PG1211+143: a 'timing' approach

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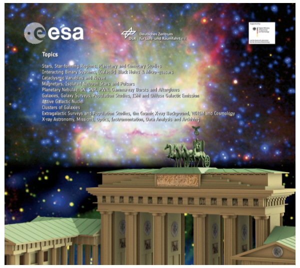
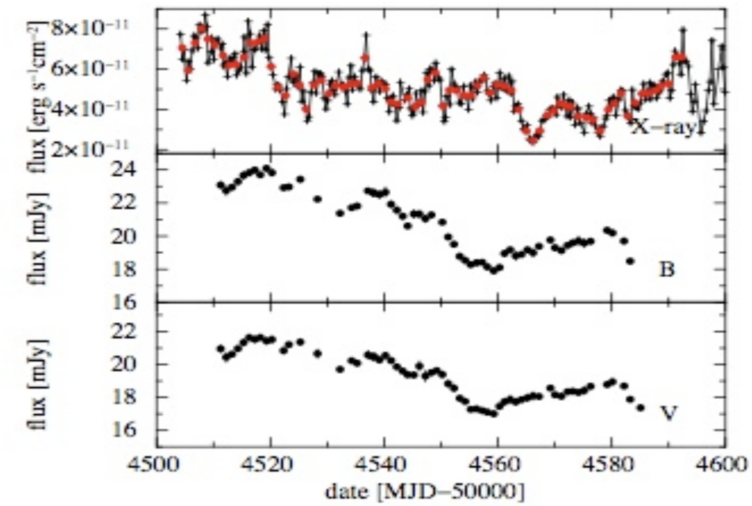
The X-ray Universe 2011 - Berlin



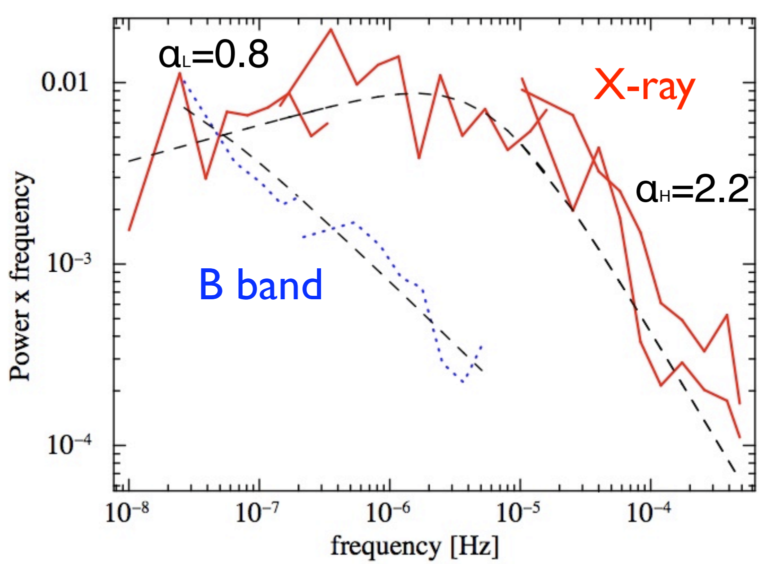
WHY TIMING?

Timing techniques make use of the rapid variability of AGN to understand their physics

NGC 3783



Variability is observed in different energy bands



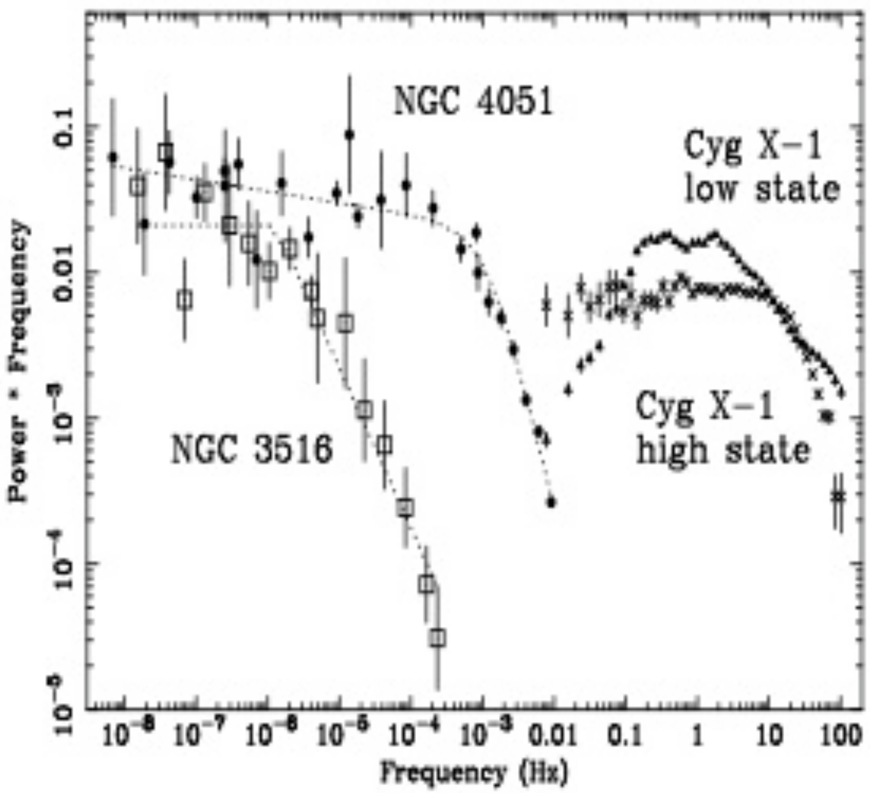
Arévalo et al. 2009

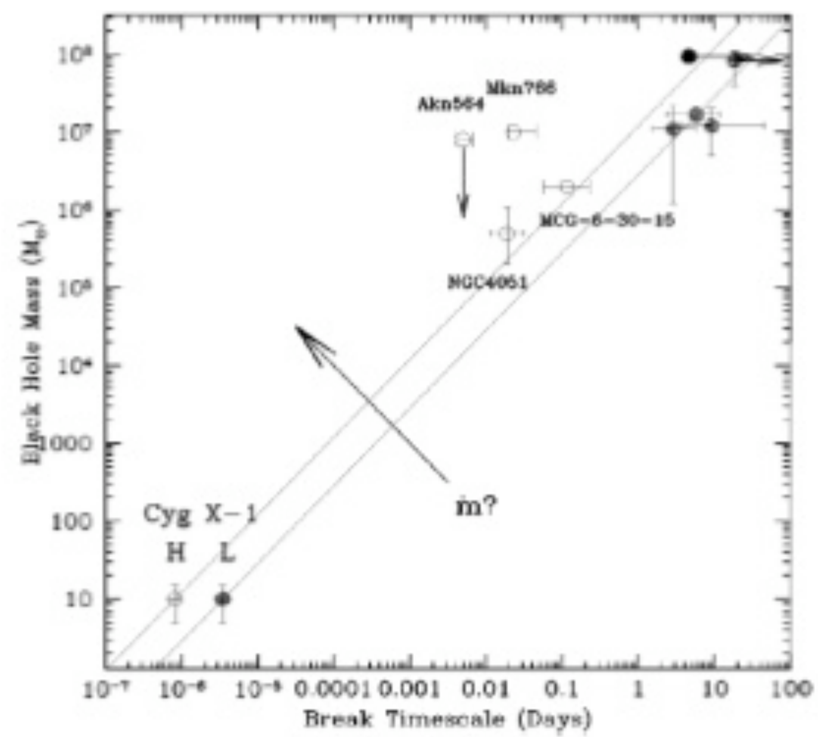
but in the X-ray it occurs on very short time scales, allowing to test the inner regions of AGN

MASS-SCALING

Close similarities with smaller size systems (BHXRBs) provided the characteristic time scales are re-scaled for the mass

Uttley & McHardy 2004





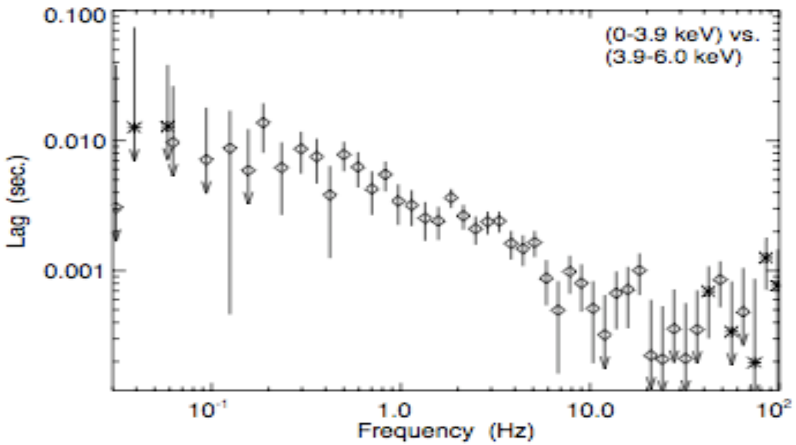
$$\log(T_{\rm b}) = 2.1\log(M_6) - 0.98\log(L_{44}) - 2.32$$

McHardy et al. 2006

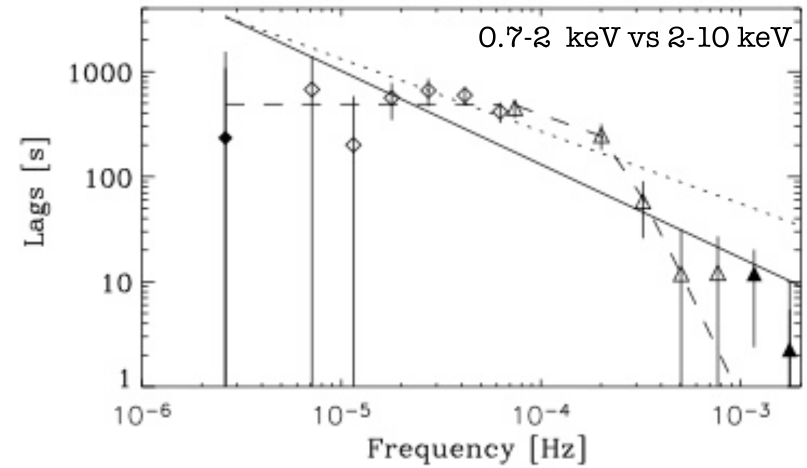
HARD TIME LAGS

At relatively low frequencies "positive" soft-to-hard lags are detected, having similar Fourier-frequency trend...

Cyg X-1- Nowak et al. 1999

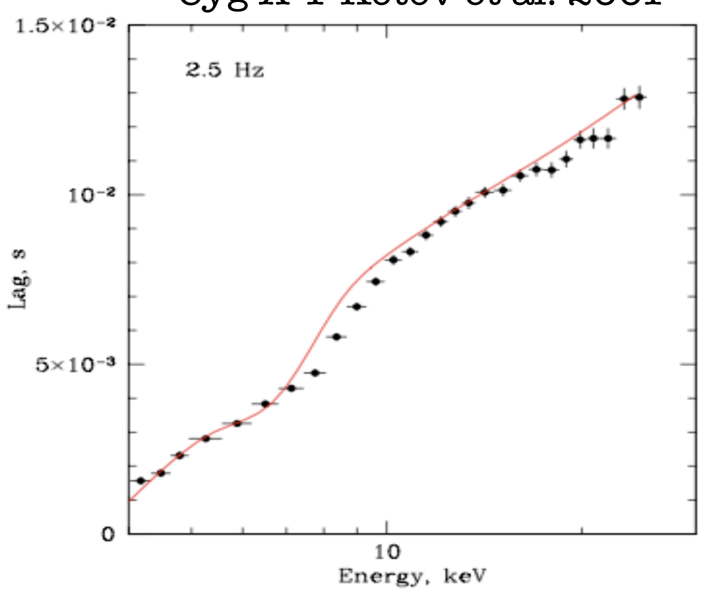


Ark 564 - Arévalo et al. 2006

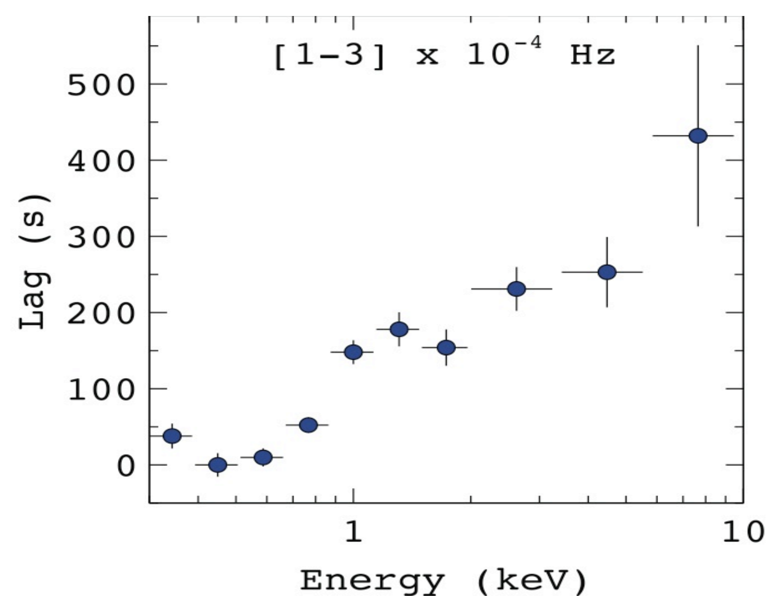


...and energy dependence

Cyg X-1-Kotov et al. 2001



1H0707-495 - Zoghbi et al. 2011



HARD TIME LAGS

Origin is debated...

Accretion rate propagation models?? (e.g. Kotov et al. 2001)

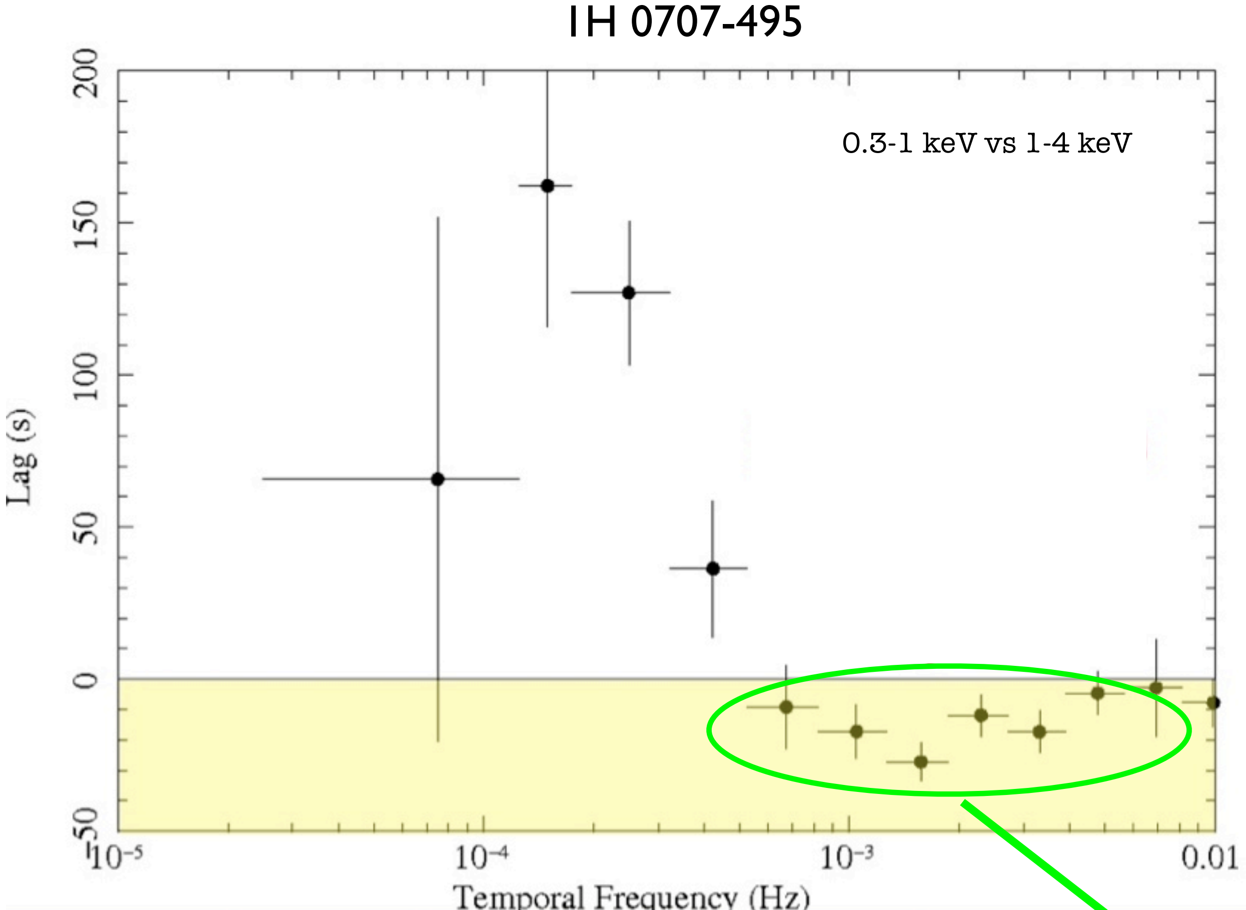
Comptonization?? (e.g. Dewangan et al. 2007)

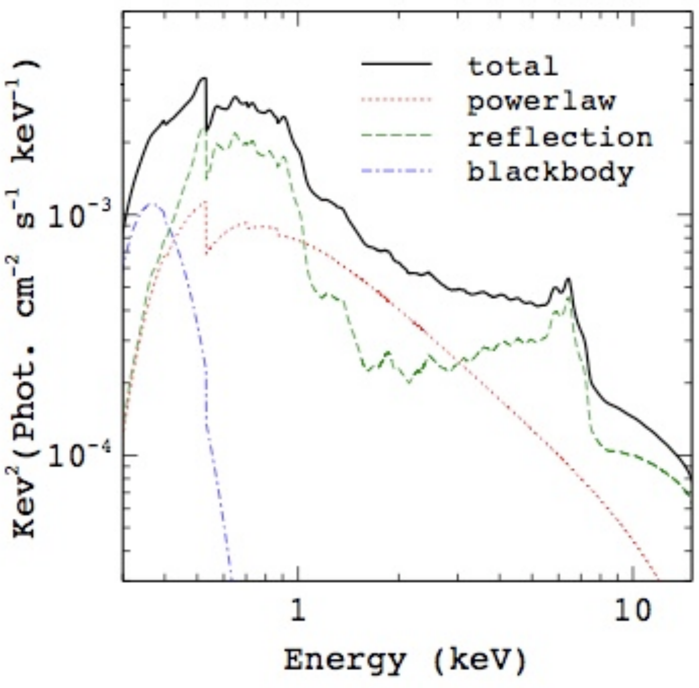
"NEGATIVE" SOFT LAGS

Tentative detections in some AGN, but most significant detection in 1H 0707-495

(see also results in Papadakis talk)

Fabian et al. 2009, Zoghbi et al. 2010, 2011





High frequency hard-to-soft lag

M_{BH}~2x10^6 M_{sol} Zhou & Wang 2005 + estimates from PSD break

"NEGATIVE" SOFT LAGS

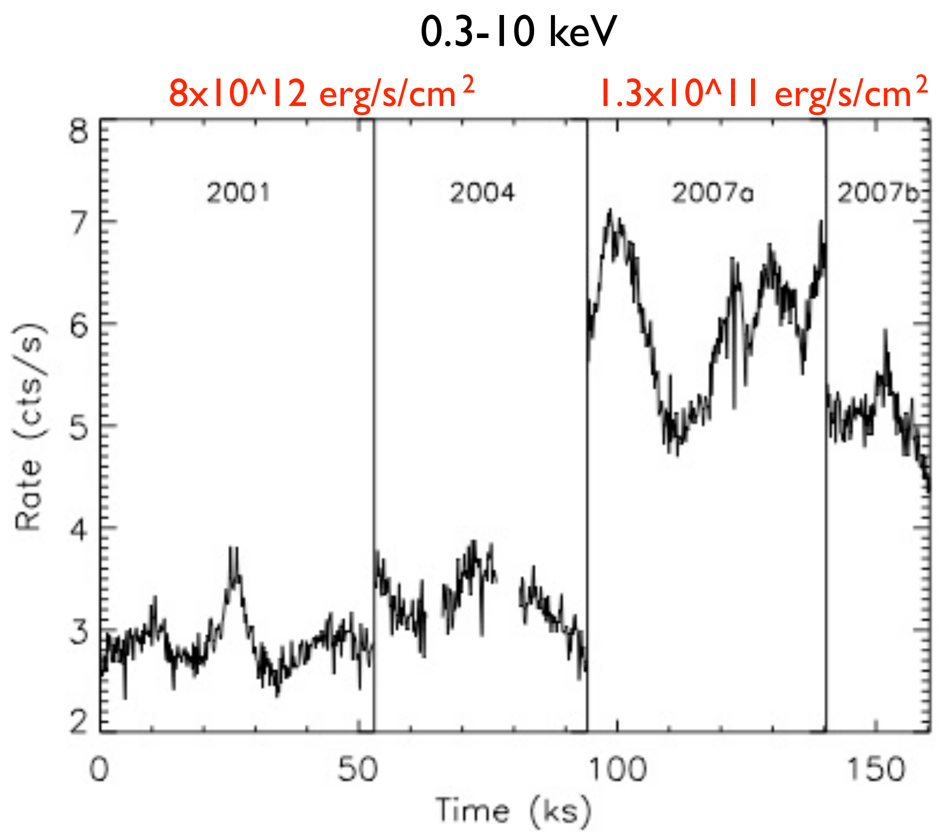
Represents the hint of a distinct component in the lag frequency-spectrum: plausibly reverberation

(see discussion in Zoghbi et al. 2010, 2011 and Miller et al. 2011)

Reflection from the inner disk

Reflection from a distant medium close to the line of sight

PG1211+143 - light curves



relatively variable source (fvar = 7-10%)

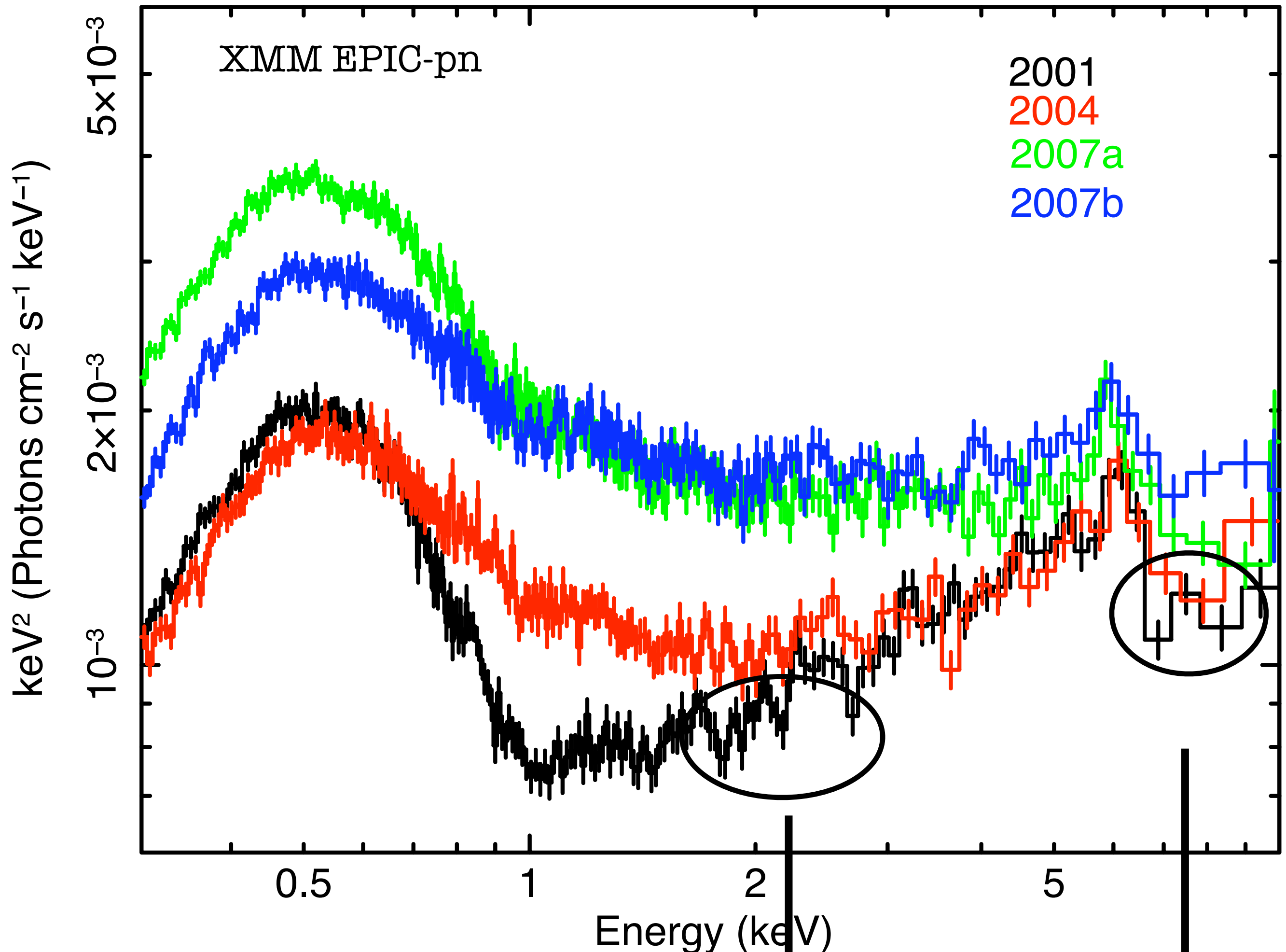
M_{BH}~ 2.4 (±0.7) x10^7 M_{sol} Kaspi et al. 2000, Woo & Urry 2002

14.6 (±4.4) x10^7 M_{sol} Peterson et al. 2004

10-100 times more massive than 1H 0707-495!

(as well as than MCG-6-30-50 and Mrk 766 - see Papadakis talk)

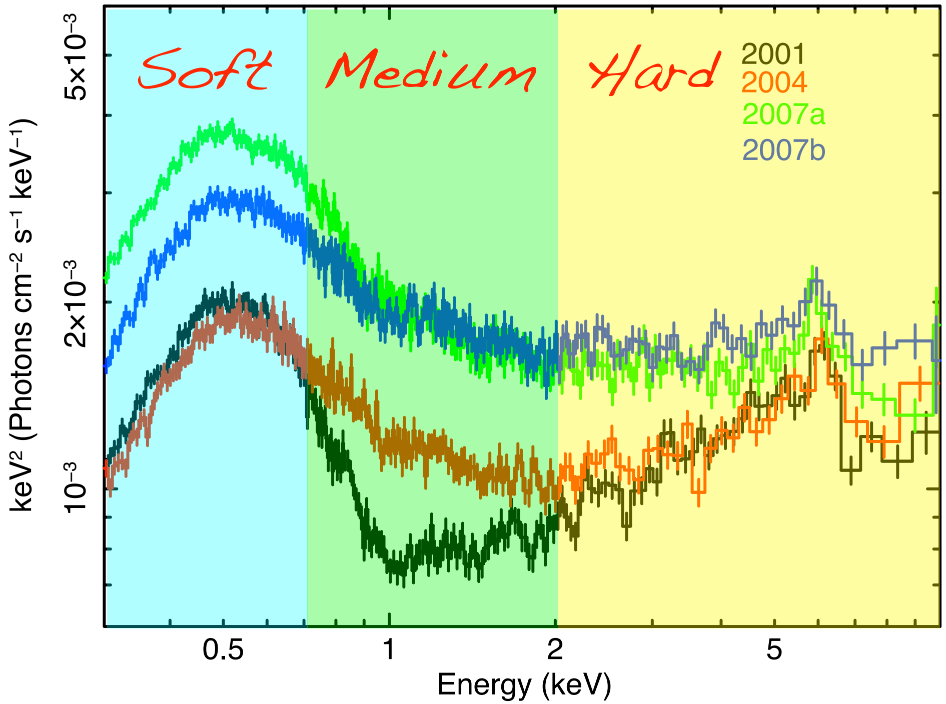
PG1211+143 - spectra



Time-averaged spectral analysis:
e.g. Pounds & Reeves 2007
Reeves et al. 2008

Analysis of absorption features:
e.g. Pounds et al. 2003,
Kaspi & Behar 2006

PG1211+143 - analysis

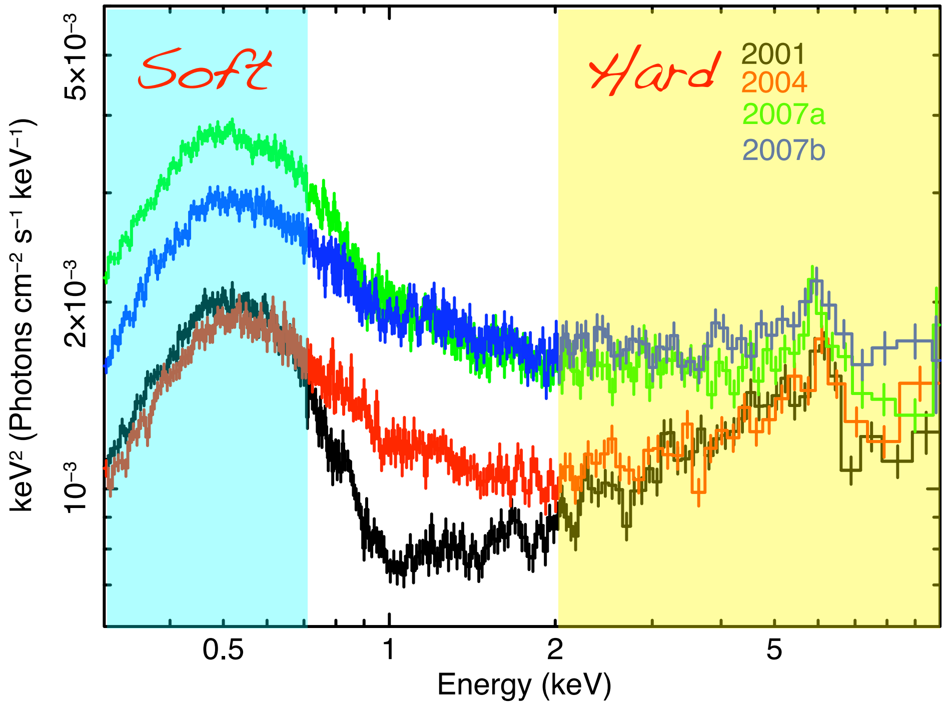


Soft (0.3-0.7 keV) -> Excess

Medium (0.7-2 keV) -> Absorption

Hard (2-10 keV) -> Hard power law

PG1211+143 - analysis



Soft (0.3-0.7 keV) -> Excess

~~Medium (0.7-2 keV) -> Absorption~~

Hard (2-10 keV) -> Hard power law

PG1211+143 - analysis

$$x(t_j) \Rightarrow a(f_k)\exp(-2\pi ijk/N)$$

Time domain

↓

Energy-resolved light curves

Frequency domain

↓

Power spectrum

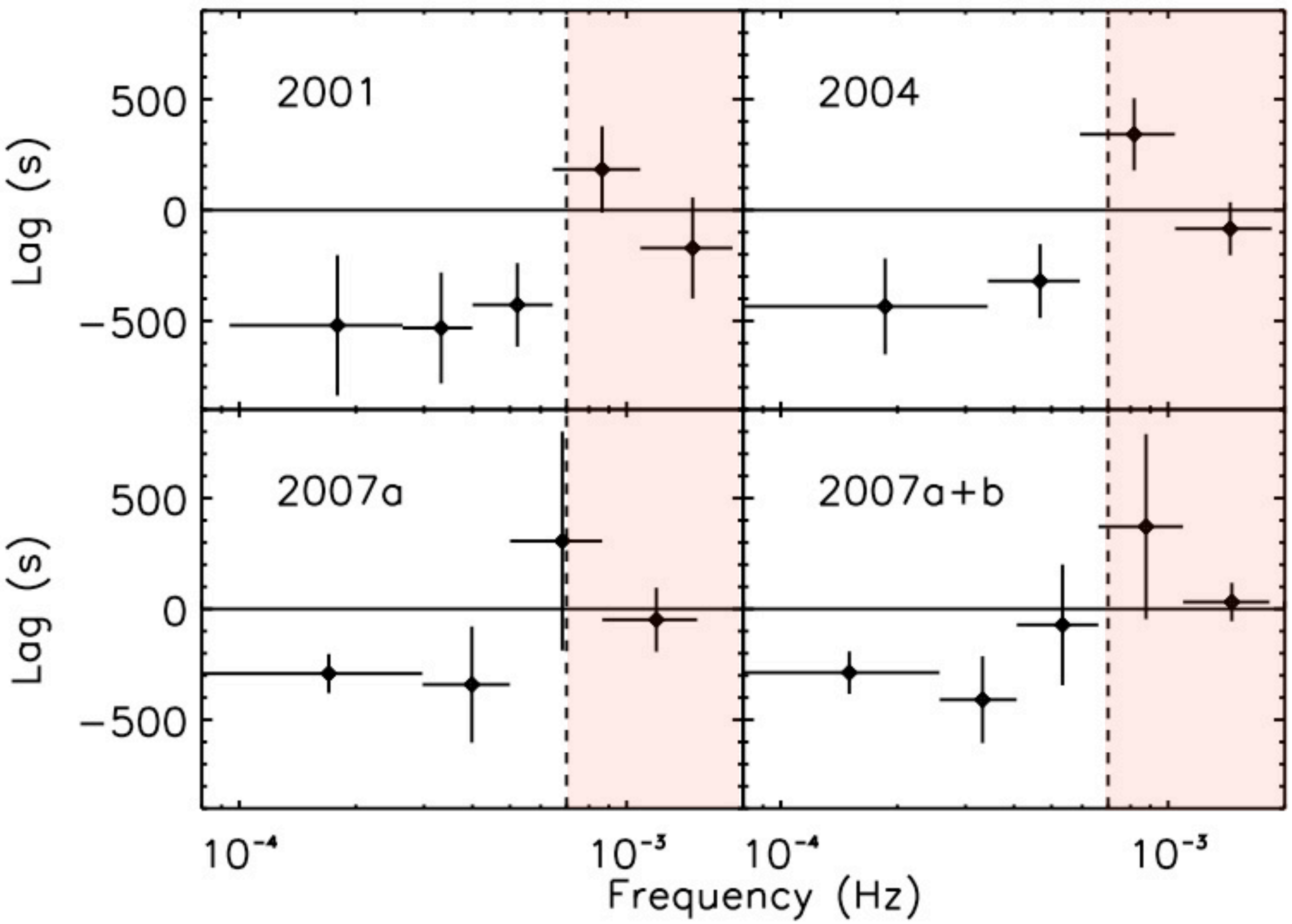
coherence

time lags

PG1211+143 NEGATIVE SOFT LAG

Negative Lags (=hard leads the soft) detected in all the observations

0.3-0.7 keV vs 2-10 keV

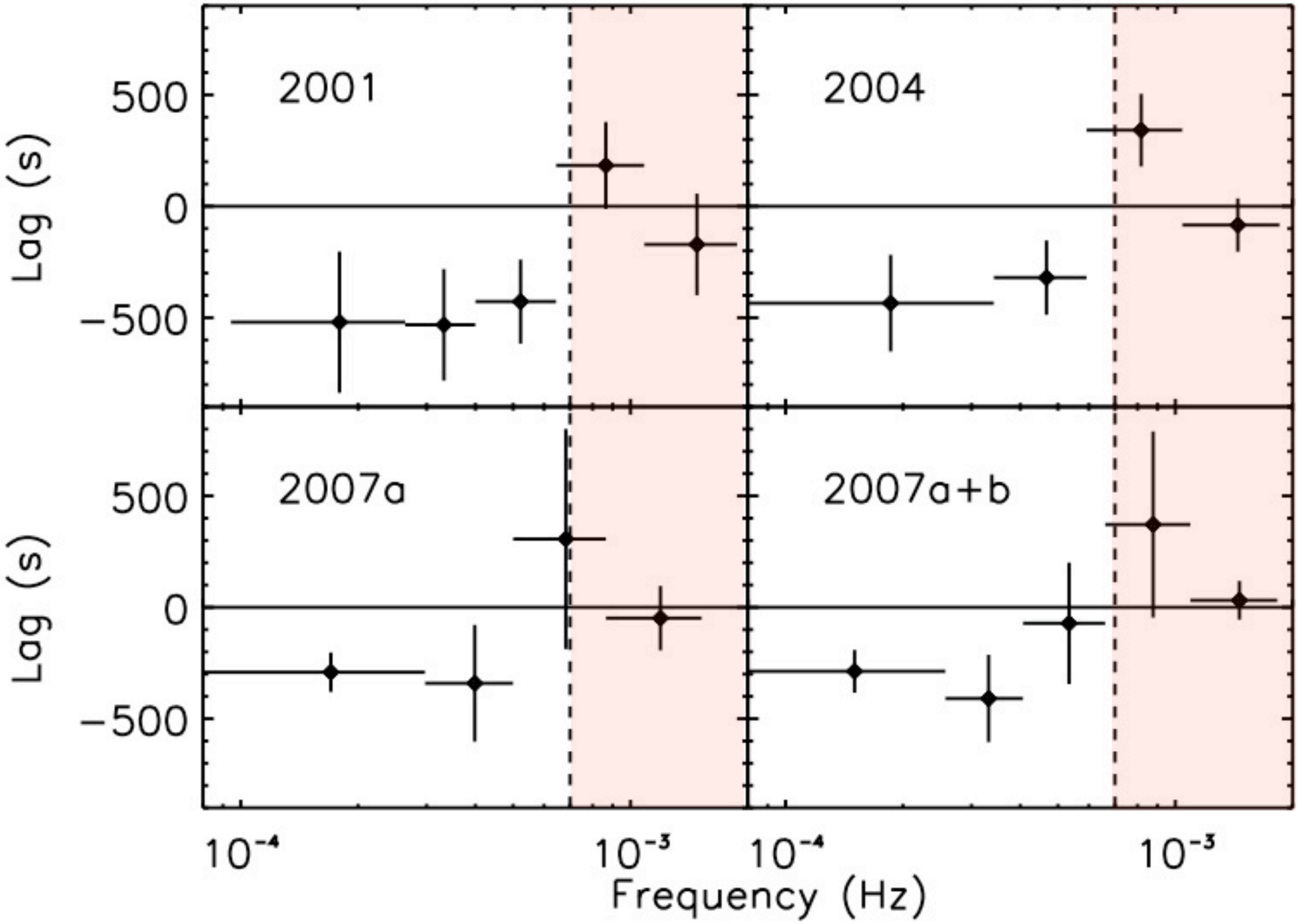


Poisson noise-dominated frequency range

PG1211+143 NEGATIVE SOFT LAG

Negative Lags (=hard leads the soft) detected in all the observations

Reference band 0.3-0.7 keV vs 2-10 keV

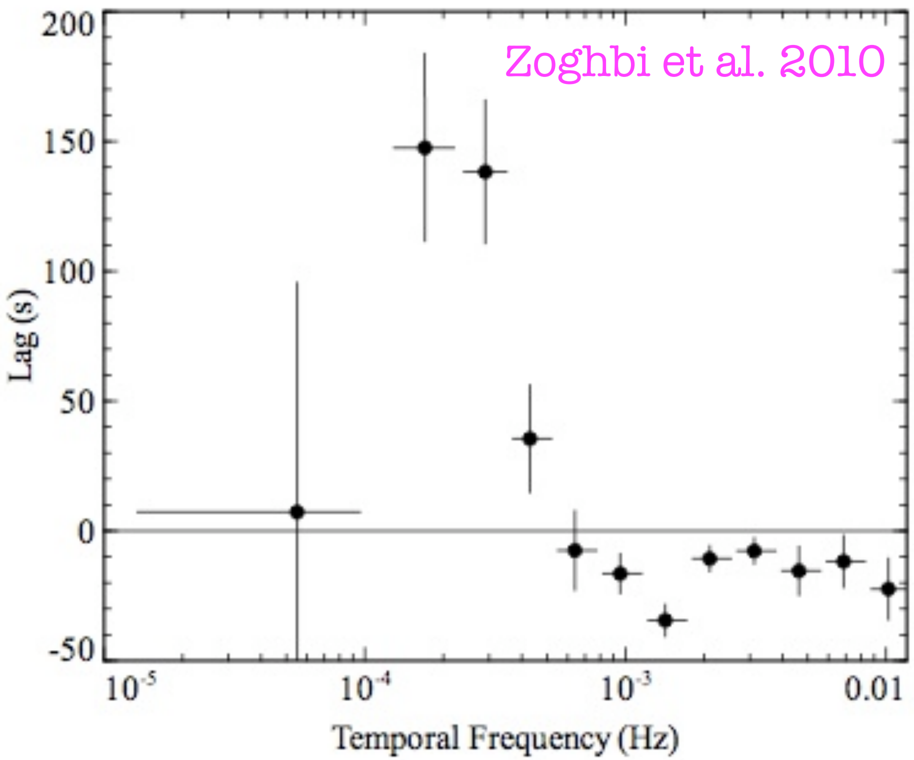


Poisson noise-dominated frequency range

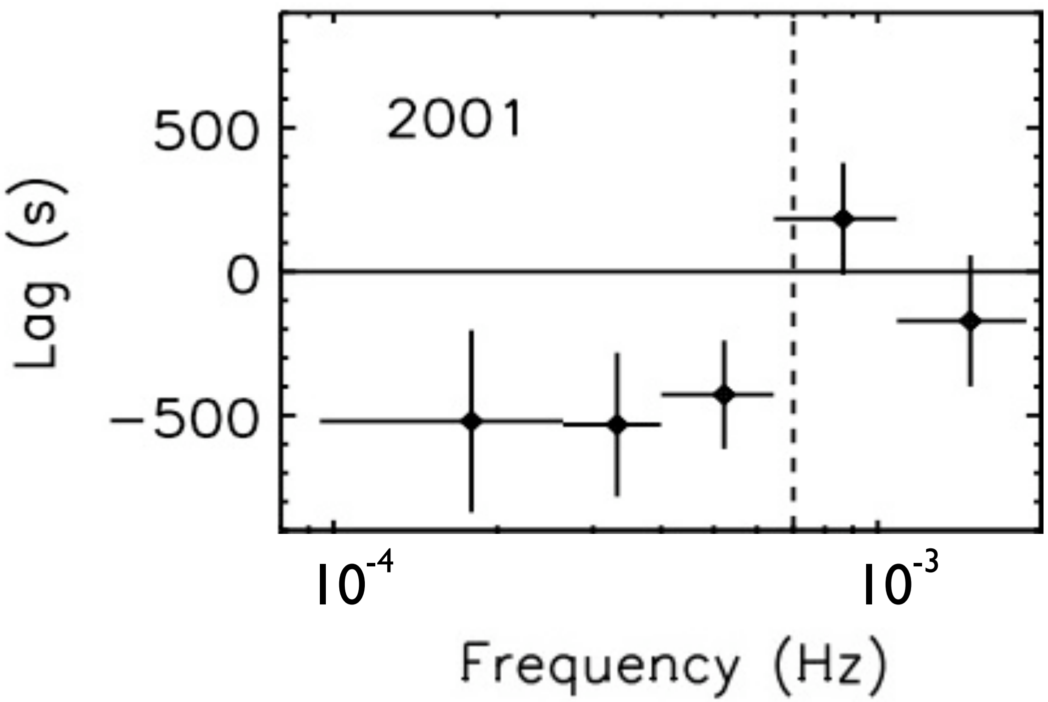
COMPARISON WITH 1H 0707-495

Lag frequency ν_{neg}

1H 0707-495



PG 1211+143



$\nu_2 \sim \nu_1 \, M_1/M_2$

McHardy et al. 2006

$\nu_{neg} \sim 1.5e\text{-}3$ Hz

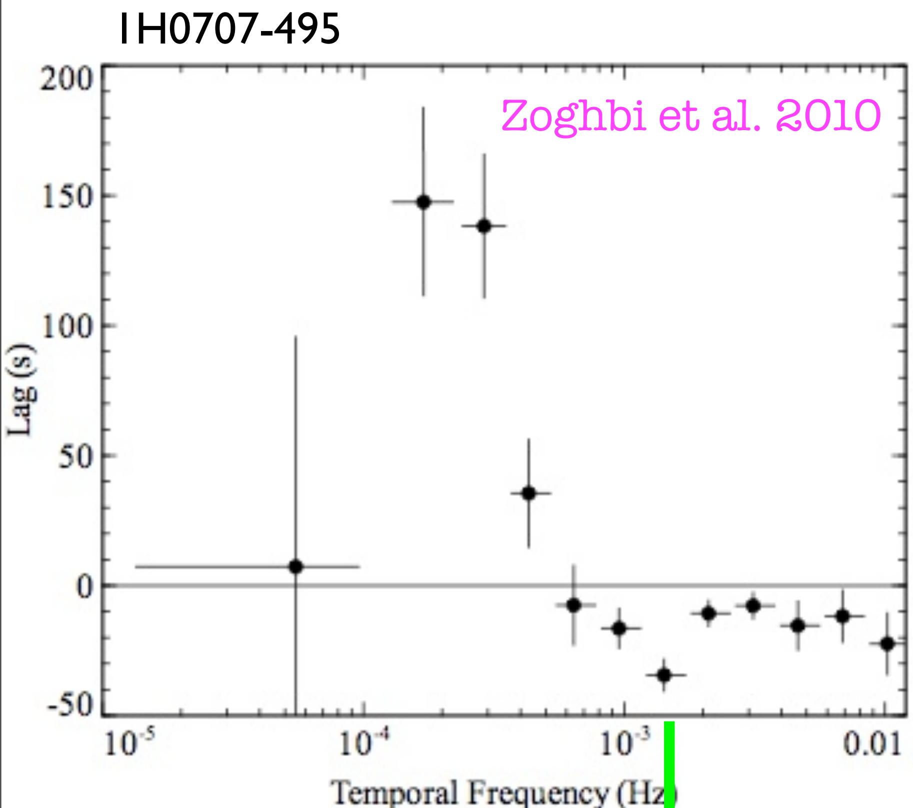
$M_{BH} \sim 2x10\text{^}6 \, M_{sol}$

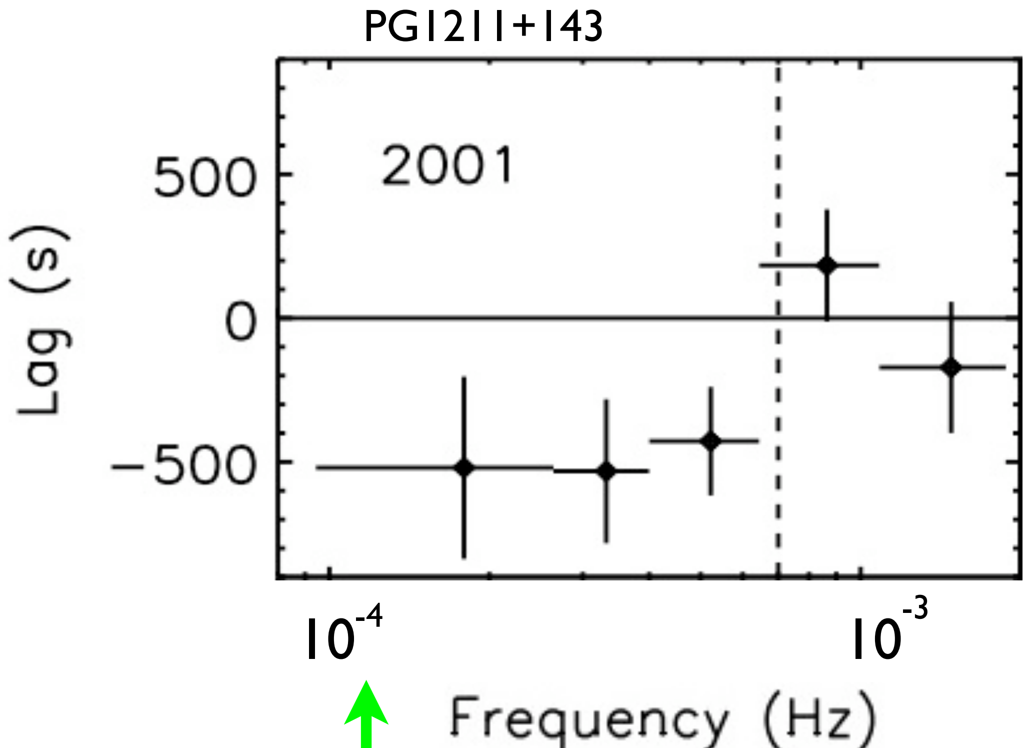
Zhou & Wang 2005 + estimates from PSD break

$\nu_{neg} \lesssim 1.3e\text{-}4$ Hz

COMPARISON WITH 1H0707-495

Lag magnitude τ





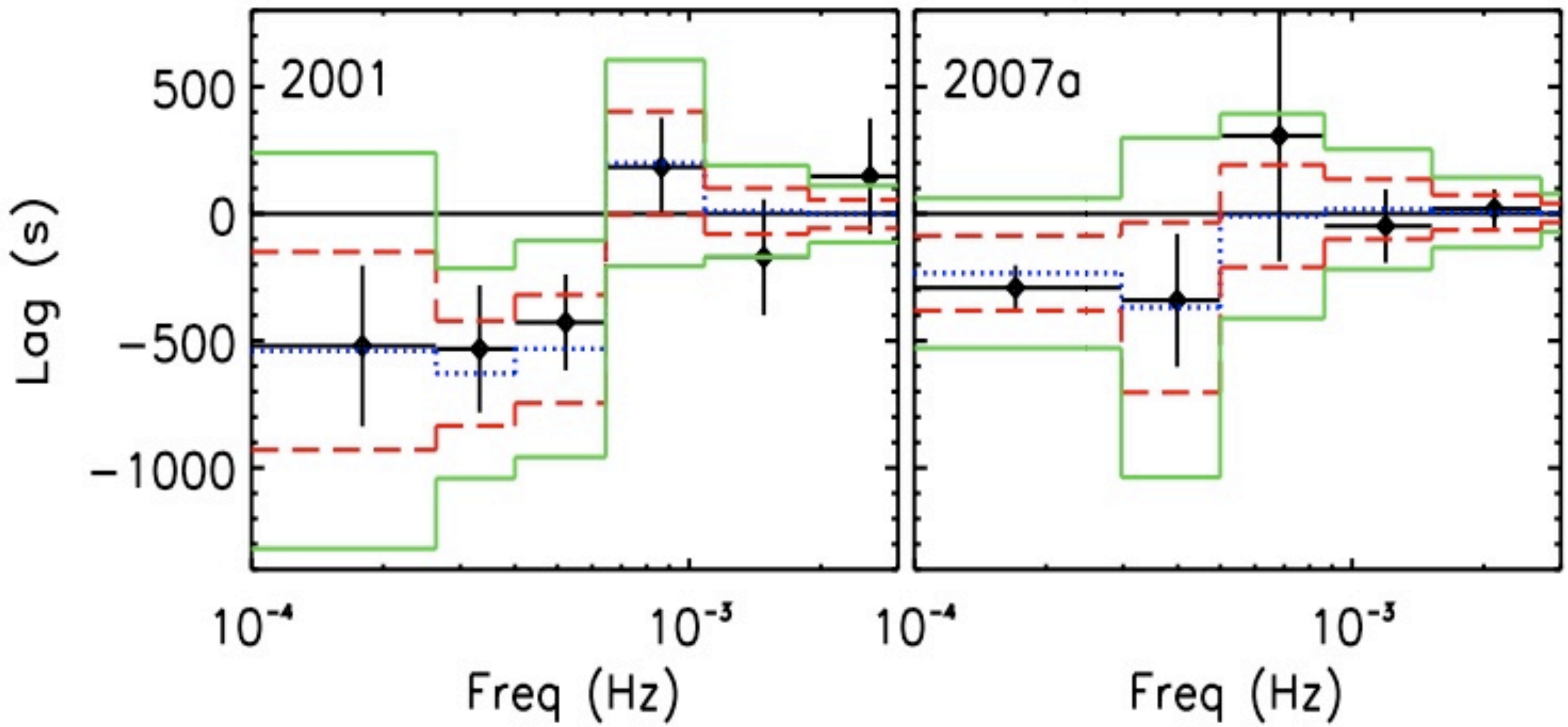
$\nu_2 \sim \nu_1 \, M_1/M_2$

McHardy et al. 2006

$\tau \sim 30$ sec → $\tau \gtrsim 300$ sec

COMPARISON WITH SIMULATIONS

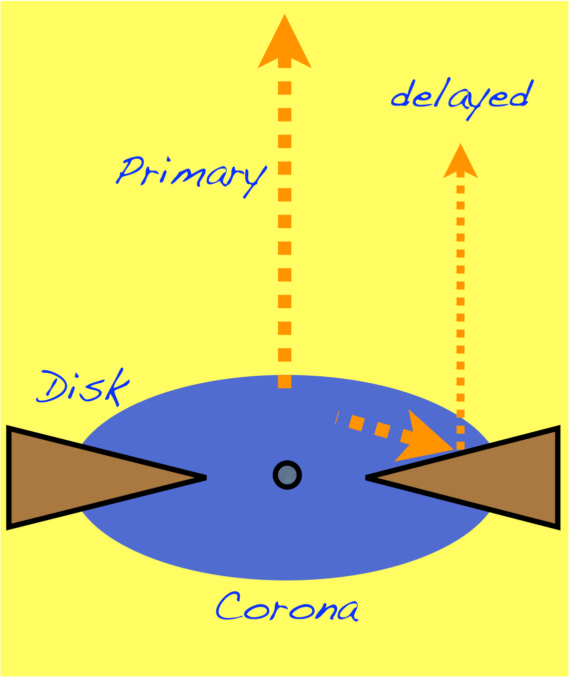
Lag consistent with being constant over the entire sampled frequency range



$\tau \sim$ 650-740 sec

(from simulations and after correction from time dilation)

REVERBERATION SCENARIO

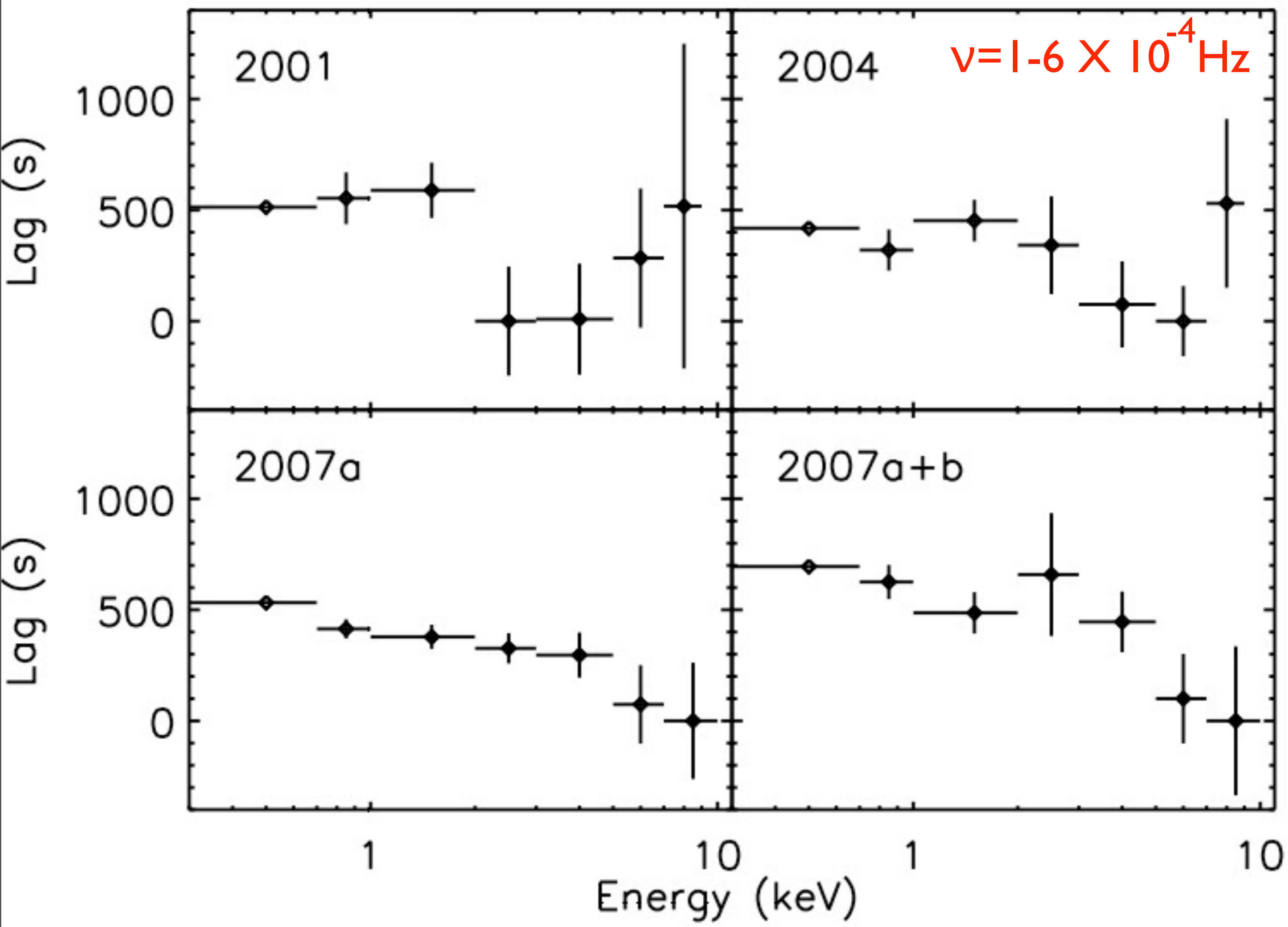


From our lag estimate (i.e. $\tau \sim$ 650-740 sec)

d<2.2x10^13 cm <=> few-to-tens r_g

LOW FREQUENCY LAG ENERGY SPECTRA

Shifted so that the minimum lag corresponds to zero



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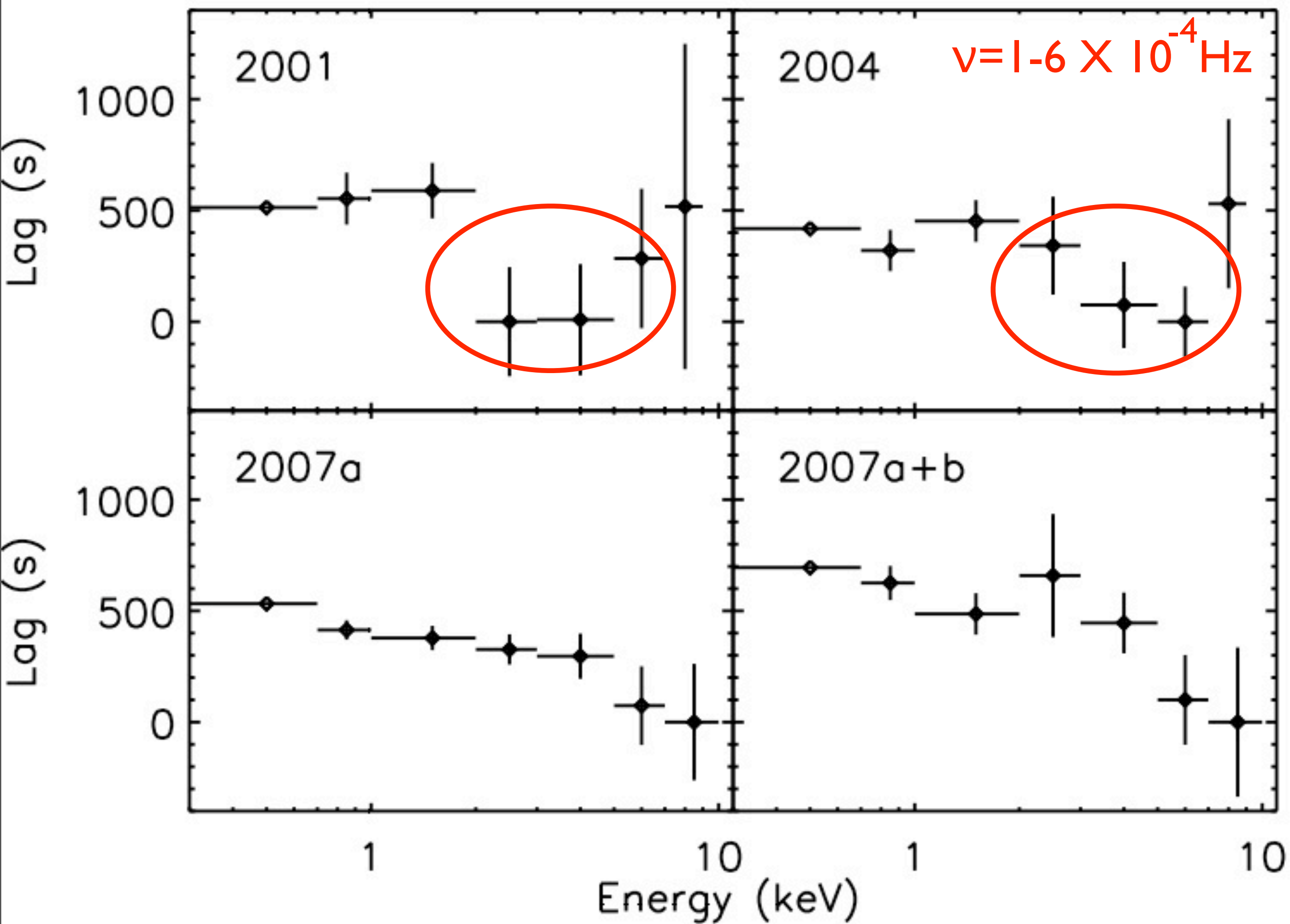
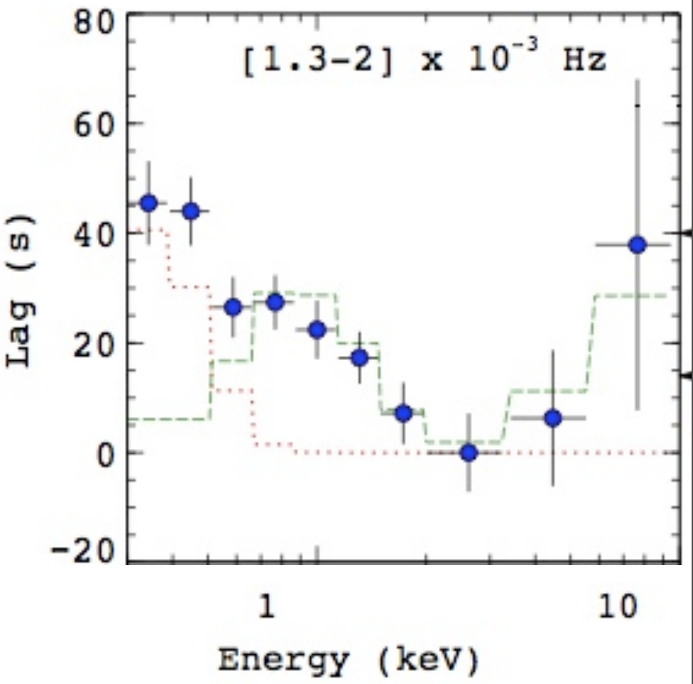


1H 0707-495



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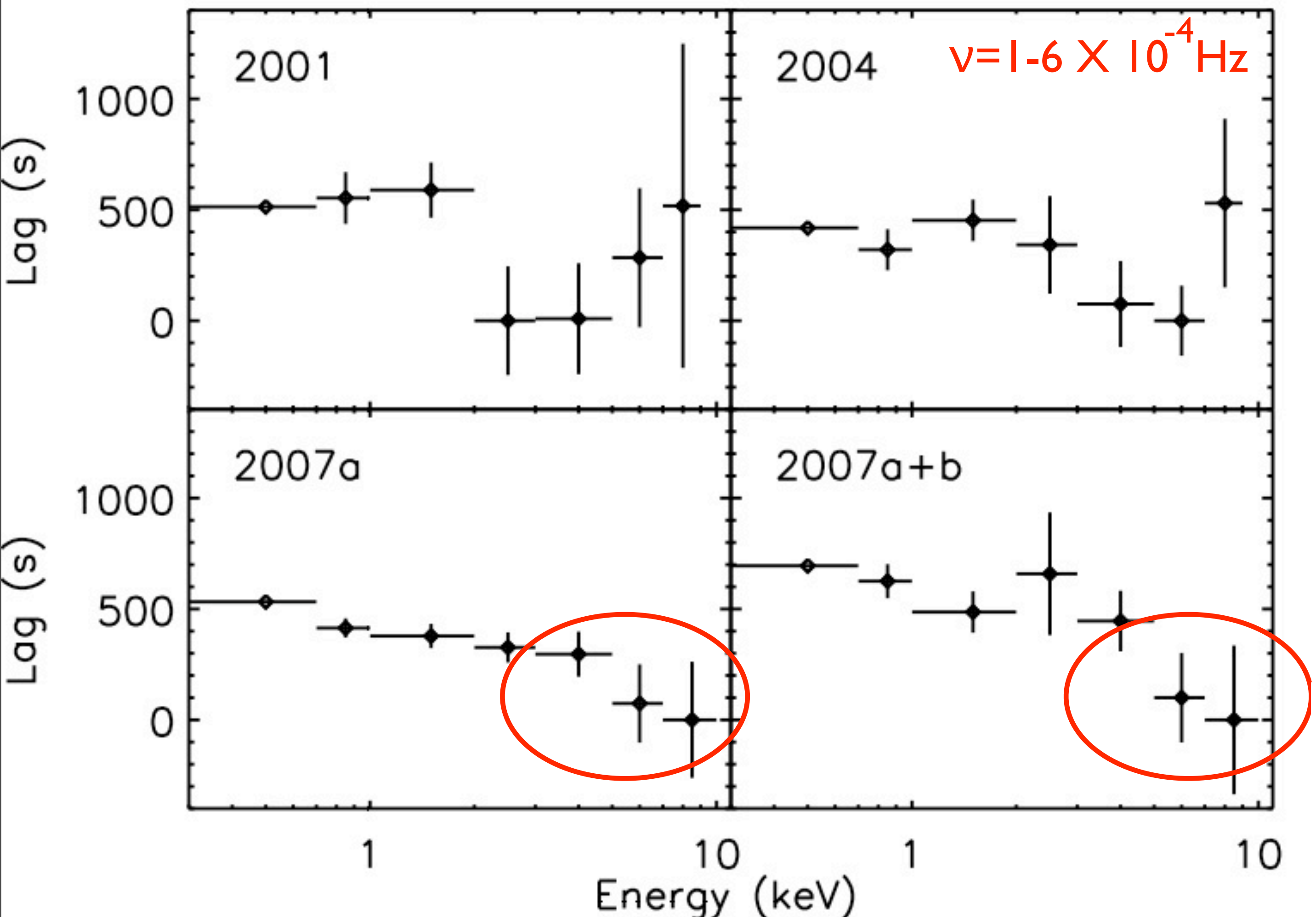
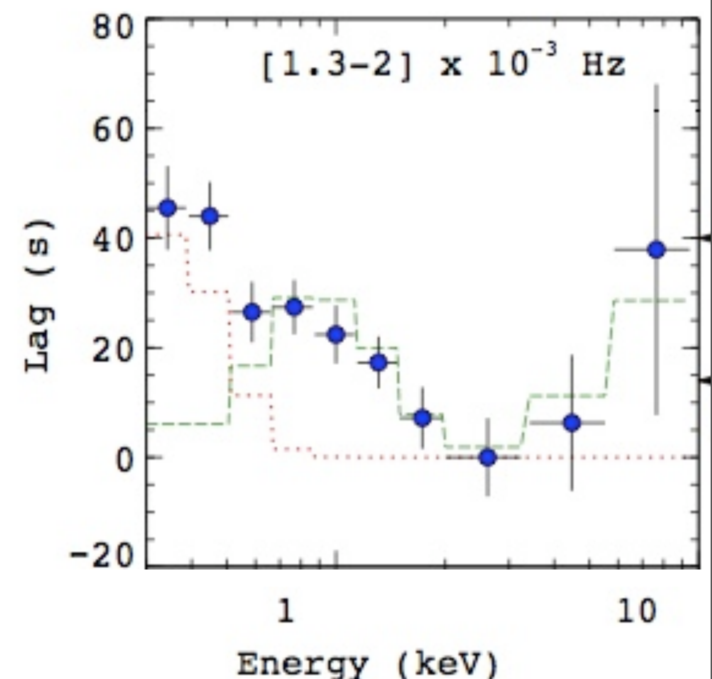
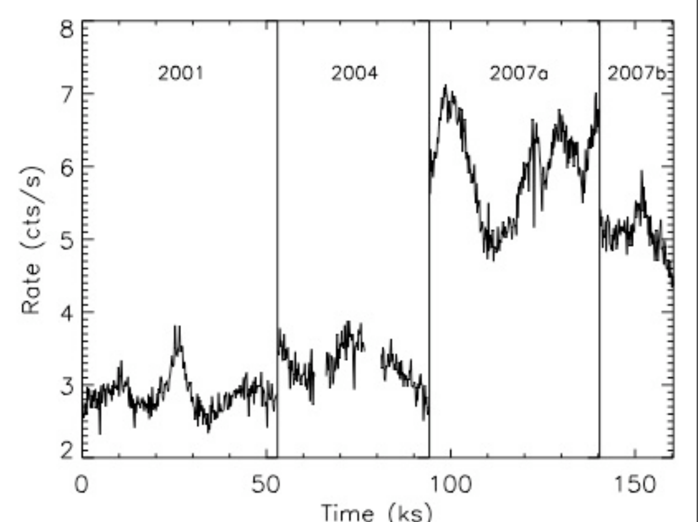


1H 0707-495

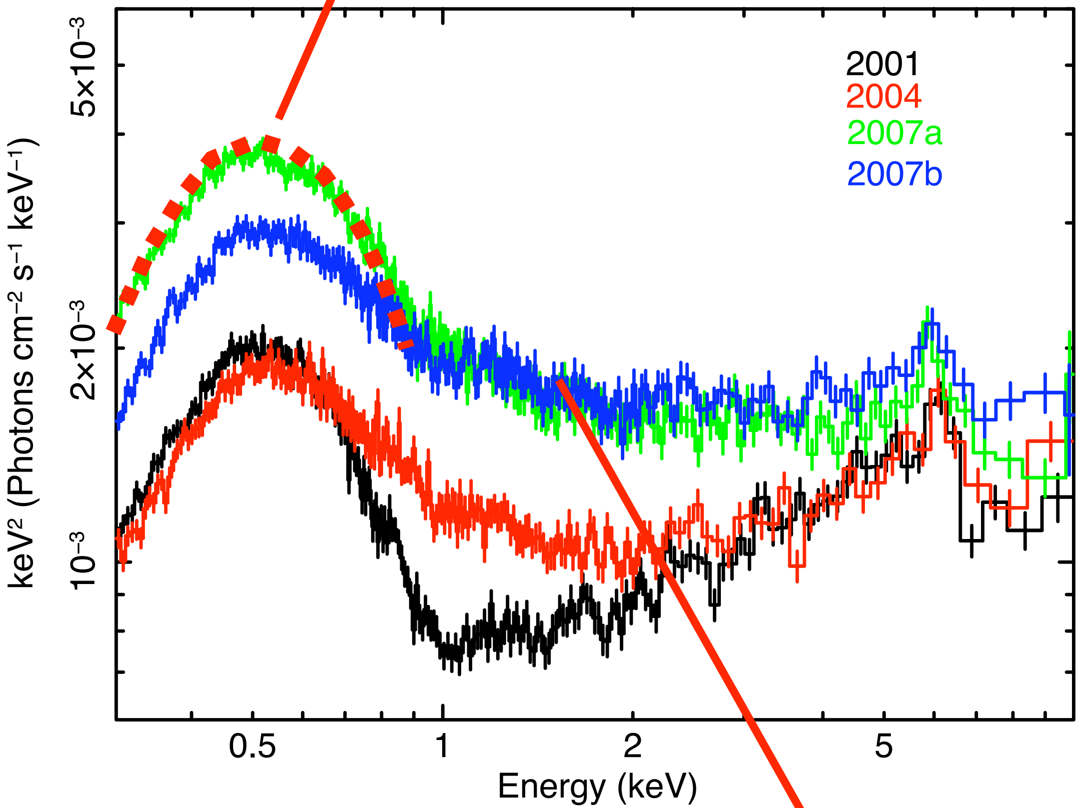




Apparently different trend during higher flux observations

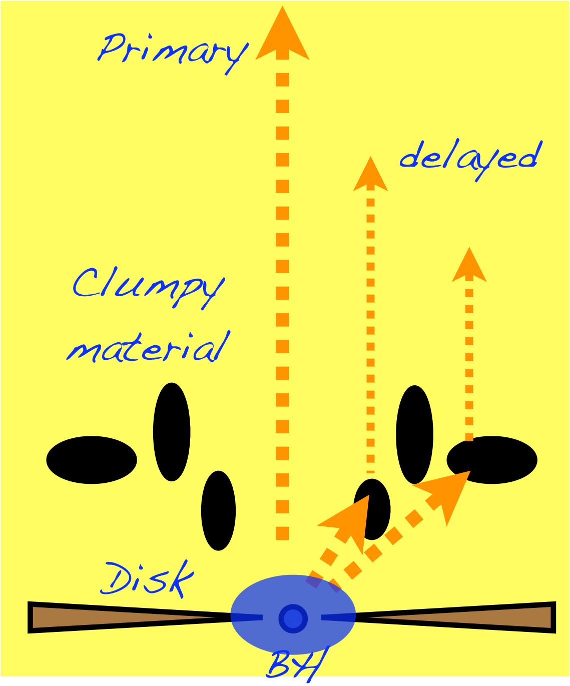
POSSIBLE EXPLANATIONS FOR THE 2007 LAG ENERGY SPECTRA

Secondary Comptonization gas layer?



Disk-corona feedback process that gradually softens the spectrum? (e.g. Malzac & Jourdain 2000)

ALTERNATIVES TO DISK REVERBERATION



From PG 1211+143 absorbing gas estimated distance $r \gtrsim 300\ r_g$ (Blustin et al. 2005 => v_{esc}=24000 km/s, Pounds et al. 2003) and the measured lag:

$\theta \lesssim 10$ deg <=> highly collimated structure

CONCLUSIONS

* The observed soft lags in PG 1211+143 resemble the negative lag observed in 1H 0707-495:

  * lags in the two sources (frequency/magnitude) well match after scaling for the mass

  * the lag energy spectra of PG 1211+143 in 2 out of 3 observations are consistent with the high frequency energy lag spectrum of 1H 0707-495

  * same considerations valid for MCG-6-30-15 and Mrk 766 (Papadakis talk)

* The reverberation scenario is favoured, although the 2007 observation lag energy spectrum probably requires contribution from another component

* The fact that 1) the lag is apparently constant in magnitude/frequency over 6 yrs and 2) the need for a highly collimated structure disfavours the distant reflector (e.g. winds, clouds.. etc) scenario

THE END