The scaling of X-ray variability with luminosity in Ultra-luminous X-ray sources

(Gonzalez-Martin et al. 2010, A&A submitted)

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Introduction I

Ultra Luminous X-ray sources (ULX) are compact objects out of the center of the galaxies with luminosities log(Lx)>39. These luminosities imply intermediate mass black holes (IMBHs, 1000-100000M☉ Colbert & Mushotzky 1999) between Galactic binary systems and SMBHs. However, there nature is uncertain and other explanations as anisotropic emission (King et al. 2001) or super Eddington rates (Begelman 2002) have also been proposed.

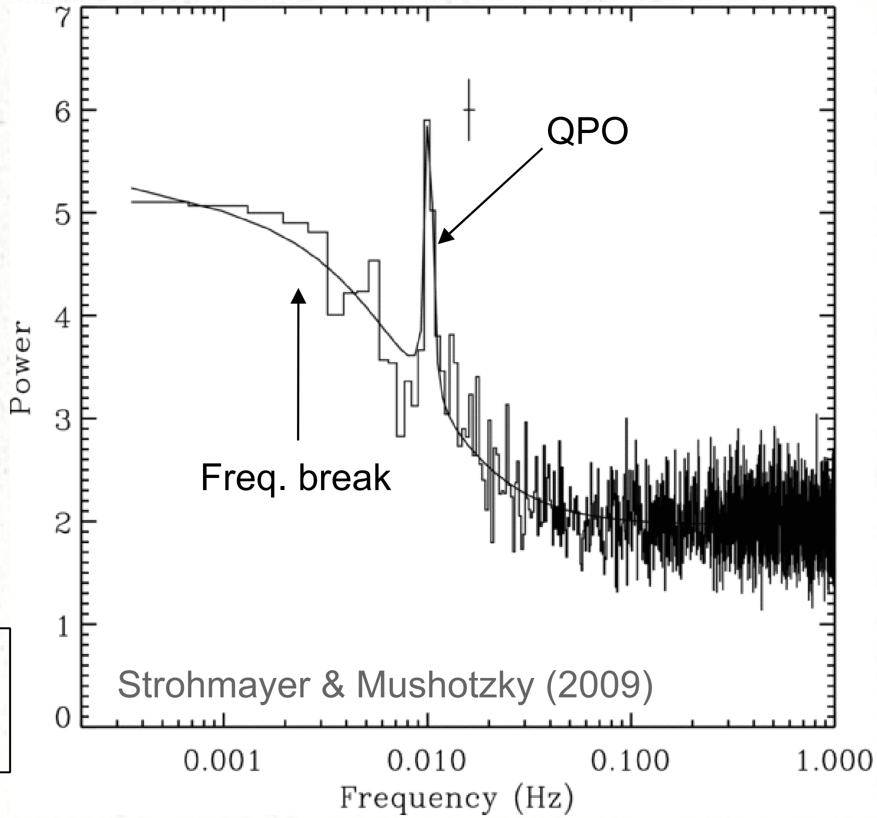
We need to determine the BH mass:

1. From the spectral fitting, with temperature and luminosity (Stobbart, Roberts & Wilms 2006).

2. From timing methods:

- QPO detections (e.g. Strohmayer & Mushotzky 2009).
- Scaling relationships of the characteristic time scales with the BH mass and accretion rate (Mc Hardy et al. 2006).
- Anticorrelation of the variability amplitude with the luminosity in AGN (Nandra et al. 1997; Leighly 1999; Turner et al. 1999).

NGC5408 X-1



Strohmayer & Mushotzky (2009)

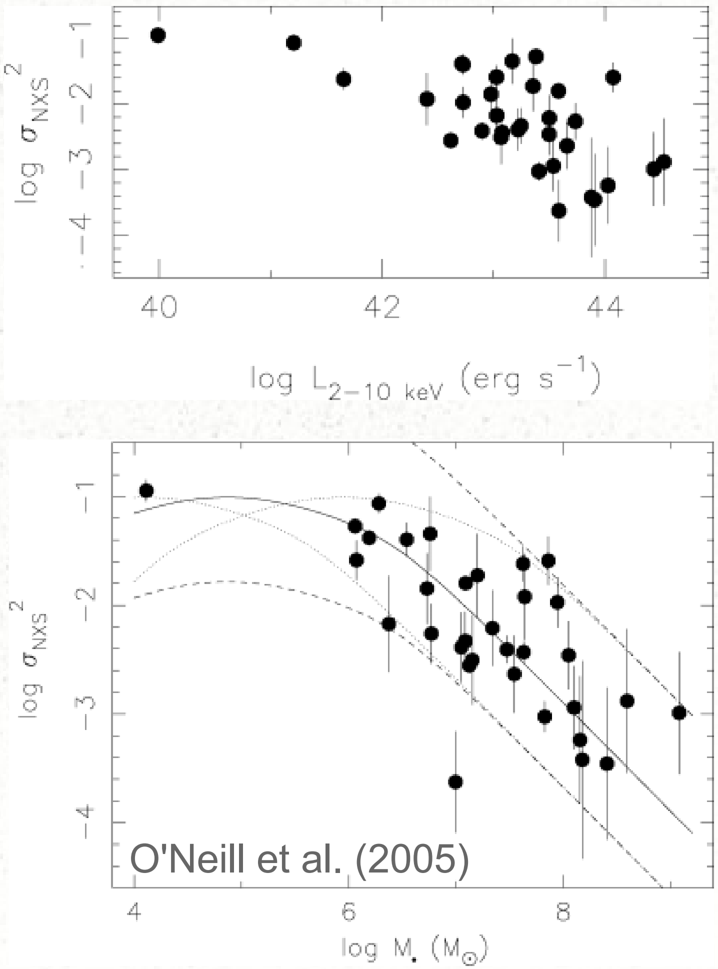
Introduction II

Our aims are:

1. Study the correlation of the normalised excess variance (as an estimate of the variability amplitude) with the luminosity of ULX.

2. Compare this correlation with that for AGN.

3. Compare it with the expected correlation assuming a Power Spectral Density (PSD) shape.



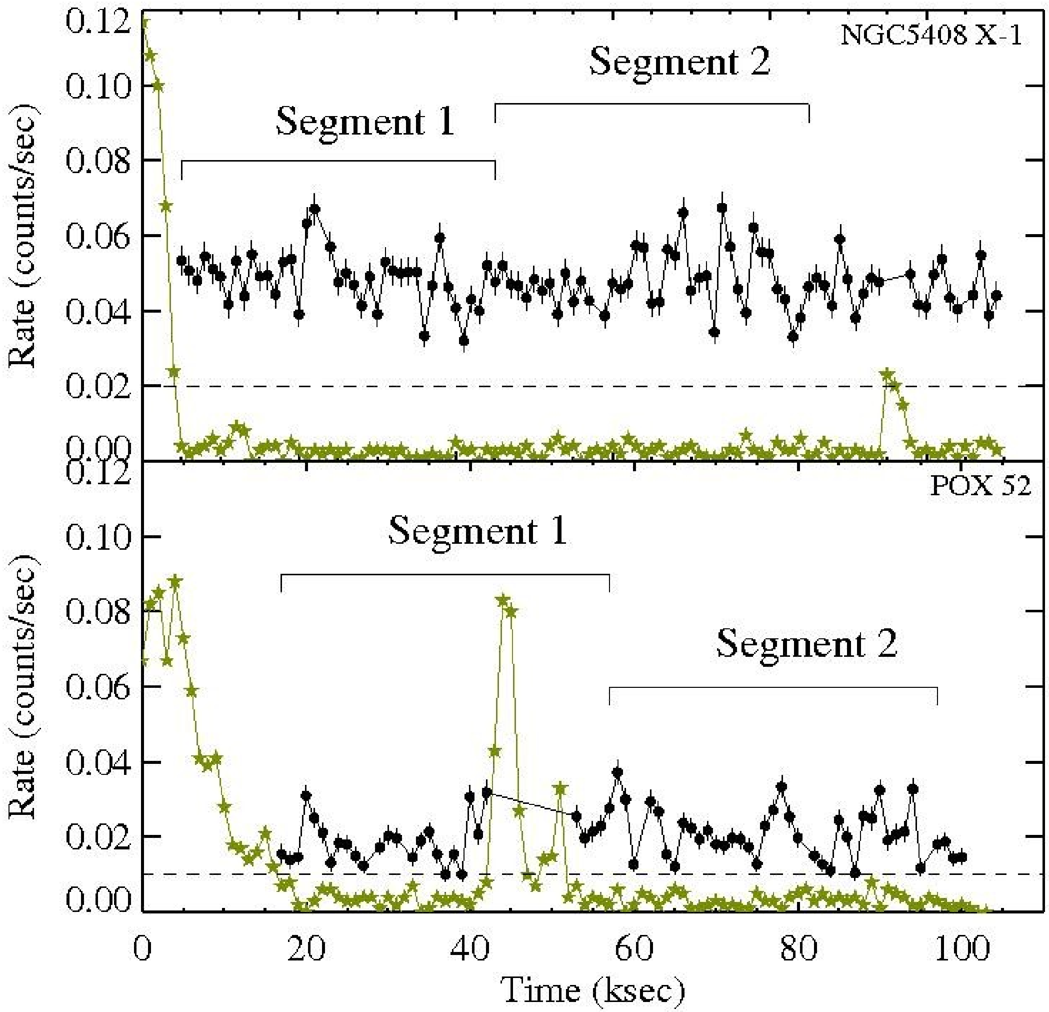
Sample

We considered all the ULXs reported in the literature (in particular those reported by Gladstone et al. 2009 and Heil et al. 2009) with net exposure times > 30 ksec observed with *XMM-Newton*/pn data. The final sample comprises 14 ULXs and 18 observing files. We also added the low BH mass AGN POX 52 for comparison purposes.

Table 1. The sample and observational details.

Name	R.A. (J2000)	Dec (J2000)	Dist. (Mpc)	ObsID	Mode*	Filter	Back. Radius (pixels)	Seg.(T_{net}) (ksec)
NGC55ULX	00 15 28.9	-39 13 19.1	1.8	028740201	FW	Thin1	534	1(30)
NGC253PSX-2	00 47 32.9	-25 17 50.3	3.3	152020101	FW	Thin1	500	2(35,40)
				125960101	FW	Medium	500	1(39)
NGC1313X-1	03 18 20.0	-66 29 11.0	3.9	106860101	FW	Medium	930	1(31)
				405090101	FW	Medium	677	3(40,38)
NGC1313X-2	03 18 22.3	-66 36 03.8	3.9	106860101	FW	Medium	500	1(31)
				405090101	FW	Medium	500	2(40,38)
NGC2403X-1	07 36 25.6	+65 35 40.0	3.6	164560901	FW	Medium	556	2(40,30)
HoIIX-1	08 19 29.0	+70 42 19.3	3.7	200470101	FW	Medium	998	1(37)
M81X-6	09 55 32.9	+69 00 33.3	3.6	111800101	SW	Medium	500	2(40,37)
M82X-1	09 55 50.2	+69 40 47.0	4.5	206080101	FW	Medium	500	2(40,37)
HoIXX-1	09 57 53.2	+69 03 48.3	2.6	200980101	LW	Thin1	737	2(40,37)
NGC3628X-1	11 20 15.8	+13 35 13.6	12.0	110980101	EFW	Thin1	500	1(38)
NGC4559X-1	12 35 51.7	+27 56 04.1	9.5	152170501	FW	Medium	1038	1(37)
NGC4945X-2	13 05 33.3	-49 27 36.3	4.3	204870101	FW	Medium	500	1(40)
NGC5204X-1	13 29 38.6	+58 25 05.7	5.3	405690201	FW	Medium	831	1(37)
NGC5408X-1	14 03 19.6	-41 22 59.6	4.9	500750101	FW	Thin1	500	1(40)
				302900101	FW	Thin1	500	2(40,40)
POX52	12 02 56.9	-20 56 03.3	96.1	302420101	FW	Medium	500	2(40,40)

Normalised excess variance



We construct light curves of 1000 sec bins.

We chose segments of 40 ksec excluding large background flares.

Therefore we sample variations with frequency between:
v(min) = 1/40000 Hz
v(max) = 1/2000 Hz.

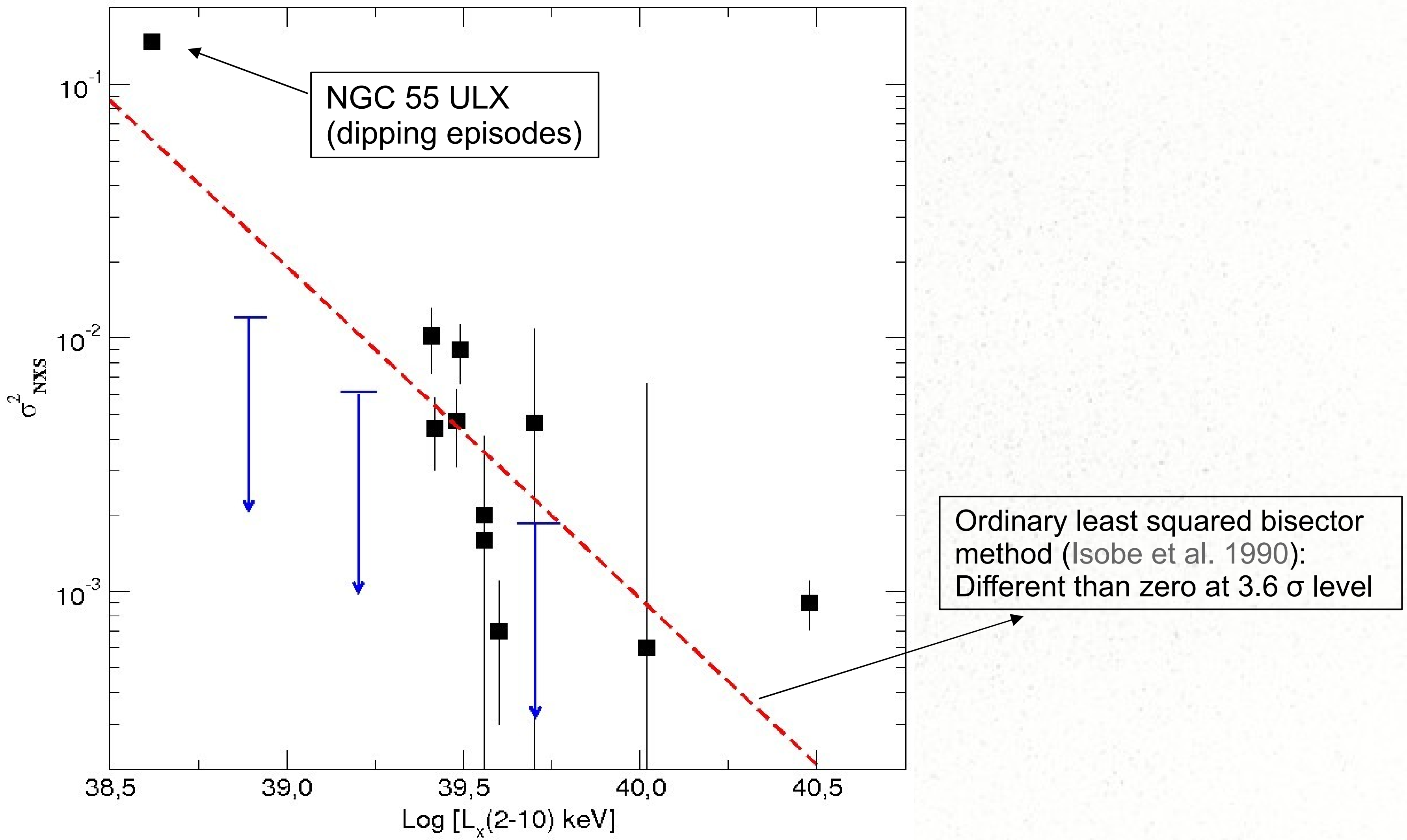
$$\sigma^2_{NXS} = \frac{S^2 - <\sigma^2_{err}>}{<x>^2},$$

$$err(\sigma^2_{NXS}) = \sqrt{\frac{2}{N}\left(\frac{<\sigma^2_{err}>}{<x>^2}\right)^2 + \frac{<\sigma^2_{err}>}{N}\frac{4\sigma^2_{NXS}}{<x>^2}},$$

This error is only based on Poisson error (Vaughan 2003), where:

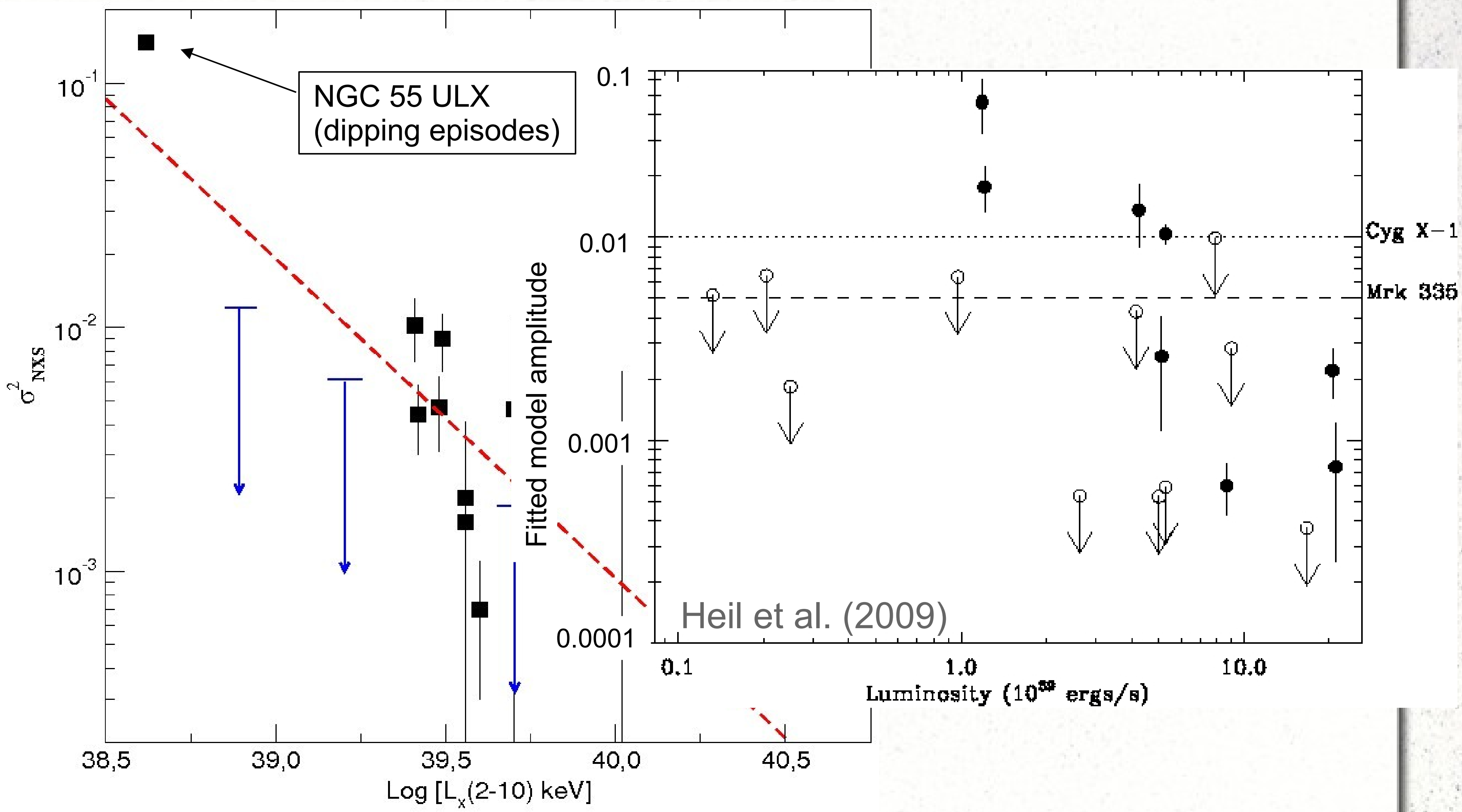
$$S^2 = \frac{1}{N-1}\sum_{i=1}^{N}(x_i - <x>)^2.$$

Normalised excess variance versus Luminosity



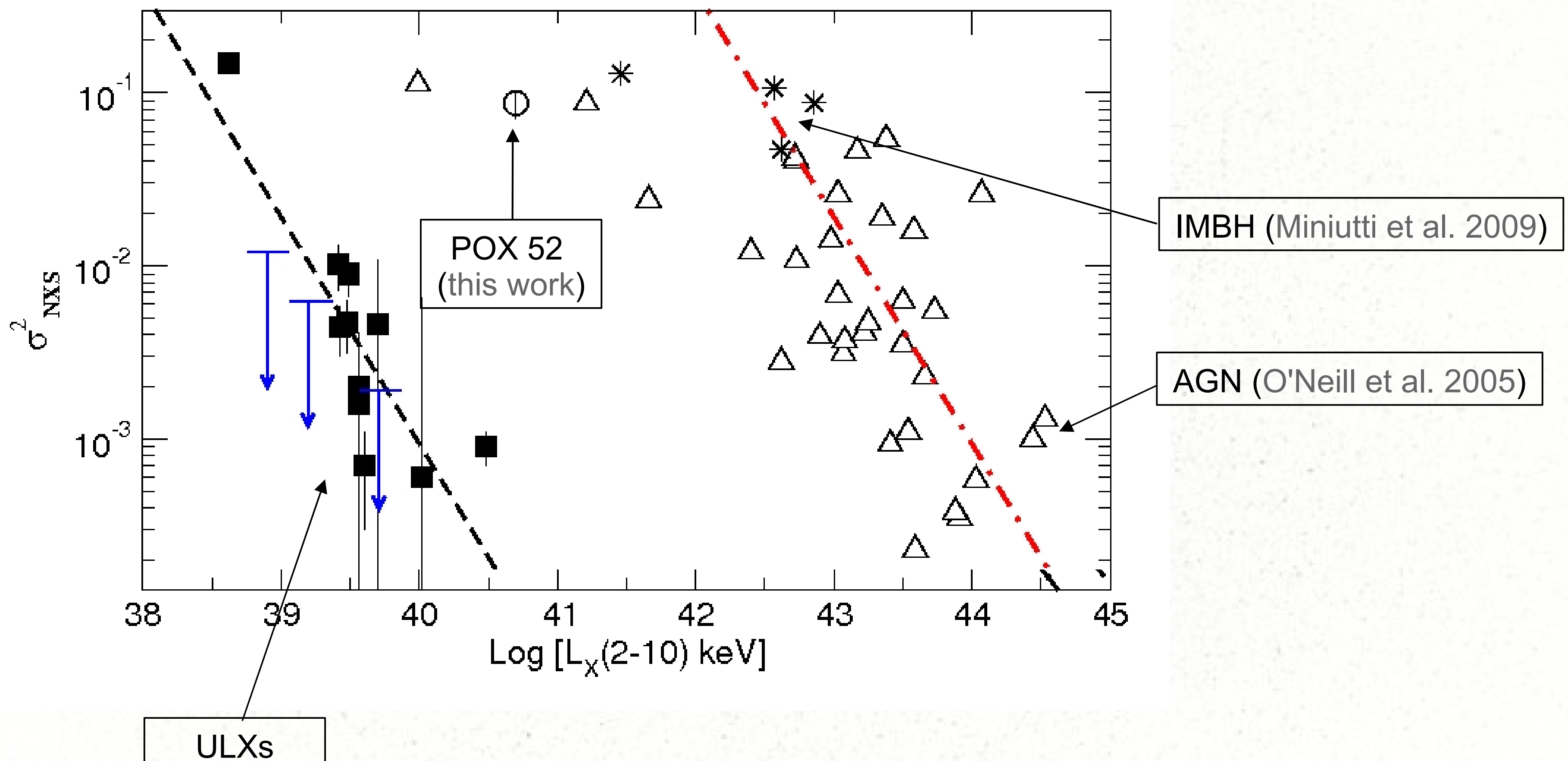
$\text{Log}(\sigma_{NXS}) = (49 \pm 14) - (1.31 \pm 0.36) \times \log L(2\text{-}10\ \text{keV})$

Normalised excess variance versus Luminosity



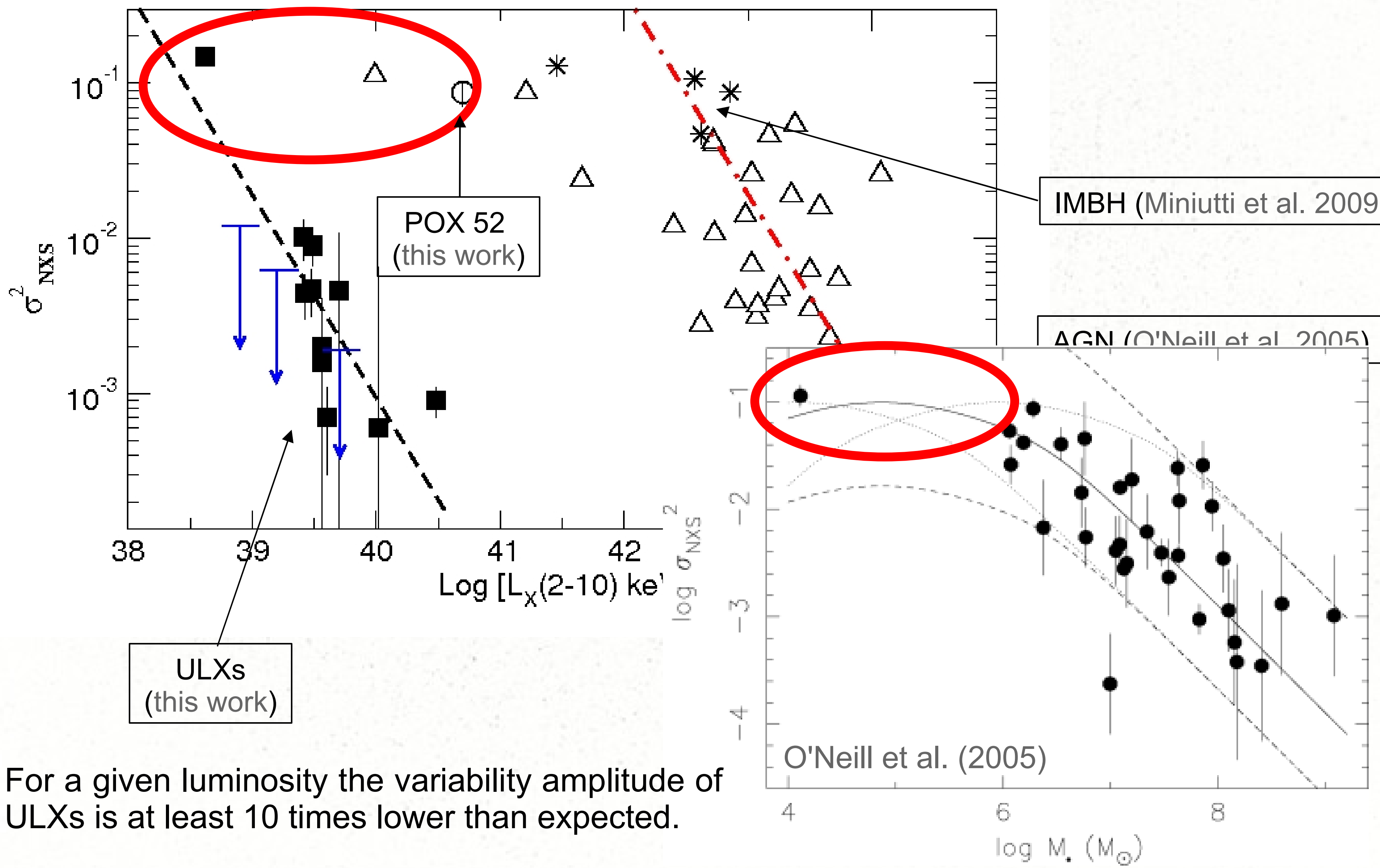
$$\mathrm{Log}(\sigma_{NXS}) = (49 \pm 14) - (1.31 \pm 0.36) \times \log L(2\text{-}10\ \mathrm{keV})$$

Comparison with AGN



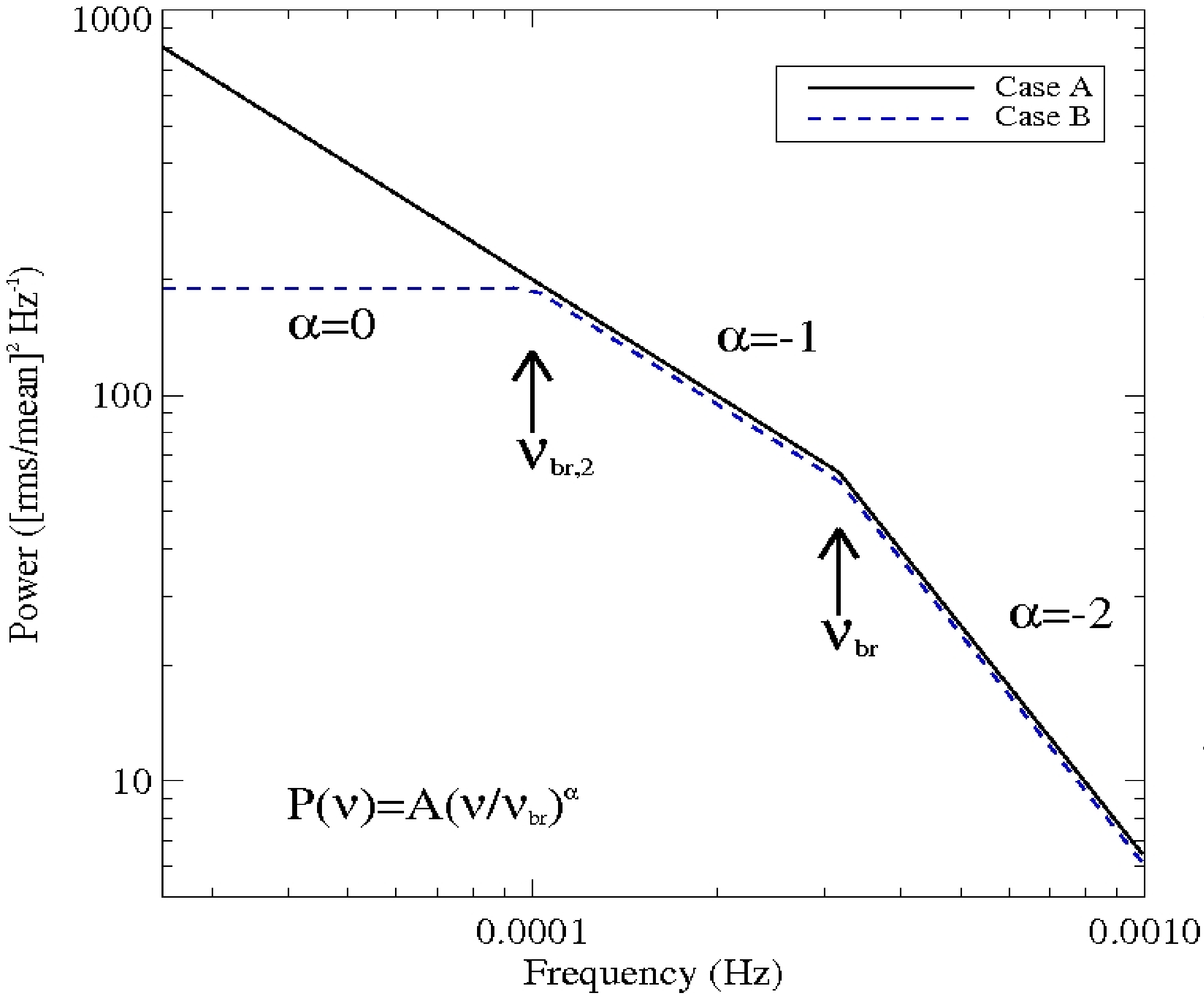
ULXs follow the same relation than AGN but about 4 orders fainter.

Comparison with AGN



For a given luminosity the variability amplitude of ULXs is at least 10 times lower than expected.

Model 'variability-luminosity' relations:



Can ULXs be similar to AGN? i.e.:

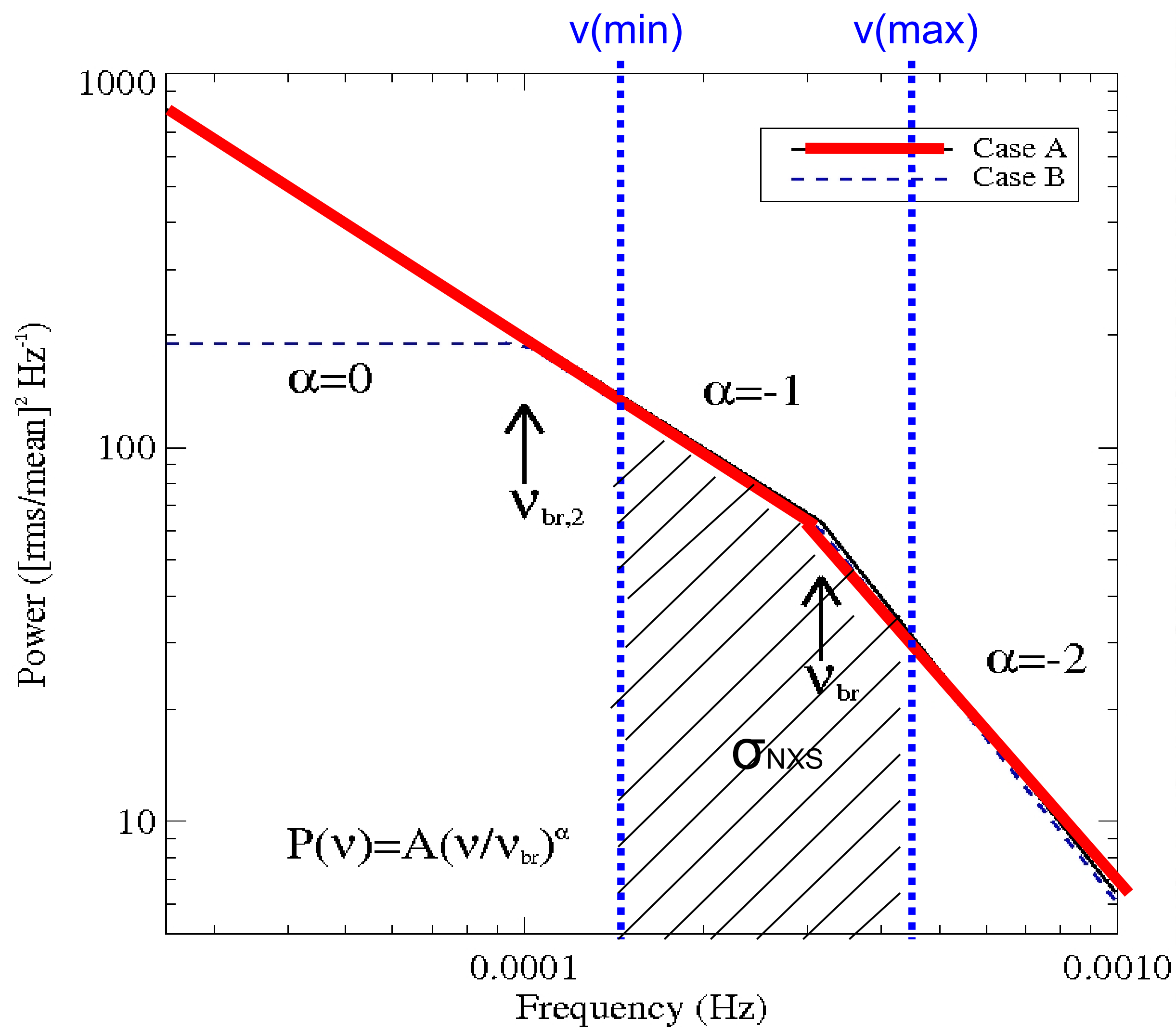
► Same variability mechanism (i.e. **same PSD** shape).

► Same scaling of the ν_{br} with the BH mass and accretion rate (Mc Hardy et al. 2006).

$$\nu_{br} \propto \dot{m}_{edd} / M_{BH}$$

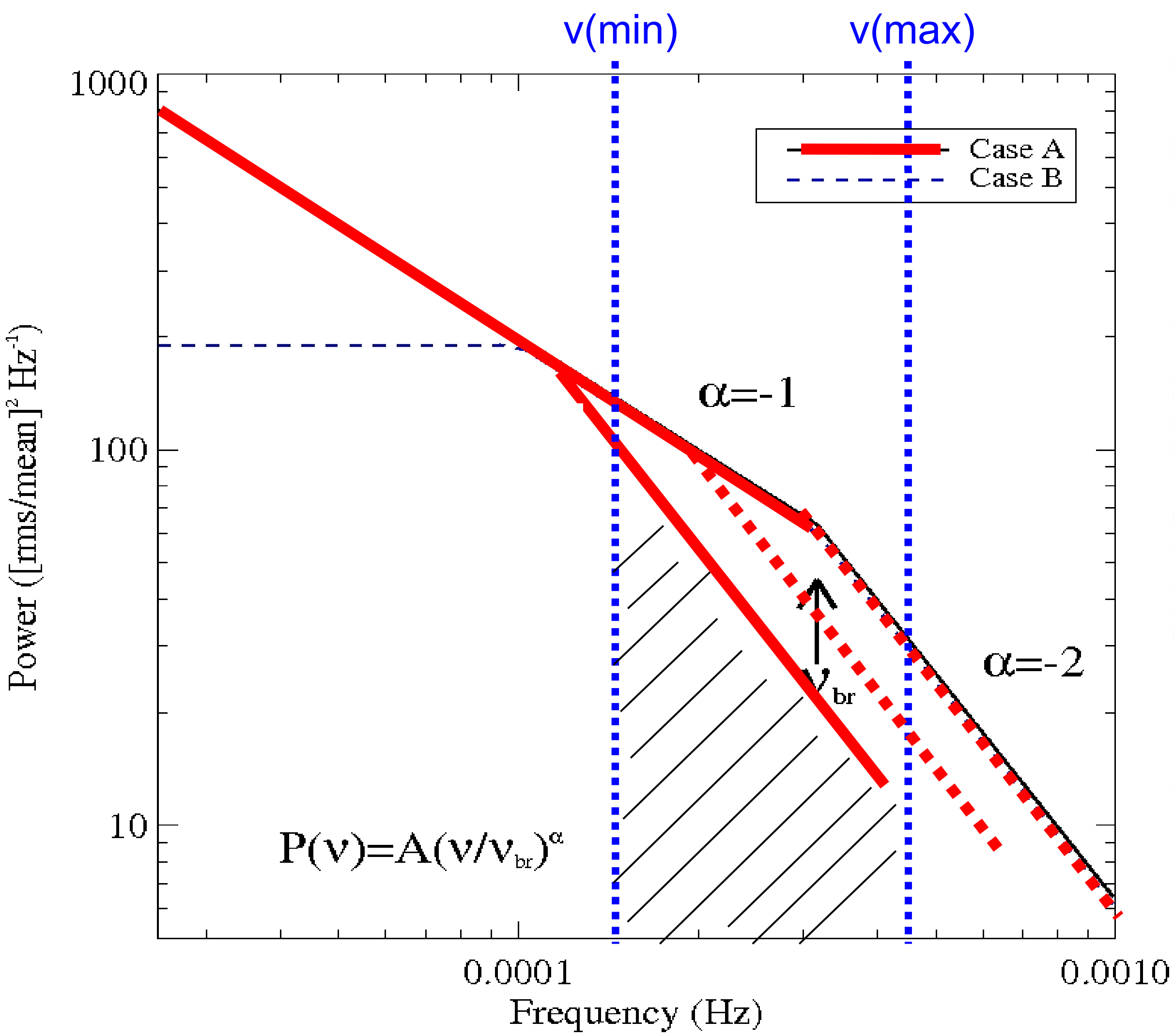
► Same **X-ray to L_{bol}** conversion factor.

Model 'variability-luminosity' relations: Case A



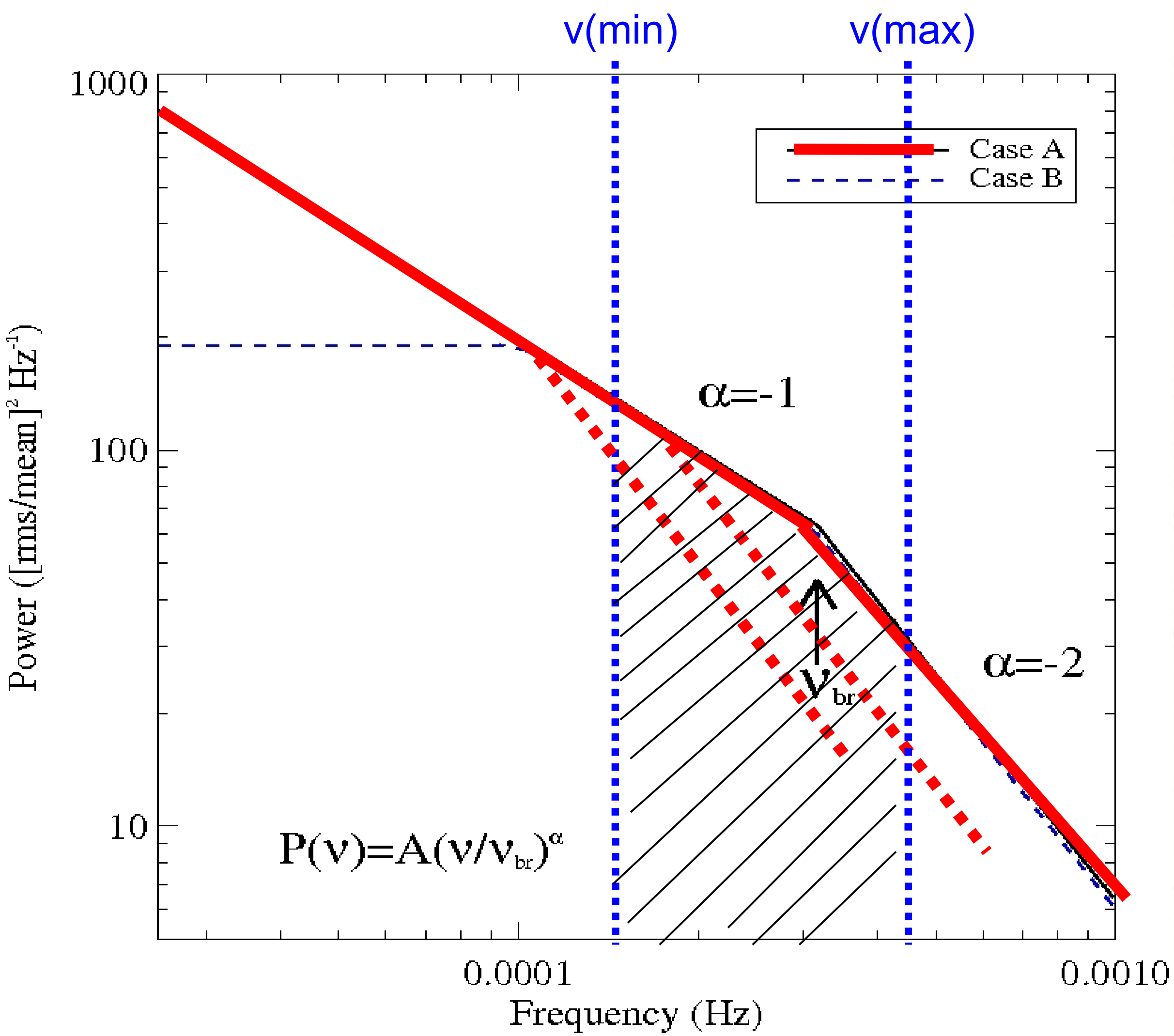
$\nu_{br} \propto \dot{m}_{edd} / M_{BH}$

Model 'variability-luminosity' relations:
Case A



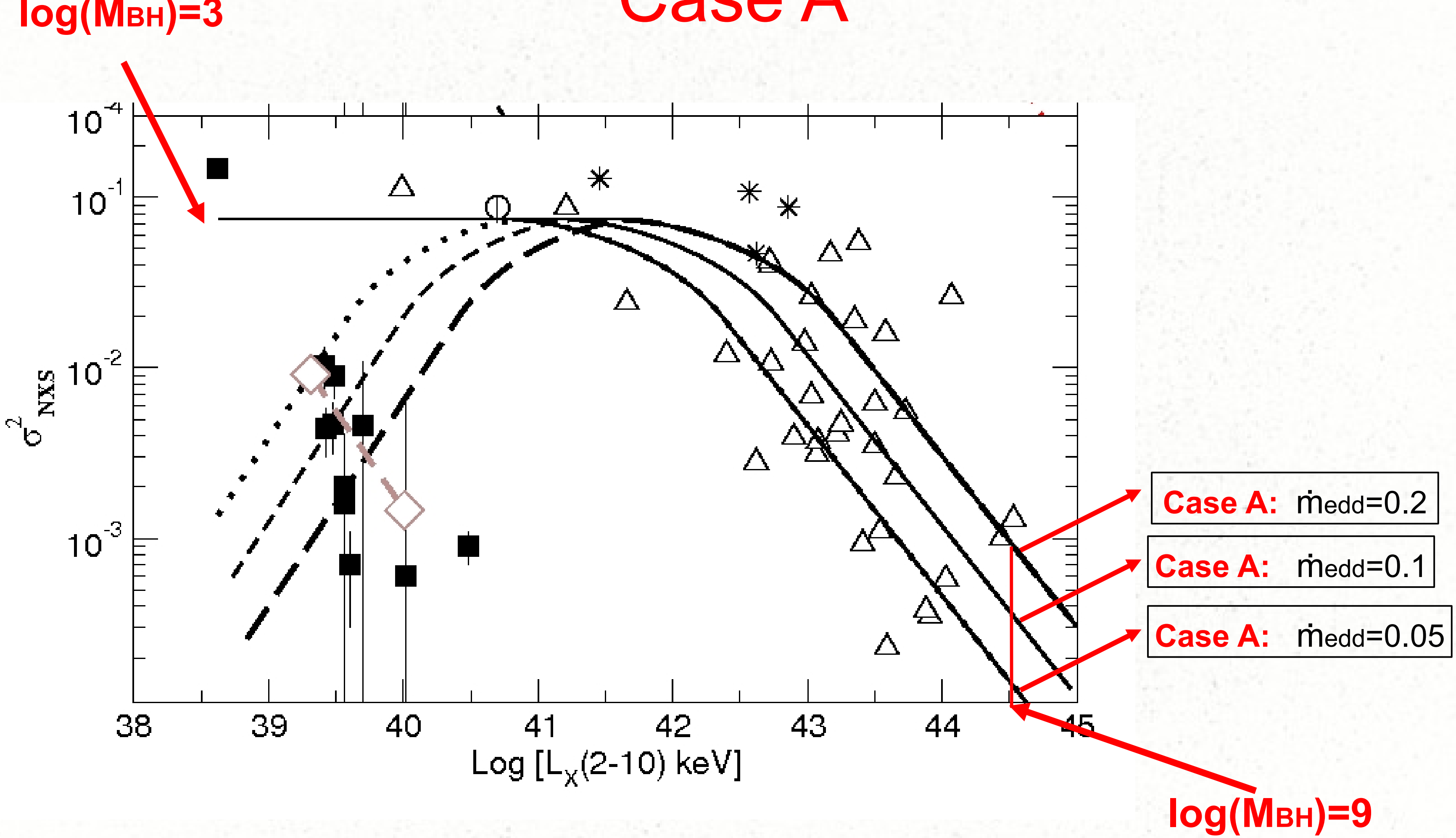
$\nu_{br} \propto \dot{m}_{edd} / M_{BH}$ ↑

Model 'variability-luminosity' relations:
Case A



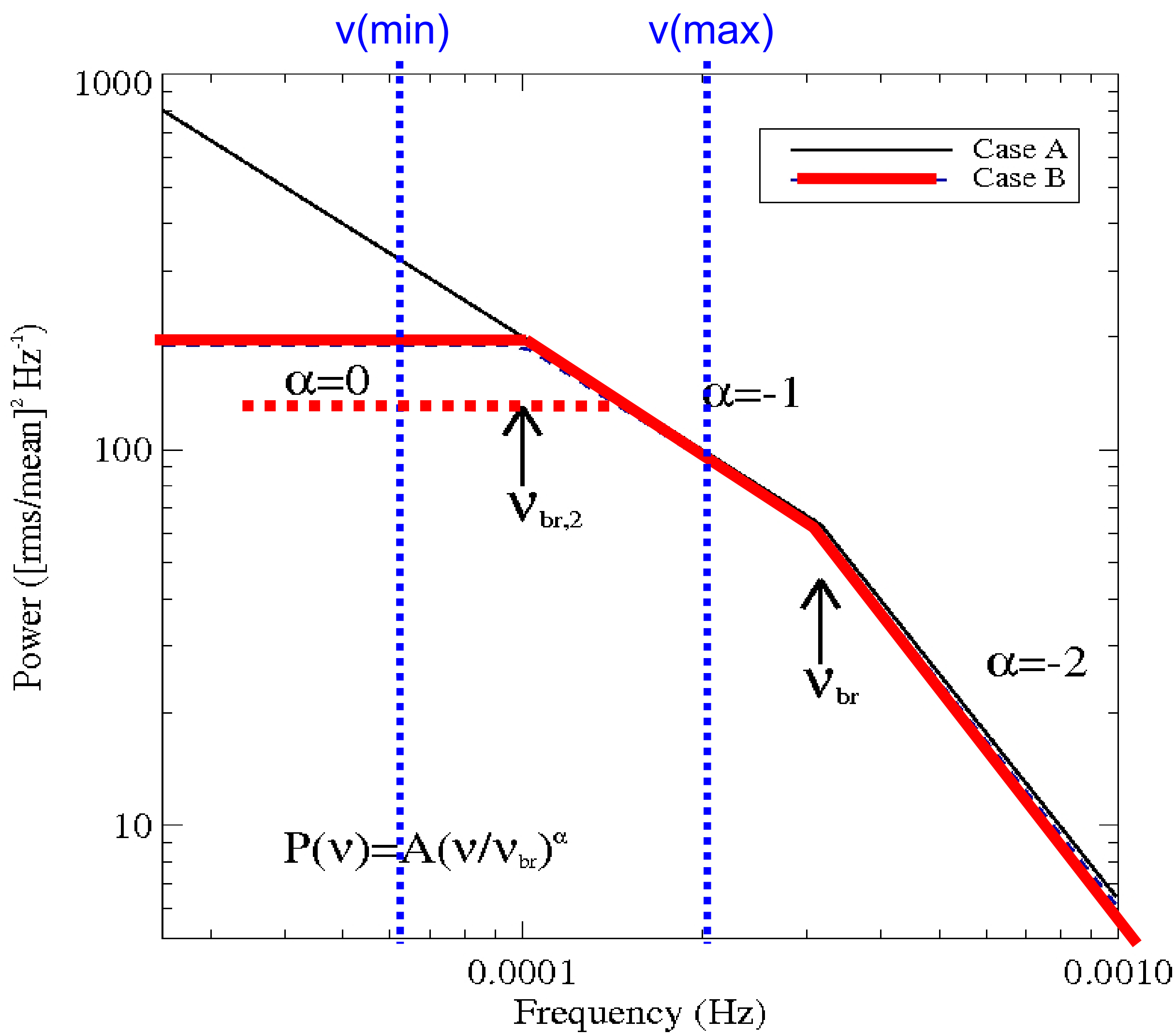
$\nu_{br} \propto \dot{m}_{edd} / M_{BH}$ ↓

Model 'variability-luminosity' relations:
Case A



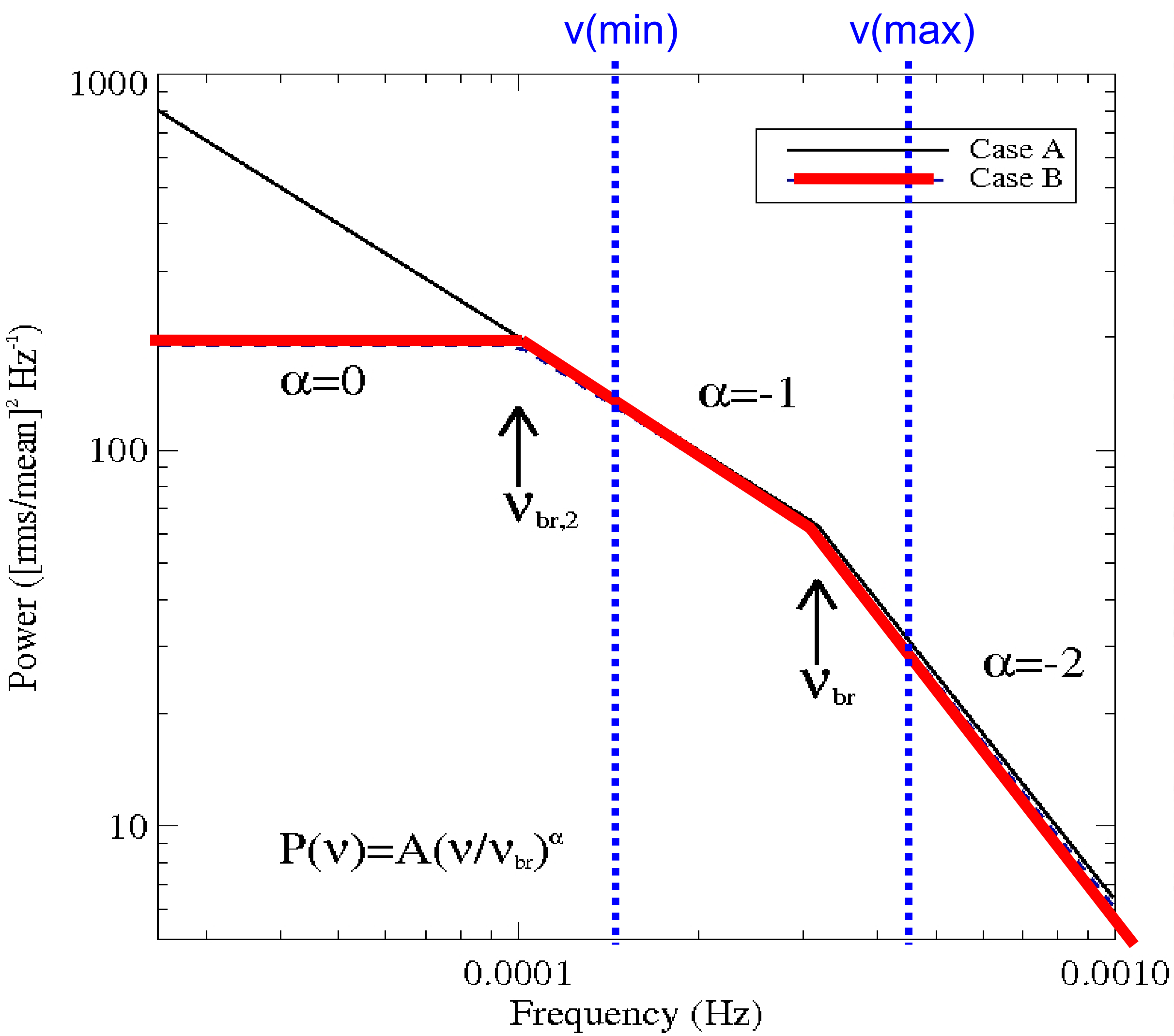
POX 52 follow the predicted *Case A* correlation for AGN with low BH mass. However, ULX are far from this correlation.

Model 'variability-luminosity' relations:
Case B



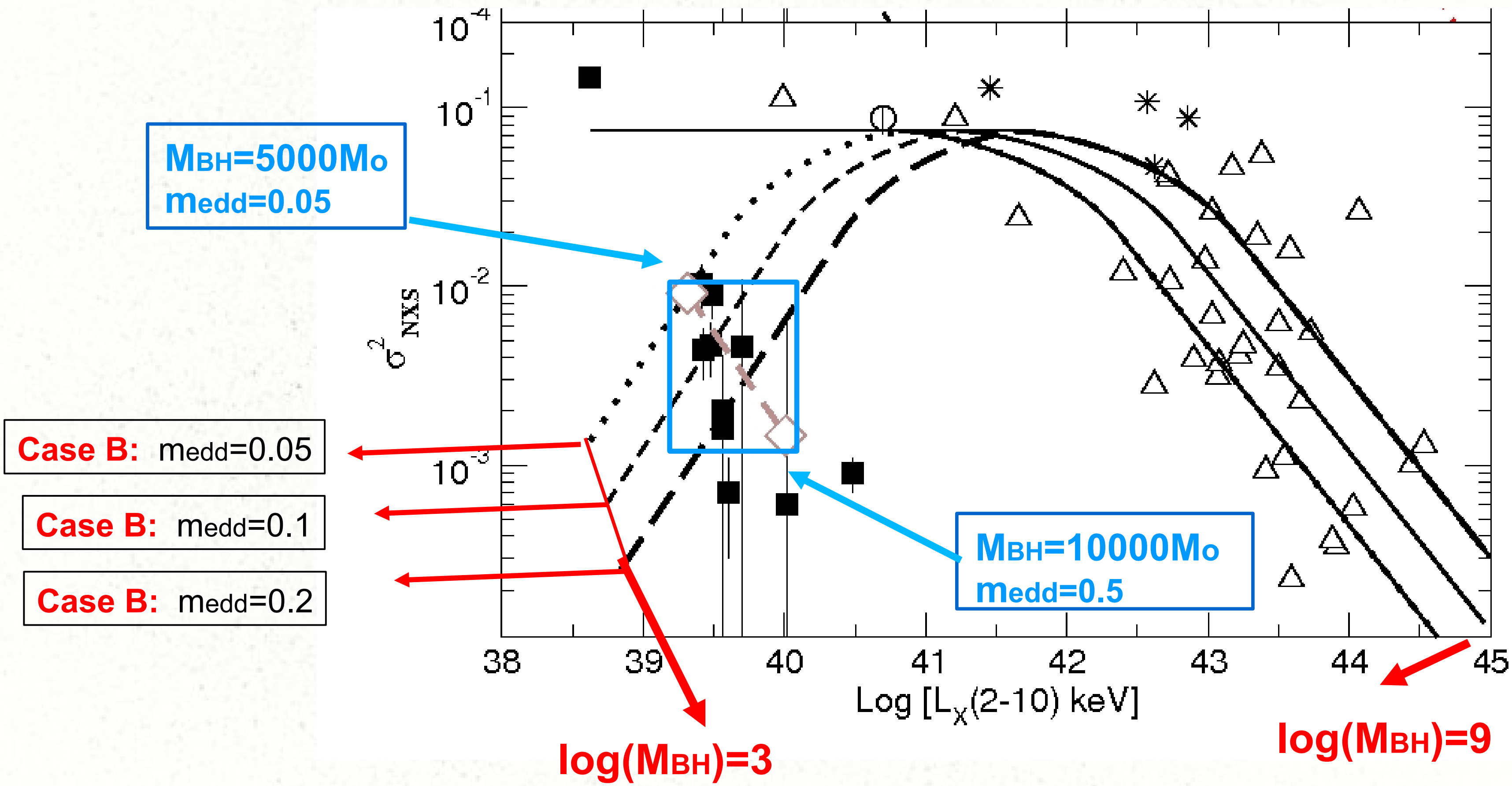
$\nu_{br} \propto \dot{m}_{edd} / M_{BH}$ ↓

Model 'variability-luminosity' relations:
Case B



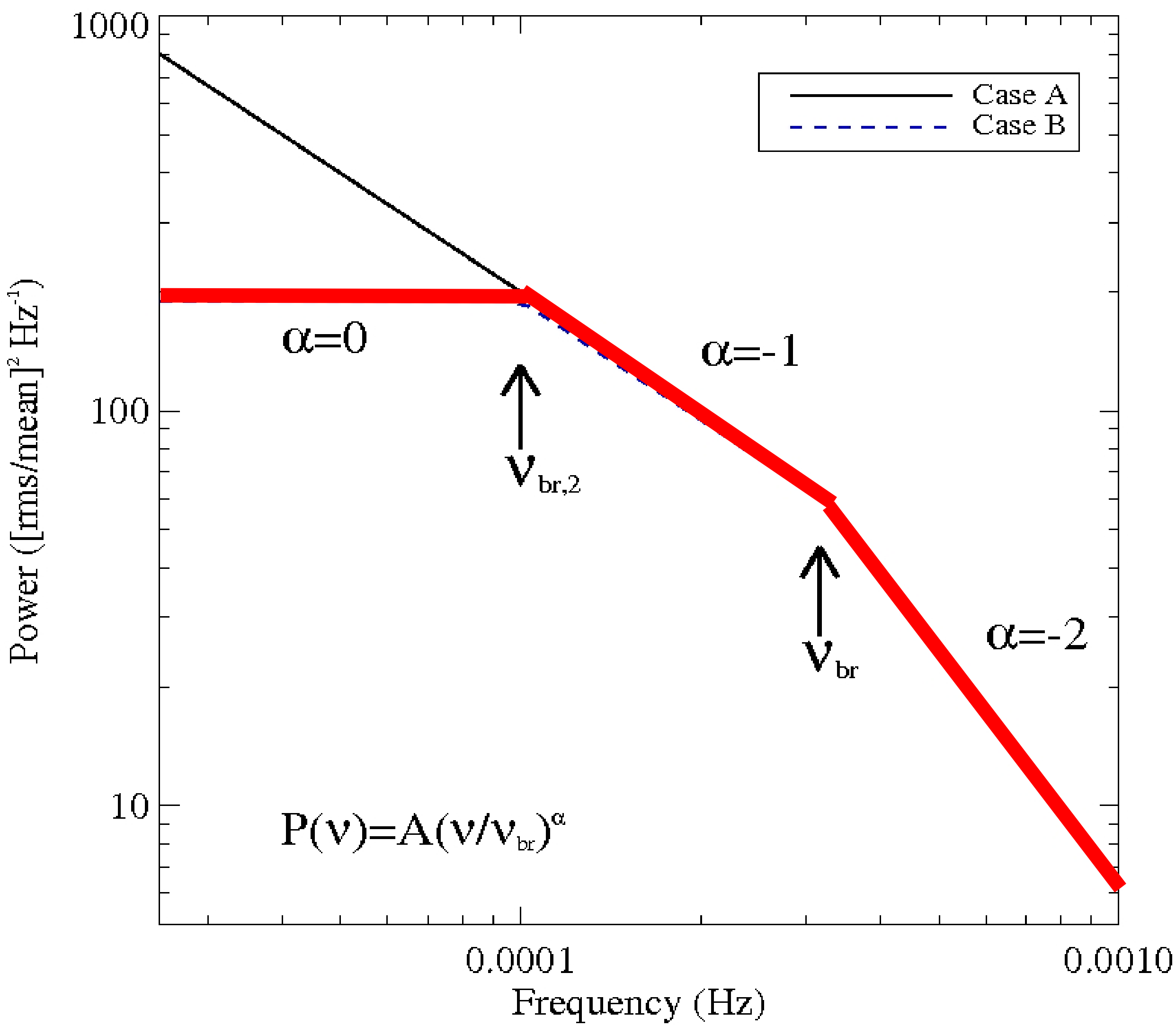
$\nu_{br}\ \alpha\ \dot{m}_{edd}\ /\ M_{BH}$ ↑

Model 'variability-luminosity' relations:
Case B



ULXs could be explained using Case B model with IMBH of ~5000-10000 M○ and accretion rate > 5% of the Eddington limit.

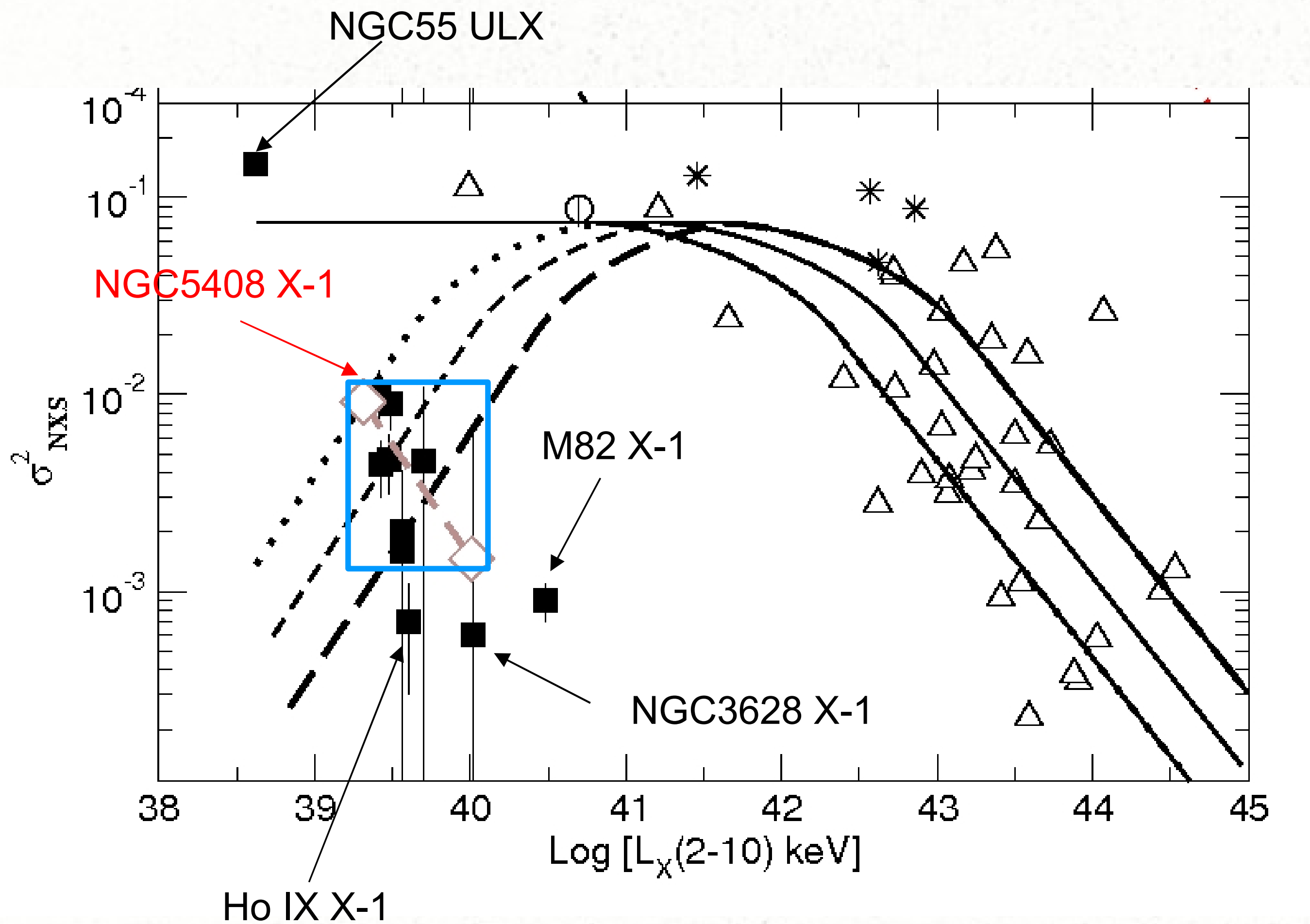
Model 'variability-luminosity' relations: Case B



This second break has been observed in at least one AGN (Ark 564, Papadakis et al. 2002) and in GBHs in low/hard and very high states (Klein-Wolt & van der Klis 2008).

Moreover Heil et al. (2009) detected the required 0 to -1 break in some of their PSDs (e.g. M82 X-1 and NGC 5408 X-1) and in other cases is consistent with it including the error bars.

Model 'variability-luminosity' relations:



Mix group of object

Conclusions:

♠ We have found an anti-correlation between the normalised excess variance and the luminosity for ULXs.

♠ The slope is consistent with that found for AGN although luminosities are 4 orders of magnitude lower.

♠ The variability amplitude of ULXs is significantly lower than that predicted by a simple extrapolation of AGN.

♠ It can be consistent with the hypothesis that some ULXs operate like AGN but only if: (i) they host an IMBH of ~5000-10000 $M_\odot$, (ii) their accretion rate is > 5% of the Eddington limit, and (iii) their PSDs should have a shape showing two breaks.

End