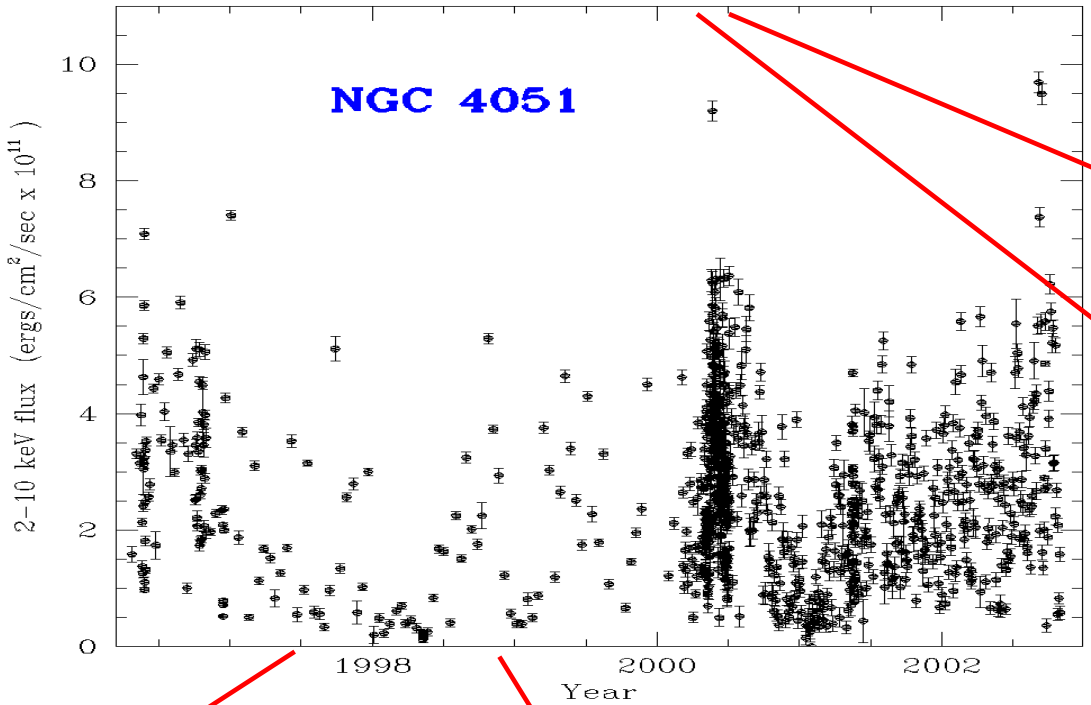
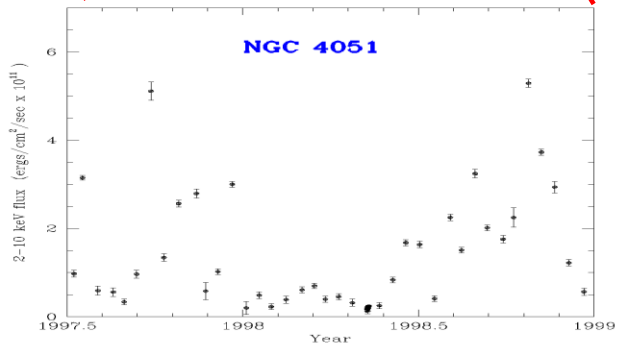
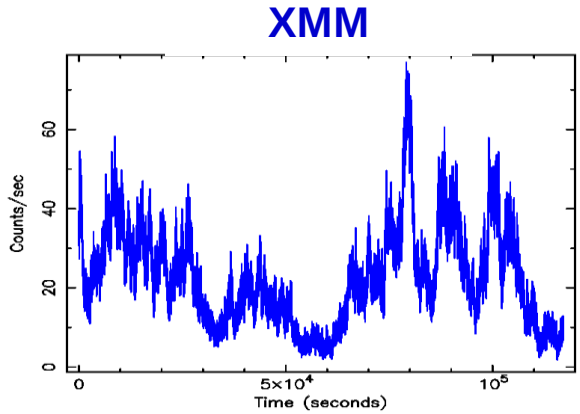
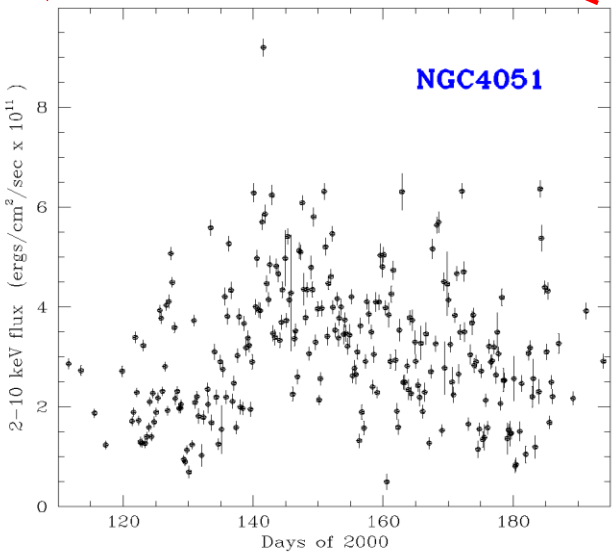
TYPICAL AGN X-RAY DATA….
Eg NGC4051 RXTE Long Timescale Observations

(McHardy et al 2004)





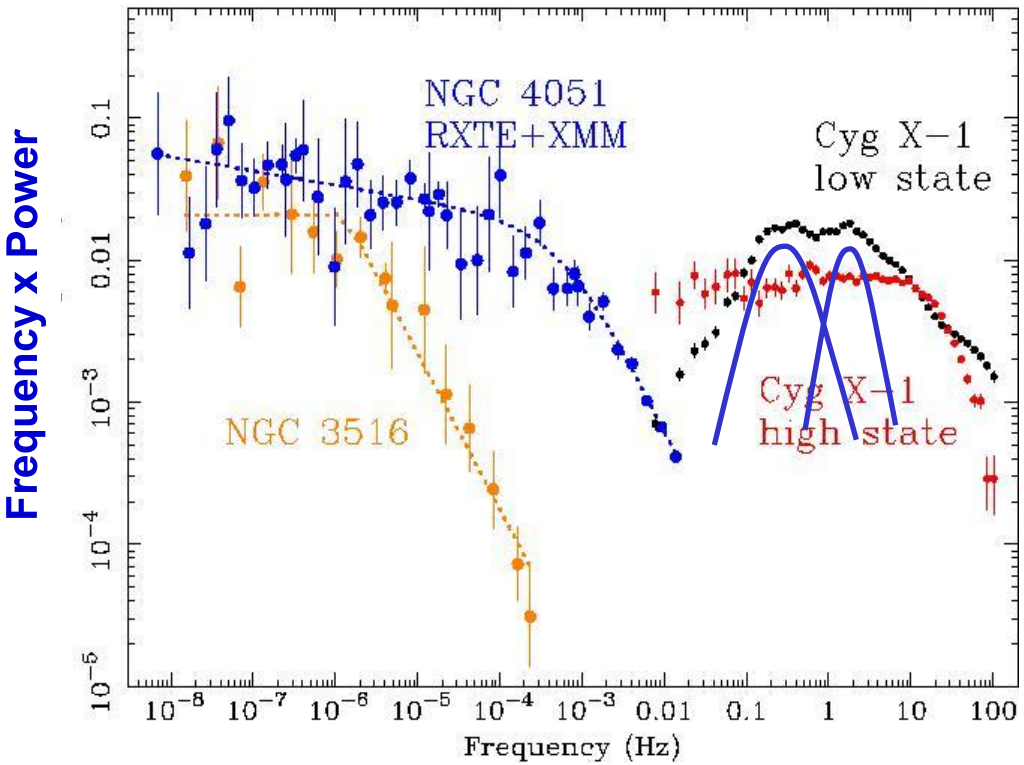




TIMING STATES

Frequency x Power

`Unfolded' Power Spectral Density (PSD)



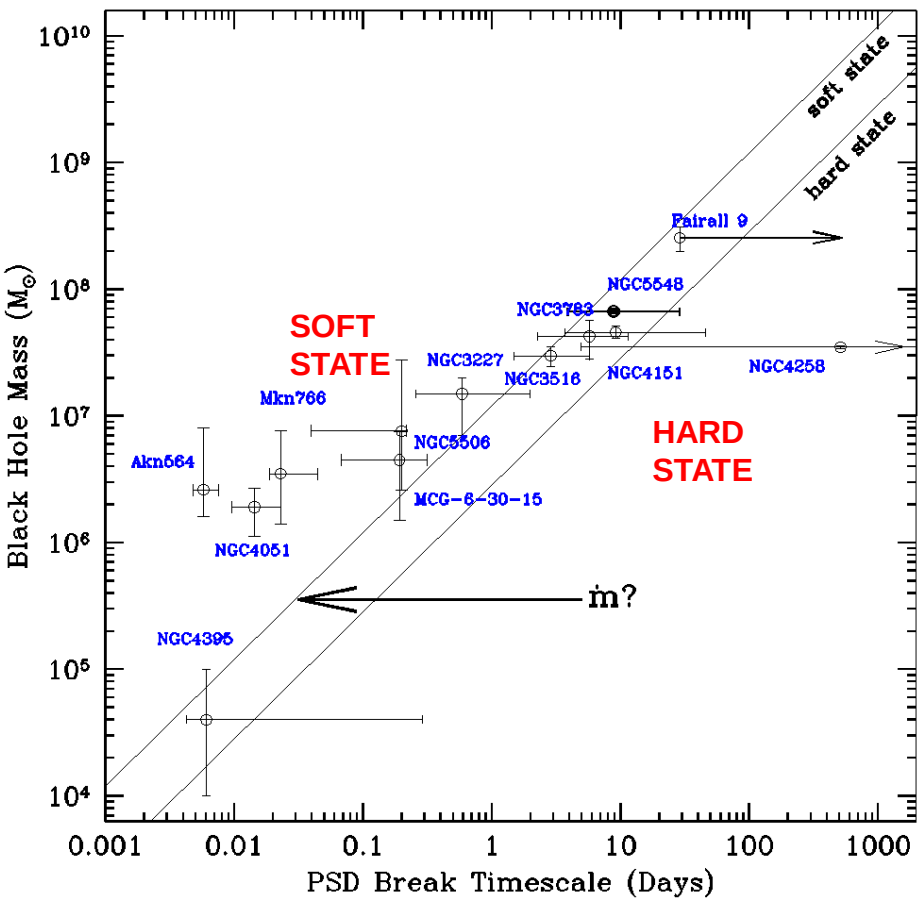
(McHardy et al., 2004)

Cyg X-1 Low-hard state PSD:

Can be described either as powerlaw with two bends, or as sum of `Lorentzian' shaped bumps

- **NGC4051 partly like Cyg X-1 low-hard state, but no second break at low-frequency**
- **More like high-soft state of Cyg X-1**
- **High break timescale scales approximately linearly with mass**

Black Hole Mass vs. PSD Break Timescale (T_B)



AGN with narrower lines and higher accretion rates have shorter T_B.

T_B associated with inner edge of disc?

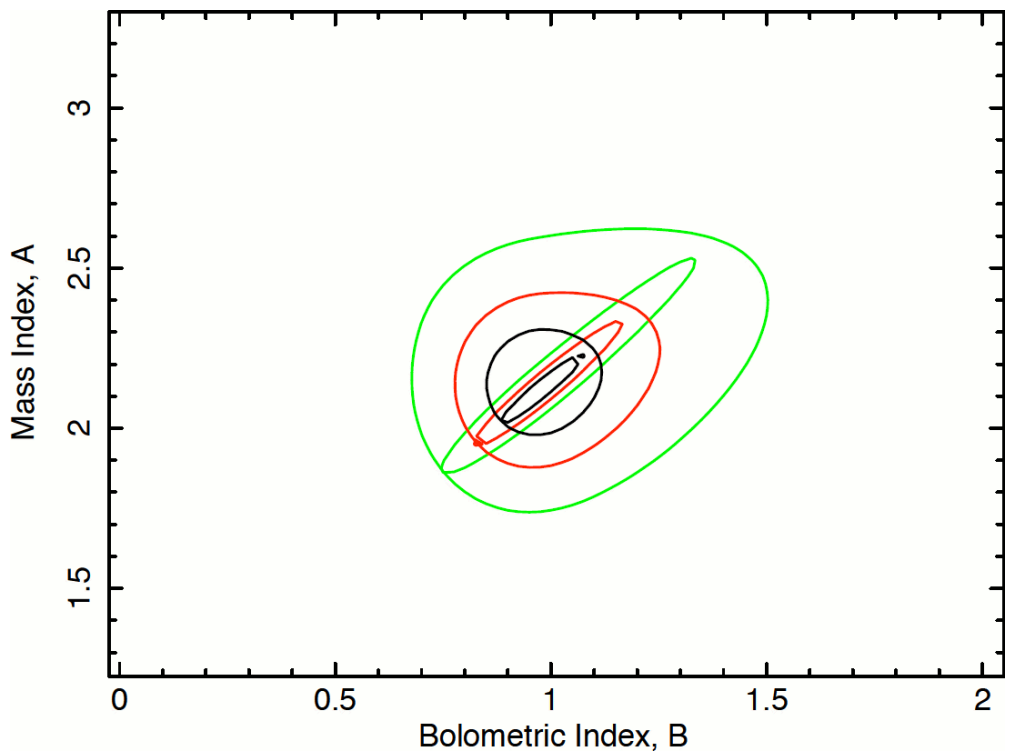
Higher accretion rate pushes in disc?

(McHardy et al 2004, MN, 348, 783)

(Note rough lines of linear scaling, not fits, from Cyg X-1 in its `low-hard' and `high-soft' states)

Proper 3D fit to T_b, M, $\dot{m}_E$

(McHardy et al, 2006; Summons et al in prep)



Large contours, just to AGN (20)
(mostly soft state)

As $\dot{m}_E = L_{Bol} / M$

we fit to $T_B \sim M^{A} L_{Bol}^{-B}$

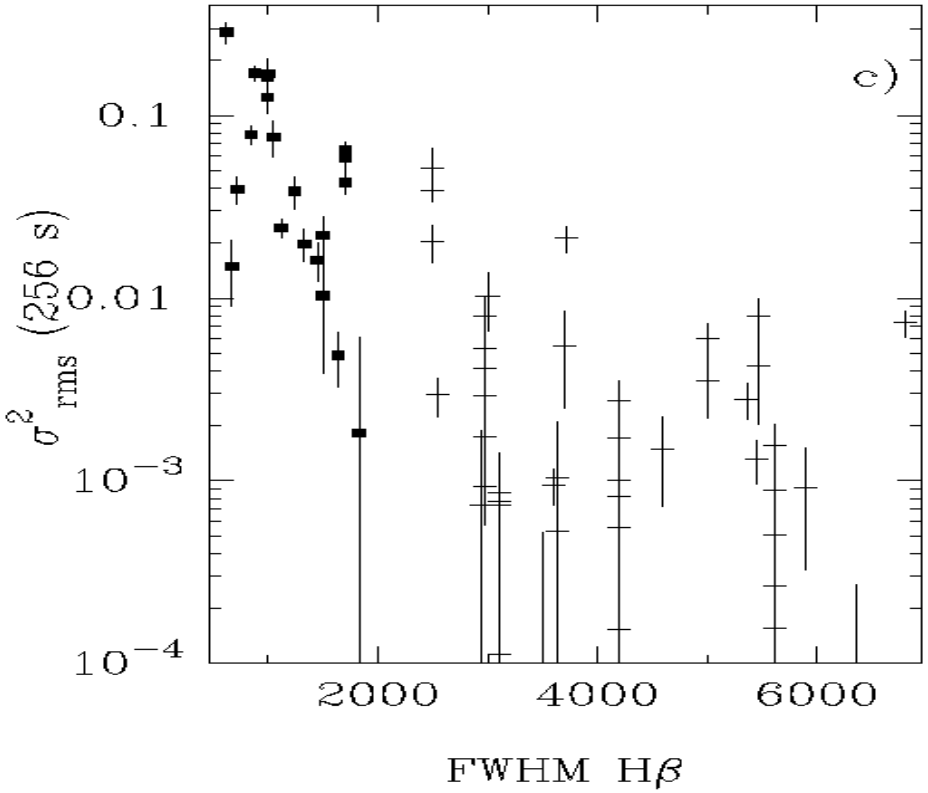
Smaller contours include soft state binaries, GRS1915+105 and Cyg X-1

Good fit. Additional parameter (eg spin) not needed.

i.e $T_B \sim M^{1.12} \dot{m}_E^{-0.98}$

(eg, for $M=10^8 M_O$, mdot =0.1, T_B = 6d)

AGN X-Ray Variability and Optical Linewidth



Optical linewidth correlates with X-ray variance

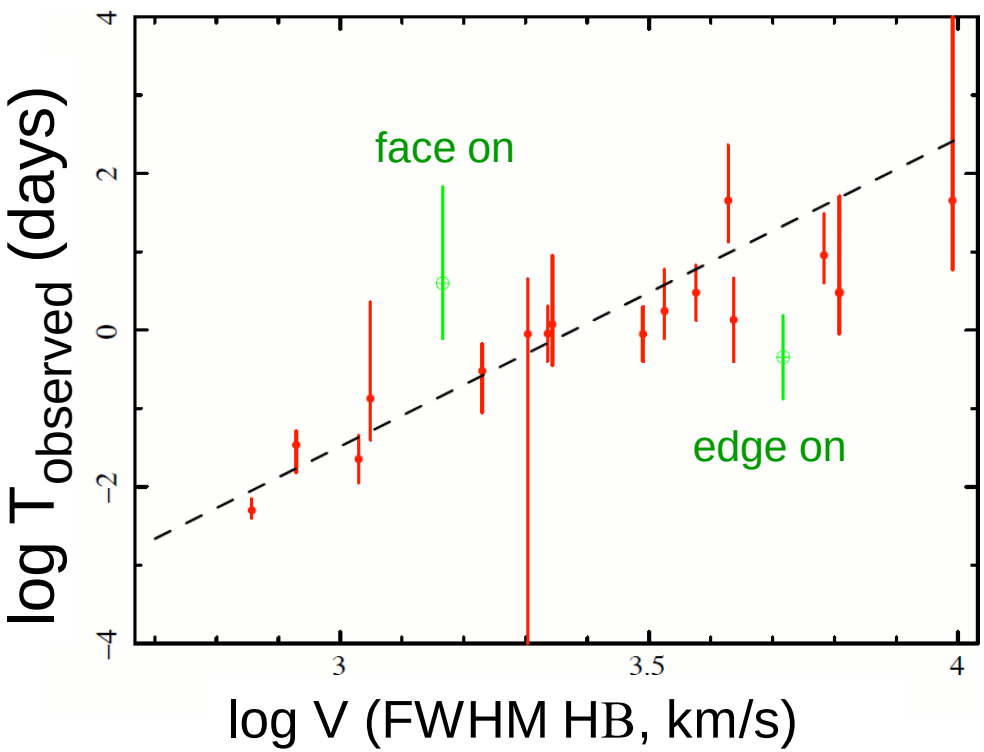
-but, physically, how?

(Turner et al 1999)

NLS1s are the filled squares

T_B and Linewidth, V

(McHardy et al, 2006; Summons et al in prep)



$T_B \sim V^{3.8 +/- 0.6}$

Simple scaling relationships:

1. $L \sim M\dot{m}_{Edd}$
2. $R_{BLR} \sim L^{0.5}$ **(LOC - Kaspi etal 1996)** Bentz etal 2006
3. $v^2 \sim GM/R_{BLR}$

Then expect

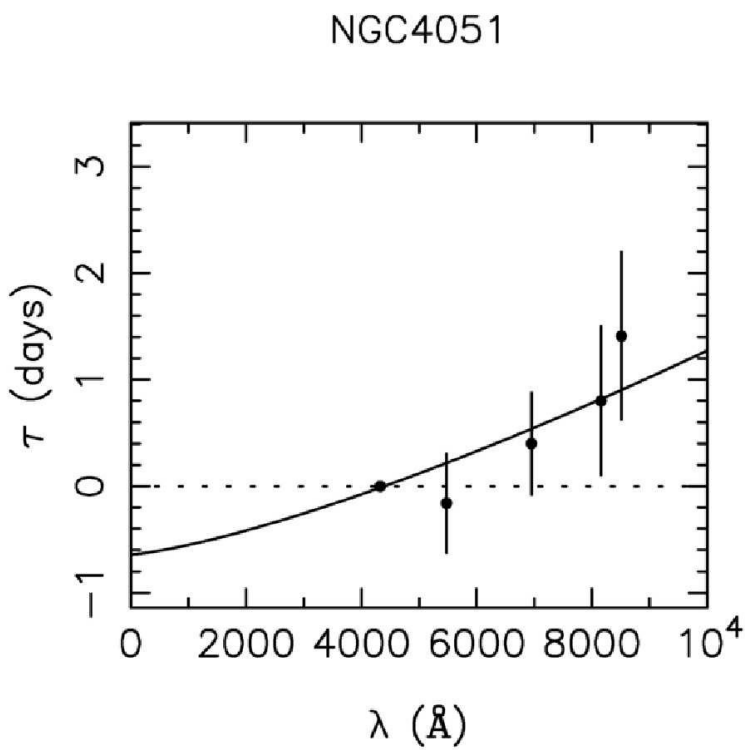
$$\text{Linewidth, } V^4 \sim \frac{M}{\dot{m}_{Edd}}$$

Powerful confirmation that $T_B \sim M / \dot{m}_E$

Strong link between Black Hole timing and larger scale AGN properties

IMPLICATION: NLS1 same as other AGN, just have smaller ratios of $M / \dot{m}_E$
Small masses are selection effect as $\dot{m}_E$ can't easily exceed unity

Optical Variability in AGN:
Reprocessed X-rays or intrinsic disc variability?

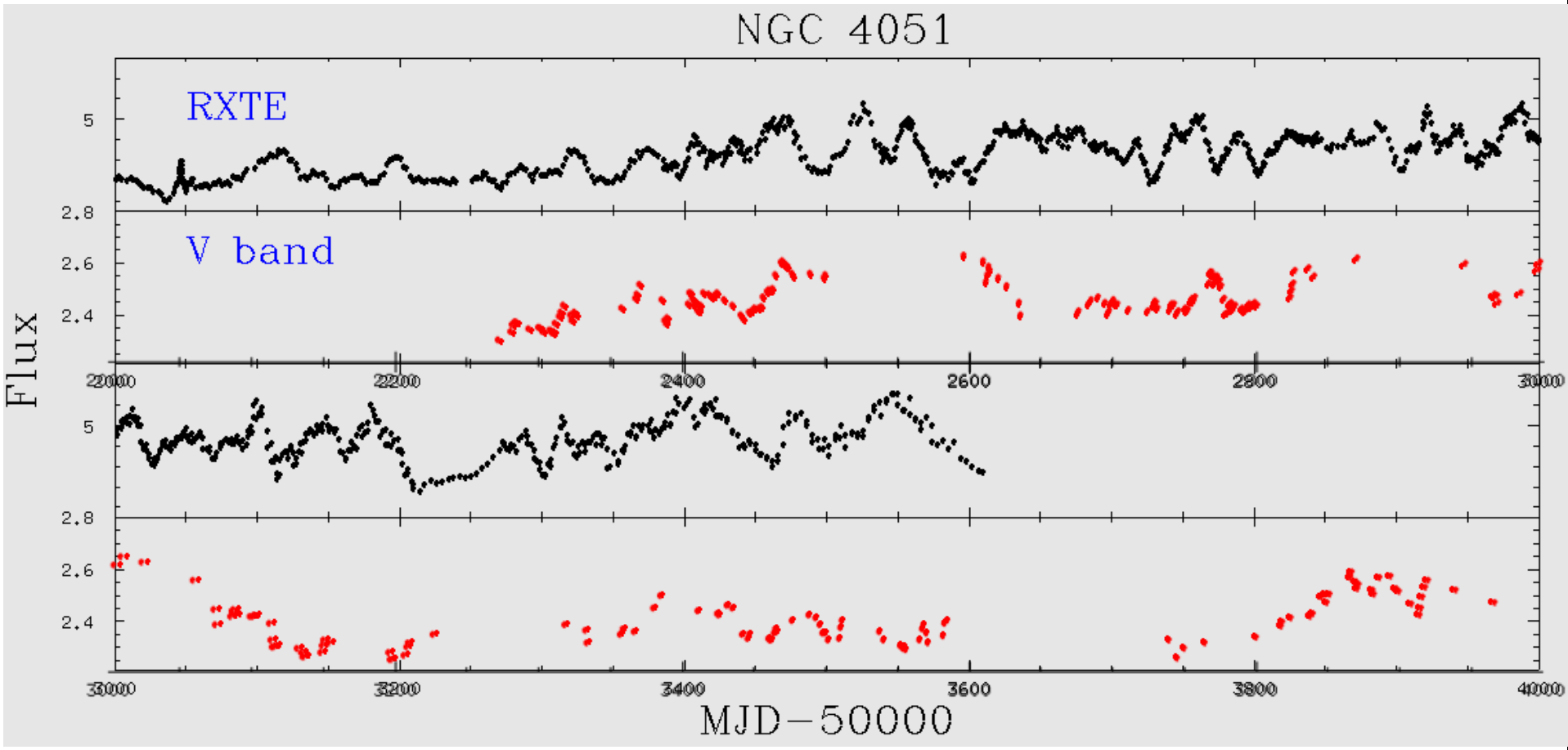


$$T \propto M_{BH}^{-1/4} \dot{M}^{1/4} R^{-3/4}$$

Solid line gives fit of lags between optical bands to reprocessing model

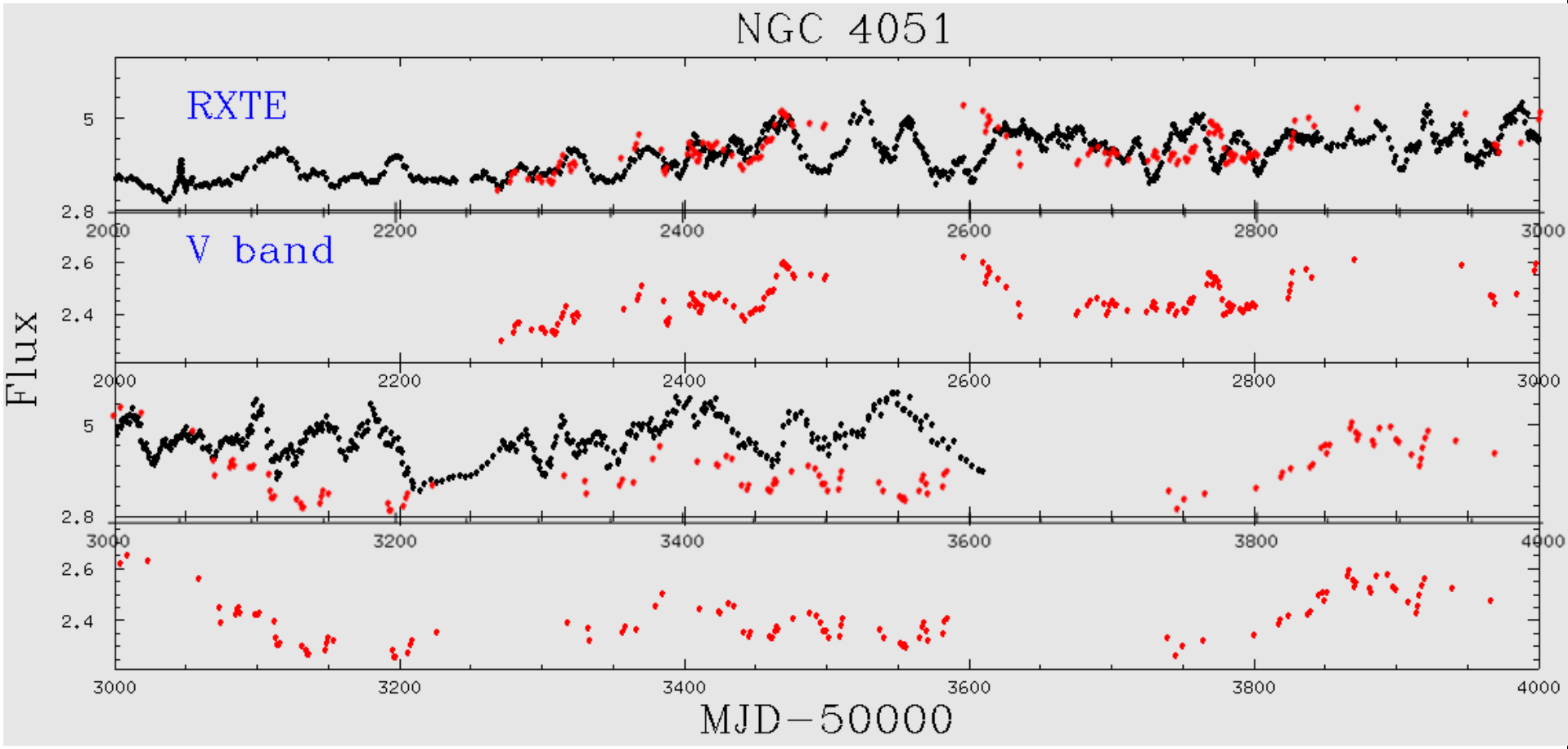
(Cackett et al, 2006; Sergeev et al 2005,6)

NGC 4051

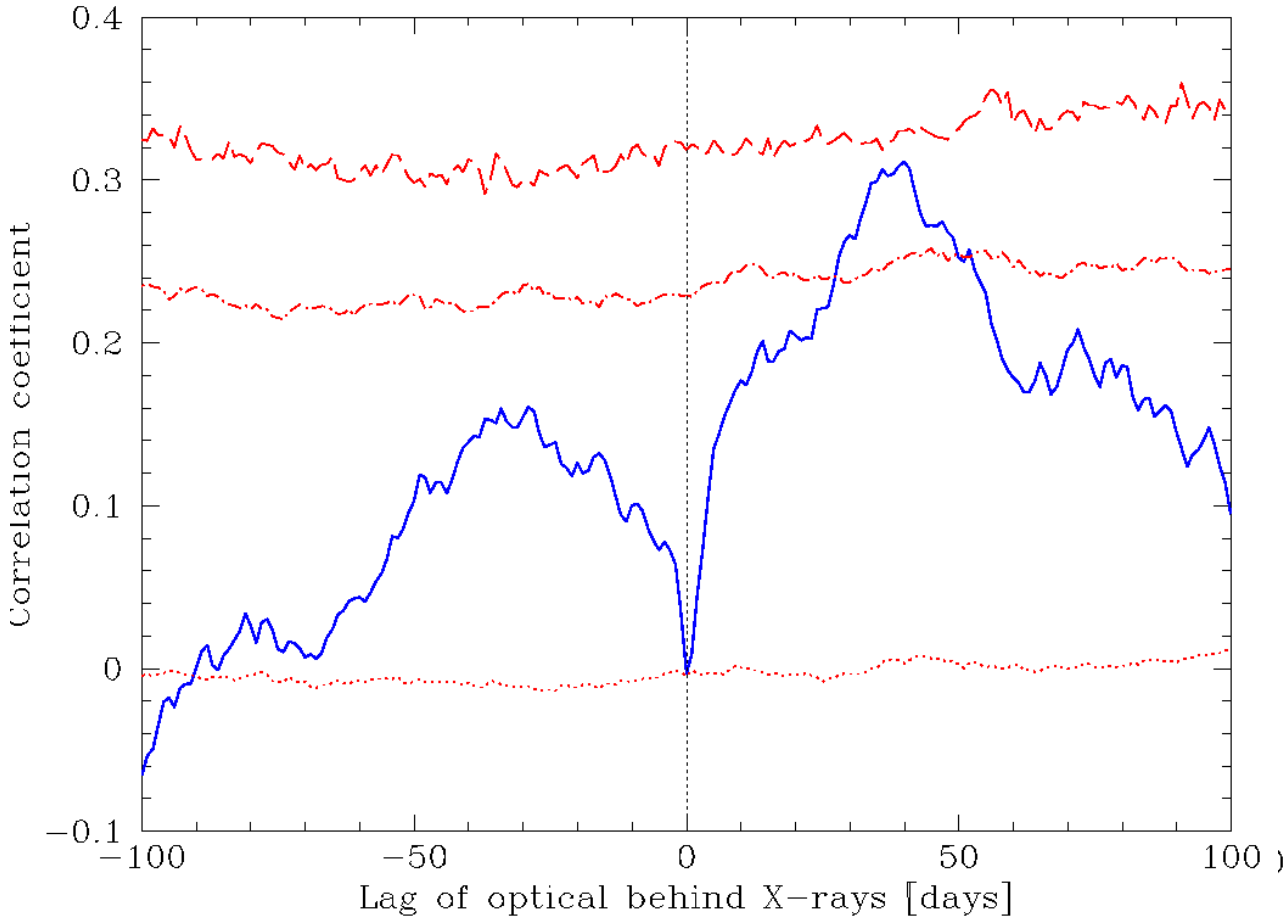

NGC 4051
RXTE
V band
Flux
5
2.8
2.6
2.4
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
MJD−50000

Southampton

NGC 4051



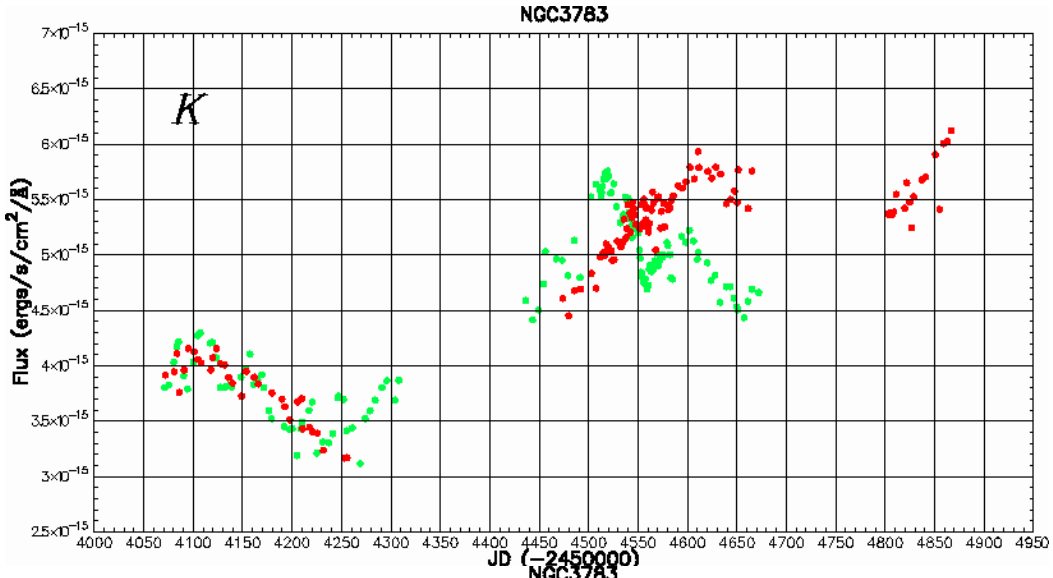
NGC4051

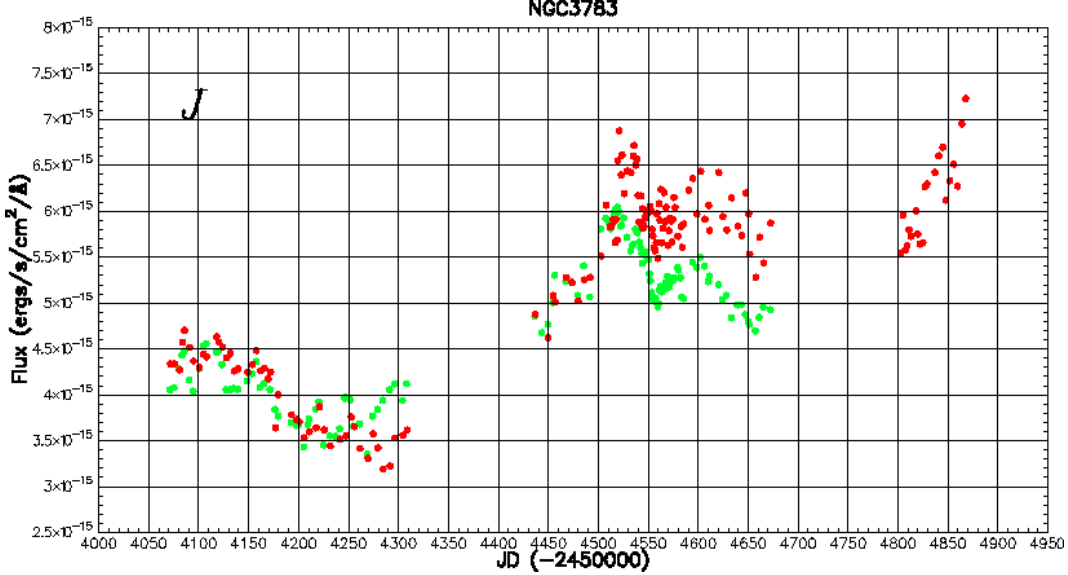


Optical lags by 1.5+/- 0.5 d (above 99% confidence) Breedt et al 2010

Remove reprocessed model lightcurve. Still leaves second lag peak at ~40d - Torus??

Infrared – Optical Lags: NGC3783





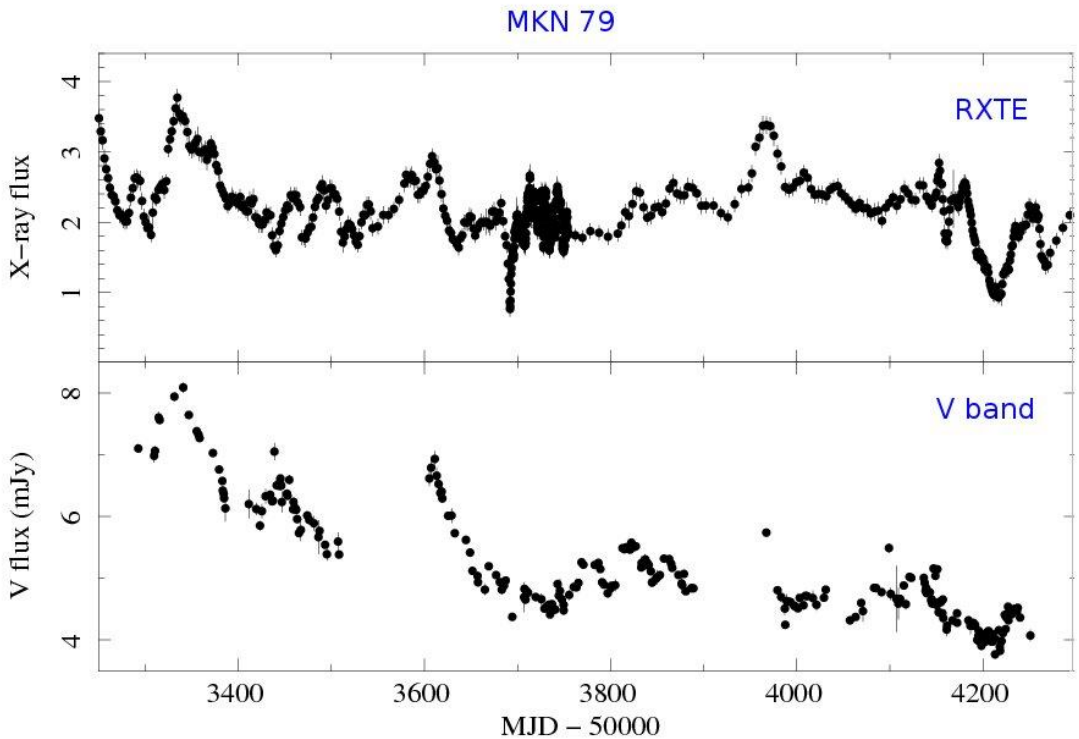
Green is V-band, for comparison.

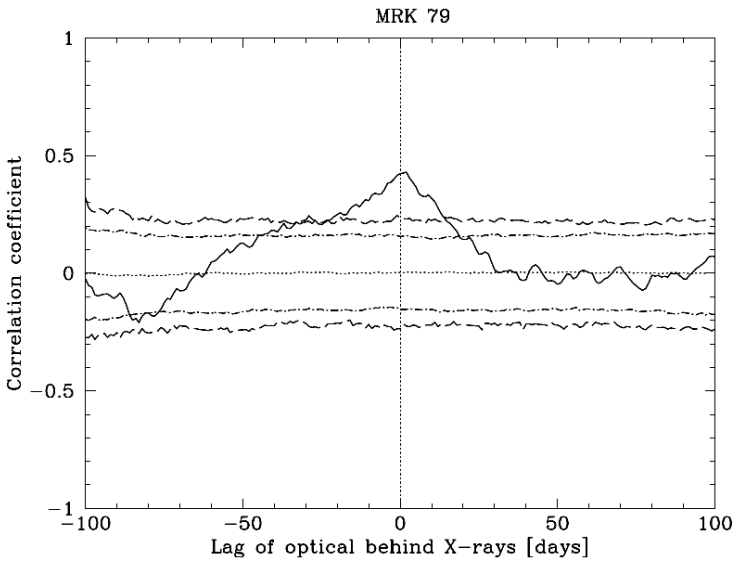
J-band similar lightcurve to V-band, but K-band lags.

V and J mostly reprocesing from disc, K includes some torus contribution

Lira et al, submitted also
Saganuma et al 2006

MKN 79



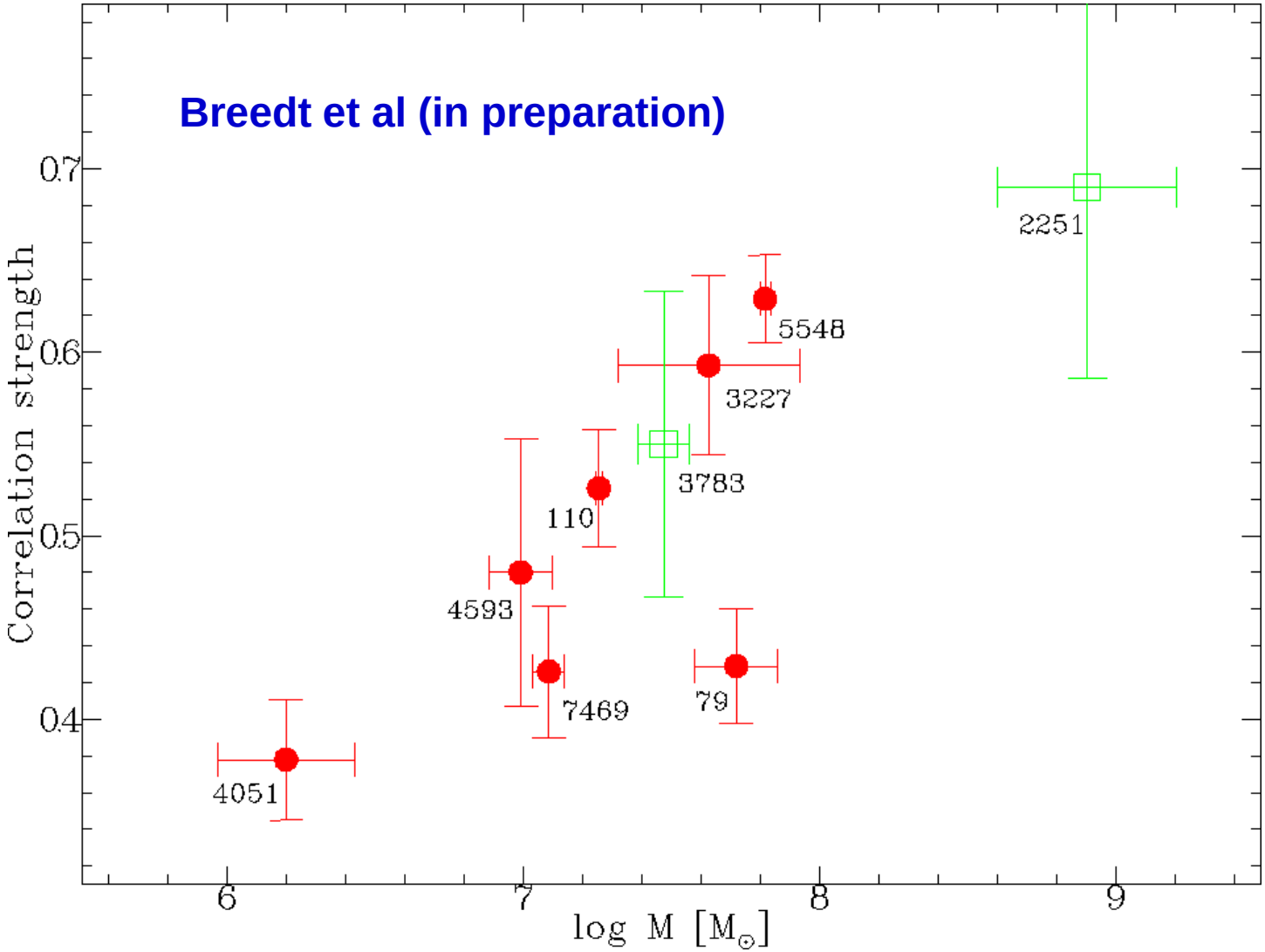


Short term correlation but different long term trends

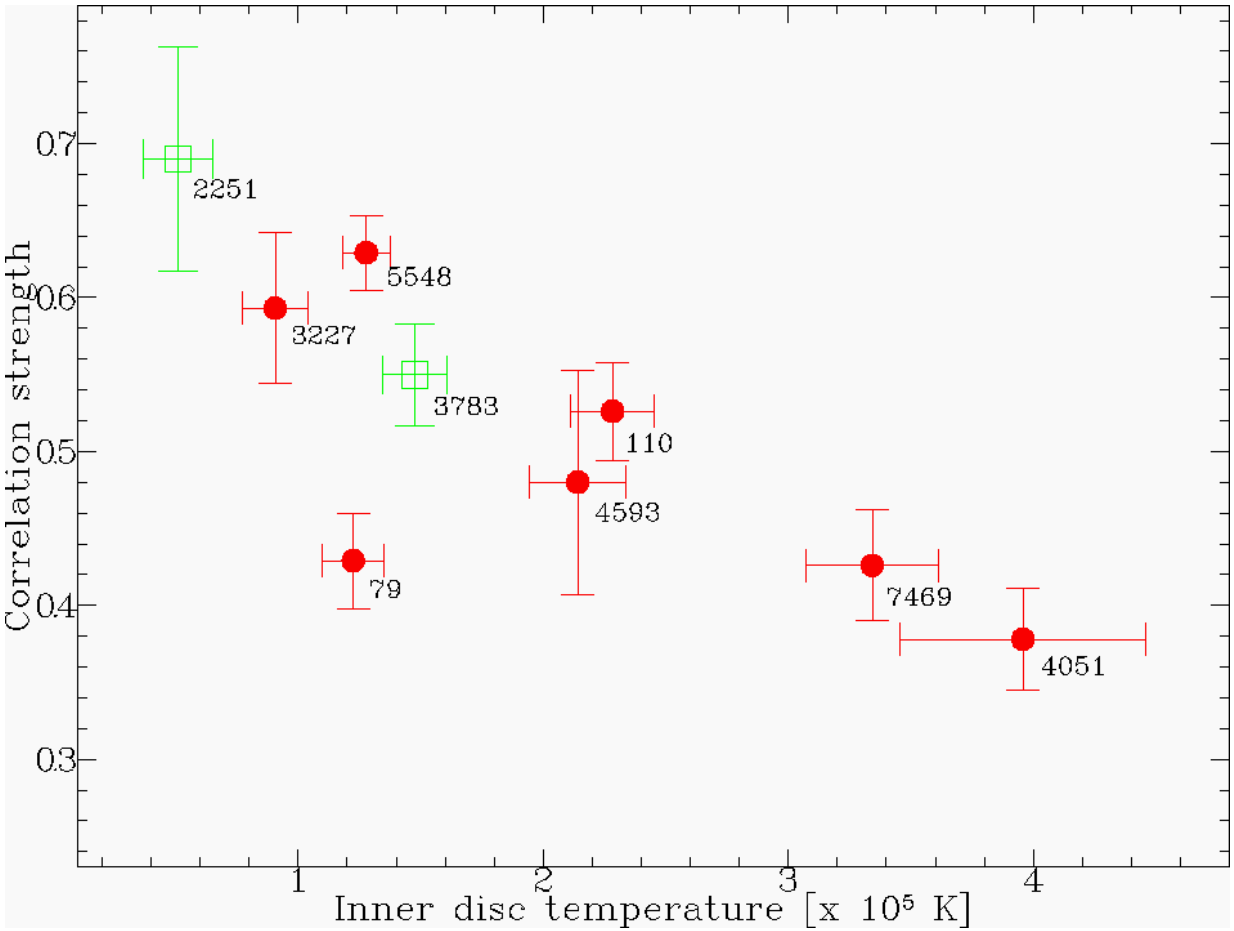
Optical probably a combination of X-ray reprocessing and intrinsic disc variations (inwardly propagating fluctuations)

(Breedt et al, 2009, MNRAS)

X-ray/optical peak correlation coefficient vs. black hole mass



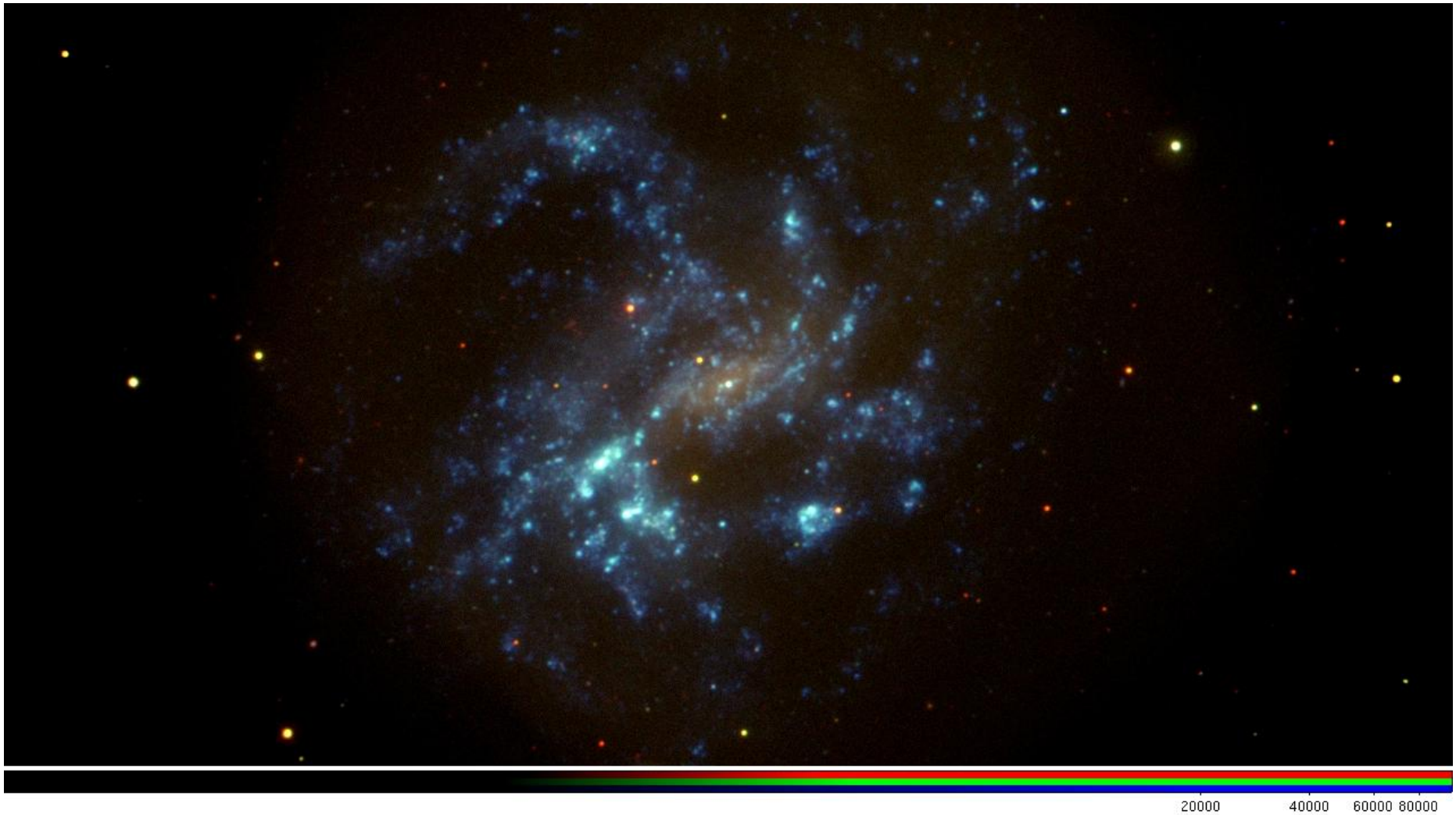
X-ray/optical peak correlation coefficient vs. disc temperature



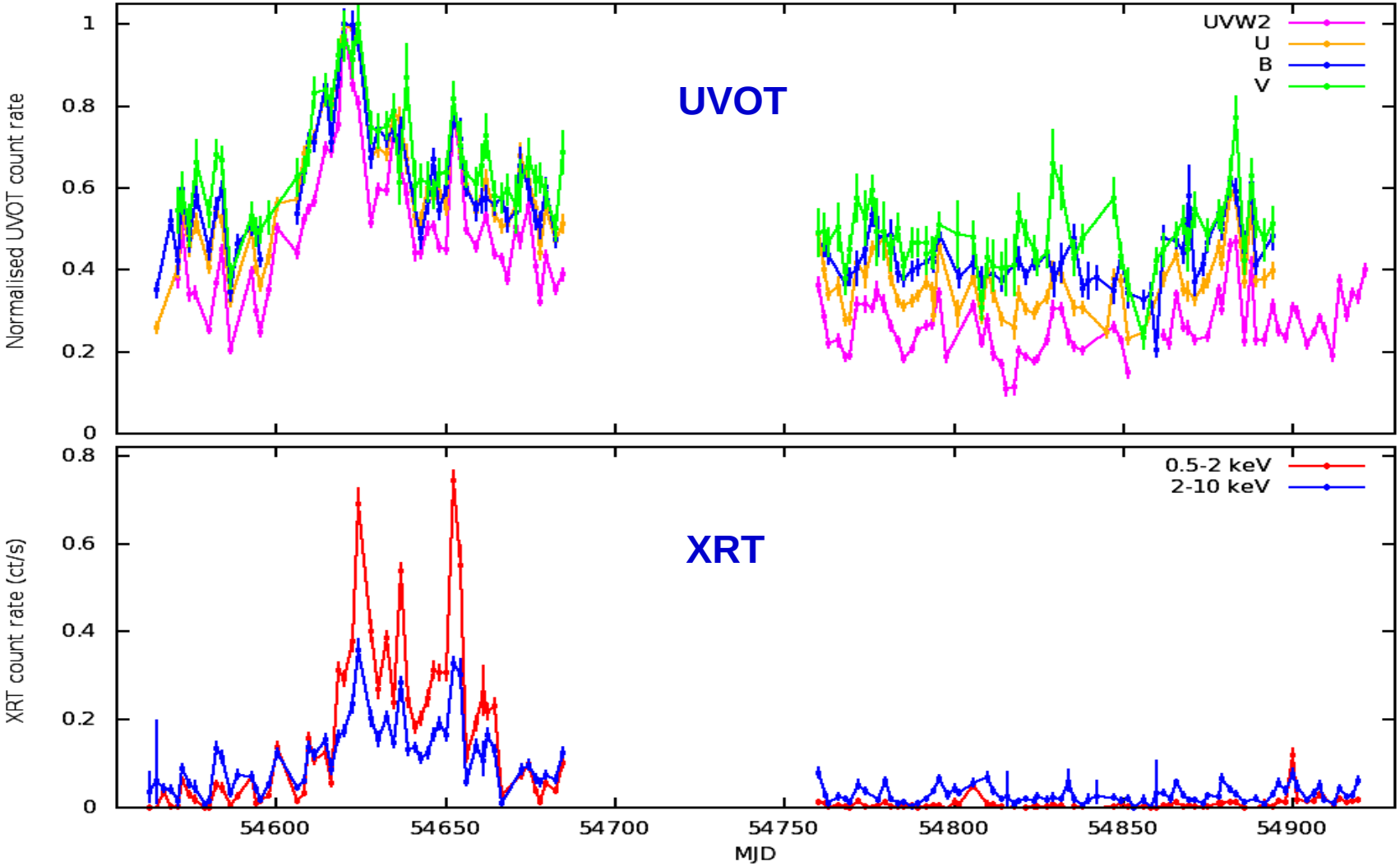
Correlation looks tighter than with mass, but is statistically very similar.

Temperature correlation explained by solid angle subtended by the optical emitting region at X-ray source

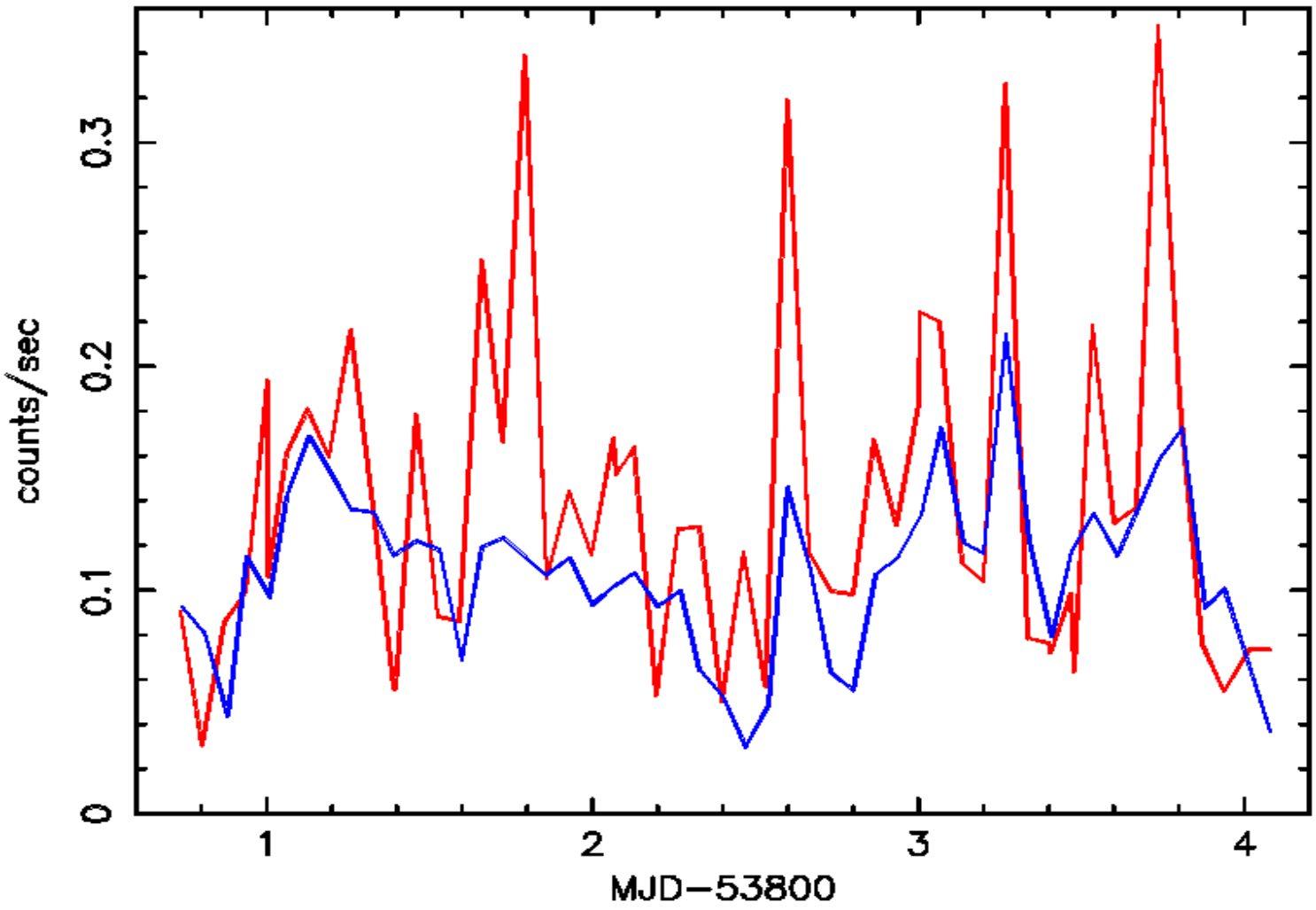
NGC4395 (~10^5 solar mass BH)- Swift



NGC4395 lightcurves



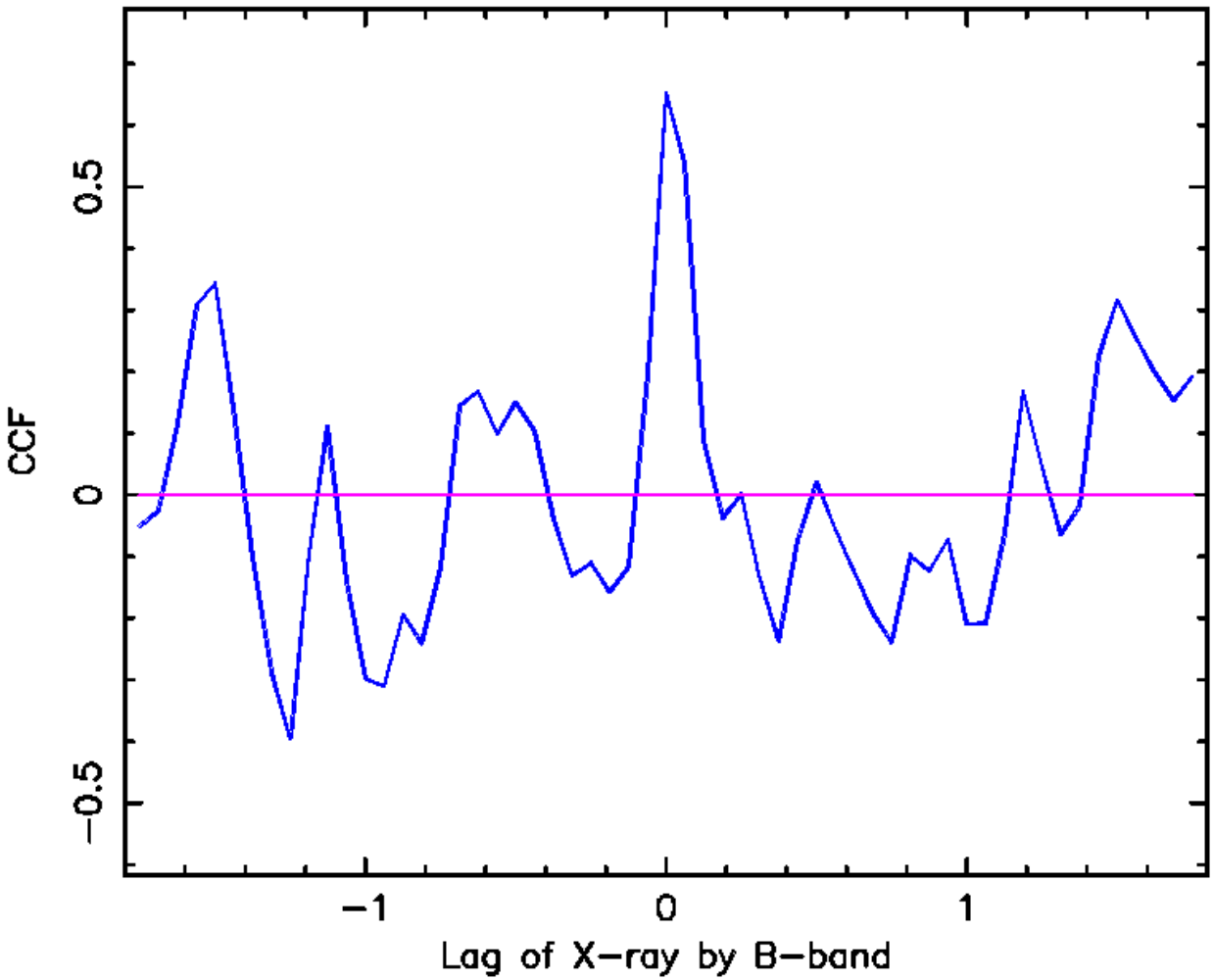
NGC4395: Shorter timescale (hours- days)



X-RAYS

B-BAND

NGC4395: Short timescale CCF



(days)

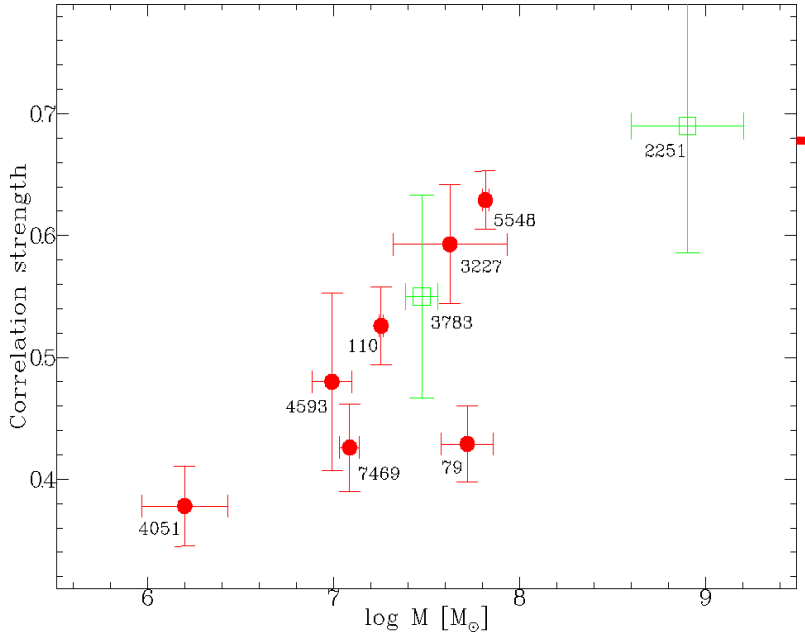
Very small lag < 45min

again indicating reprocessing

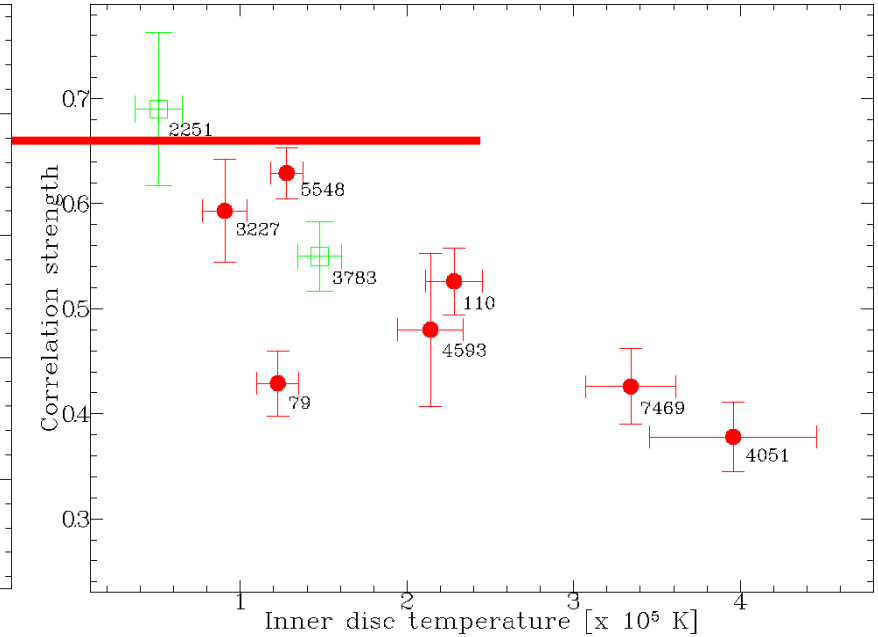
(Cameron et al, in prep)

How does NGC4395 fit the M, T correlations?

MASS

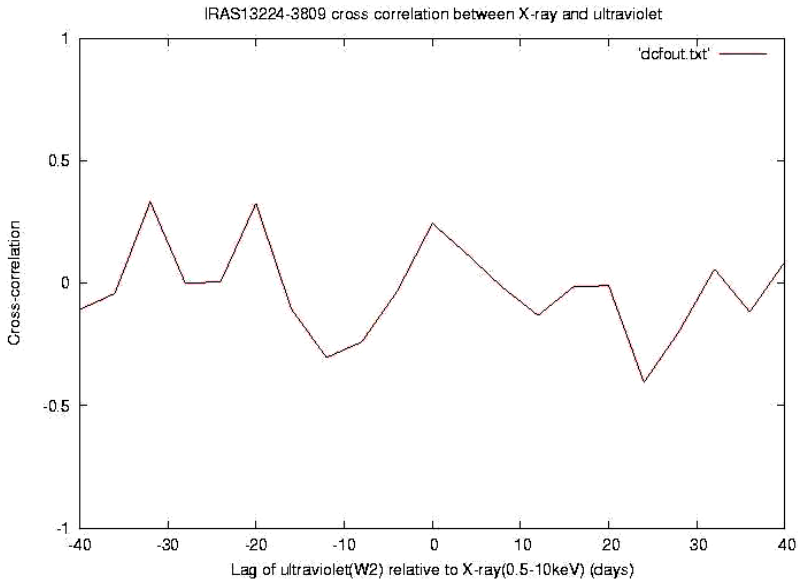


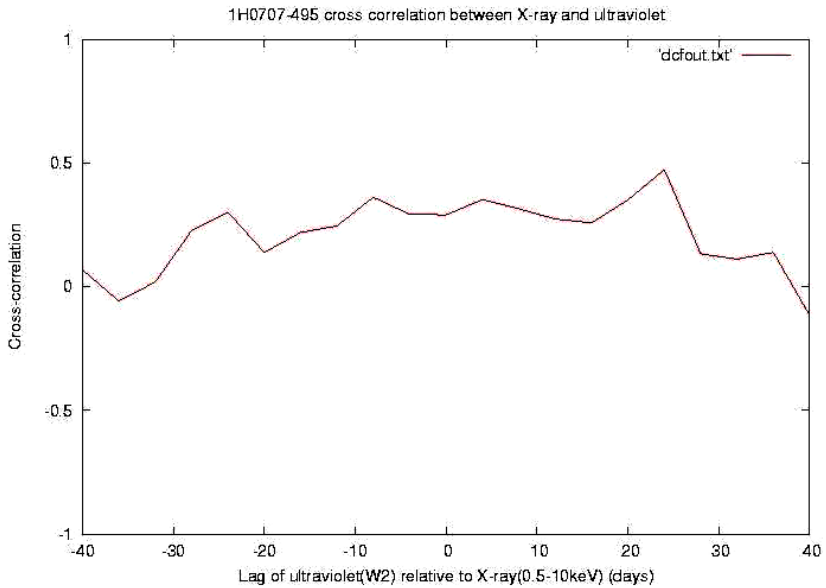
DISC TEMPERATURE



NGC4395 does not agree with pure mass scaling but is consistent with disc temperature scaling

Swift X-ray/Optical Correlations for NLS1s 1H0707 and IRAS13224





..nothing much, in agreement with the temperature correlation

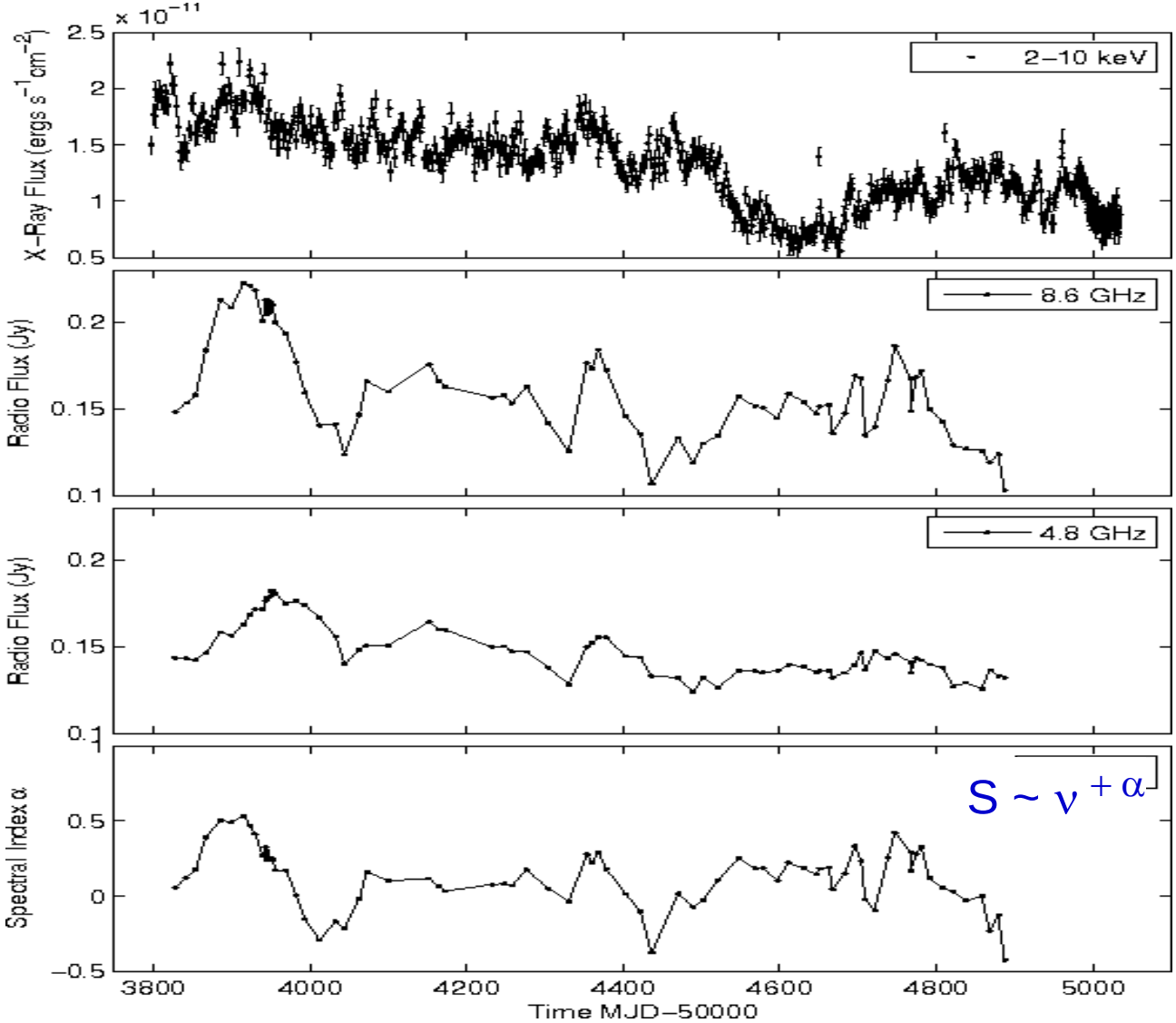
(Cameron, with McH, Fabian, Uttley..)

Radio/X-Ray Variability

1. Liners -NGC7213 +M81

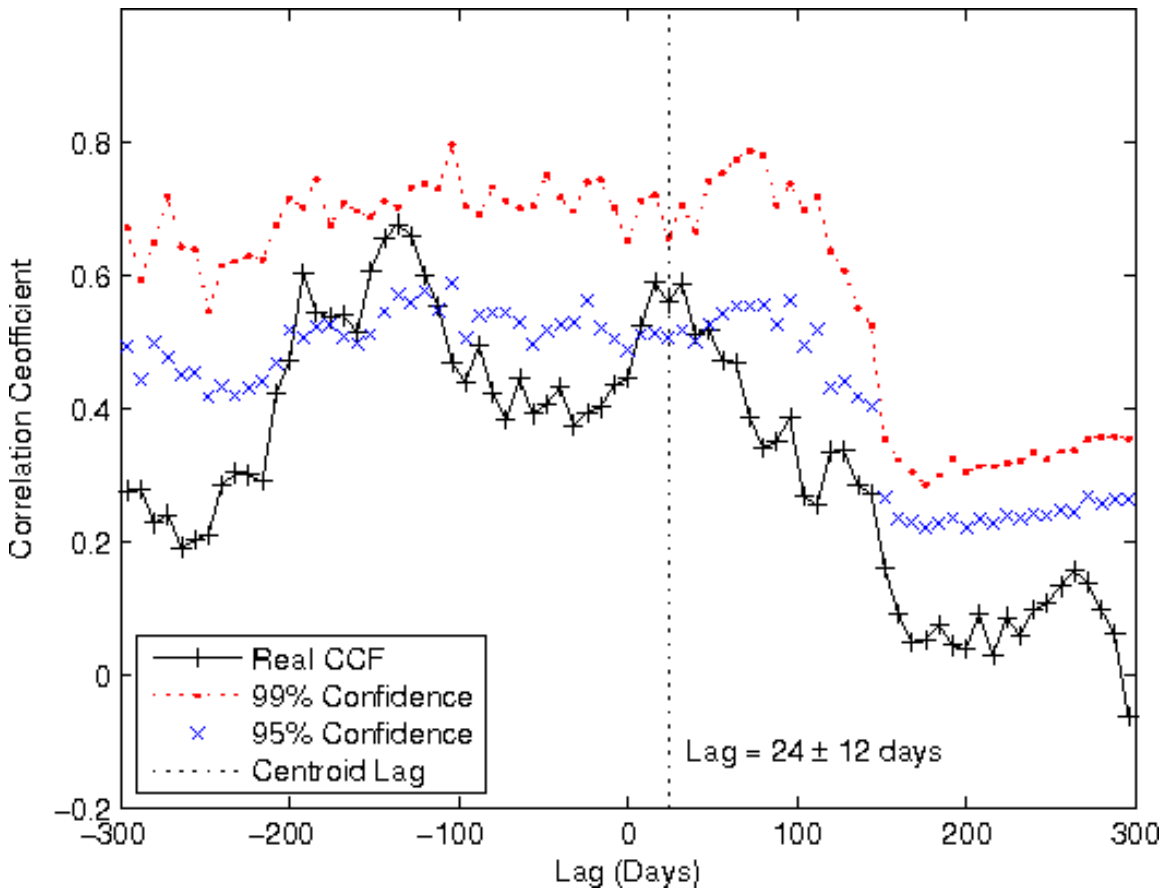
2. Seyfert – NGC4051

NGC7213 – X-RAY/RADIO



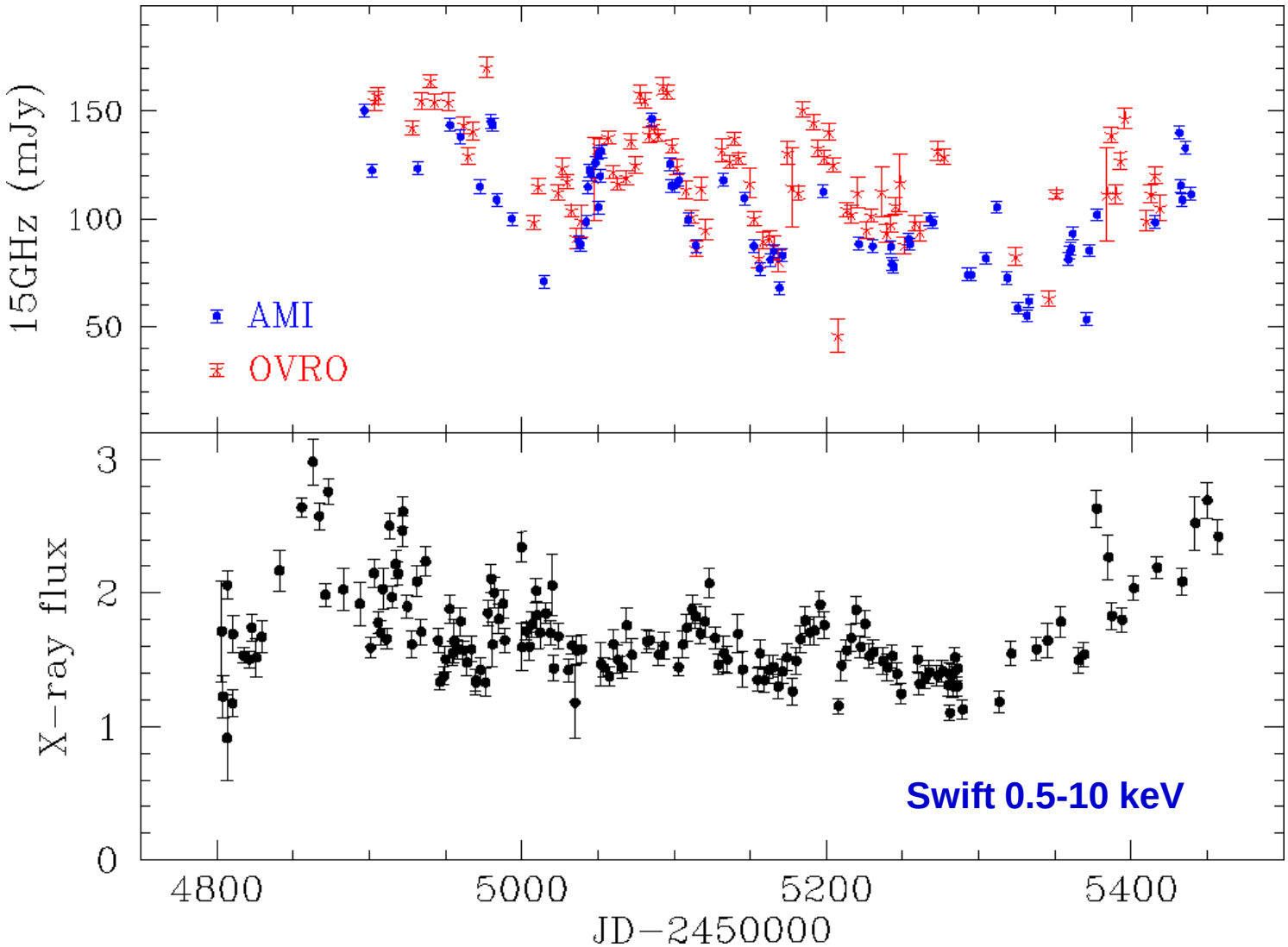
(Bell et al, 2010)

NGC7213 – X-RAY/RADIO

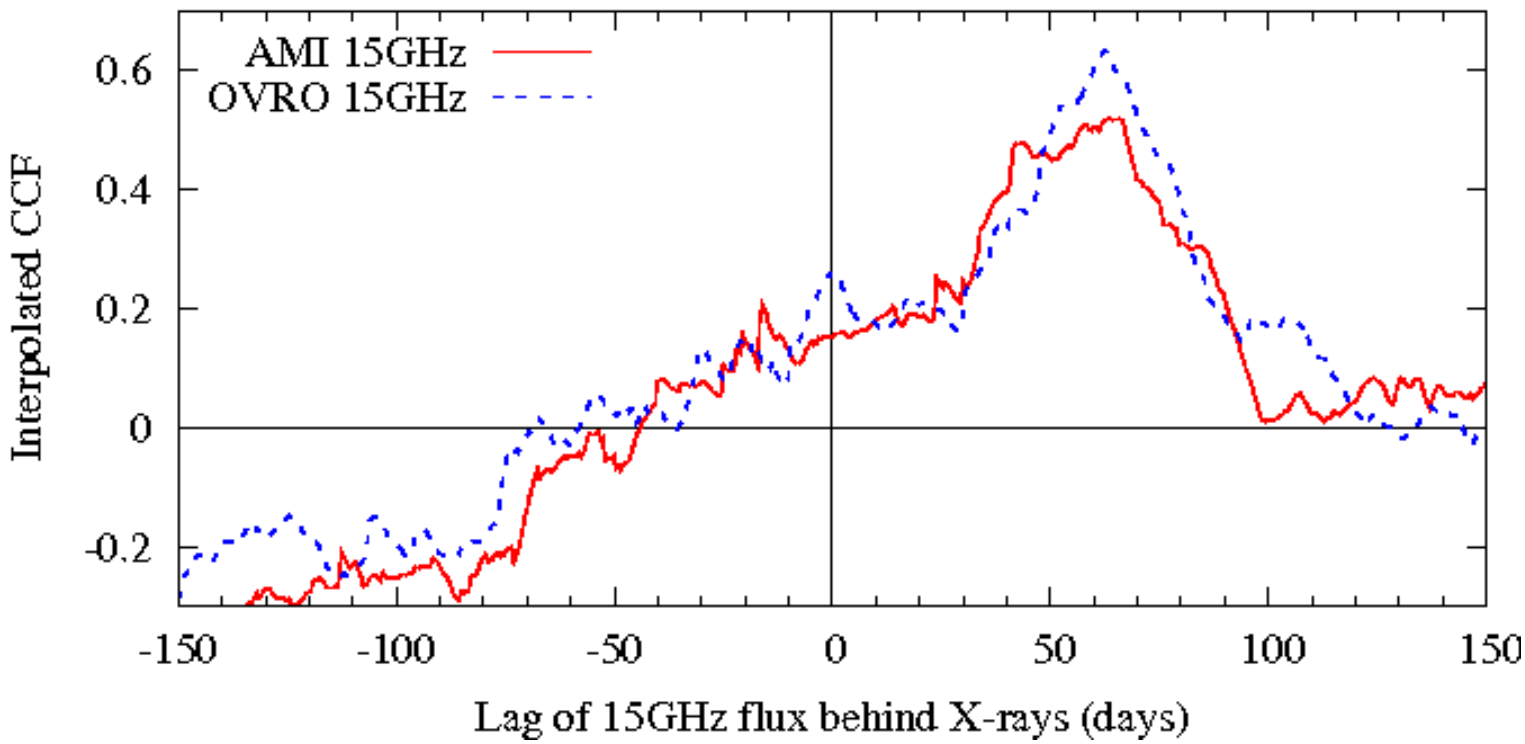


8 GHz lags X-rays by ~24 days

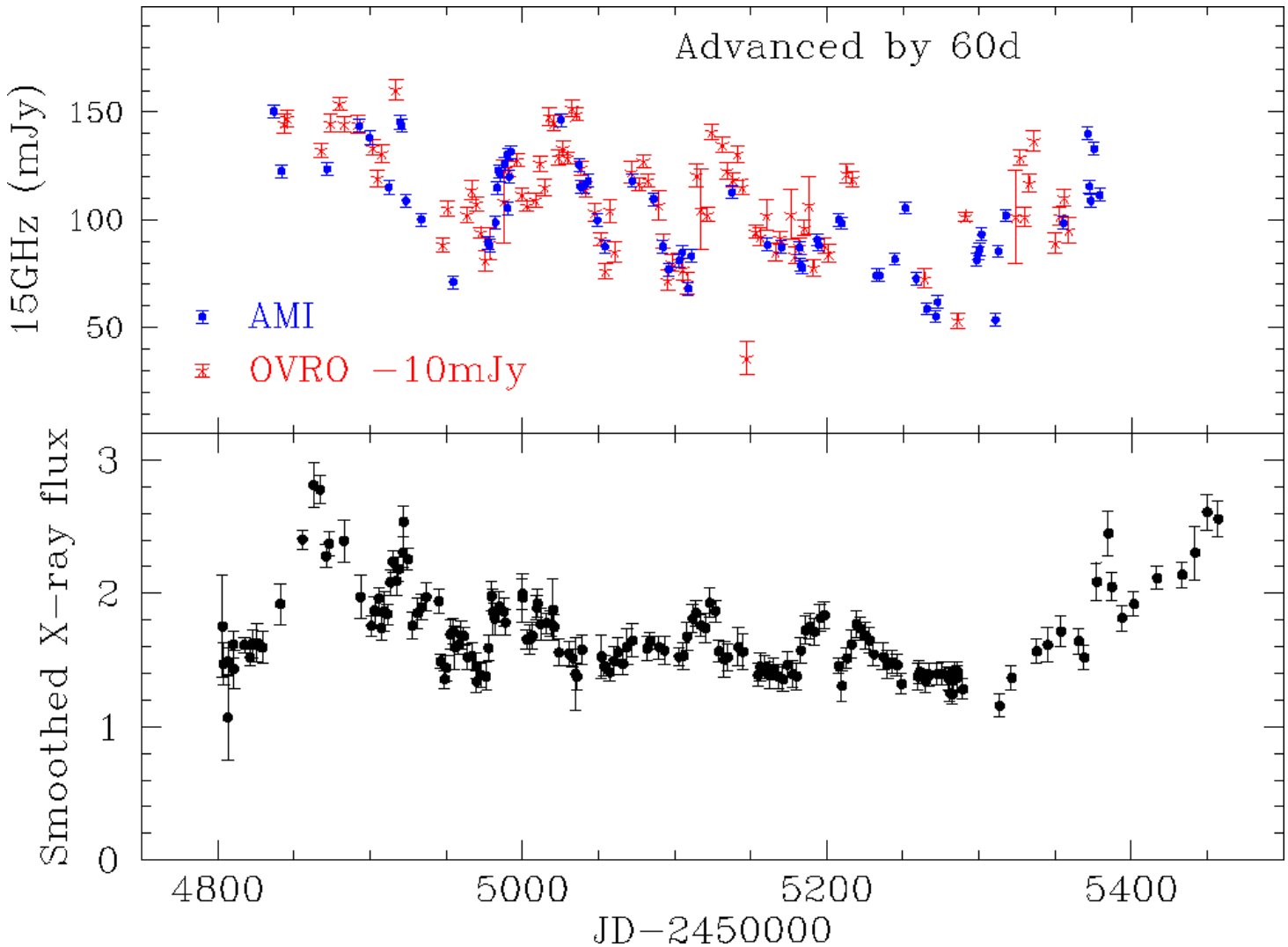
M81 X-ray and 15GHz lightcurves



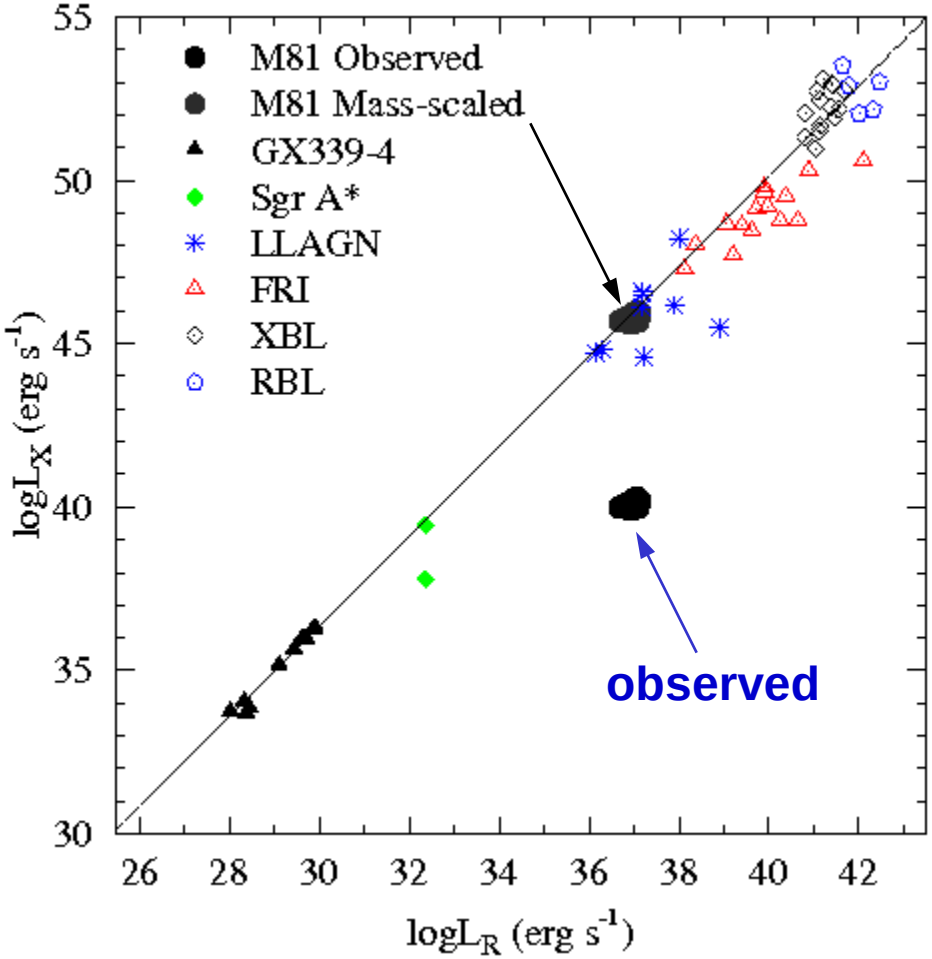
M81 X-ray and 15GHz Cross-correlation

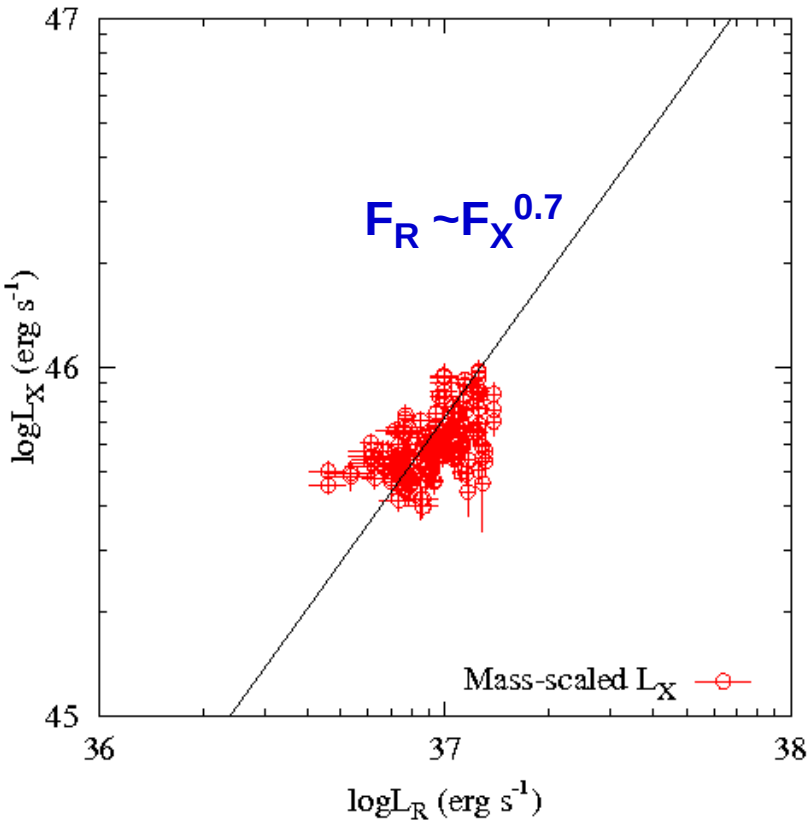


X-ray and 15GHz lightcurves of M81



M81 X-ray and 15GHz



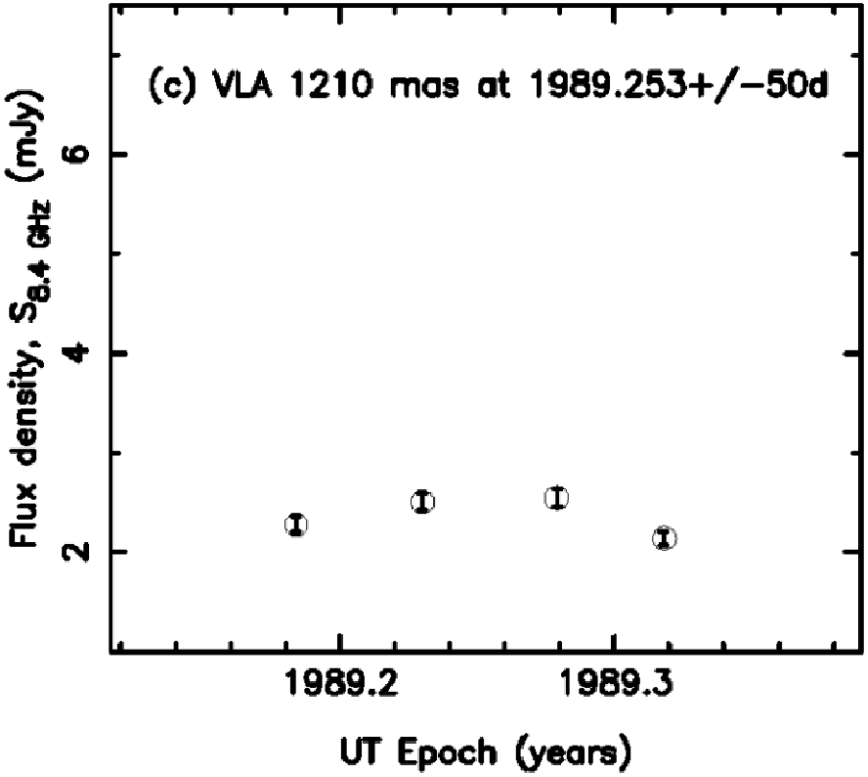


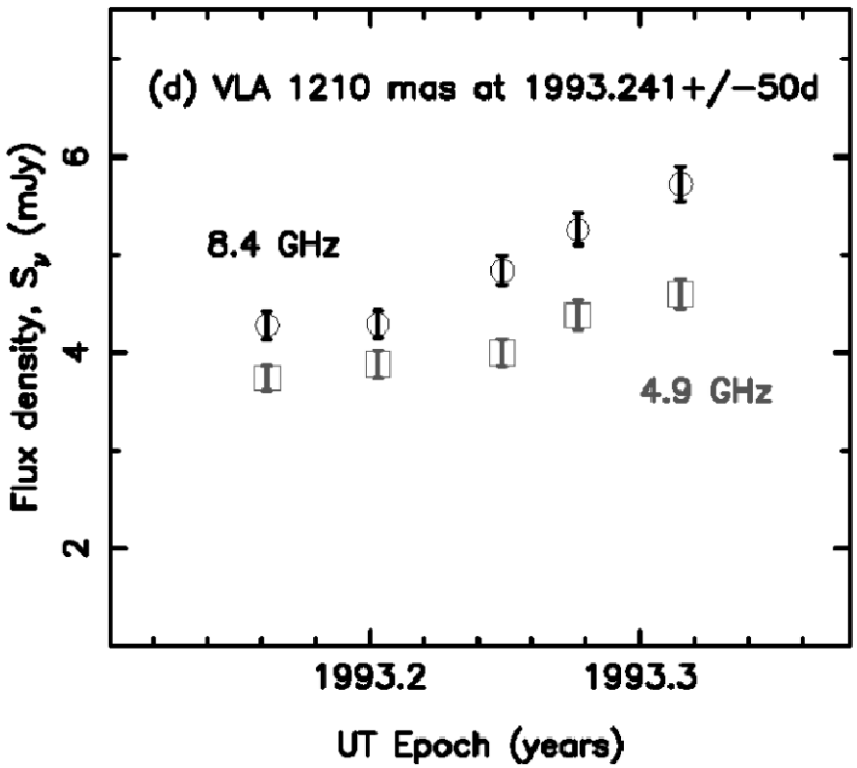
From Falcke et al 2004
cf Merloni et al 2003

Mass-scaling assuming X-rays and radio are jet-dominated (ie sync.)

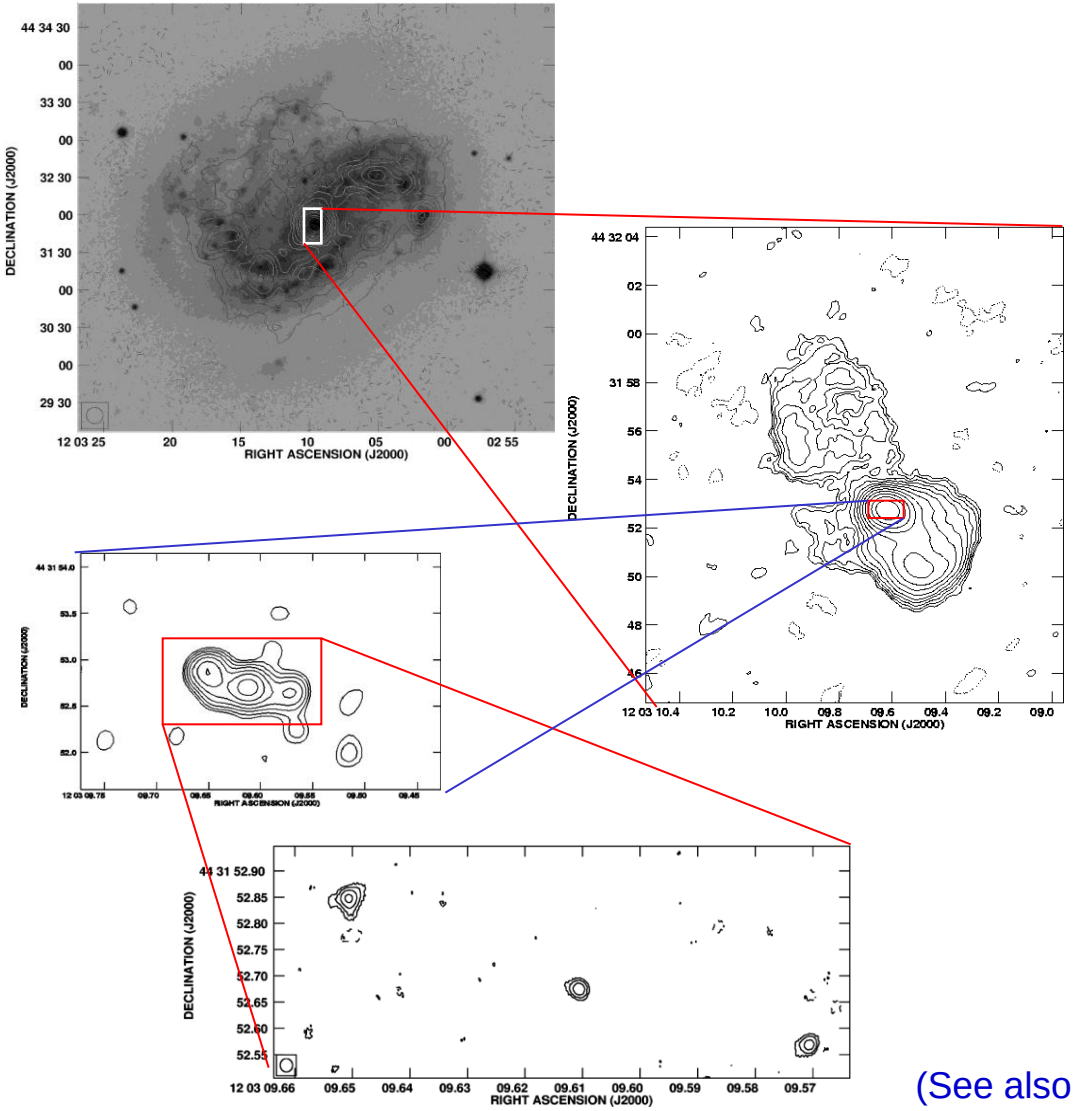
Radio variability from Seyferts, ie high accretion rate, Soft State, AGN

NGC5548 – Wrobel 2000 - no parallel X-ray observations





NGC4051

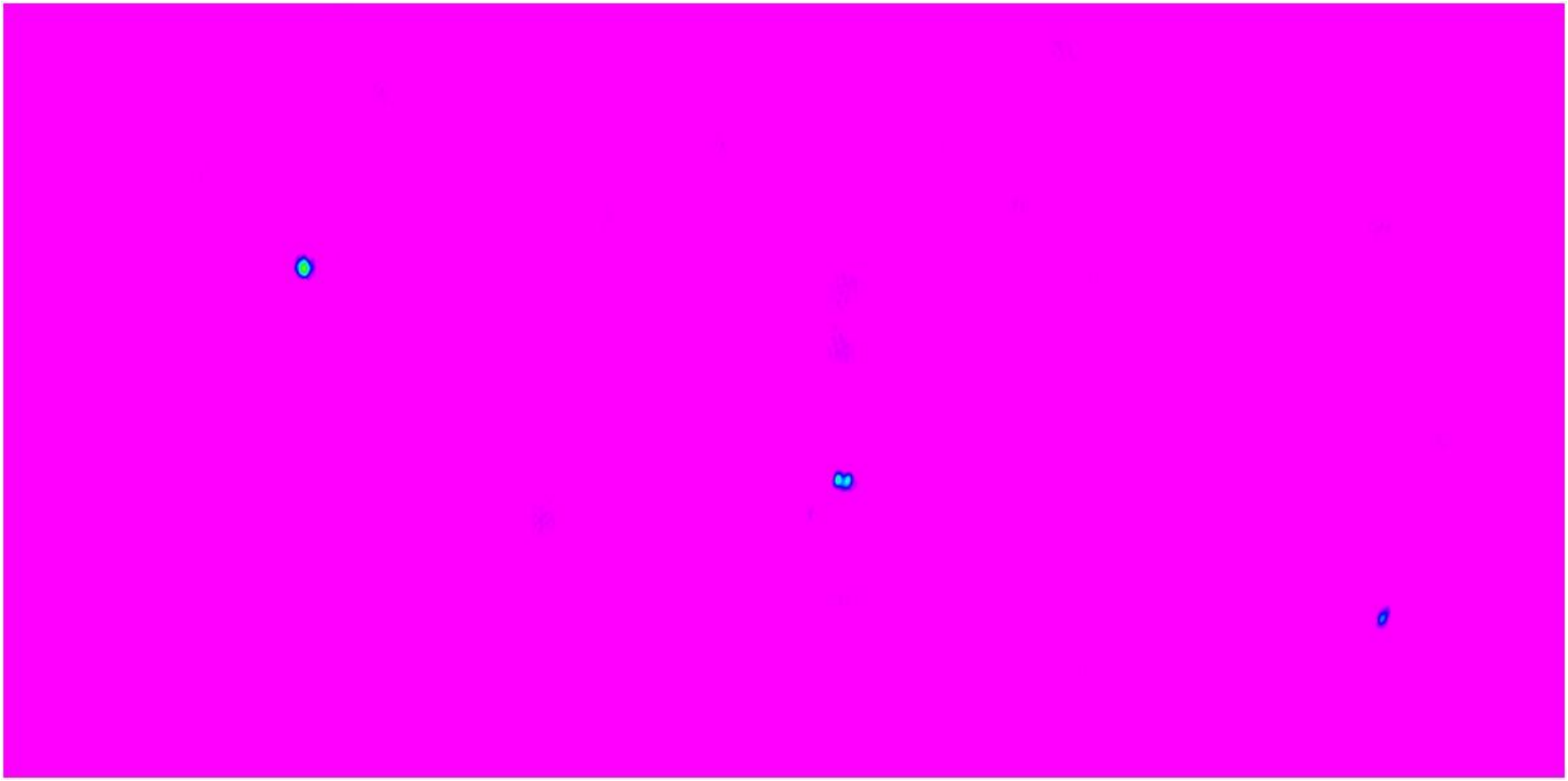


- **Looks just like a classical radio galaxy – except much smaller and of much lower luminosity.**

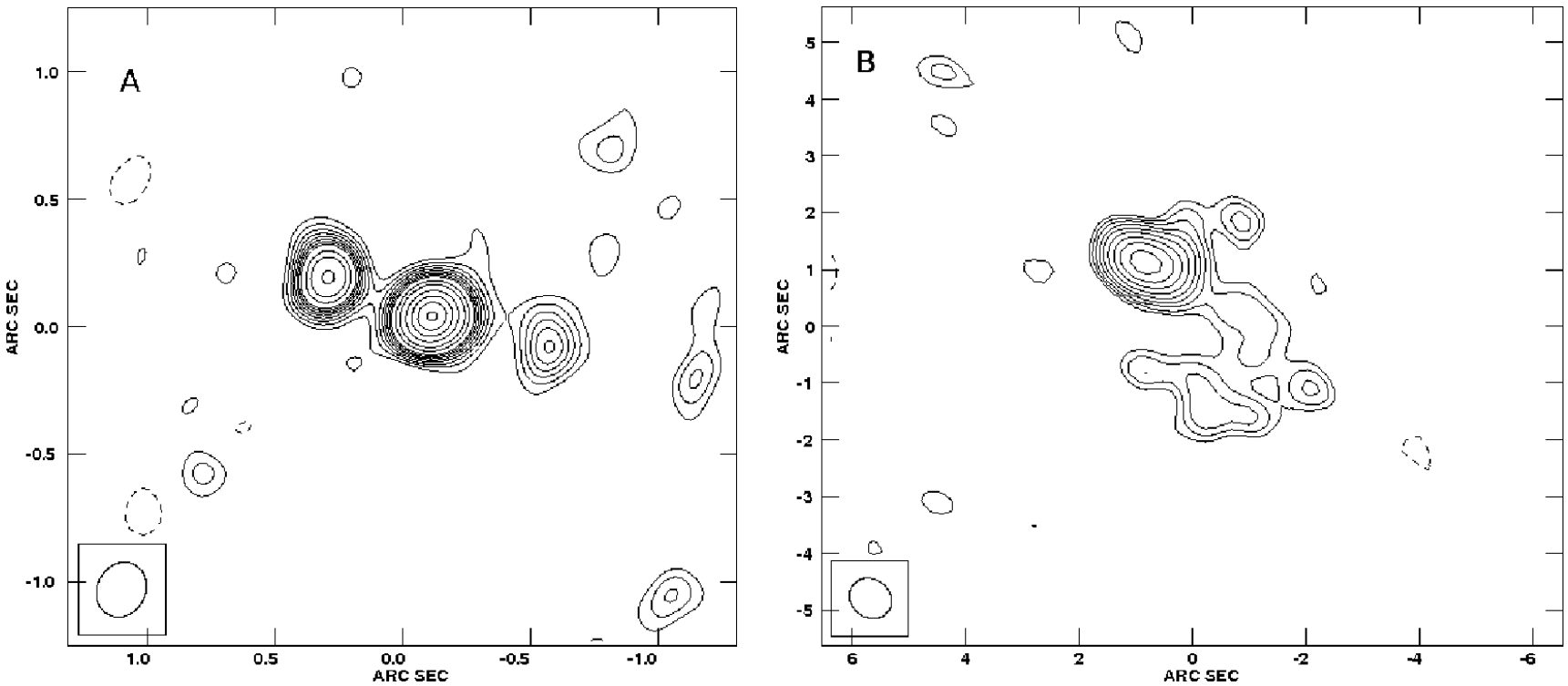
- **Component separation is ~50 light years**

(See also Girolleti and Panessa 2009)

NGC4051 – Global VBLI



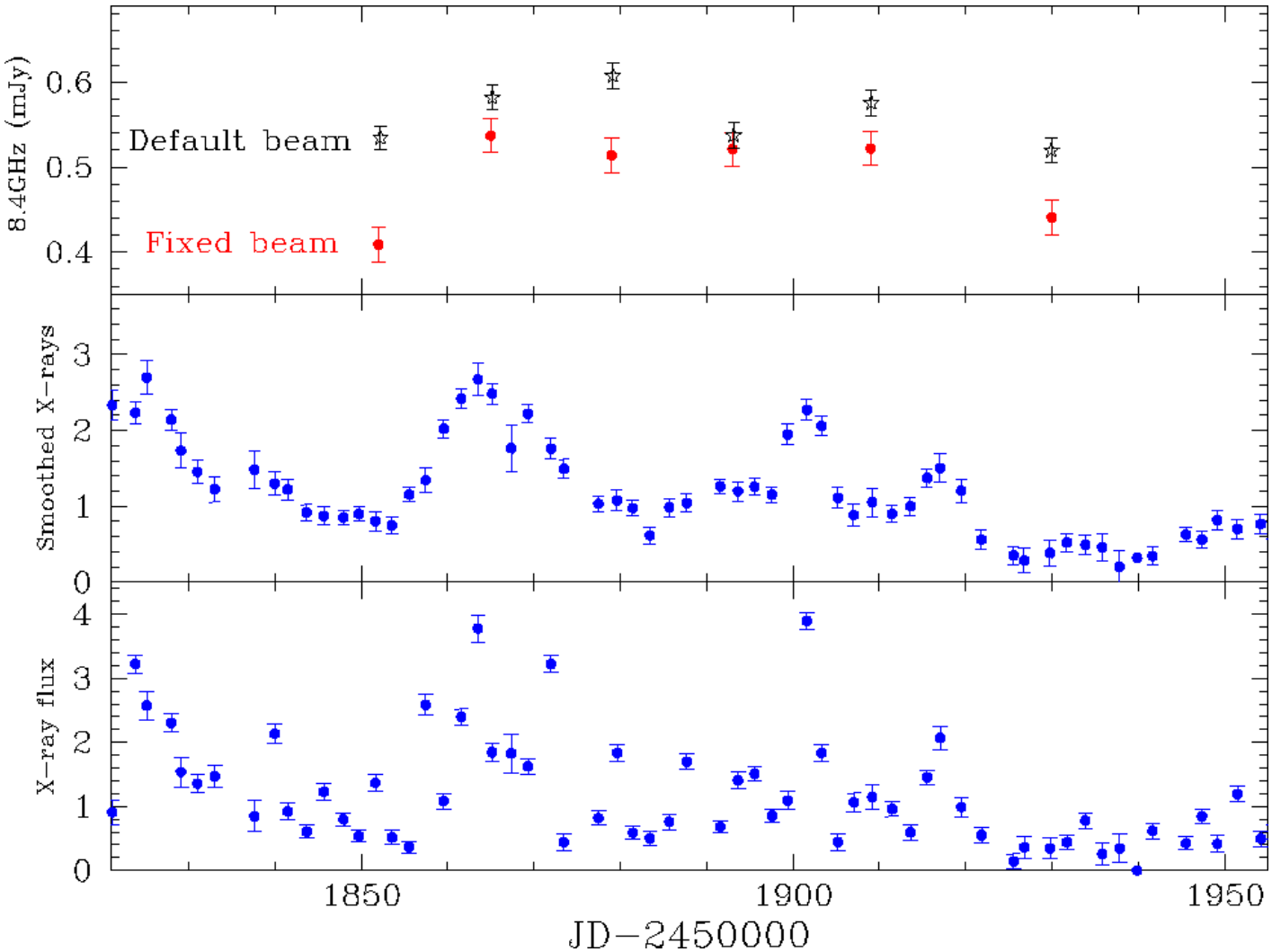
NGC4051 VLA A and B array 8GHz observations



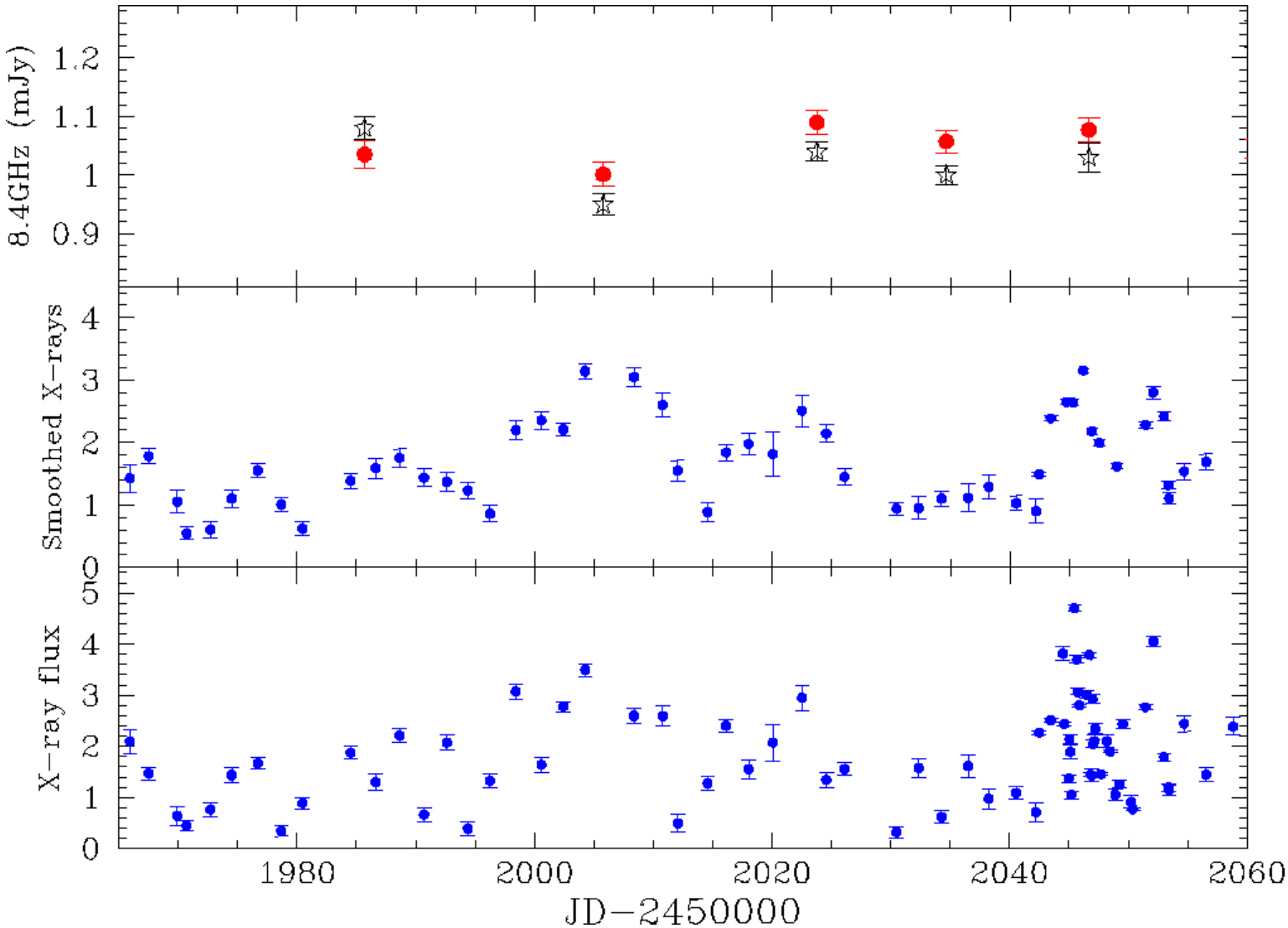
Jones et al, submitted

Peak flux ~0.5mJy in A-array

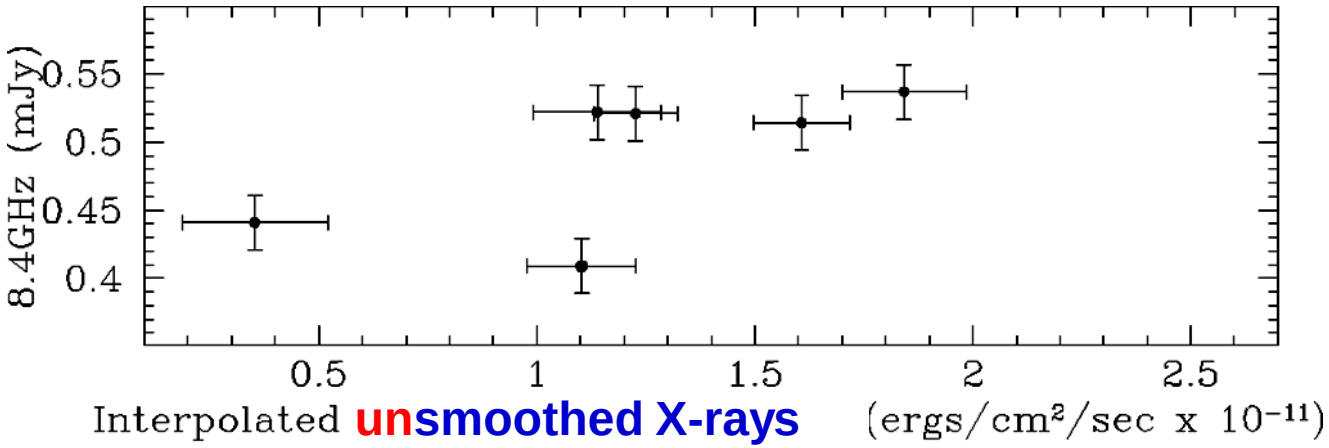
NGC4051 VLA A array observations

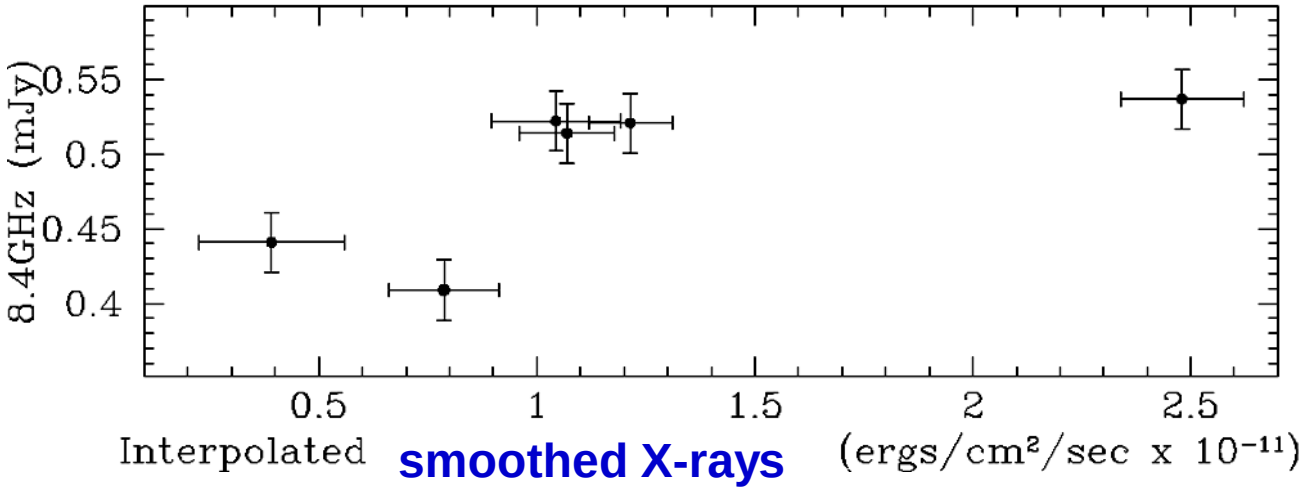


NGC4051 VLA B array observations



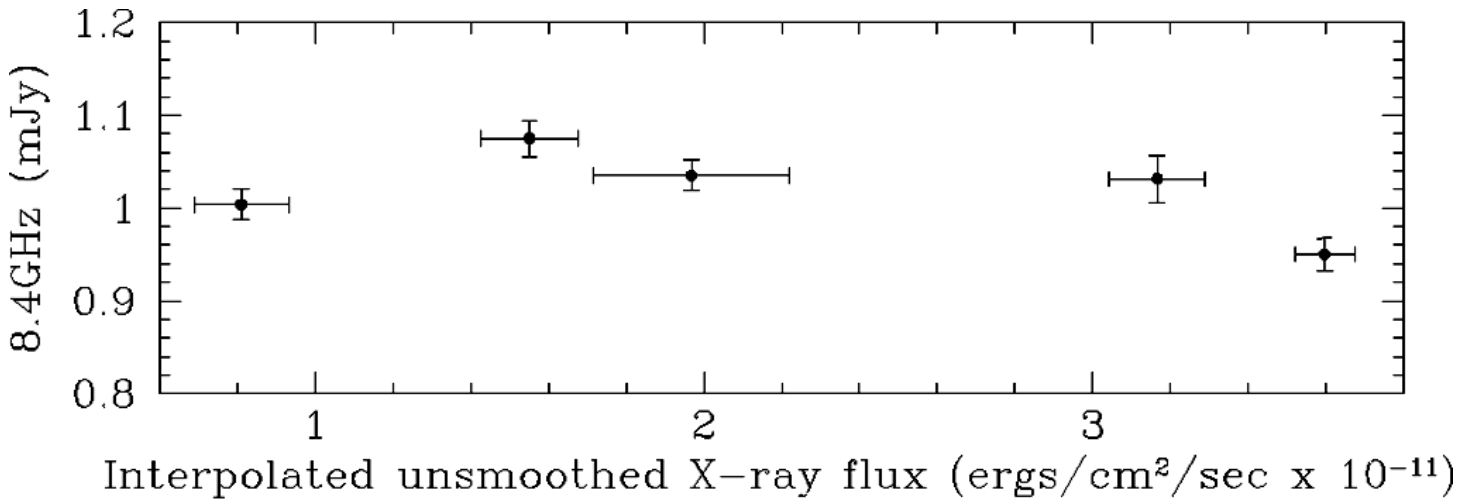
NGC4051 Radio vs. X-ray – A array

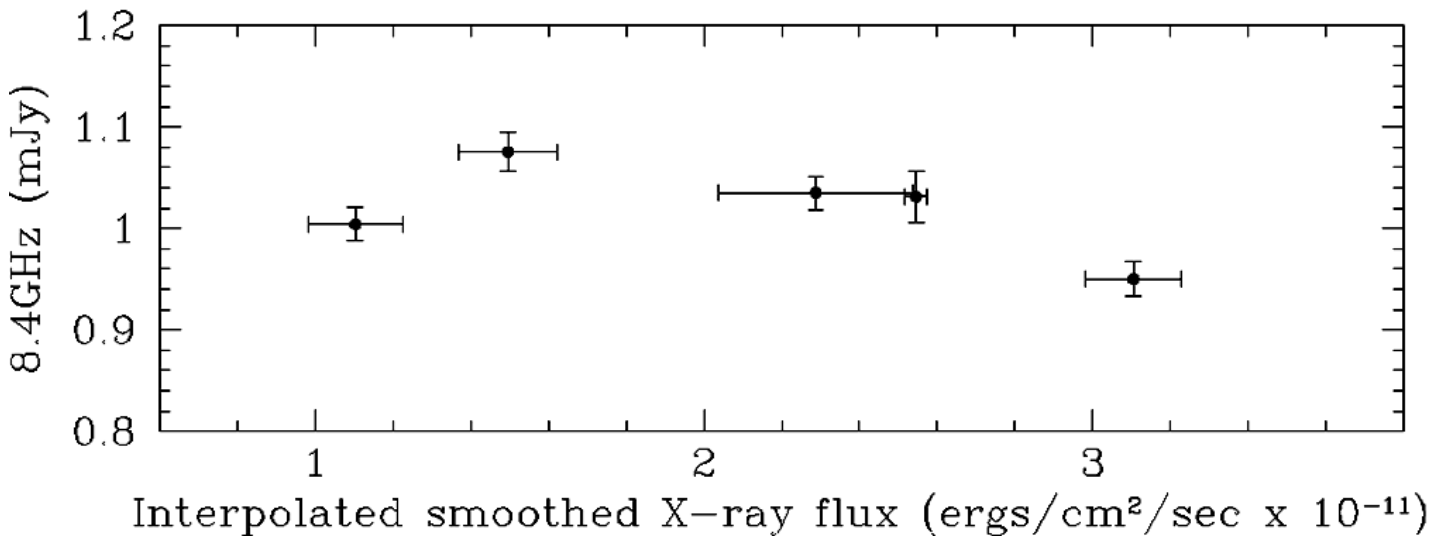




Weak correlation?

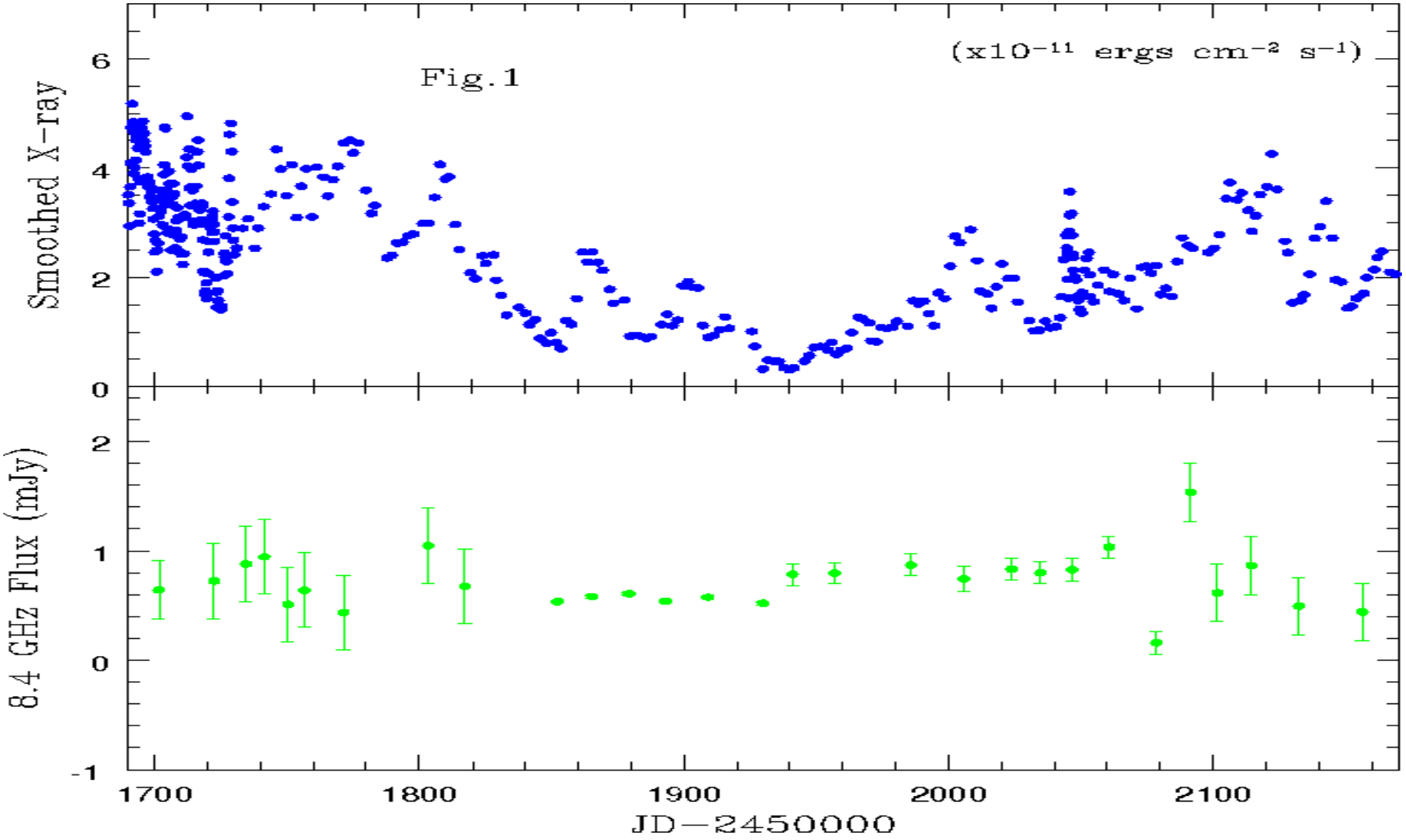
NGC4051 Radio vs. X-ray – B array





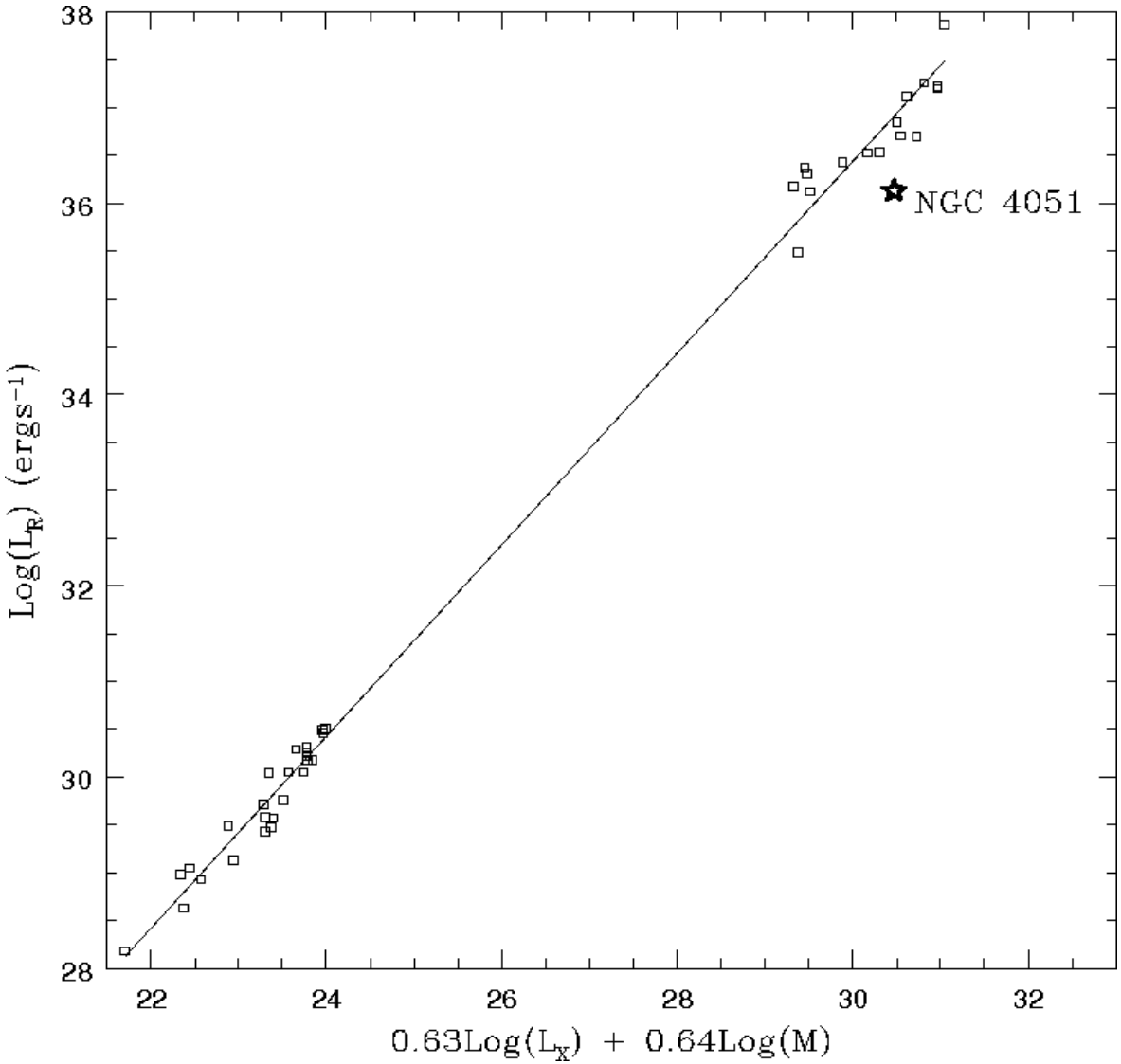
Positive correlation gone..

NGC4051 Radio vs. X-ray - all arrays



No strong evidence for large amplitude radio variability

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

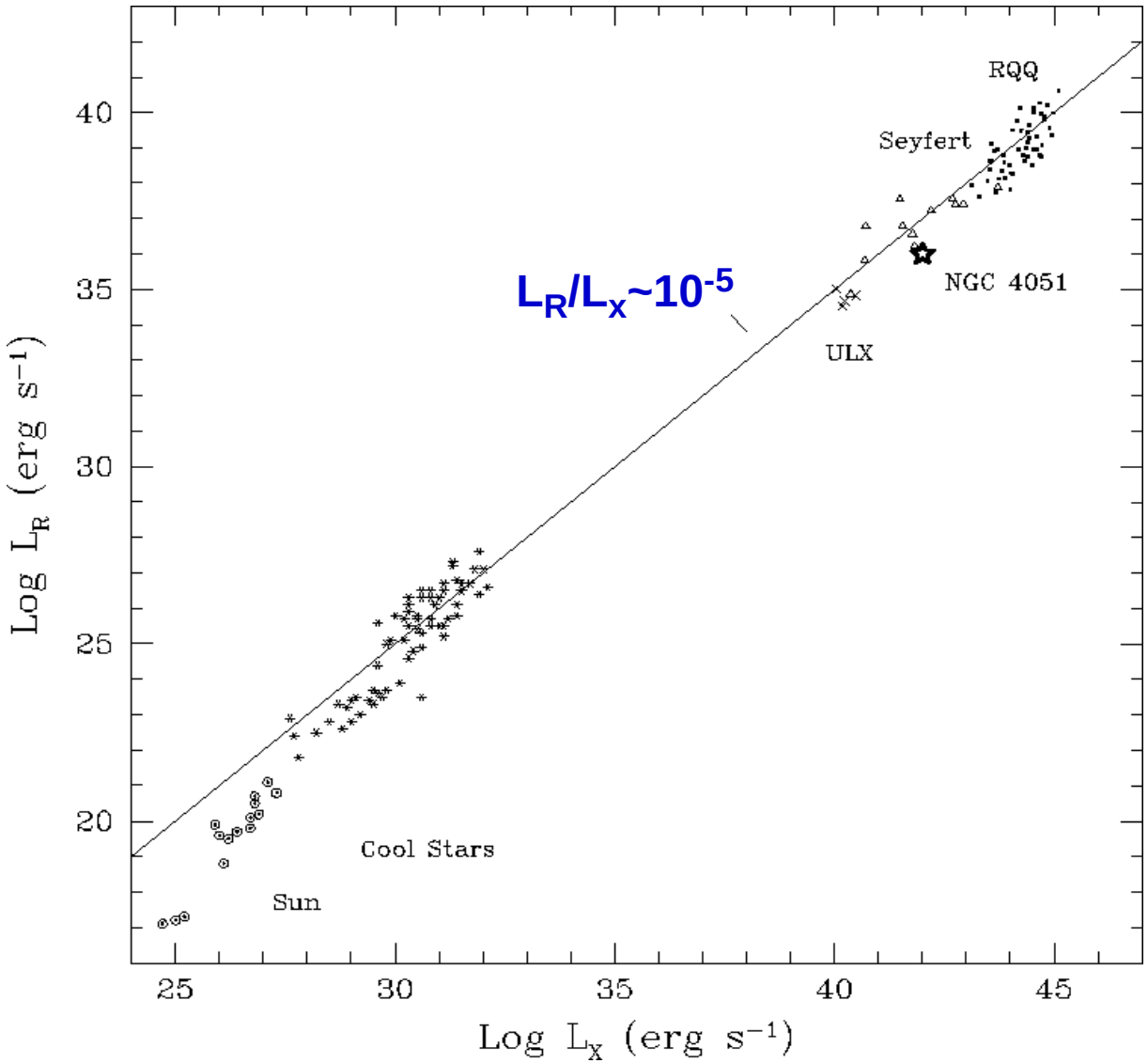


(Merloni et al 2003, Falcke et al 2004, Koerding et al 2006

Here plotting just hard state objects from Koerding etal

Slightly radio quiet

NGC4051 as a coronal radio source?



From Fig.6 of Laor and Behar 2008

Maybe a combination of fast inner jets and slower, more diffuse, outflow, or corona

CONCLUSIONS

Direct link between X-ray timing properties and host galaxy linewidth.

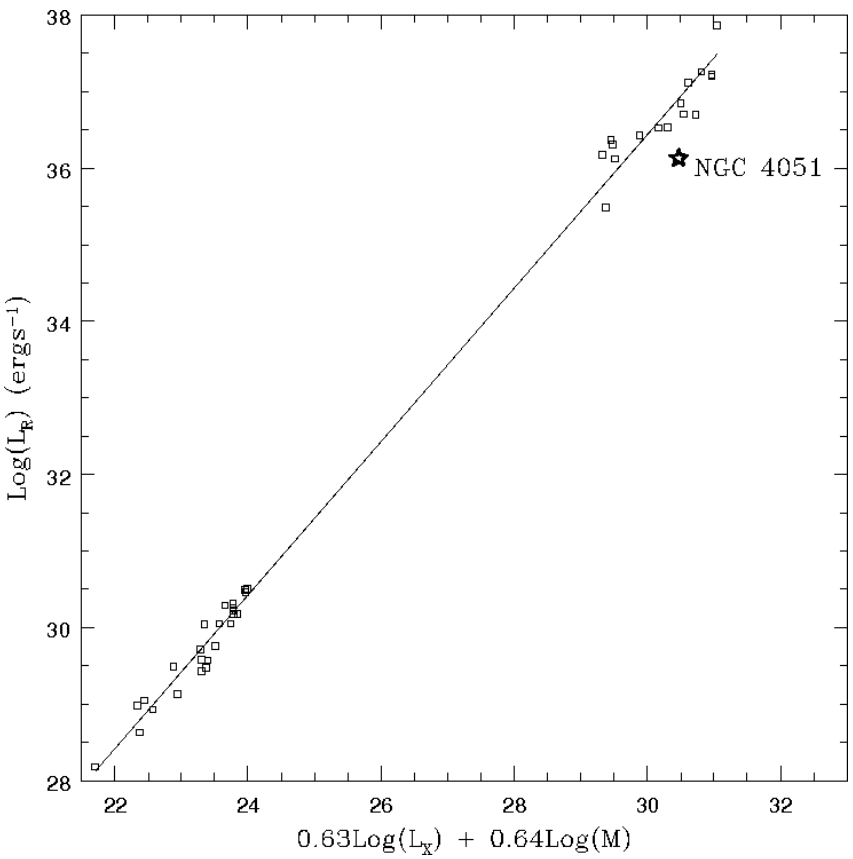
Short timescale optical variability in Seyferts dominated by reprocessing of X-rays. Strength of O/X correlation depends on disc temperature.

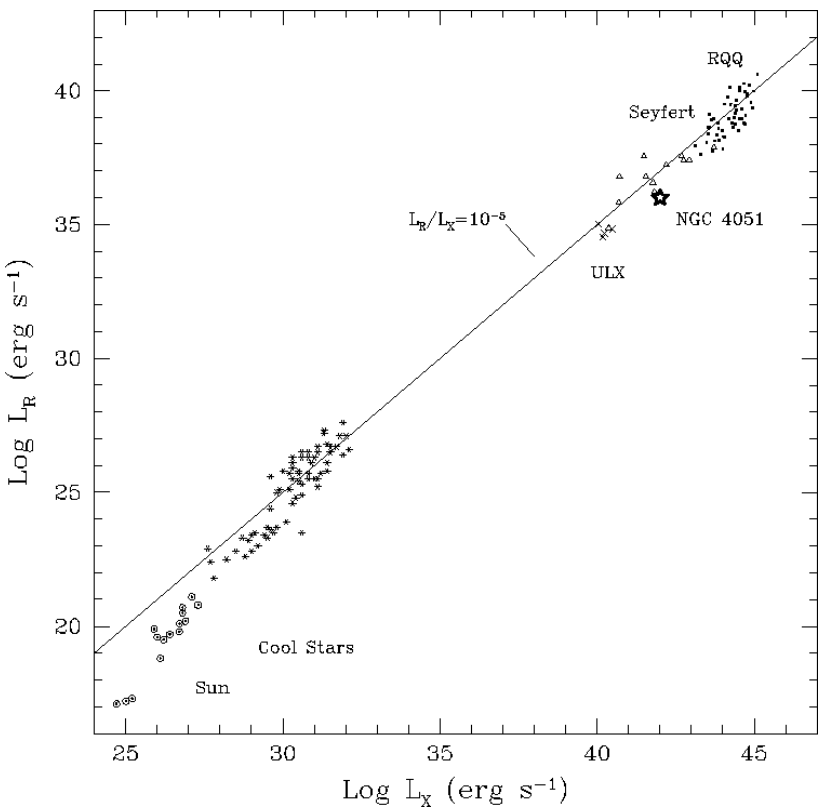
Probable contribution to optical variability on longer timescales from intrinsic disc variability.

Good correlation between X-ray and radio in liners (~10^{-4} Eddington)
Strong support for jet-dominated model for radio and X-rays

In higher accretion rate Seyferts, radio variations seen in NGC5548 but not (strongly) in NGC4051. However radio jets are seen. Radio is maybe a mixture of jet and coronal emission.

NGC4051


NGC 4051
Log(L_R) (ergs^-1)
0.63Log(L_X) + 0.64Log(M)

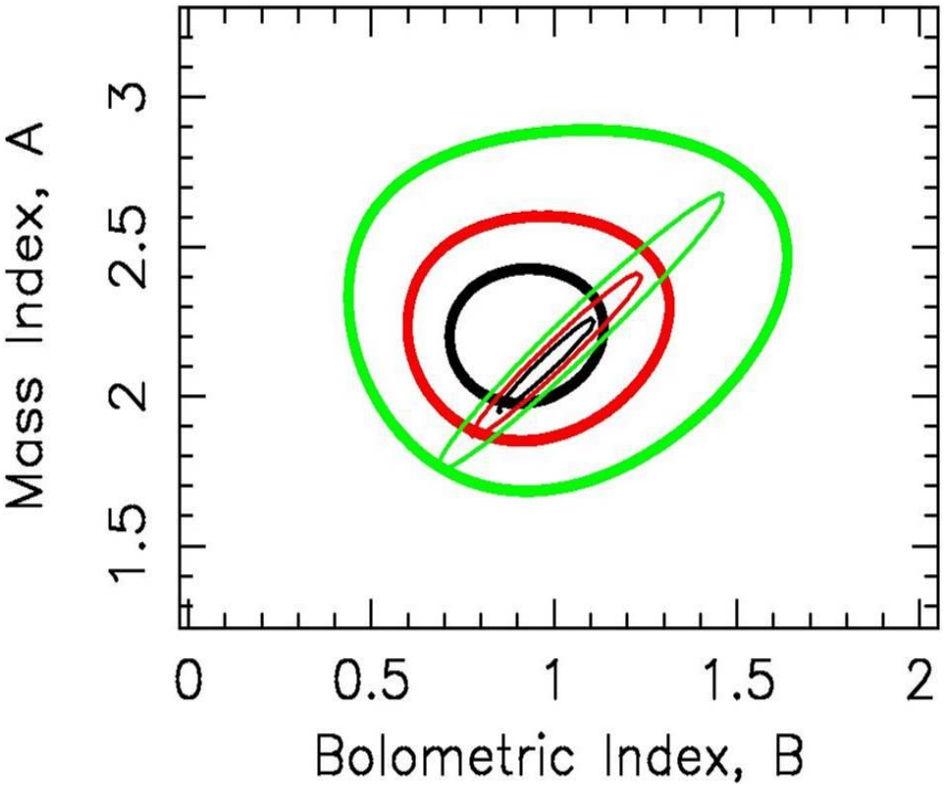

RQQ
Seyfert
L_R/L_X=10^-5
NGC 4051
ULX
Cool Stars
Sun
Log L_R (erg s^-1)
Log L_X (erg s^-1)

S

Next slide shows what you get left with if you remove Elme's reprocessed model NGC4051 lightcurve from the observed optical lightcurve. I didn't show it but it gives some idea of the intrinsic disc variations.

Proper 3D fit to T_b, M, $\dot{m}_E$

(McHardy et al, 2006)



i.e $T_B \sim M^{1.12}\ \dot{m}_E^{-0.98}$

(eg, for $M=10^8\ M_O$, mdot =0.1, T_B = 6d)

First, just to AGN (10)
(mostly soft state)

As $\dot{m}_E = L_{Bol} / M$

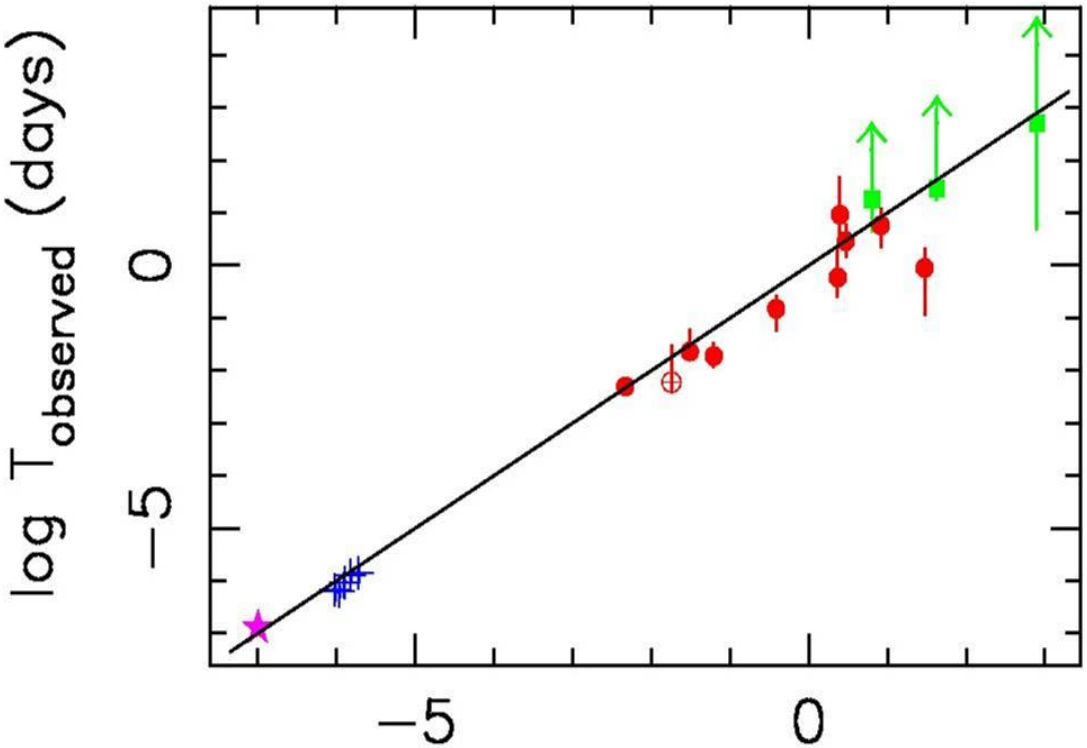
we fit to $T_B \sim M^A\ L_{Bol}^{-B}$

Add soft state binaries, GRS1915+105 and Cyg X-1

So the Binary data is entirely consistent with the AGN data

Good fit. Additional parameter (eg spin) not needed.

Projection of the Variability Plane



log $T_{predicted}$ (days) i.e ~ $M^{1.12}$ $\dot{m}_E^{-0.98}$

Red circles – fitted AGN
Open circle – LLAGN NGC4395

Green squares are AGN with poorly determined T_b, not included in the fit.

Blue crosses – Cyg X-1

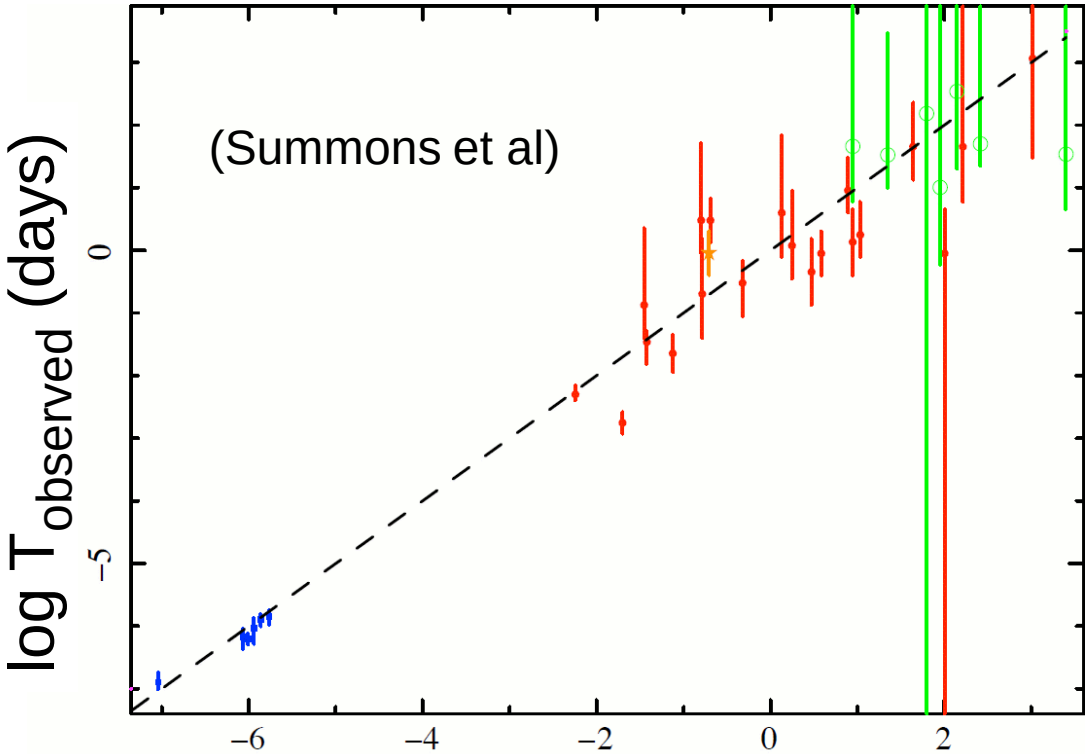
Magenta star – GRS1915+105

Outlying (red dot) AGN is NGC5506; mass is only from width of OIII lines

Useful for mass determination for IMBHs and obscured AGN

Hard state binaries are consistent (without fitting), with an offset (Koerding et al 2007)

Projection of the Variability Plane



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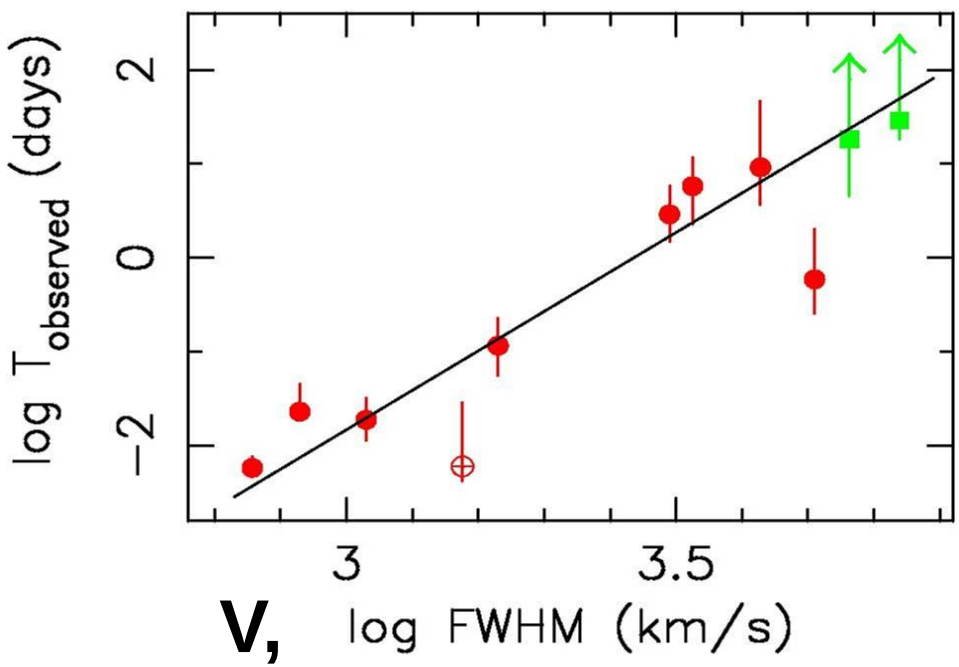
T_B and Linewidth, V

(McHardy et al, 2006)



Tight relationship

$$T_B \sim V^{4.2 +/- 0.6}$$

Simple scaling relationships:

1. $L \sim M\dot{m}_{Edd}$
2. $R_{BLR} \sim L^{0.5}$ **(LOC - Kaspi etal 1996)** Bentz etal 2006
3. $v^2 \sim GM/R_{BLR}$

Then expect

$$\text{Linewidth, } V^4 \sim \frac{M}{\dot{m}_{Edd}}$$

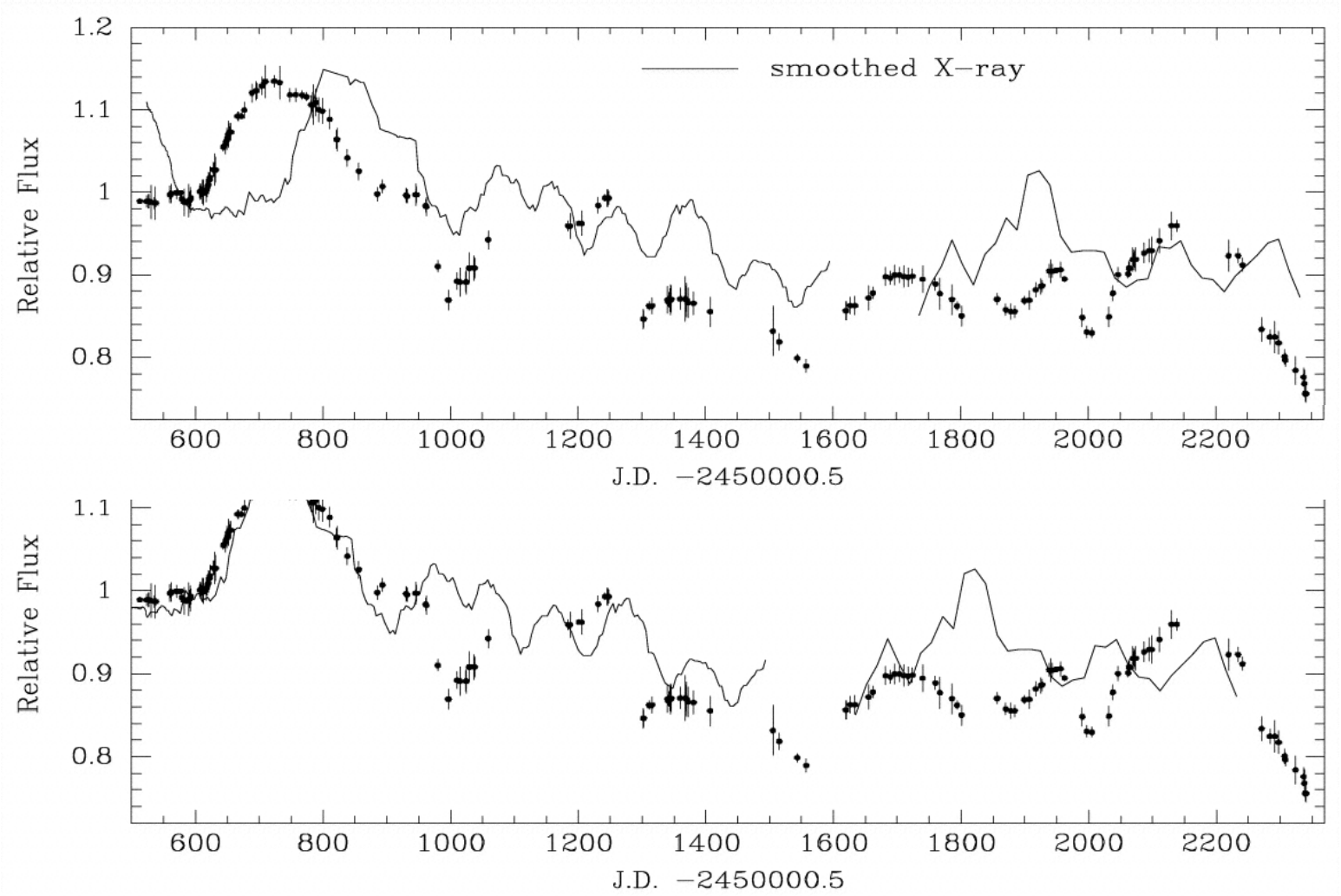
$\dot{m}_E$

Powerful confirmation that $T_B \sim M /$

New strong link between Black Hole timing and larger scale AGN properties

IMPLICATION: NLS1 same as other AGN, just have smaller ratios of $M / \dot{m}_E$
Small masses are selection effect as $\dot{m}_E$ can't easily exceed unity

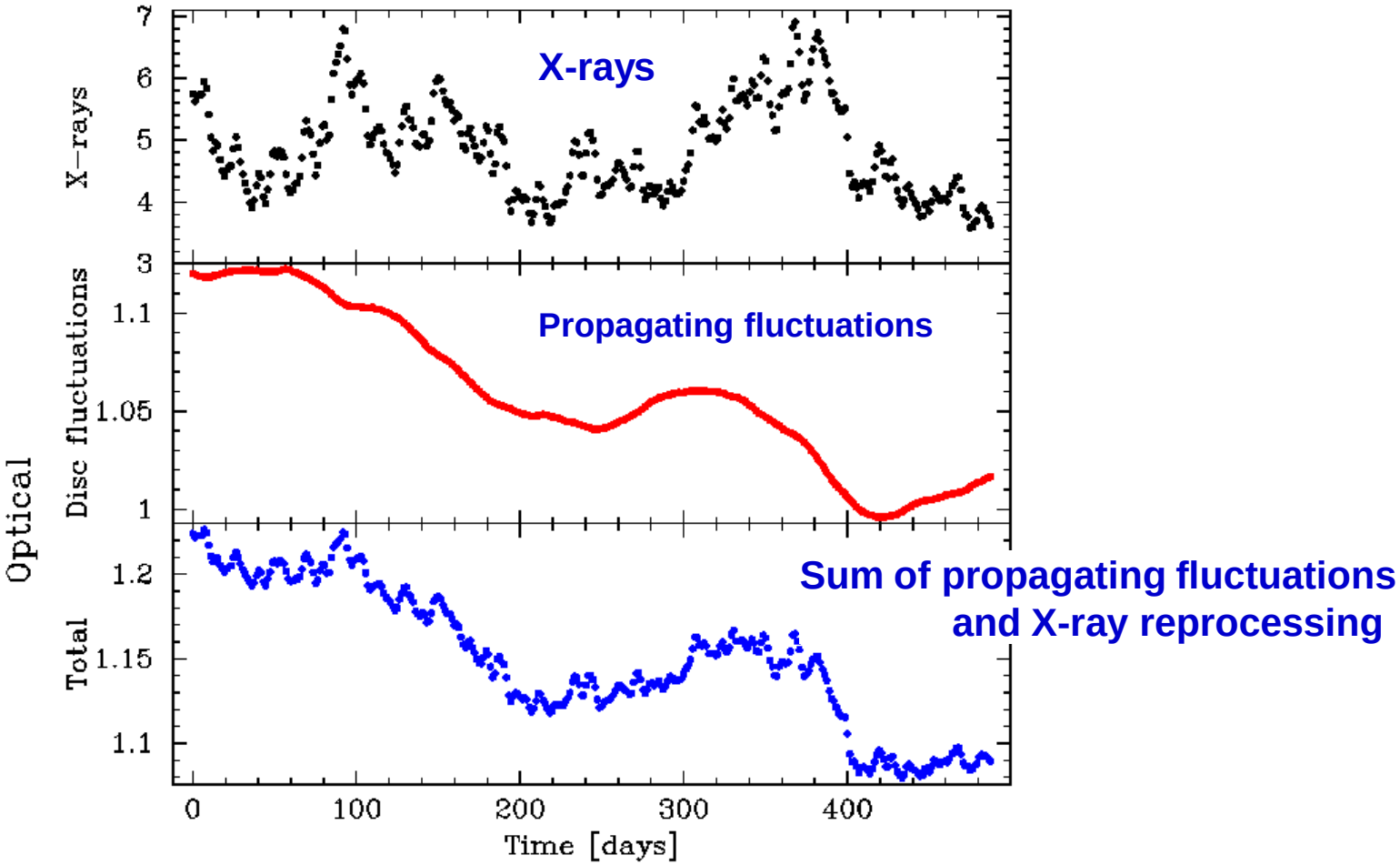
Optical Variability in AGN:
Reprocessed X-rays or intrinsic disc variability?



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

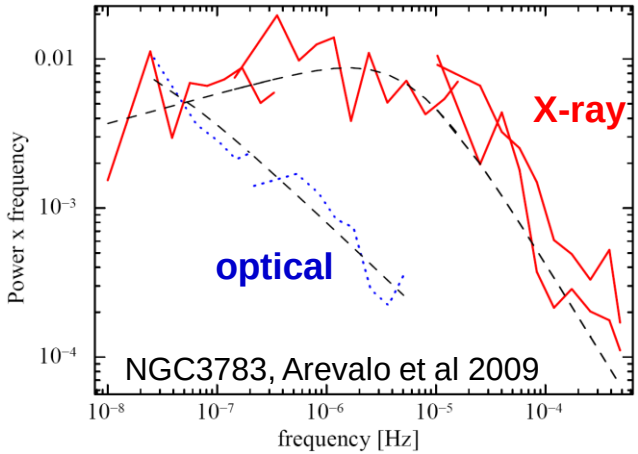
Simulated Optical Lightcurves

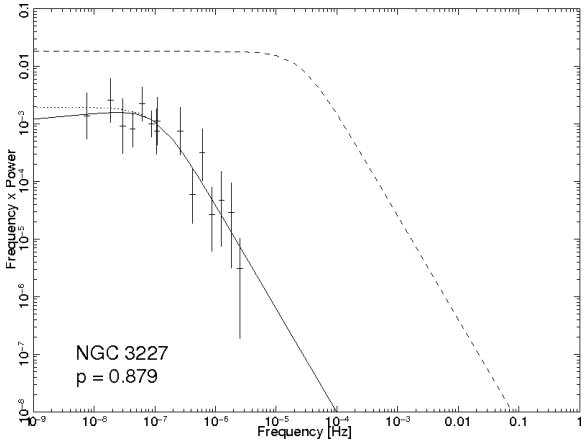
Propagating fluctuations plus X-ray reprocessing

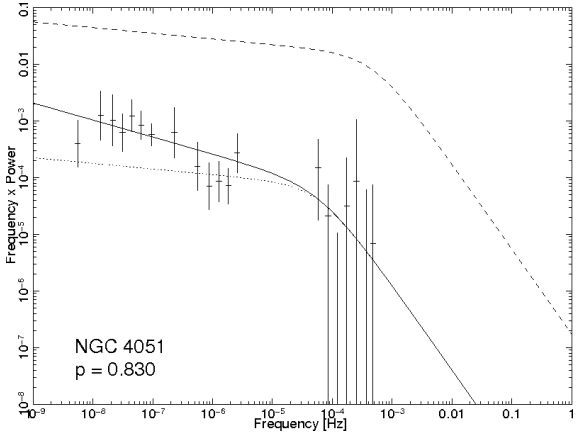


(from Arevalo et al 2008; also Arevalo and Uttley 2006)

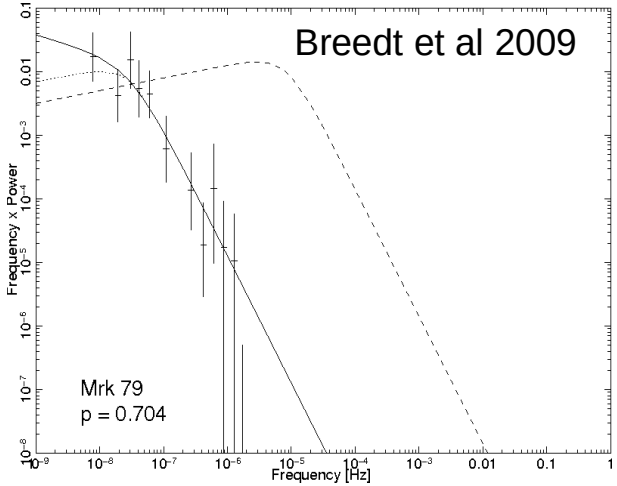
Optical and X-ray PSDs



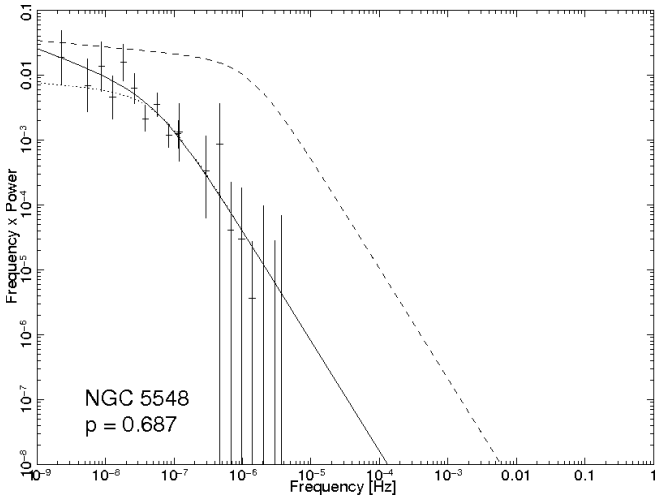




Breedt et al submitted

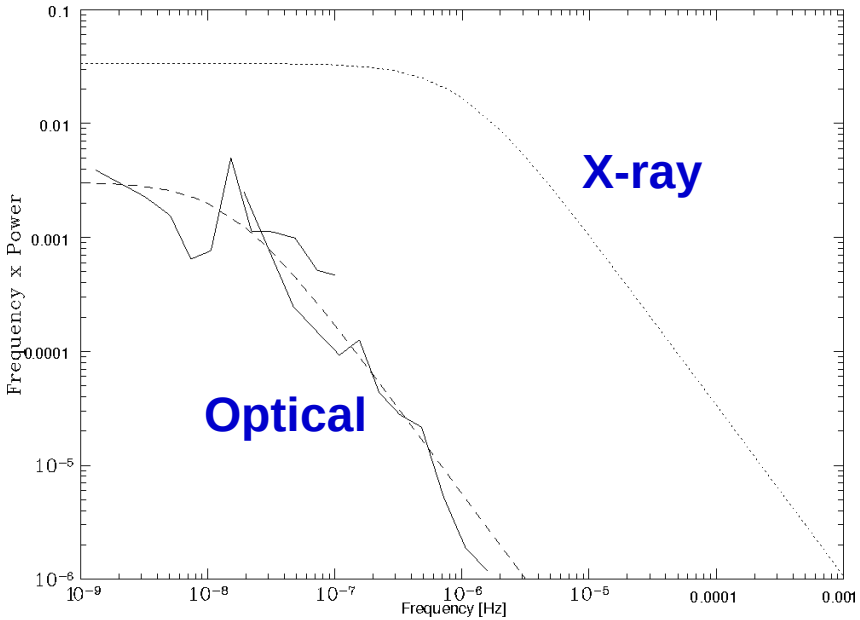


Errorbars - Optical data.
Dashed line – X-rays



Simulated optical and X-ray PSDs

Breedt et al in prep.

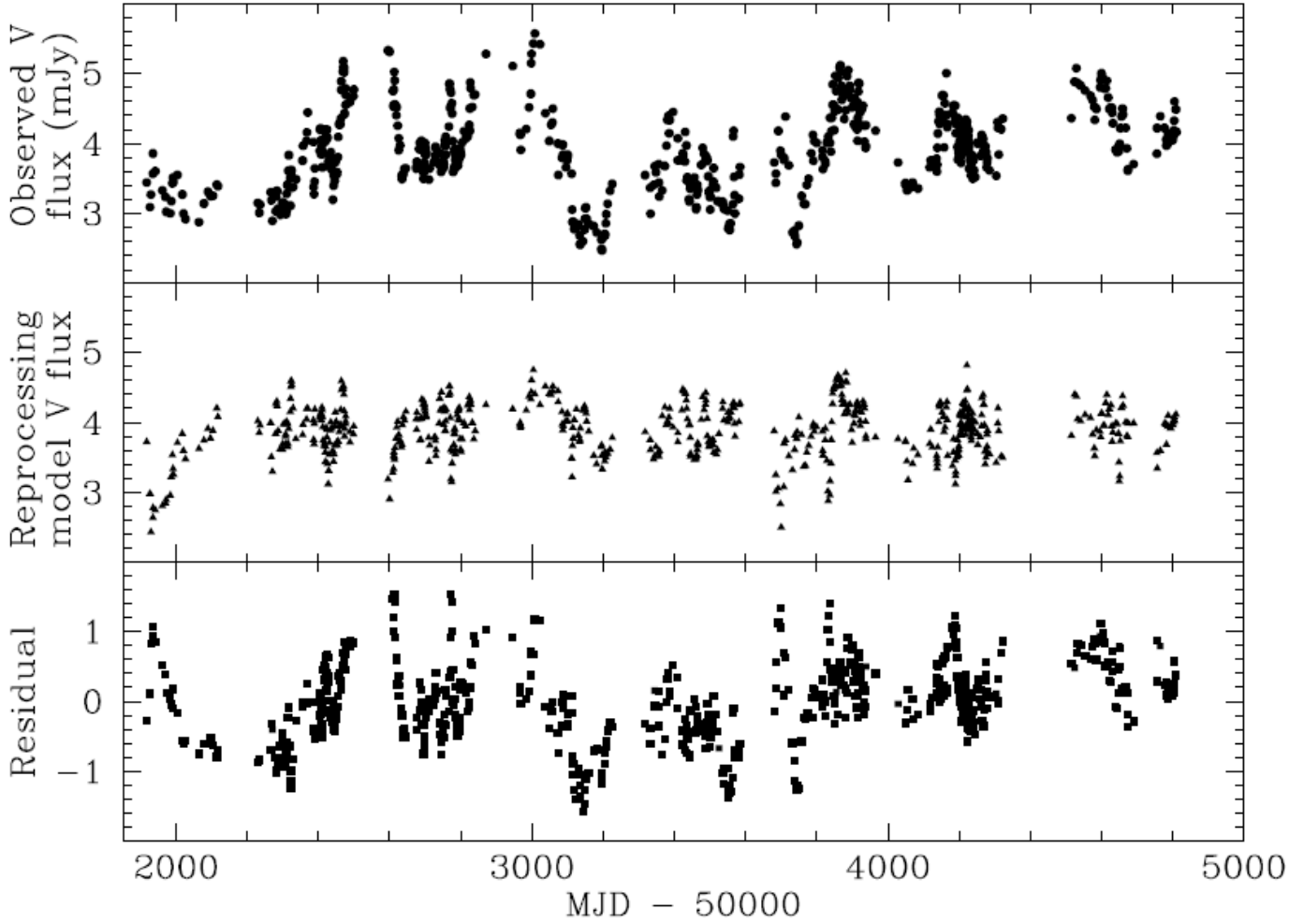


Simulated reprocessed optical PSD shows same slopes as the input X-ray PSD, but the bend is about 2.5 decades lower in frequency.

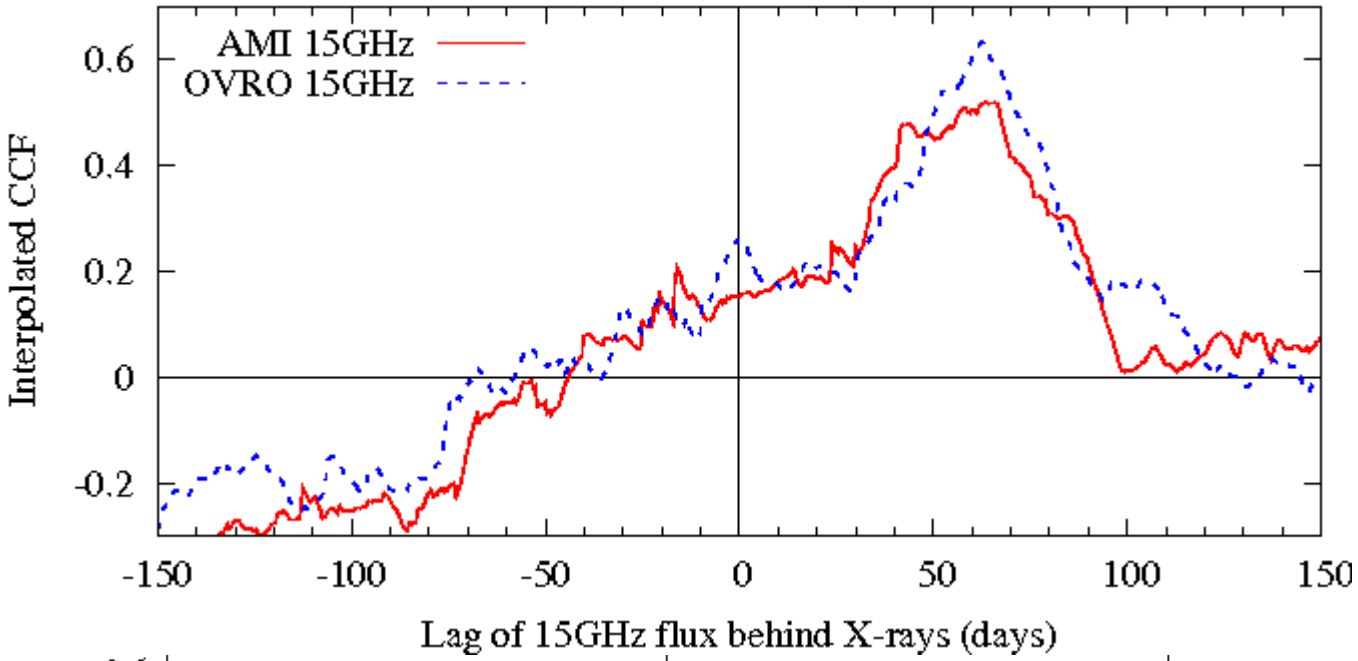
No intrinsic disc variability is included.

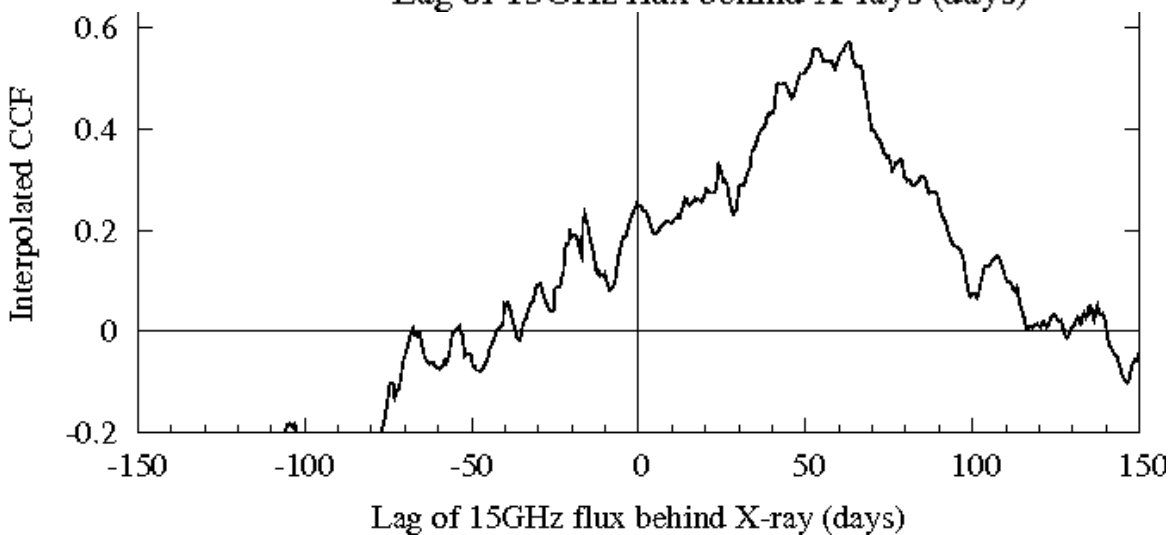
Some observed optical PSDs exceed the X-ray PSDs at low frequencies, which requires additional intrinsic disc variability.

NGC4051: Residual lightcurve

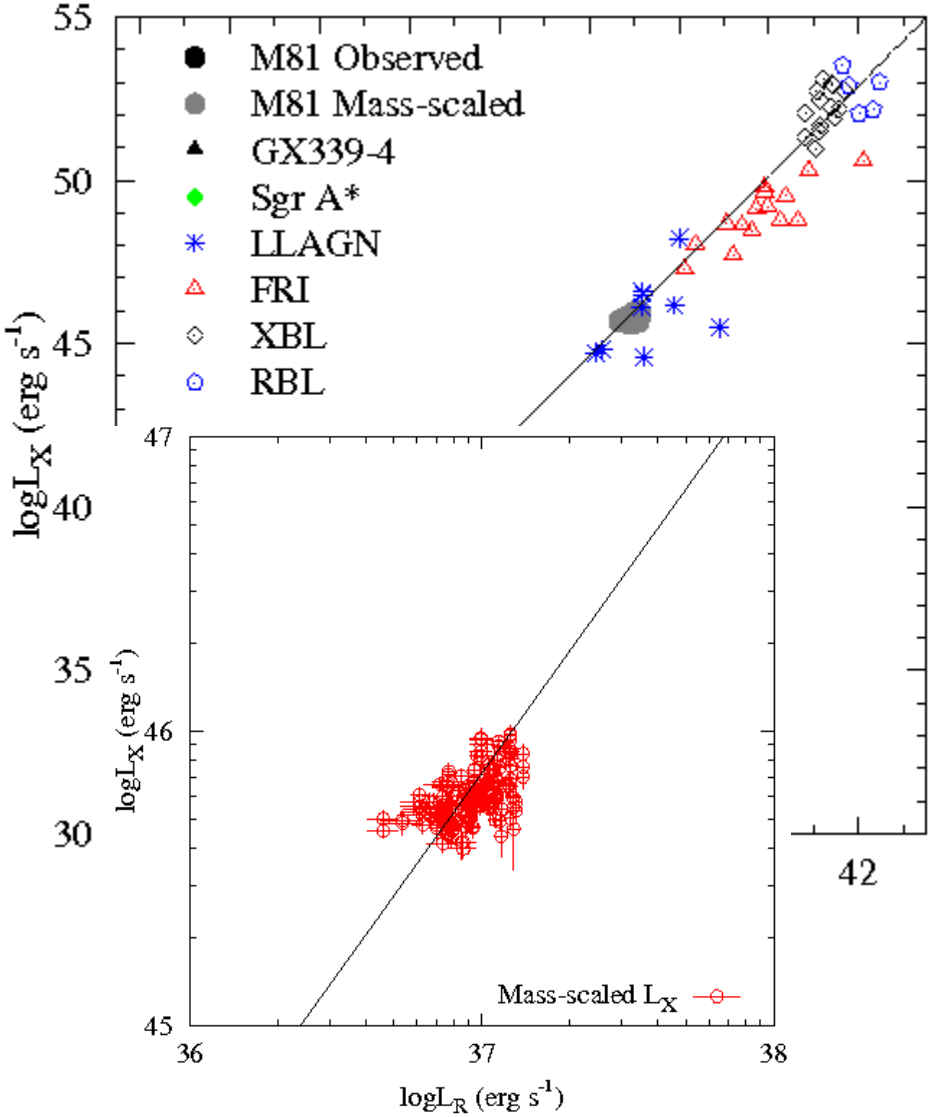


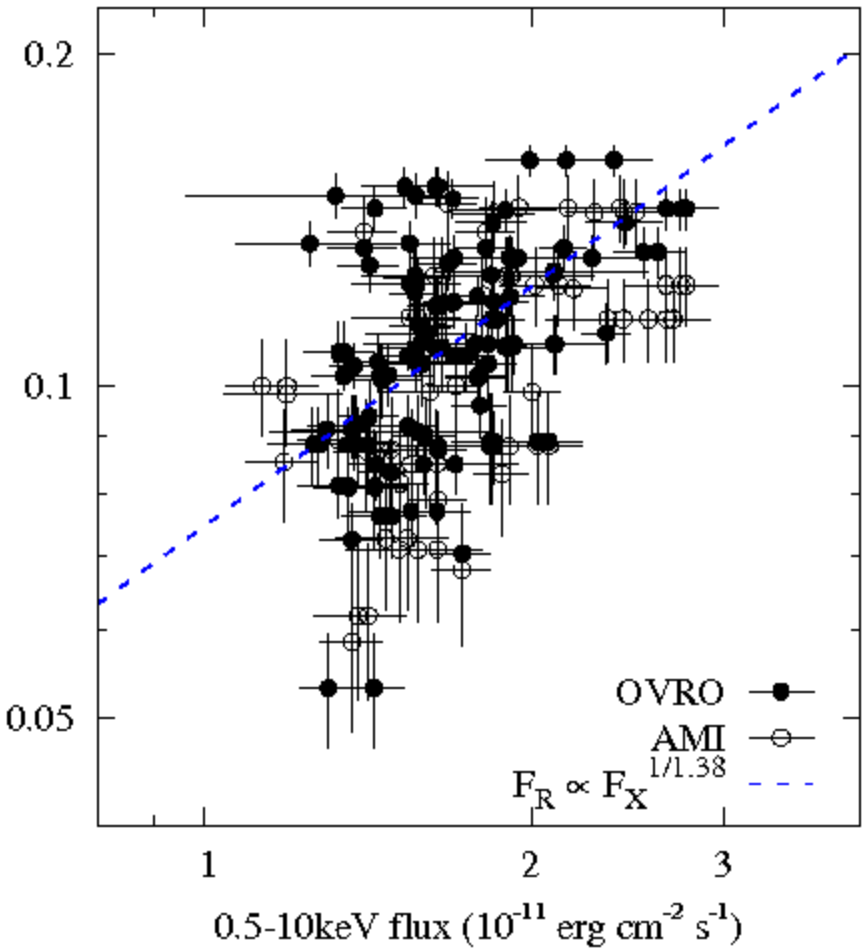
M81 X-ray and 15GHz Cross-correlation



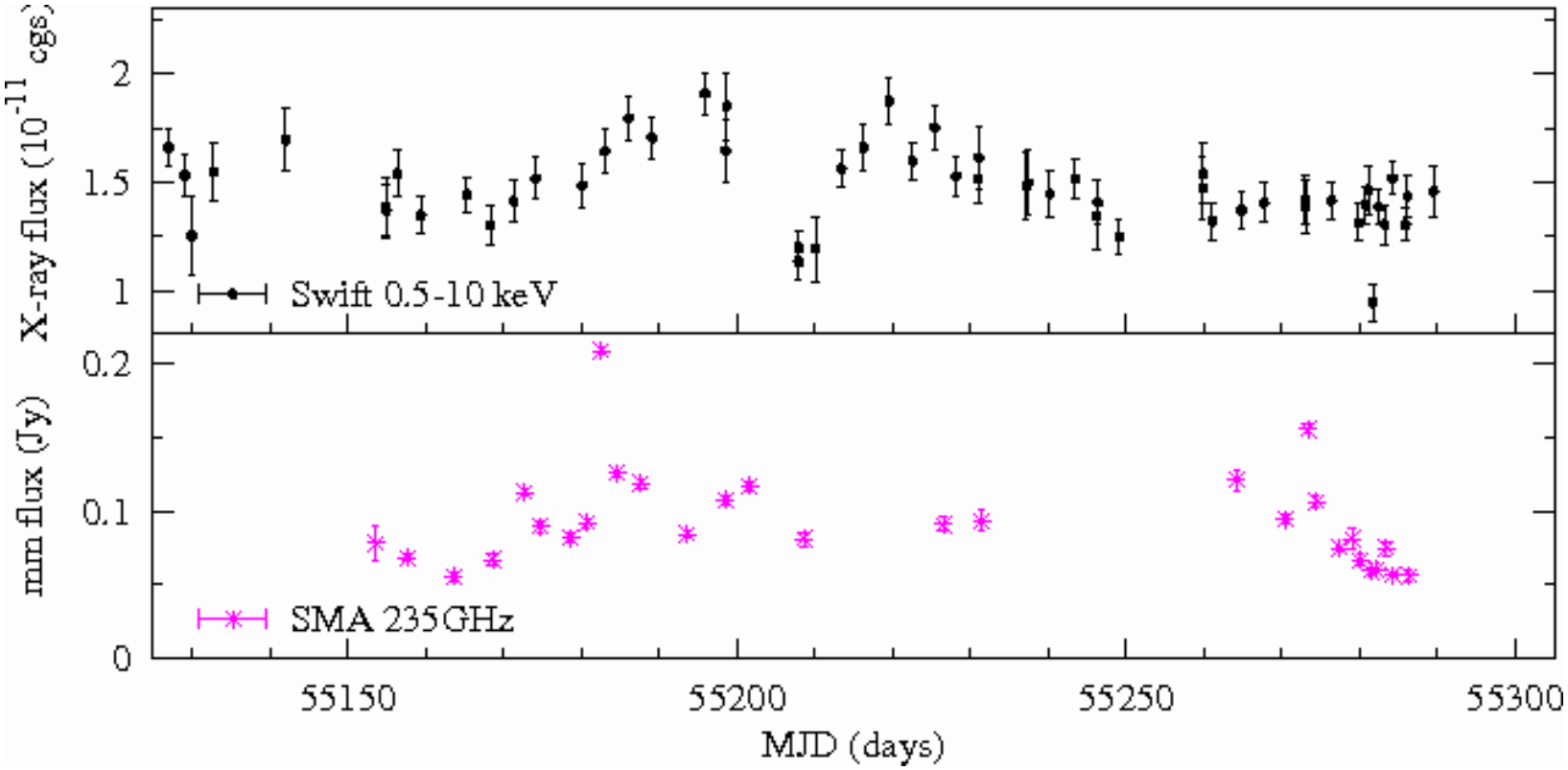


M81 X-ray and 15GHz



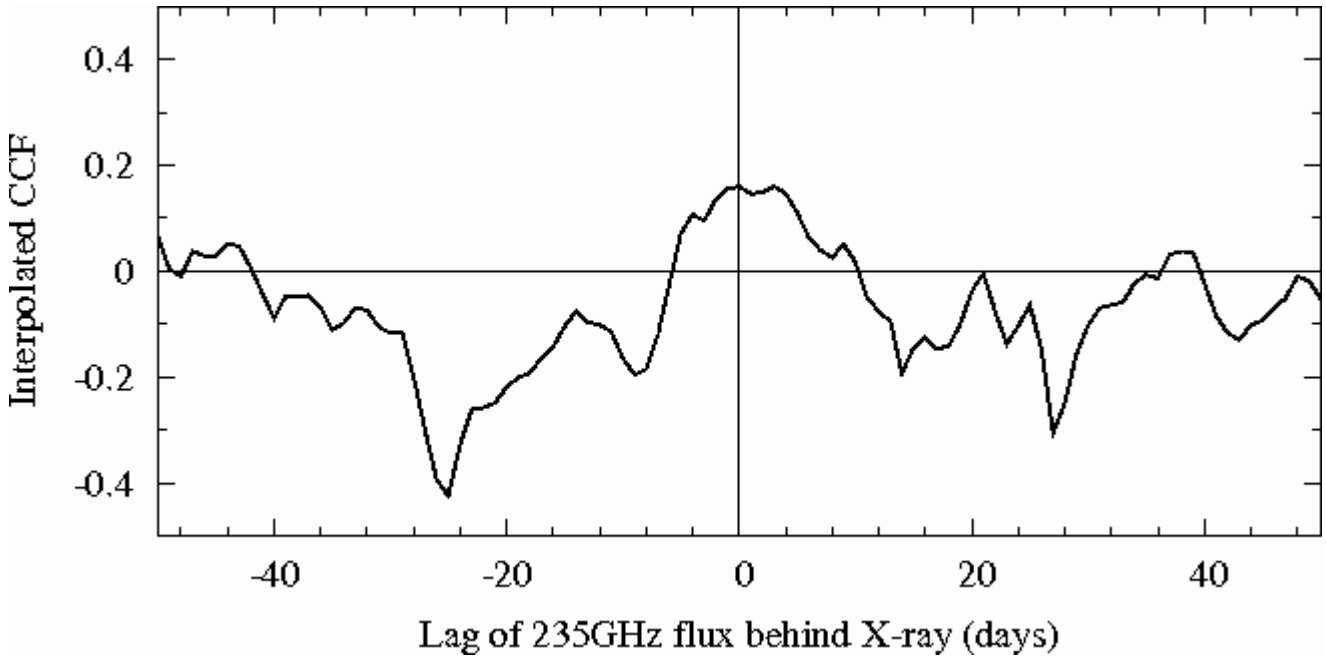


M81 X-ray and 235GHz



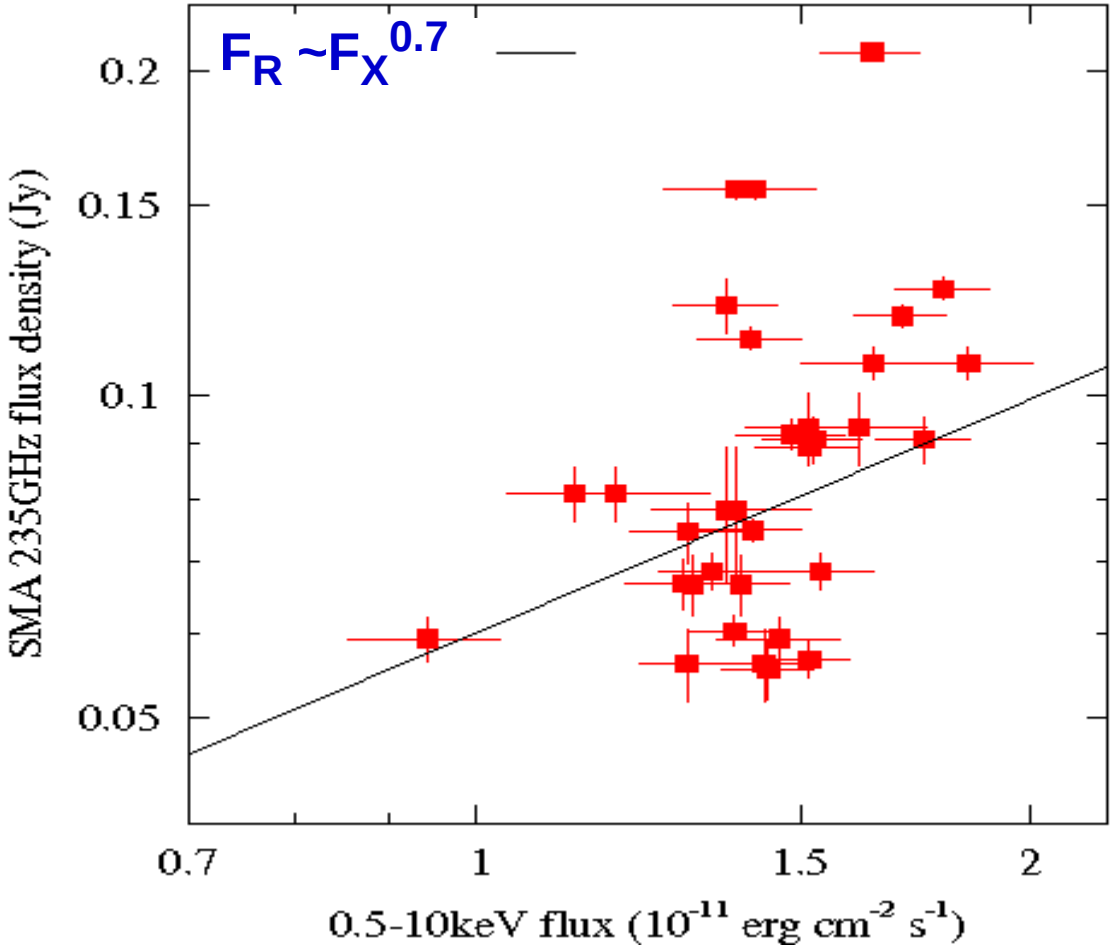
235GHz by Mark Gurwell

M81 X-ray vs. 235GHz

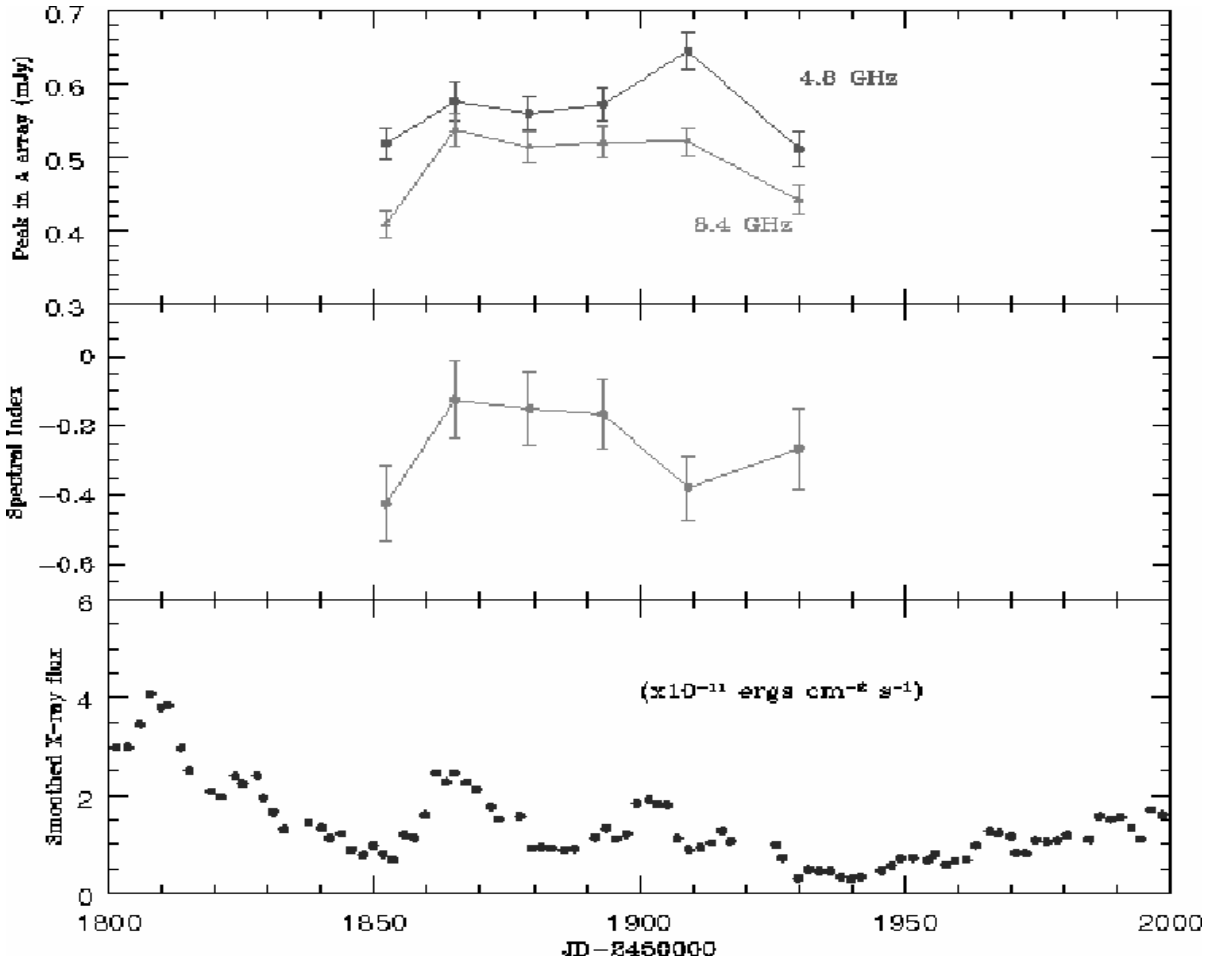


Based on ~60d lag at 15GHz, lag of ~3d expected in standard, constant velocity, jet model (Blandford and Konigl 1979) at 235GHz

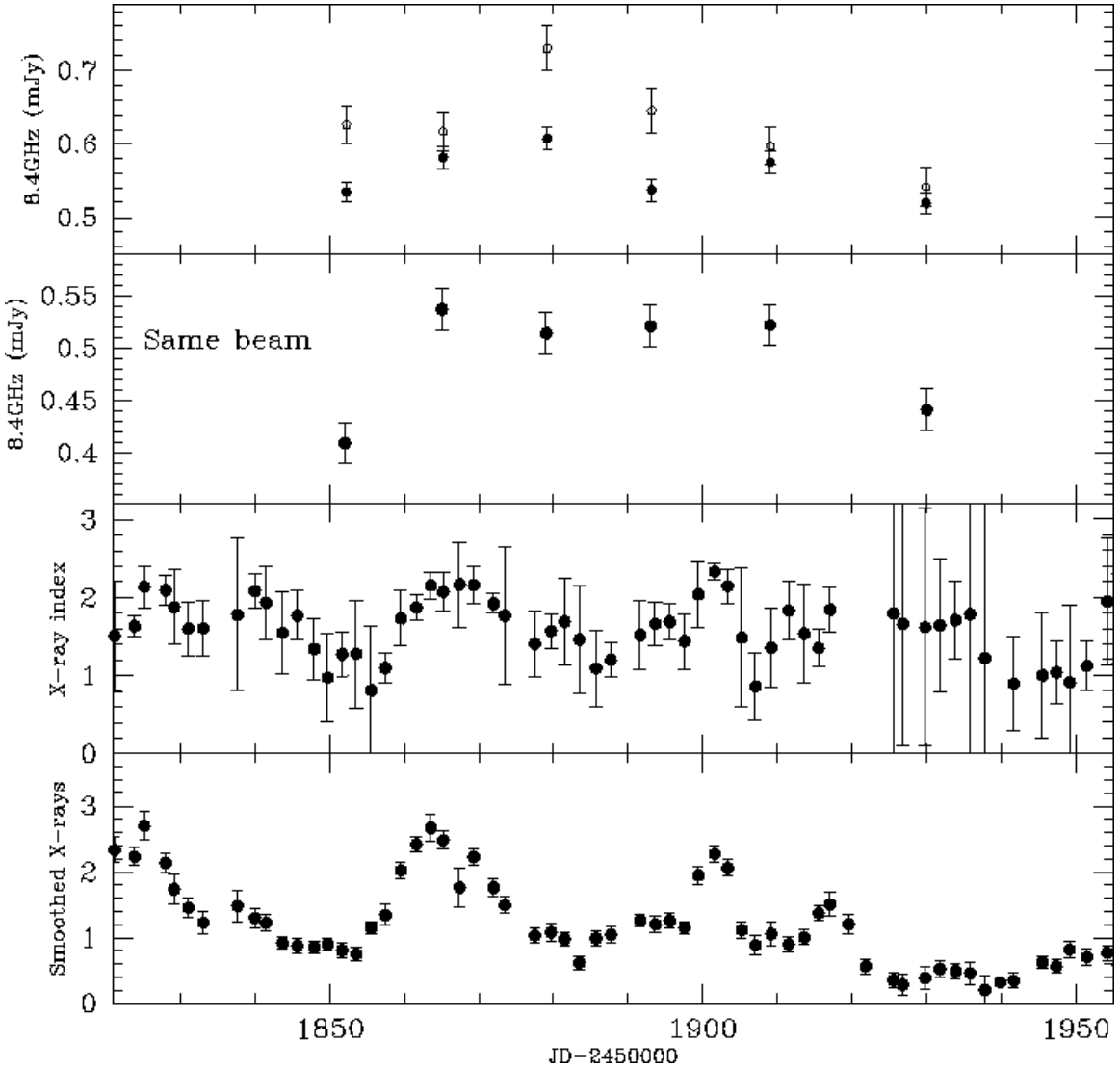
M81 X-ray vs. 235GHz



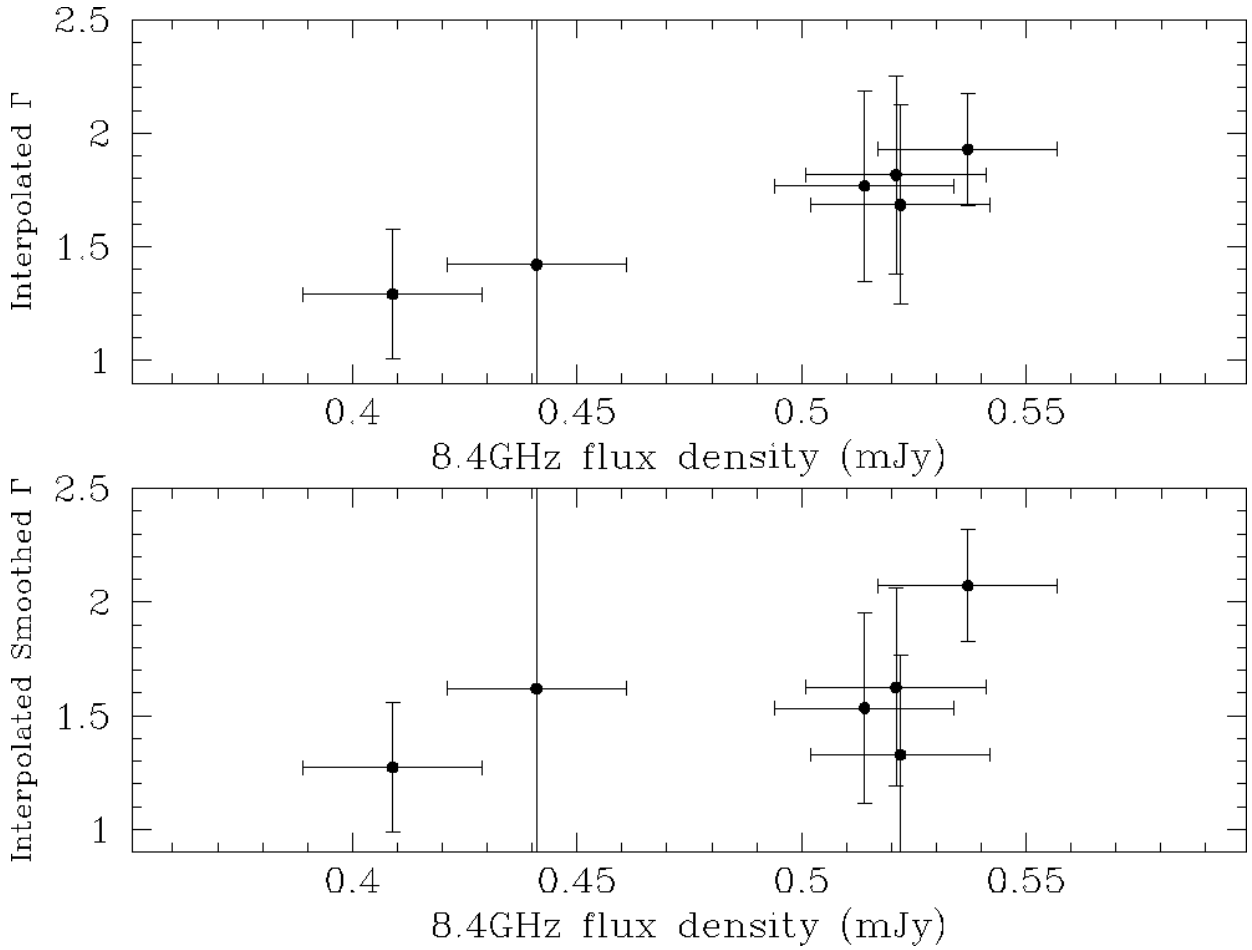
NGC4051 radio spectra



NGC4051 X-ray Spectra and radio



NGC4051


Interpolated Γ
2.5
2
1.5
1
0.4
0.45
0.5
0.55
8.4GHz flux density (mJy)
Interpolated Smoothed Γ
2.5
2
1.5
1
0.4
0.45
0.5
0.55
8.4GHz flux density (mJy)

Conclusions

Reprocessing of X-ray emission from the accretion disc is an important source of optical variability in all AGN.

Reprocessed component depends mainly on disc temperature, ie solid angle subtended by X-ray source.

But reprocessing isn't the only source of optical variability

Intrinsic fluctuations in the disc are probably also important,

and reprocessing from the torus might play a small part.