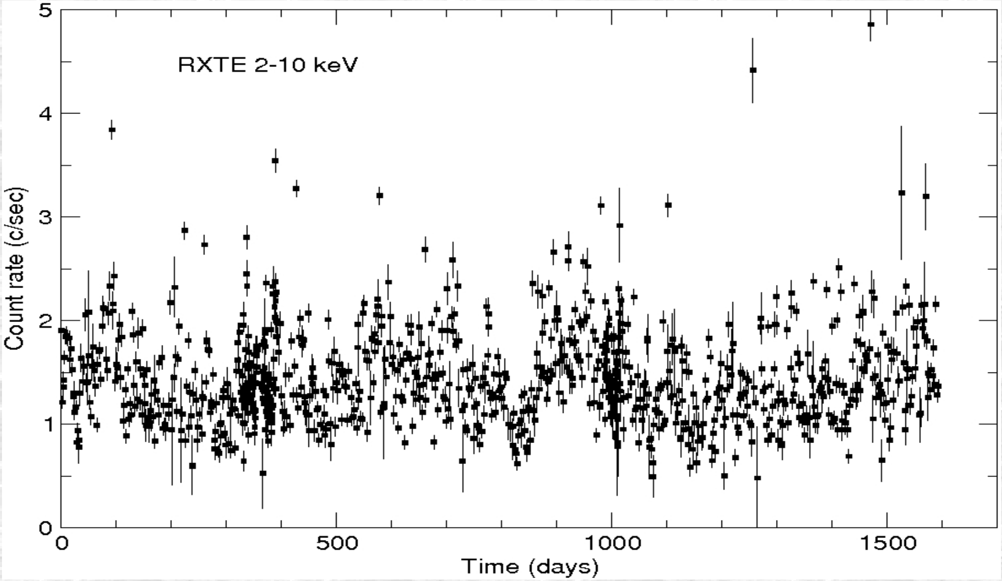
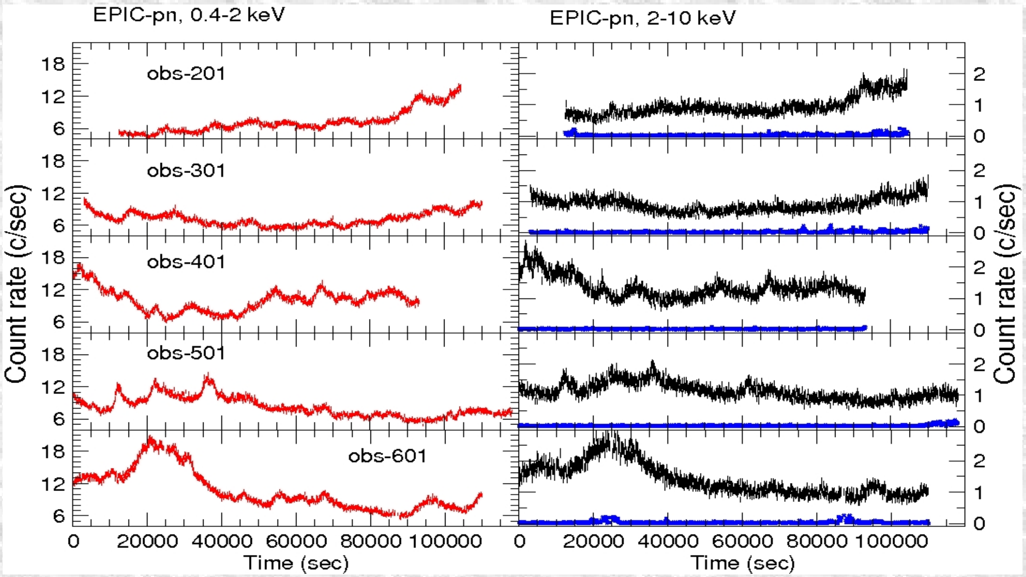
The X-Ray (continuum flux) variability of radio-quiet AGN

I. Papadakis
(Univ. of Crete)

PKS 0558-504, Papadakis et al (2010)





The combination of

1) years-long RXTE light curves and
2) day-long, high signal to noise, XMM (and Chandra) light curves

has allowed us to study the AGN X-ray variations in great detail.

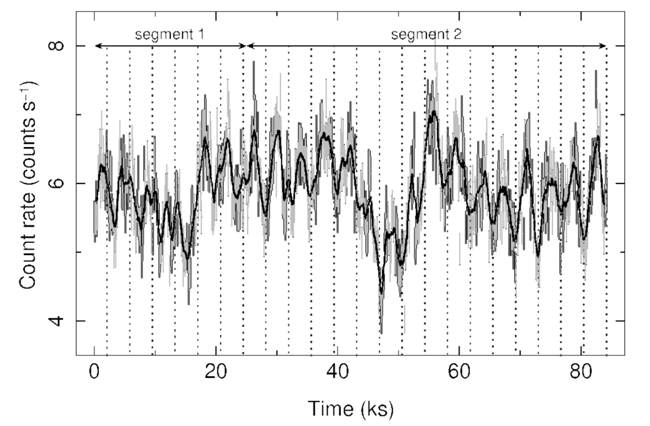
In most cases, the study of the observed variations is made with the use of ('traditional') Fourier techniques*.

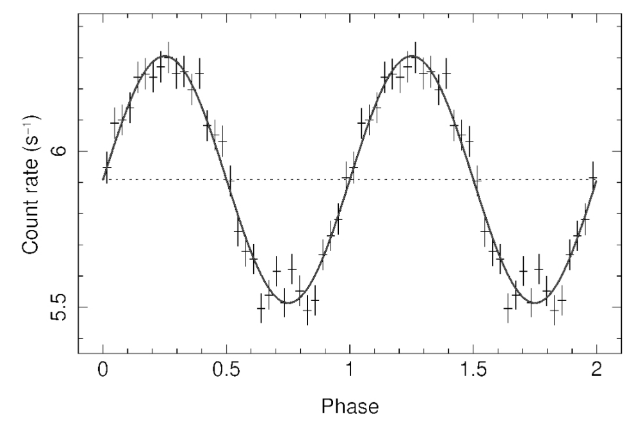
Fourier analysis is a powerful technique to reveal periodic signals.

Are there any periodicities/QPOs detected in AGN?

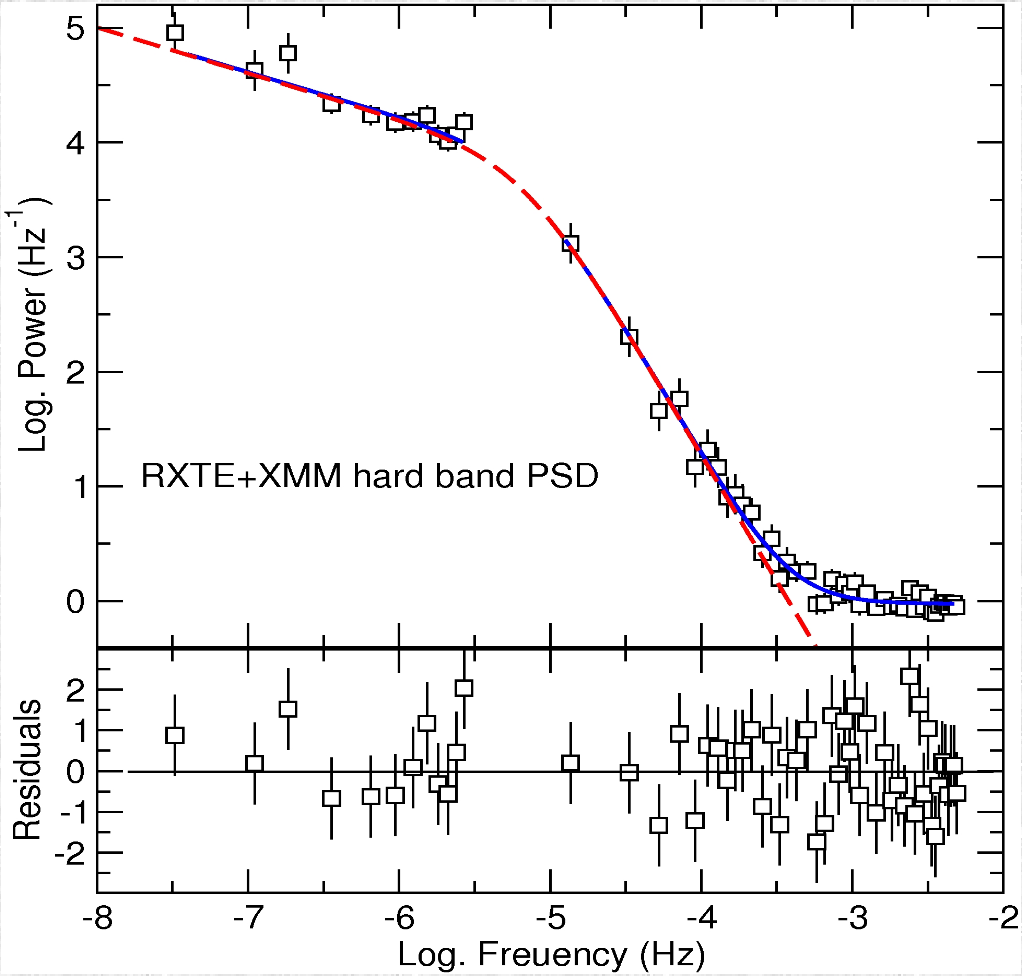
* The use of the "structure function" is not common in the X-ray variability studies of radio-quiet AGN. In any case, its use has to be treated with a great caution (Emmanoulopoulos et al. 2010, MNRAS, 404, 931)

So far, a (*statistically significant*) (quasi)periodic X-ray signal has been detected in just one AGN, namely RE J1034+396 (Gierlinski et al., 2008, Nature, 455, 369).





Nevertheless,
'*characteristic time scales*',
albeit of a different nature, have been detected
in a few (< 20) AGN.

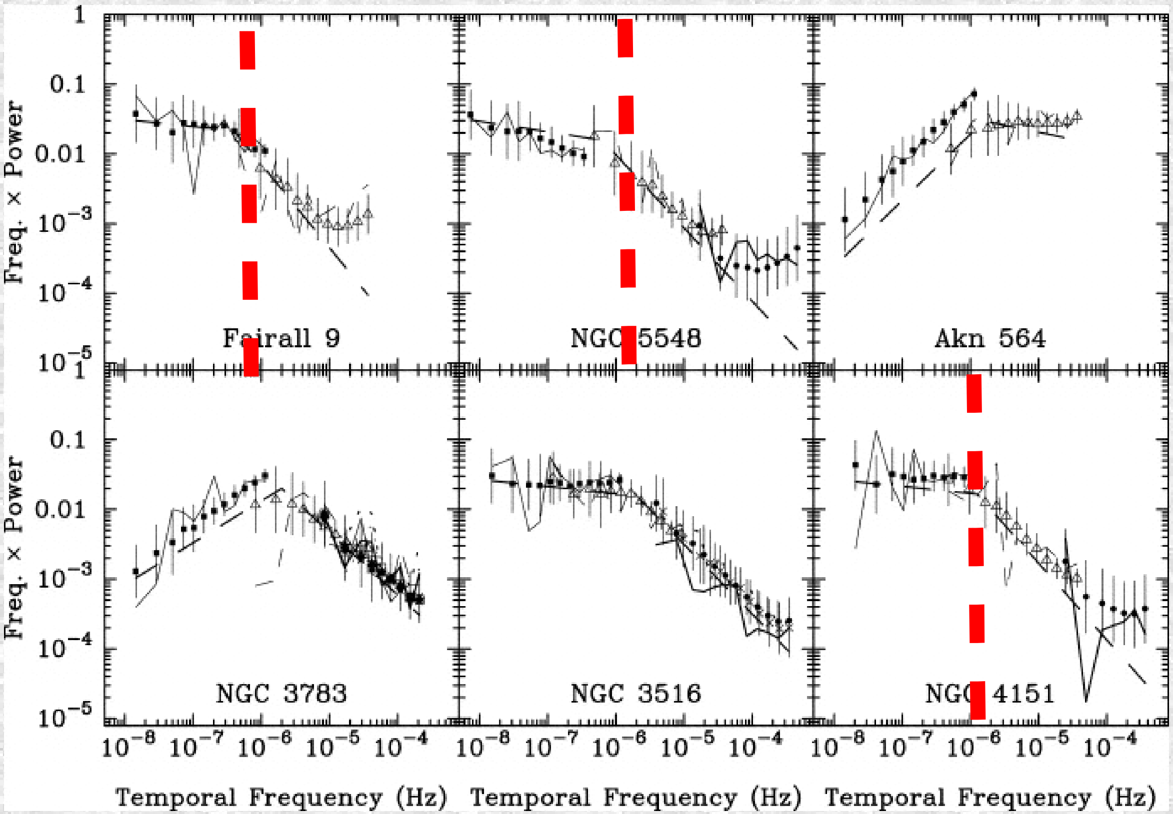


The AGN X-ray 'power spectral density' functions (PSDs) look like the GBHs PSDs (in their 'high-state')

Markowitz et al. (2003)

Uttley et al. 2002, MNRAS, 332, 231

Mueller & Madejski, 2009, ApJ, 700, 243

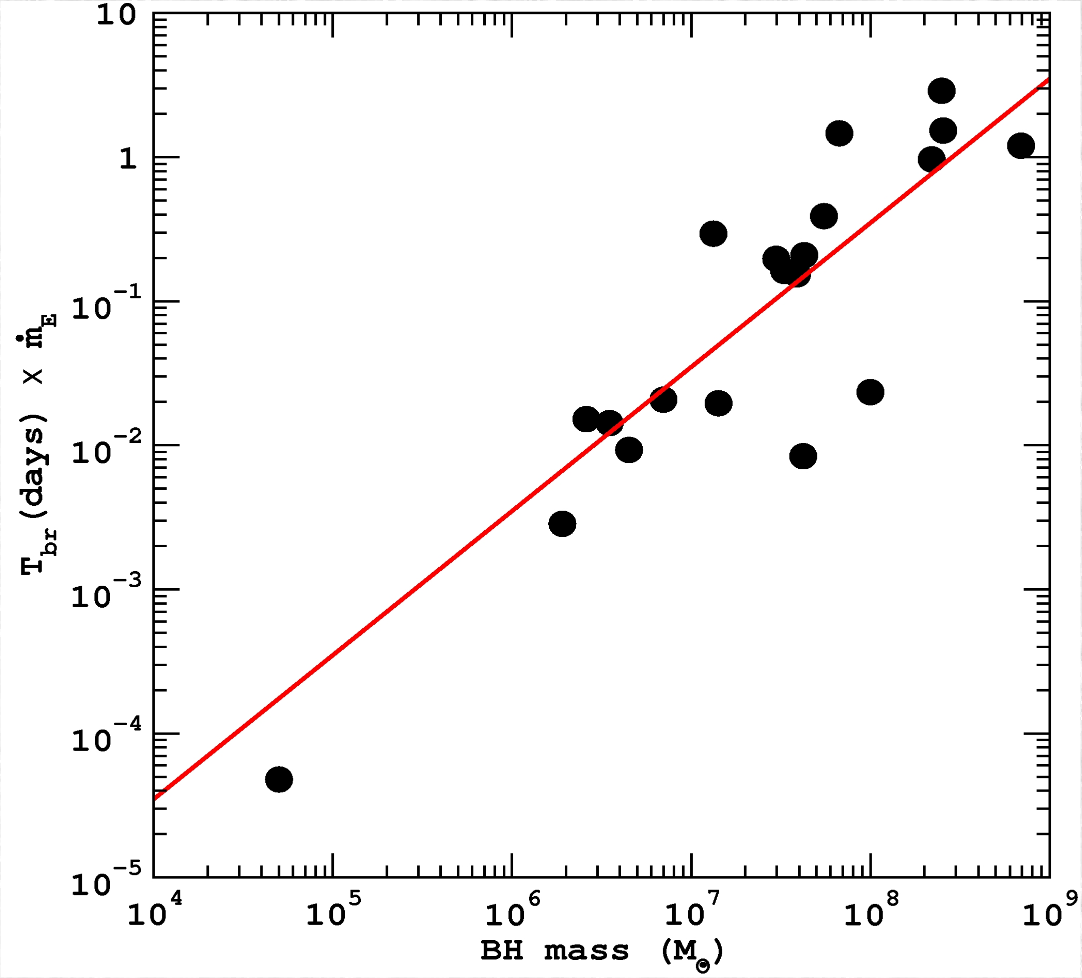


$$PSD(\nu) \propto \nu^{-1}, \nu<\nu_{br}$$

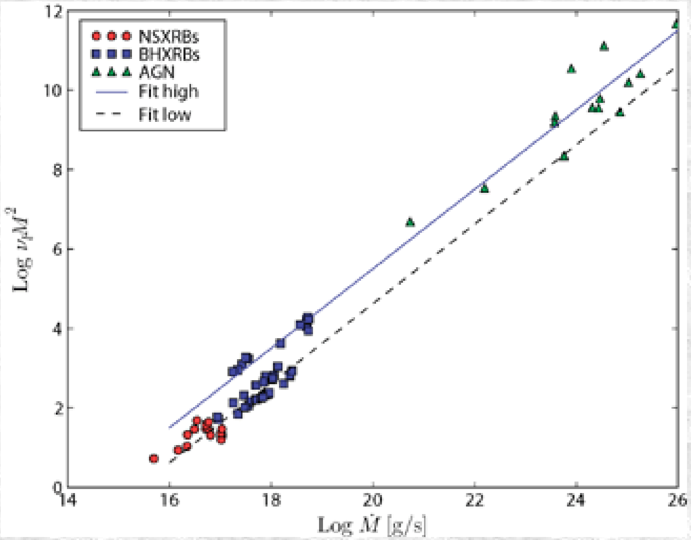
$$PSD(\nu) \propto \nu^{-2}, \nu>\nu_{br}$$

Today, we have estimated ν_{br} in ~20 AGN, for which we also have M_{BH} and $\dot{m}_E$ estimates.

McHardy et al. (2006): $T_{br}(=1/\nu_{br}) \propto M_{BH}/\dot{m}_E$

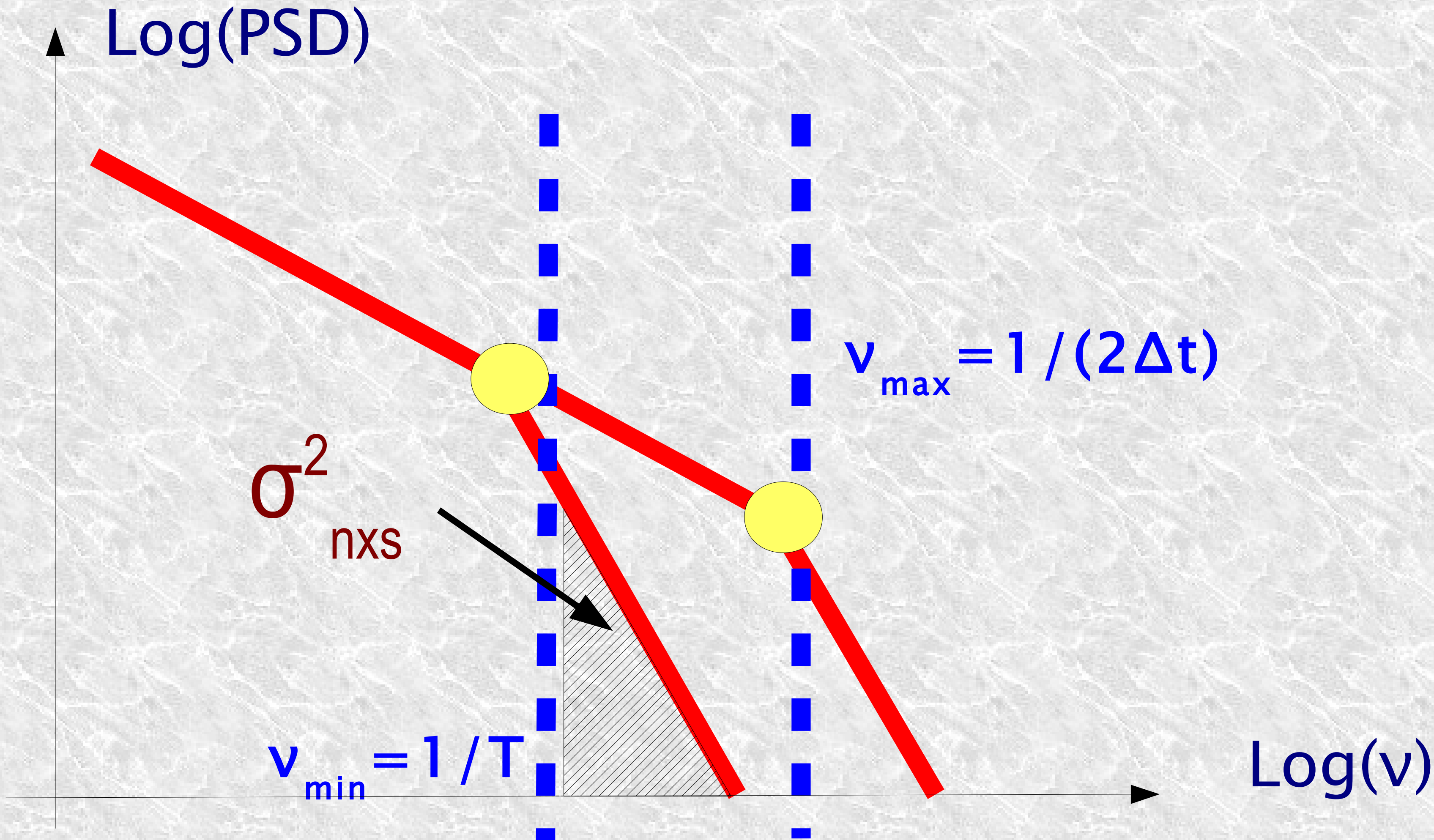


(Koerding et al 2007)



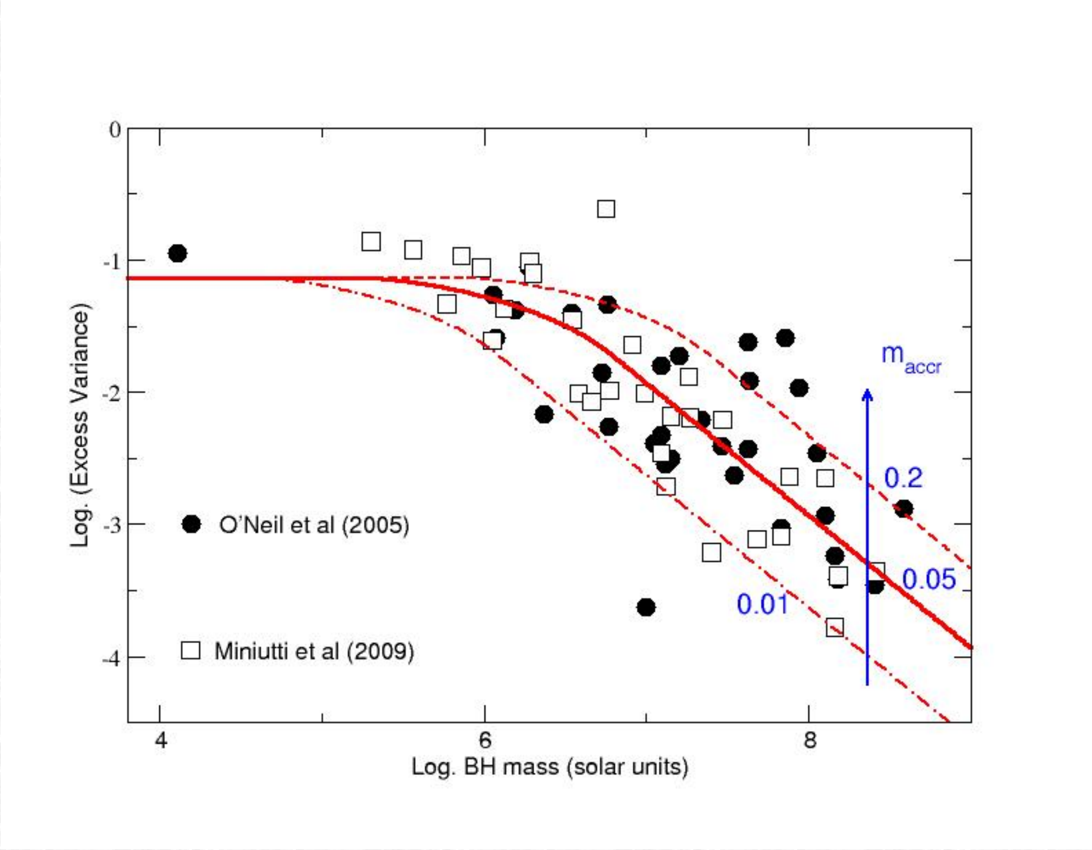
T_{br} depends on **(M_{BH}, $\dot{m}_E$**) in GBHs as well, but , the normalization is different for HS and LS systems.

We have evidence that the (Tbr, M_{BH}, $\dot{m}_E$) relation holds for more (all?) AGN, from *"normalised excess variance"* (σ^2_{nxs}) measurements.



The 'σ^2_{nxs} vs M_{BH}' relation is well established for nearby AGN.

Lu & Yu, 2001, MNRAS, 324, 653
Bian & Zhao, 2003, MNRAS, 343, 164
Papadakis, 2004, MNRAS, 348, 207
O'Neill et al, 2005, MNRAS, 358, 1405
Nikolajuk et al, 2009, MNRAS, 394, 2141
Zhou et al, 2010, ApJ, 710, 16



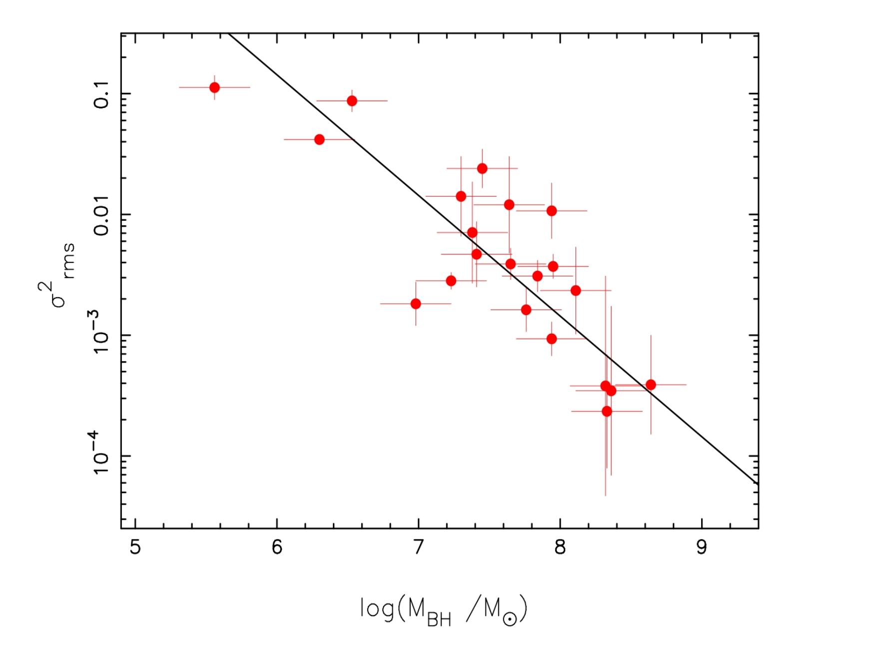
Can the large scatter be due to the T_{br} - $\dot{m}_E$ relation?

Probably not, as σ^2_{nx} does not appear to depend on $\dot{m}_E$.

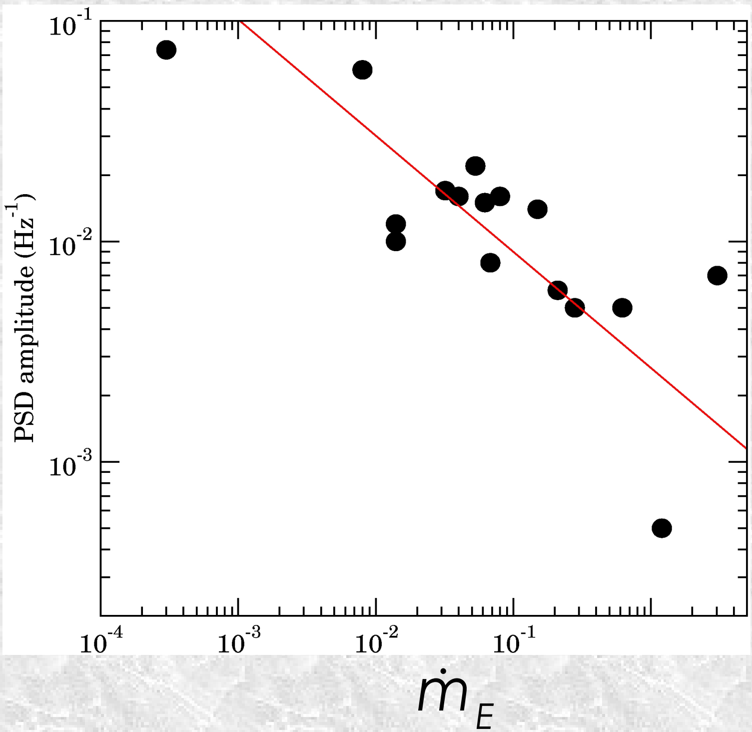
O'Neill et al, 2005
Zhou et al, 2010

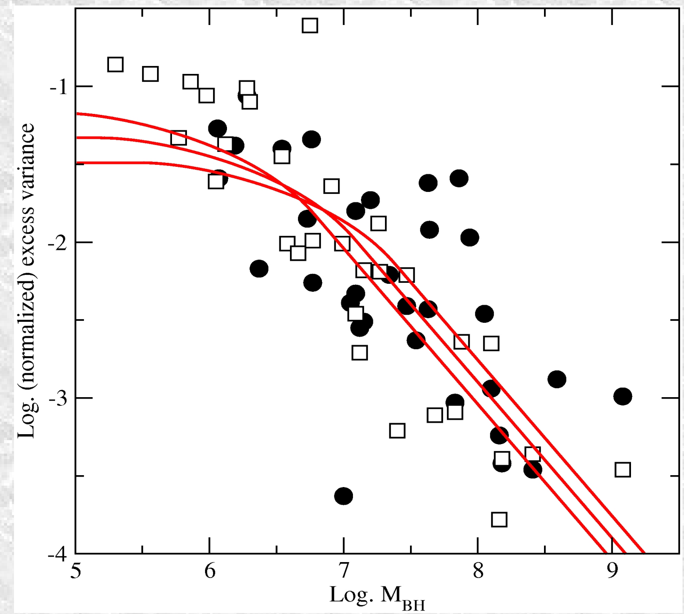
This is good news, as that suggests we can measure M_{BH} if we have computed σ^2_{nxs}.

Hayashida et al., 1998, ApJ, 500, 642
Nikolajuk et al, 2004, MNRAS, 350, 26L
Nikolajuk et al, 2006, 370, 1354
Gierlinski et al, 2008, 383, 741
Zhou et al., 2010



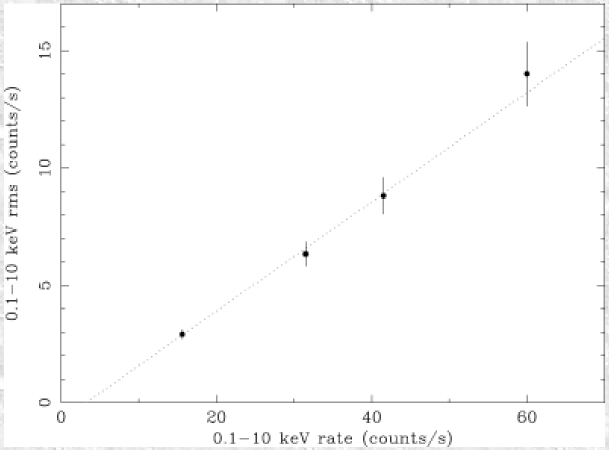
But does this result contradicts the T_{br} - $\dot{m}_E$ relation of M^cHardy et al 2006?



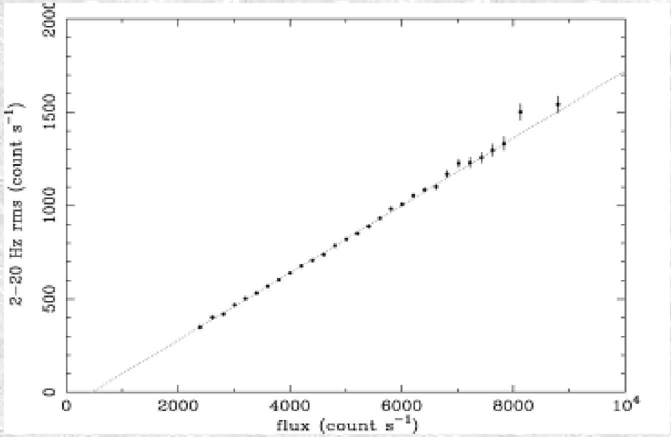


(Surprisingly) σ^2_{nxs} can be a powerful tool to study X-ray variability.

M^c^Hardy et al, 2004, MNRAS, 348, 783

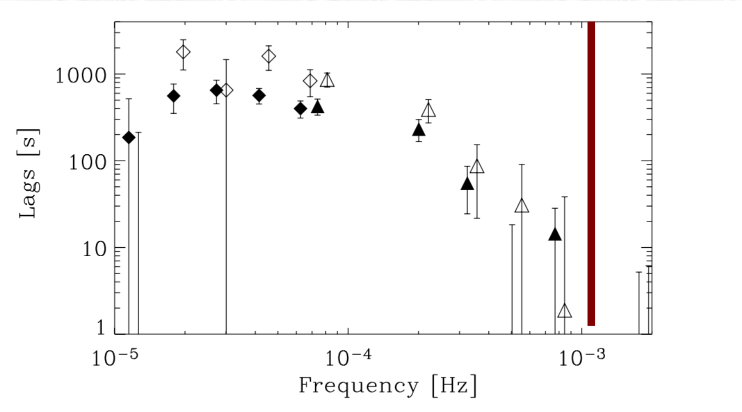


Uttley et al, 2005, MNRAS, 359, 445

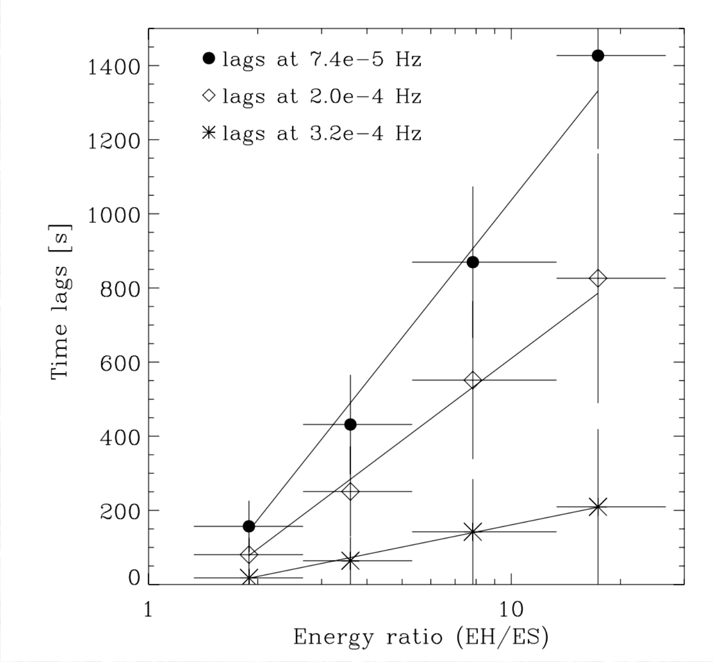


Such behaviour can put strong constraints on the **variability mechanism**. For example 'shot noise' models can**not** account for the observed X-ray variability in AGN.

Arevalo et al, 2006,MNRAS, 372, 401



Ark 564

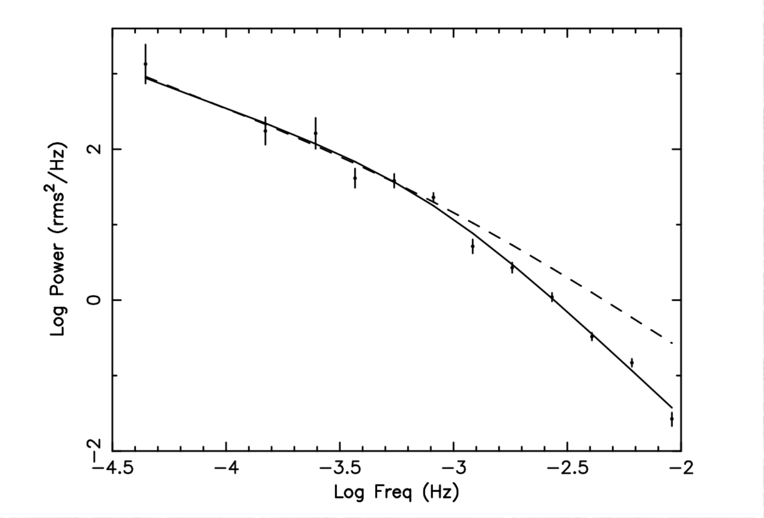


X-ray variability studies* can also provide constrains on the X-ray emission mechanism/ geometry of the source.

For example, delays between 'soft' and 'hard'-band X-ray variations are consistent with what is expected in the case of inverse thermal Comptonization, but there are many issues that need to be resolved.

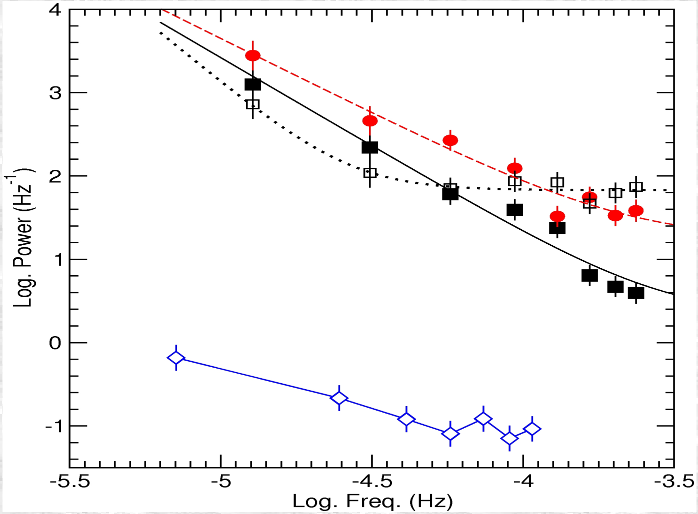
* Results for less than 10 objects.

M[c]Hardy et al, 2004.



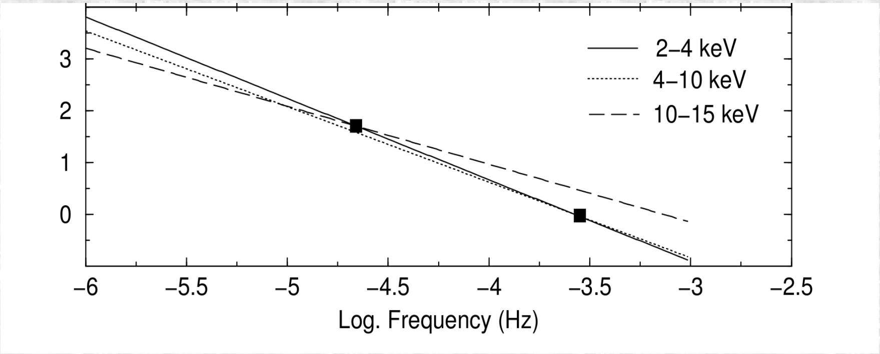
For example, the PSD energy dependence (hard band 'more' variable at high frequencies) is not expected if Comptonization is in operation.
(Results for less than 10 objects)

BUT:



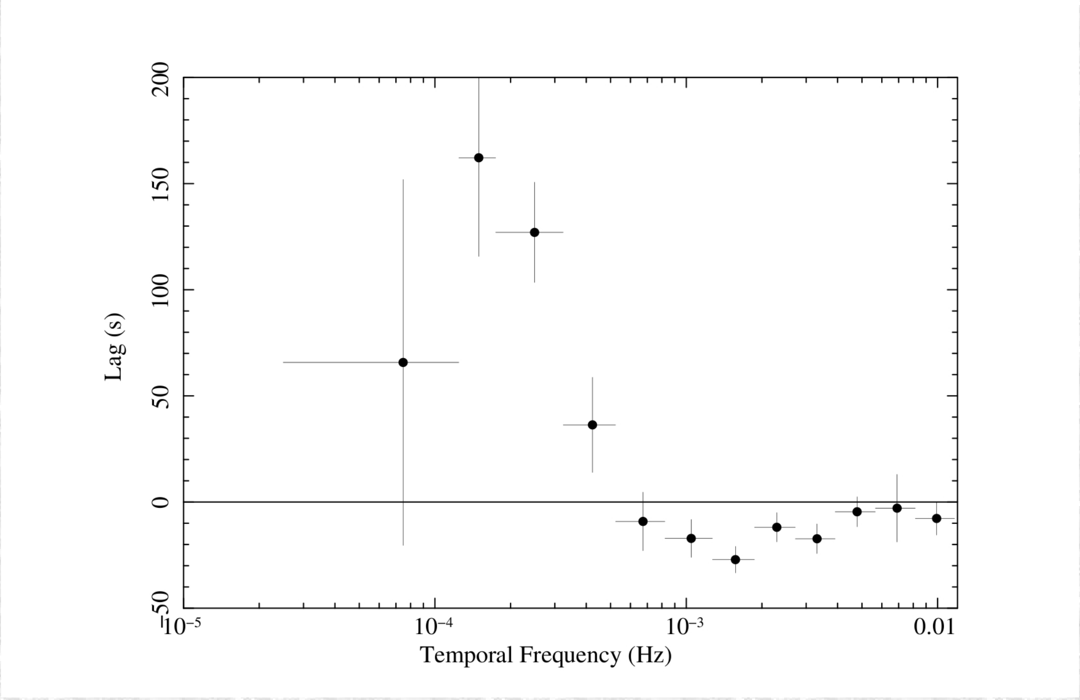
Papadakis et al, 2010, in press

We really need to look at energies > 10 keV...



NGC 7469, Nandra & Papadakis, 2001

1H 0707-495, Fabian et al., 2009, Nature, 459, 540
(but see also: Miller et al., 2010, MNRAS, in press)



In summary, X-ray (continuum flux) variability studies the last 10-15 years have:

a) shown that AGN are 'scaled-up' versions of GBHs
b) revealed characteristic time scales, which depend on BH mass and accretion rate,
c) provided a new method to weigh SMBHs
d) shown that simple variability mechanisms (like 'shot noise' models) do not work
e) revealed (complex) delays (and variability 'amplitude' differences) between the variations in different energy bands.

Can all these results be combined, and help us create a broad picture of the X-ray source?

Lets go back to the (T_{br}, M_{BH}, accretion rate) relation of M^{c}Hardy et al.

Any model for the X-ray emission from AGN (and GBHs) should be able to explain it

(Ishibashi & Courvoisier, 2009, A&A, 504, 61)

Is it possible that T_{br} is associated with one of the basic timescales of a Keplerian, geometrically-thin and optically-thick disc?

$$t_{dyn}(r)=10^4\, R_3^{3/2}\, M_8\ (s)$$
$$t_{sound\text{-}r}(r)=T_{dyn}\ (r/h_d)\ (s)$$
$$t_{th}(r)=10^5\ (a_{0.1})^{-1} R_3^{3/2}\, M_8\ (s)$$
$$t_{visc}(r)=10^7\ (a_{0.1})^{-1}(r/h_d)^2 R_3^{3/2}\, M_8\ (s)$$

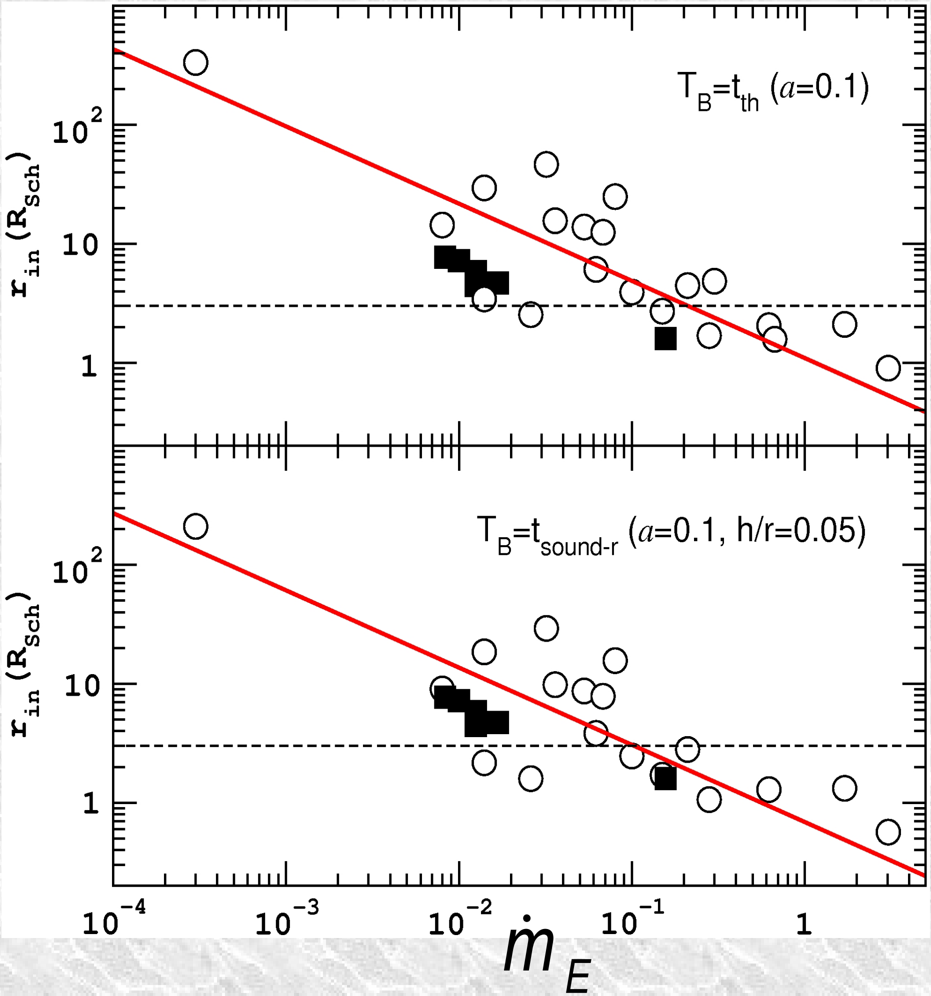
The $T_{br} \propto M_{BH}$ dependence is rather obvious, but why does $T_{br} \propto (\dot{m}_E)^{-1}$ as well?

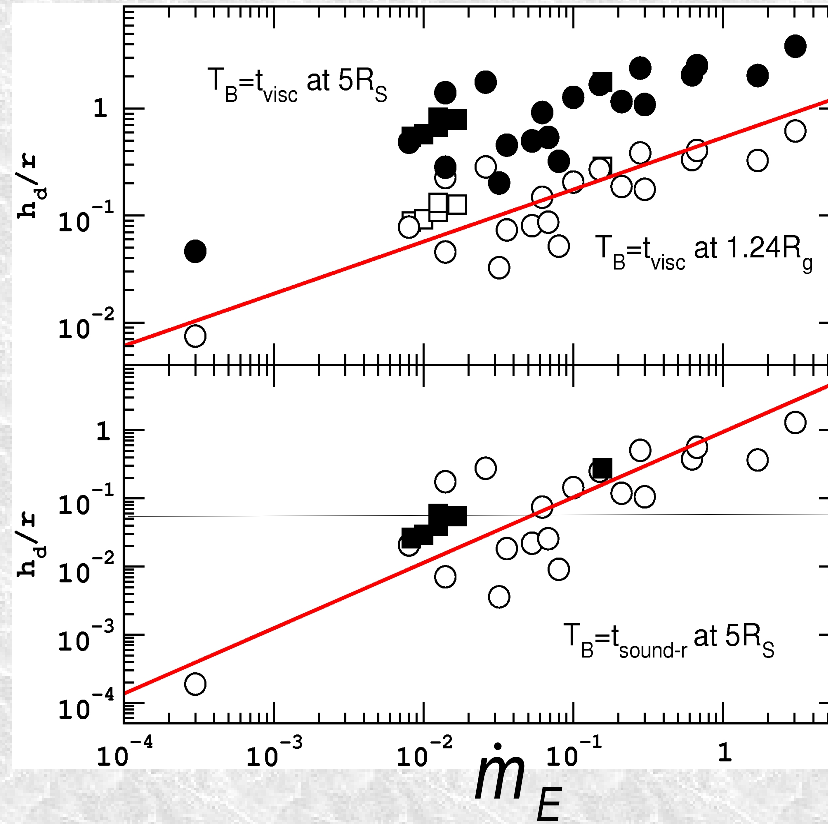
1st Possibility:

r_{inner} *decreases* with increasing $\dot{m}_E$

2nd Possibility:

r_{inner} is fixed, but (h/r) *increases* with increasing $\dot{m}_E$





$r_{inner} \propto \dot{m}_E^{-0.7}$

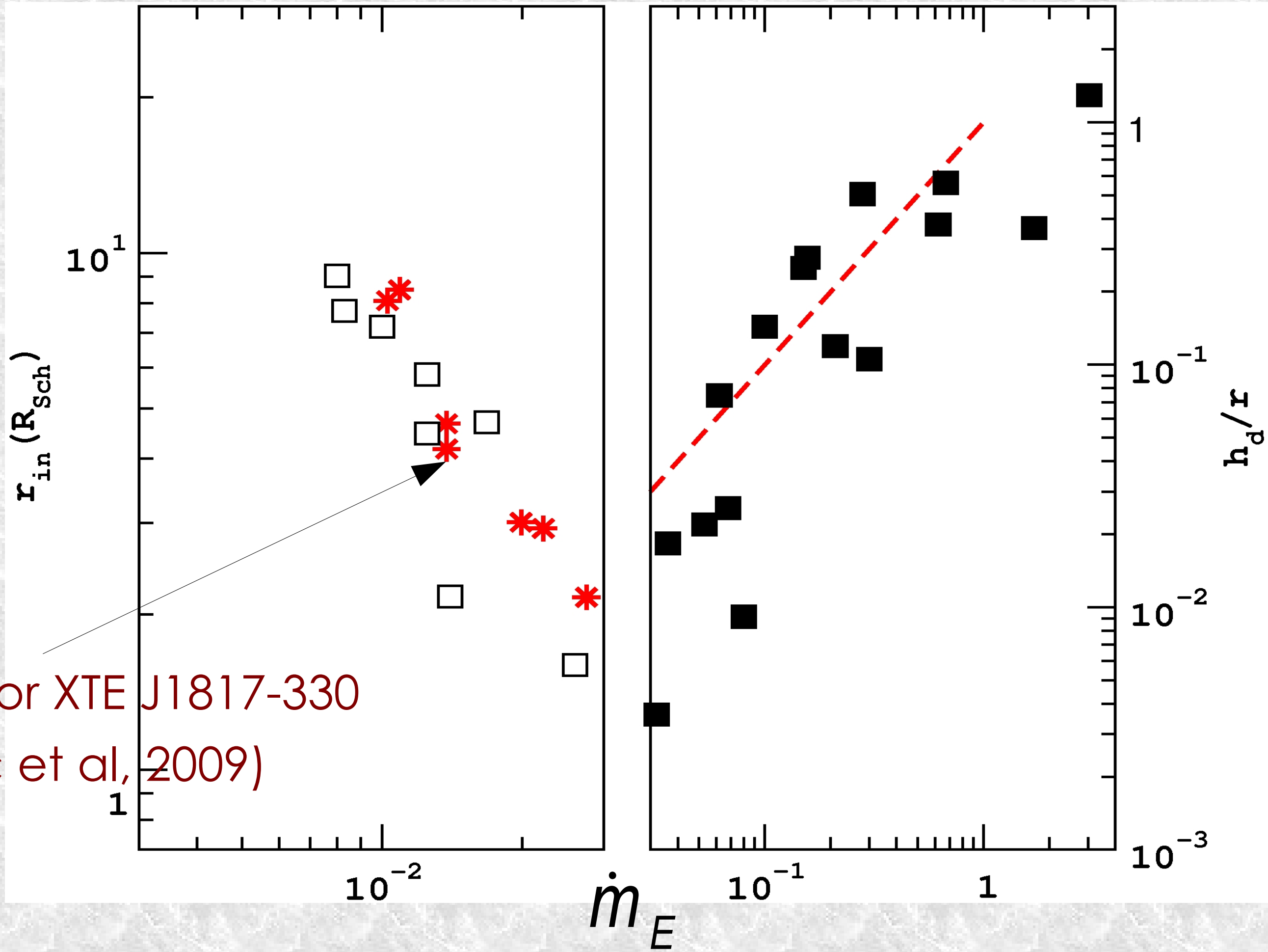
If $T_{br}=t_{visc}$, $(h/r) \propto \sqrt{\dot{m}_E}$

If $T_{br}=t_{sound\text{-}r}$, $(h/r) \propto \dot{m}_E$

Perhaps then:

a) $T_{br}=T_{sound\text{-}r}(r_{inner})$, and $r_{inner} \propto \dot{m}_E^{-0.7}$, up to $\dot{m}_E$=0.03.

b) $T_{br}\sim T_{sound\text{-}r}(5R_{SCH})$, and $(h_d/r) \propto \dot{m}_E$

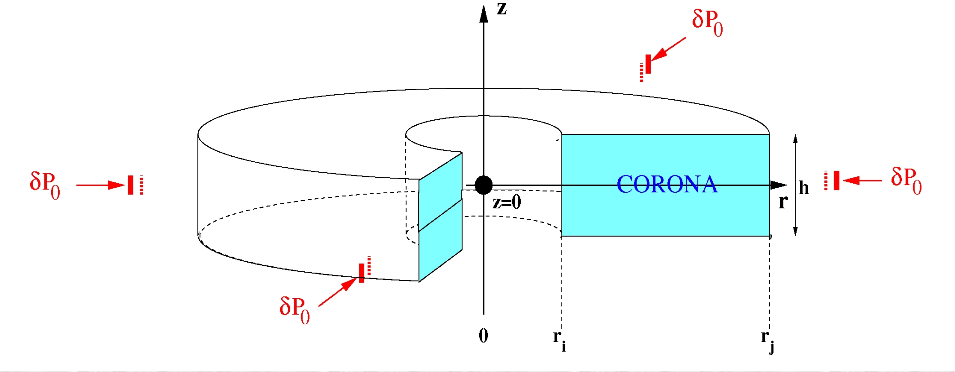


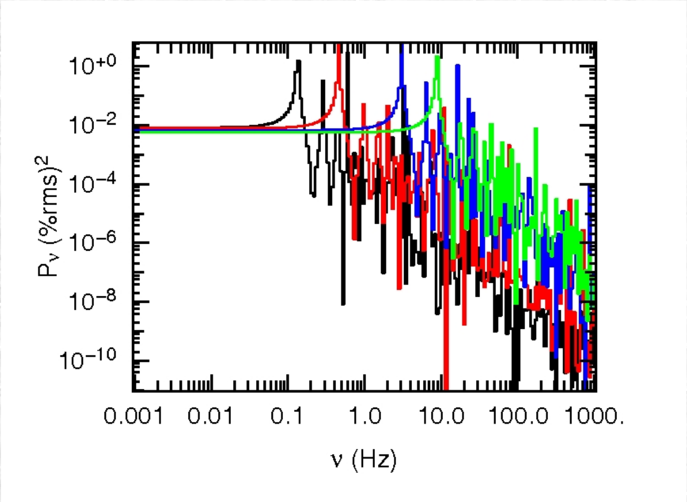
r_{inner} data for XTE J1817-330 (Cabanac et al, 2009)

BUT:

Are sound waves generated within the disc? Do they propagate radially, affecting the X-ray emitting region? Even if they do, how does the X-ray emitting region react as they propagate through?

Recently, Cabanac et al. (2010) considered the response of a cylindrical 'corona' to pressure instabilities at its external radius, r_{out}, which generate a sound wave, which propagates radial within the corona.



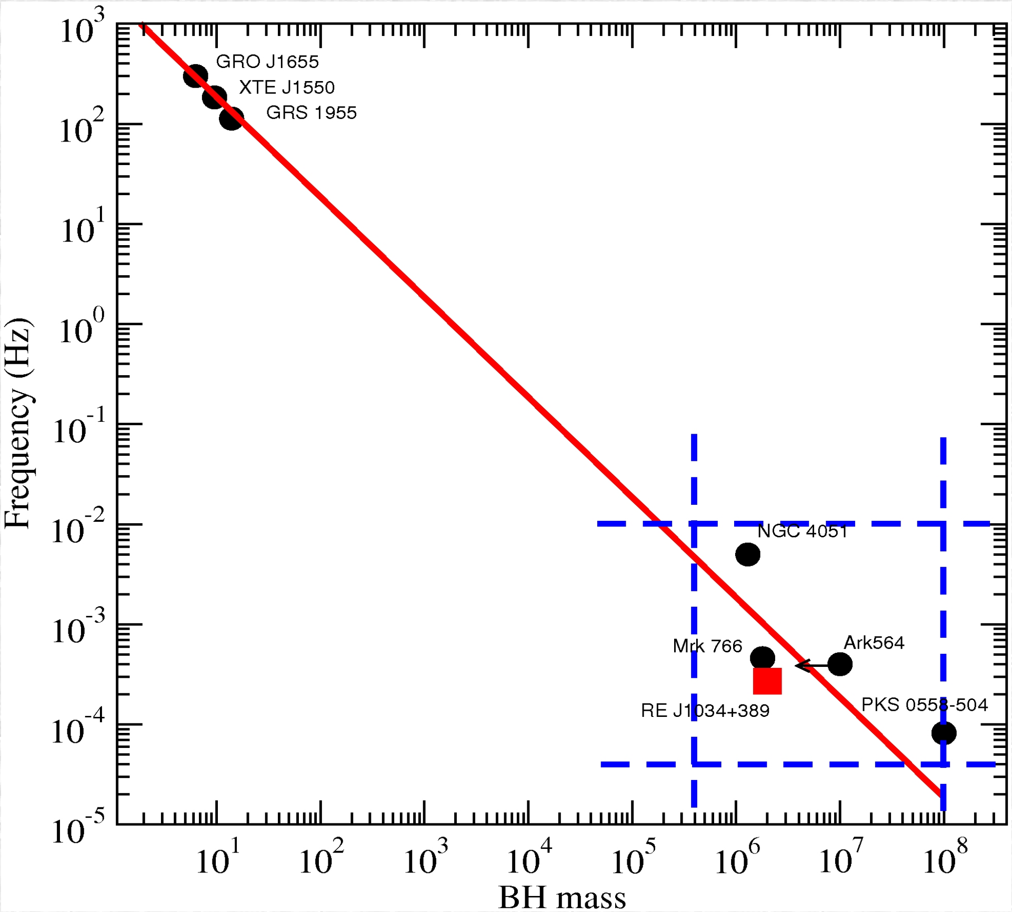


The 'future':

a) Study the 10-20 keV PSD (RXTE + Suzaku + INTEGRAL??)
b) Study the time-lags of 'all' archival (XMM+Chandra?+Suzaku) light curves.
c) Study the variability properties of high-z objects (Papadakis et al, 2008, A&A, 487, 475; Paolillo et al, 2004, ApJ, 611, 93)
d) work in the 'time' domain (Kelly et al., ApJ,2009, 698, 895), with more sophisticated tools (Gliozzi et al, 2010, A&A, 512, 21).

More data should arrive 'soon': NuSTAR, e-ROSITA, EXIST

CAUTION: One has to be **very** careful when detecting a “peak” in the PSD (Vaughan, 2005, A&A, 431, 391).



Range of frequencies sampled with a 'long' XMM observation.