On the black hole mass and soft X-ray lag relation in radio quiet AGN

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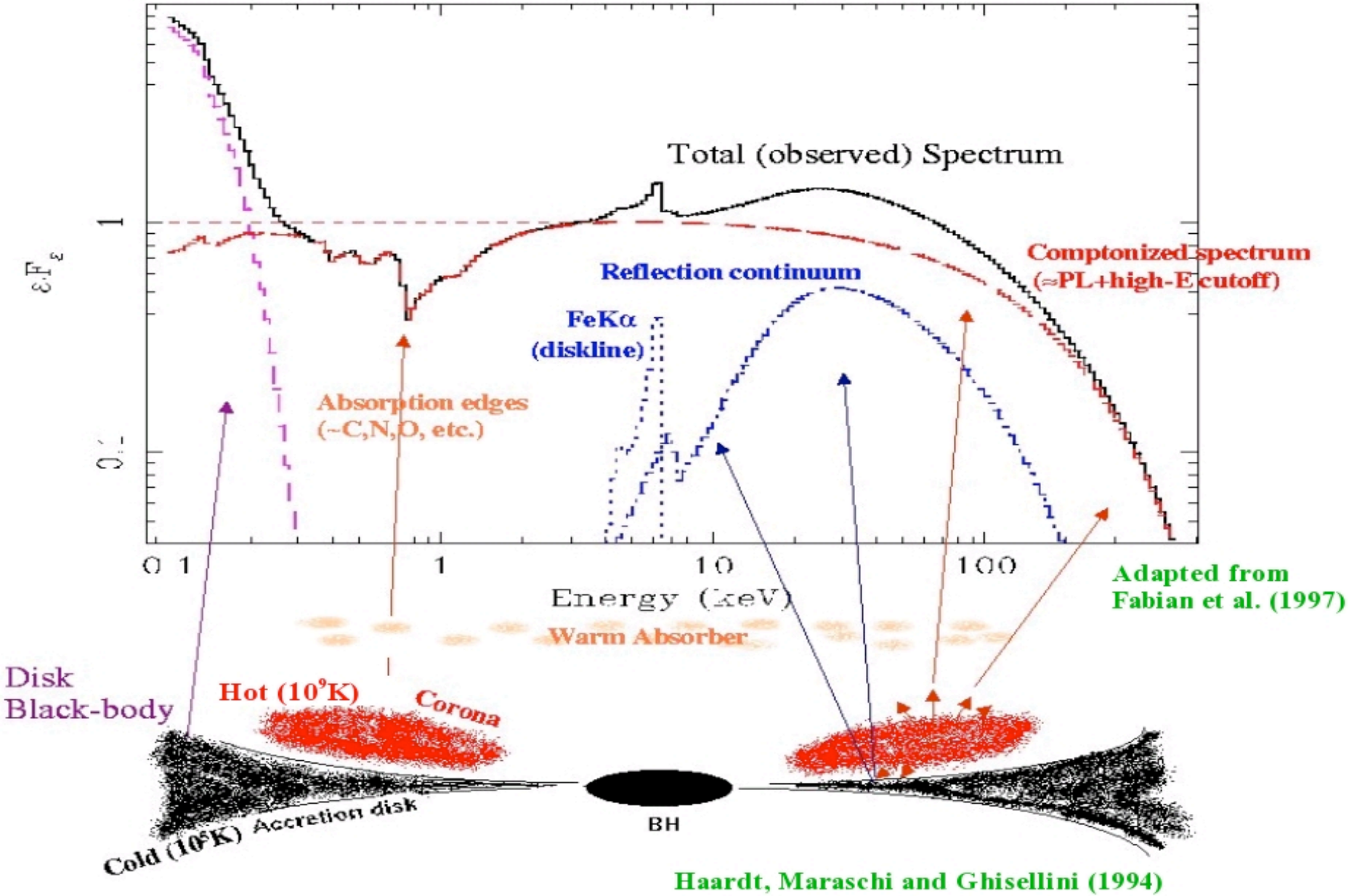
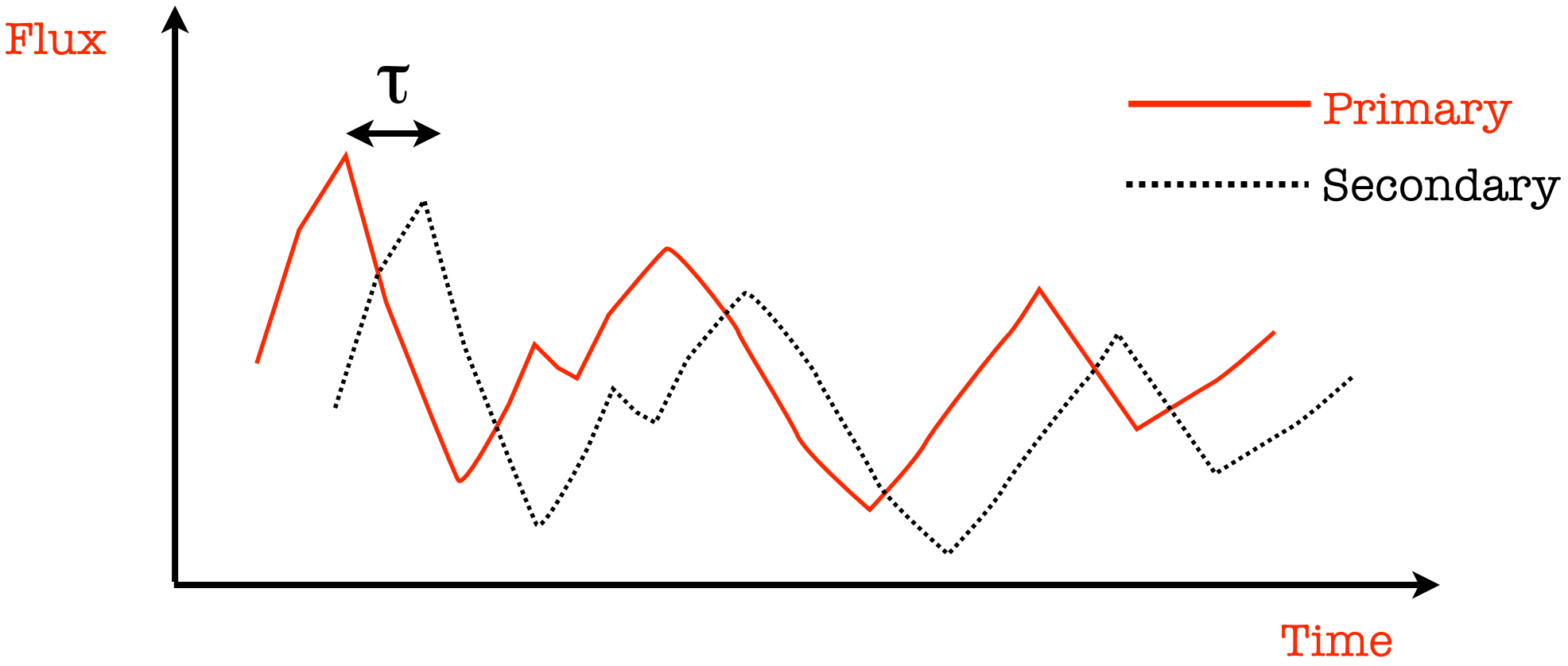
A.C. Fabian, E.M. Cackett (Institute of Astronomy, Cambridge, UK)

Letter submitted in MNRAS - arXiv: 1201.0196

Typical X-ray Spectrum of a Seyfert 1 Galaxy
⇔ Standard two-phase Comptonization model



TIME LAGS



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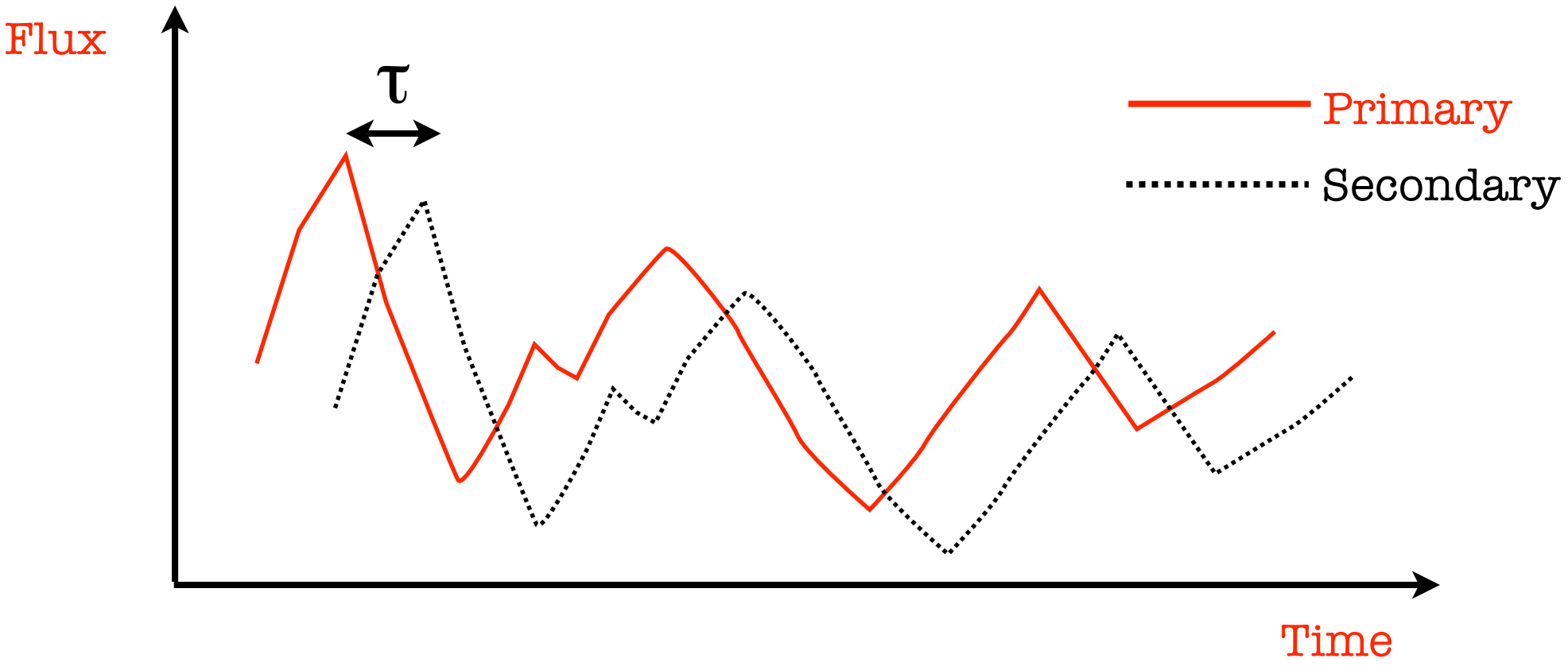
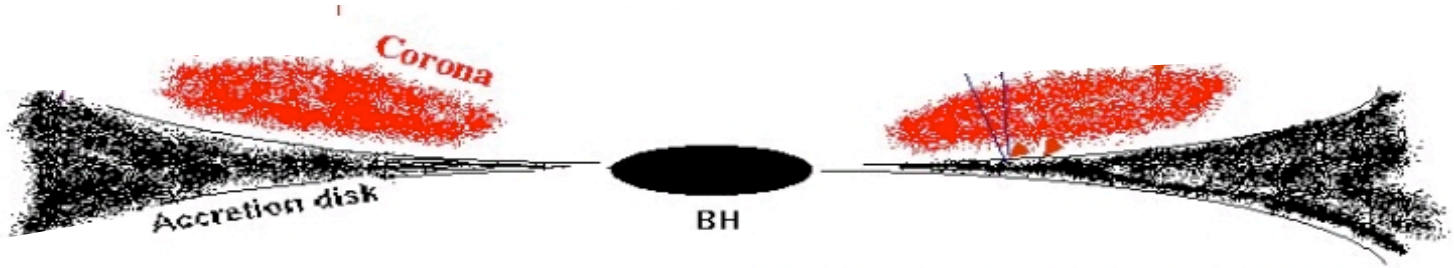
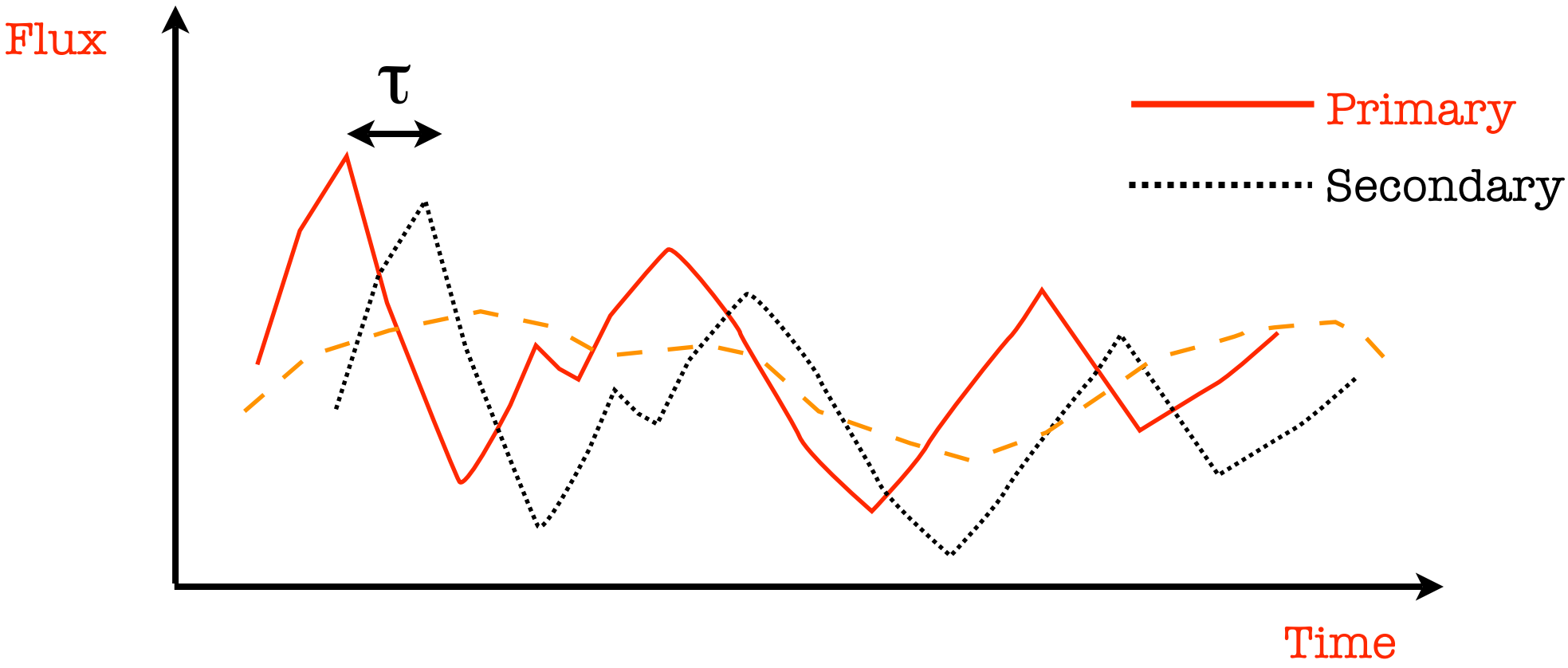
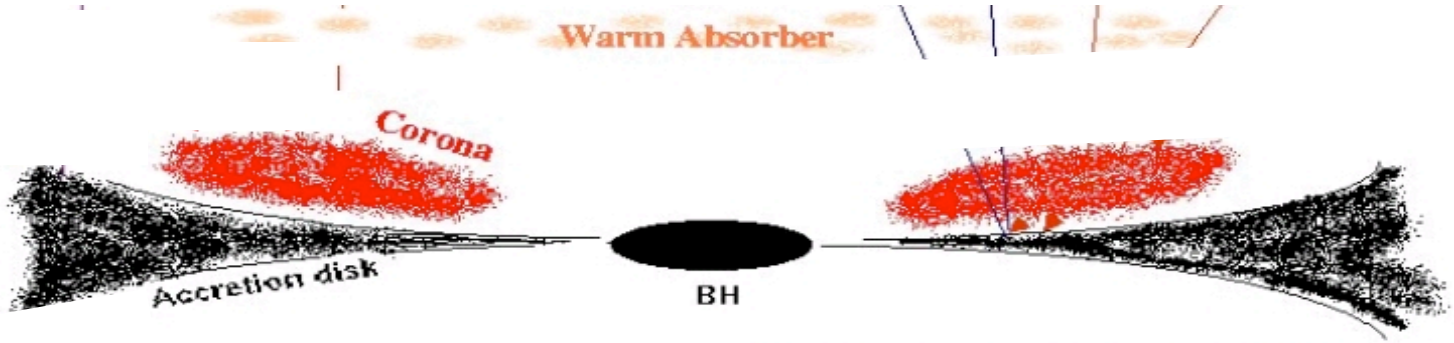




Haardt, Maraschi and Ghisellini (1994)

TIME LAGS





Haardt, Maraschi and Ghisellini (1994)

Timing analysis

$x(t_j) \Rightarrow a(f_k) \exp(-2\pi i j k / N)$

Time domain

Energy-resolved light curves

Frequency domain

Power spectrum

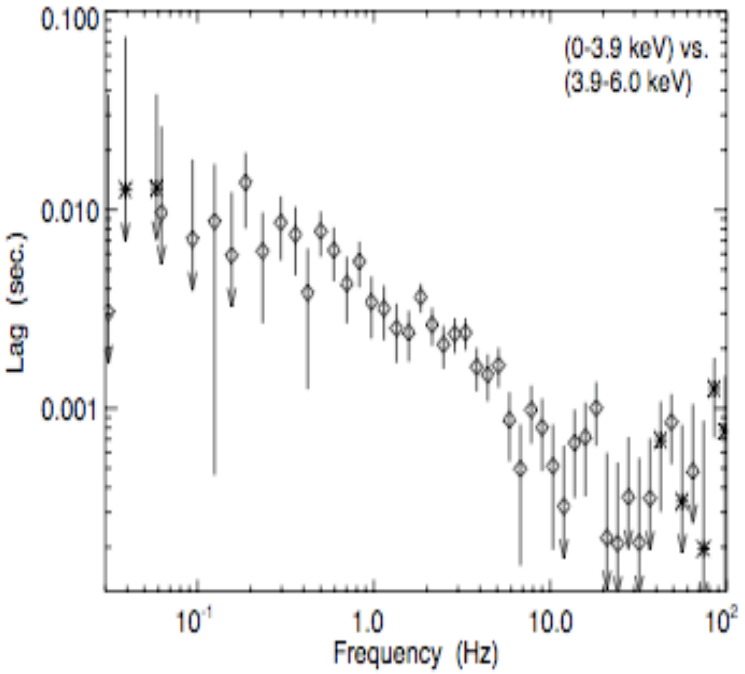
coherence

time lags

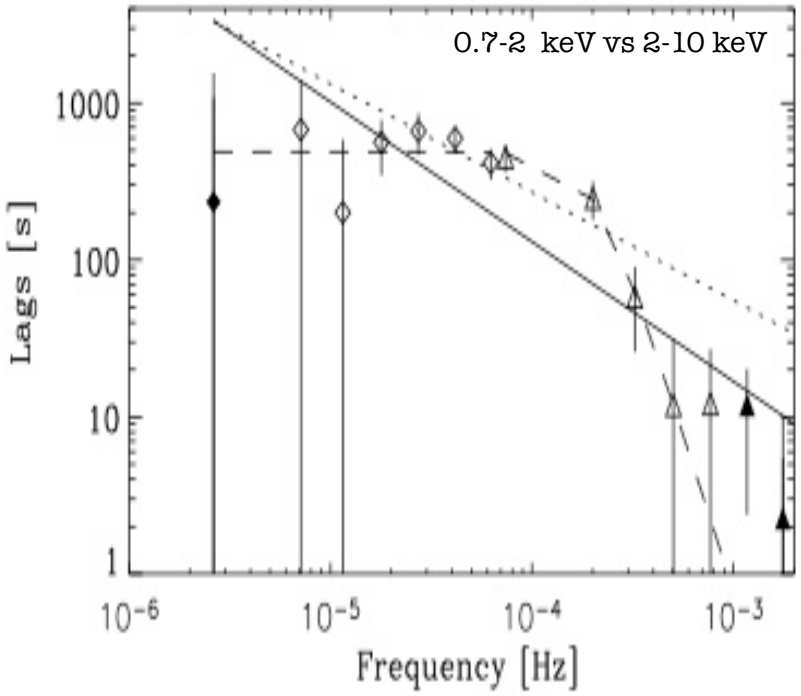
HARD X-RAY LAGS IN AGN & XRB

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

Galactic BH vs AGN



Cyg X-1- Nowak et al. 1999

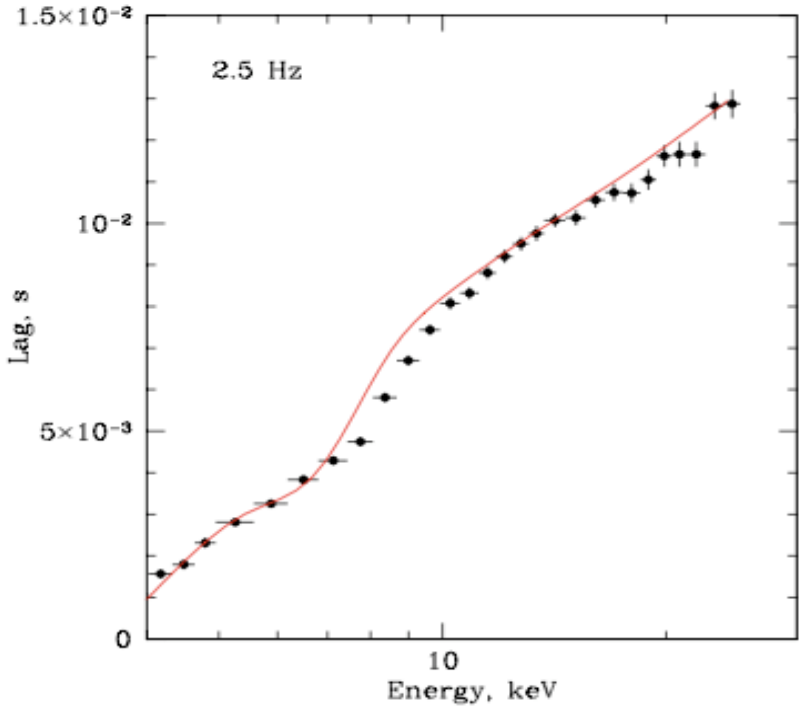


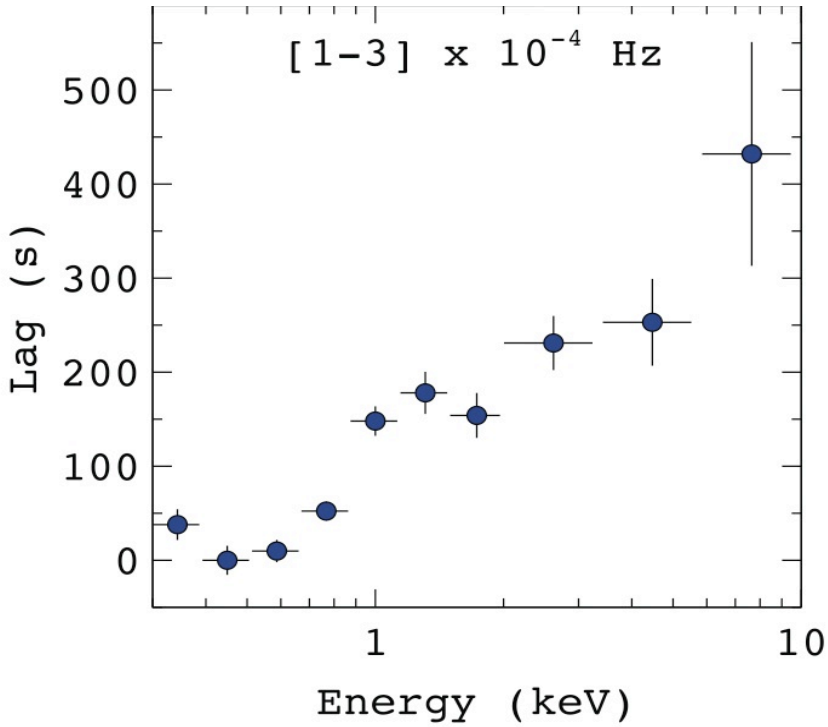
Ark 564 - Arévalo et al. 2006

HARD X-RAY LAGS IN AGN & XRB

...and energy dependence

Galactic BH vs AGN



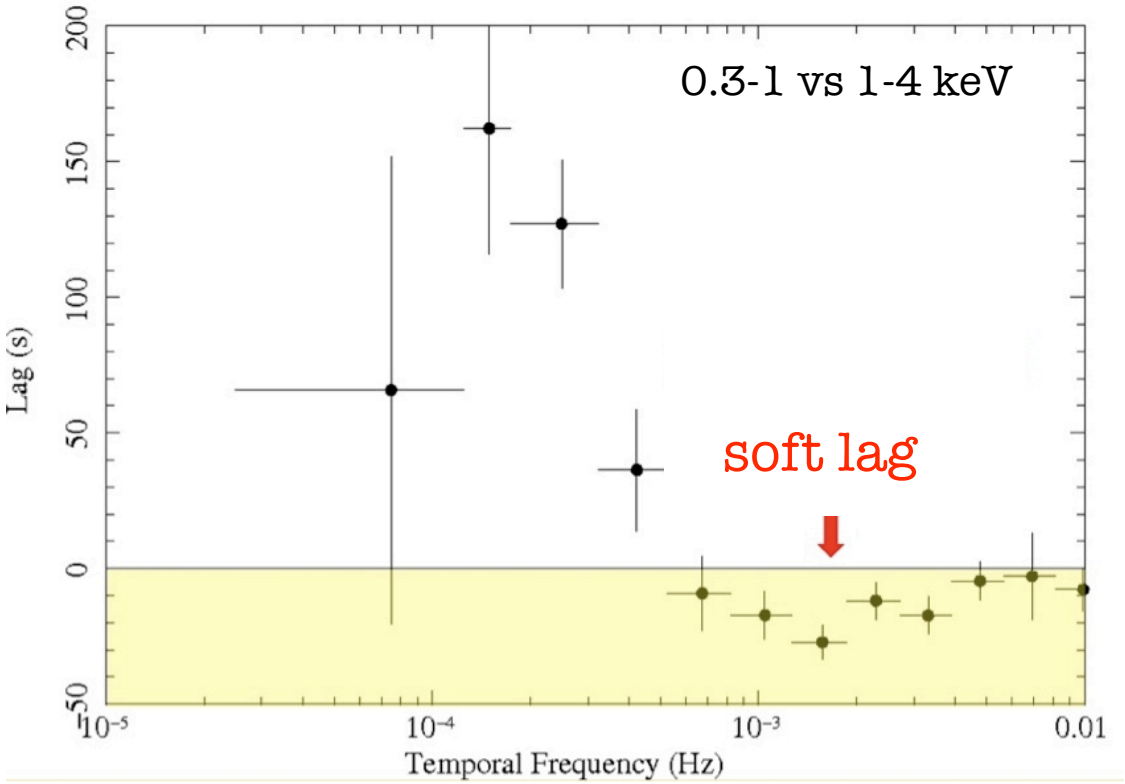


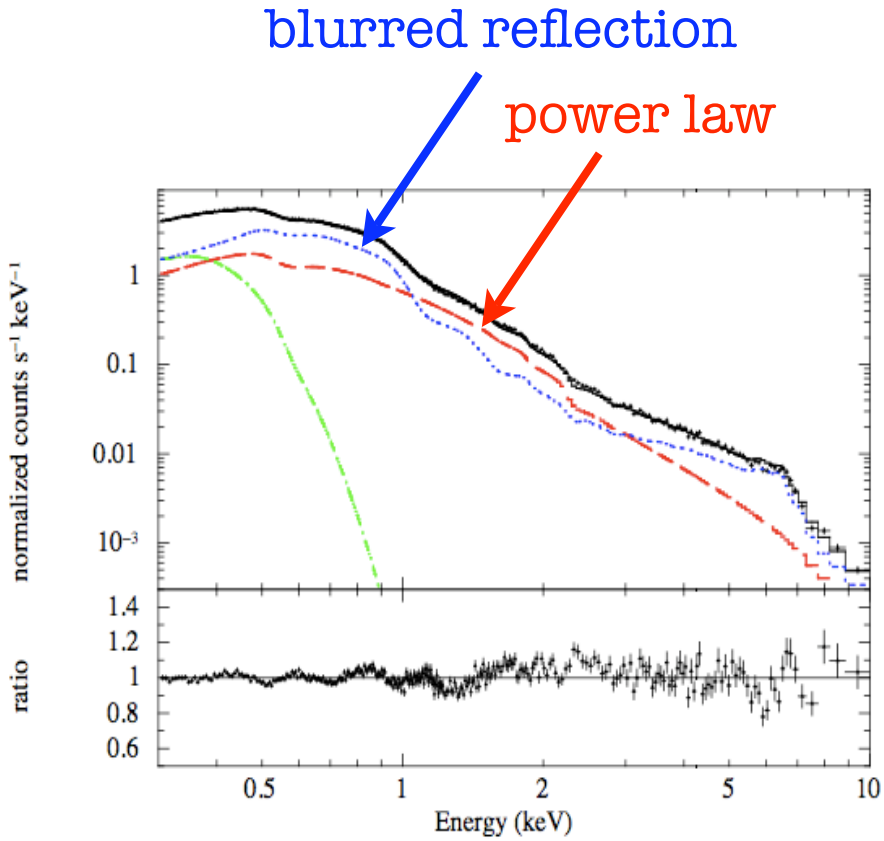
Cyg X-1-Kotov et al. 2001

1H0707-495 - Zoghbi et al. 2011

SOFT LAGS

1H 0707-495

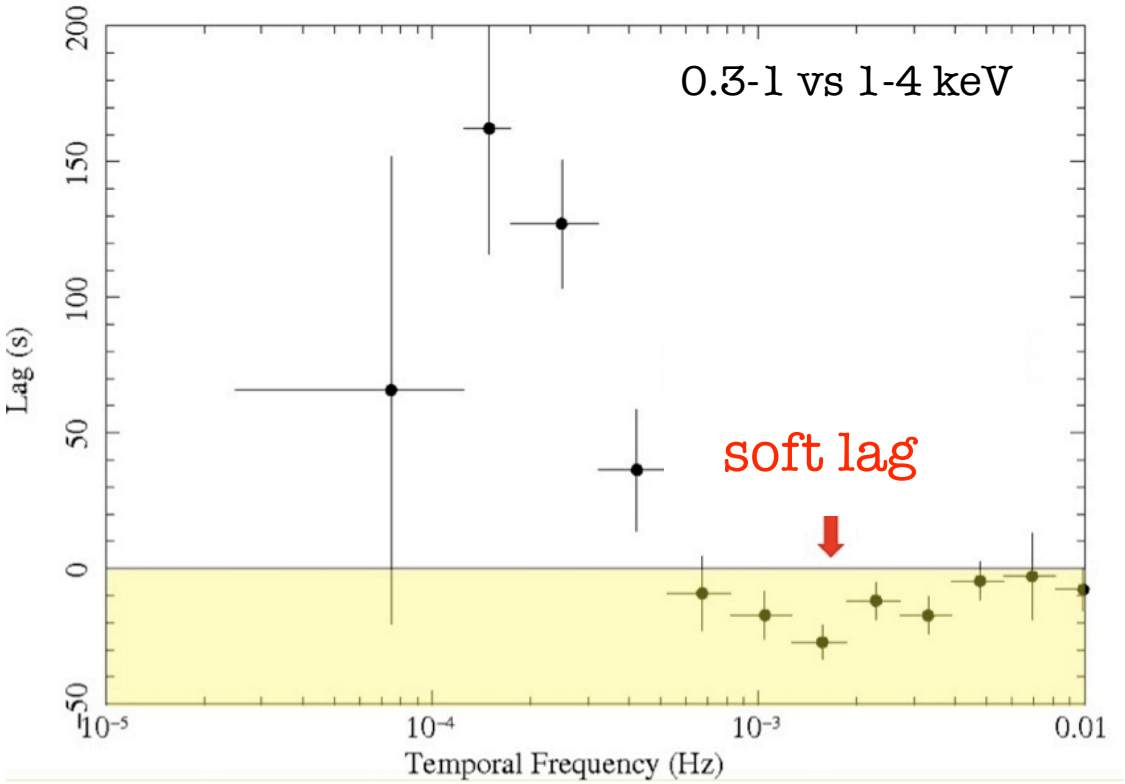


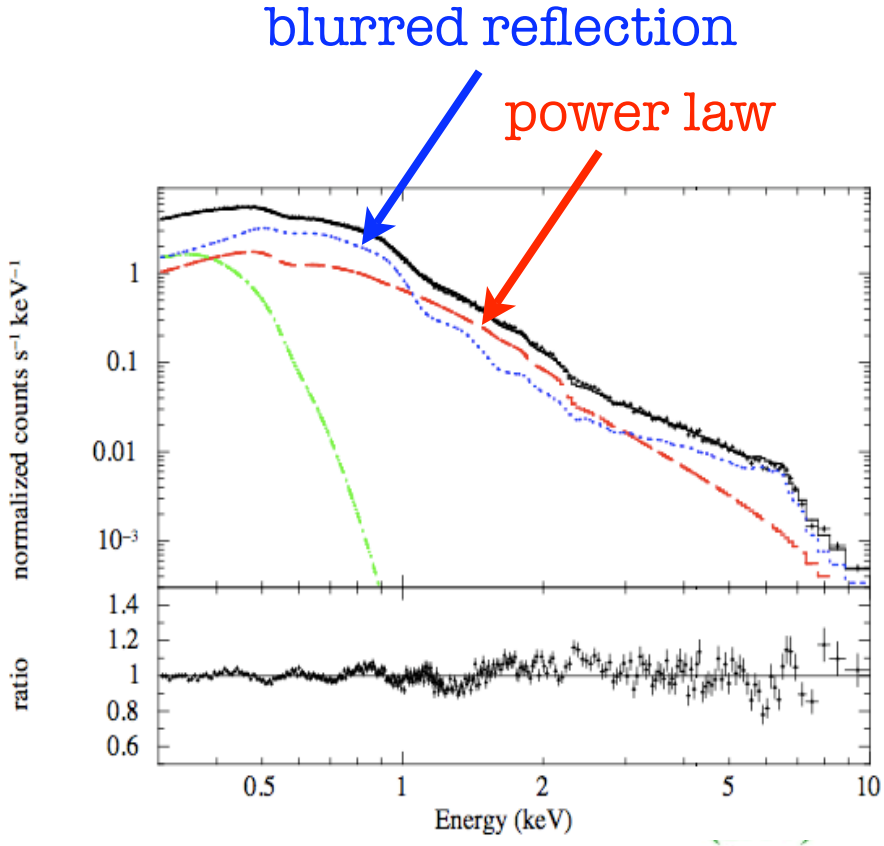


Fabian +09, Zoghbi +10, +11

SOFT LAGS

1H 0707-495





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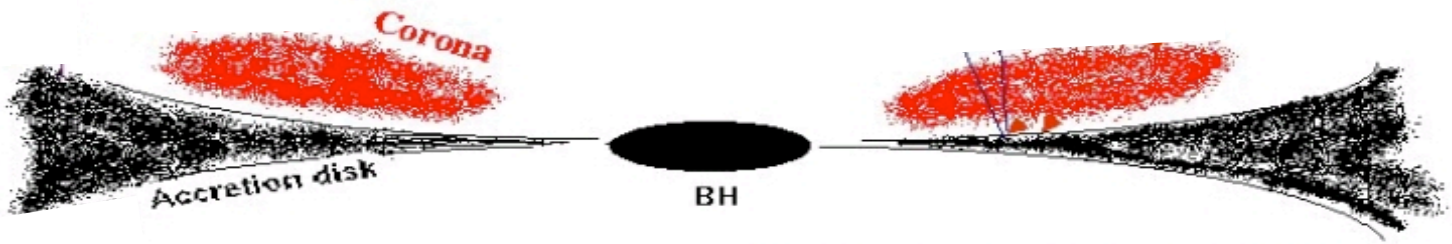
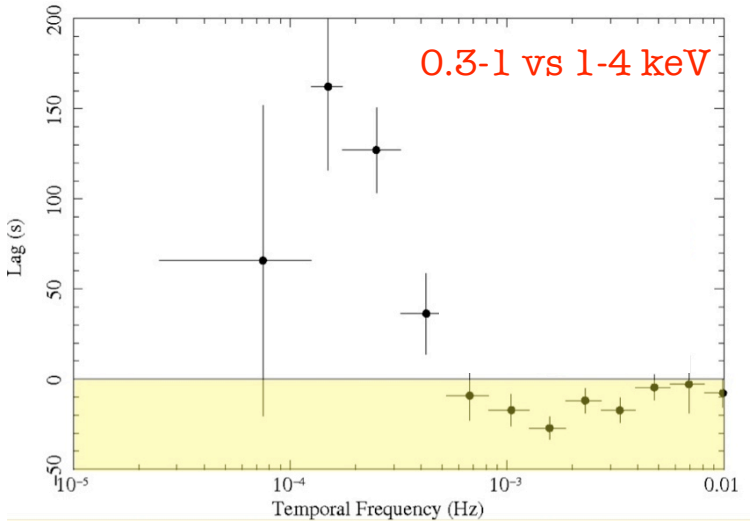


Haardt, Maraschi and Ghisellini (1994)

Several detections:

1H 0707-495



Fabian +09, Zoghbi +10, +11

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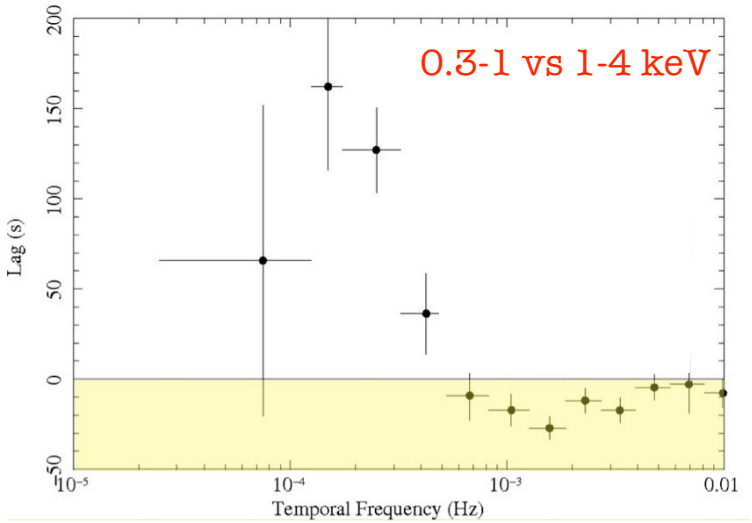

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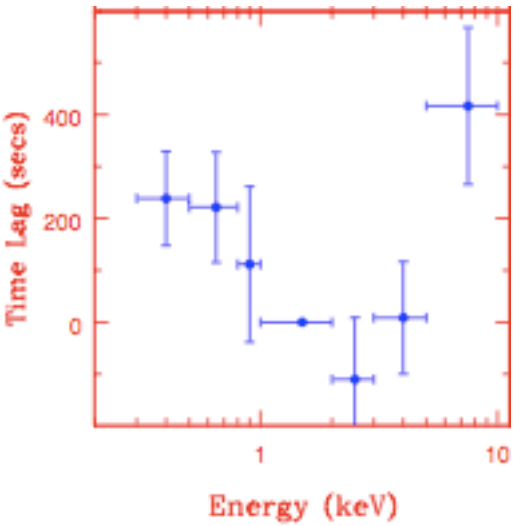
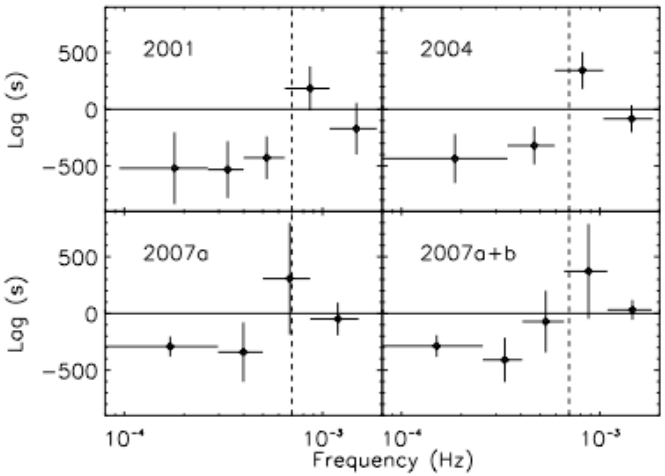
Mrk 1040



Tripathi +11

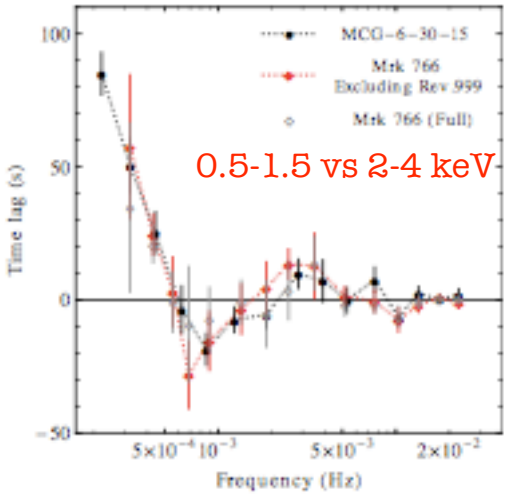
PG1211+143

0.3-0.7 vs 2-10 keV



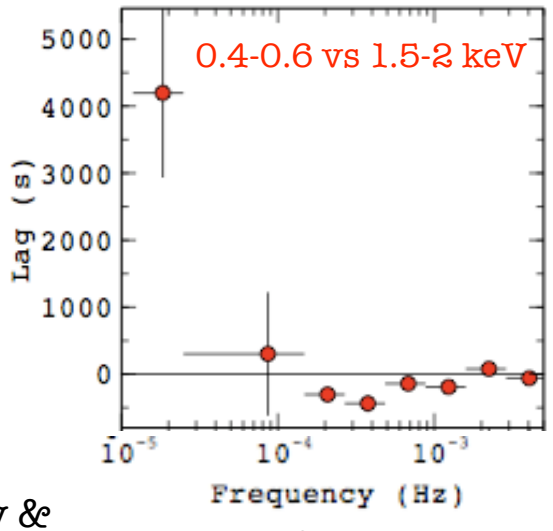
De Marco +11

Mrk 766
MCG-6-30-15



Emmanoulopoulos, McHardy & Papadakis 2011

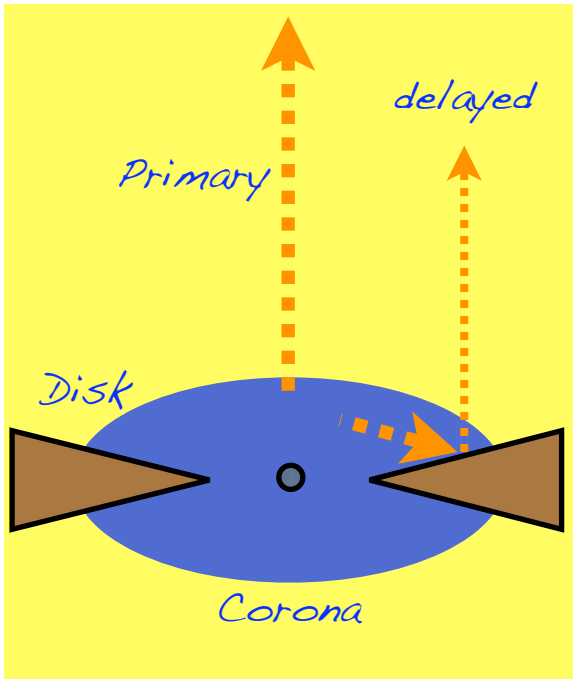
REJ1034+396



Zoghbi & Fabian 2011

INTERPRETATIONS

Inner disk reverberation



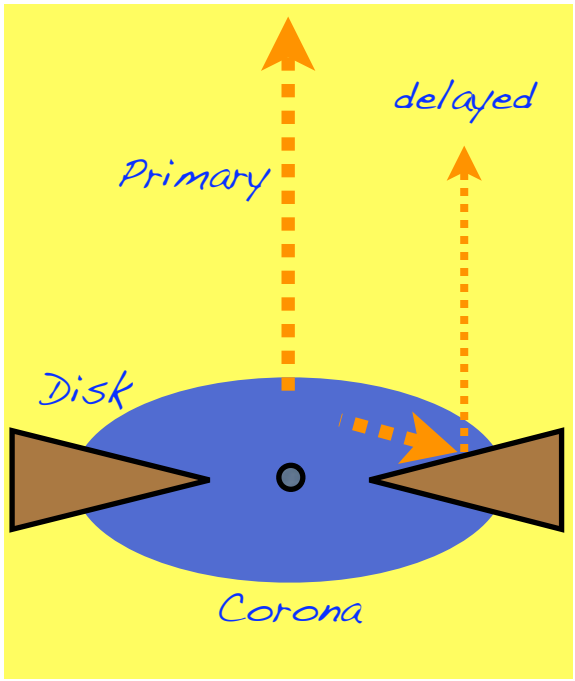
involved length scales

~r_g

Zoghbi +11

INTERPRETATIONS

Inner disk reverberation

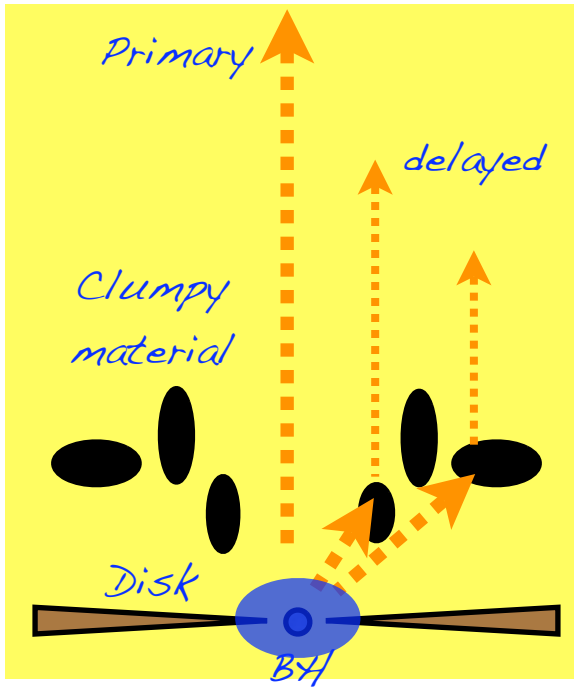


involved length scales

~rg

Zoghbi +11

Distant reflector



involved length scales

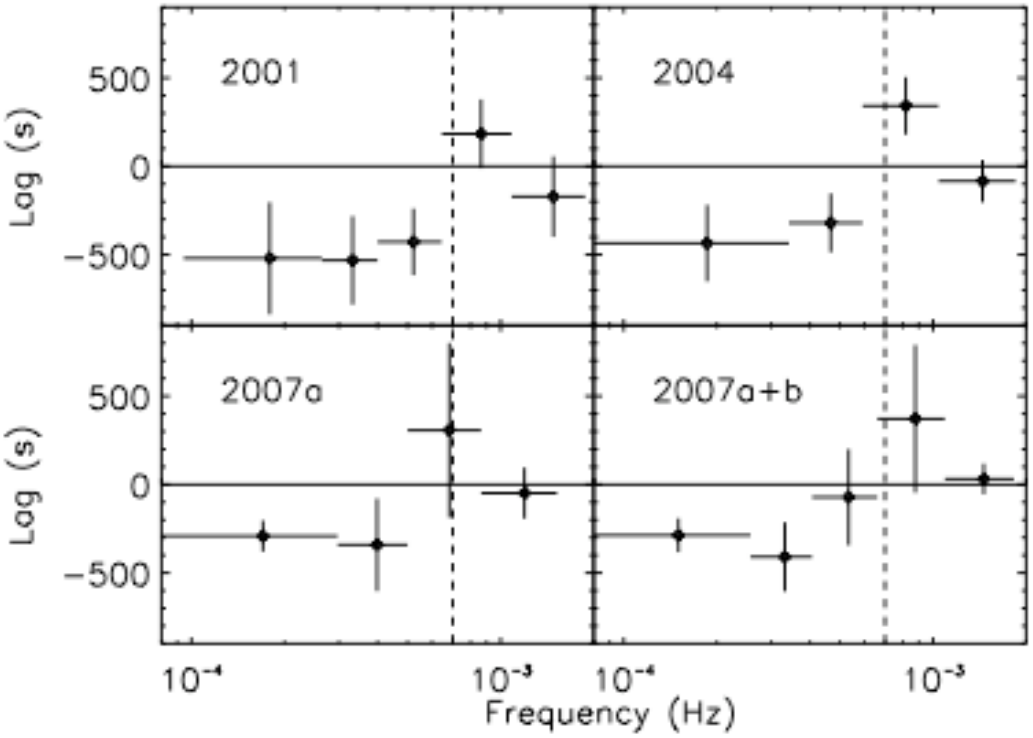
~1000 rg

Miller +11

Low mass (1H0707-495) vs high mass (PG1211+143) sources:

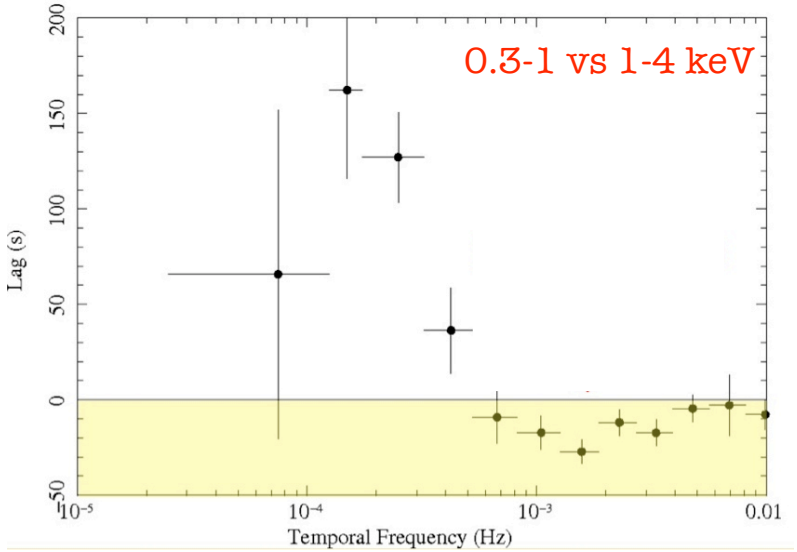
PG1211+143

0.3-0.7 vs 2-10 keV



De Marco +11

1H 0707-495



Fabian +09, Zoghbi +10, +11

Low mass (1H0707-495) vs high mass (PG1211+143)

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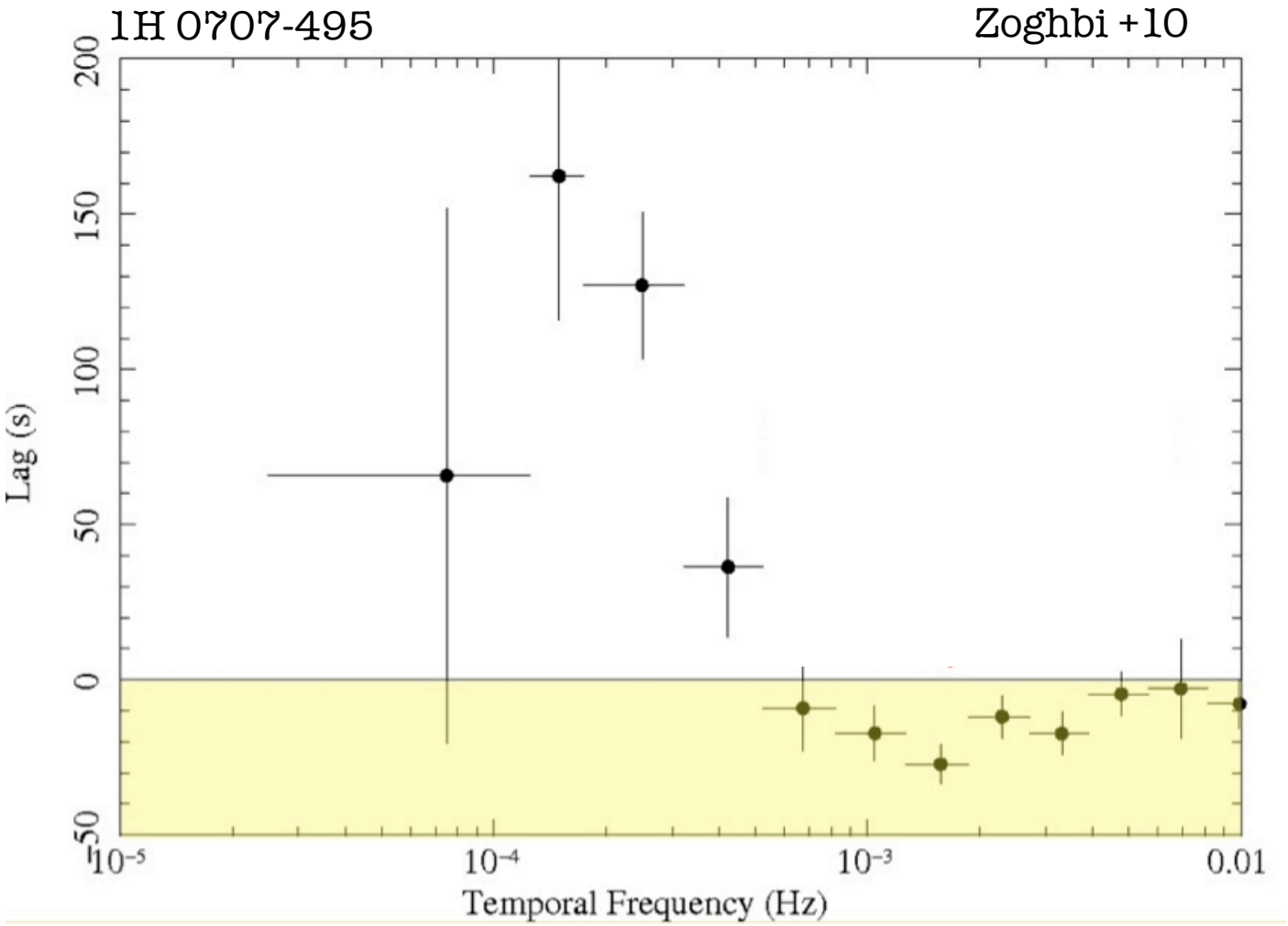

$M_{BH} \sim 2 \times 10^6 M_{sol}$

Zhou & Wang 2005 (1H0707)

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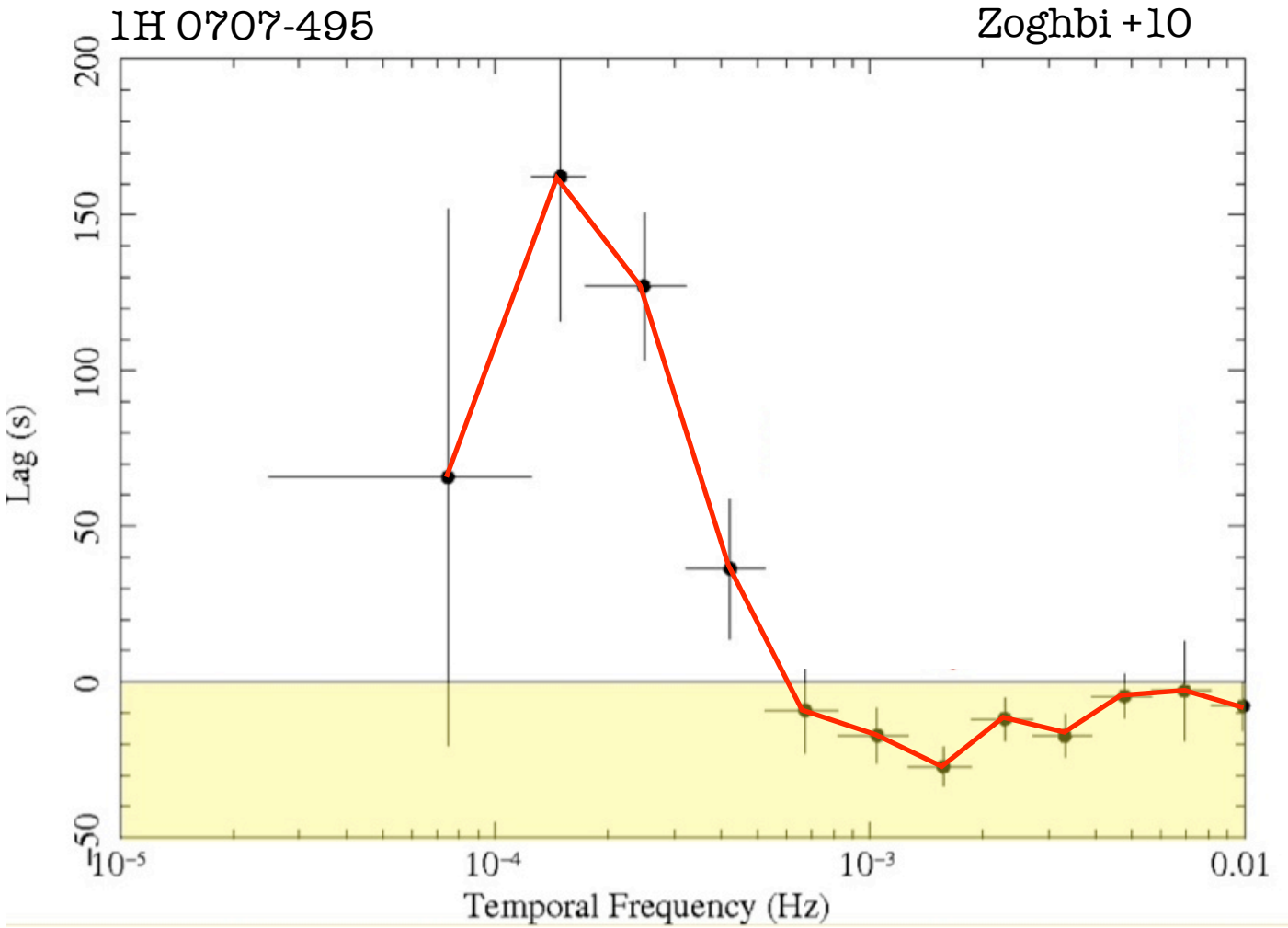

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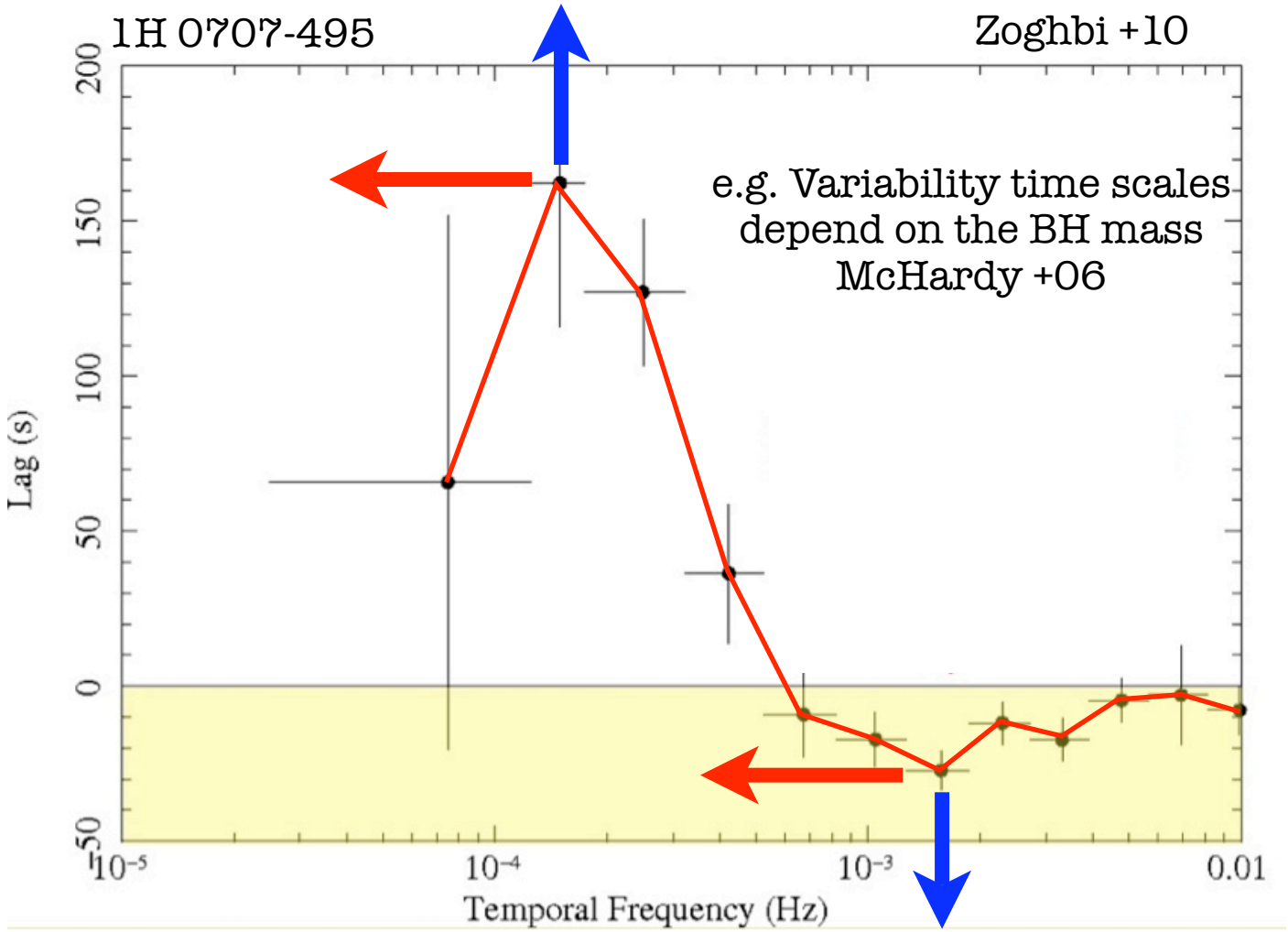
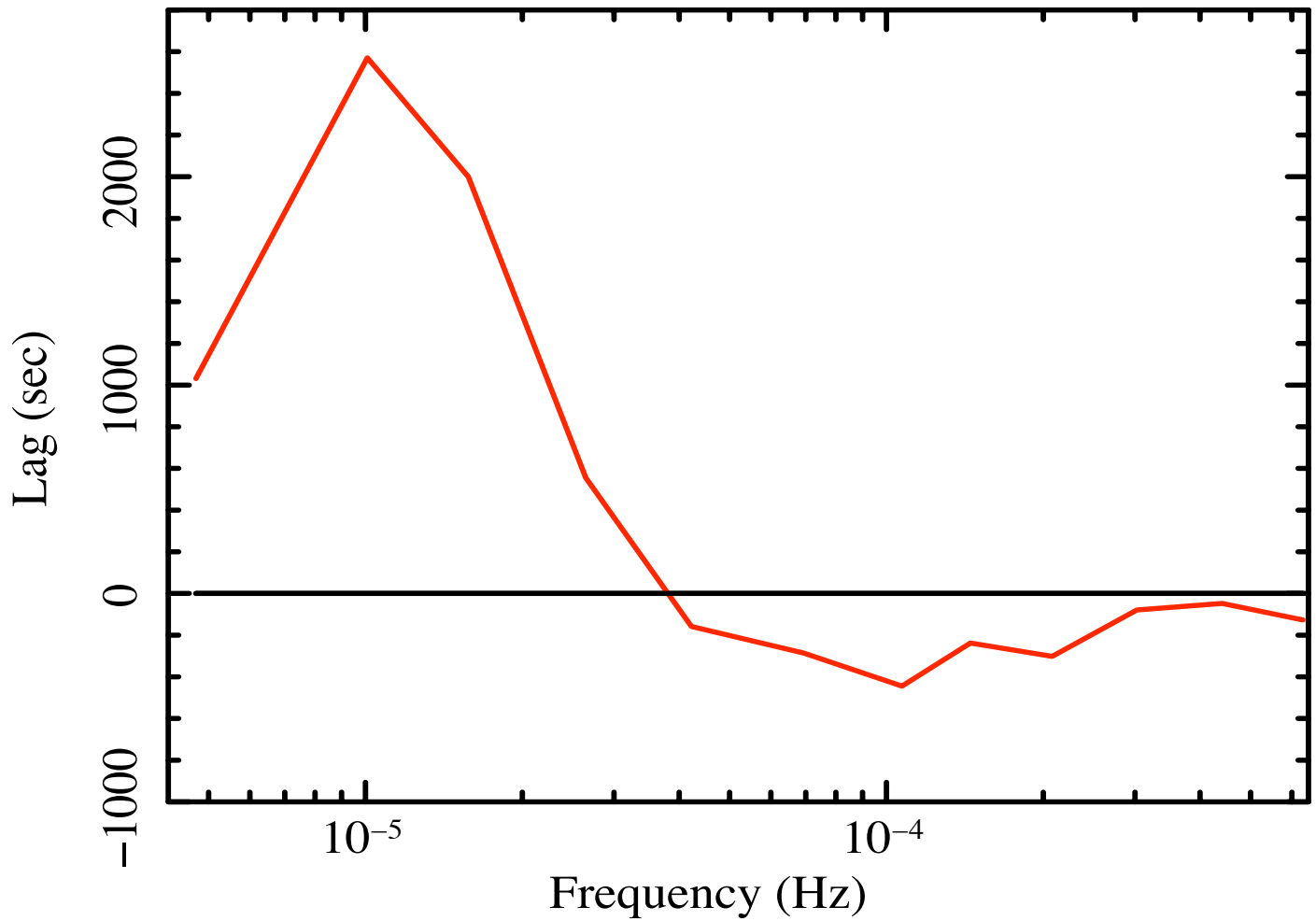


$M_{BH} \sim 2 \times 10^6 M_{sol}$
Zhou & Wang 2005 (1H0707)

$M_{BH} \sim 2.4 (\pm 0.7) \times 10^7 M_{sol}$
Kaspi et al. 2000 (PG1211)

Low mass (1H0707-495) vs high mass (PG1211+143) sources:



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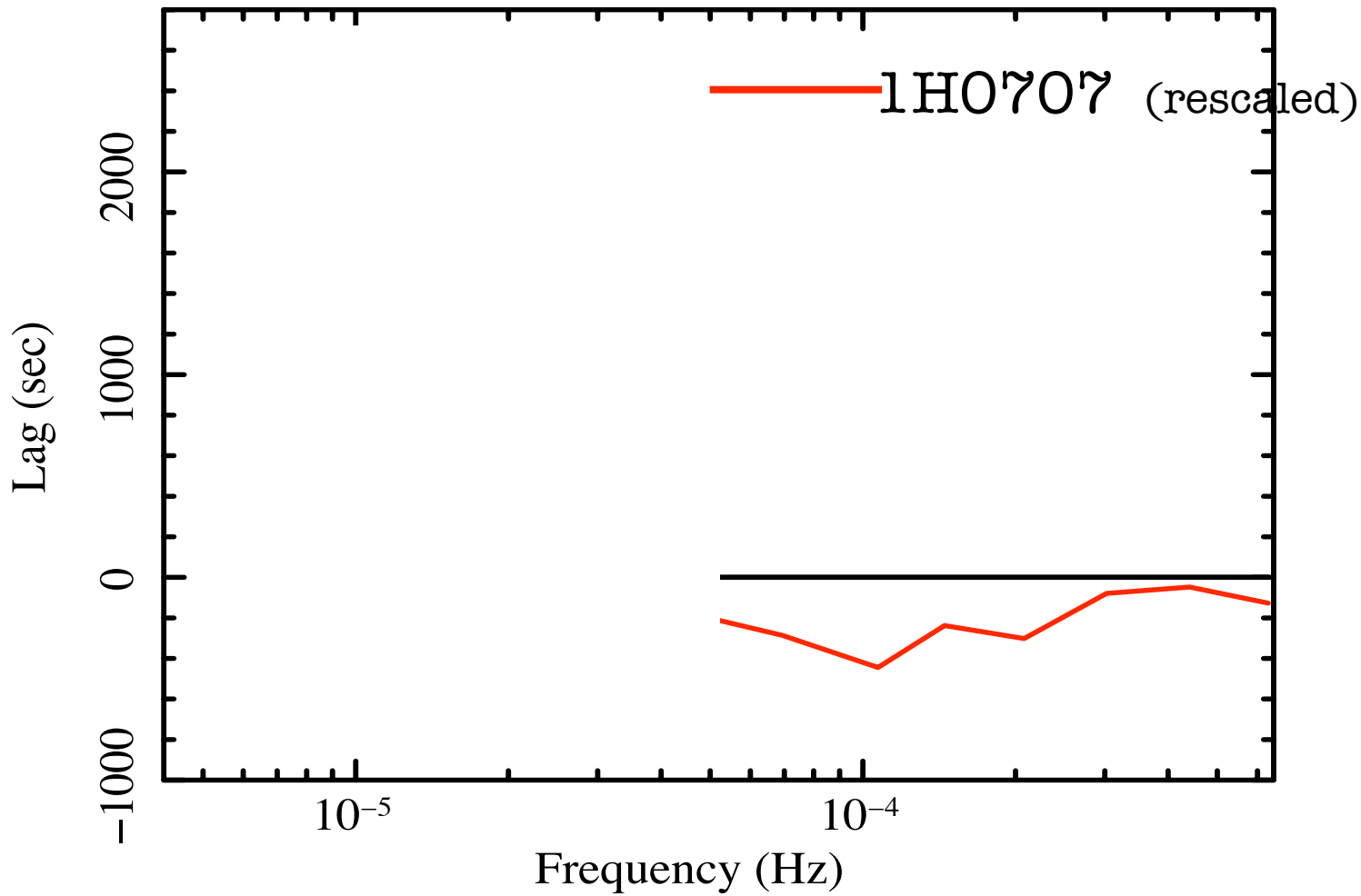
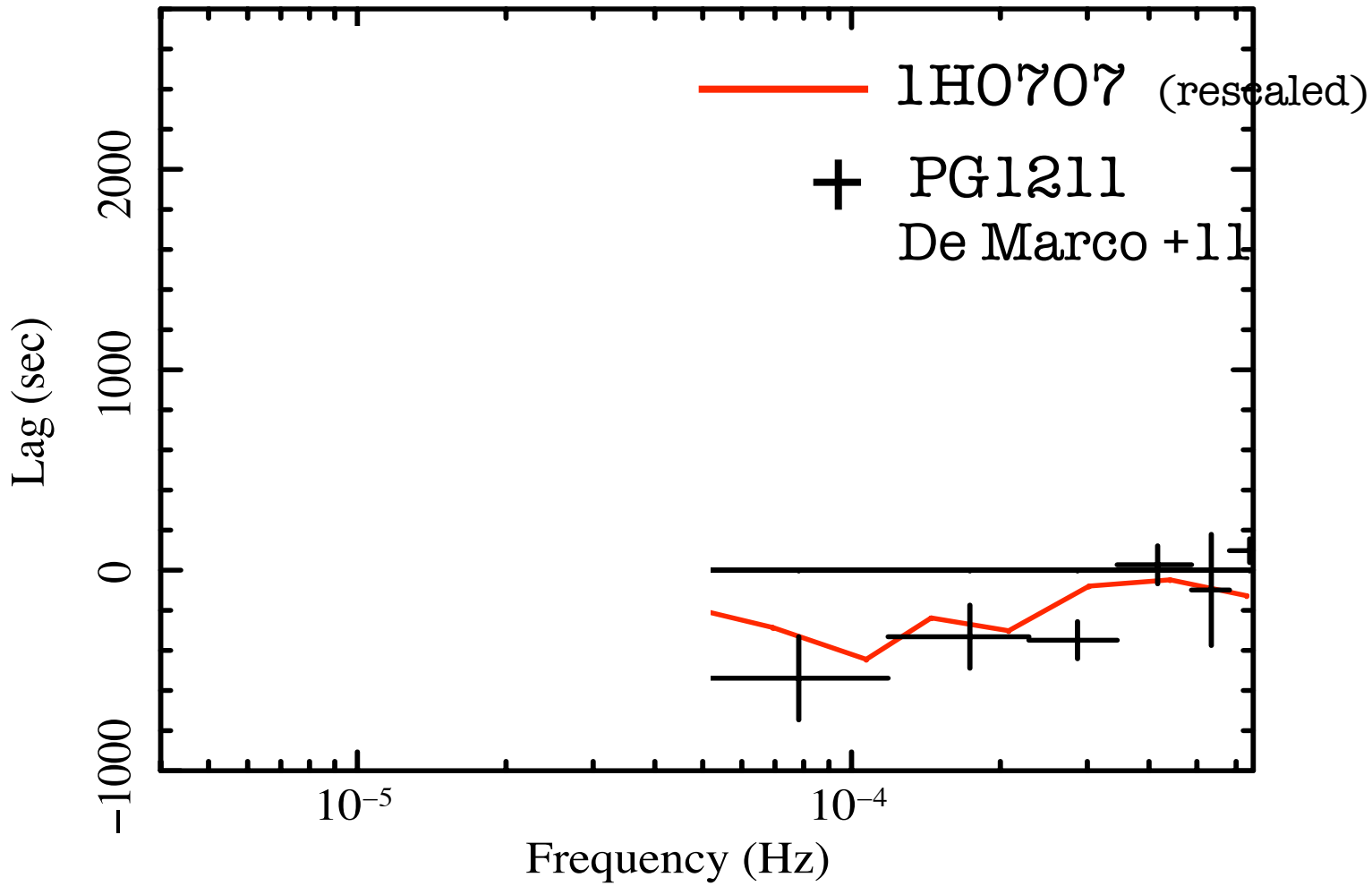


short exposure

Low mass (1H0707-495) vs high mass (PG1211+143) sources:



Our project:

The sample

well-exposed, unobscured (N_H<2e22 cm^-2) radio quiet AGN in CAIXAvar sample (Ponti +11, subsample of CAIXA by Bianchi +09)

+ at least one 40ks XMM observation as of June 2010

+ published BH mass estimate

+ estimated excess variance (0.3-10 keV) ≠0

32 sources

Details about the analysis:

EPIC pn data

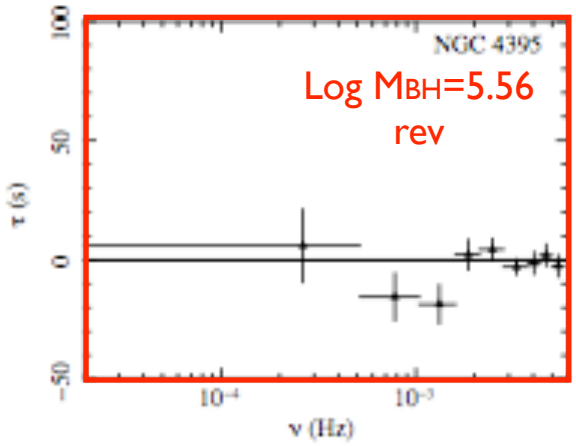
Multiple observation combined

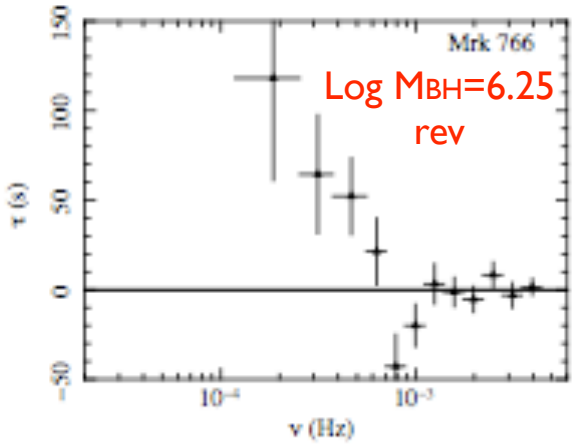
Selected energy bands dominated by the soft excess and primary power law (typically 0.3-1 vs 1-5 keV)

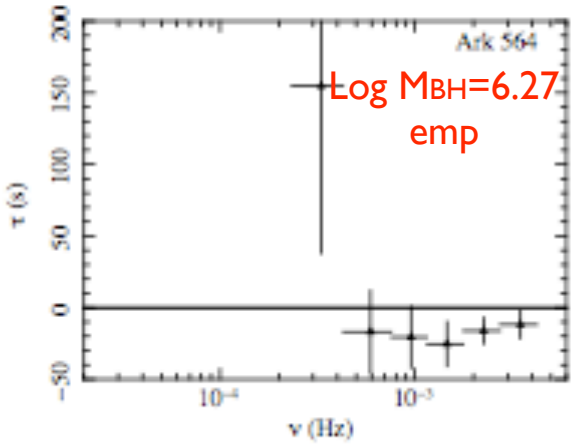
Coherence + lag spectra (in Fourier-frequency domain, Nowak +99)

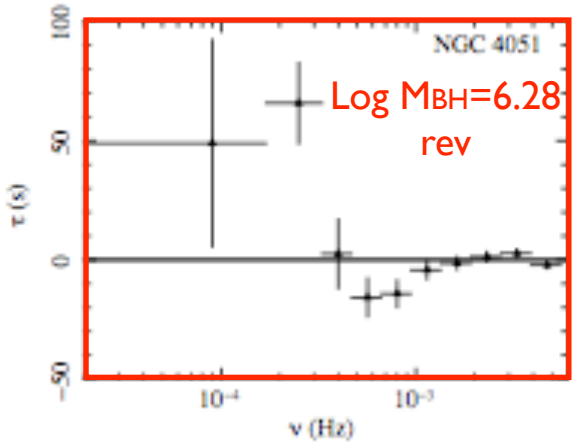
Detection requirements: combined significance $\geq 2\sigma$ + coherence significantly $\neq 0$

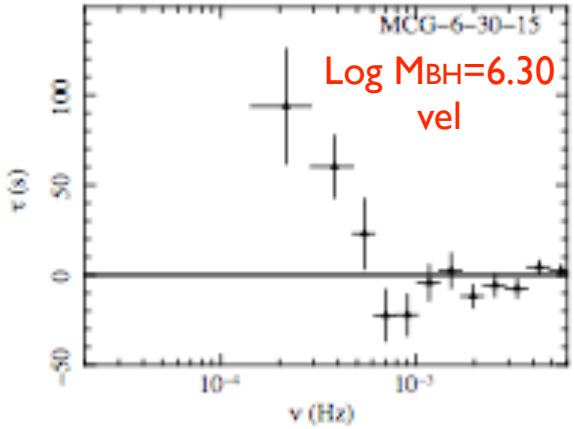
15 soft/negative lag detections:

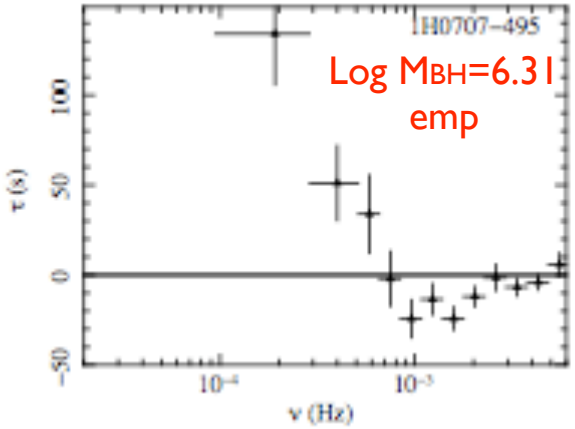


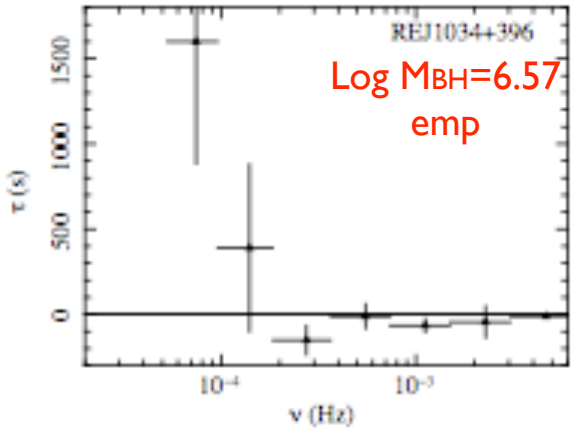


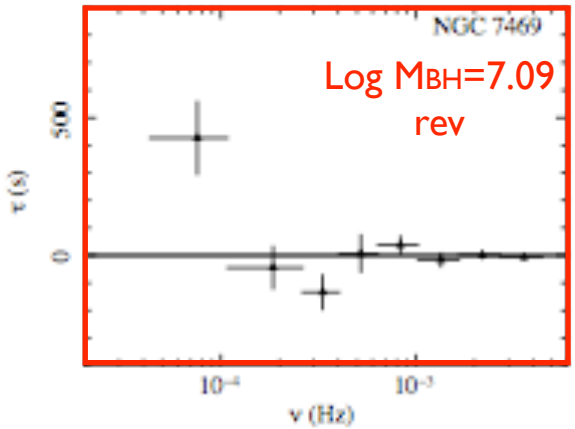


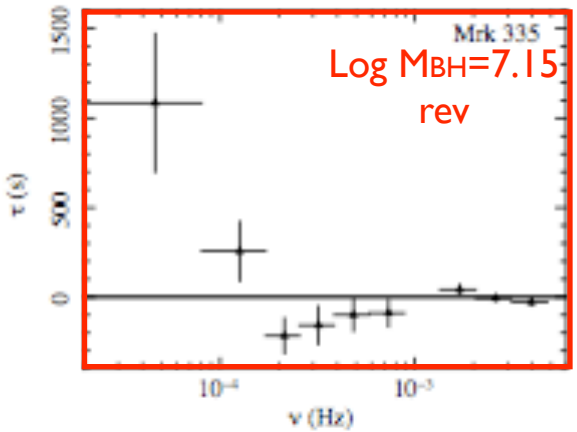












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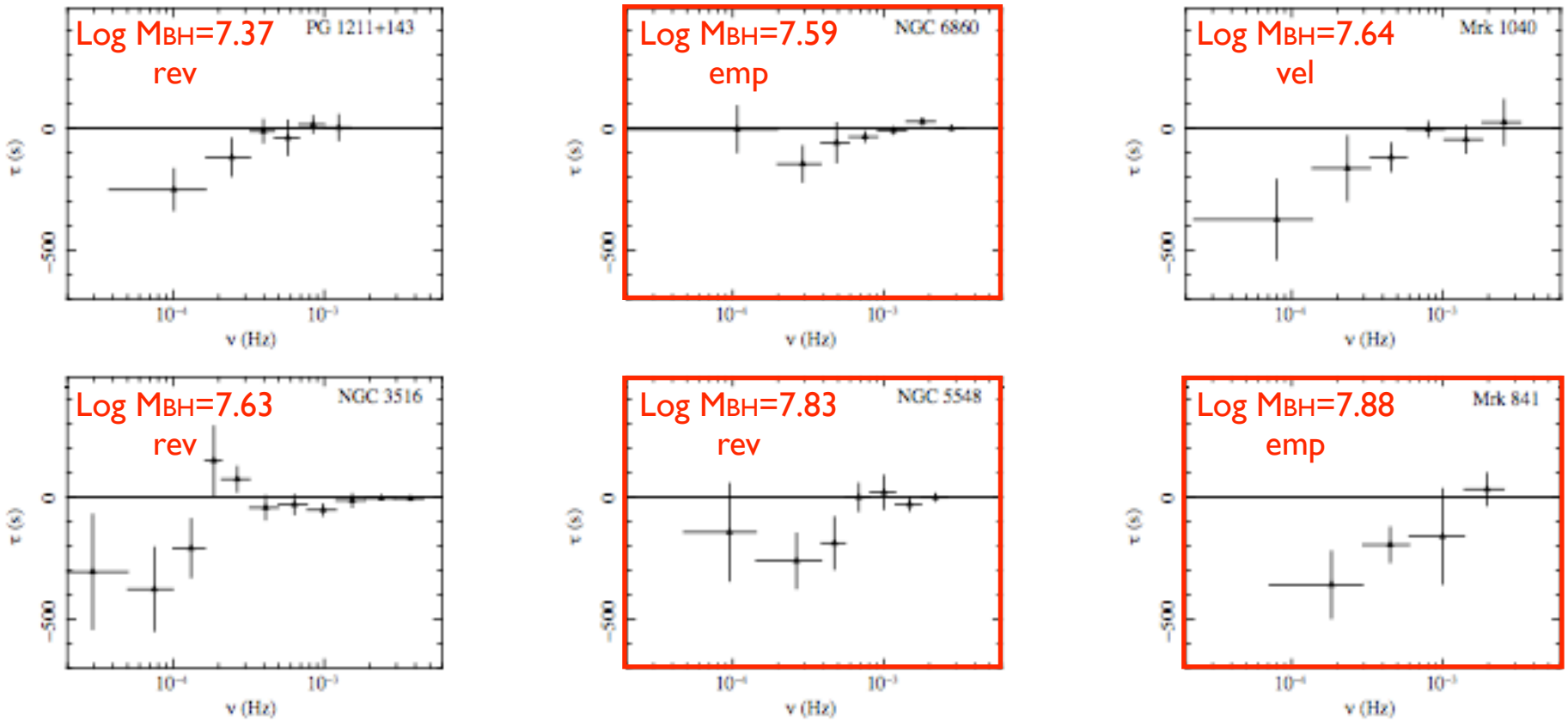


De Marco +12

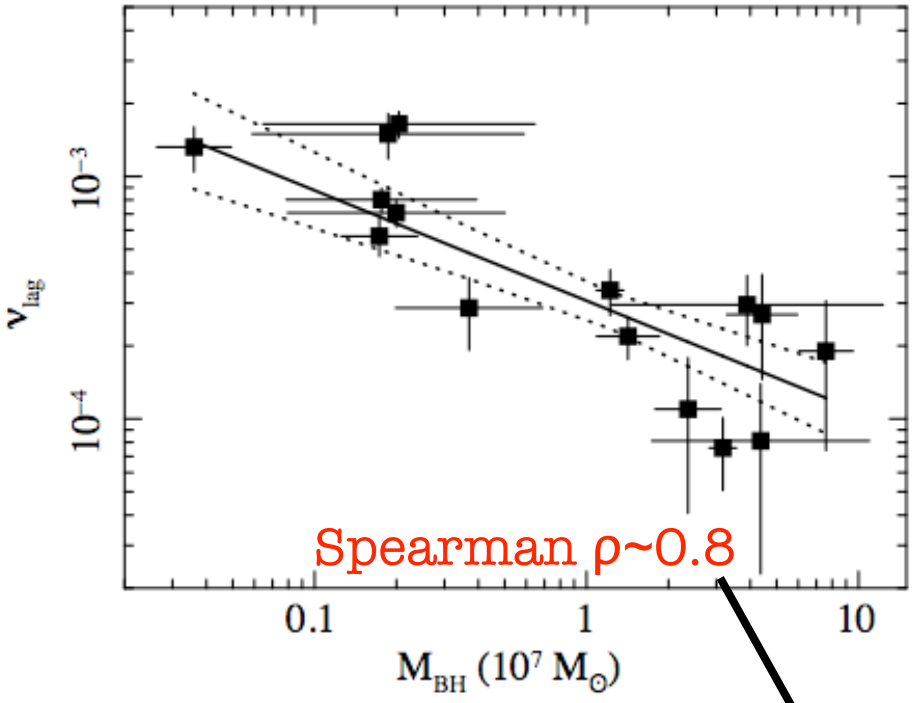
7 NEW DETECTIONS soft lags

2 orders of magnitude in mass (~0.04-7.59x10^7 M_{sol}), lag magnitude (~10-500s) and frequency (~0.07-4 x 10^-3 Hz)

Soft lags mass-scaling:

Lag frequency vs BH mass

Log ν_{lag} = -3.50[±0.07]-0.46[±0.09]Log M_7

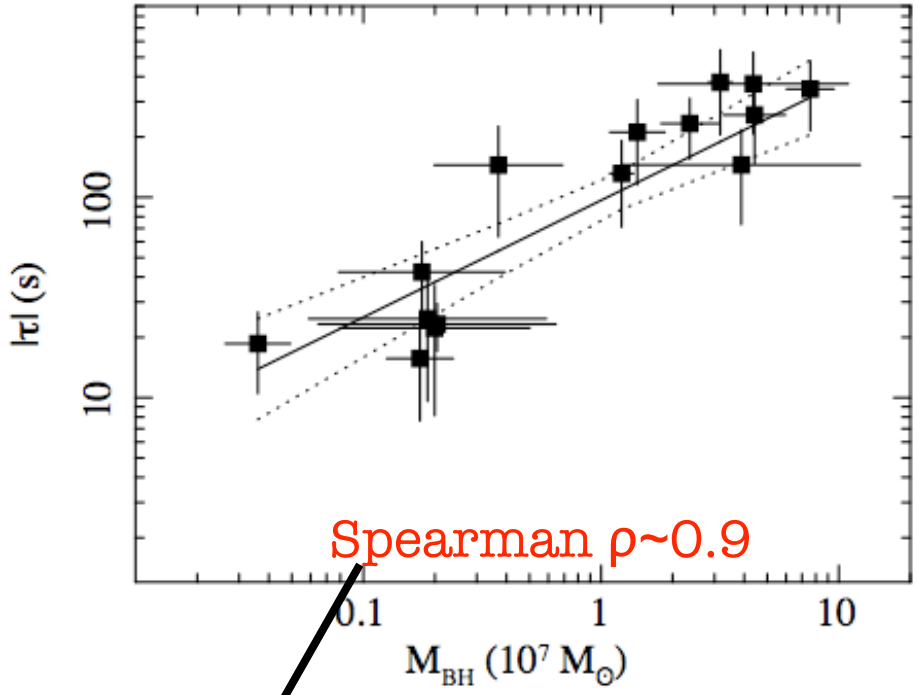


Spearman ρ~0.8

De Marco +12

Lag amplitude vs BH mass

Log $|\tau|$ = -1.98[±0.09]+0.58[±0.11]Log M_7



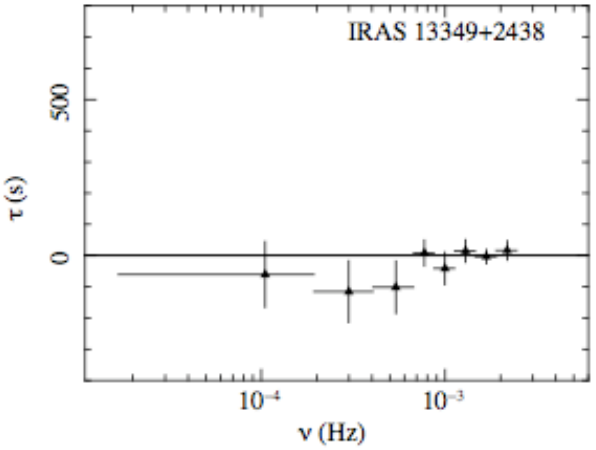
Spearman ρ~0.9

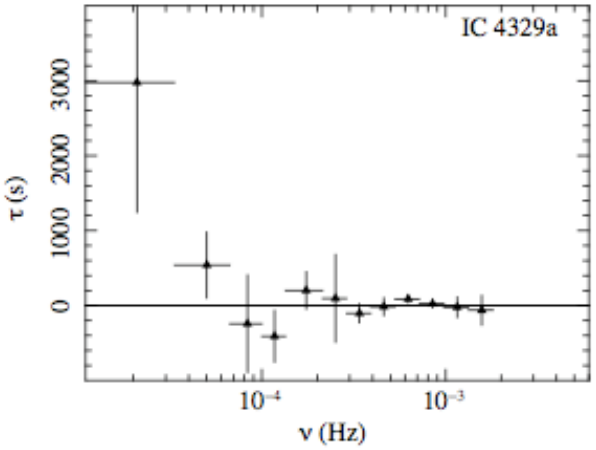
Correlation significance:

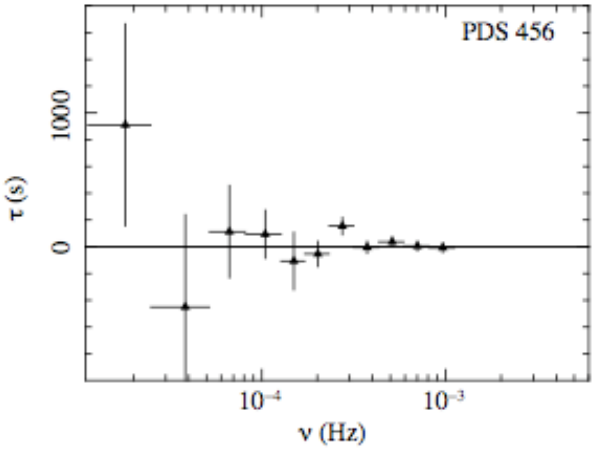
≳4 σ

Non detections:

Some examples....

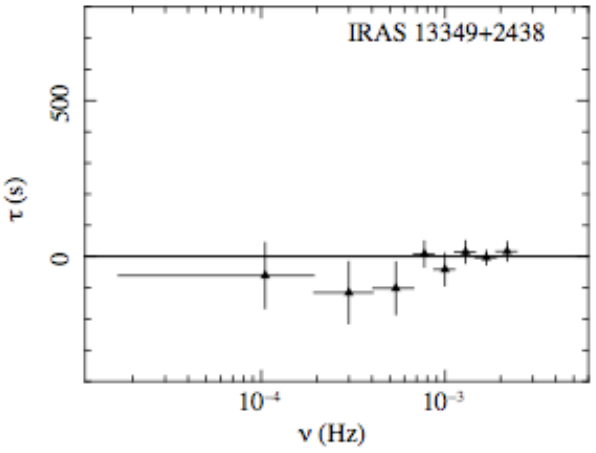


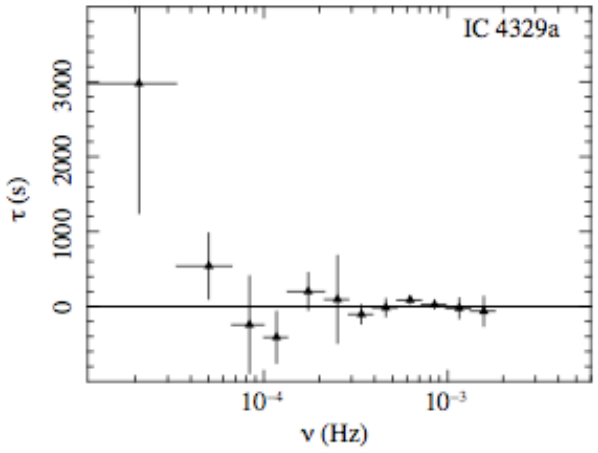


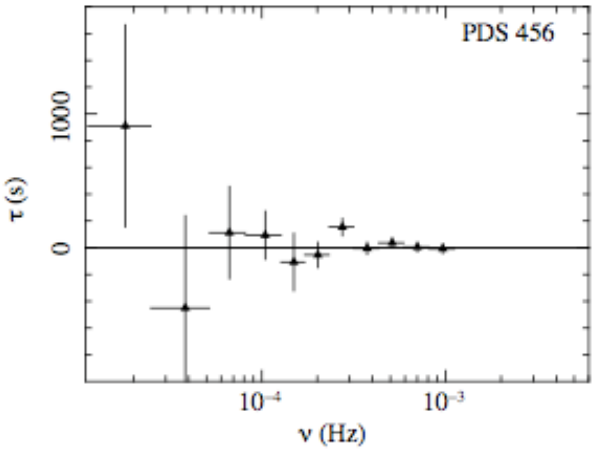


Non detections:

Some examples....



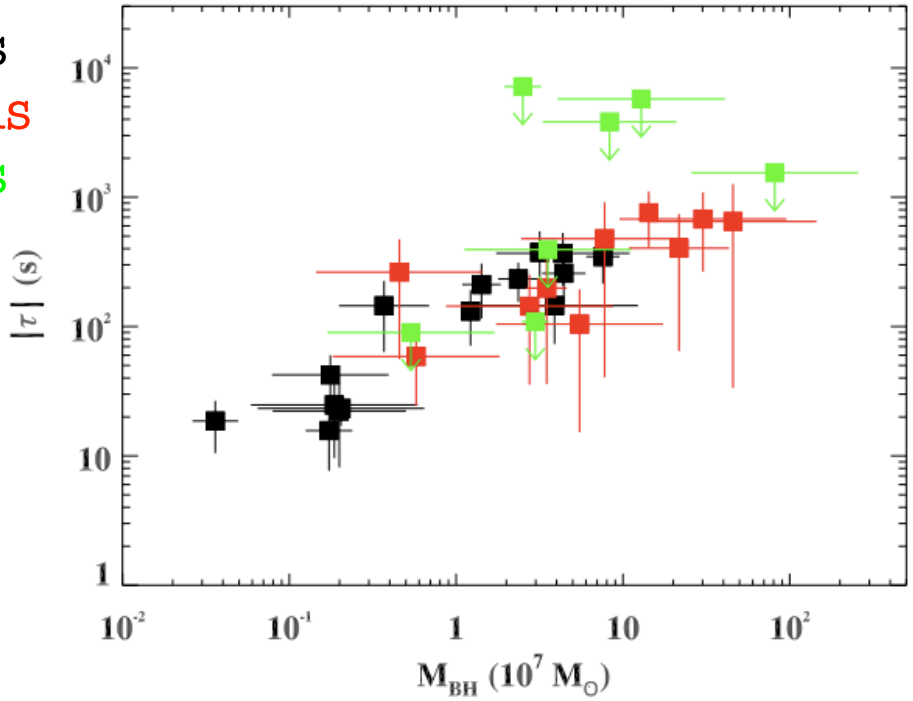




>2σ detections

1-2σ detections

<1σ detections (upper limits)



correlation significance increasing to >5σ!!!! (using Isobe +86)

Discussion of results:

- 7 new detections of soft lags

- Soft lag time scales (frequency and amplitude) do show a highly significant correlation with the BH mass

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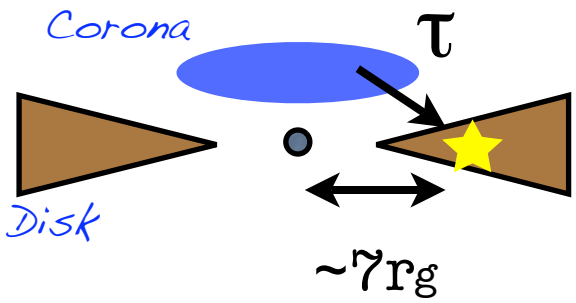
Naturally expected in a reverberation scenario given that:

$$t_c = r_g/c = GM/c^3$$

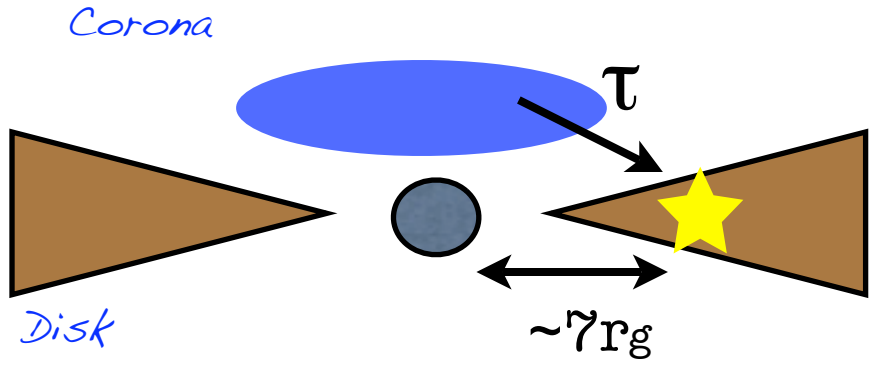
$$t_c \propto M$$

The gravitational radius light crossing time scales linearly with the BH mass

Discussion of results:



Low BH Mass



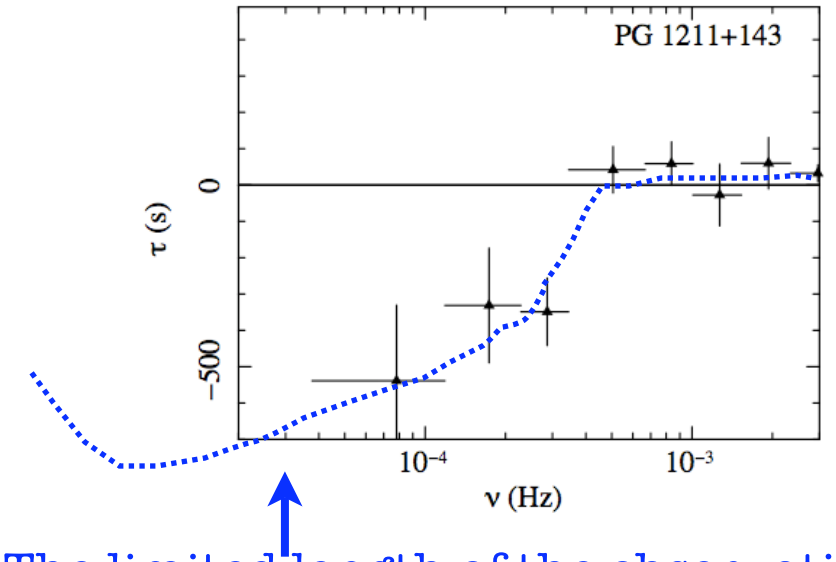
High BH Mass

$$\tau \propto M$$

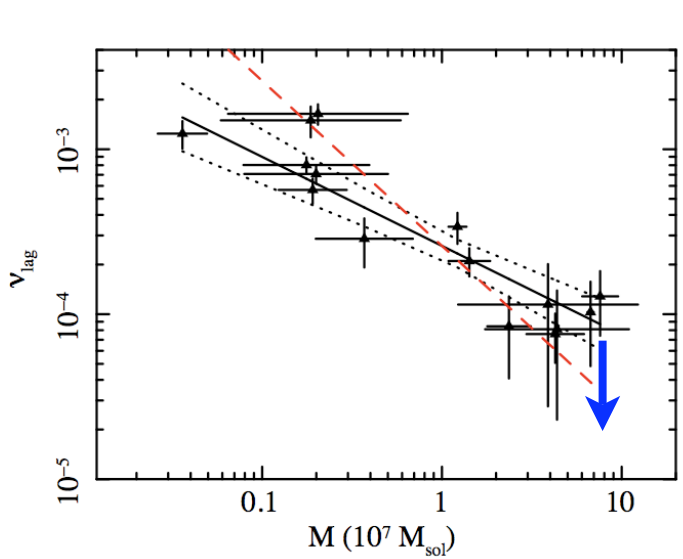
$$\tau / t_c = \text{constant}$$

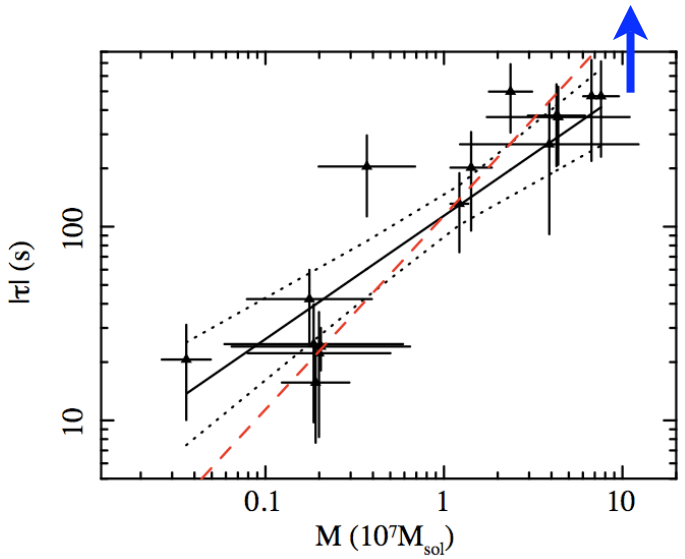
Discussion of results:

High BH Mass



The limited length of the observations does not allow to observe the entire soft lag profile





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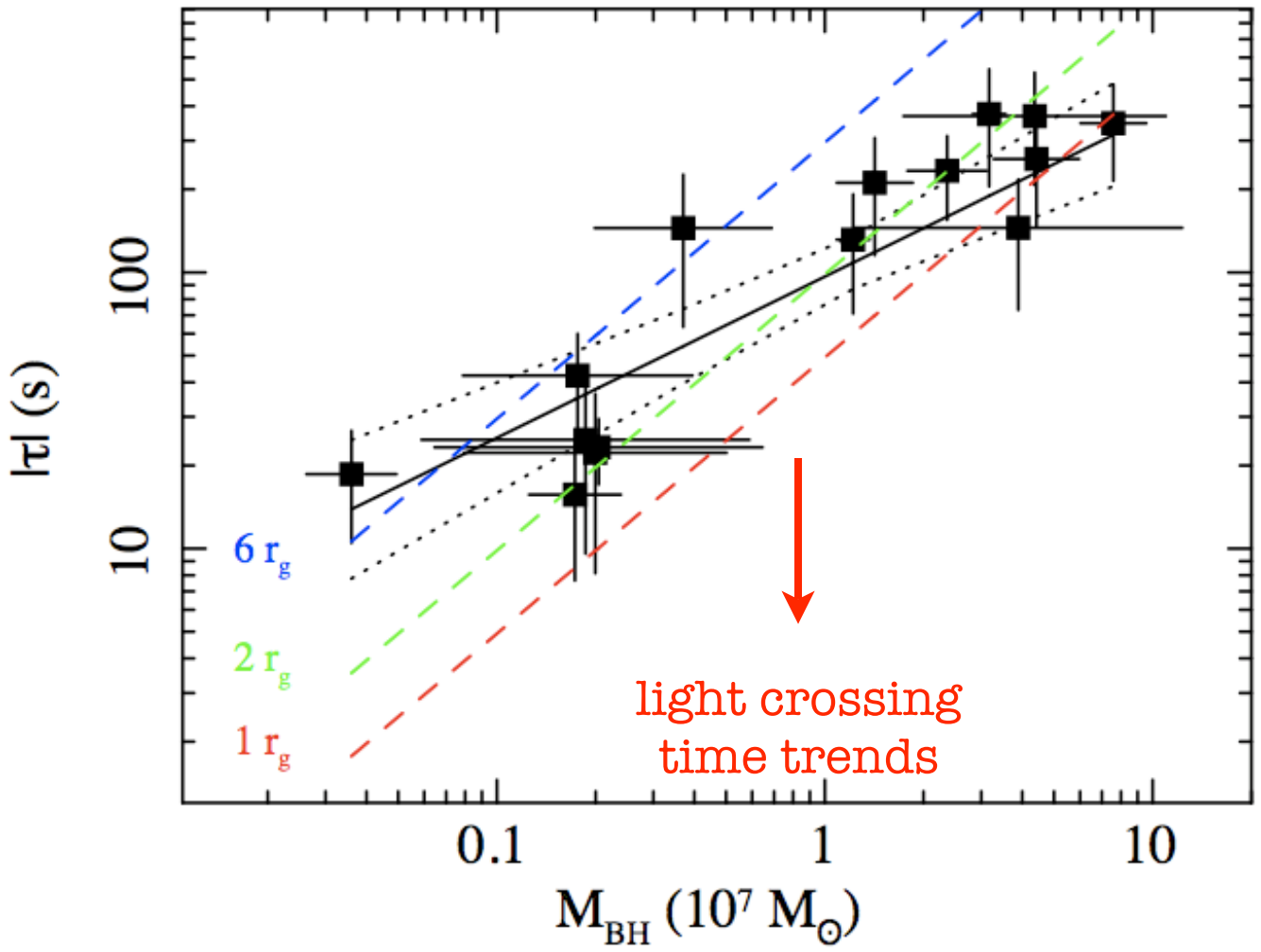

Involved distances are very small!!!!

Conclusions:

In good agreement with prediction of reflection models in standard Shakura-Sunyaev accretion discs

Understanding soft lags properties will allow to probe the physics and geometry of the inner regions of AGN

THANKS!