What causes high energy variability in Blazars?

Ian M^c^Hardy

University of Southampton

Talk Outline

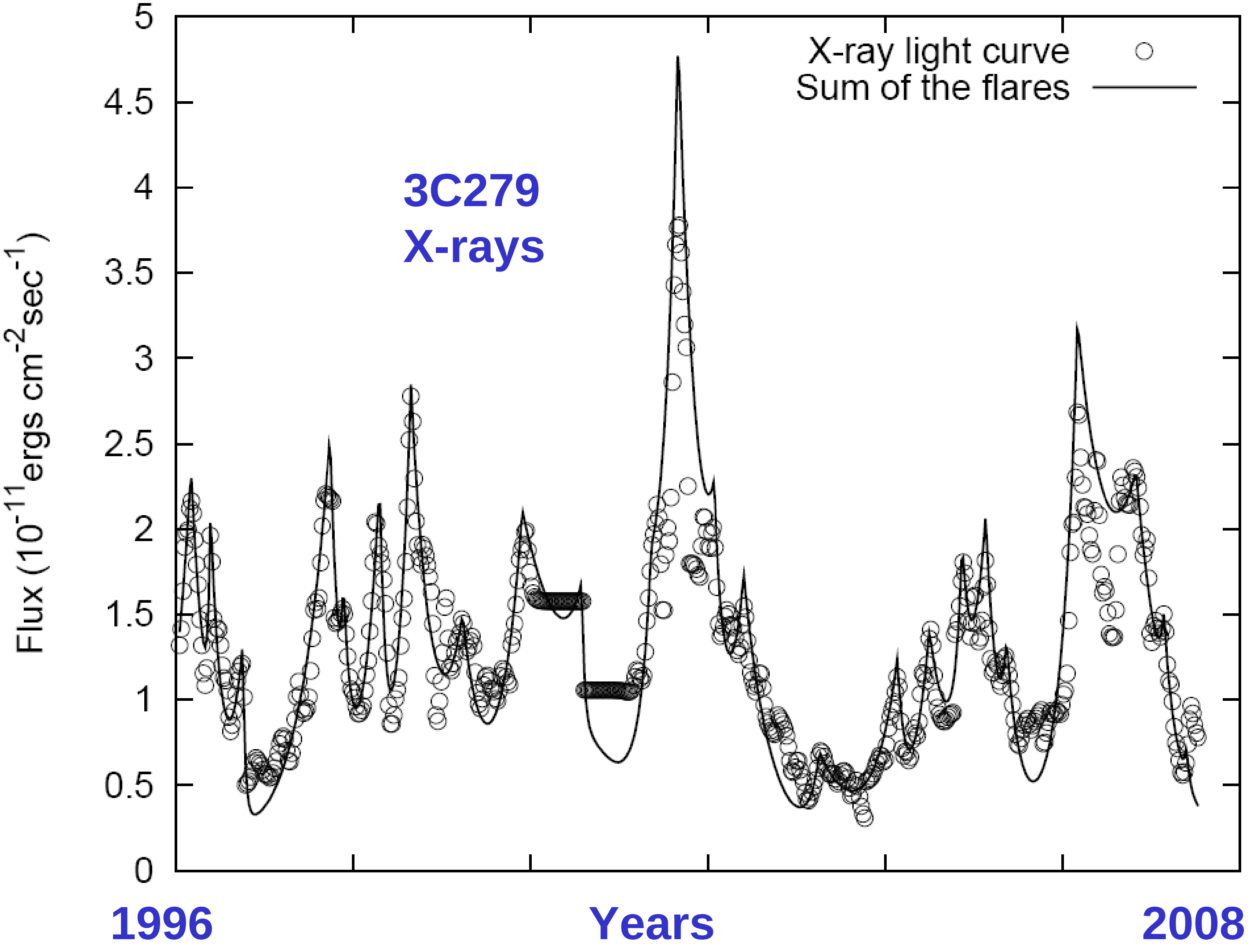
Variability – special shots or just a noise process?

What can we learn from X-ray binaries and Seyfert Galaxies?

Do blazars fit the pattern of Seyferts and binaries?

(at least a bit…)

Variability as the sum of flares?



Possibly..

-But where do the flares come from?

Chatterjee et al, in prep

What can we learn from Seyferts and Binaries?

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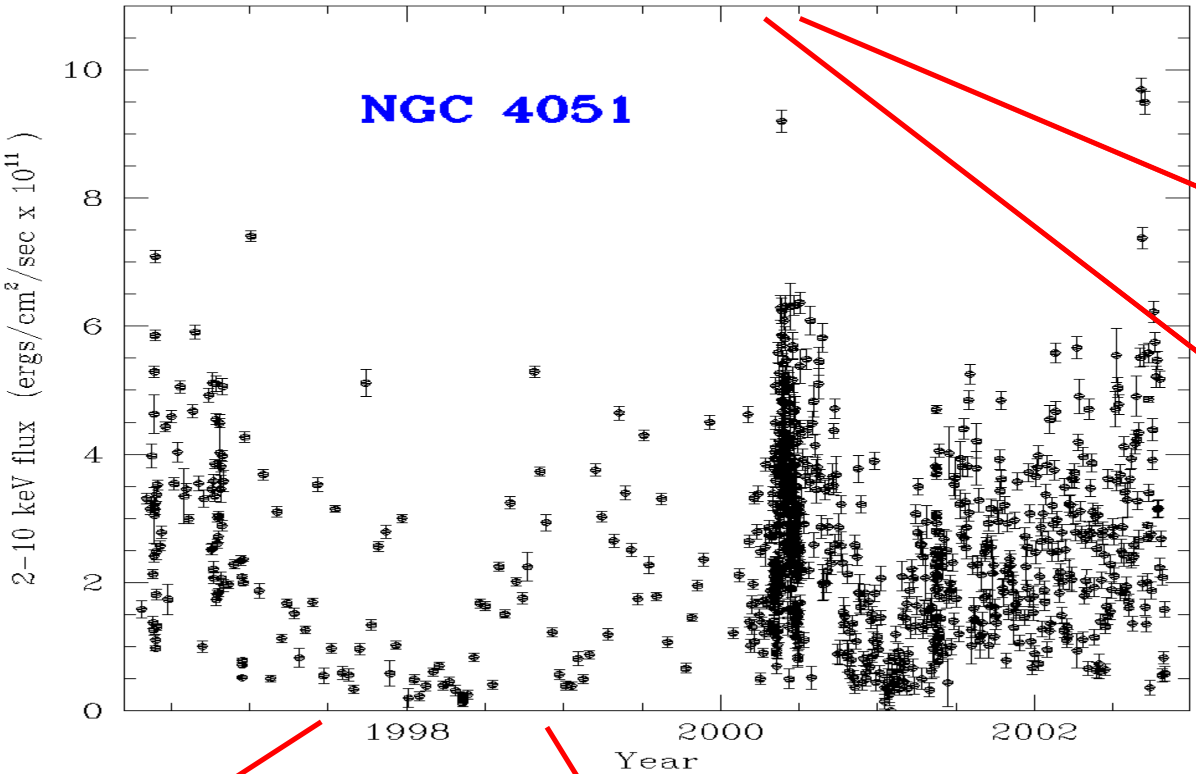
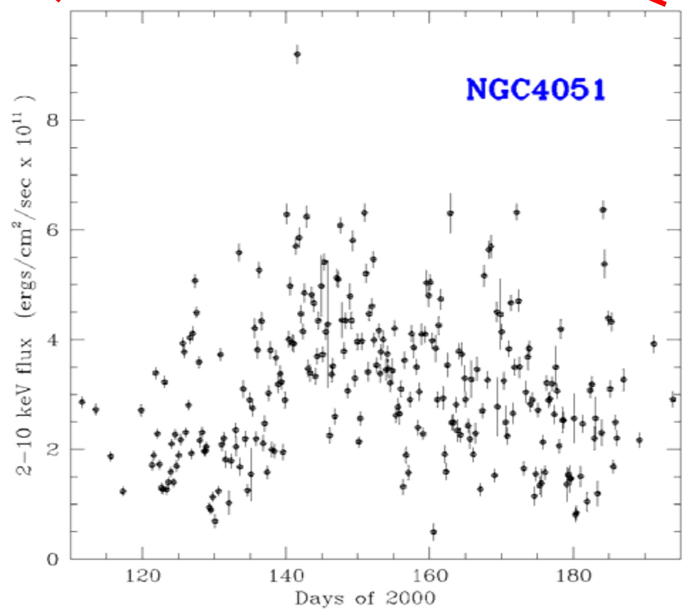
NGC4051 RXTE Long Timescale Observations

(M[c]Hardy et al 2004, MN, 348, 783)

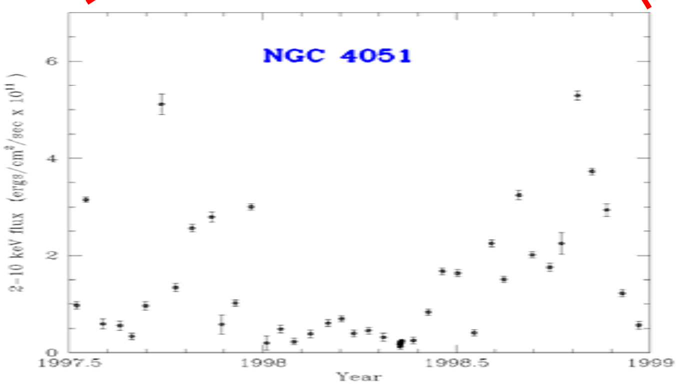


Unusual phenomena seen - `low-flux states' (Uttley et al 1999)

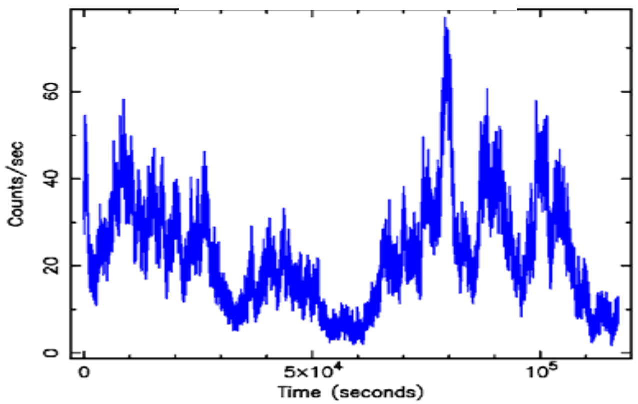
Tricky to simulate with random shots



'low-flux period'



XMM



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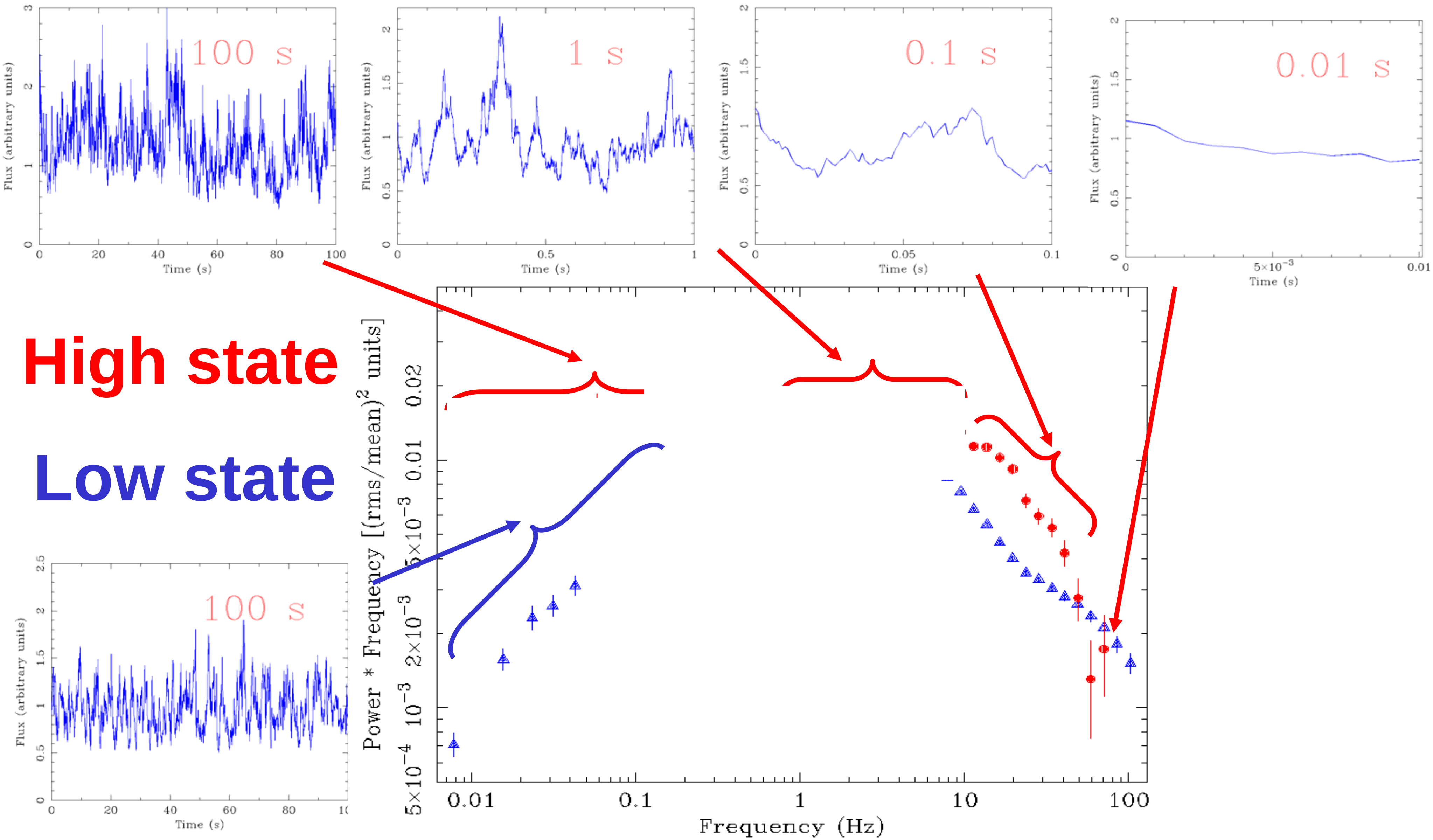
Quantifying variability: the ‘power spectrum’ of Cyg X-1



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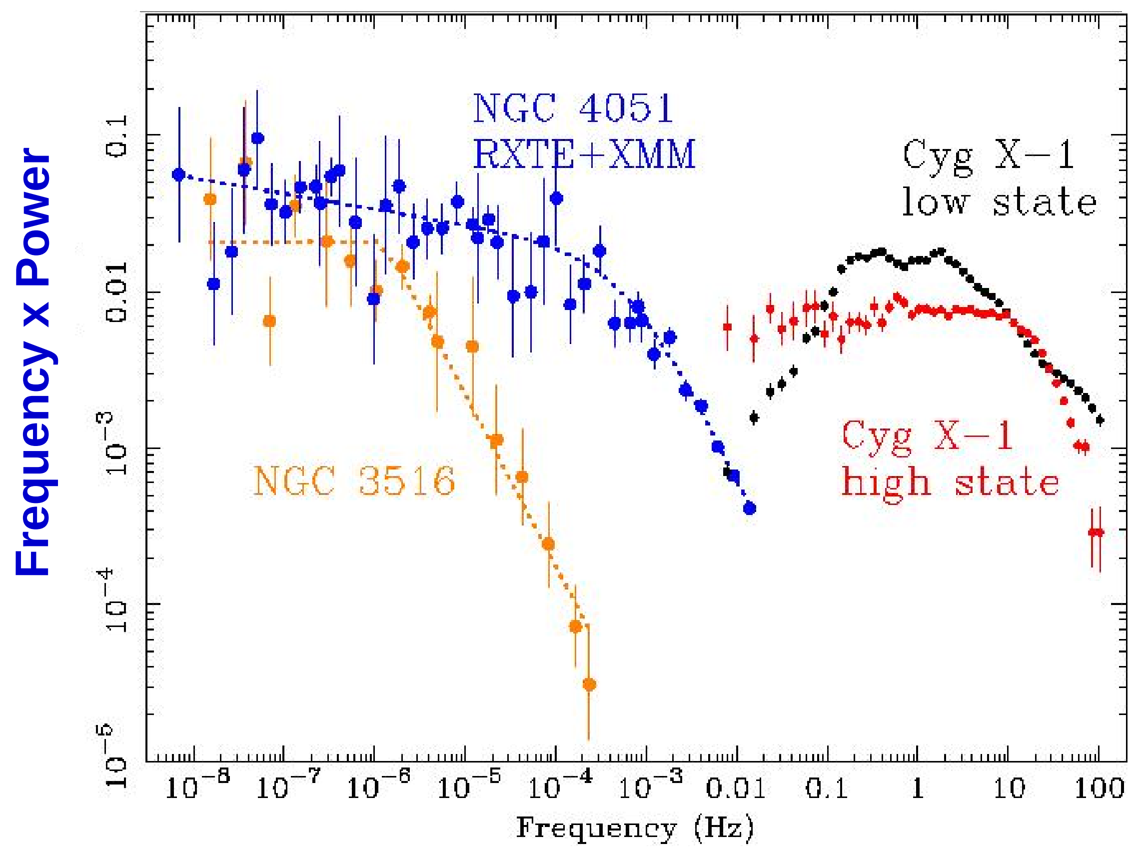
Seyfert and X-ray binary powerspectra

Frequency x Power

`Unfolded' Power Spectral Density (PSD)



(McHardy et al., 2004)

Seyfert and X-ray binary variability well described as a noise process

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**

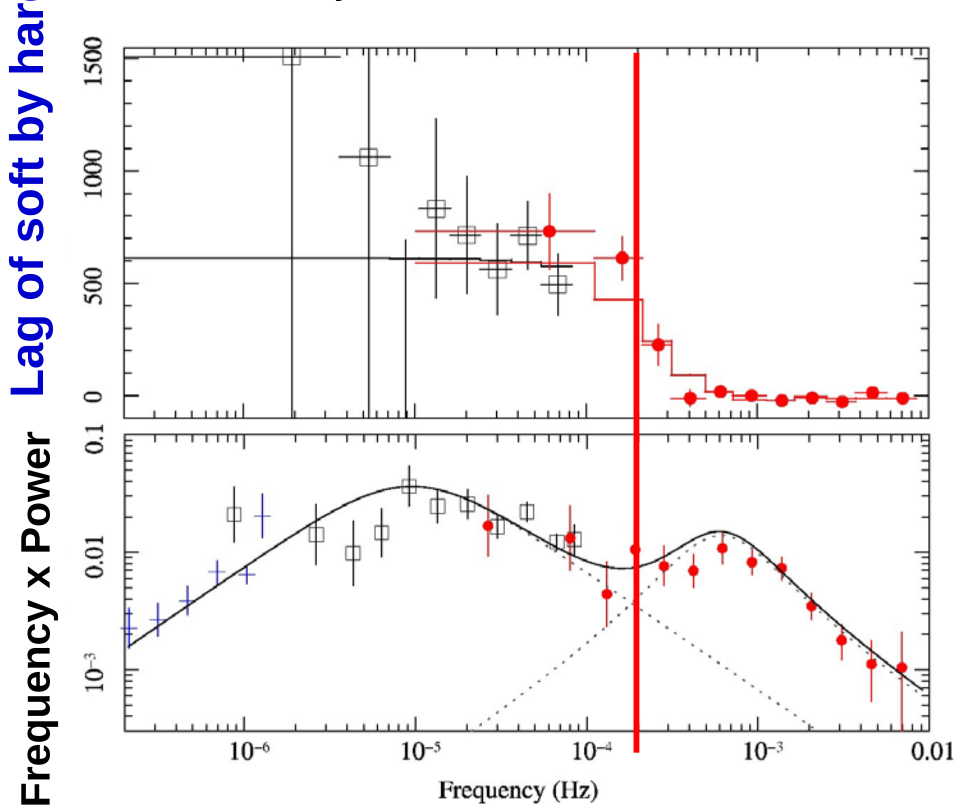
•High break timescale scales approximately linearly with mass

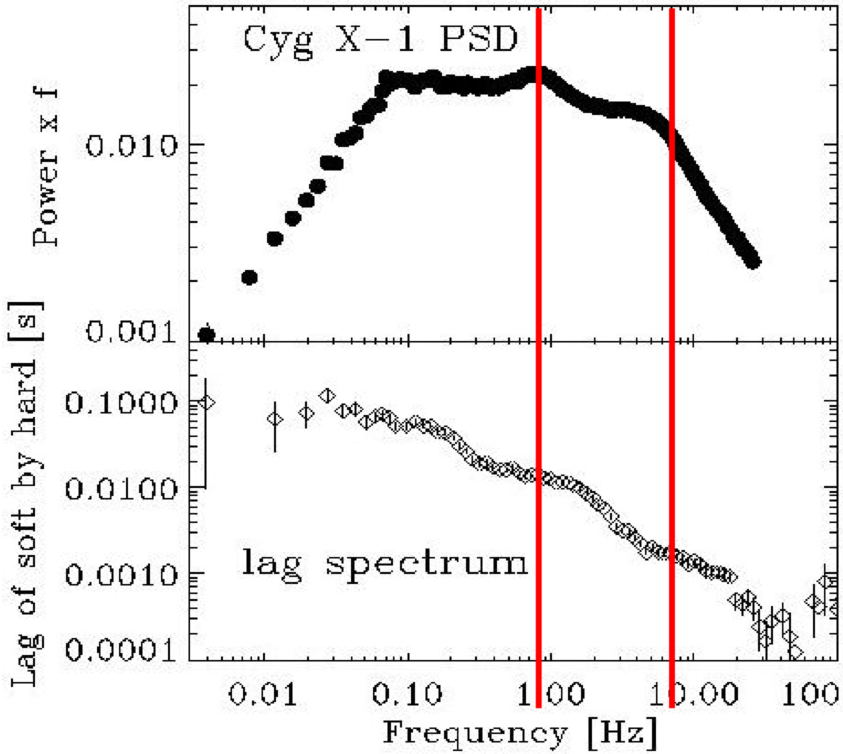
(We compare the timescales of the HIGH frequency break)

PSDs modelled by simulation – PSRESP, Uttley et al 2002

Further state diagnostics Lorentzians and Time Lags: Akn564 – Very High State

McHardy et al 2007





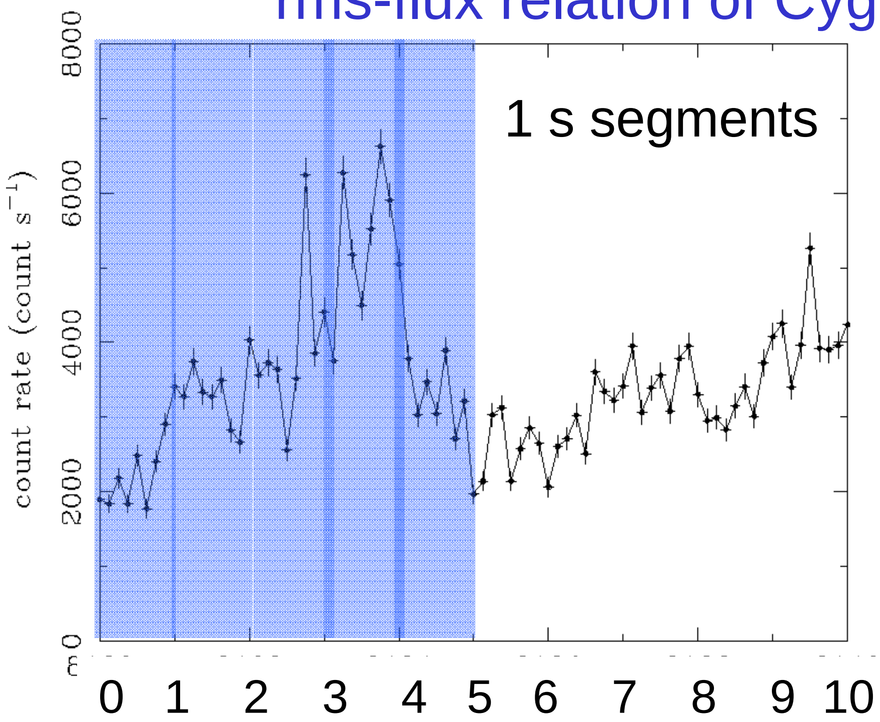
For binaries in hard or VHS state, lag is ~constant when one Lorentzian dominates, and changes as we move to next Lorentzian.

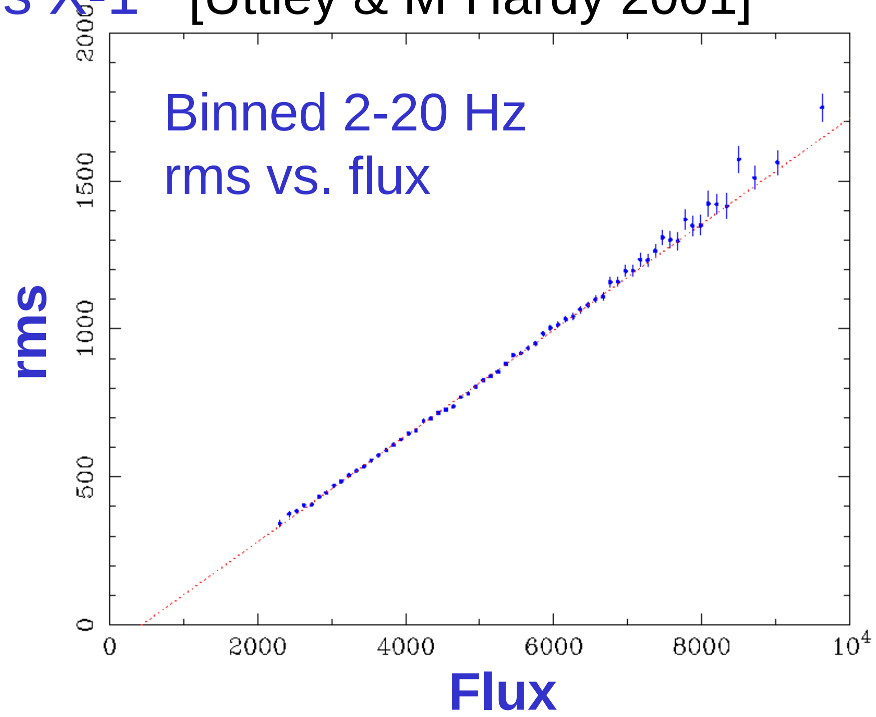
..same in Akn564 As $\dot{m} \geq 1$ implies VHS, not `hard' state)

→ **At least 2 physically distinct sources of variability**

The rms-flux relation

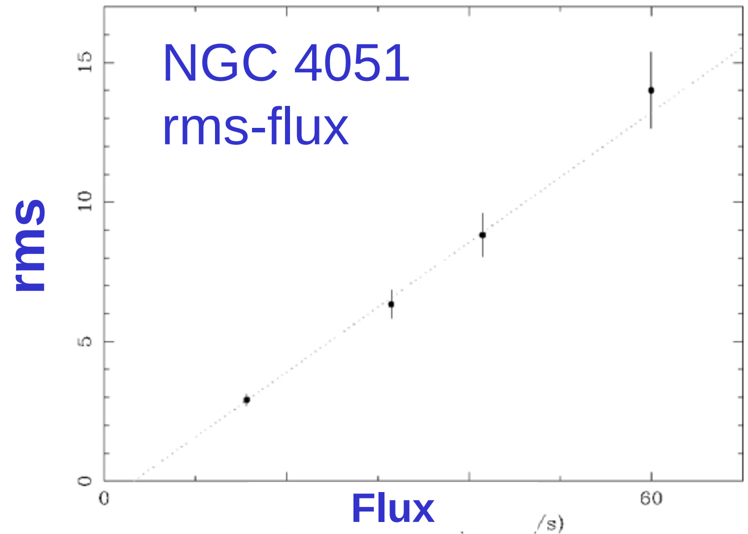
rms-flux relation of Cygnus X-1 [Uttley & McHardy 2001]





rms = sqrt (excess variance)

Also seen in AGN



RMS Variability (σ) vs. FLUX

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

This relationship holds whatever timescales we probe.

So variations on short timescales depend on variations on all longer timescales – explains extended `low states' in AGN.

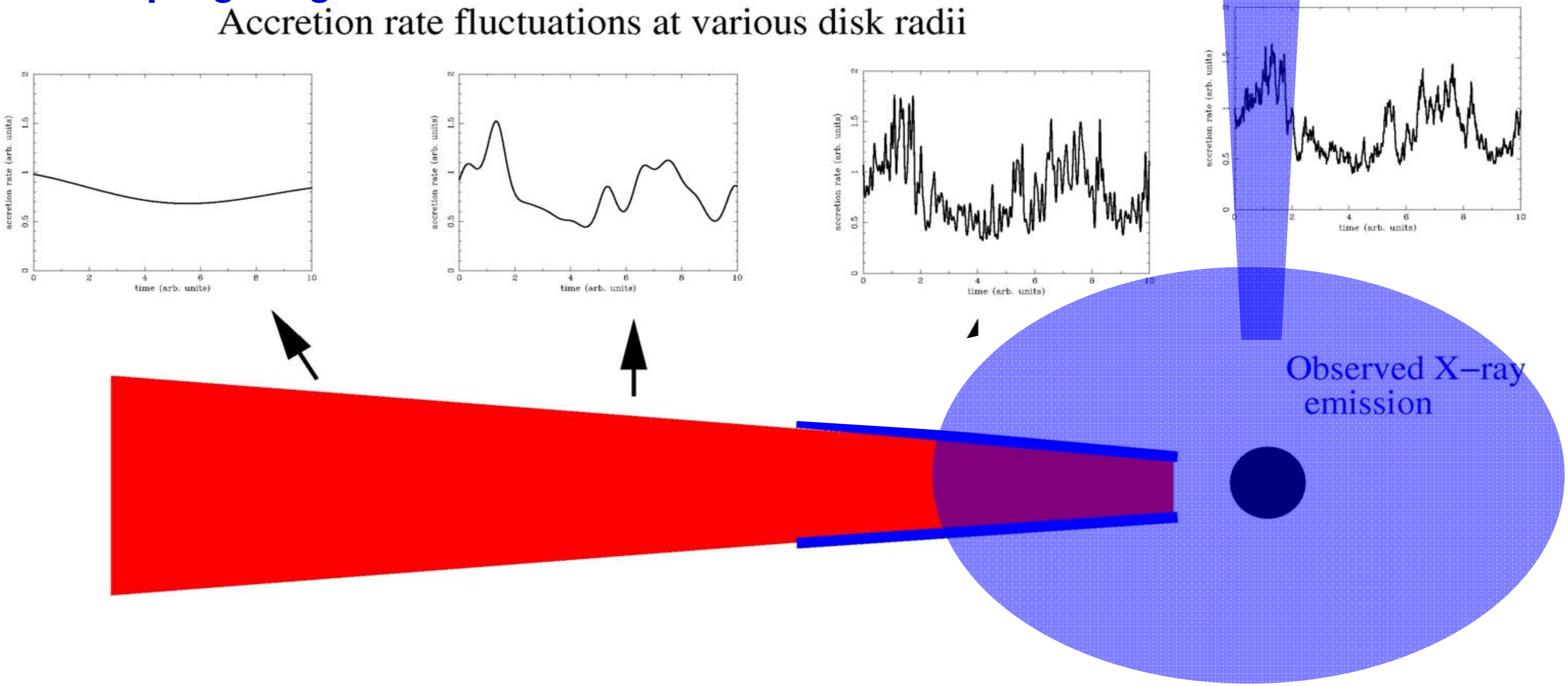
Rules out simple shot noise models with uncorrelated shots.

This strong coupling of timescales leads to non-linear variability.

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

Variations propogate inwards through a corona over surface of disc, to modulate X-ray emitting region. (Kotov et al 2001; Churazov et al 2001; Arevalo + Uttley 2006)

Amplitude of fluctuation in each annulus is modulated by total amplitude of inward progating fluctuations.



The variability mechanism is independent of the emission mechanism

RMS-FLUX IMPLICATIONS

A mean-subtracted lightcurve, X(t) can be written

$$X(t) = \Sigma_{i=1}^{\infty} A_i sin(2\pi\nu_i t + \phi_i)$$

To produce a linear rms-flux relationships, A_i must scale with the flux associated with all variations at frequencies $\nu < \nu_i$

i.e. the total flux, L,(t), associated with variations at frequencies up to and including ν_i is

$$L_i(t) = L_{i-1}(t)(1 + A_i sin(2\pi\nu_i t + \phi_i))$$

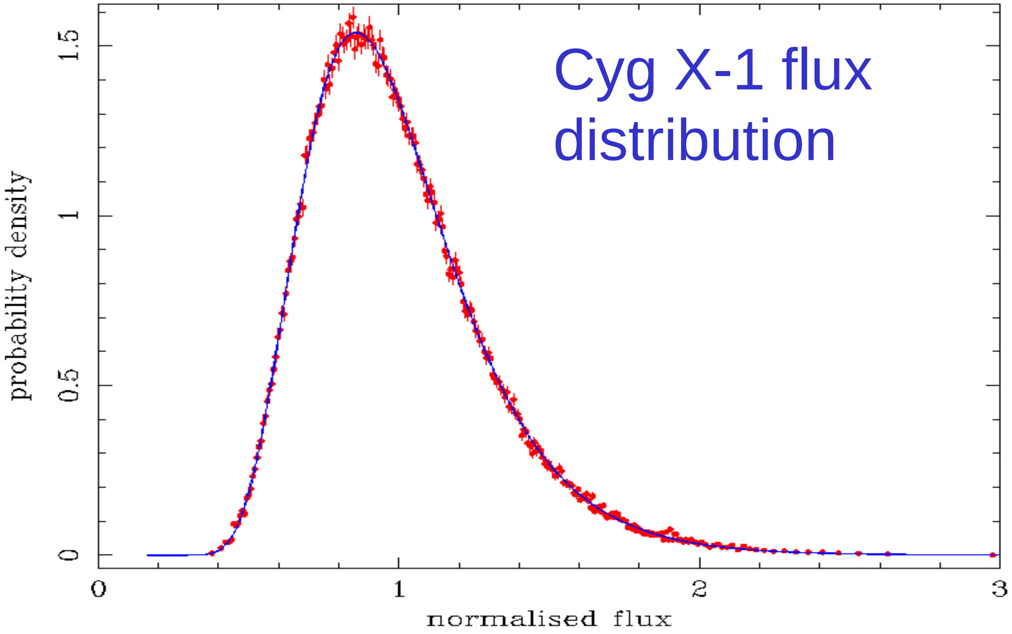
$$i.e.\ L(t) = \Pi_{i=1}^{\infty} [(1 + A_i sin(2\pi\nu_i t + \phi_i)]$$

e_x~1+x as x is small as the flux remains finite, then

$$L(t) = \prod_{i=1}^{\infty} e^{A_i \sin(2\pi\nu_i t + \phi_i)} = e^{\sum_{i=1}^{\infty} A_i \sin(2\pi\nu_i t + \phi_i)} = e^{X(t)}$$

The rms-flux relation: phenomenological implications

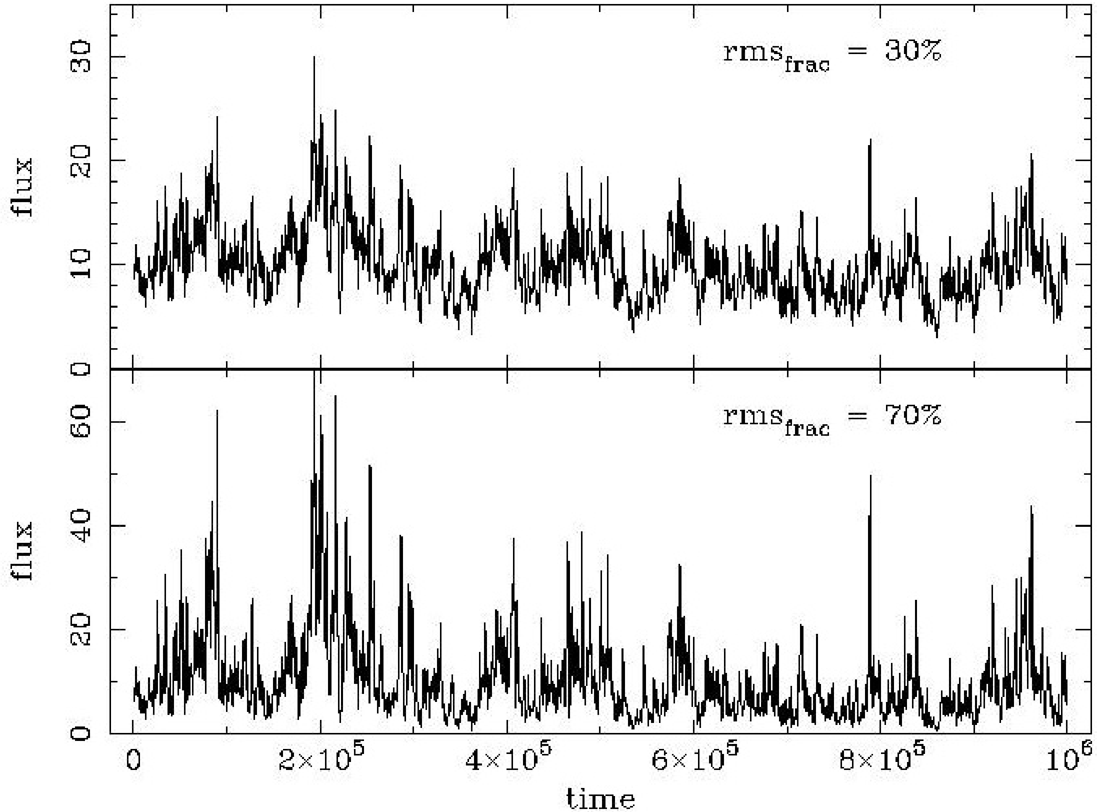
(Uttley, McHardy & Vaughan 2005)



- If a large number of independently distributed components in the light curve multiply together, the resulting distribution of fluxes will be lognormal

Variability and non-linearity

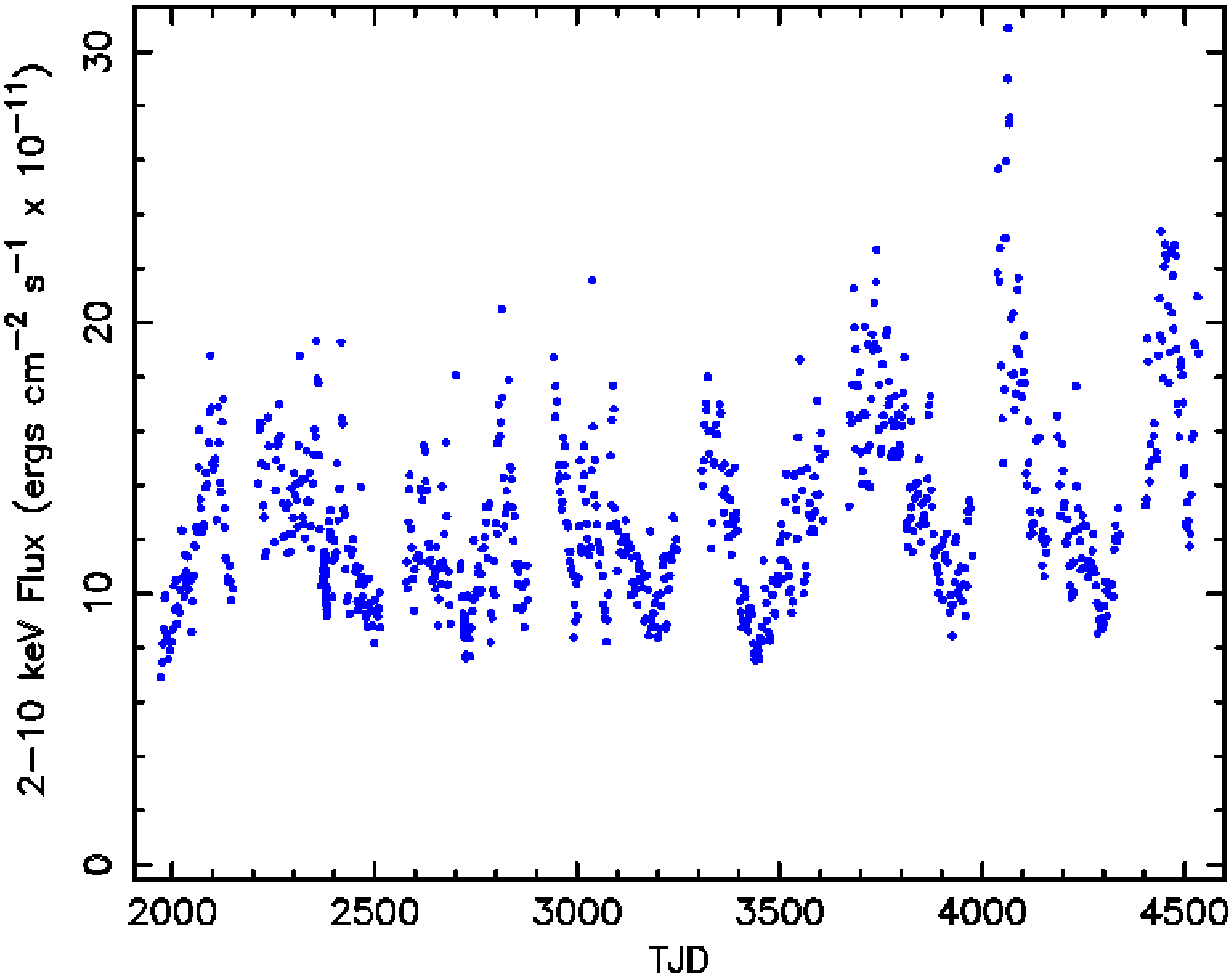
- Prediction from rms/flux relationship is that sources with higher fractional variability, like the NLS1s, will be intrinsically more non-linear



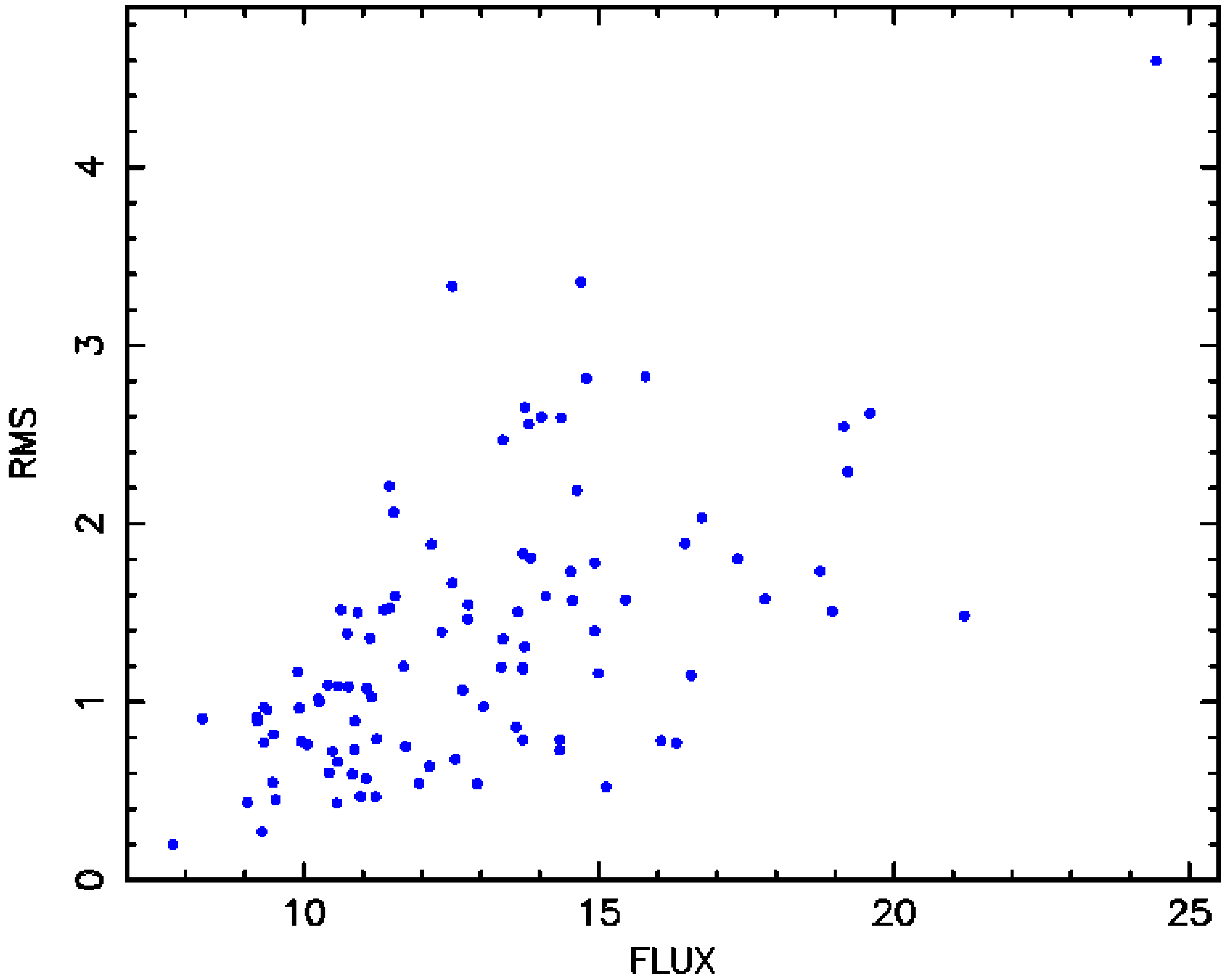
they are

What do blazars look like?

3C273 – rms/flux

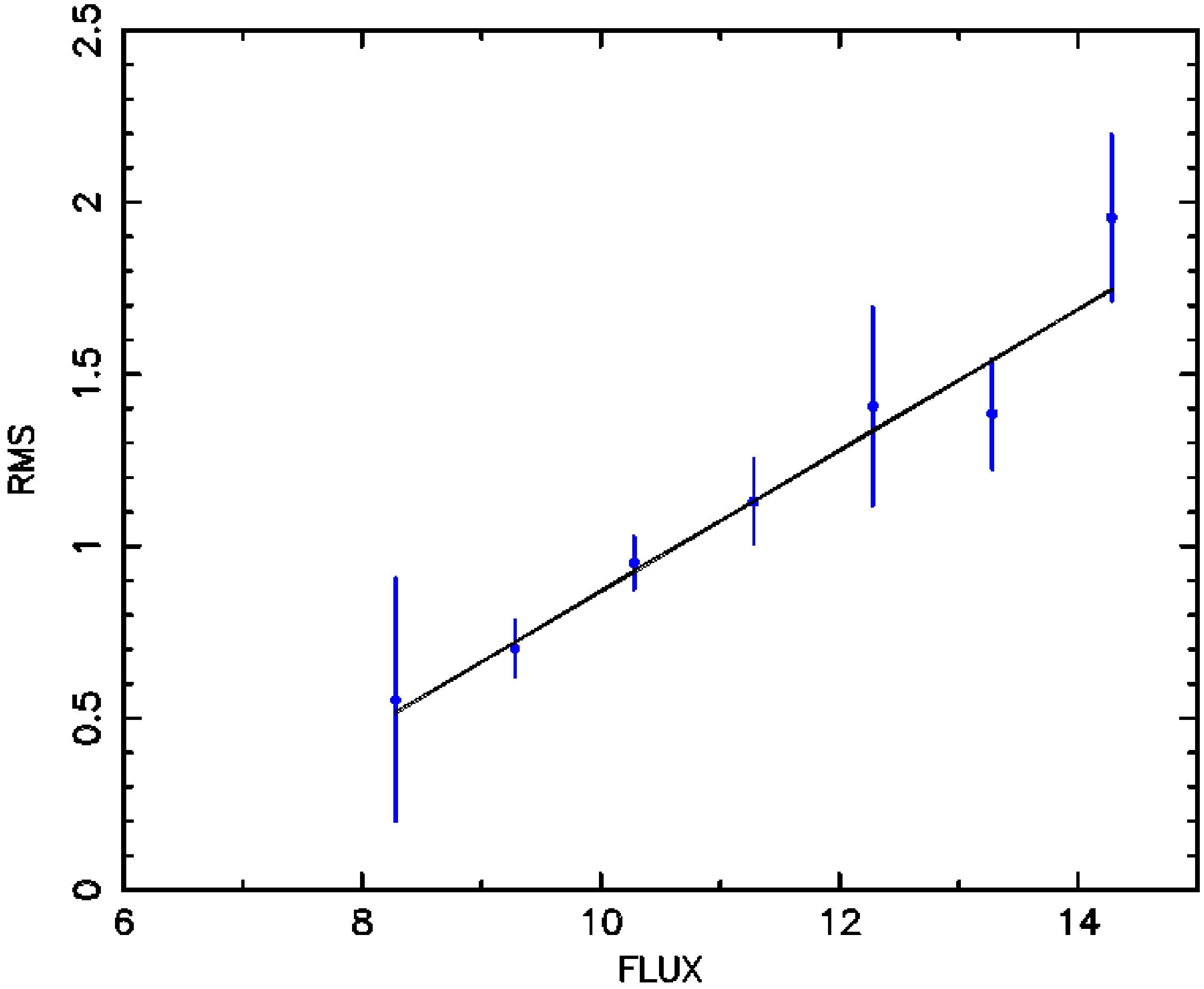


3C273 RMS/Flux



(Unbinned)

3C273 RMS/Flux



Binned

Very tight rms/flux relationship

Note offset on flux axis.

Constant component

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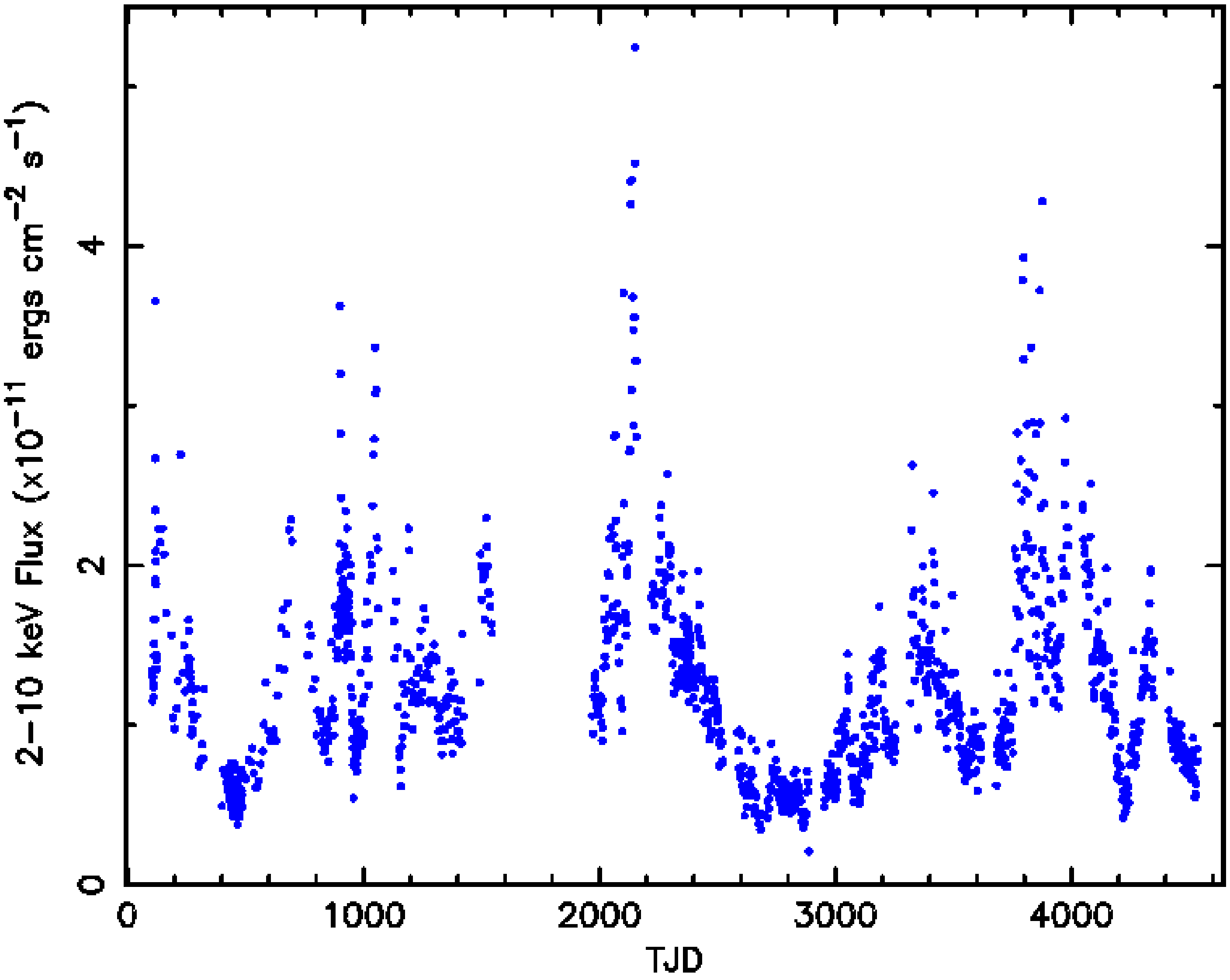
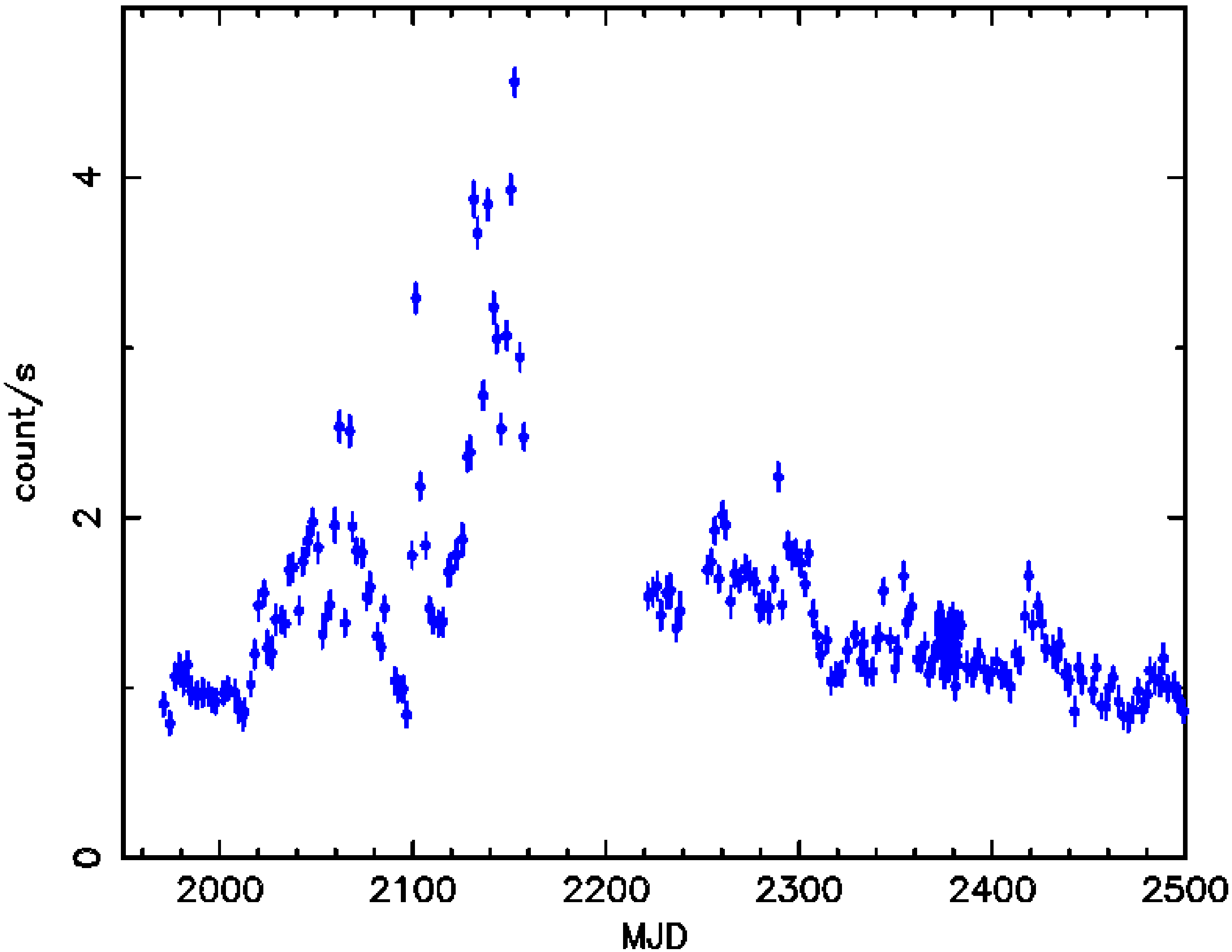
3C279

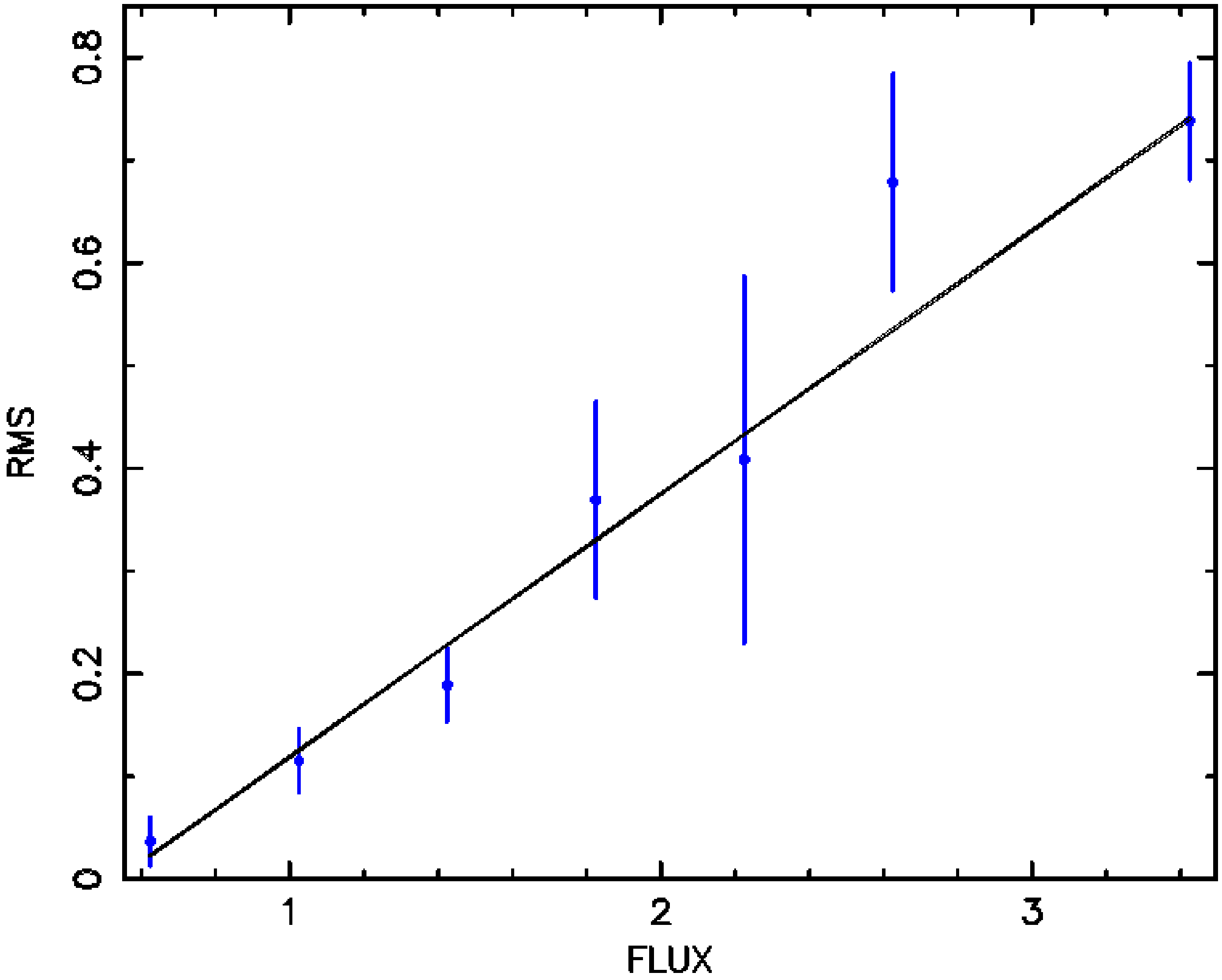


3C279 Rms/Flux



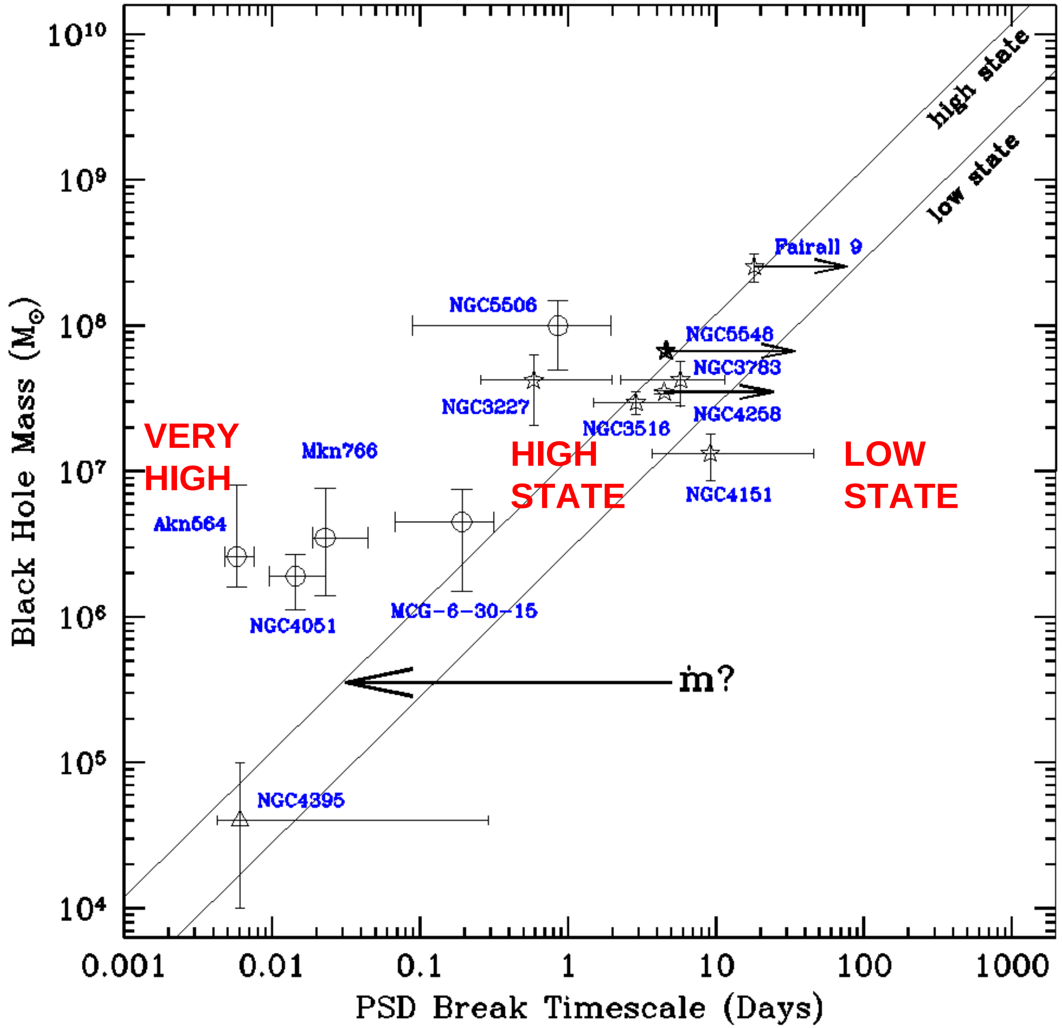
Note large amplitude variability when bright and very little variability when faint.

3C279 Rms/Flux Relationship



POWERSPECTRAL SCALING RELATIONSHIPS

Seyferts and Binaries: 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?

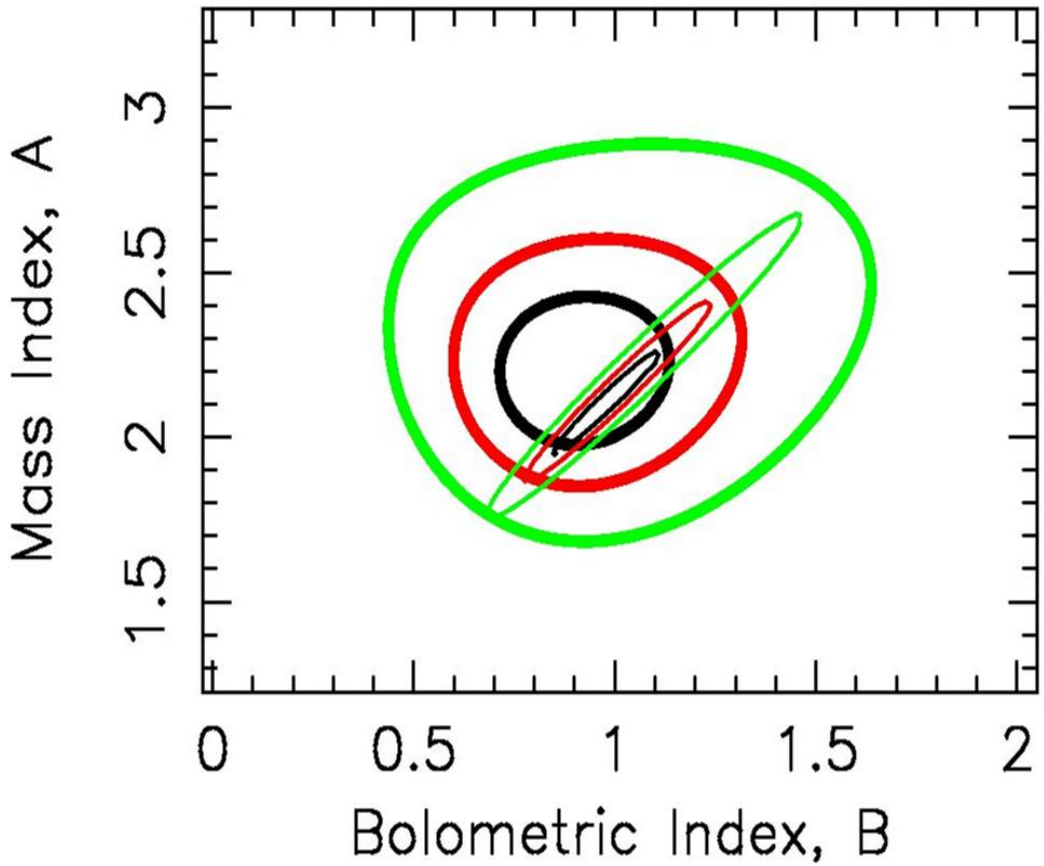
Higher accretion rate pushes in disc?

(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, Dec 2006, Nature, 444, 730)



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 fit to AGN

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

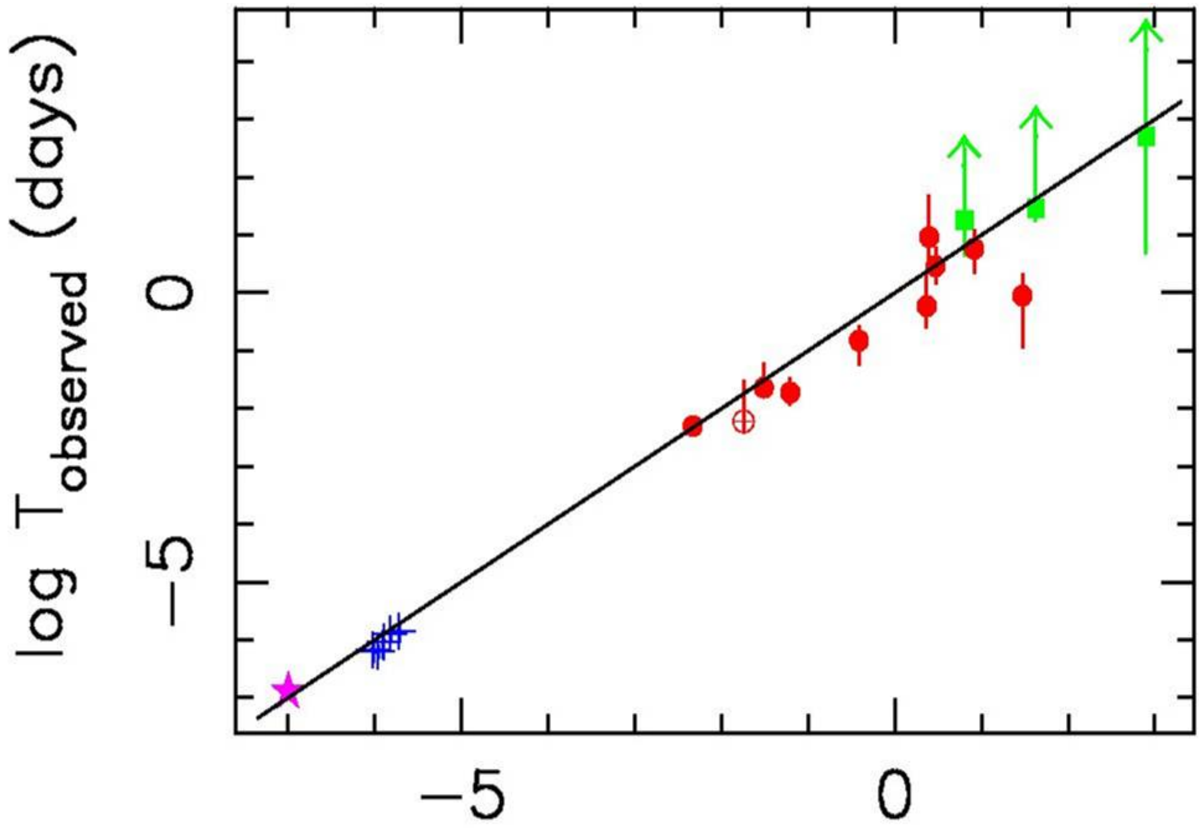
we fit to $T_B \sim M^A\ L_{Bol}^{-B}$

Add binary sources
(Cyg X-1 and **GRS1915+105)**

Excellent agreement

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

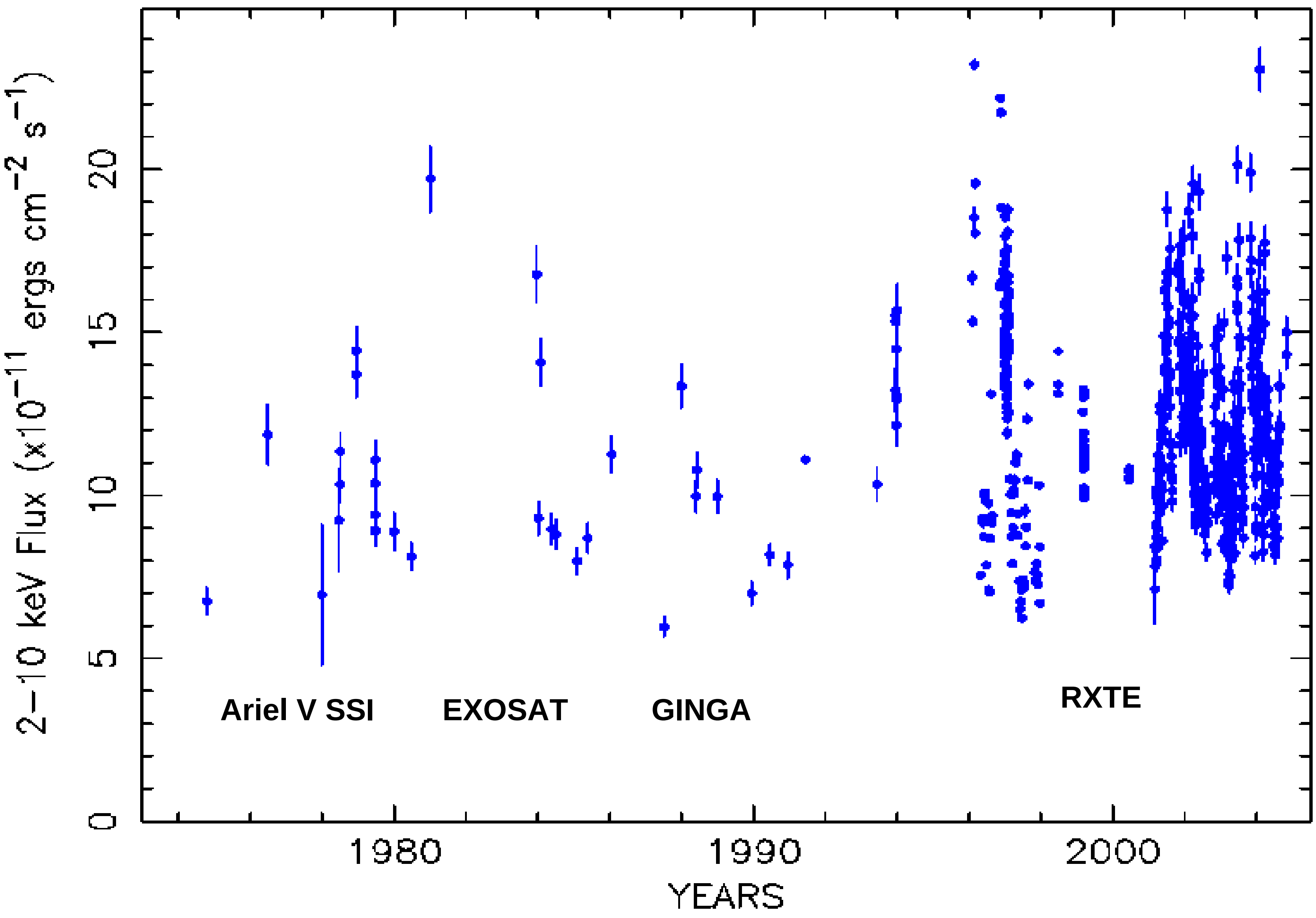
Green squares AGN with poorly determined T_b, not included in the fit.

Blue crosses – Cyg X-1
Magenta star – GRS1915+105

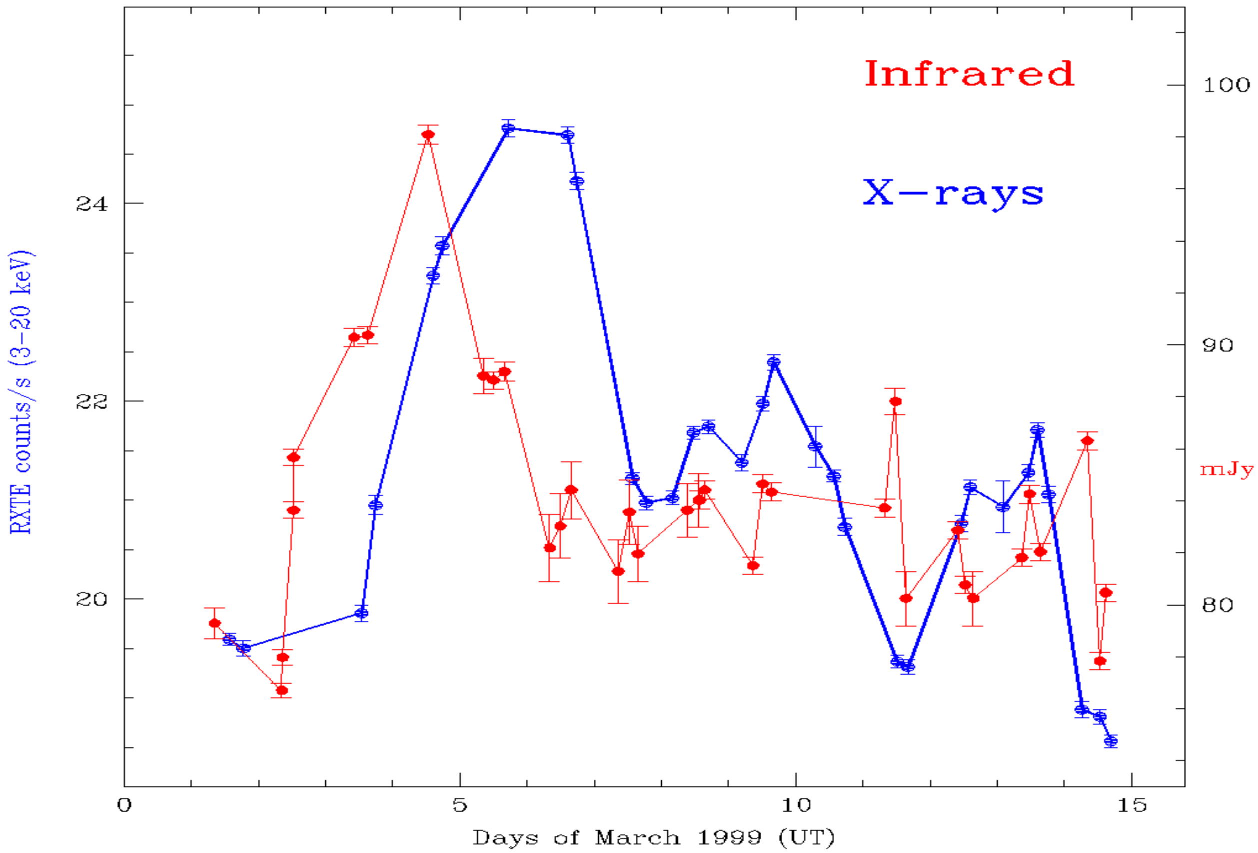
Useful for mass determination for IMBHs and obscured AGN

Does it work for blazars?

3C273


2–10 keV Flux (x10^{-11} ergs cm^{-2} s^{-1})
0
5
10
15
20
1980
1990
2000
YEARS
Ariel V SSI
EXOSAT
GINGA
RXTE

Reminder about emission mechanisms



Sokolov et al 2004
McHardy et al 2007

Many observations (eg X-rays lagging opt/ir; flare spectral evolution) support non-thermal Comptonisation (eg SSC) as the main X-ray emission mechanism in blazars.

X-ray emission mechanism probably different (eg thermal Comptonisation) in the radio-quiet, non-beamed, Seyfert galaxies.

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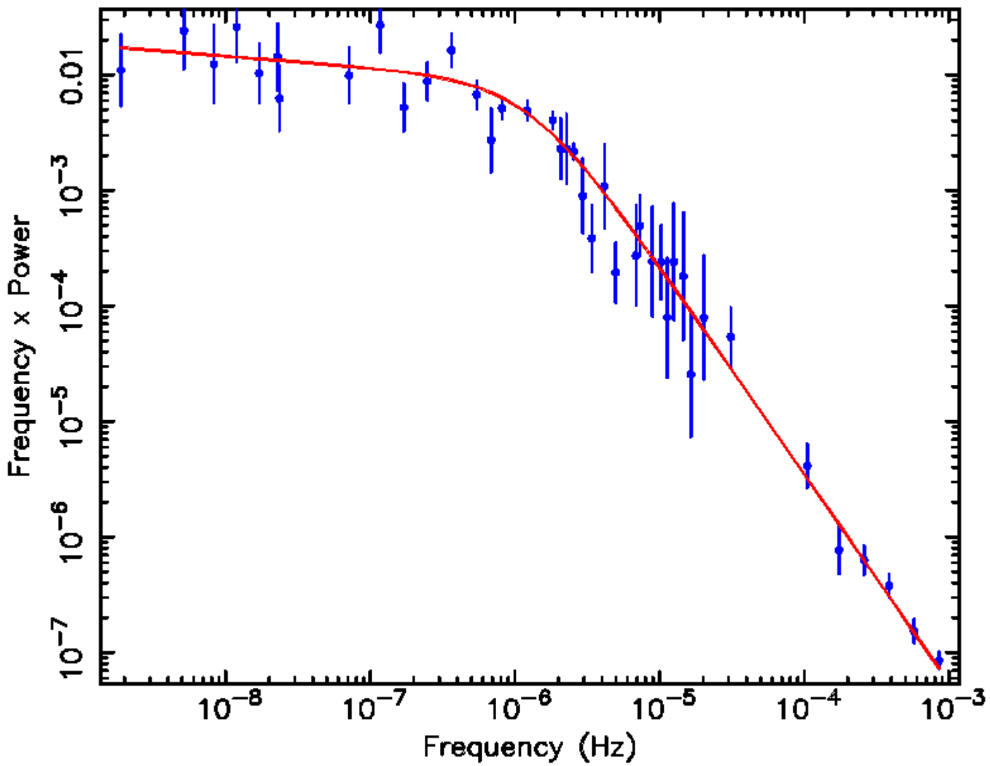
OVERALL PSD OF 3C273

Frequency x Power



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

So SSC X-ray emission from jet in 3C273 is subject to same variations as seen by Seyfert coronae.

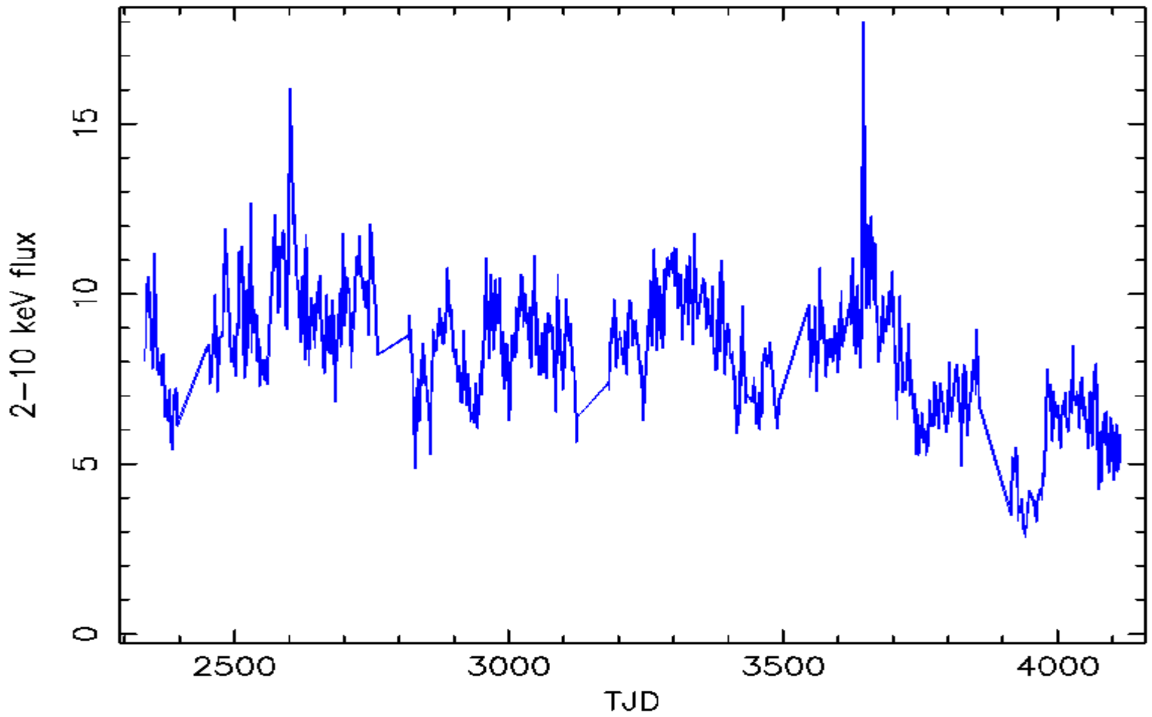
(Accretion) variations propogate in through disc and modulate the X-ray emission region.

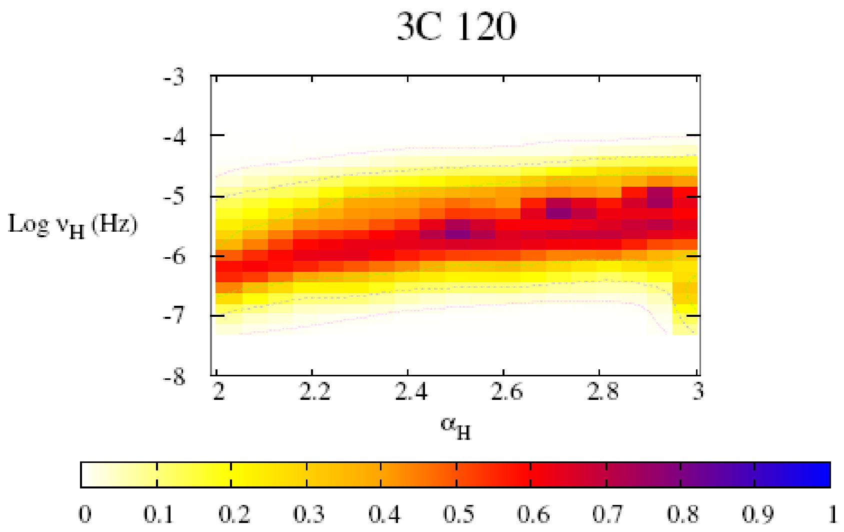
(McHardy et al, in preparation)

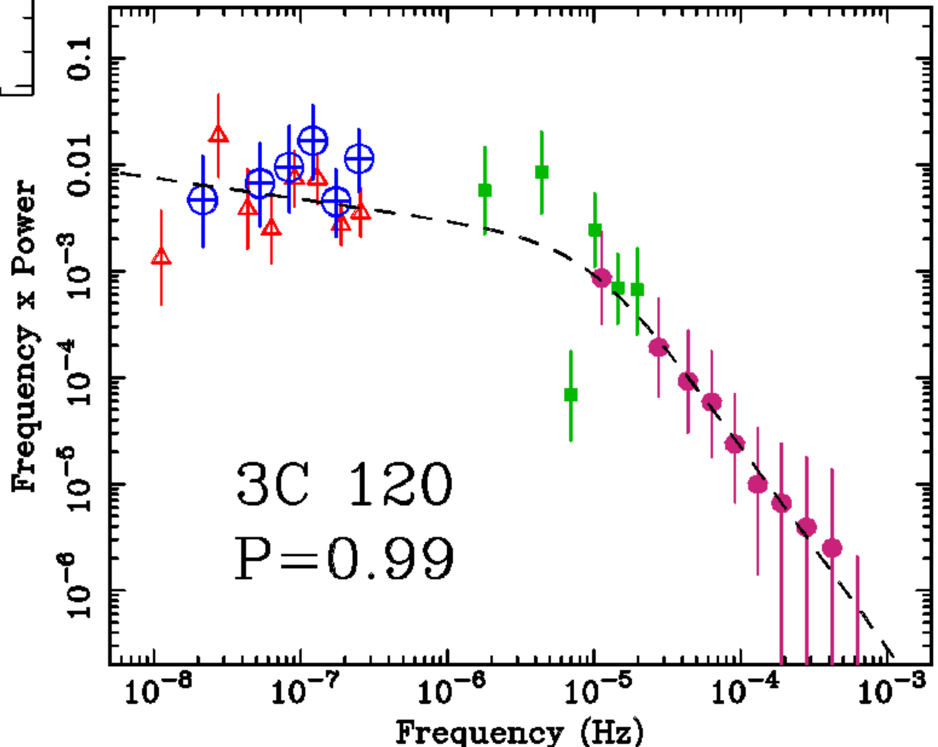
Jet has to be intimately connected to corona.

3C120

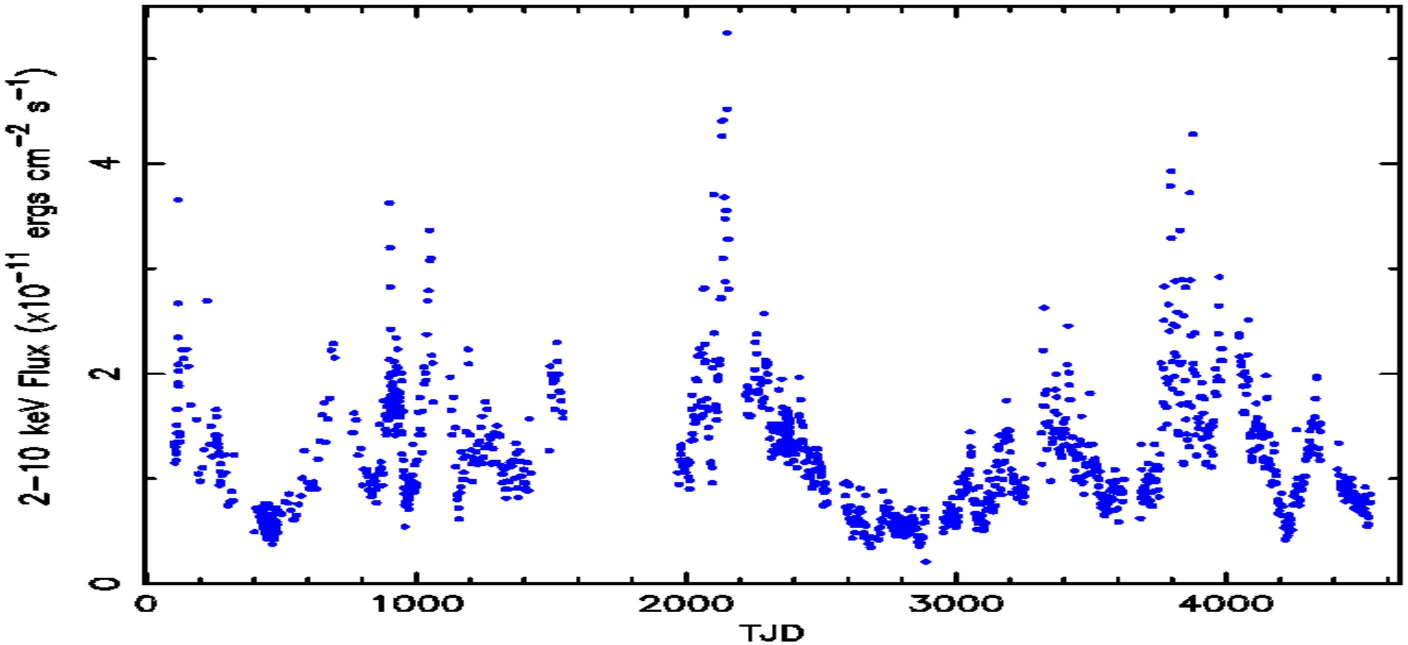
(With Miller, Marscher, Jorstad et al)



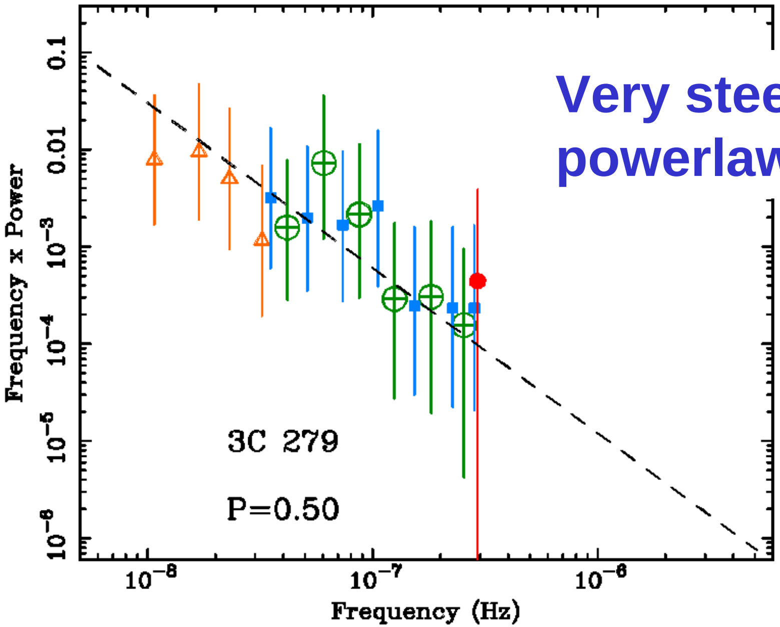




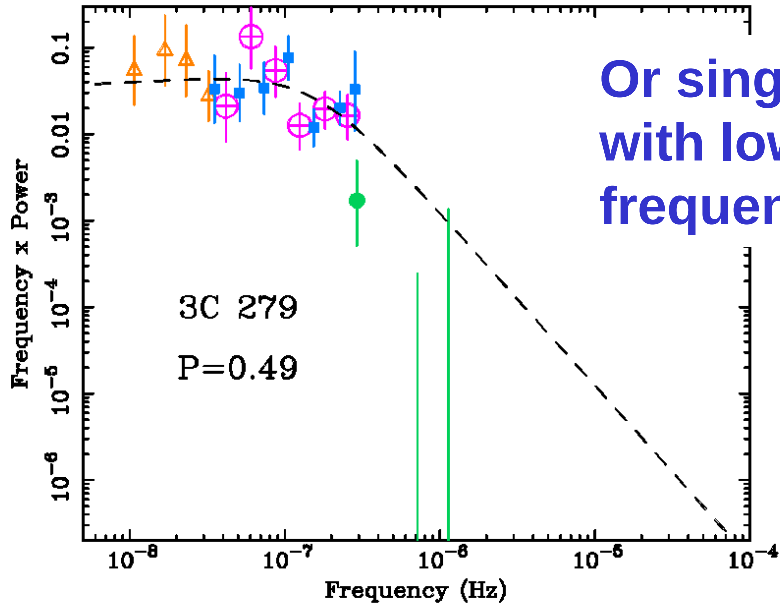
3C279



PSDs

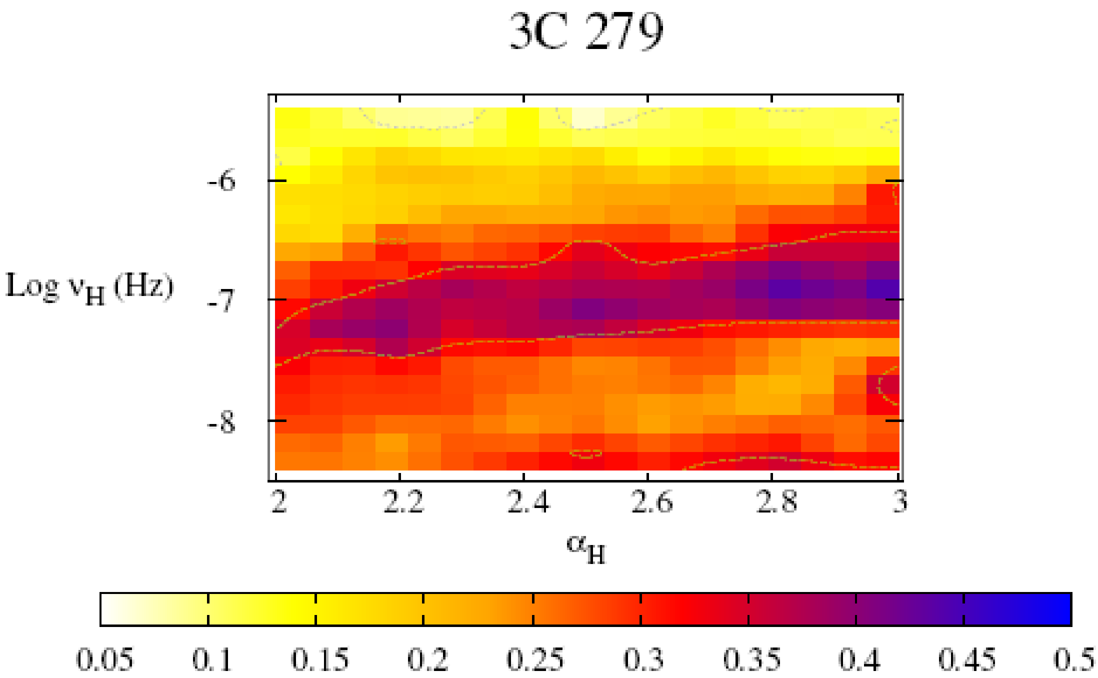


Very steep powerlaw



Or single bend with low bend frequency

3C279 : Guestimated limits on black hole mass

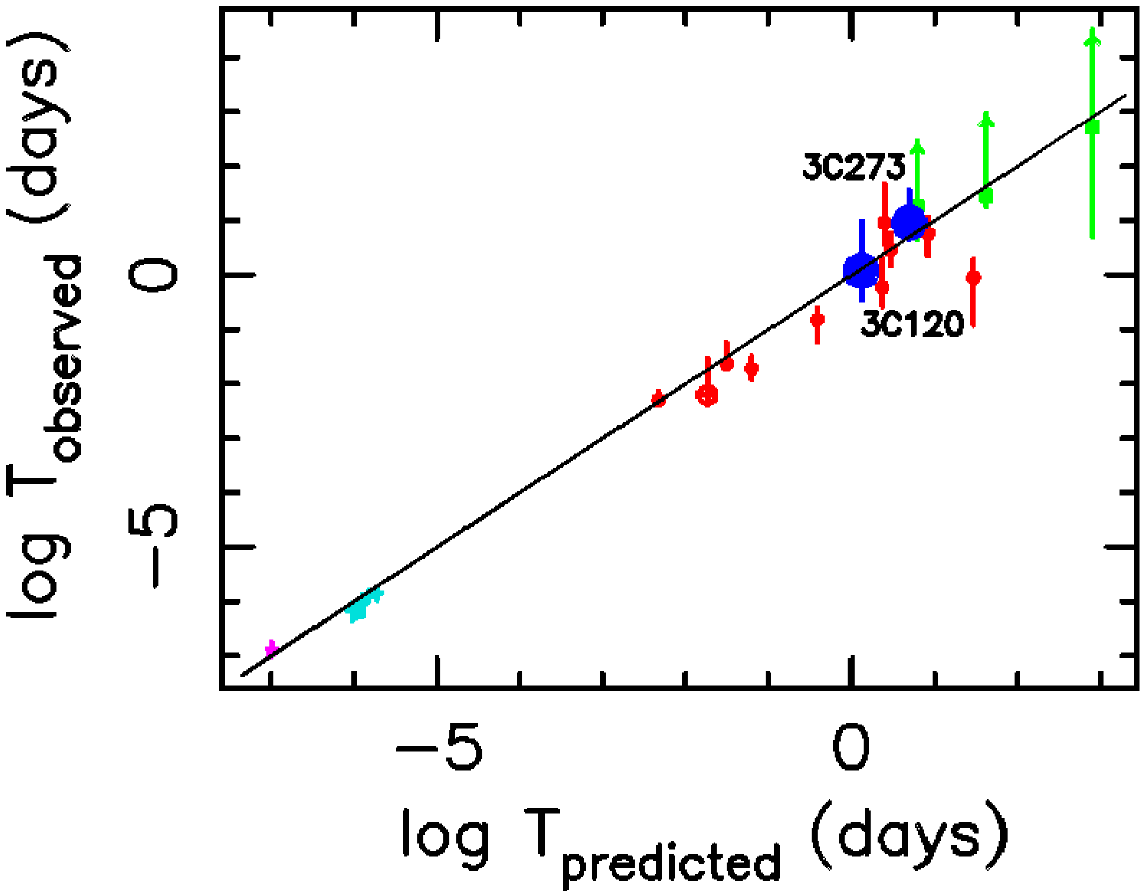


(Assuming low frequency PSD slope of -1)

Taking $\nu_B < 5\times10^{-7}$ Hz, ie T_B >24 days,

$M_{BH} > 4 \times 10^8 \times \dot{m}_E$ (with $\dot{m}_E$ in units of 0.1 Eddington)

Scaling plots plus blazars..



3C120 and 3C273 agree very well with unbeamed systems, without altering bend timescales to account for time dilation.

IMPLICATION: The clock producing the variations is OUTSIDE the jet.

Possible scenario for blazar variability

Source of variability

eg accretion rate fluctuations in disc

→ variations hit jet →

Jet Physics

Non-linear response

→

Observed Flux variations

Test with GLAST /LOBSTER– do blazar PSDs retain any memory of their black hole masses and accretion rates?

- we need black hole masses and accretion rates

(but don't do it for a few years until we have long enough lightcurves)

CONCLUSIONS

- Blazar variability is similar, in some respects, to that of unbeamed AGN and X-ray binaries
- At least some follow the rms/flux relationship
- ..and their PSDs are broadly similar
- Where found, break timescales are consistent with those of Seyferts, without invoking time dilation.
- The variability probably originates OUTSIDE the jet, although the X-ray emission is produced IN the jet.
- The jet will act as a non-linear modulator
- Could test with GLAST/LOBSTER