

AGN X-ray Variability and relationship to optical and radio emission

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OUTLINE OF TALK

AGN X-ray continuum variability and its origin

Optical variability – relationship to X-rays

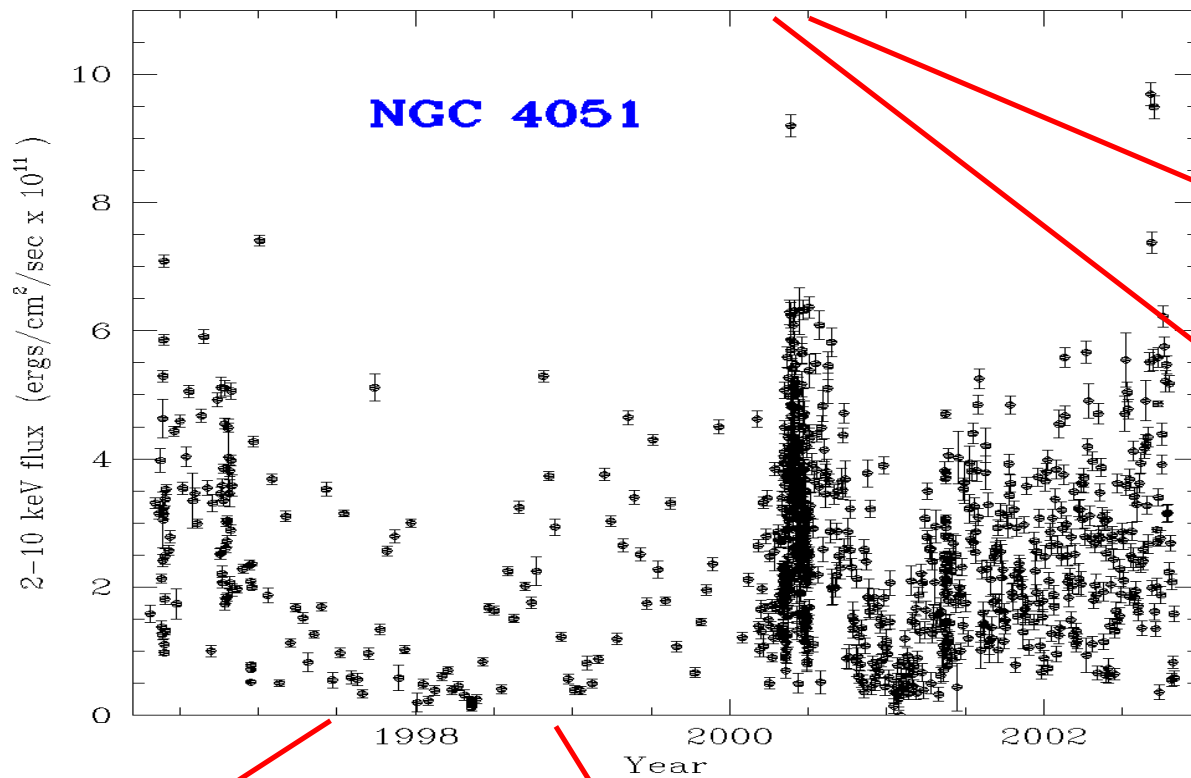
Radio variability of AGN – relationship to X-rays



TYPICAL AGN X-RAY DATA....

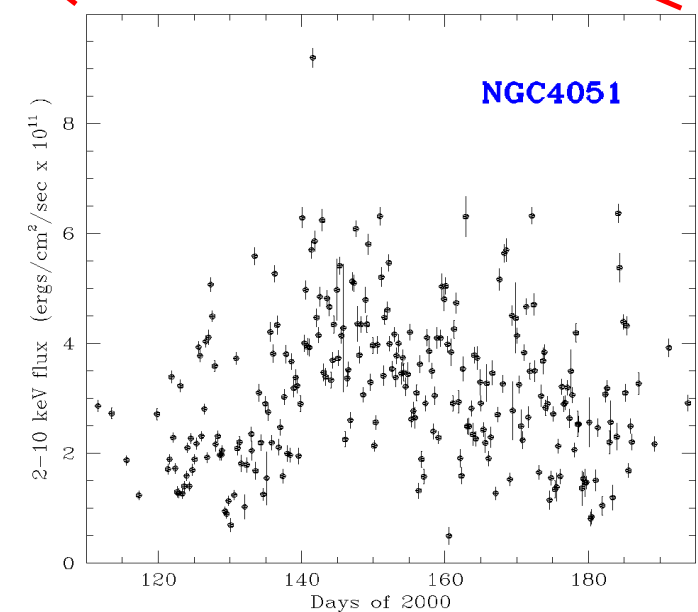
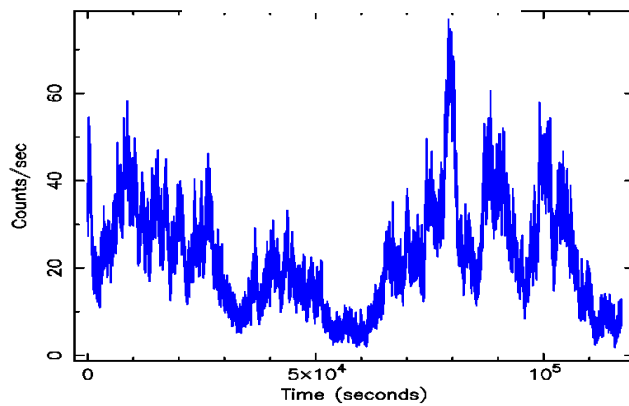
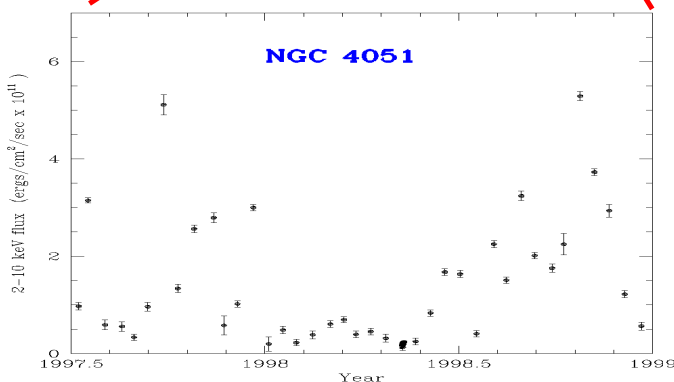
Eg NGC4051 RXTE Long Timescale Observations

(McHardy et al 2004)



'low-flux period'

XMM

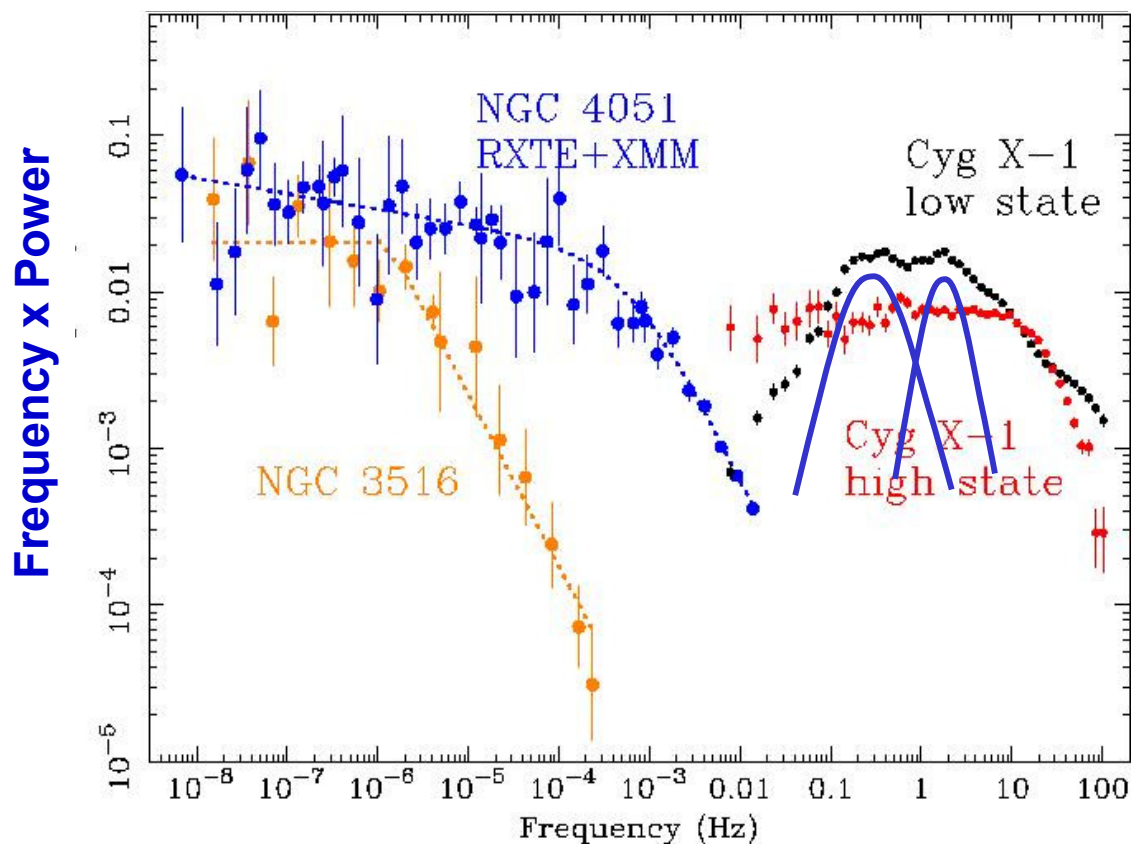




TIMING STATES

Frequency x Power

'Unfolded' Power Spectral Density (PSD)



(M^cHardy et al., 2004)

Cyg X-1 Low-hard state PSD:

Can be described either as powerlaw with two bends, or as sum of 'Lorentzians'

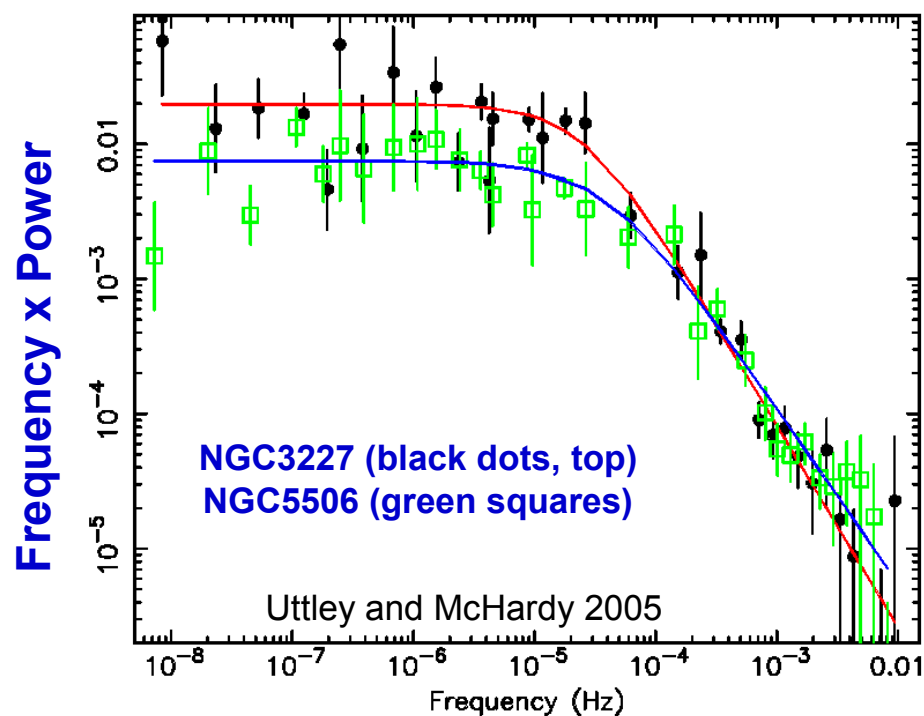
- **NGC4051** partly like Cyg X-1 low-hard state, but no second break

- More like high-soft state of Cyg X-1

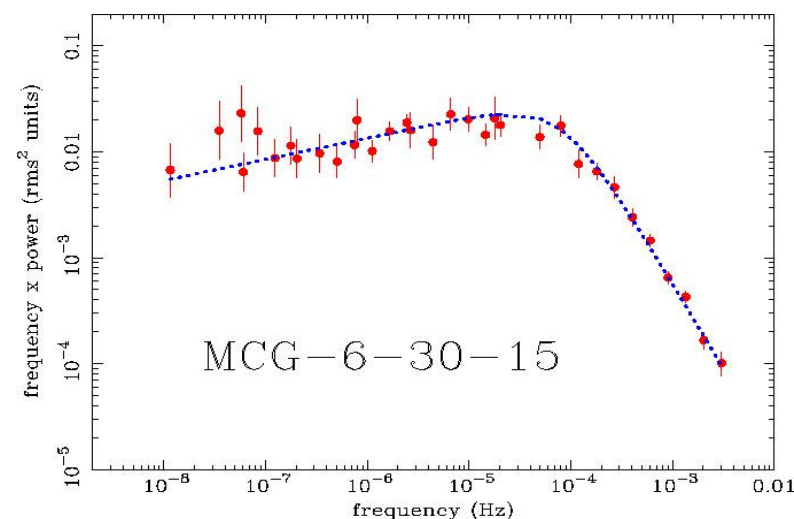
- High break timescale scales approximately linearly with mass



PSDs of other AGN?



Frequency x Power



Vaughan et al 2003
McHardy et al 2005

No (timing) hard states confirmed yet.

NGC3227 has a hard spectrum ($\Gamma=1.6$)

Timing may be more fundamental than spectra

**Lack of low state systems is probably a selection effect.
Present targets are X-ray bright - higher accretion rates**

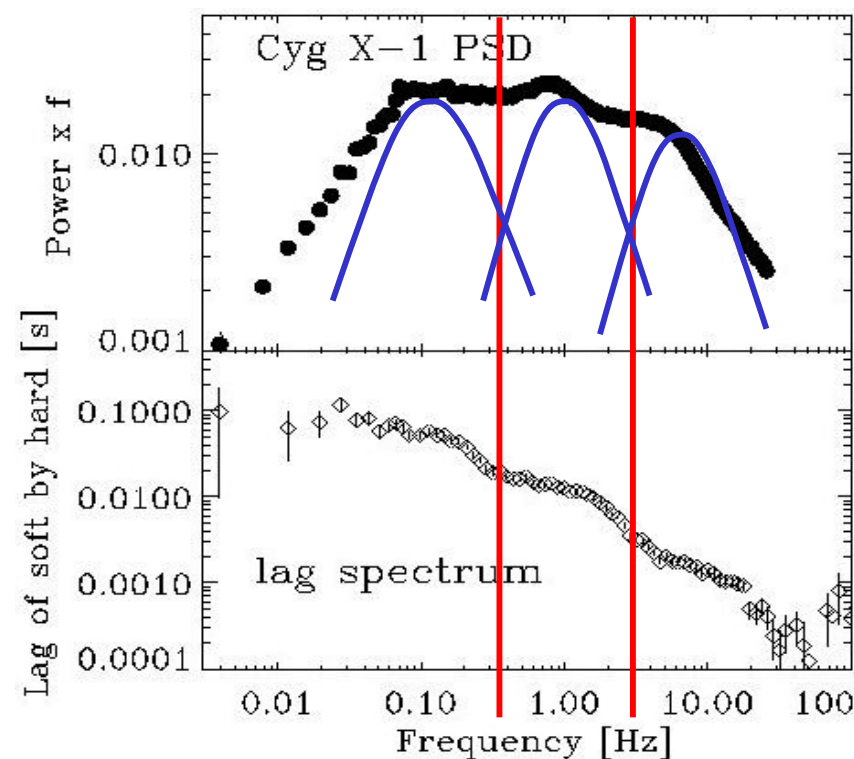
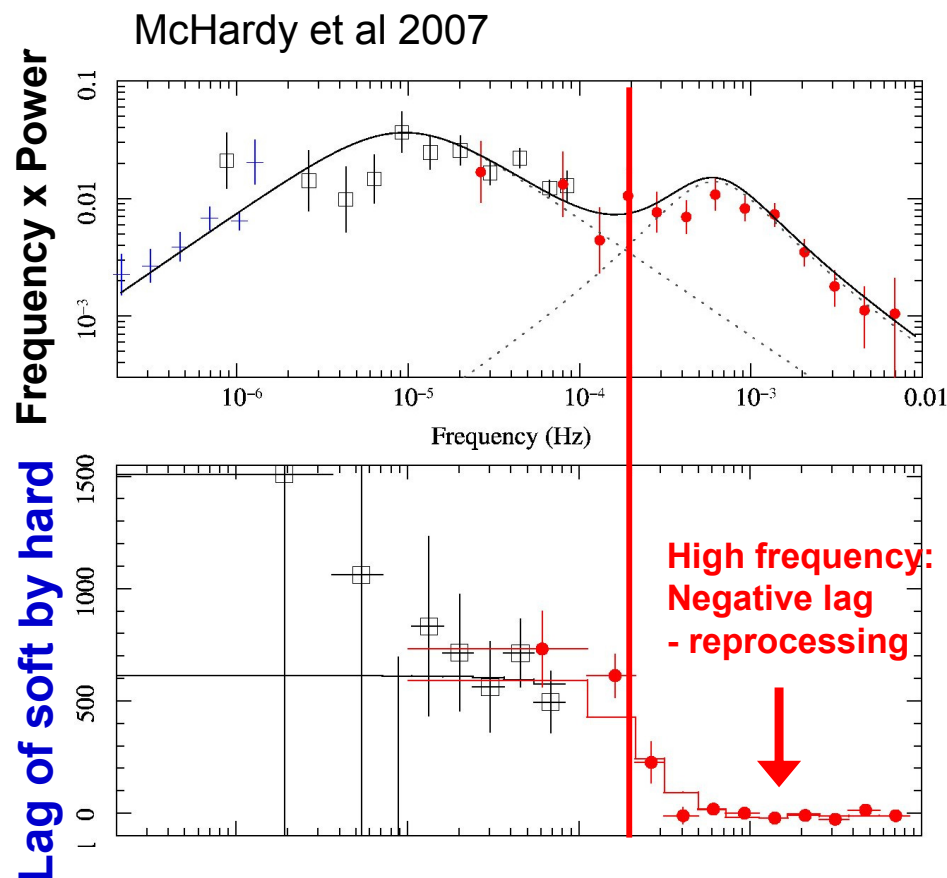
Another state diagnostic: Time Lags



- **Take lightcurves in 2 different energy bands**
- **Split each lightcurve into separate Fourier components**
- **Measure time lag between the two energy bands as function of Fourier timescale.**
- (See Nowak and Vaughan 1996)



Lorentzians and Time Lags: Akn564

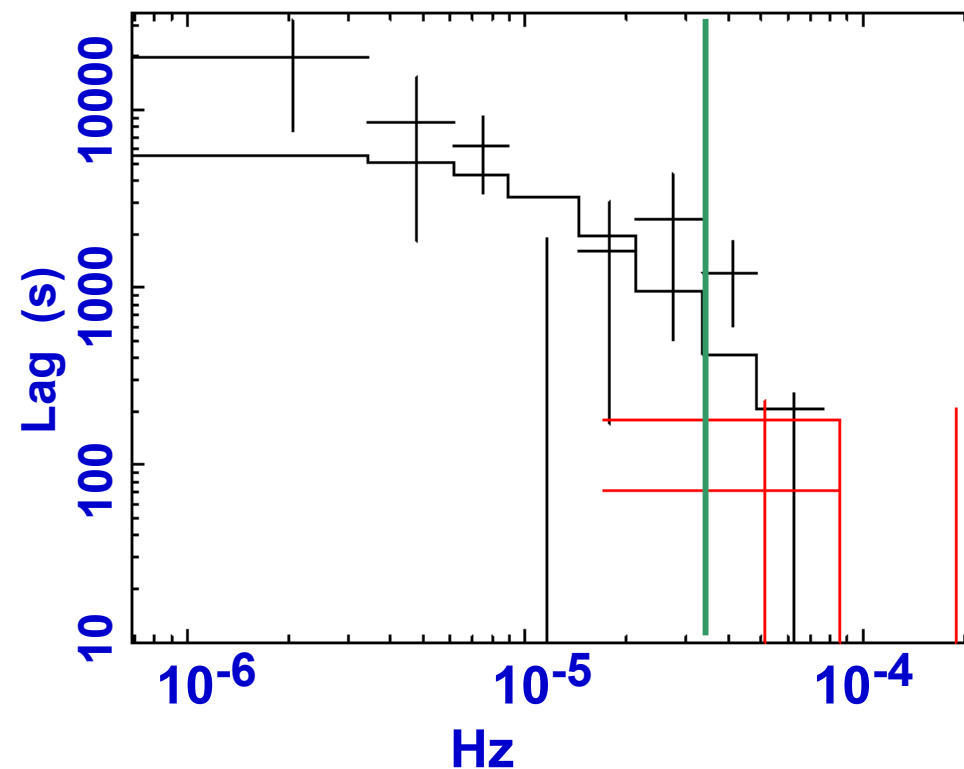
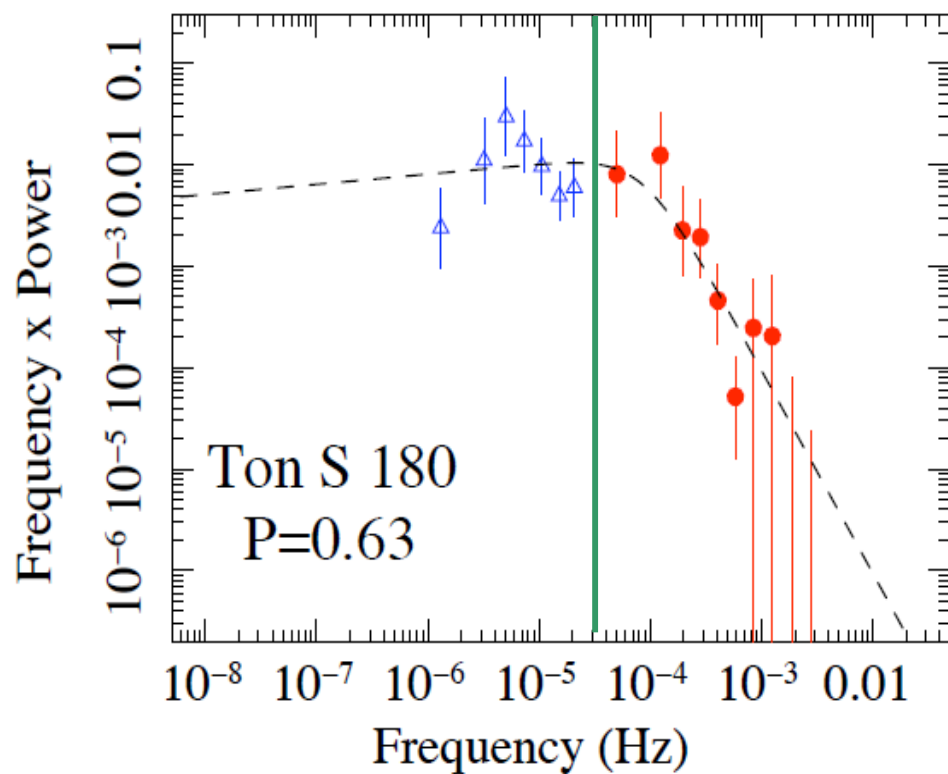


For binaries in hard or VHS state, lag is \sim constant when one Lorentzian dominates

..same in Akn564 (As $\dot{m} \geq 1$ implies VHS, not 'hard' state)



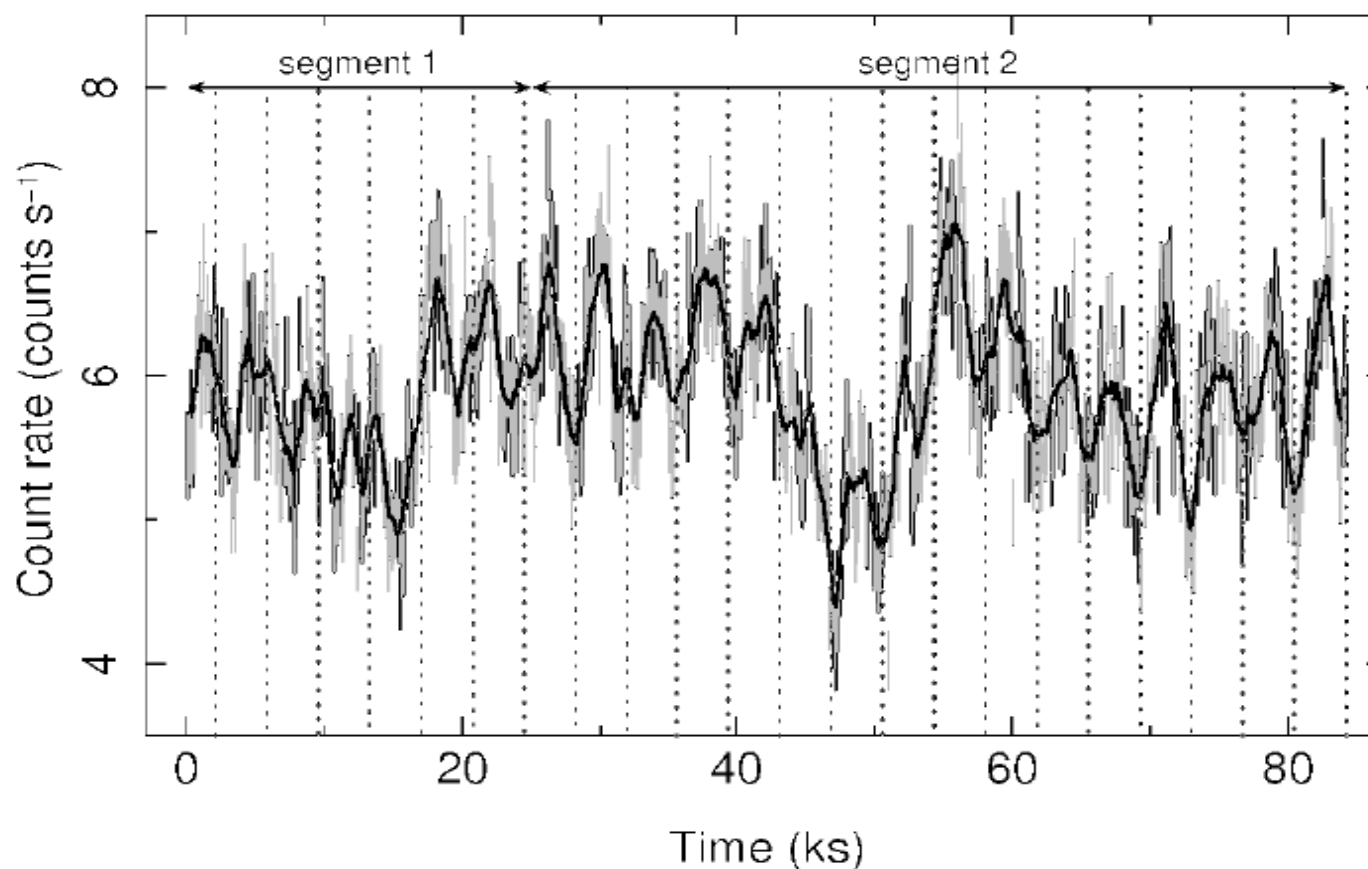
TonS180 – another possible VHS AGN



Good ASTROSAT target



AGN QPO: REJ1034+396

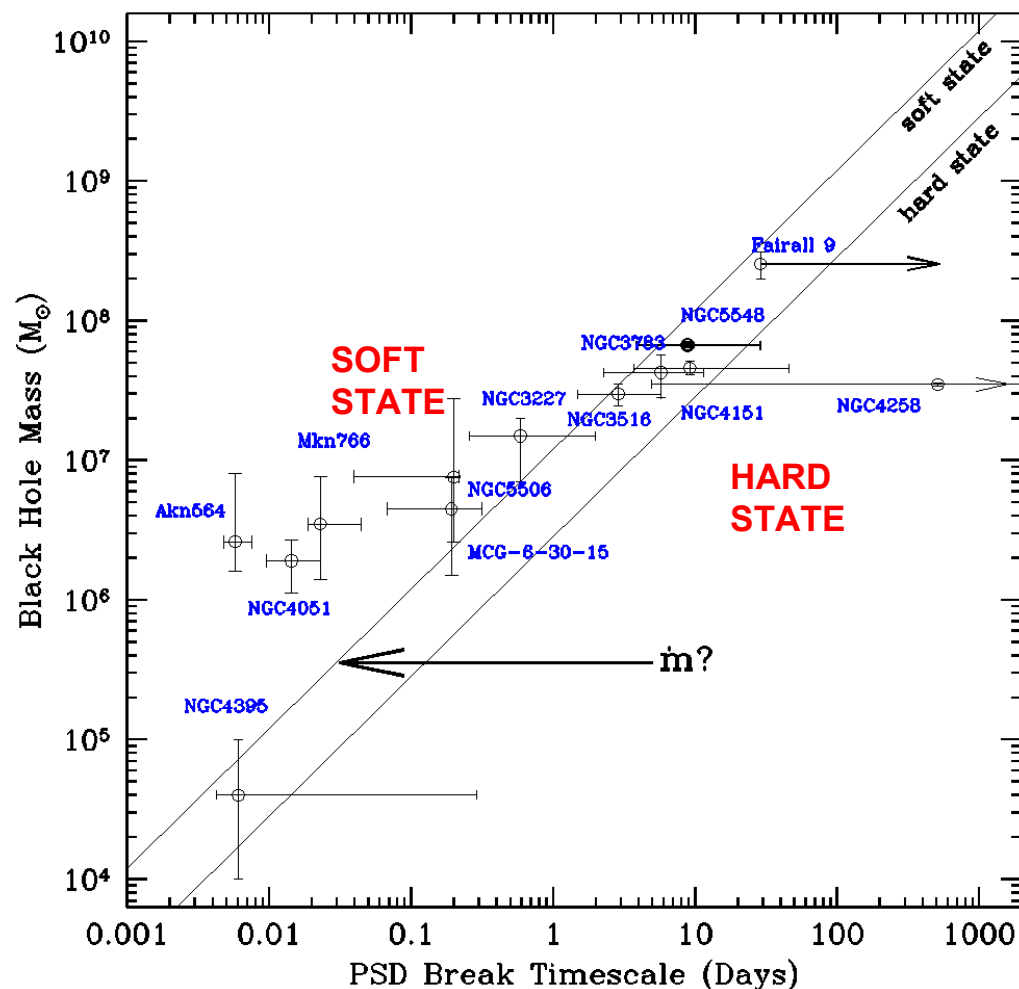


Gierlinkski et al 2008; Middleton et al 2009, 2010

Similar to 67Hz QPO in GRS1915+105 with pure mass scaling



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?

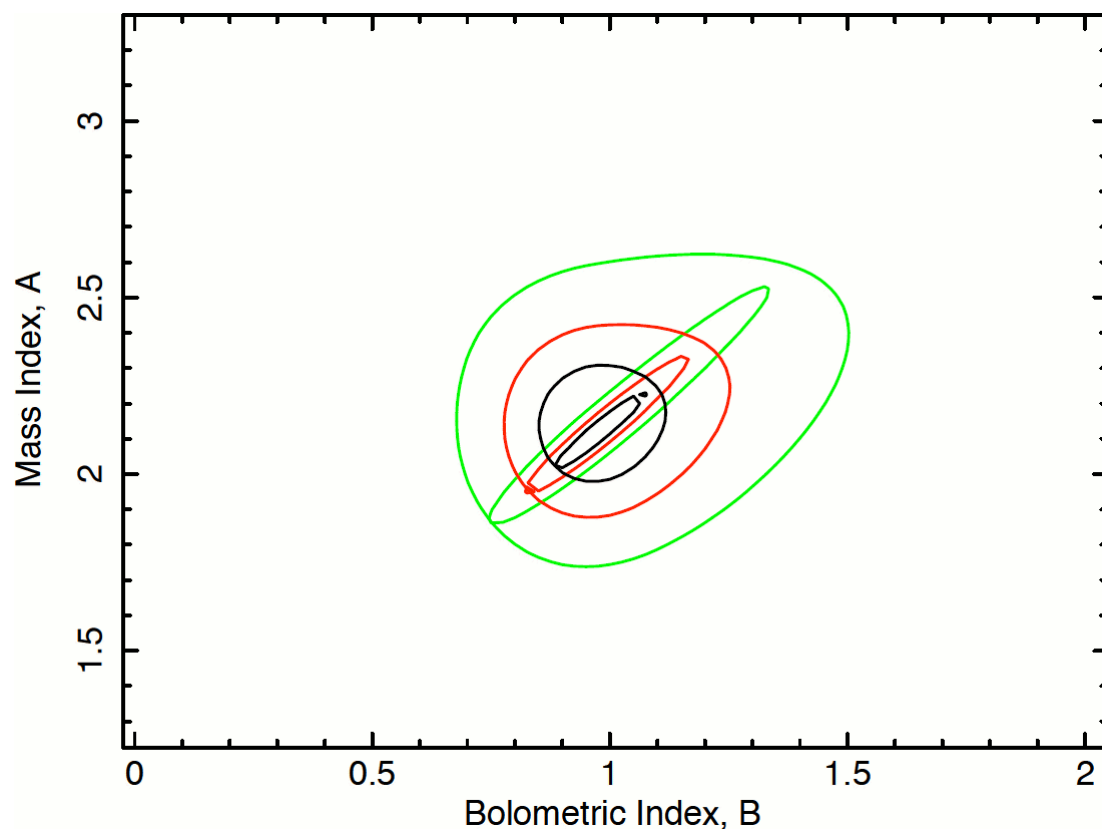
(McHardy et al 2004, 5)

(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)



$$\text{AGN } T_B \sim M^{1.28} \dot{m}_E^{-0.85}$$

$$\text{AGN+binaries } T_B \sim M^{1.12} \dot{m}_E^{-0.98}$$

(eg, for $M=10^8 M_\odot$, $\dot{m} = 0.1$, $T_B = 6d$)

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

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

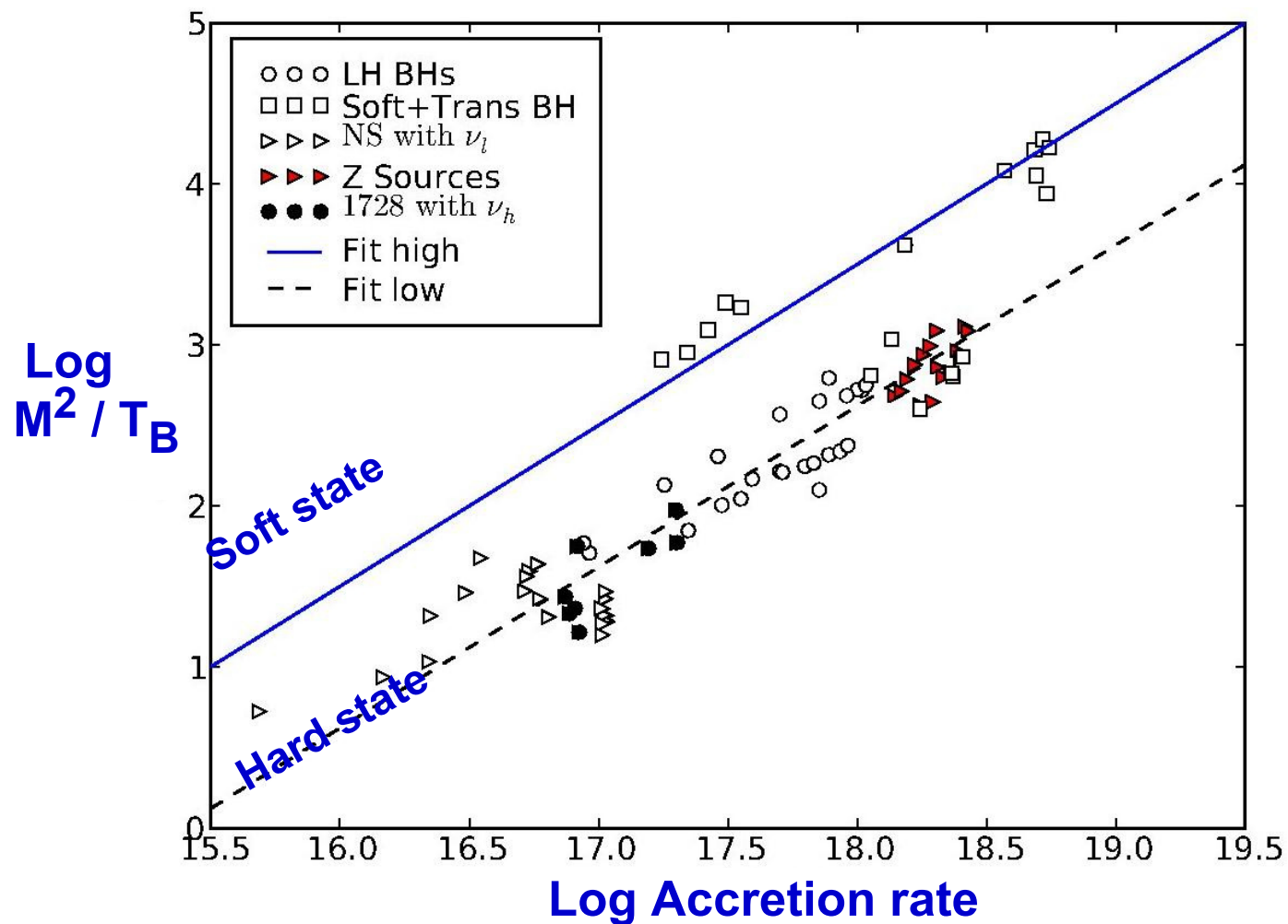
$$\text{we fit to } T_B \sim M^A L_{\text{Bol}}^{-B}$$

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

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



Hard-State Binaries



Hard/soft offset

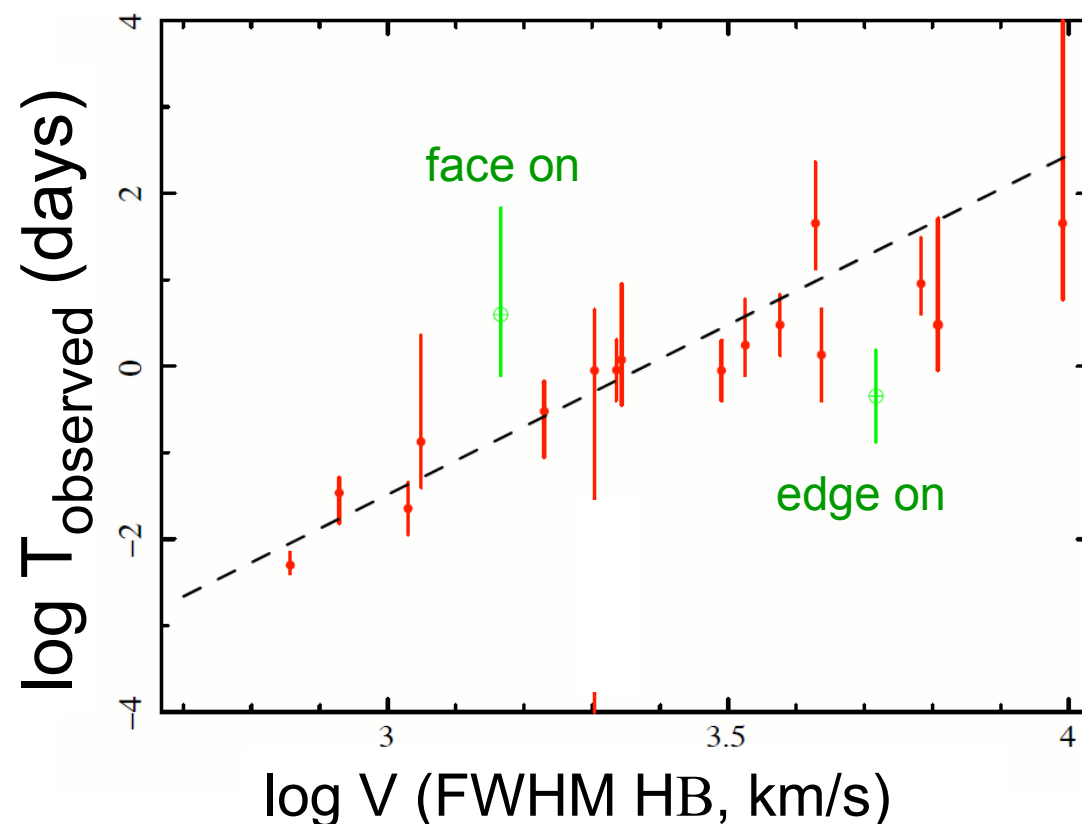
Part due to different measurement techniques but part is physical.



T_B and Linewidth, V

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

$$T_B \sim V^{3.8 \pm 0.6}$$



Simple scaling relationships:

1. $L \sim M \dot{m}_{\text{Edd}}$

2. $R_{\text{BLR}} \sim L^{0.5}$ (LOC - Kaspi et al 1996)
Bentz et al 2006

3. $v^2 \sim GM/R_{\text{BLR}}$

Then expect

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

Consistent with $T_B \sim M / \dot{m}_E$

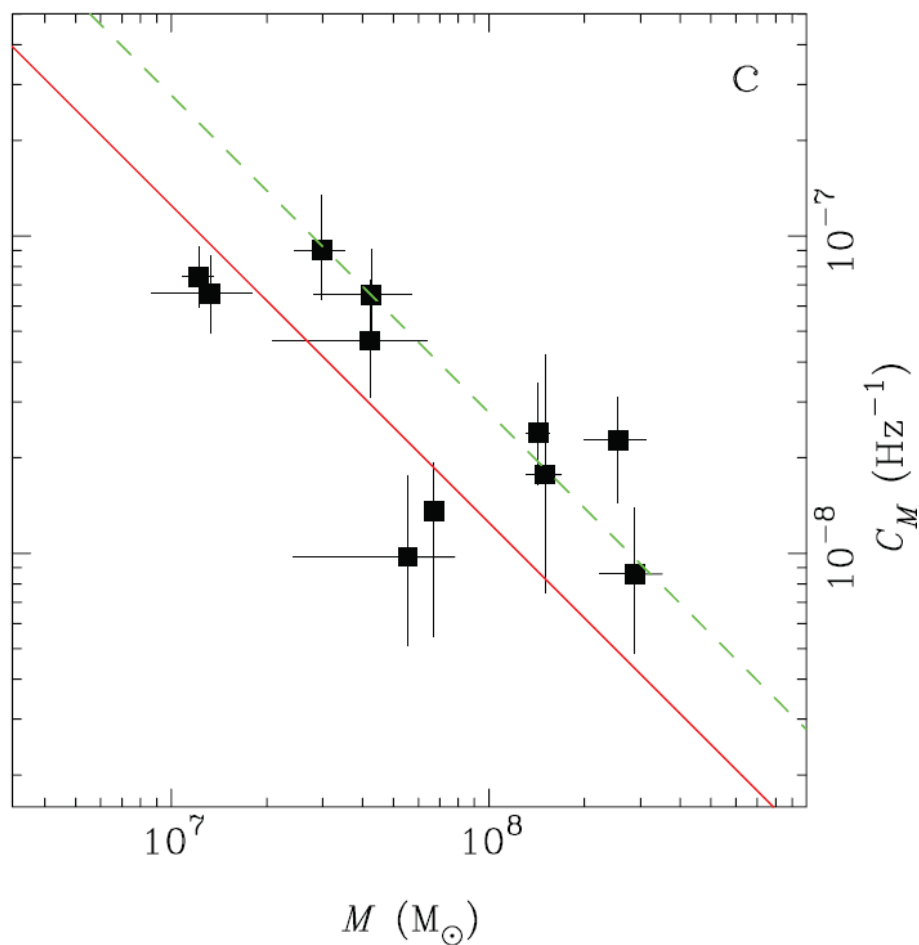
link between BH timing and larger scale AGN properties

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

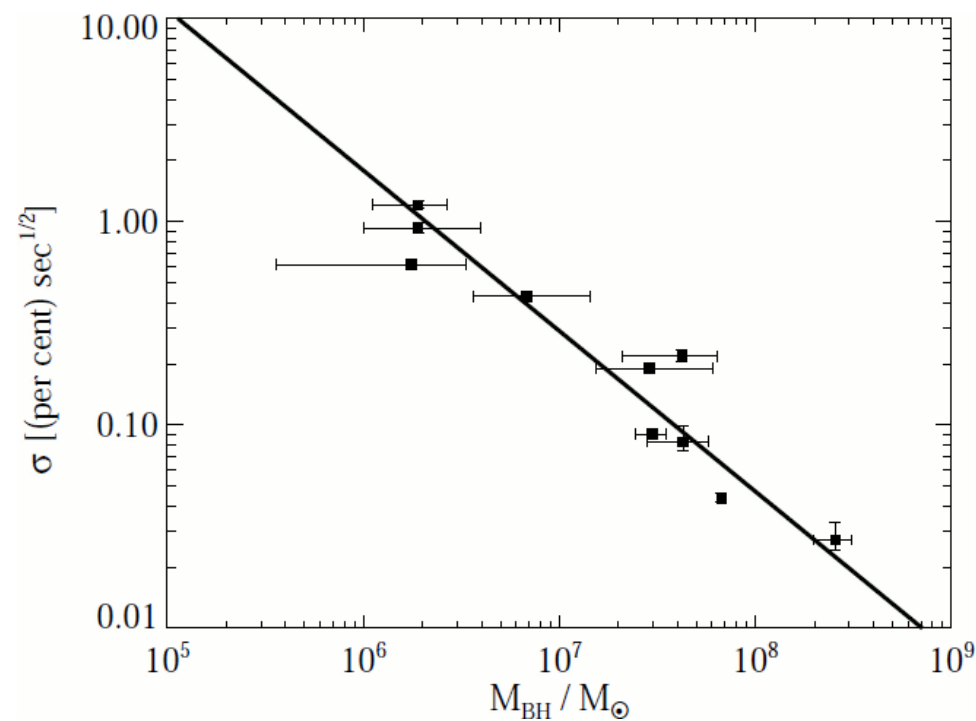


The high frequency PSD

(eg McH 1988; Green et al 1993; Hayashida et al 1998; Gierlinski et al 2008; Kelly et al 2010)



Gierlinski et al 2008

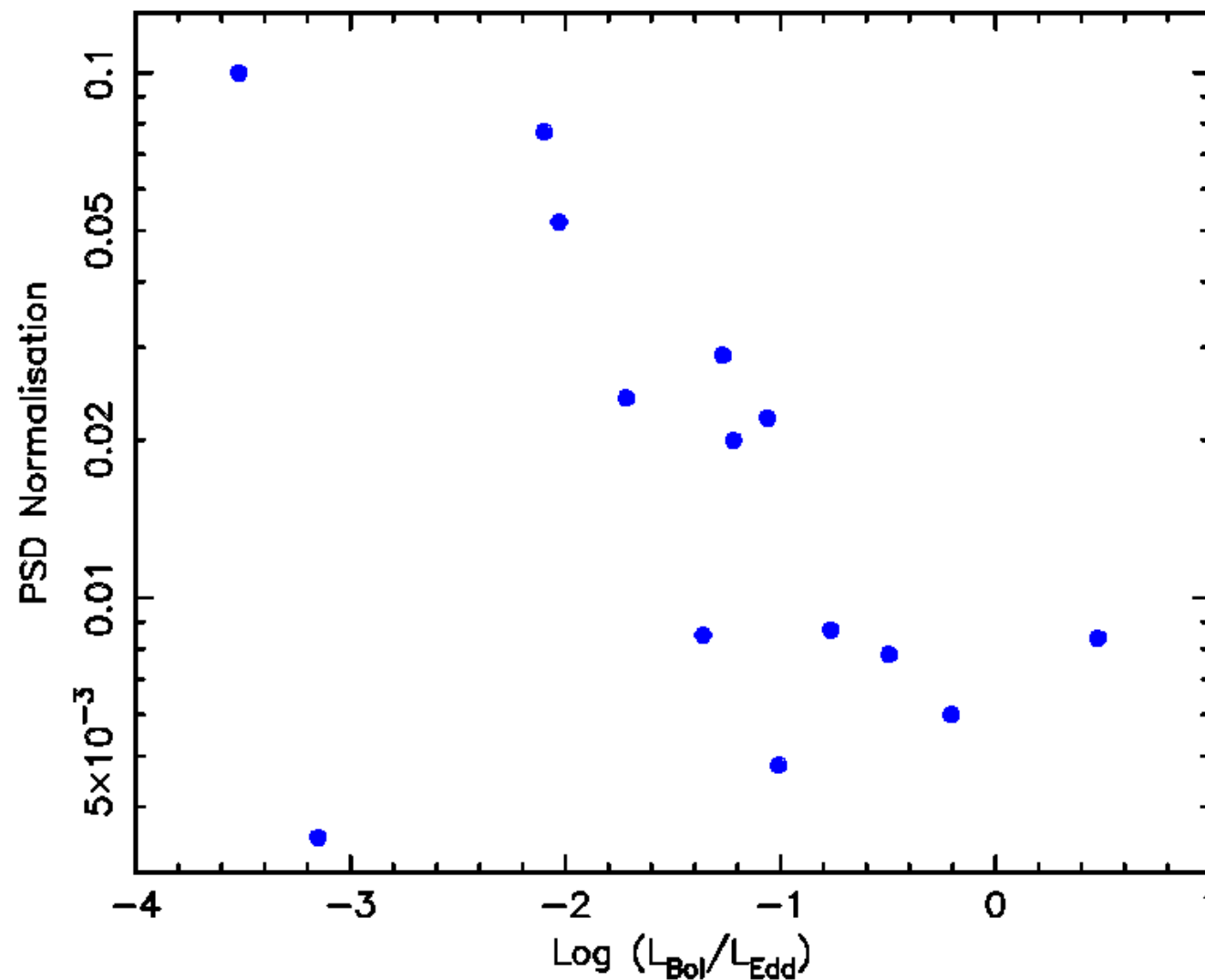


Kelly et al 2010



Low frequency PSD Normalisation

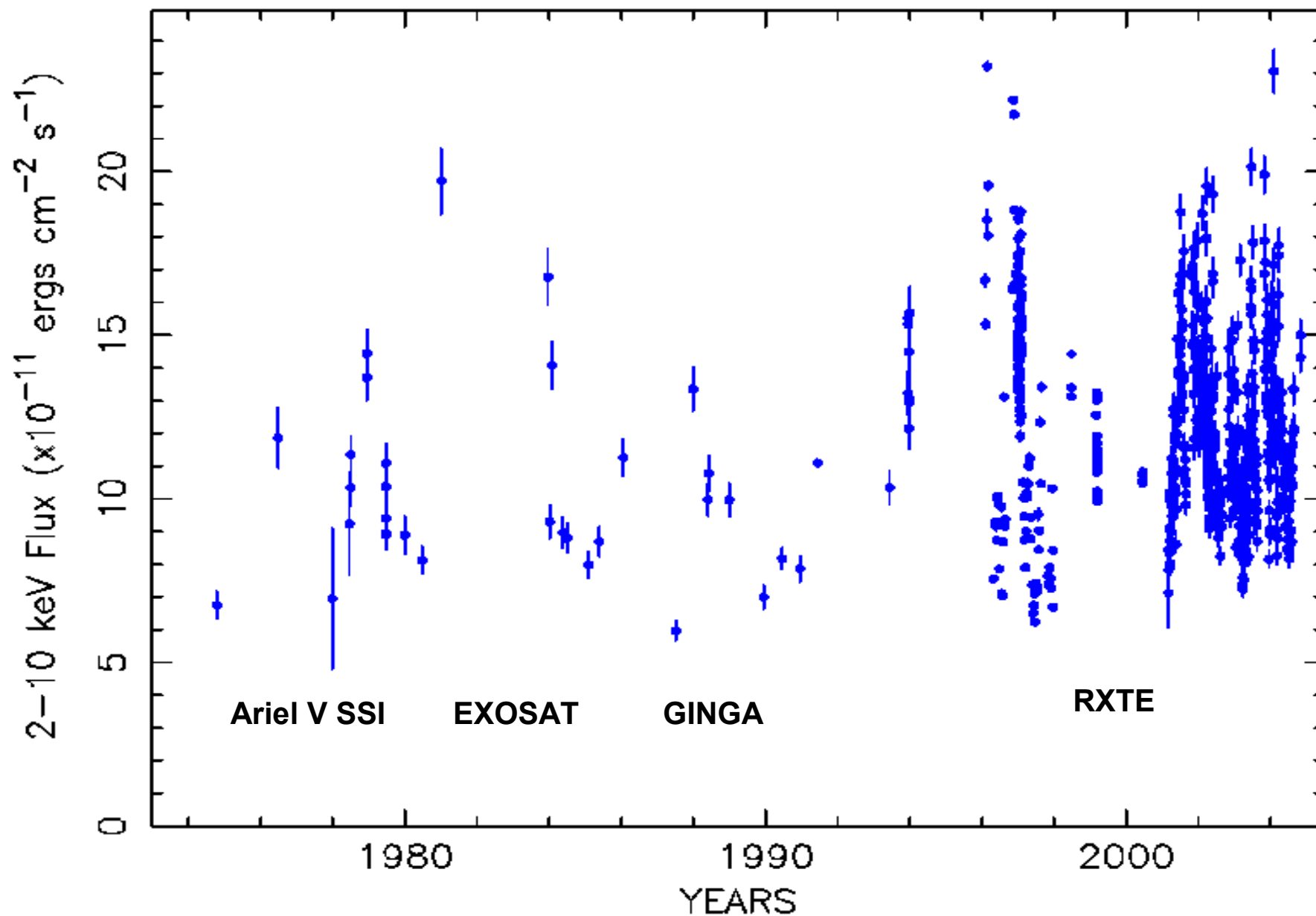
(Low frequency slope fixed at -1)



(Data from
Summons et al,
in prep)

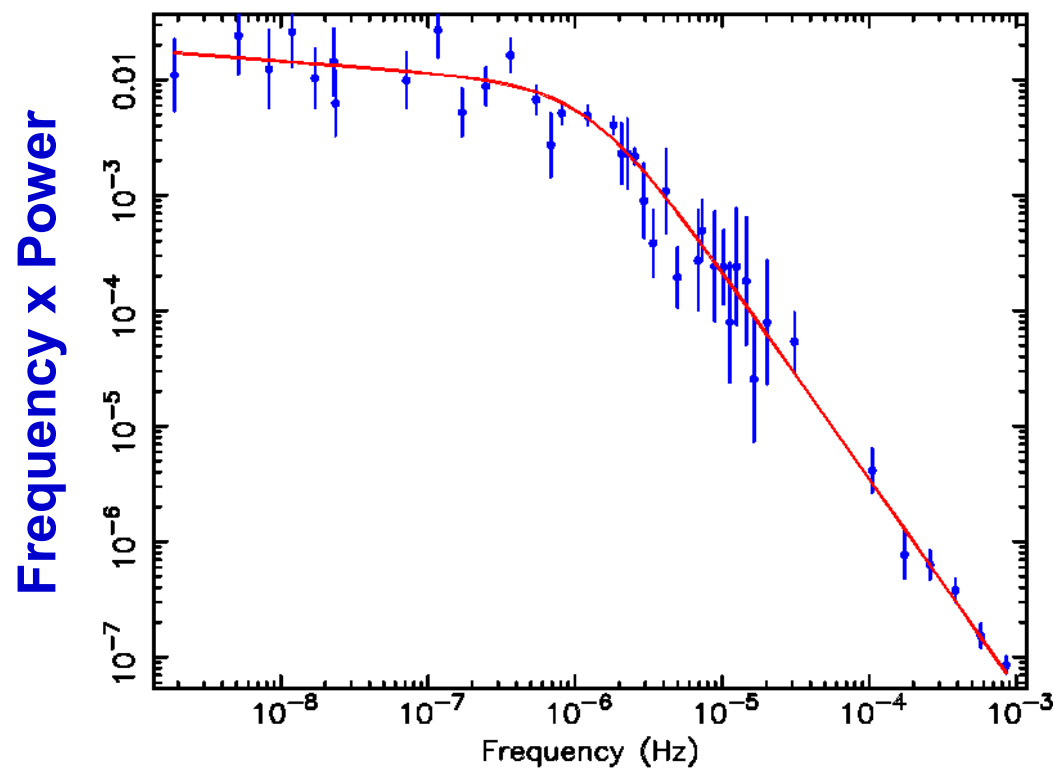


Jet-dominated sources: 3C273



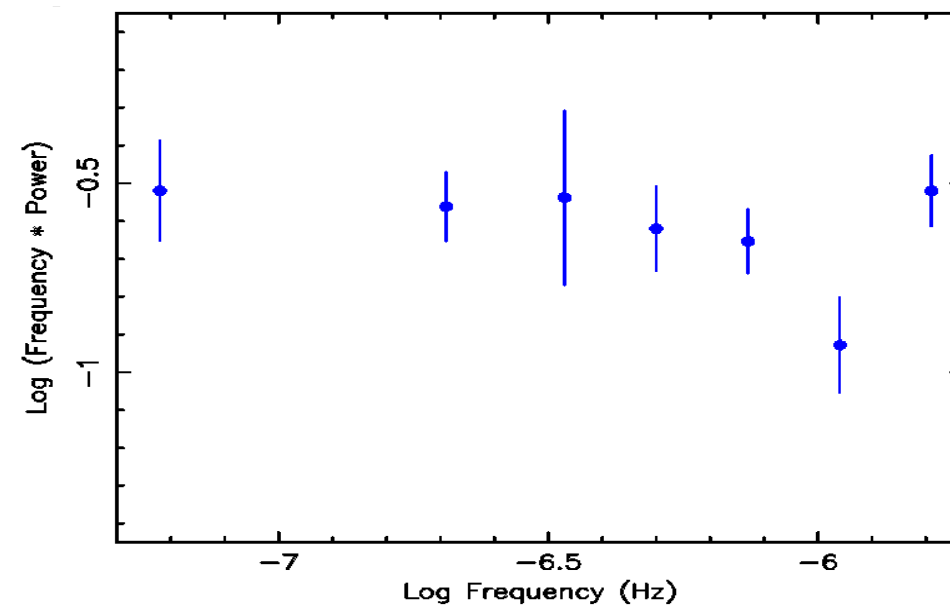


OVERALL PSD OF 3C273



Good fit to 'soft' state model
Break timescale ~ 10 days

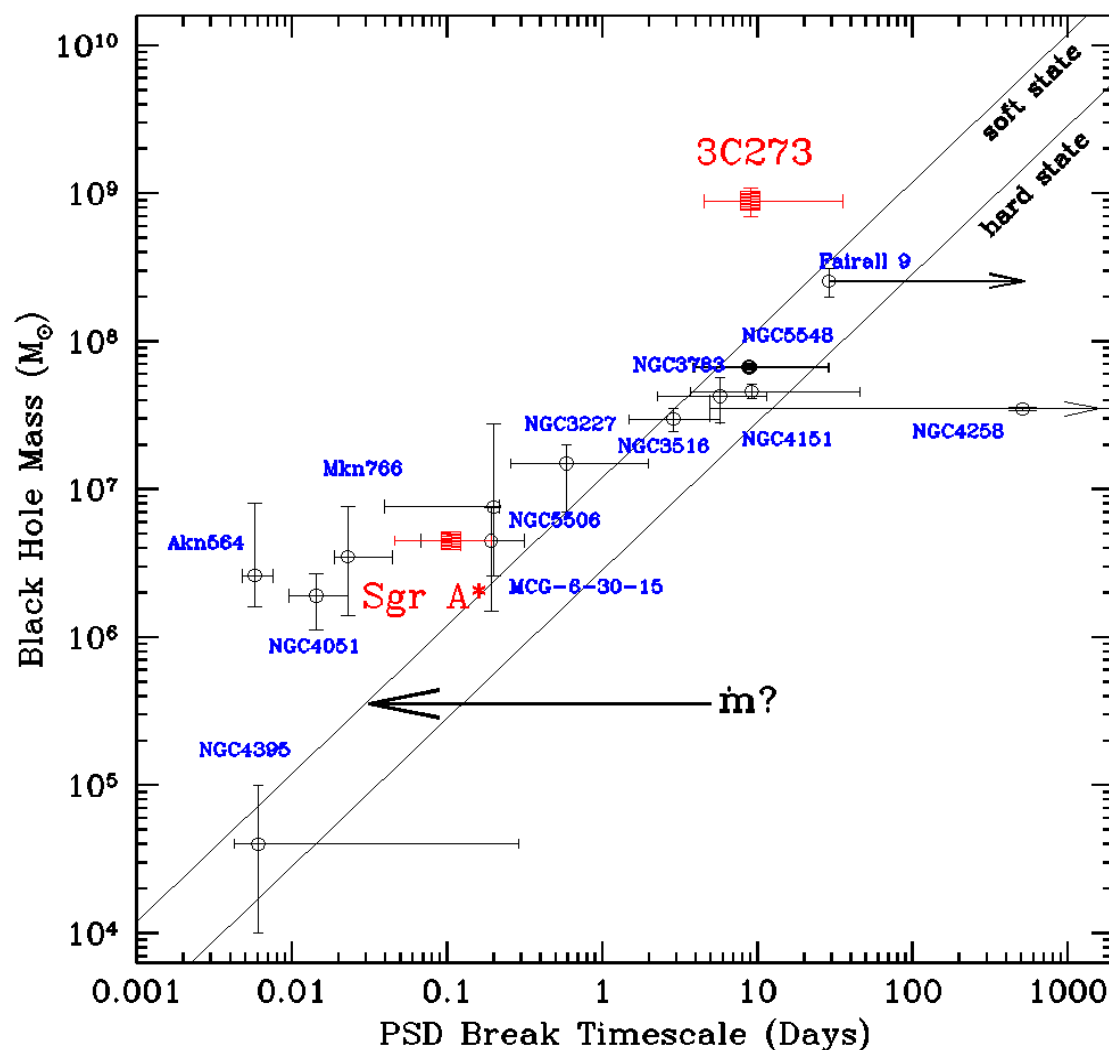
FERMI



(McHardy et al, in prep)



Jets and timescales



3C273 fits M / \dot{m}_E scaling

Different X-ray emission process (SSC from jet) from Seyferts but same source of variations?

But....

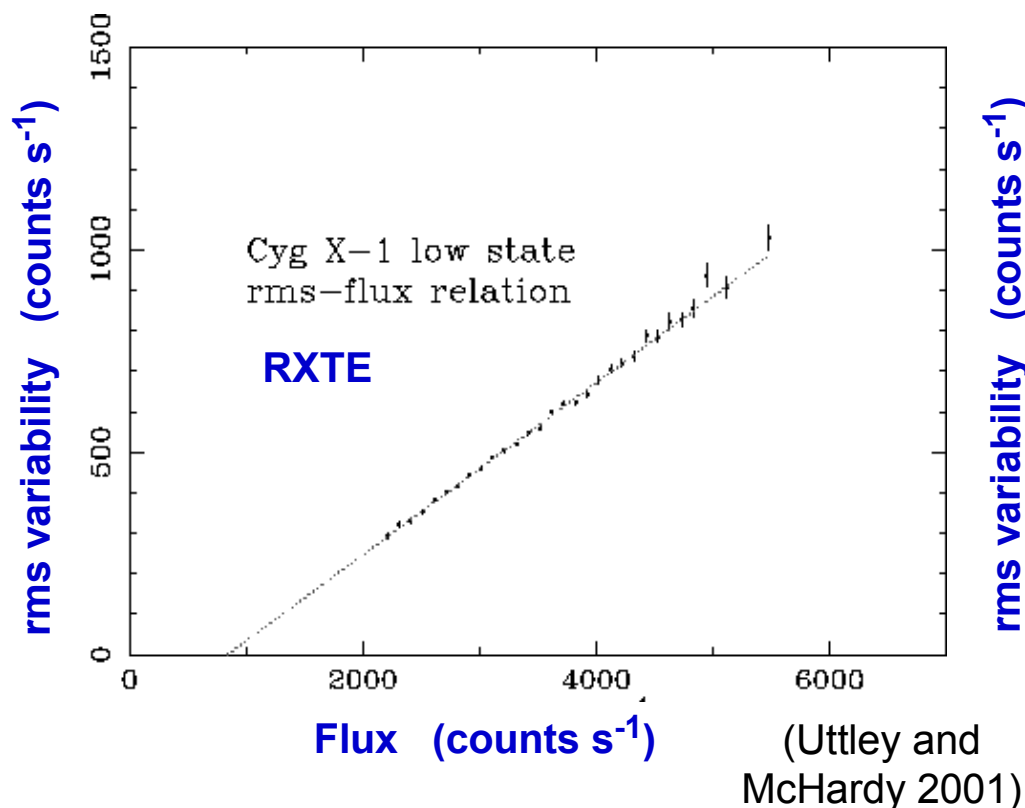
Sgr A* (in IR) (Meyer et al 2009) doesn't fit at all.
-VERY LOW ACCRETION RATE,
COMPLETELY JET DOMINATED-

Do jets follow pure mass scaling?
X-rays from same distance from BH?

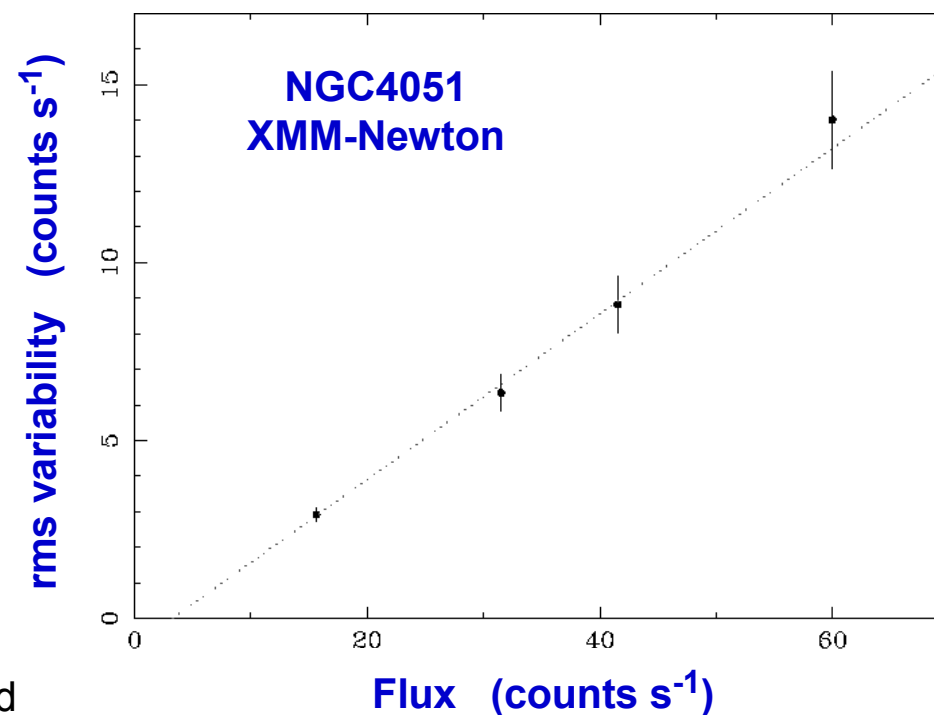


Origin of the Variability

Observations: RMS Variability (σ) vs. FLUX



Amplitude of short timescale variations respond to long timescale average flux.



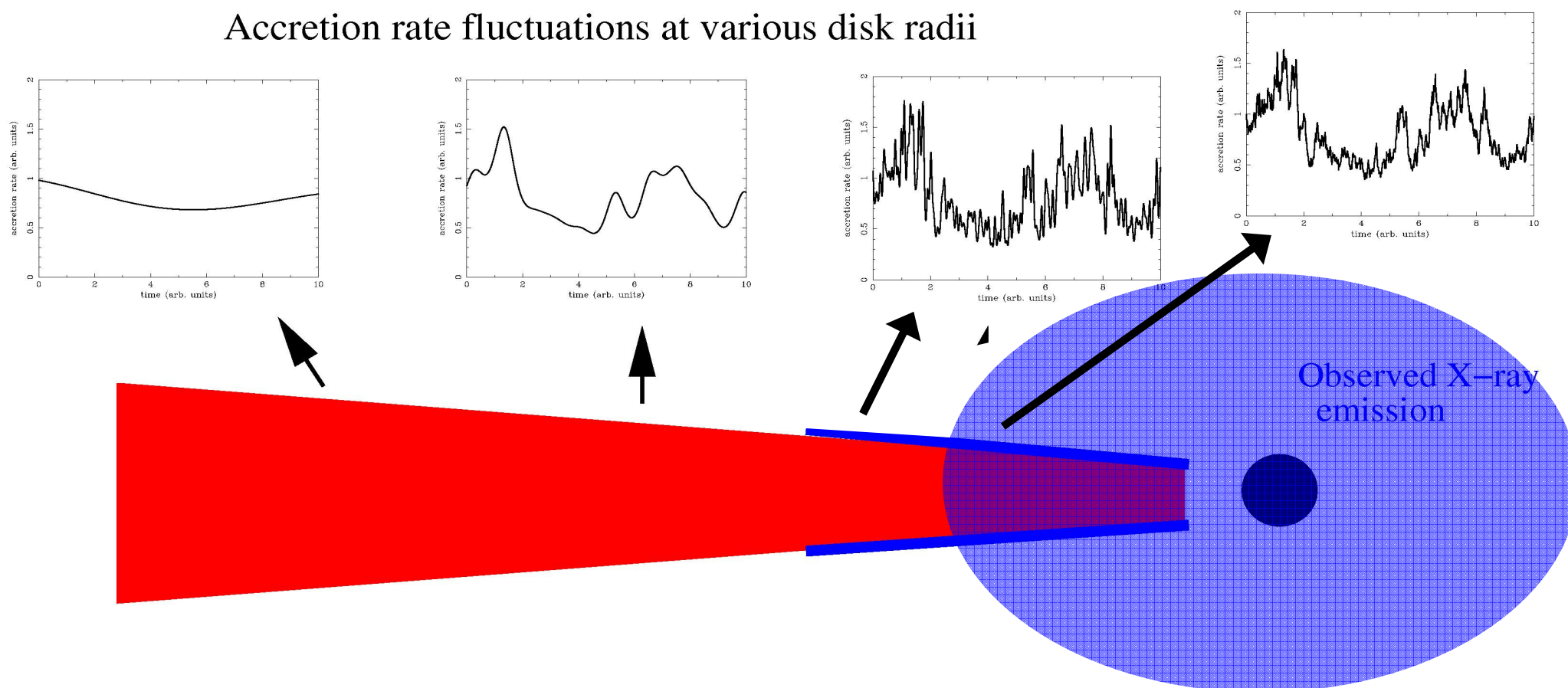
Same in NGC4051 as in GBHs.



Theory: a fluctuating accretion flow drives the variability (e.g. Lyubarskii 1997)

Variations propagate inwards. Amplitude of fluctuation in each annulus is modulated by total amplitude of inward propagating fluctuations.

Accretion rate fluctuations at various disk radii

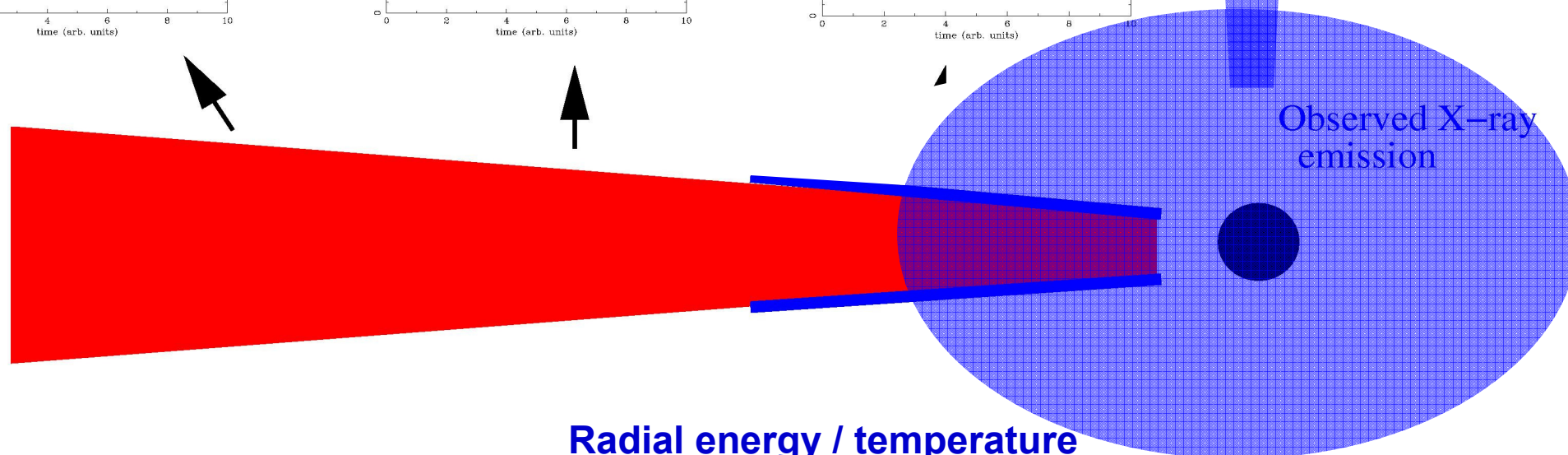
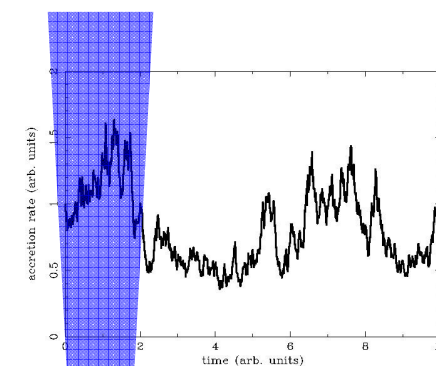
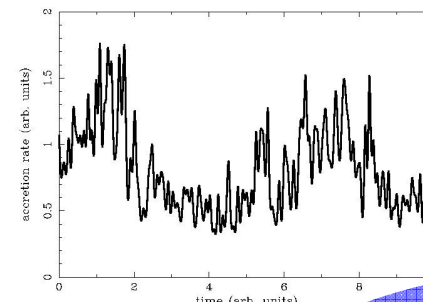
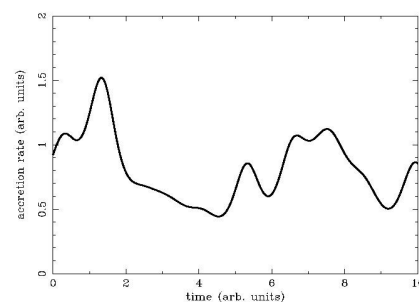
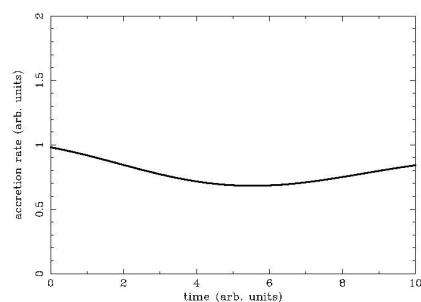




Separate source of variability and source of emission

Fluctuations eventually hit, and modulate, the X-ray emitting region
(Kotov et al 2001; Churazov et al 2001; Arevalo and Uttley 2006)

Accretion rate fluctuations at various disk radii

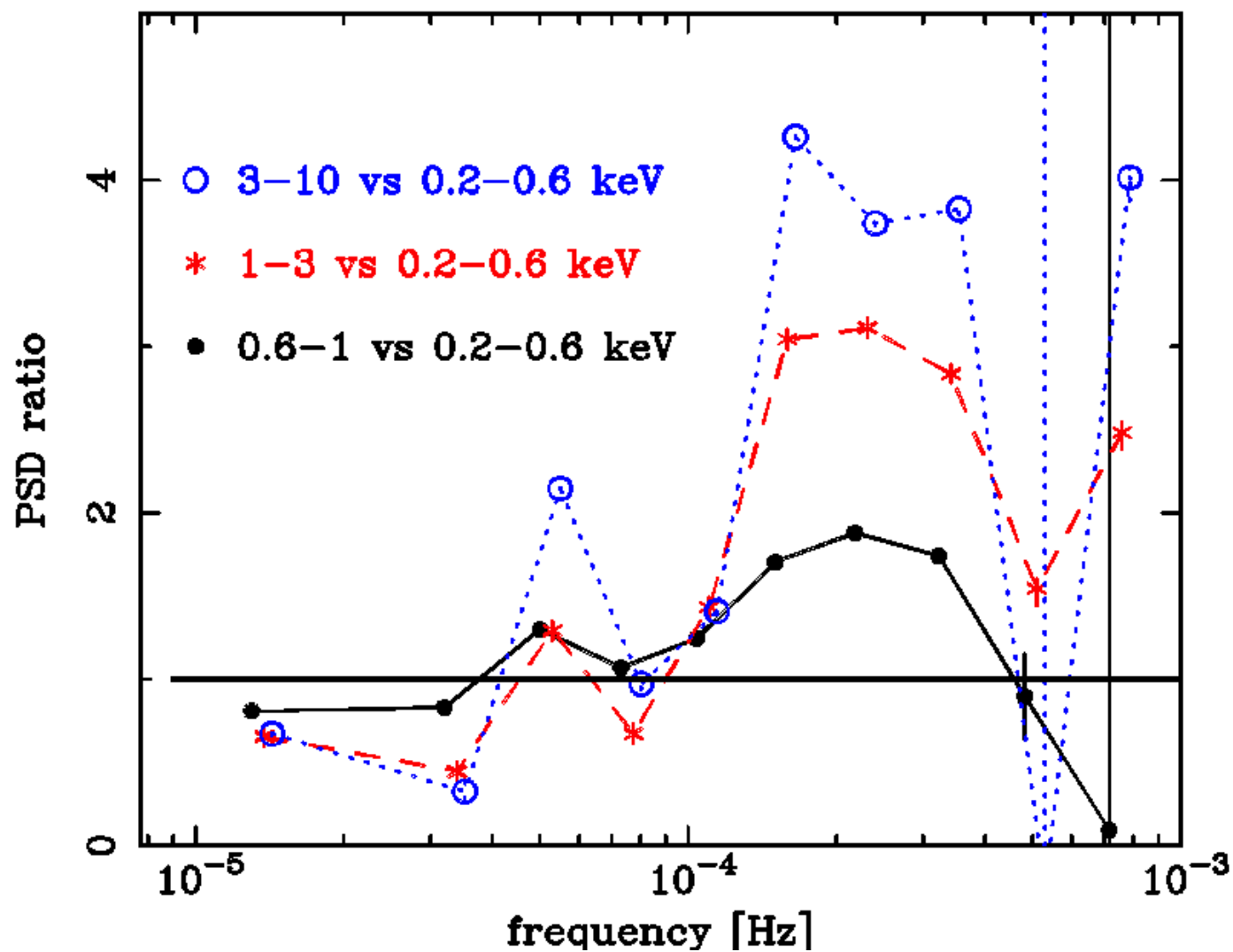


Radial energy / temperature
gradient in emission region



Mkn335: PSD ratios vs Frequency and Energy

Mrk 335

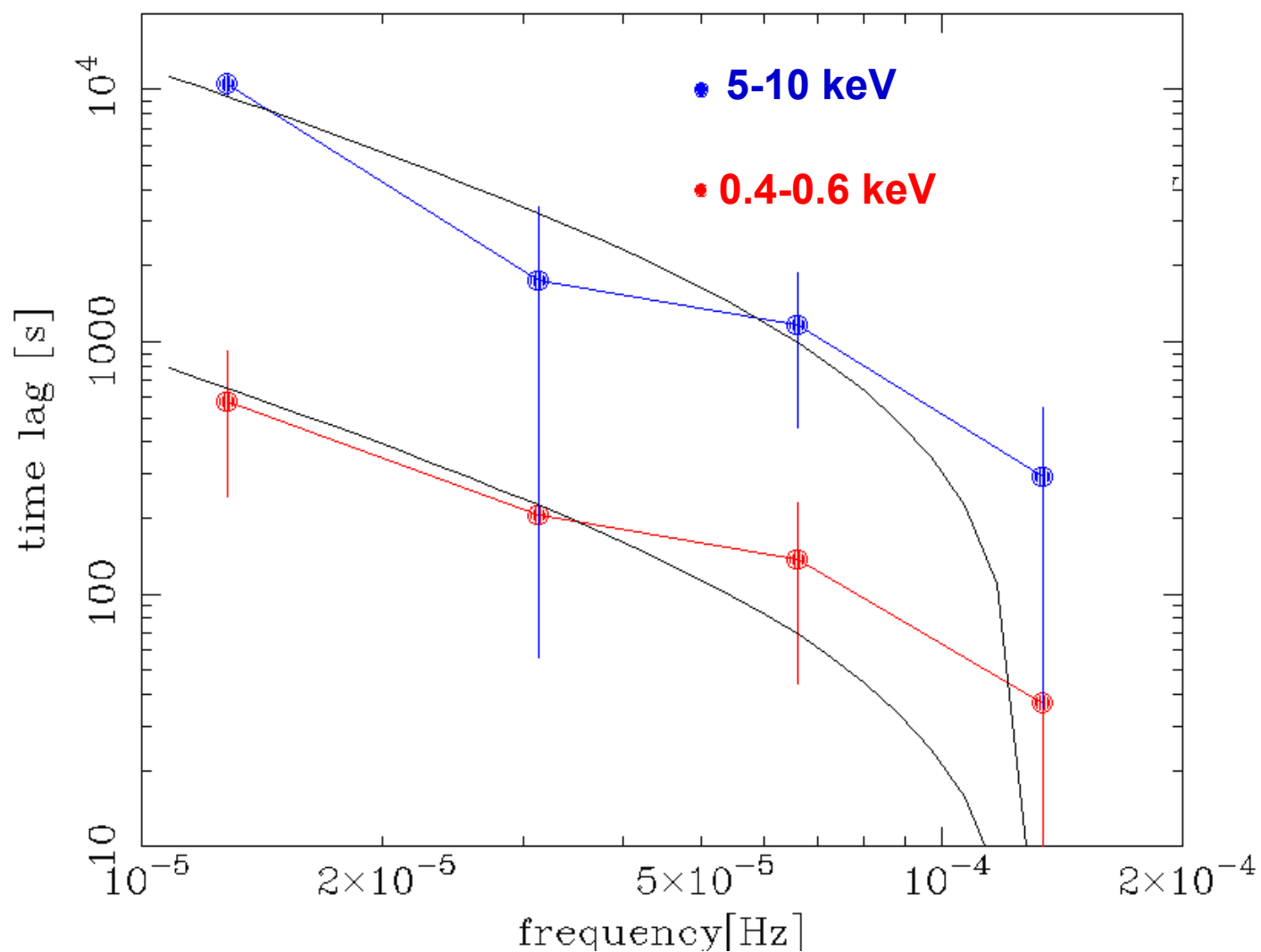


More variability at high frequencies at high energies



MKN335 Lags

Lag of higher energy relative to low energy (0.2-0.4 keV)



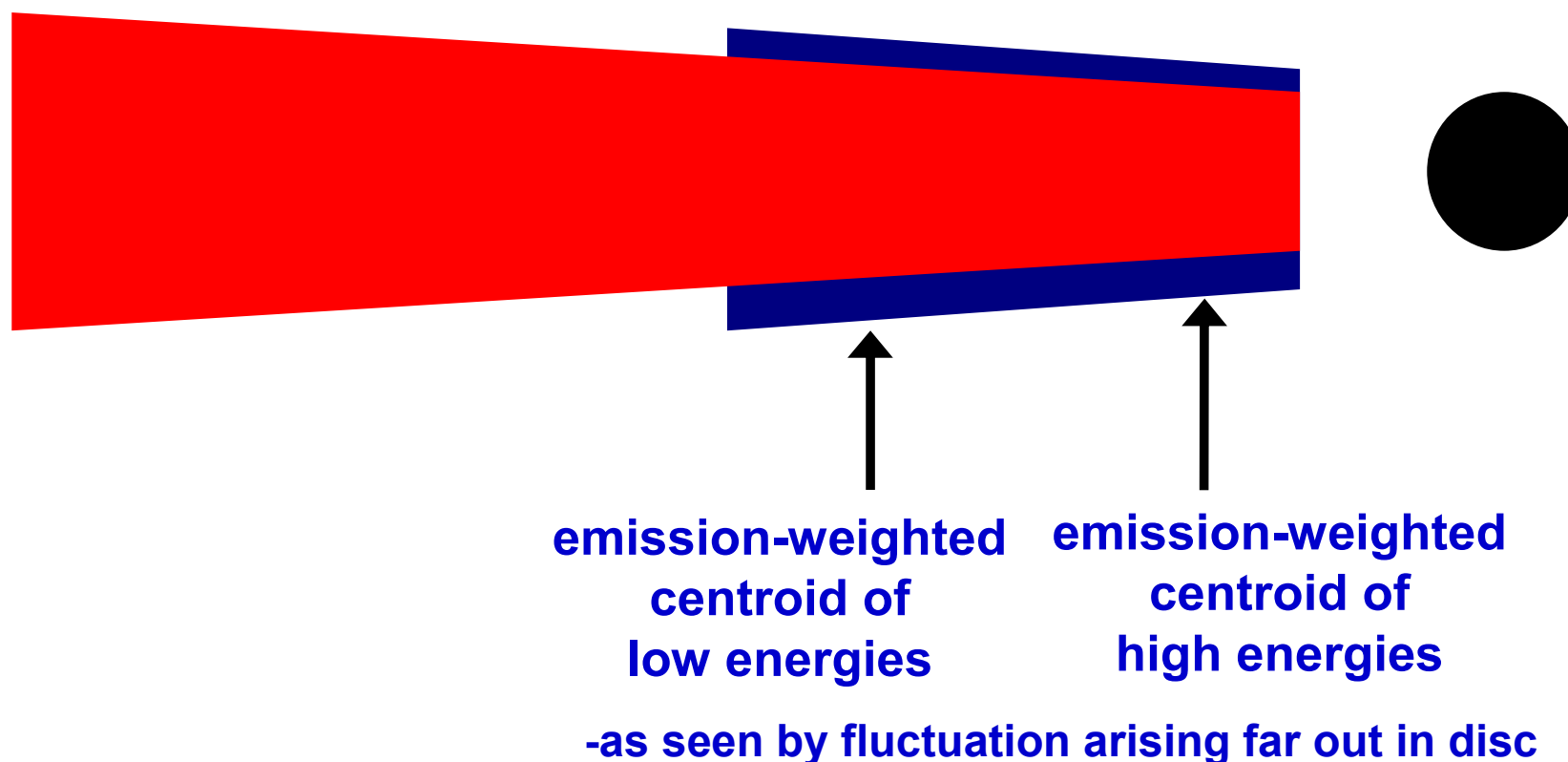
Lags increase as energy separation increases.

Lags decrease at higher Fourier frequencies

So emission region is harder at smaller radii.



e.g., LAGS

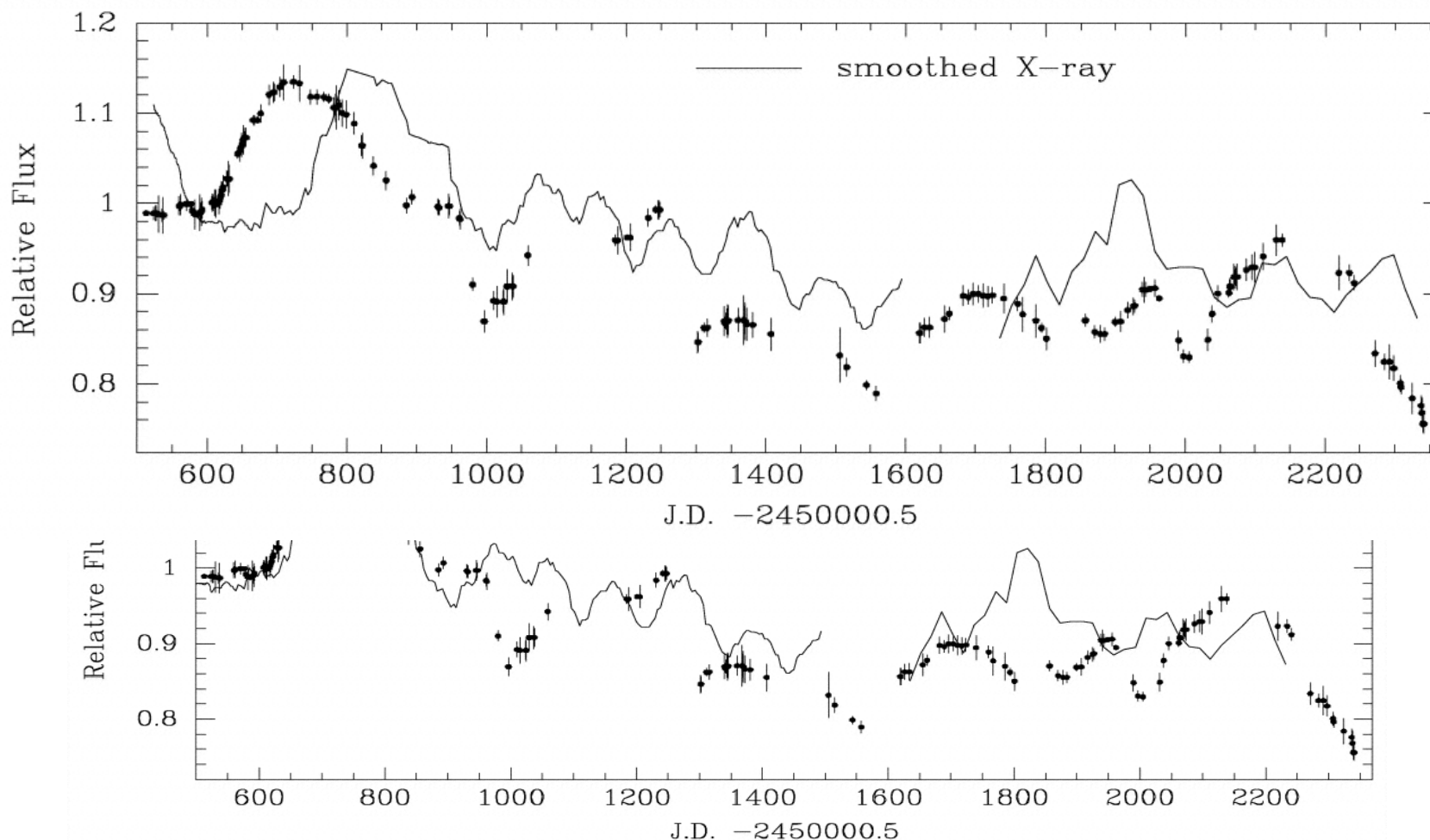


The lag is then the time for the fluctuation to travel between centroids.

For higher frequency fluctuations, generated within the X-ray emission region, the low energy centroid moves inwards so lags decrease.

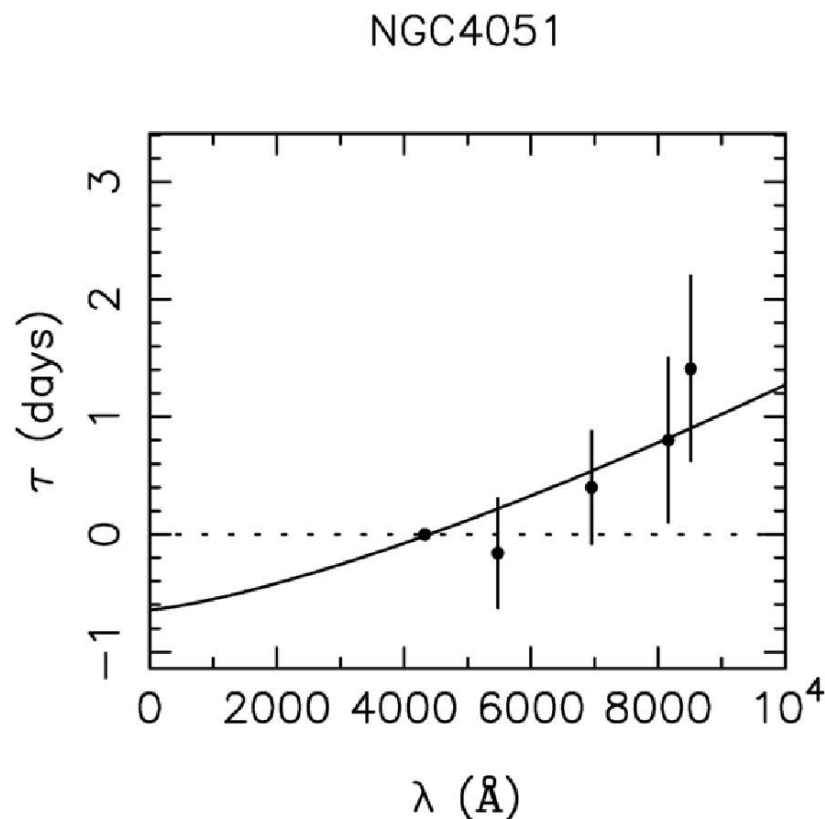


Optical Variability in AGN: Reprocessed X-rays or intrinsic disc variability?





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



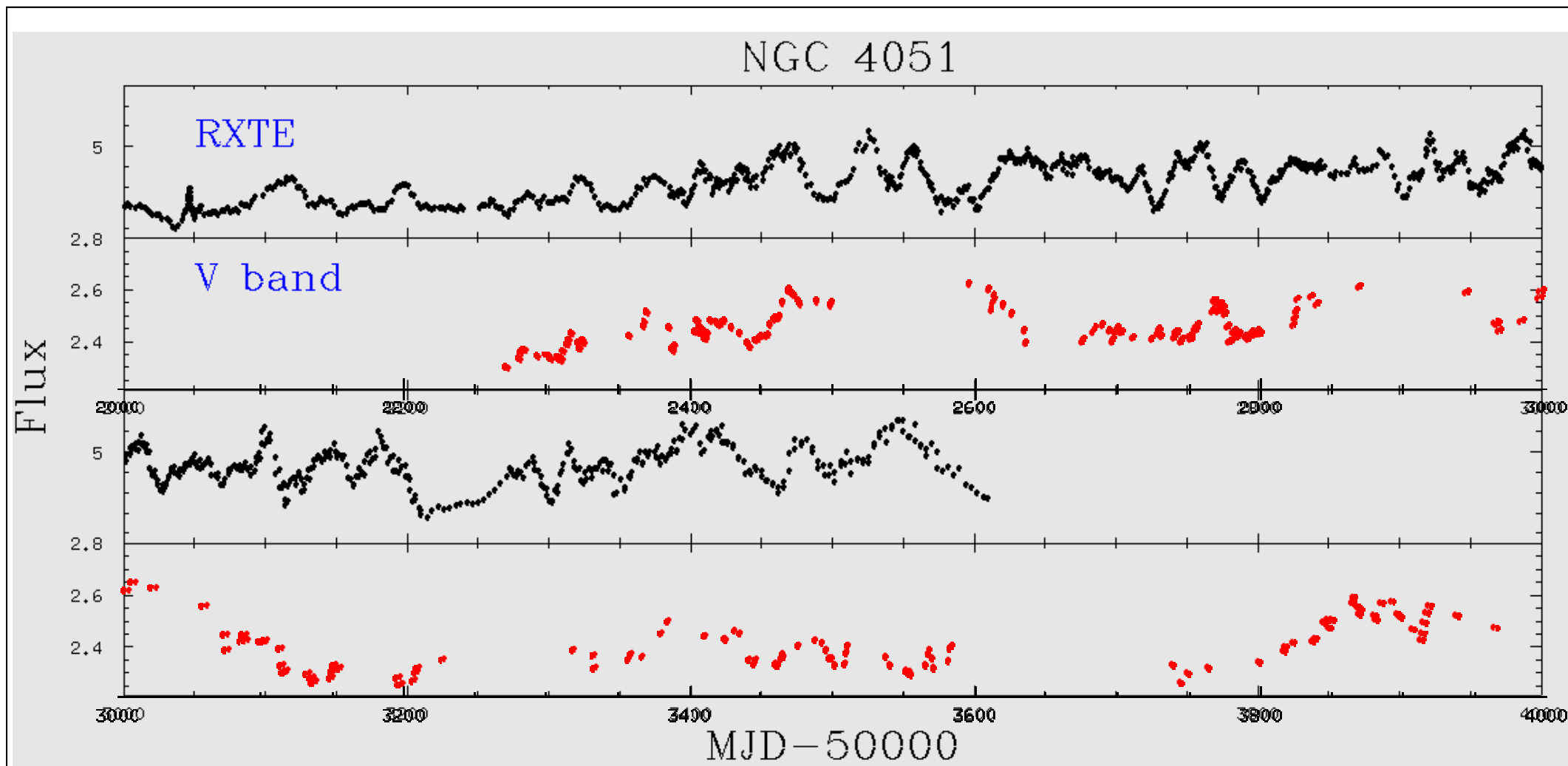
$$T \propto M_{BH}^{-1/4} \dot{M}^{1/4} R^{-3/4}$$

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

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

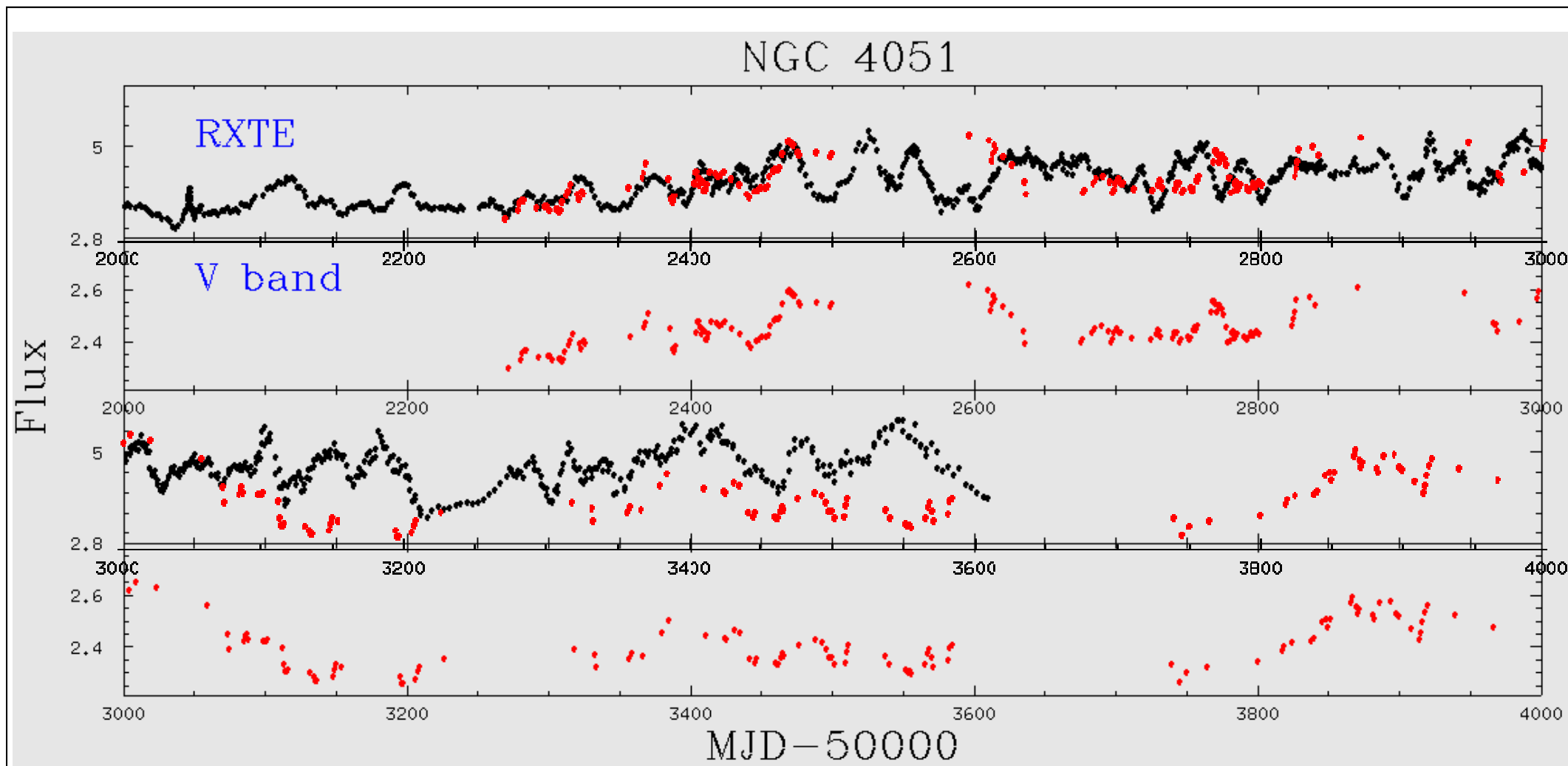


NGC 4051



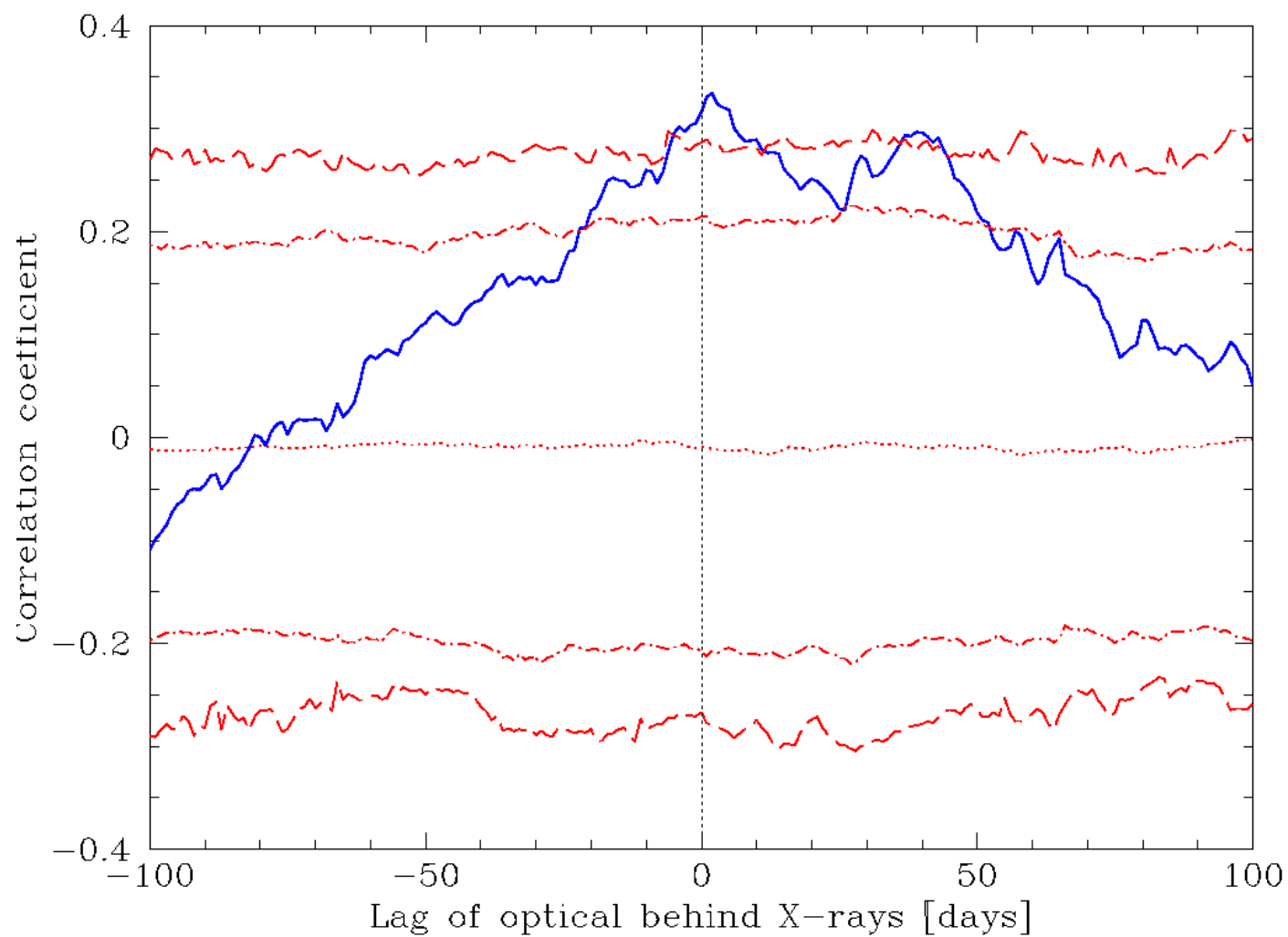


NGC 4051





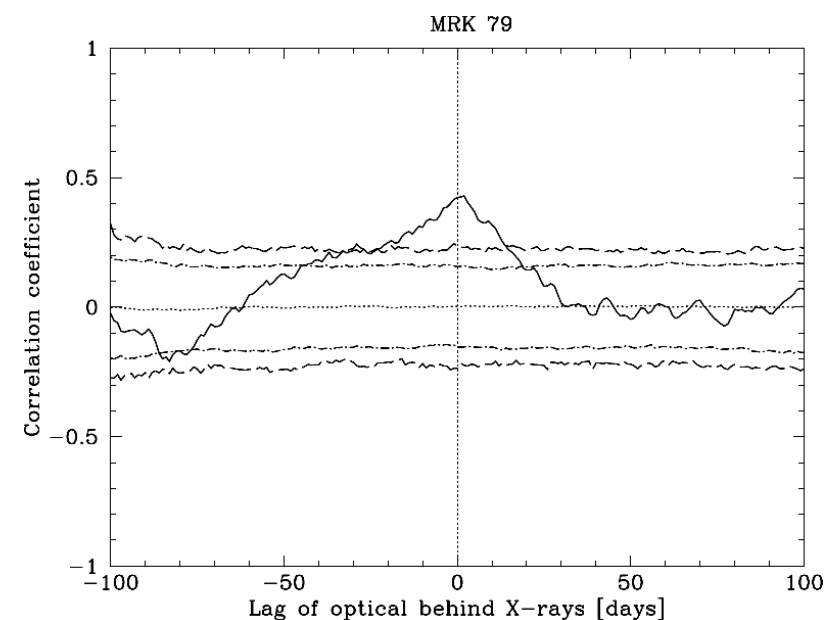
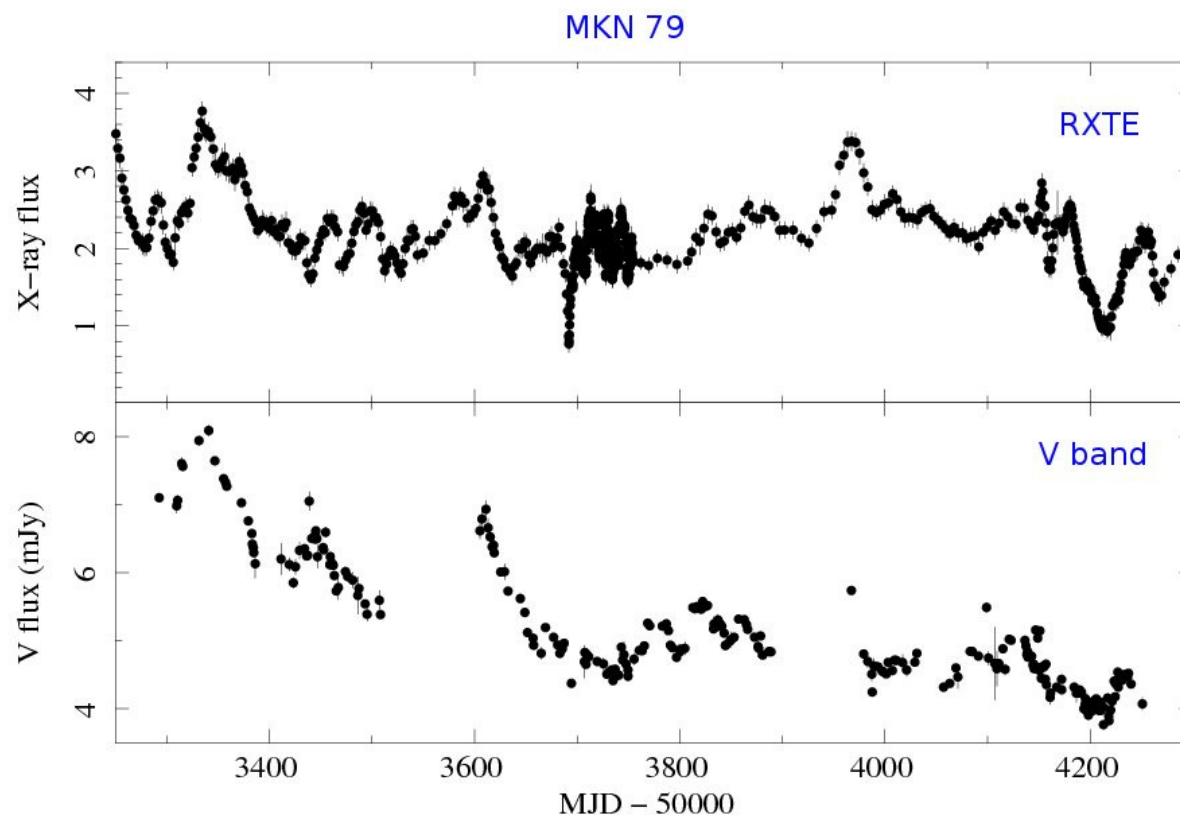
NGC4051



**Optical lags by 1.5 ± 0.5 d
(above 99% confidence)**



MKN 79



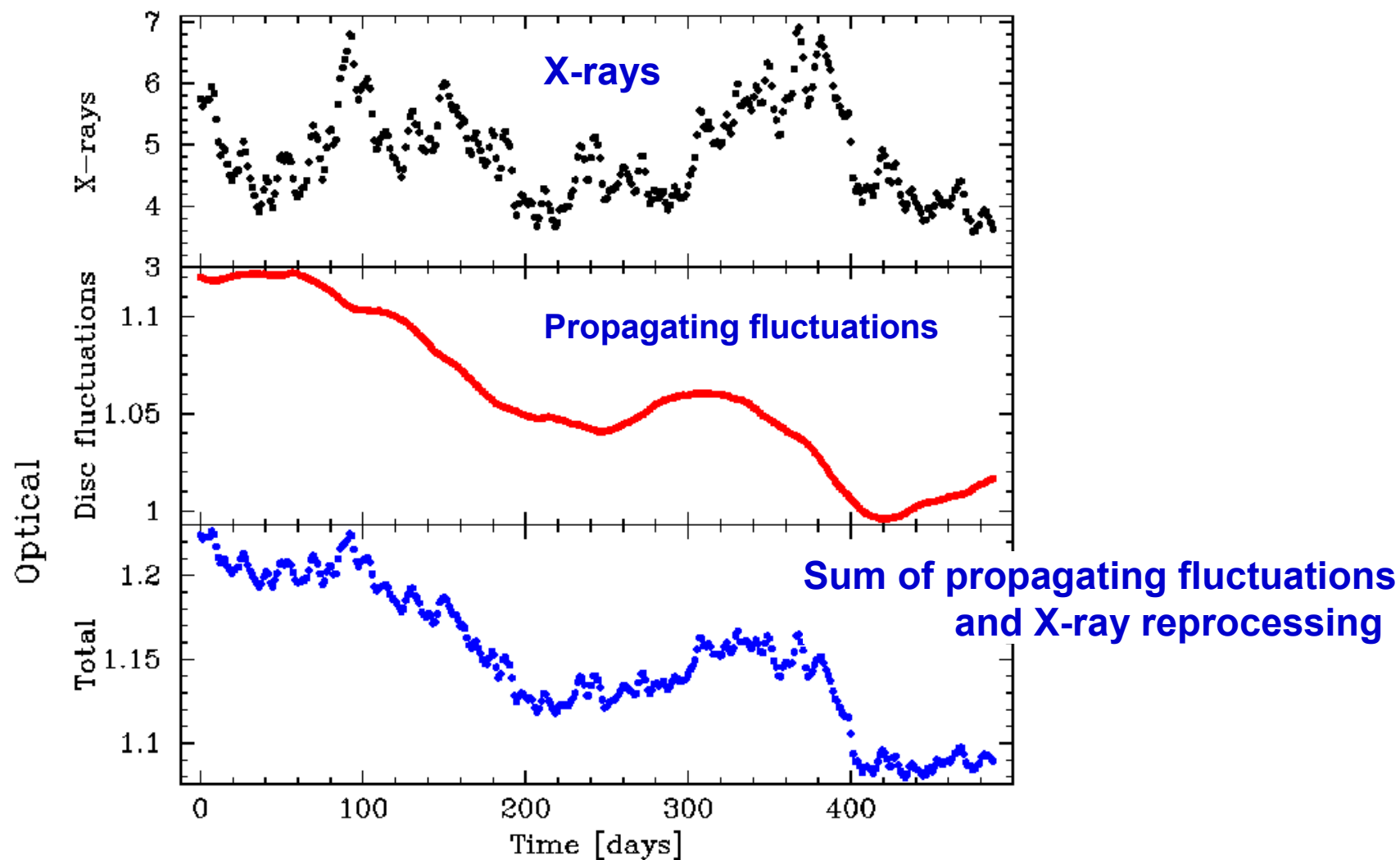
Short term correlation but different long term trends

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



Simulated Optical Lightcurves

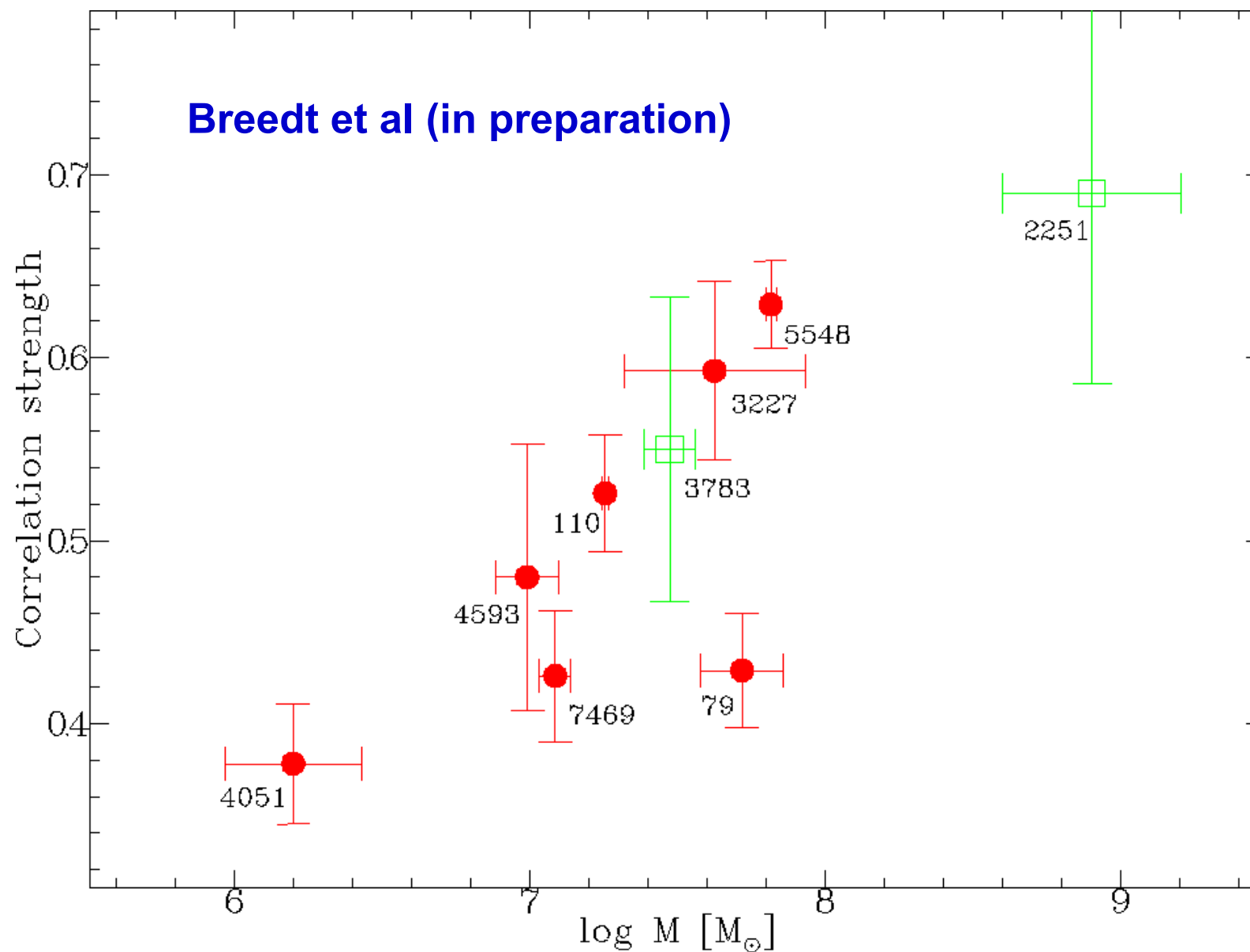
Propagating fluctuations plus X-ray reprocessing



(from Arevalo et al 2008)

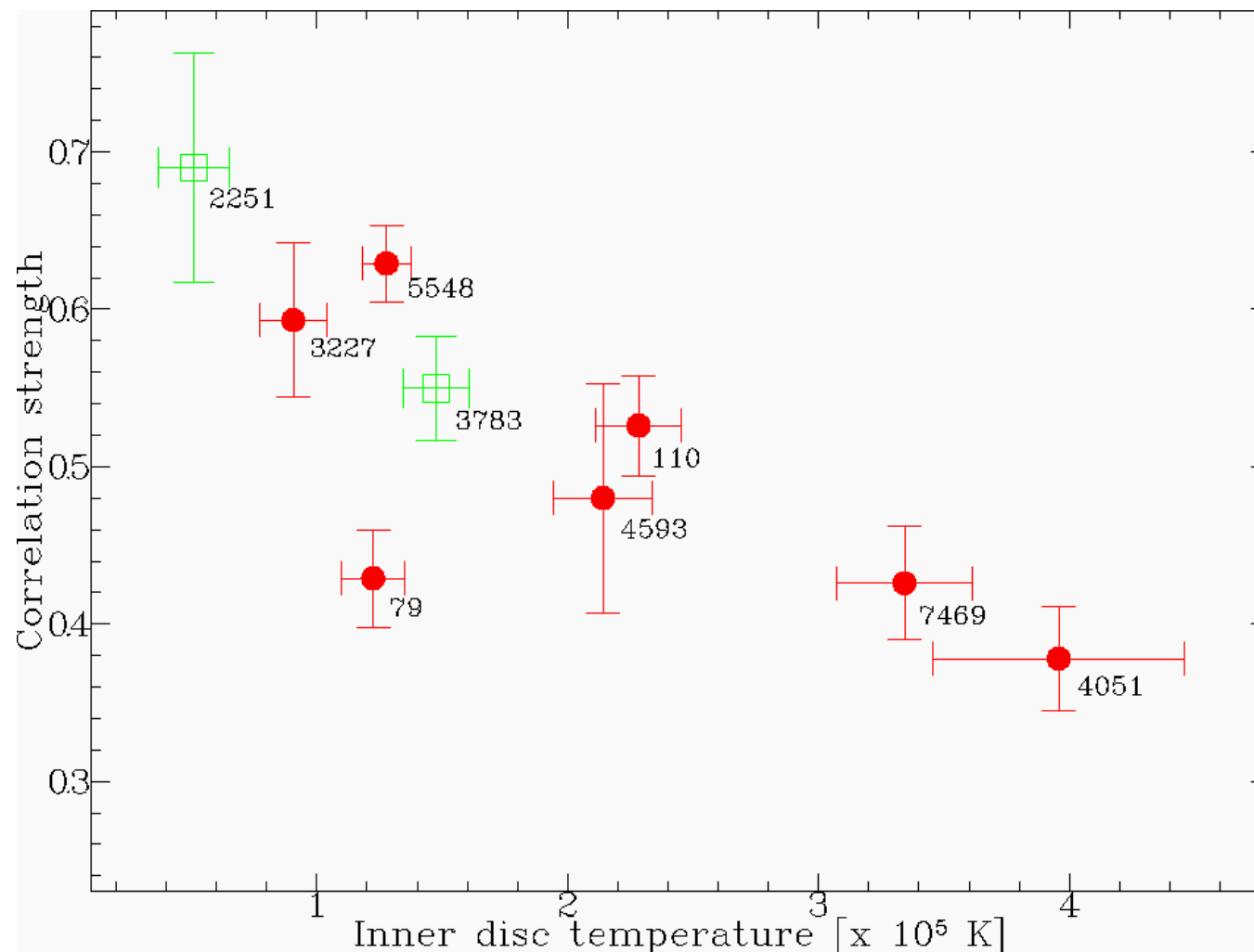


X-ray/optical peak correlation coefficient vs. black hole mass





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

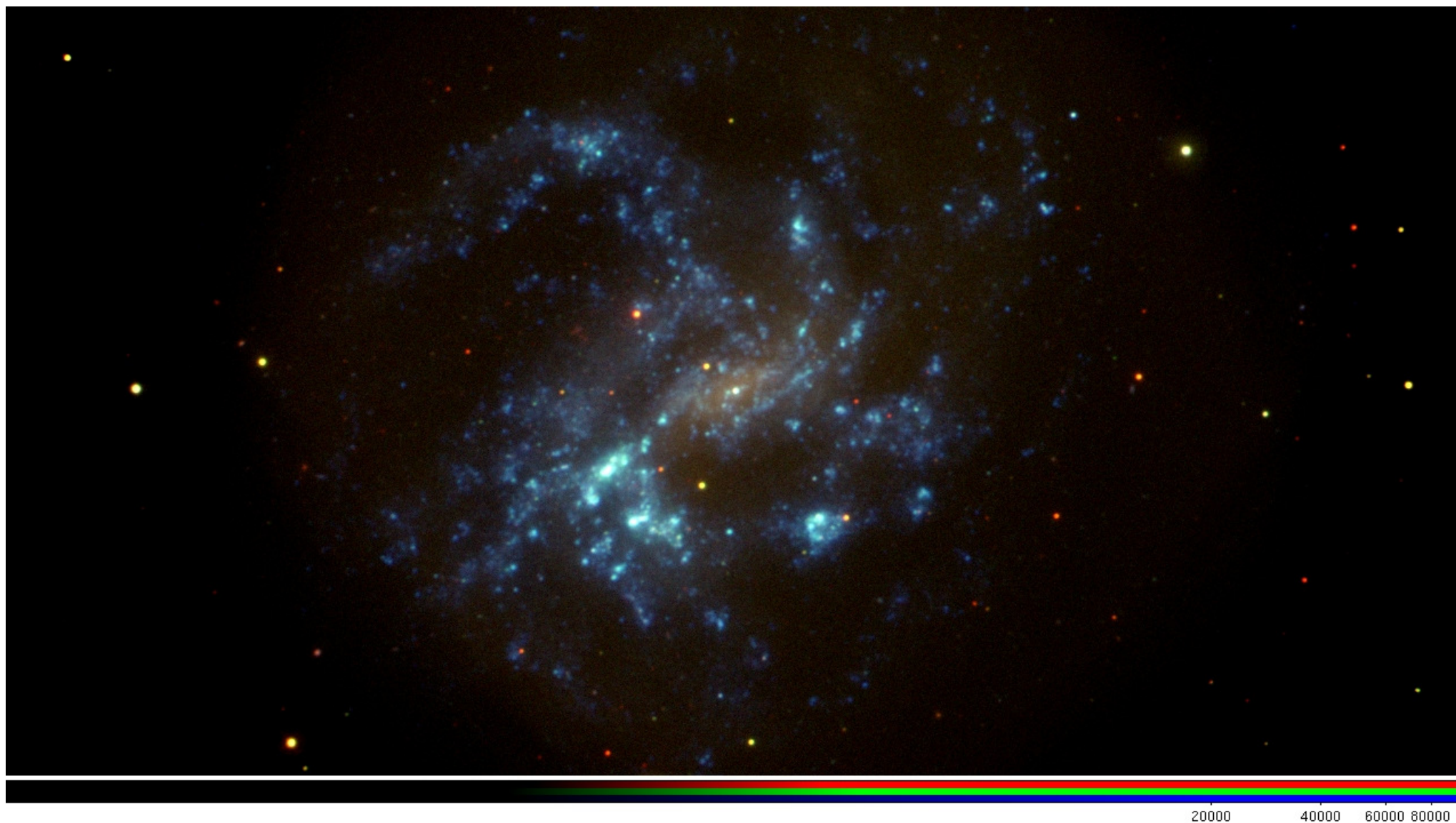


Correlation looks tighter than with mass, but is statistically very similar.

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



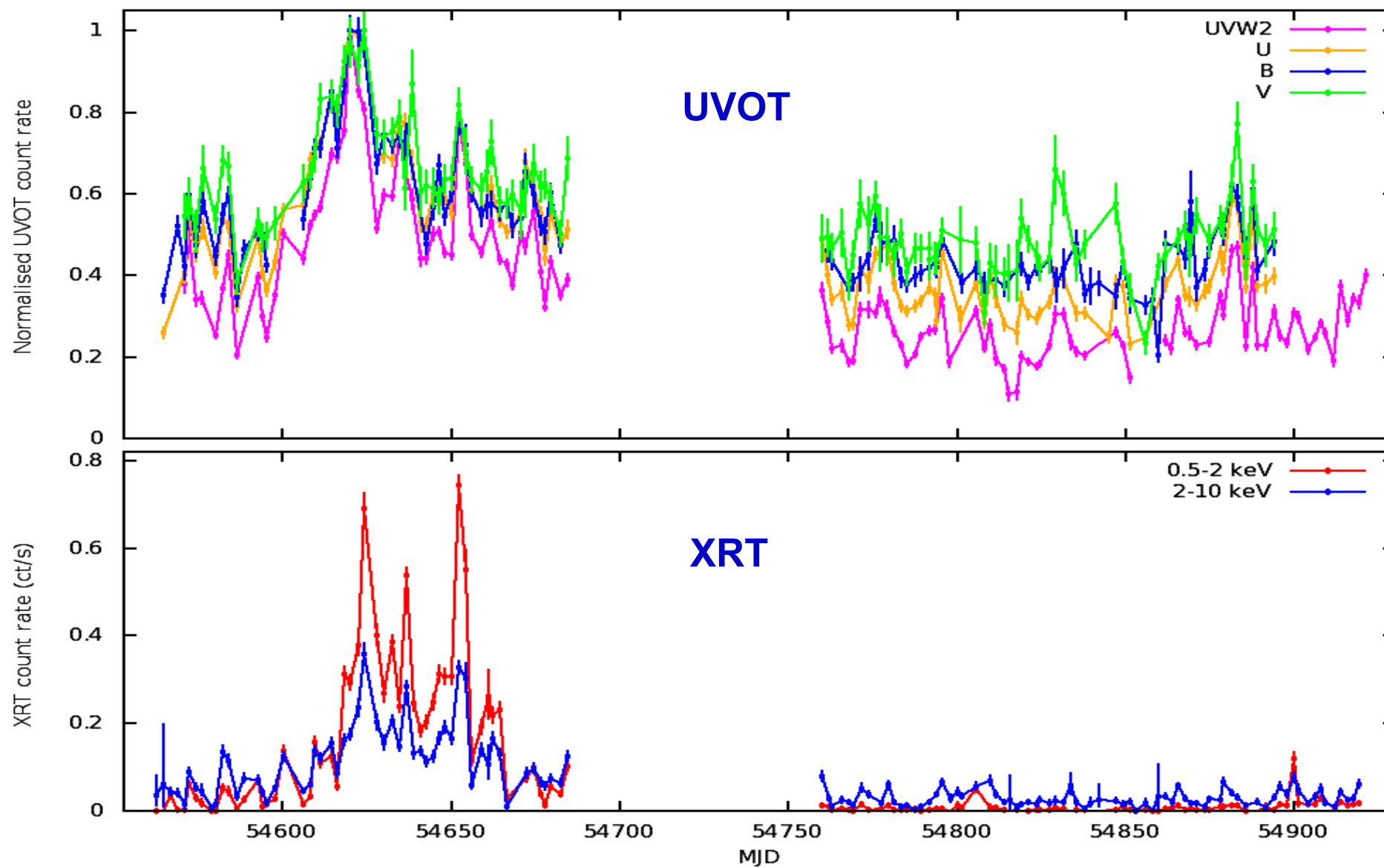
NGC4395 ($\sim 10^5$ solar mass BH)- Swift



20000 40000 60000 80000

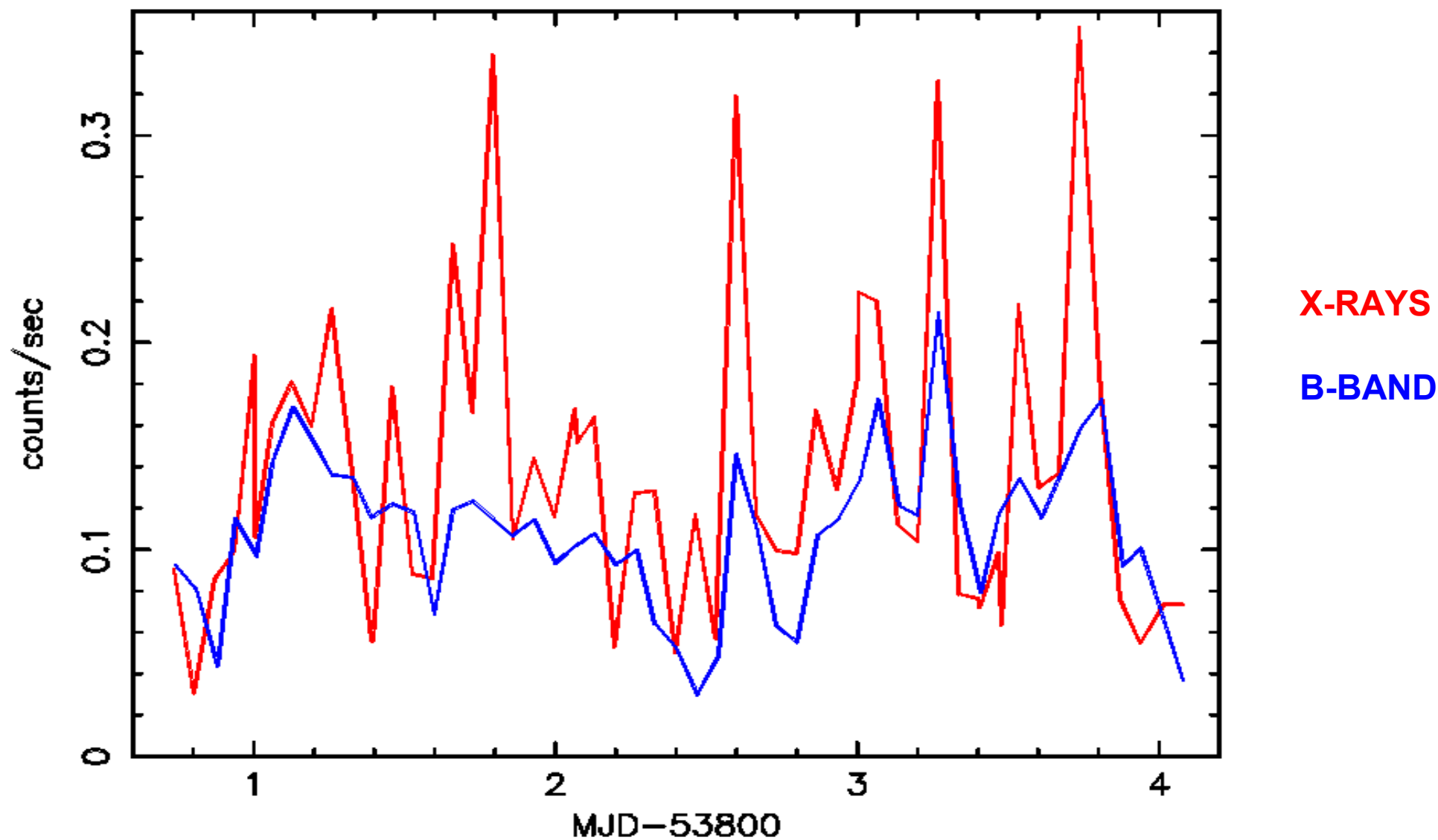


NGC4395 Swift lightcurves



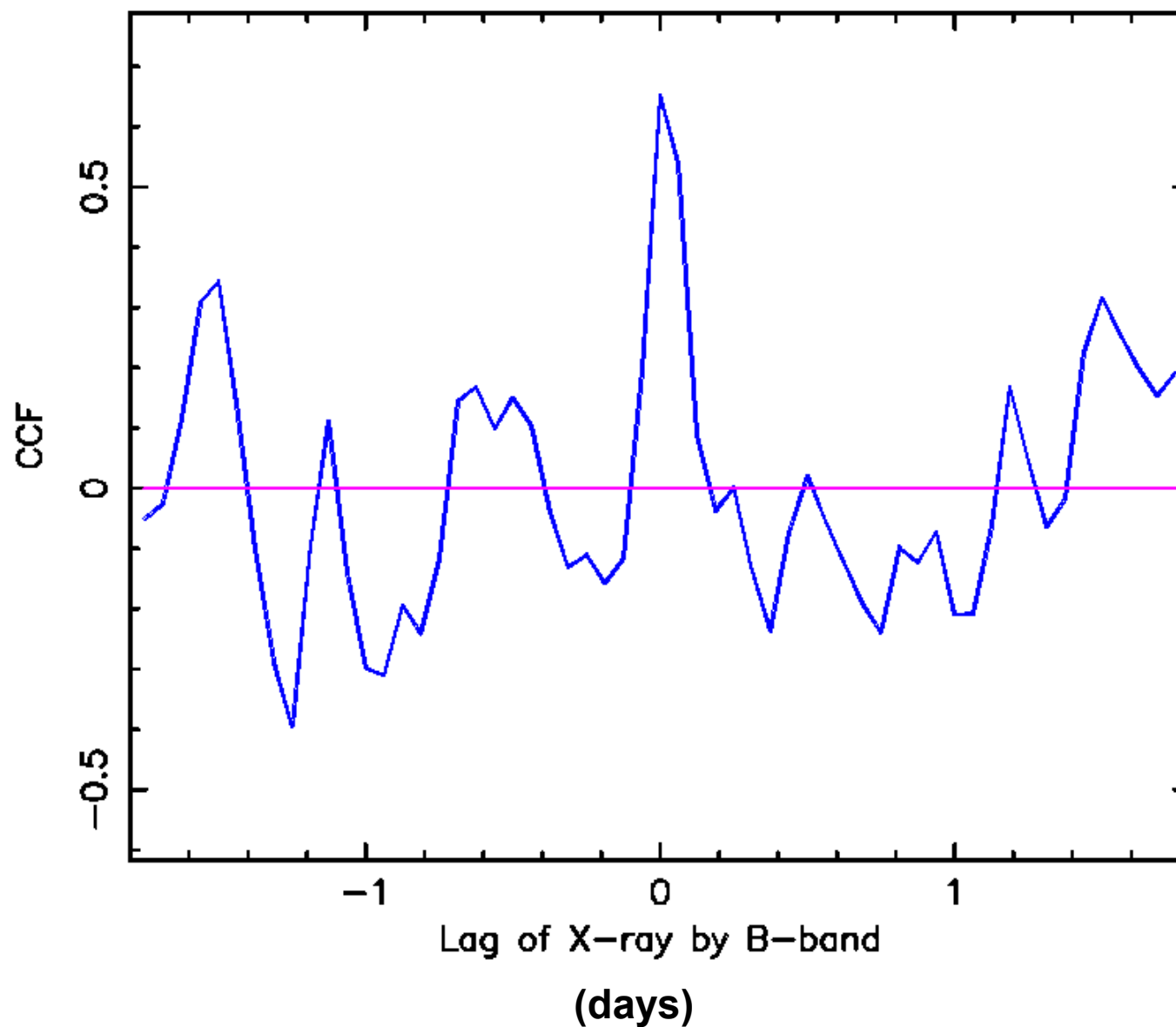


NGC4395: Shorter timescale (hours- days)





NGC4395: Short timescale CCF



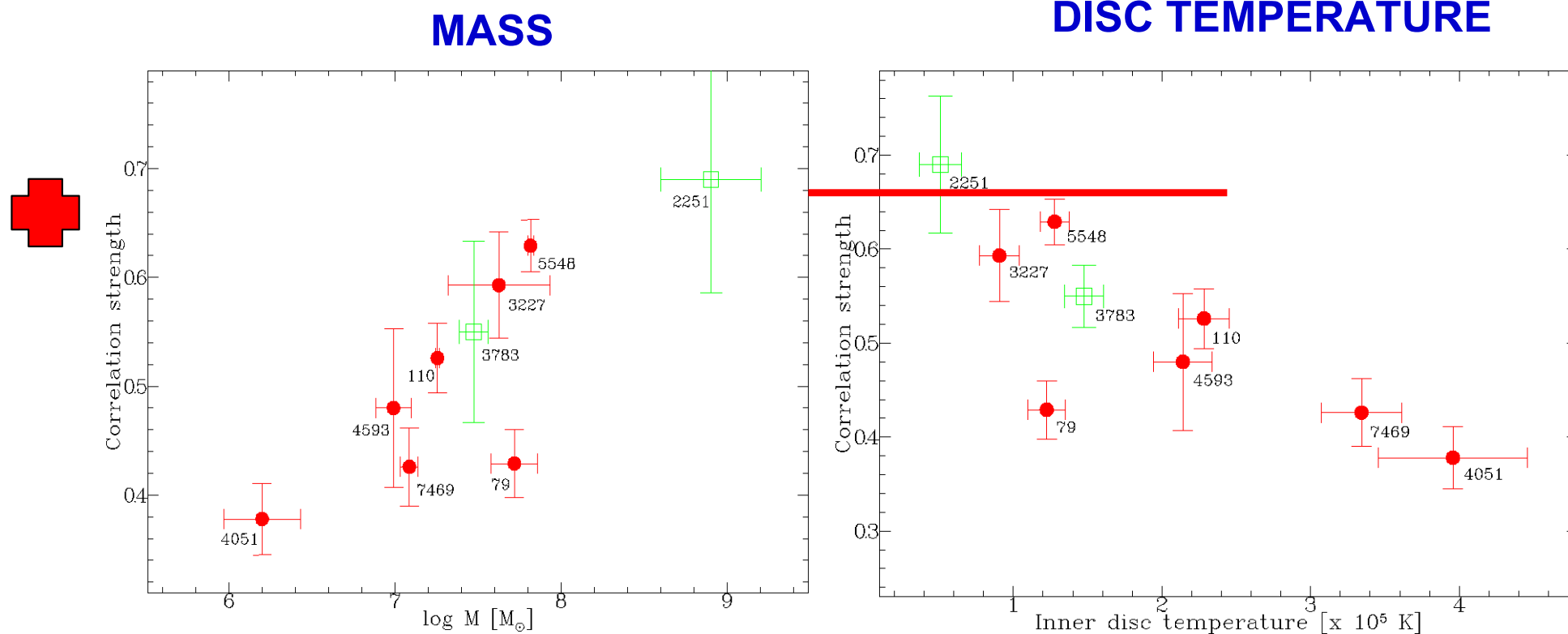
**Very small lag
< 45min**

**again indicating
reprocessing**

**(Cameron et al,
in prep)**



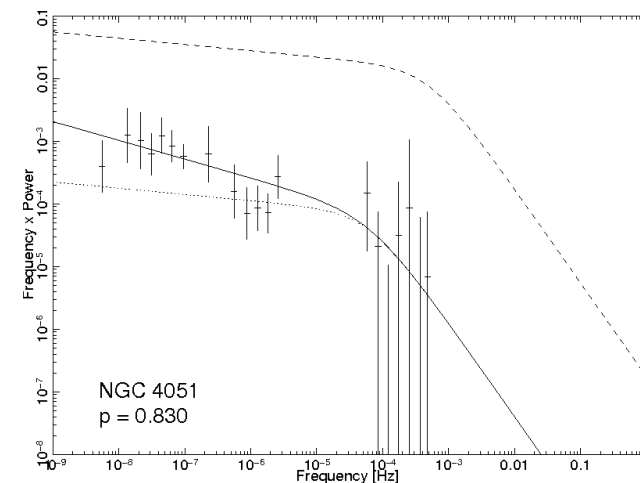
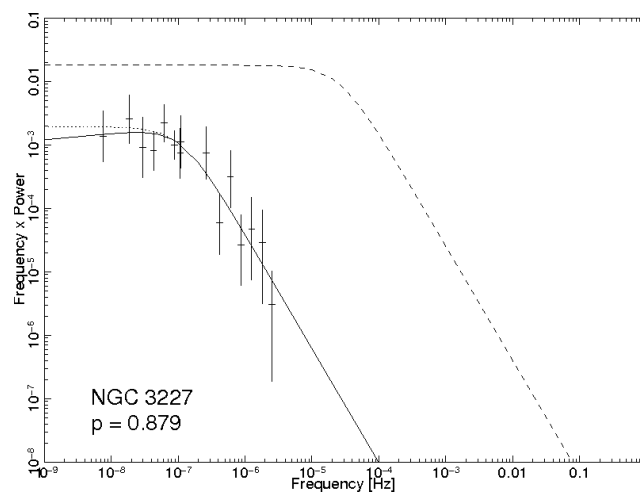
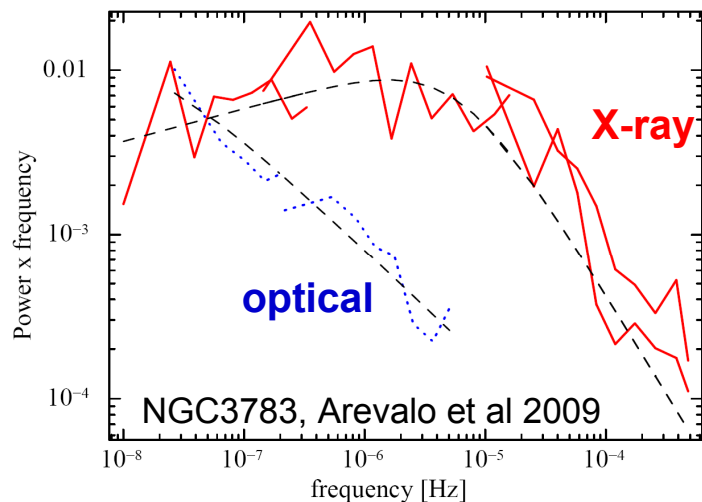
How does NGC4395 fit the M, T correlations?



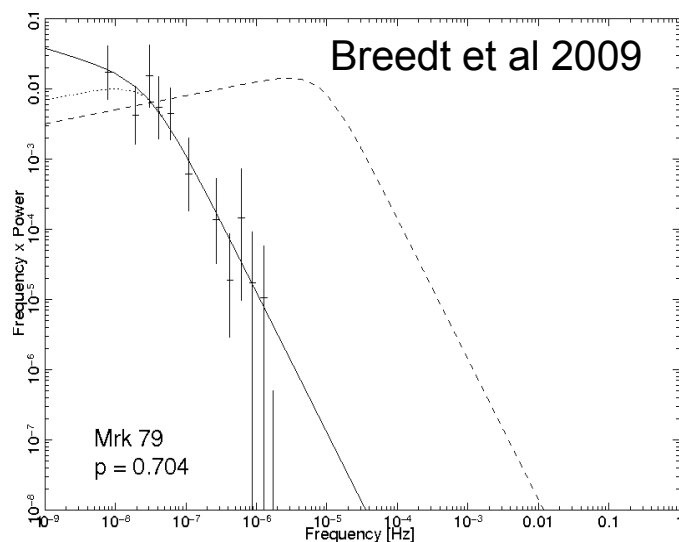
NGC4395 does not agree with pure mass scaling but is consistent with disc temperature scaling



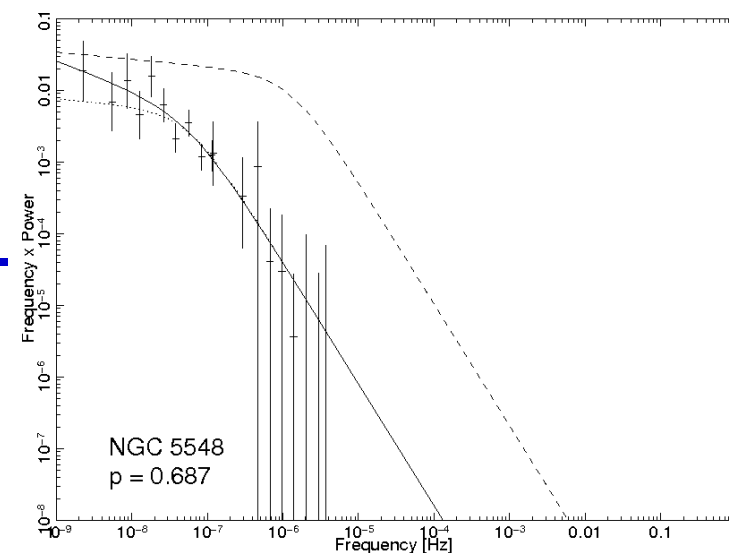
Optical and X-ray PSDs



Breedt et al, in prep



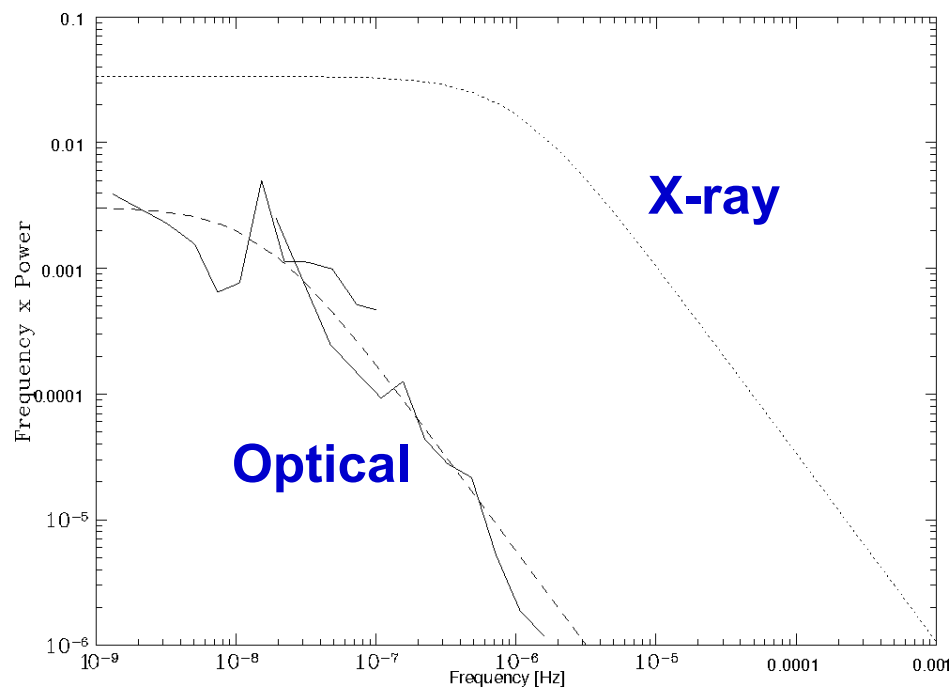
**Errorbars - Optical data.
Dashed line - X-rays**





Simulated optical and X-ray PSDs

Breedt et al in prep.



Simulated reprocessed optical PSD.

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

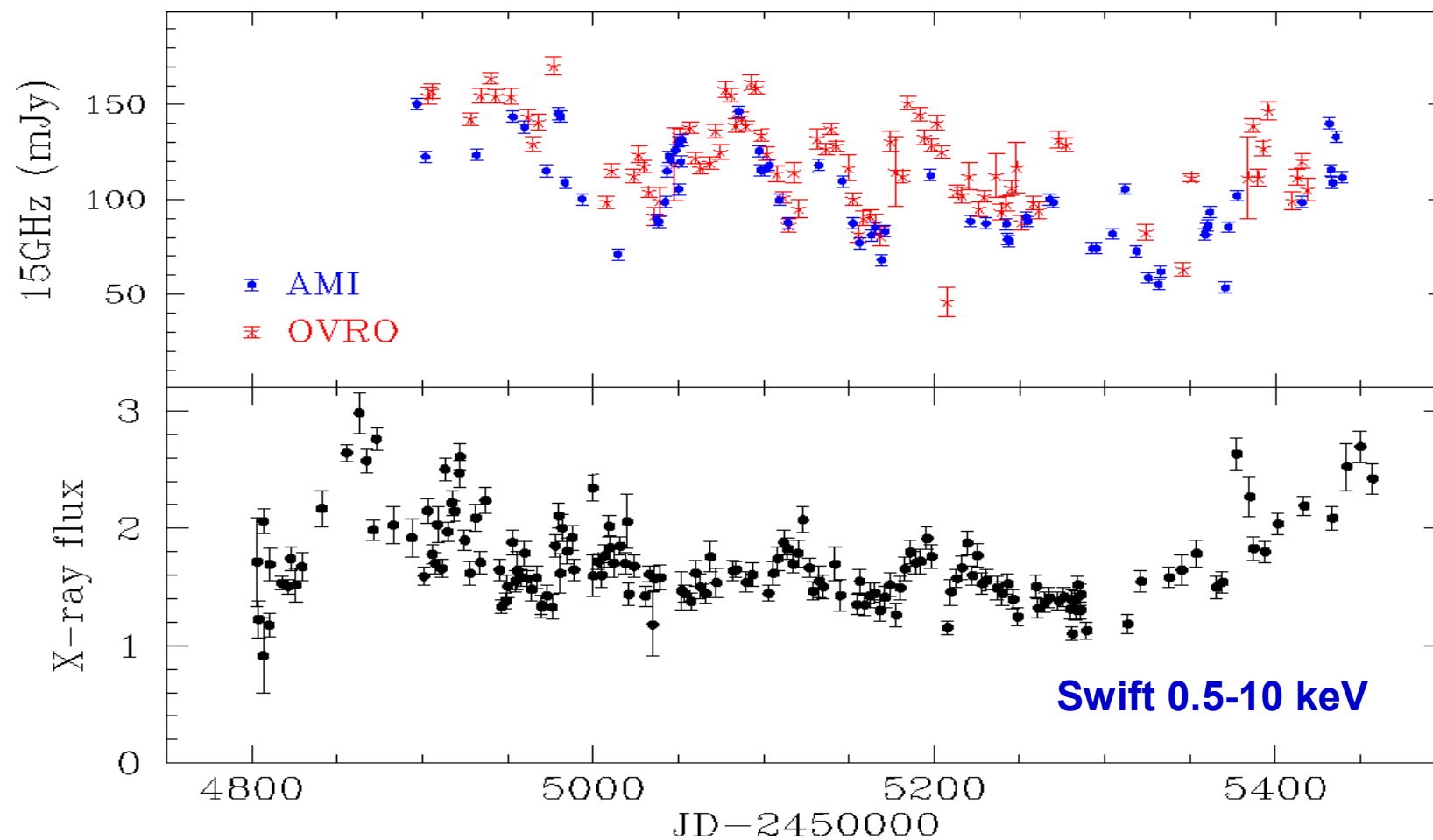


Radio/X-Ray Variability

1. **Liners - M81** (See also NGC7213, Bell et al 2010)
2. **Seyfert – NGC4051**



M81 X-ray and 15GHz lightcurves

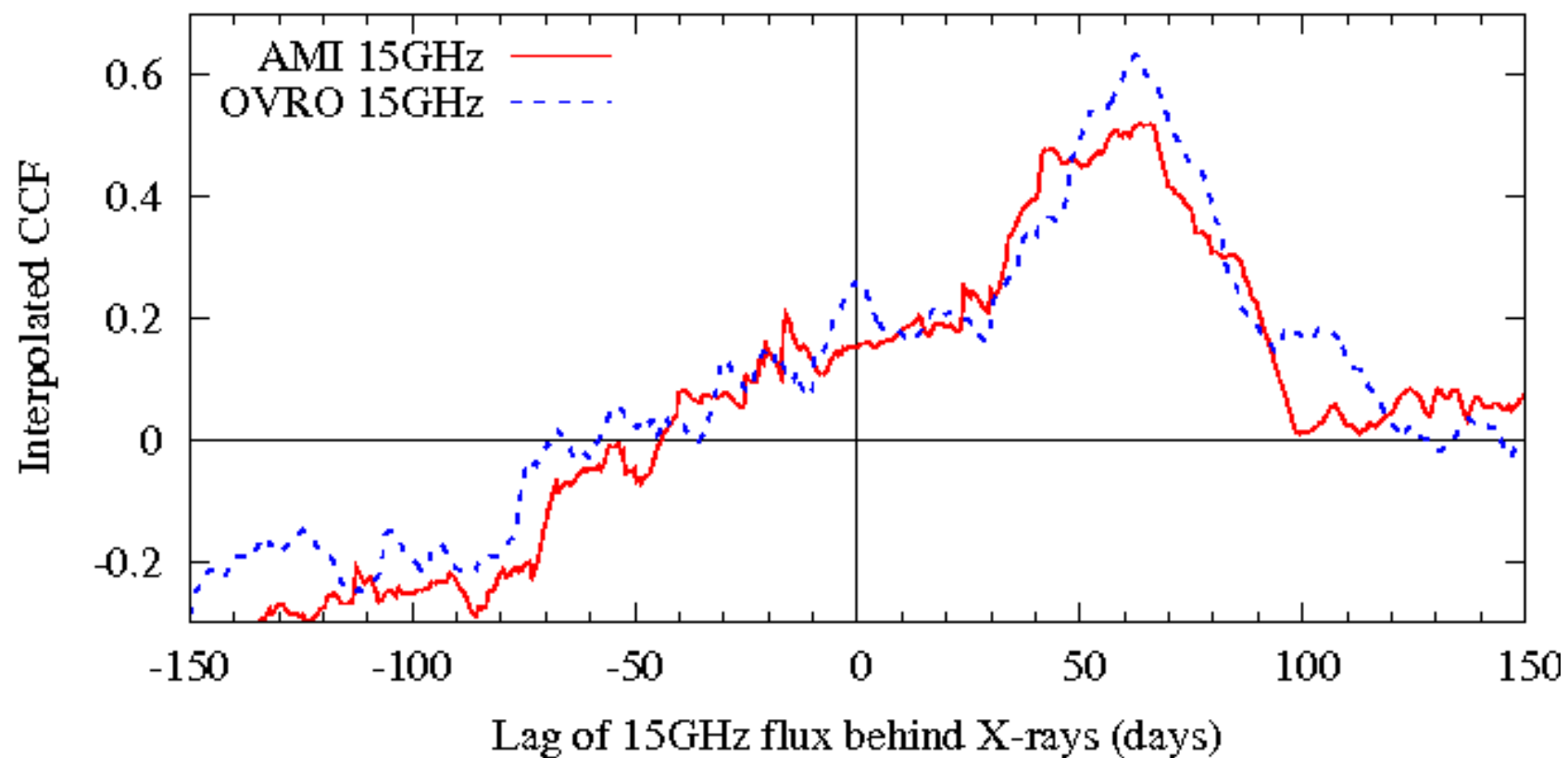


AMI – Pooley

OVRO – Richards, Readhead, Pearson

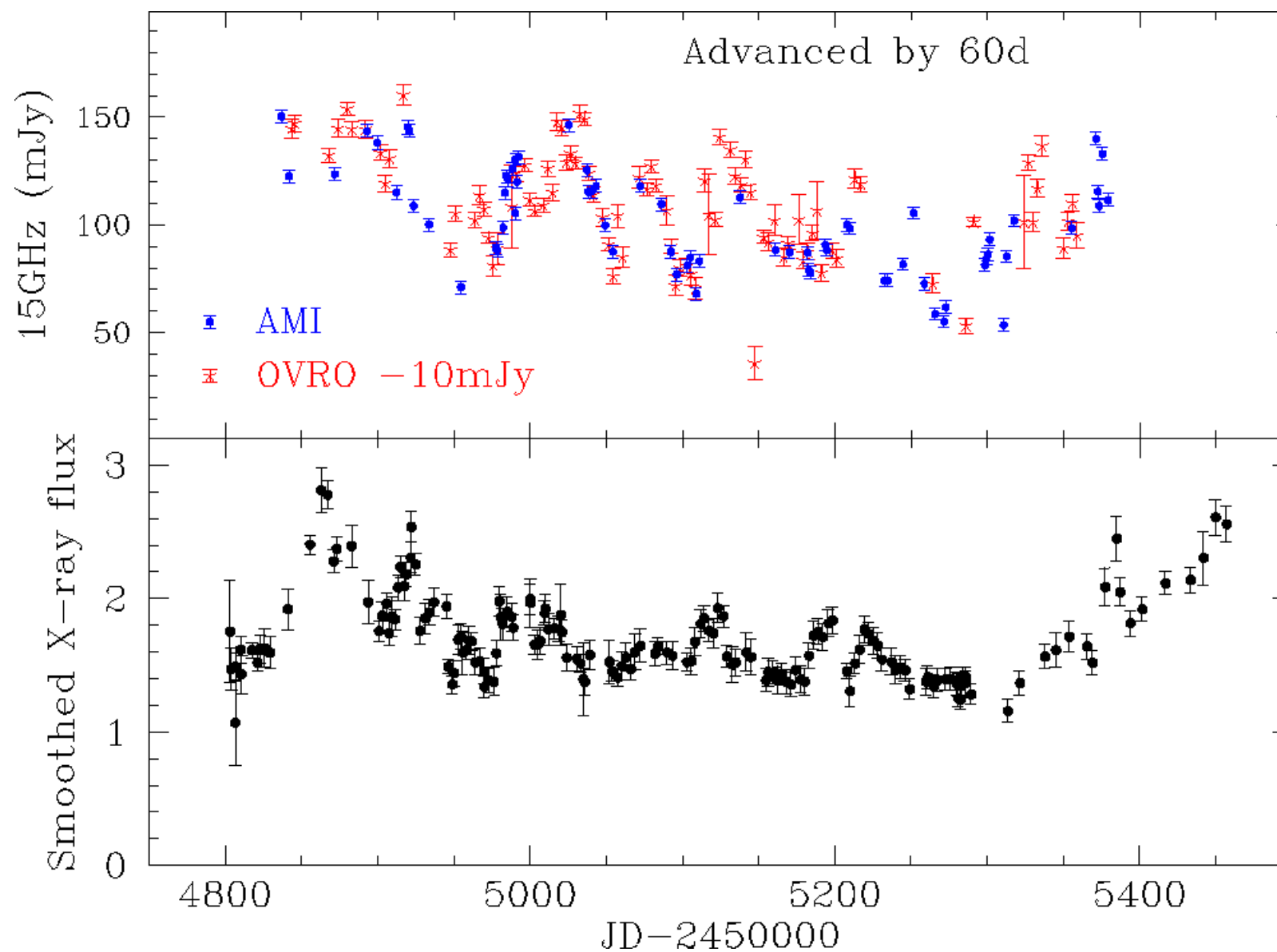


M81 X-ray and 15GHz Cross-correlation



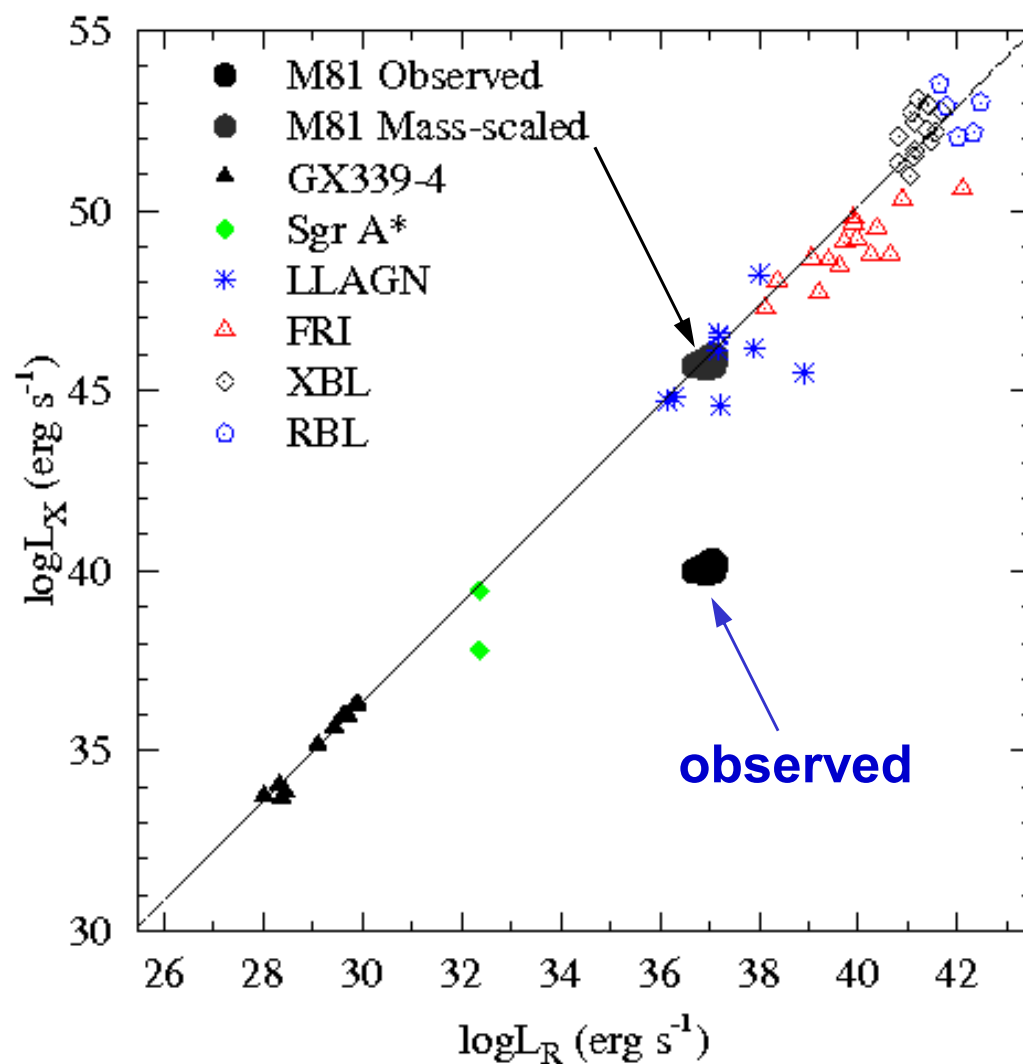


X-ray and 15GHz lightcurves of M81

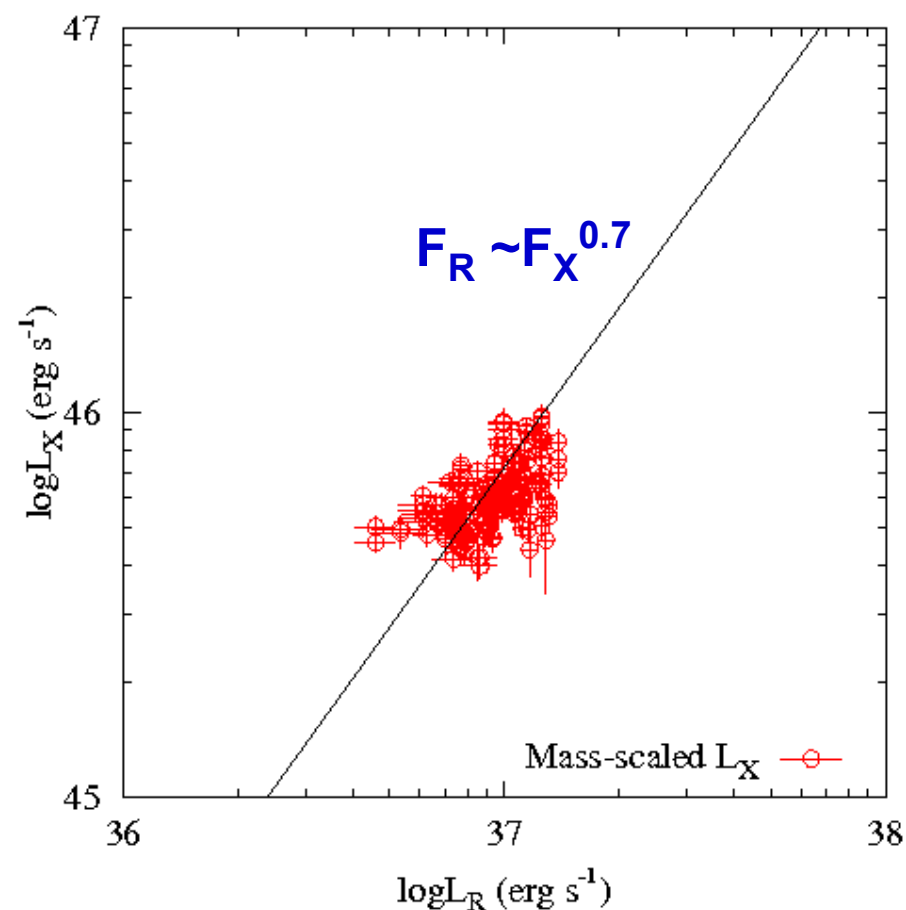




M81 X-ray and 15GHz



From Falcke et al 2004

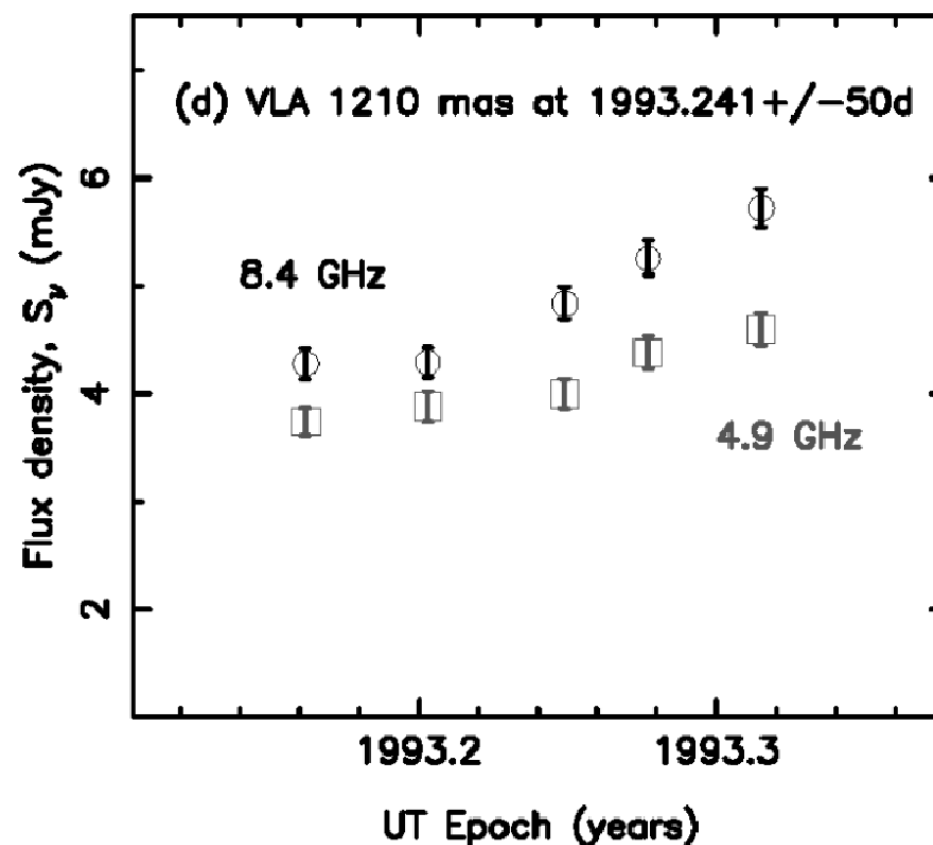
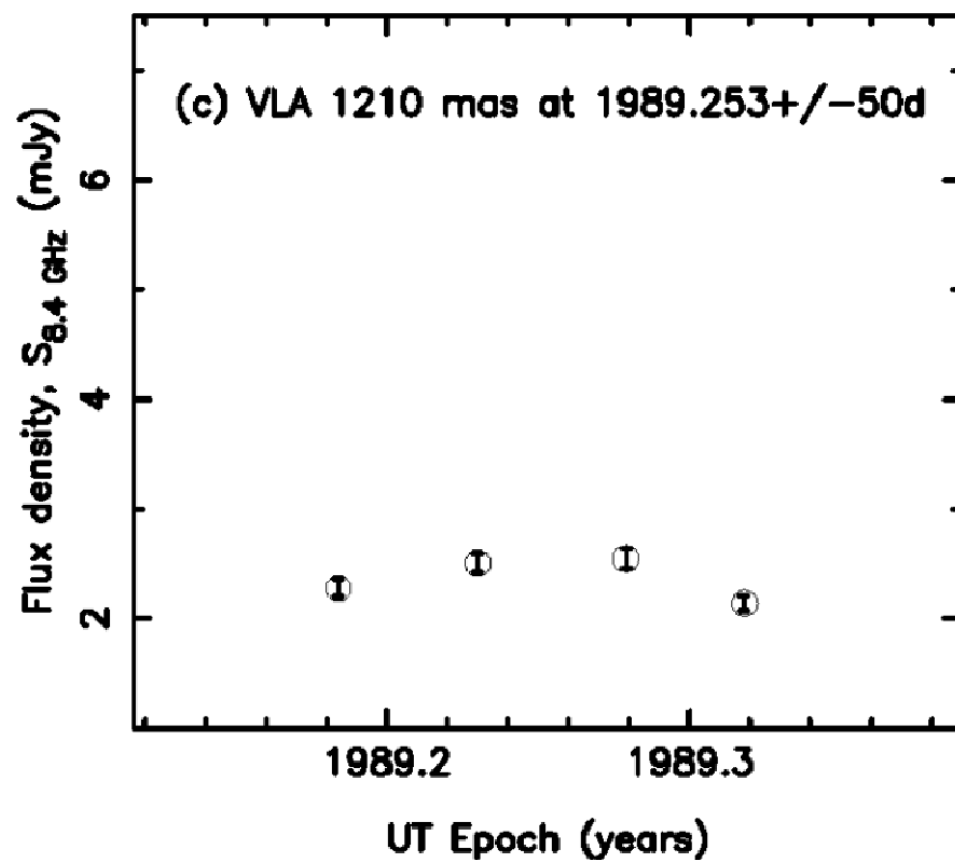


Mass-scaling assuming Falcke's jet model



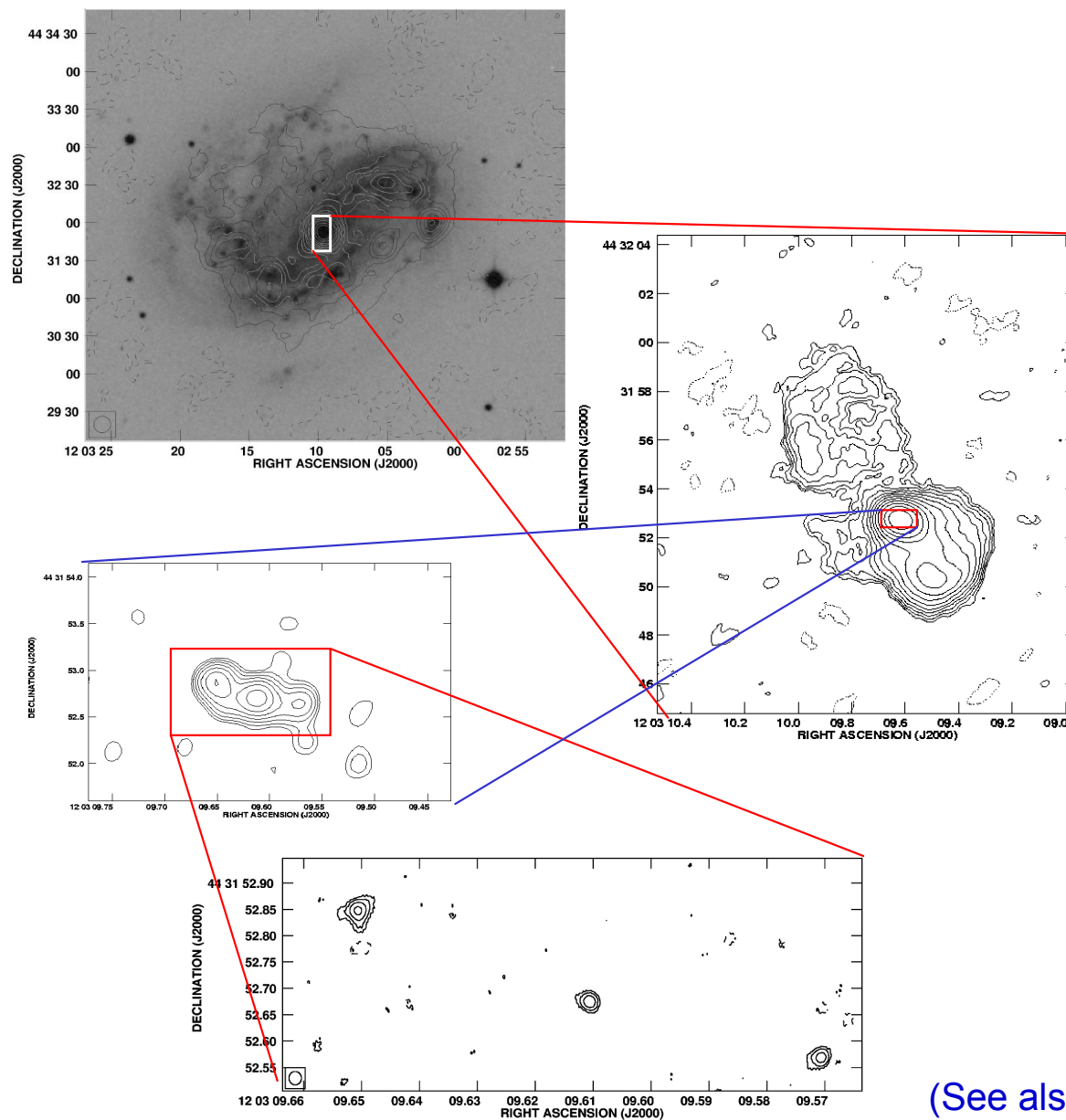
Radio variability from Seyferts, ie high accretion rate, Soft State, AGN

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 Girolletti and Panessa 2009)

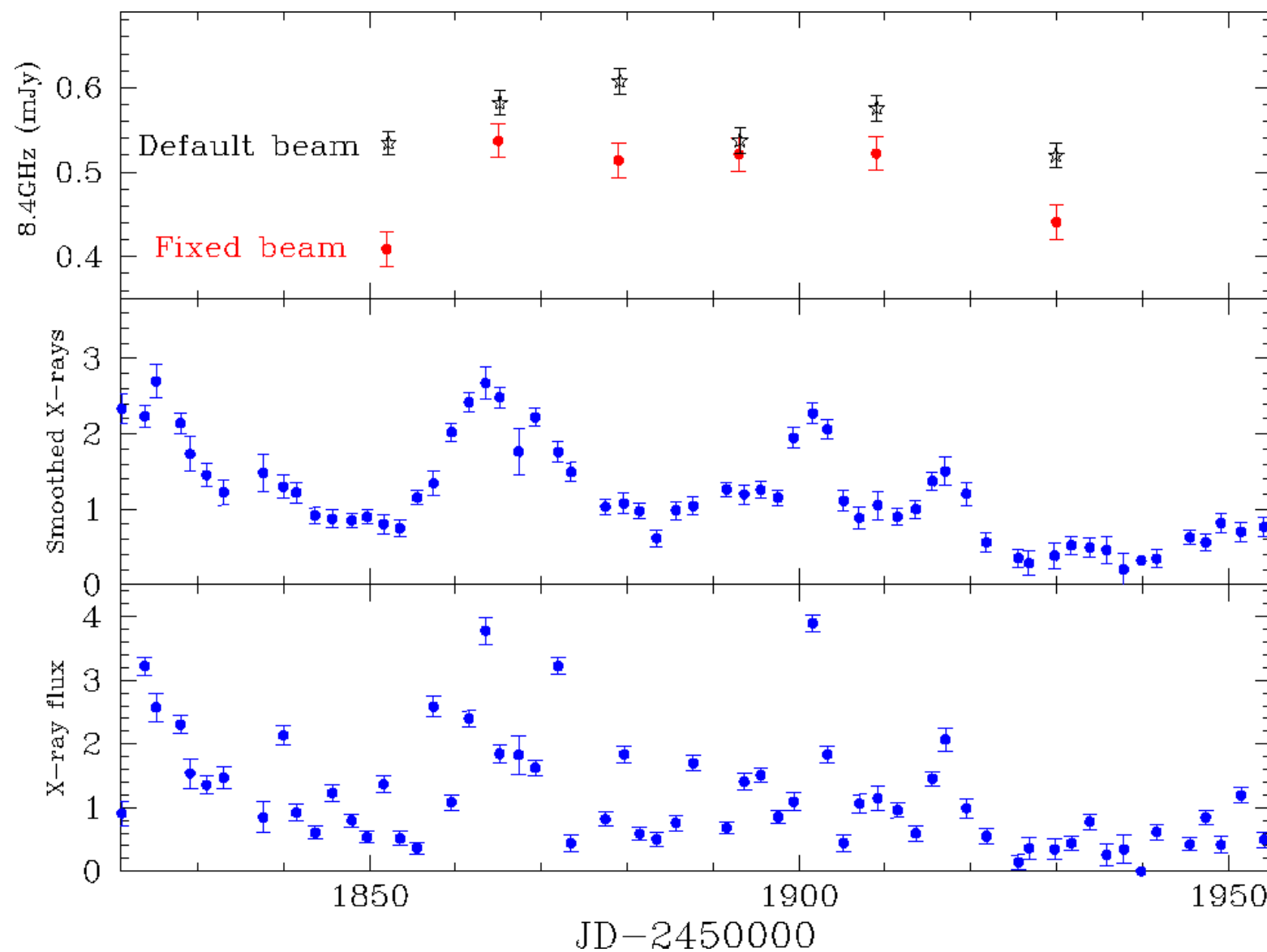


NGC4051 – Global VBLI



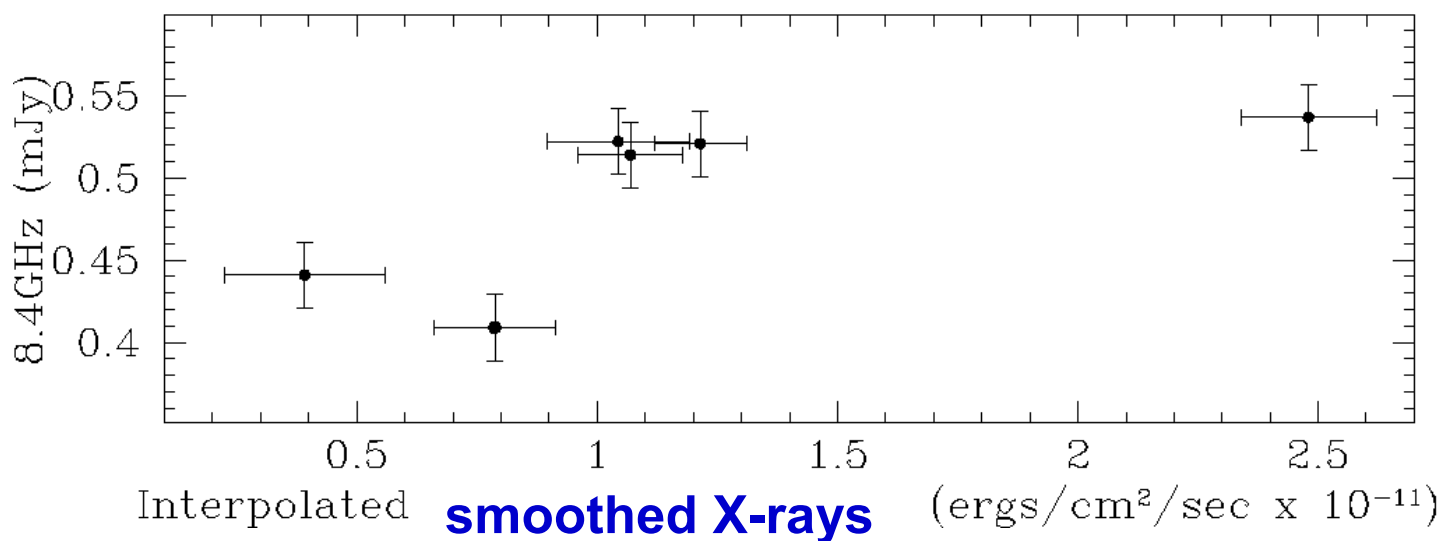
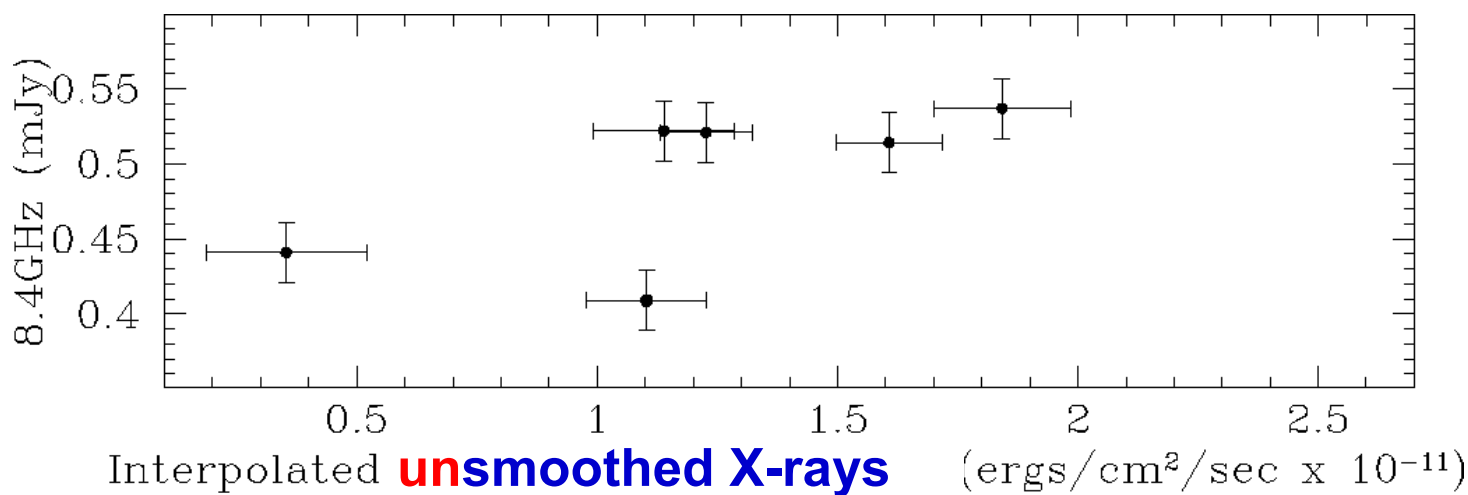


NGC4051 VLA A array observations



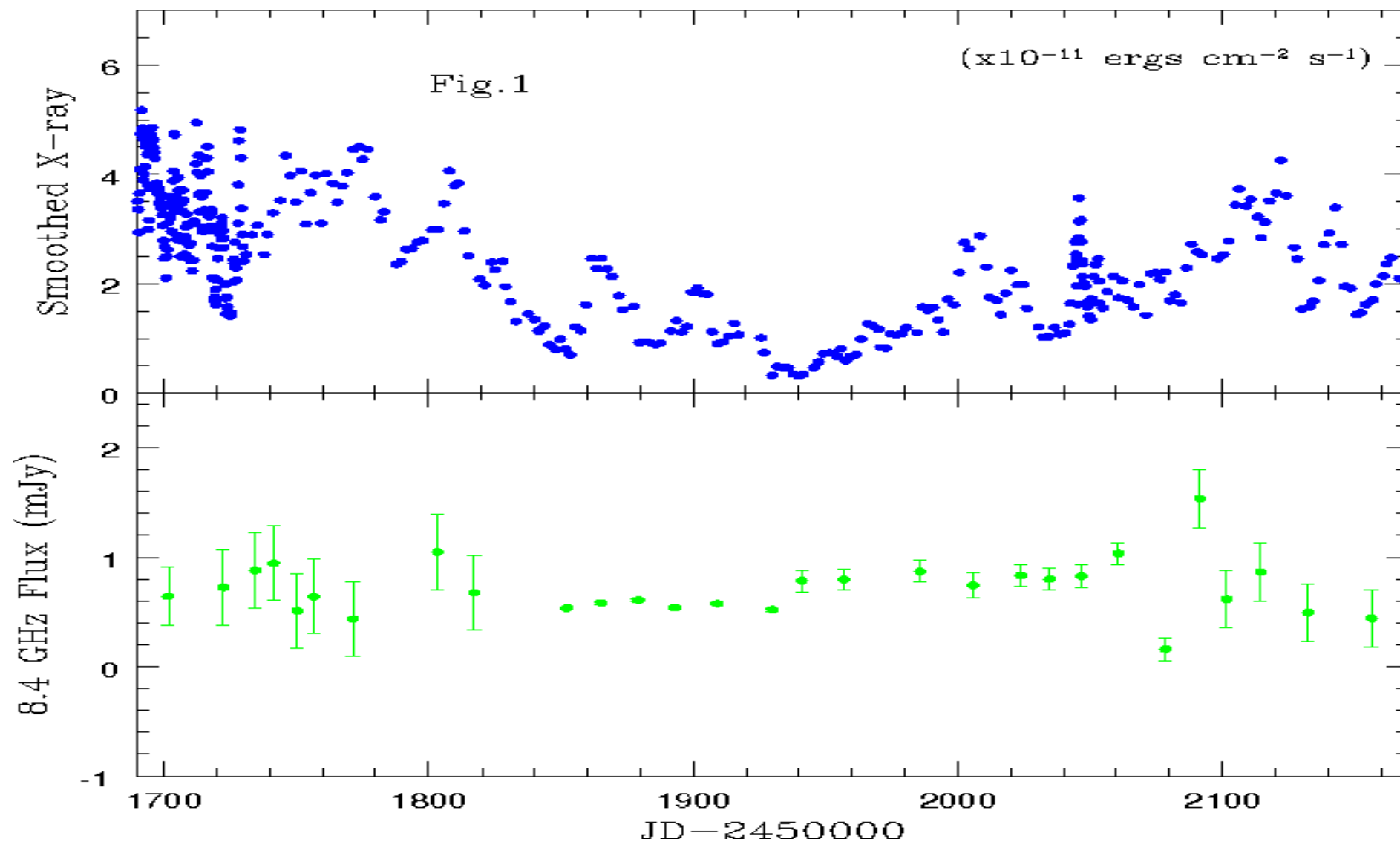


NGC4051 Radio vs. X-ray – A array





NGC4051 Radio vs. X-ray - all arrays

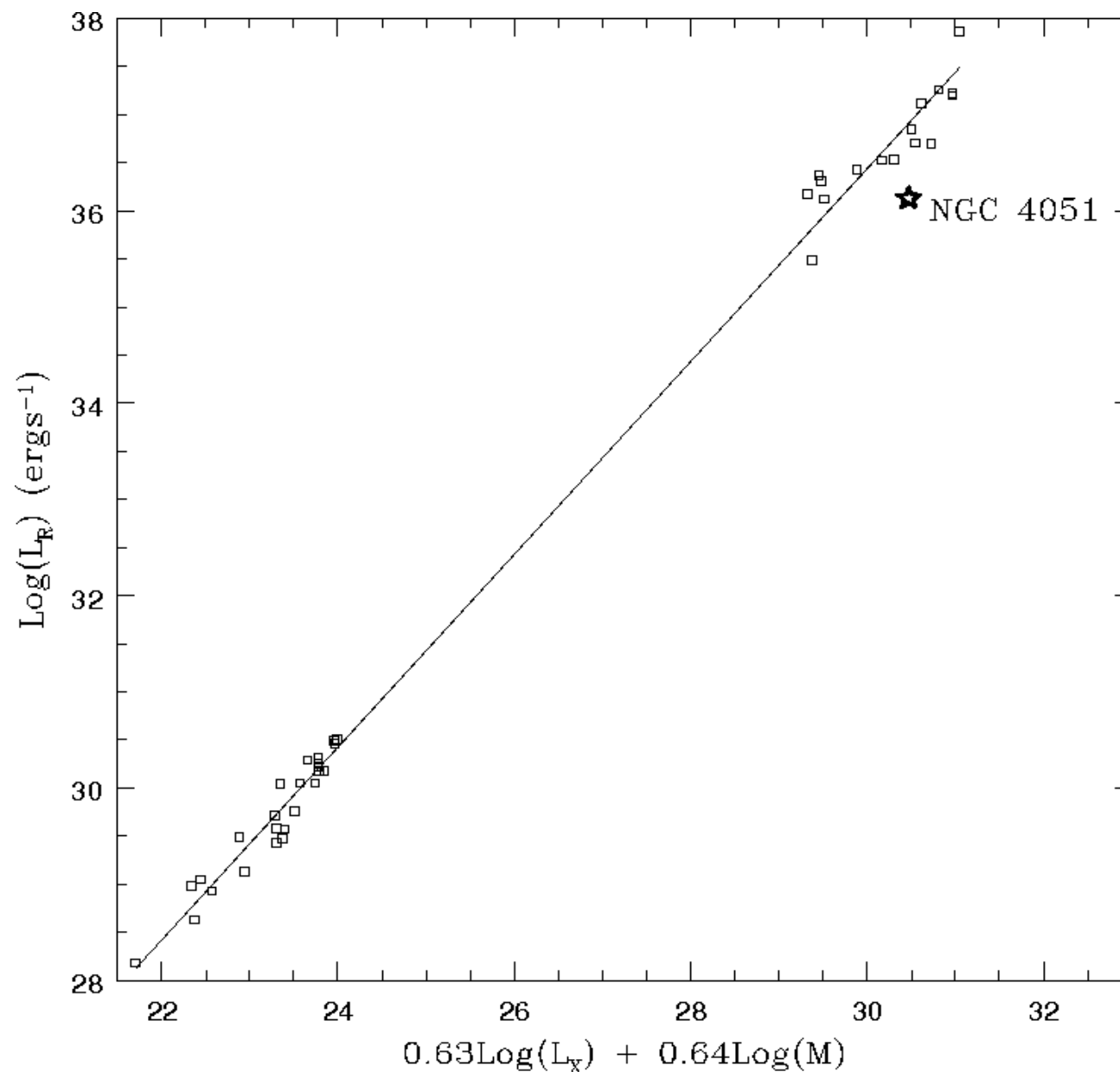


No strong evidence for large amplitude radio variability

(Jones et al,
arXiv1011.6633J
)



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



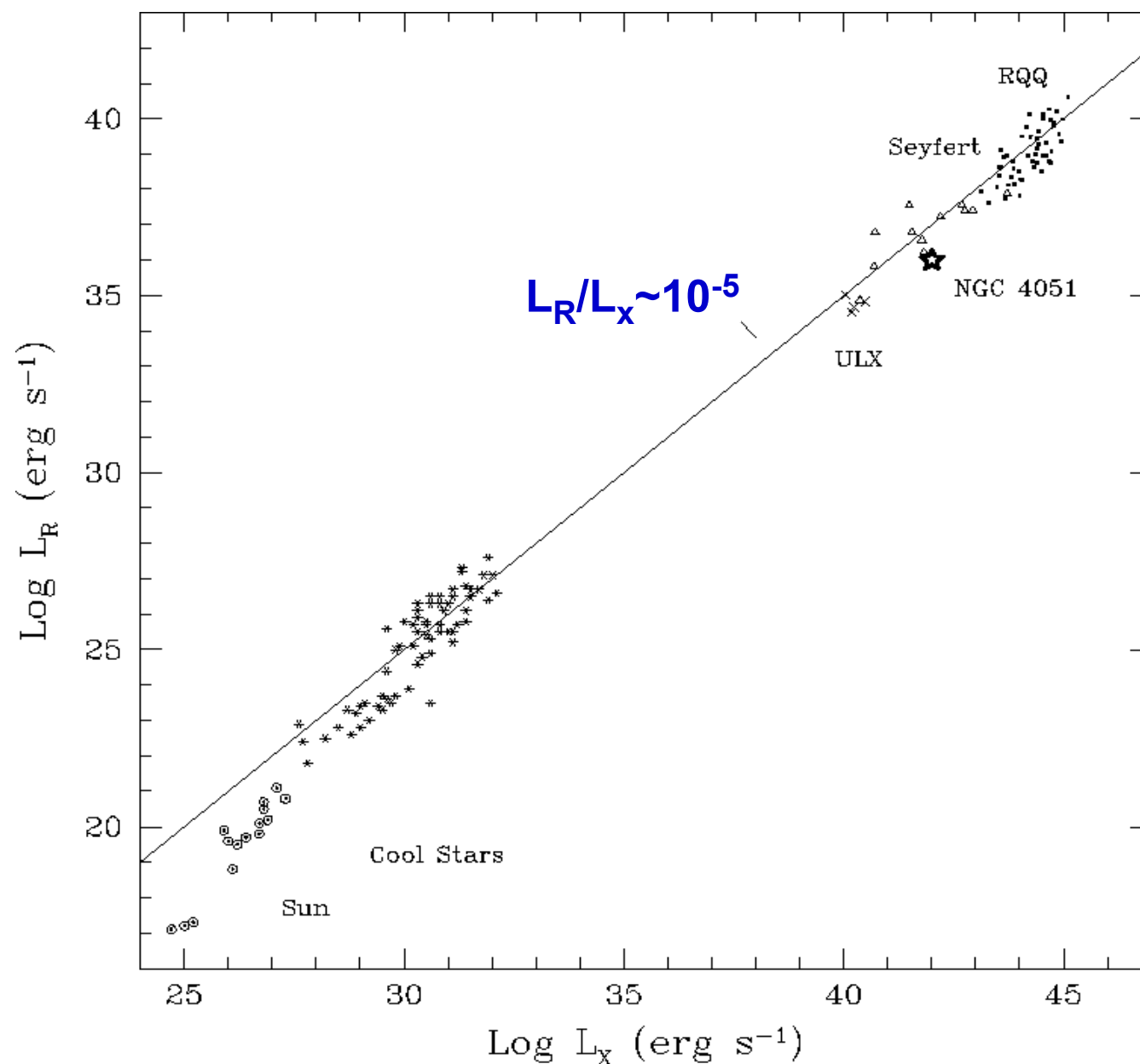
(Merloni et al 2003,
Falcke et al 2004,
Koerding et al 2006

Here plotting just
hard state objects
from Koerding et al

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

Or just jet orientation?



CONCLUSIONS

AGN probably occupy all the same spectral-timing states as GBHs.

PSD bend timescales scale with mass and accretion rate; high frequency PSD normalisation probably purely mass dependent.

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

Short timescale optical variability in Seyferts dominated by reprocessing of X-rays, strength dependent on disc temperature.

Optical variability on longer timescales from intrinsic disc variability.

Good correlation between X-ray and radio in liners ($\sim 10^{-4}$ Eddington) consistent with jet emission

In higher accretion rate Seyferts, origin of radio emission is mystery.

All of these studies would greatly benefit from ASTROSAT observations