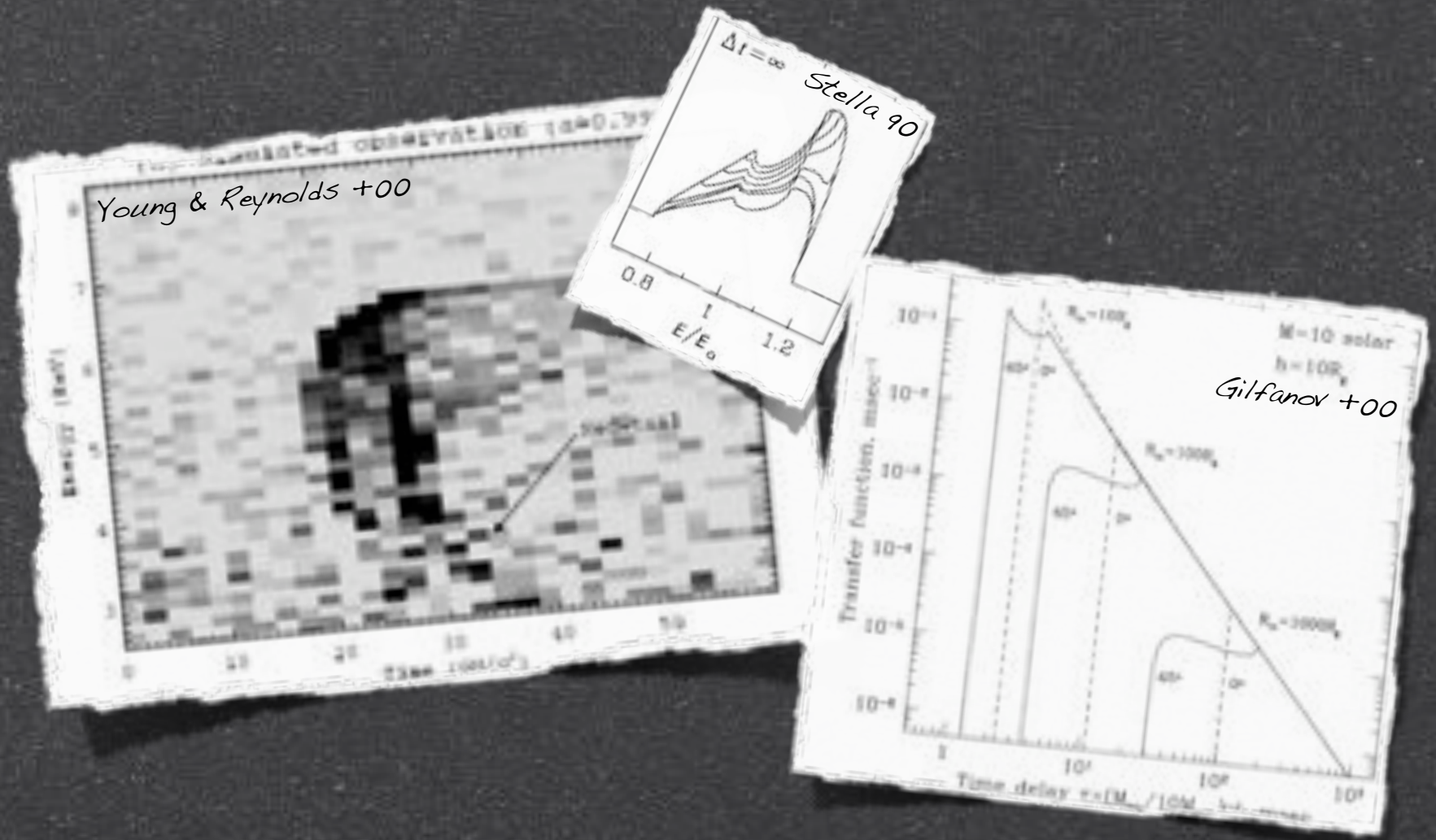
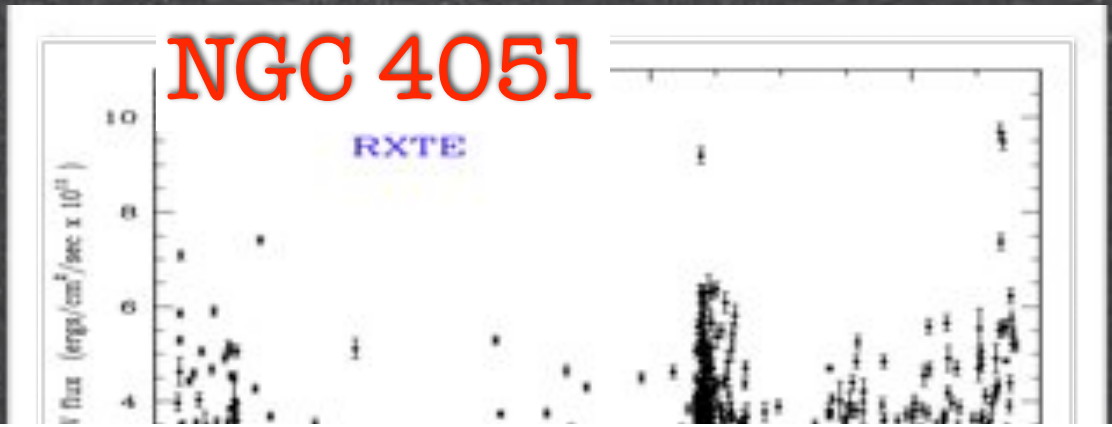
Spectral/timing properties of AGN

B. De Marco
(Max-Planck Institute for Extraterrestrial Physics)

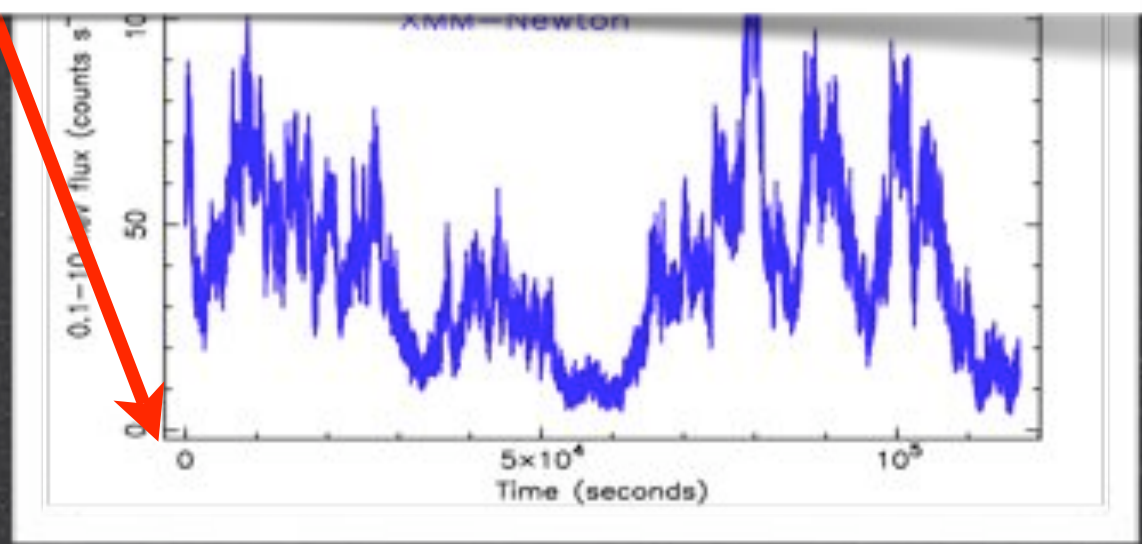


X-ray variability in AGN



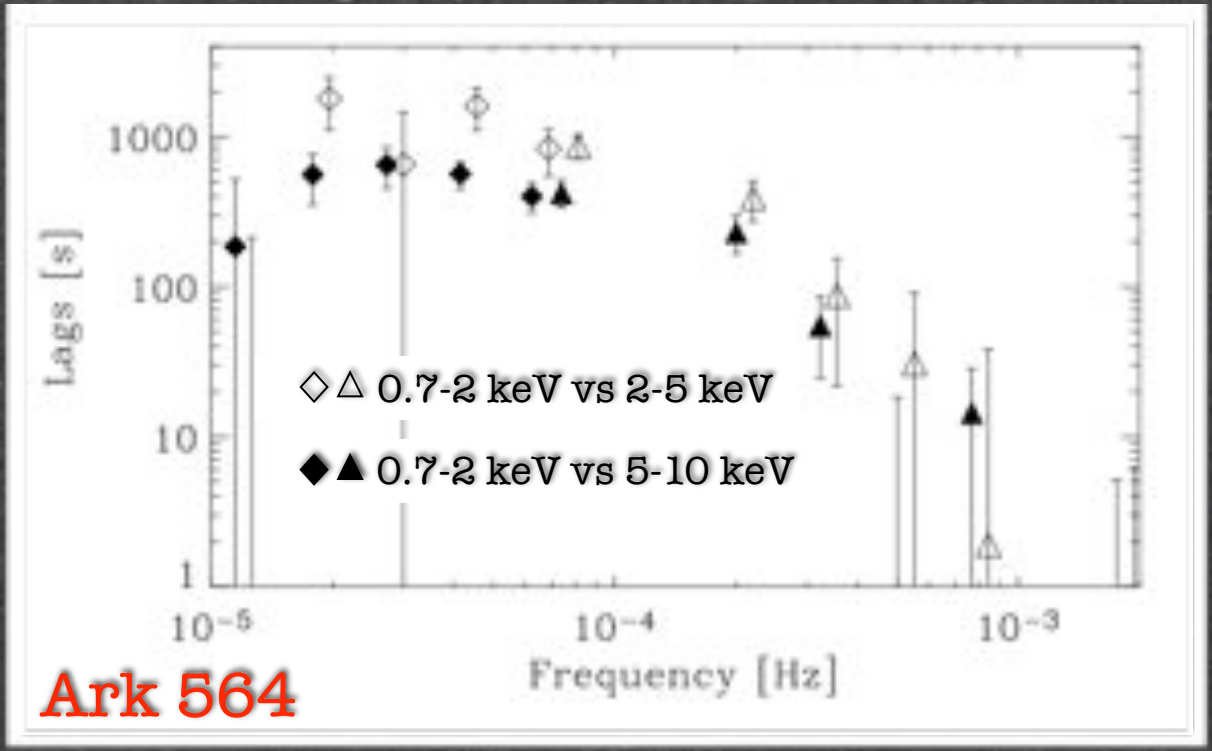
X-ray time lags are diagnostics of the emission process and geometry

Variability →
Time-dependent spectra

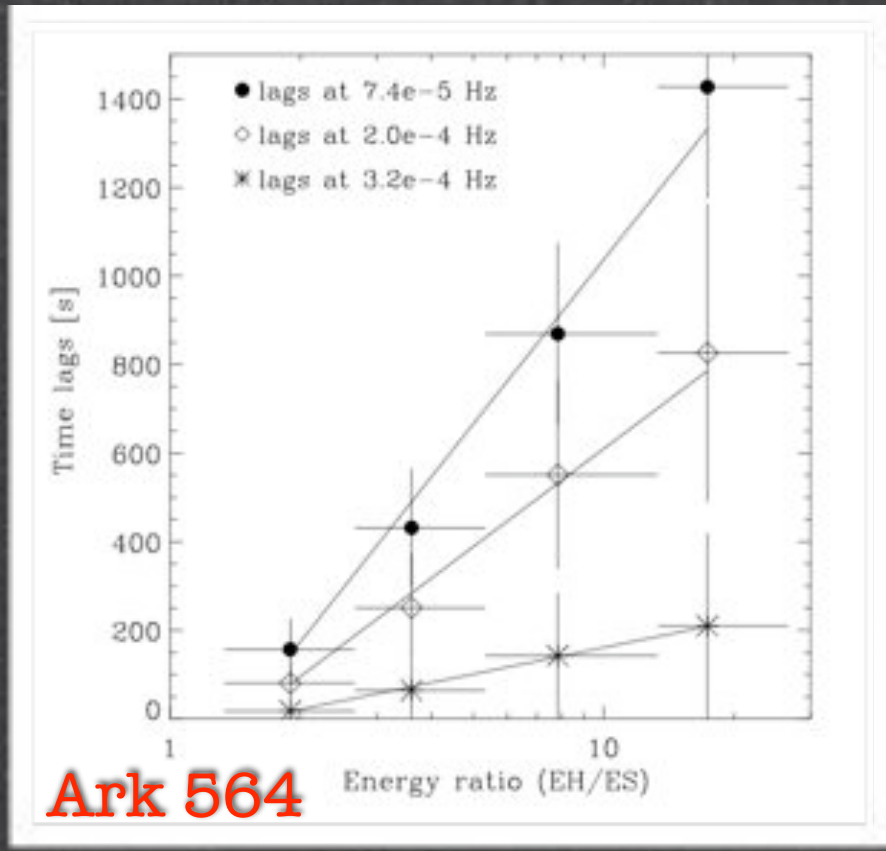


Hard X-ray lags in AGN...

[Arévalo +06]

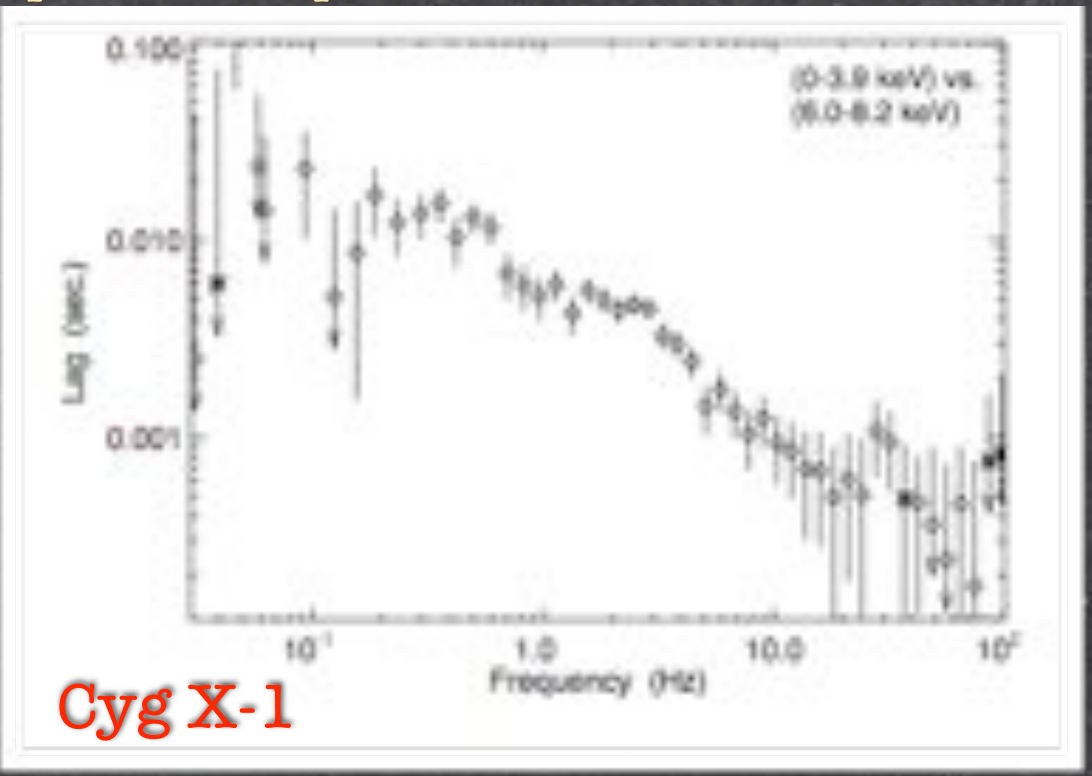


See also:
Papadakis +01 (NGC 7469),
Vaughan +03 (MCG -6-30-15),
McHardy +04 (NGC 4051) ,+07 (Ark 564),
Markowitz 05 (NGC 3783), +07 (Mrk 766),
Arévalo +08 (Mrk 335)

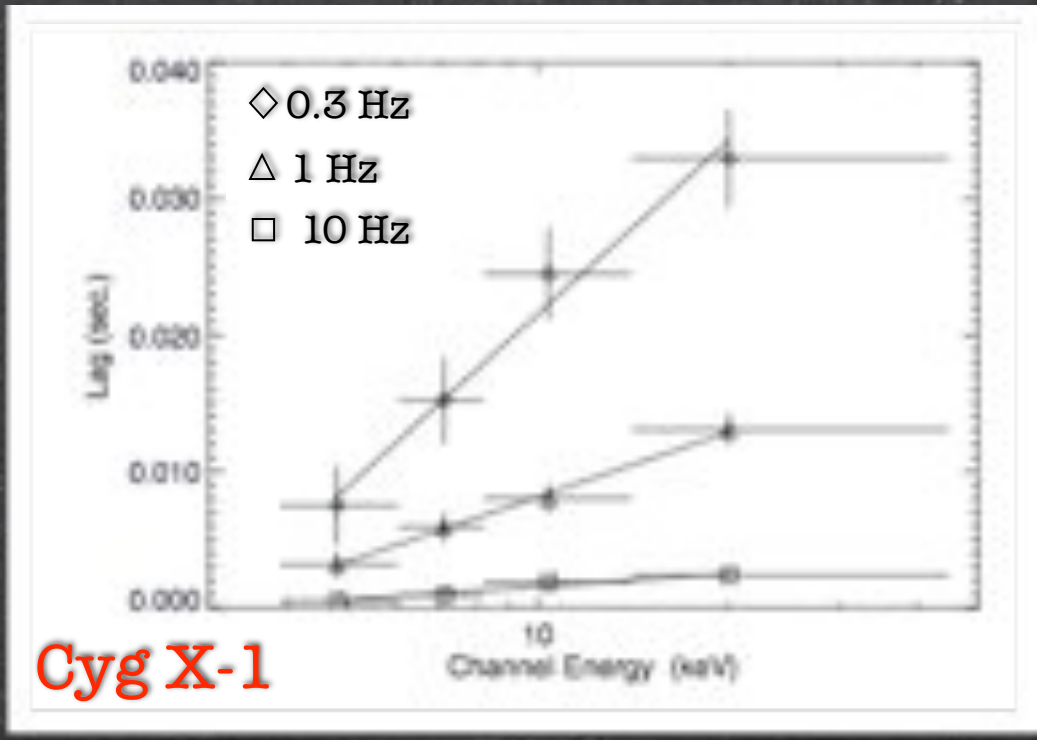


...and in X-ray binaries

[Nowak +99]



Cyg X-1



Cyg X-1

See also:
Miyamoto & Kitamoto +89,
Nowak +00,
Ford +99 (neutron stars)
and many others....

Properties of hard X-ray lags in AGN and XRBs

FREQUENCY DEPENDENCE

Larger time lags associated to longer time scales

$$\sim f^{[-0.77,\ -1]}$$

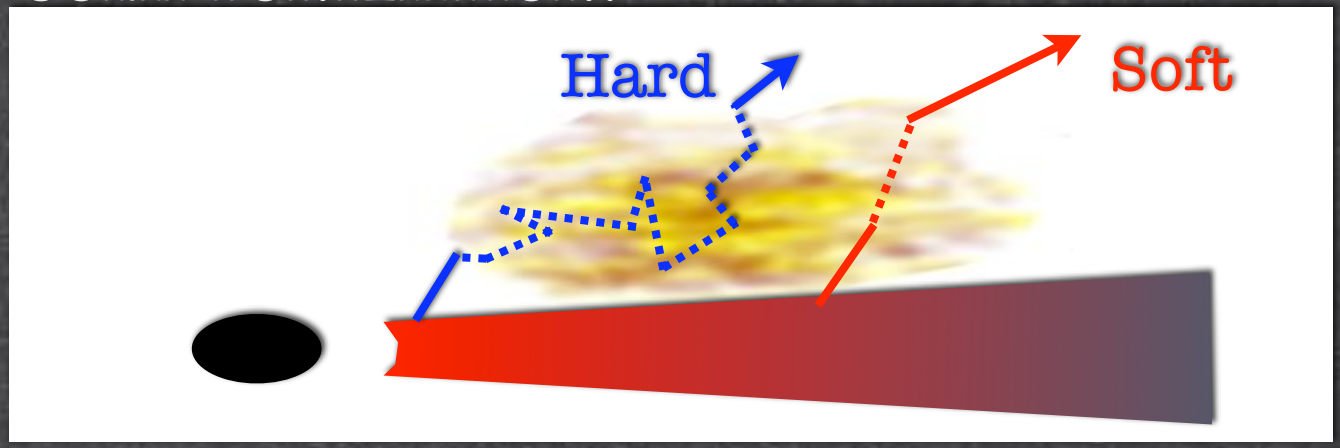
ENERGY DEPENDENCE

The magnitude of the lag increases with energy separation of the energy bands

$$\sim \mathrm{Log}\,(E_1/E_2)$$

Possible physical interpretations

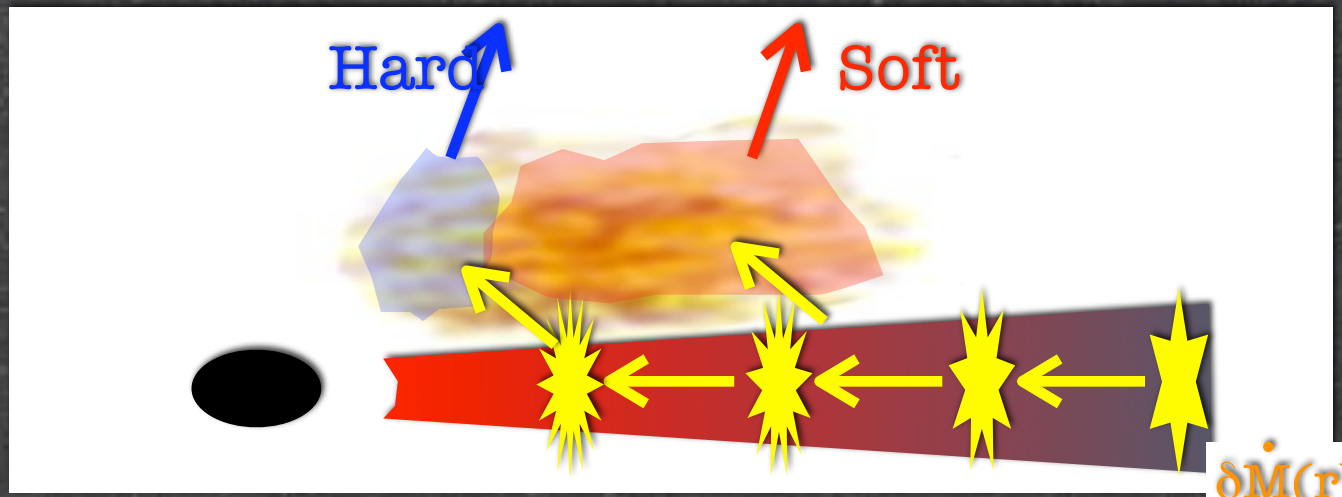
COMPTONIZATION:



[Kazanas +97, Nowak +99 (Paper II and III), Hua +99]

* Number of scatters hard photons > soft photons

PROPAGATION OF MASS ACCRETION RATE FLUCTUATIONS:

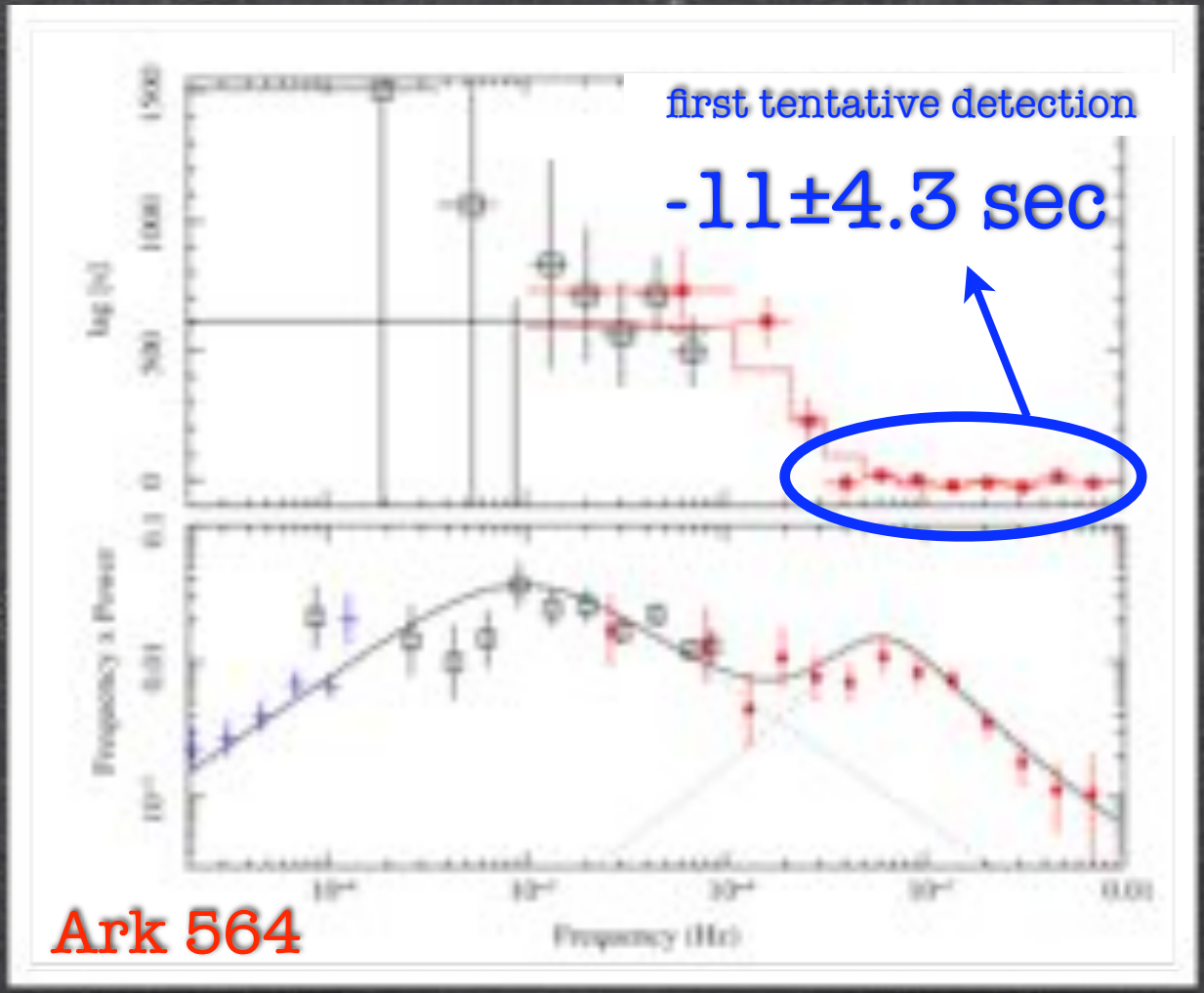


[Lyubarskii 97, Kotov +01, Arévalo & Uttley +06]

* Perturbations propagate inwards, combine multiplicatively, and modulate the X-ray emitting region

$\delta\dot{M}(r) \rightarrow t_{visc}(r)$

Complexities in the lag profile

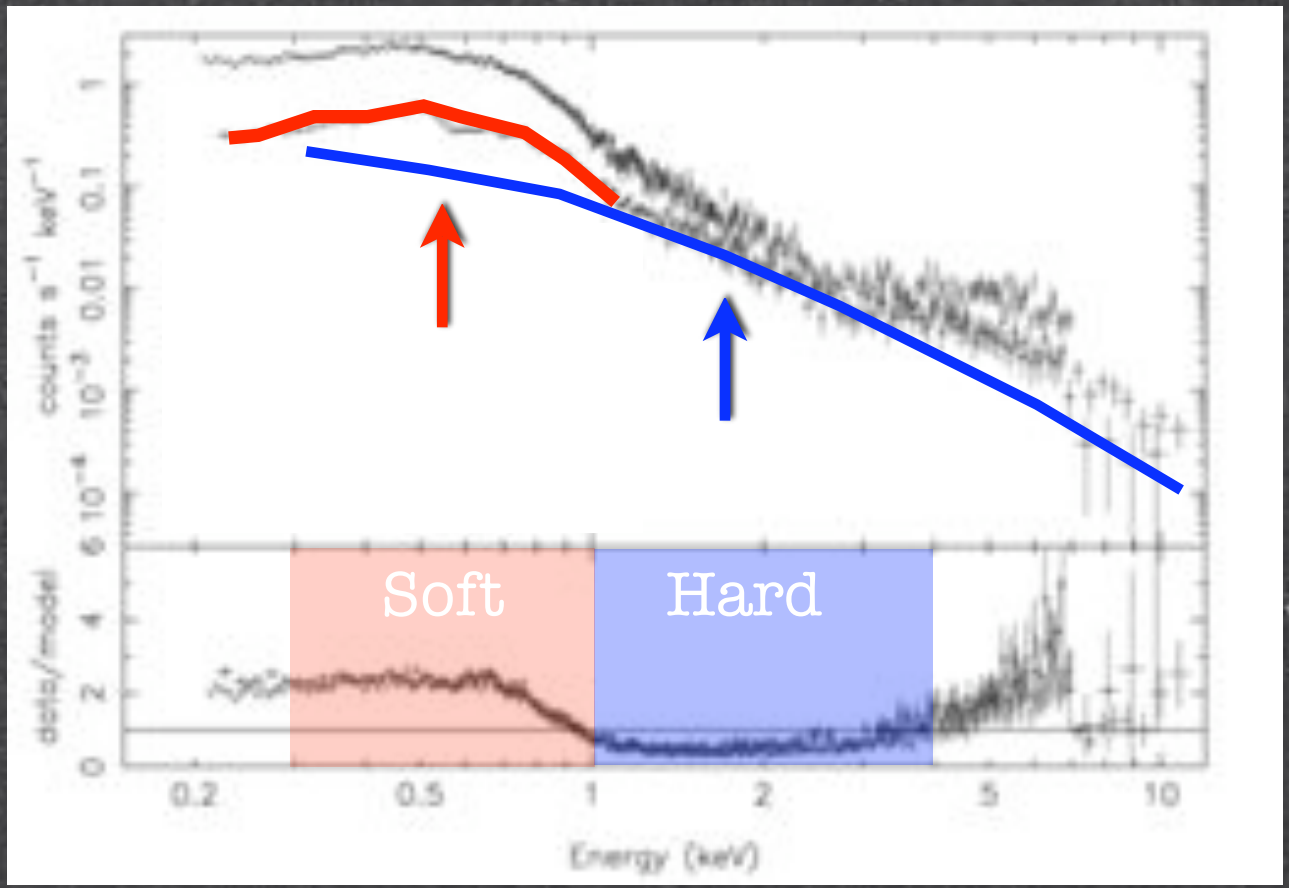


[McHardy +07]

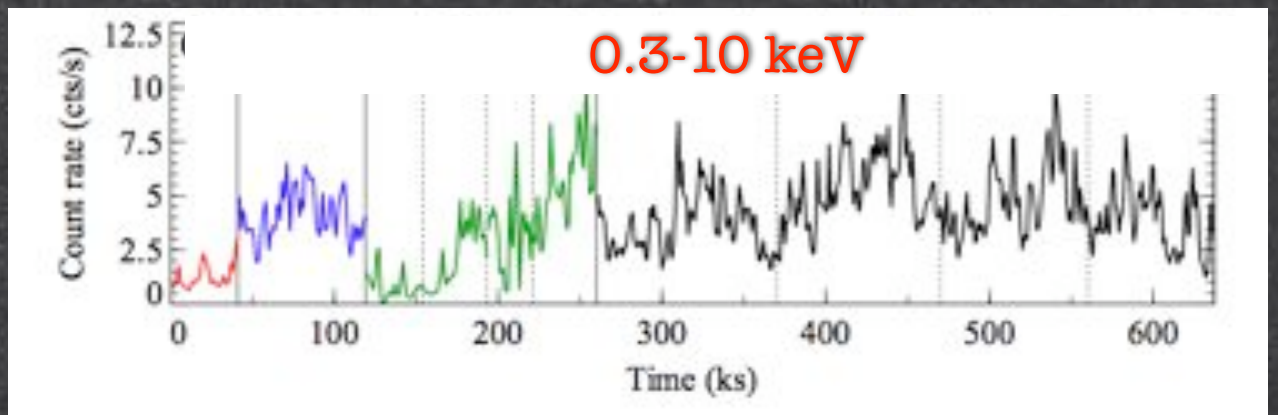
See also:
Markowitz +07
(Mrk 766)

(e.g. step-like structures, seen also in GBHs)

Clear detection of a soft lag: 1H0707-495



[Boller +02]

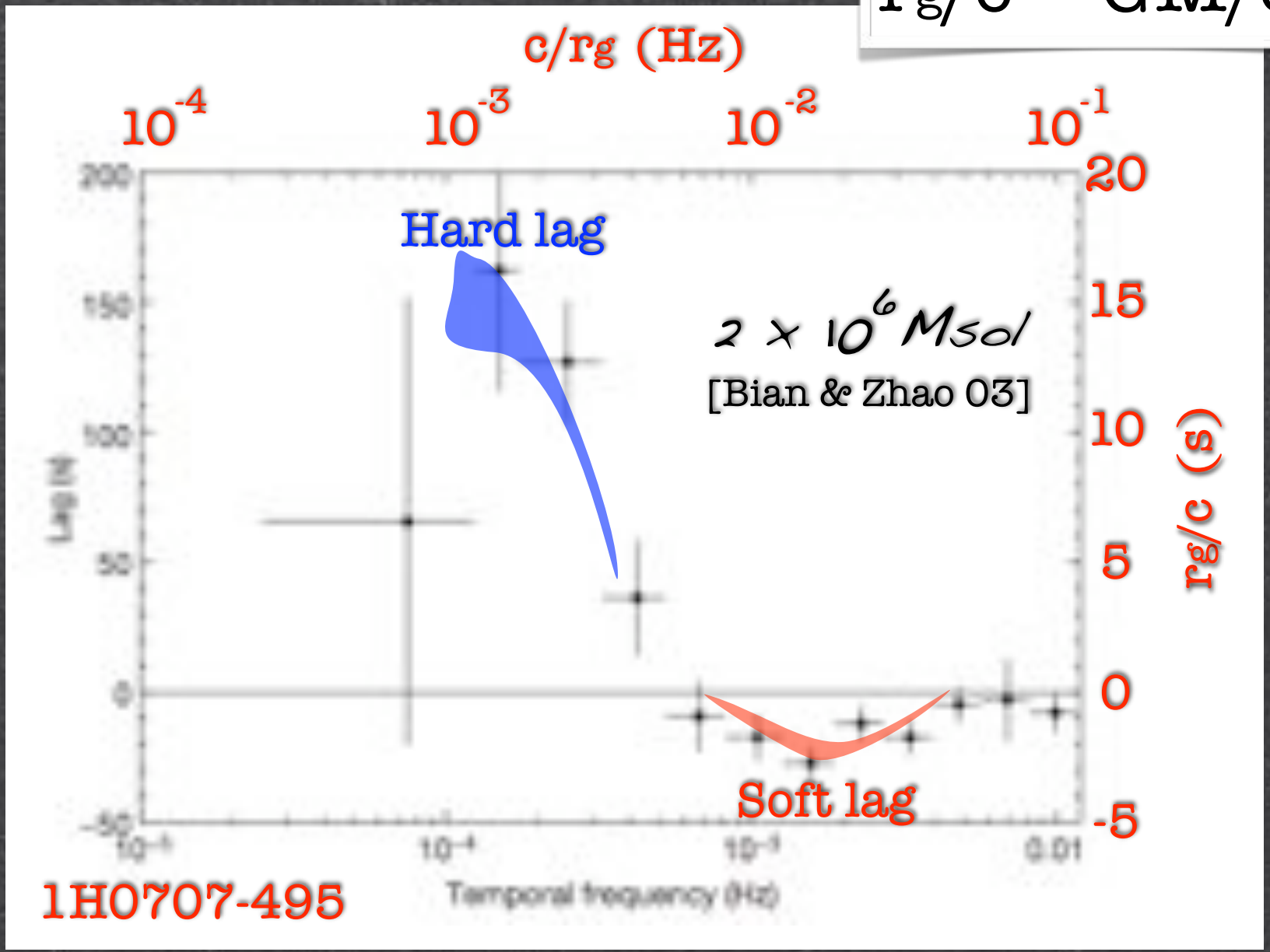


[Zoghbi +10]

Soft-hard time lags

[Fabian +09, Zoghbi +10]

$r_g/c = GM/c^3$



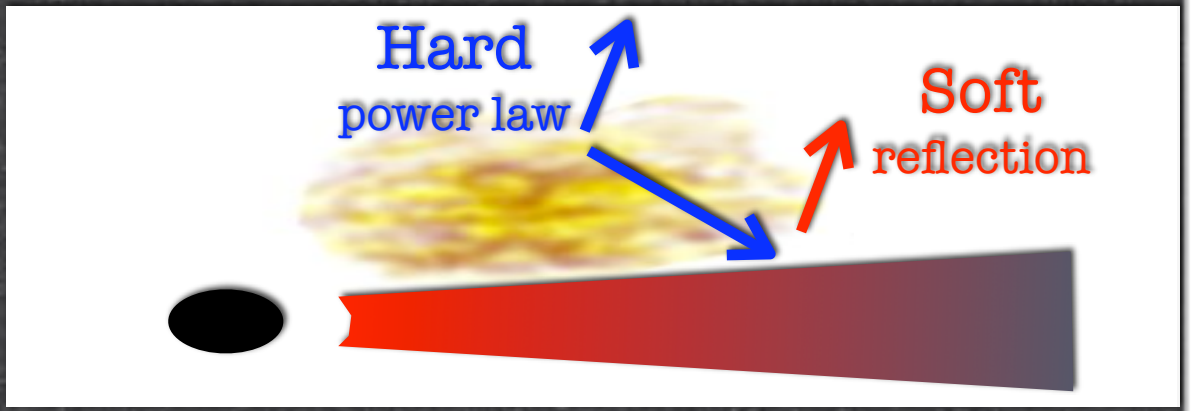
Physical interpretations

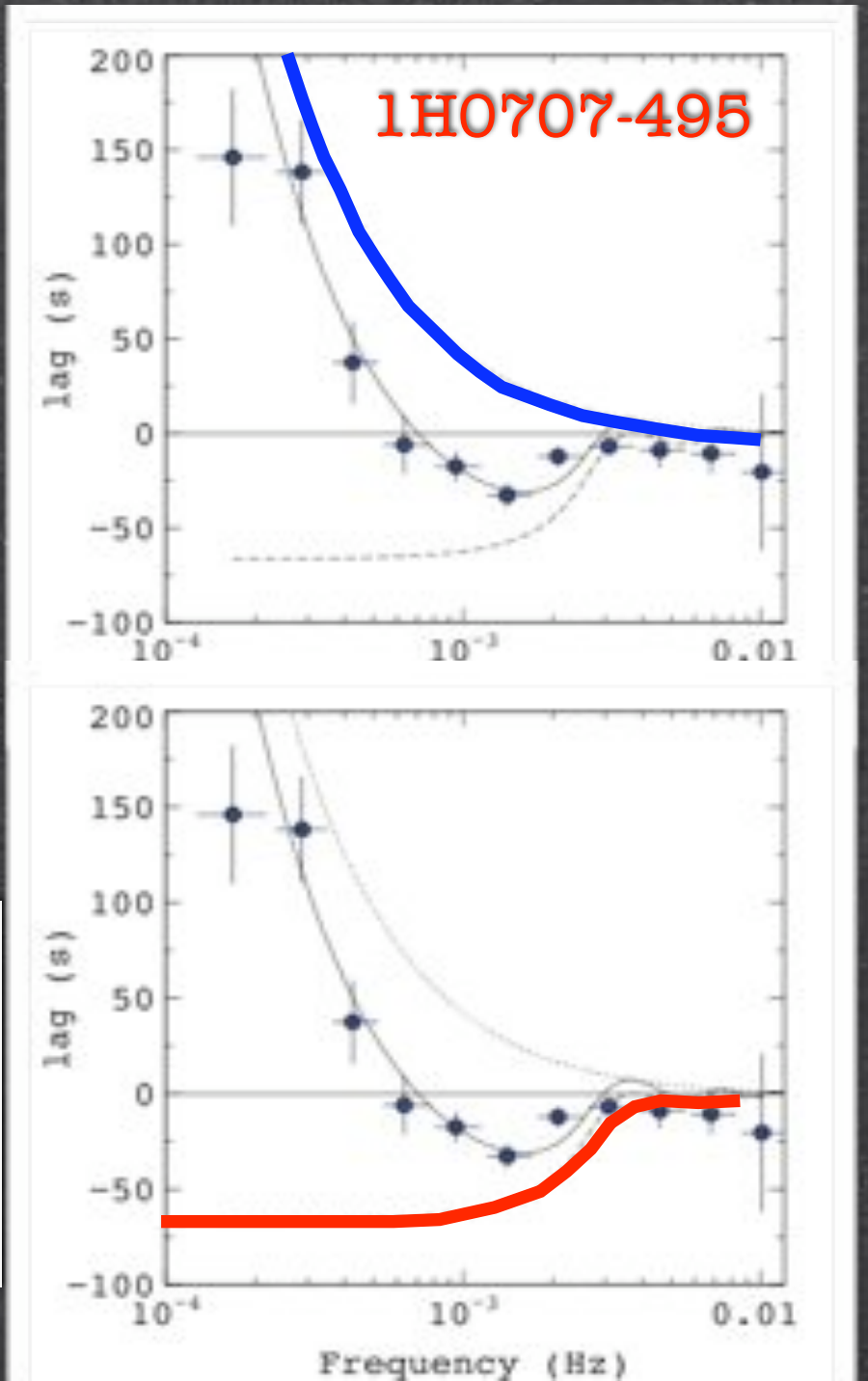
I. Reverberation off the inner disc

[Zoghbi +11, Kara +13a]

LOW FREQUENCY
Same hard lag as seen in other AGN and XRBs

HIGH FREQUENCY
Reverberation

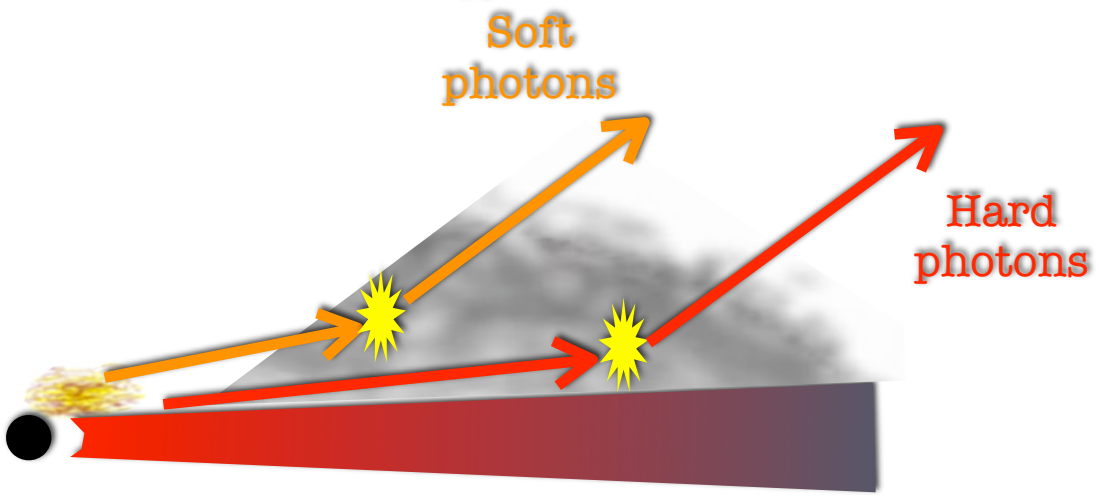




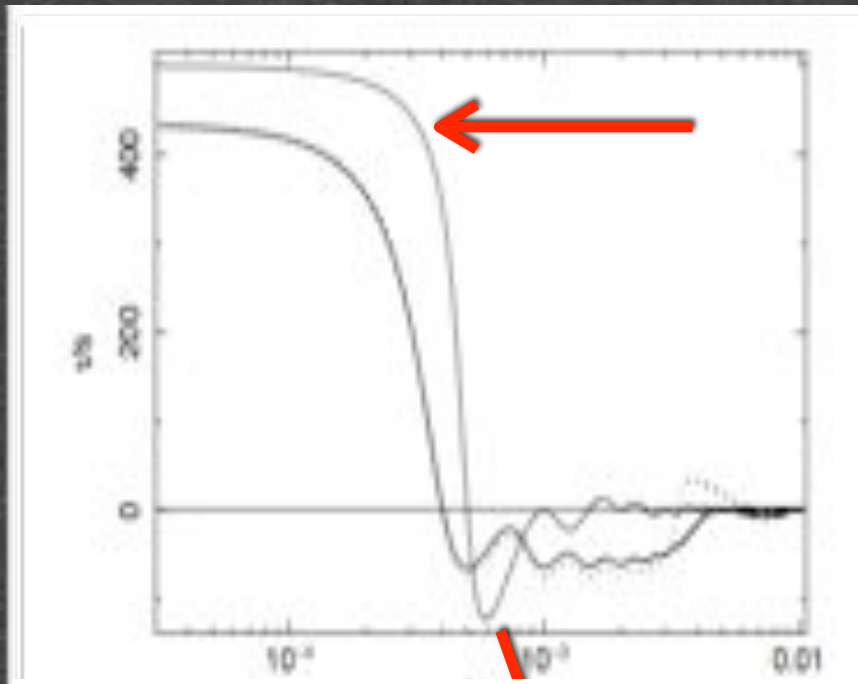
II. Reverberation off a distant reflector

[Miller +10, +11]

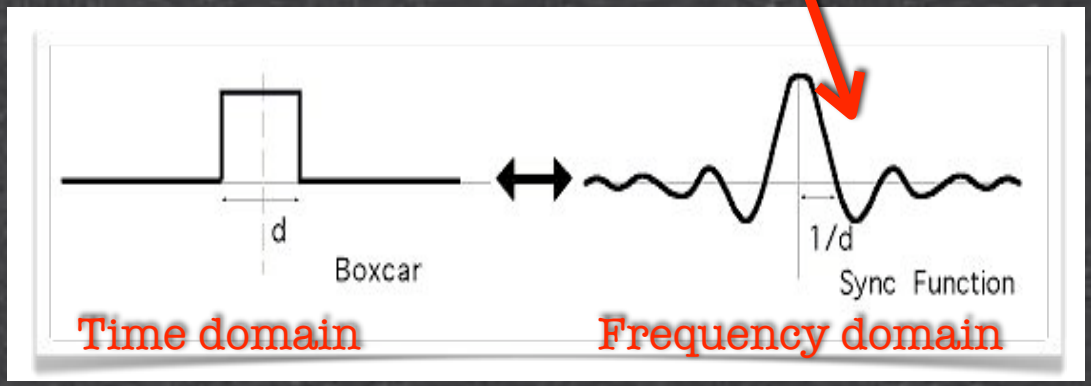
*The opacity of the scattering medium decreases with energy



100-1000 rg



*The negative lag is not physical



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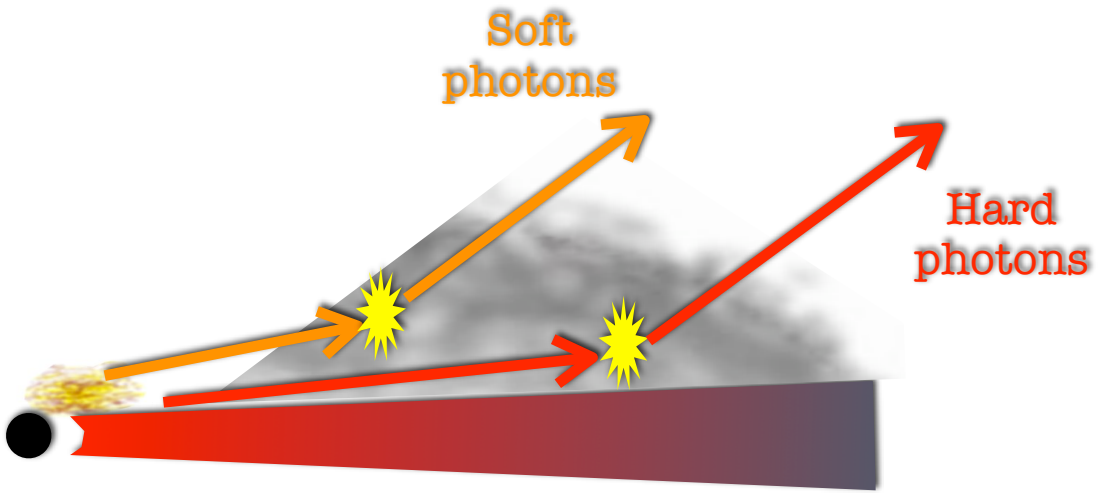
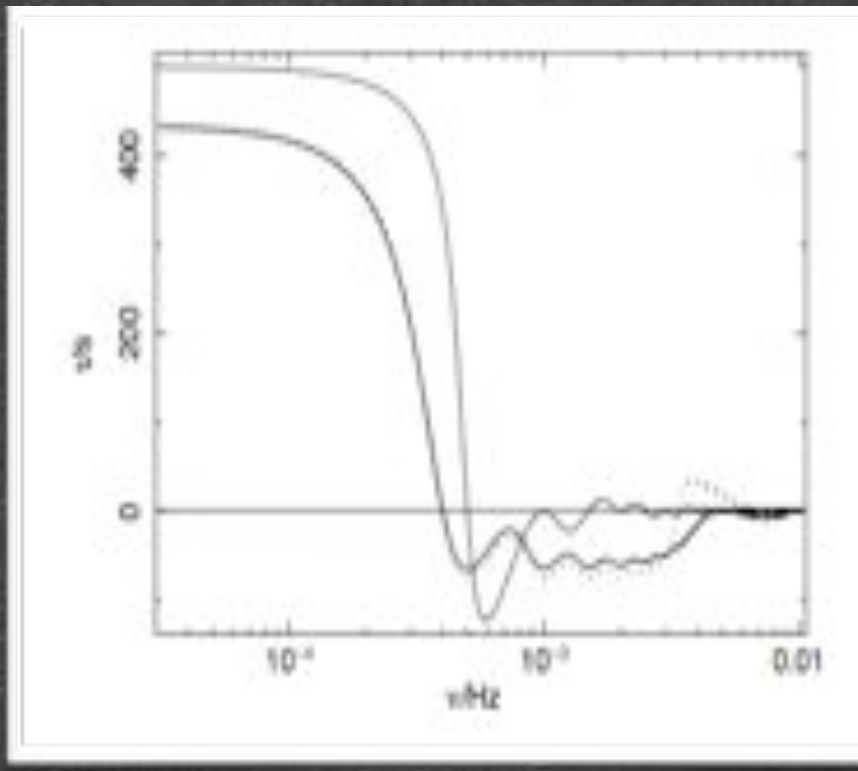
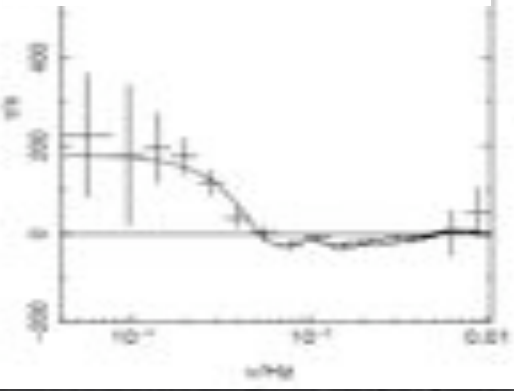




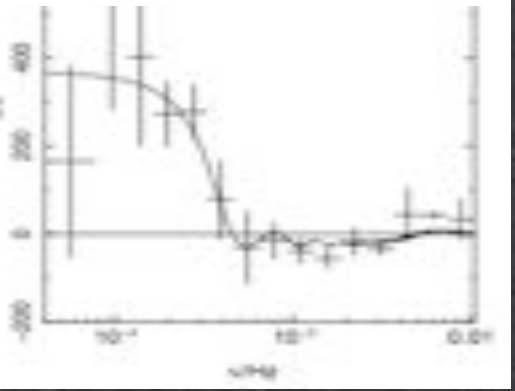
*Fits well the lag profile, but self consistent modeling of 1H0707 spectra not yet provided

1H0707-495

(0.3-1 keV) vs (1-4 keV)

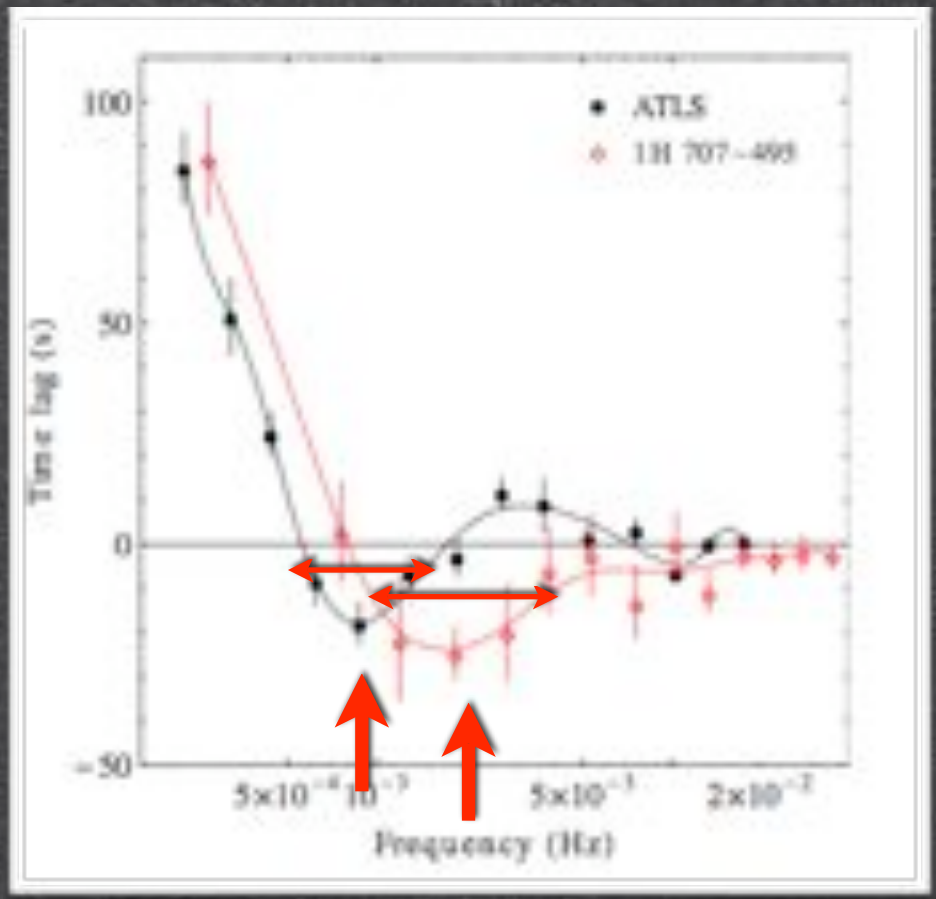


(0.3-1 keV) vs (4-7.5 keV)



Soft lags: more detections

[Emmanoulopoulos +11]



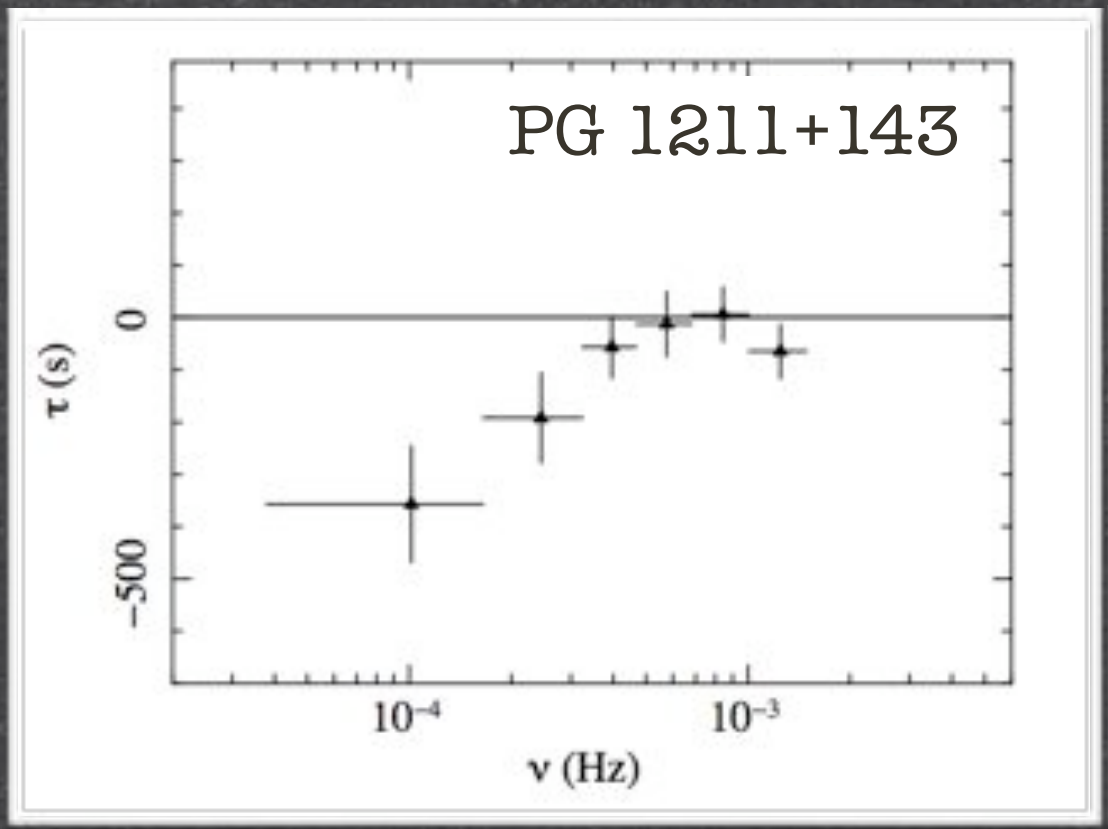
Slight changes in the lag profile

ATLS=
MCG-6-30-15
+
Mrk 766

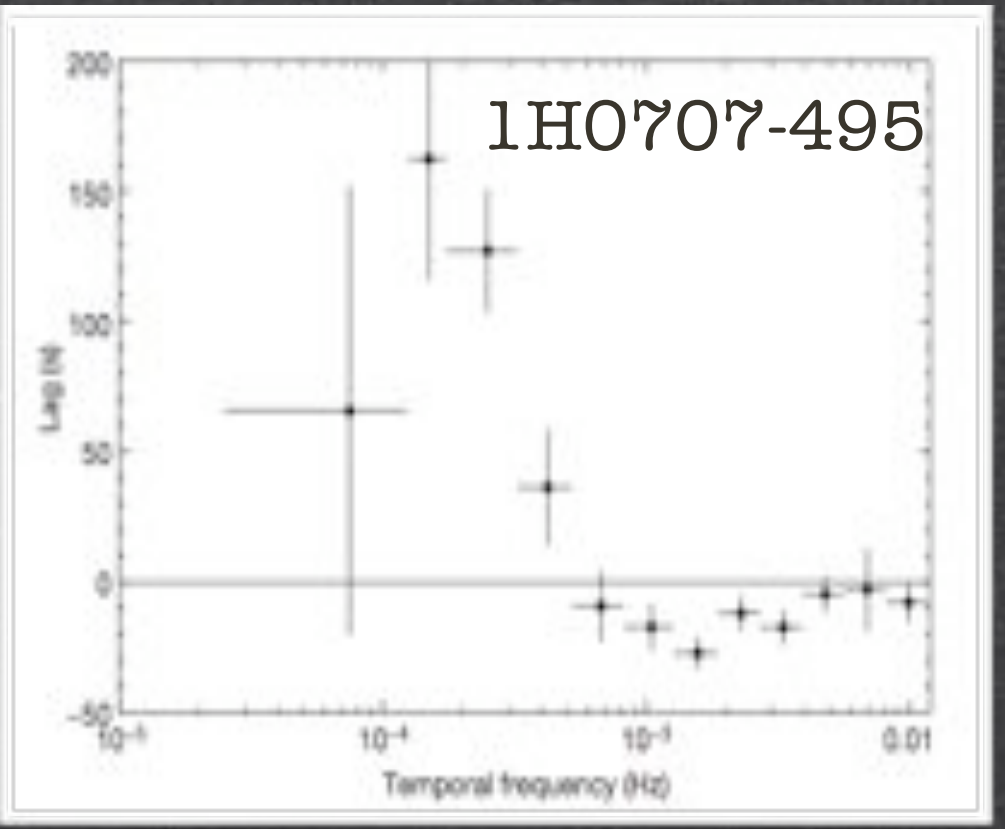
See also:
Turner +11 (NGC 3516)
Tripathi +11 (Mrk 1040)
Zoghbi +11 (REJ 1034+396)
Cackett +13 (ESO 113-G010)

Soft lags in high mass sources: PG1211+143

[De Marco +11]



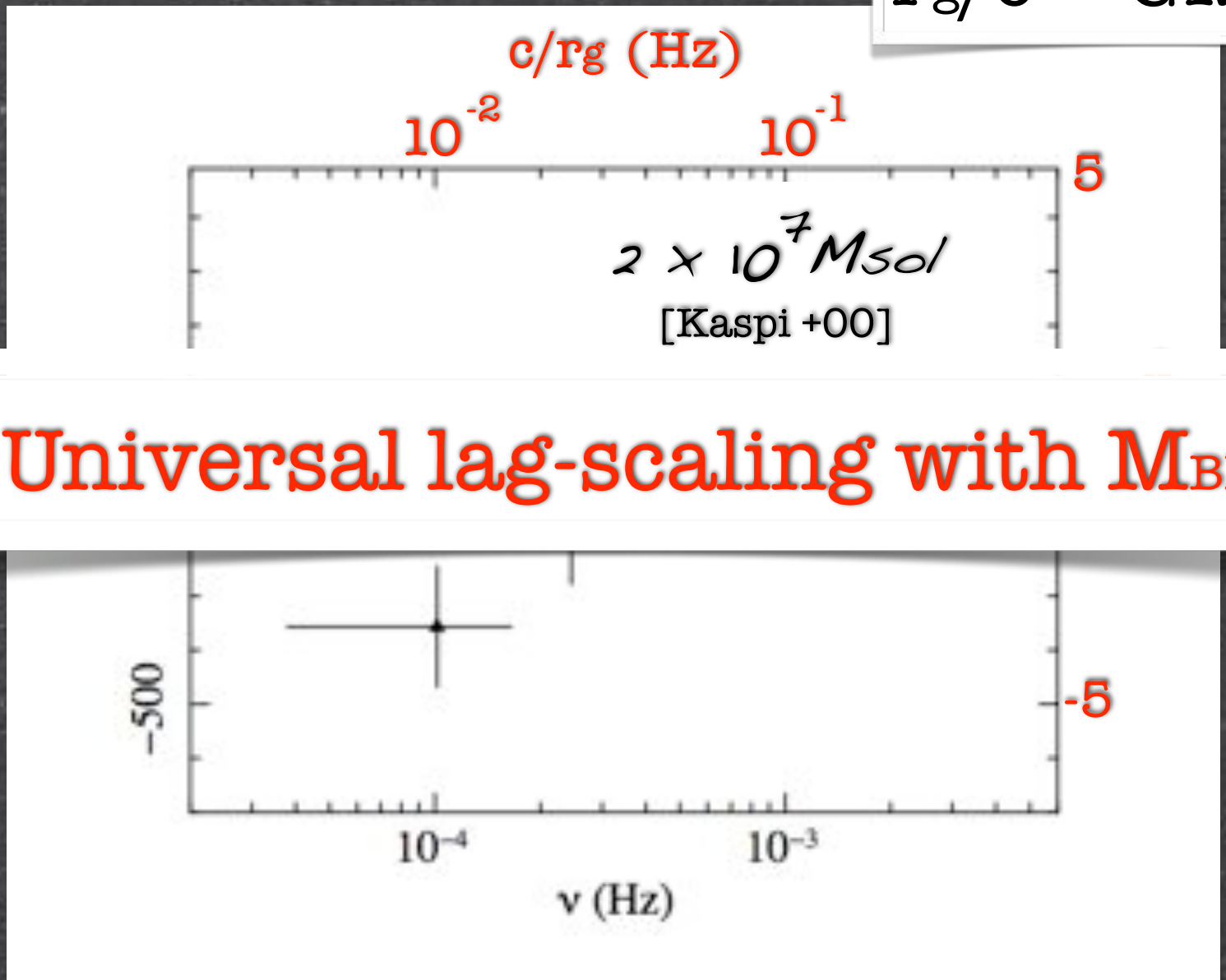
[Fabian +09]



Soft lags in high mass sources: PG1211+143

$r_g/c = GM/c^3$

[De Marco +11]



➔ Universal lag-scaling with M_{BH} ?

Are soft lags common in AGN?

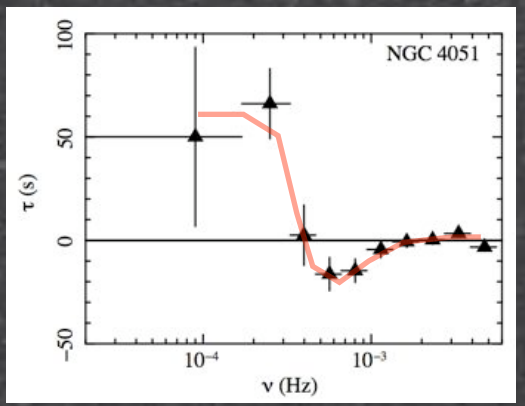
Radio quiet,
X-ray unobscured AGN,
long XMM-Newton
observations (>40 ks)

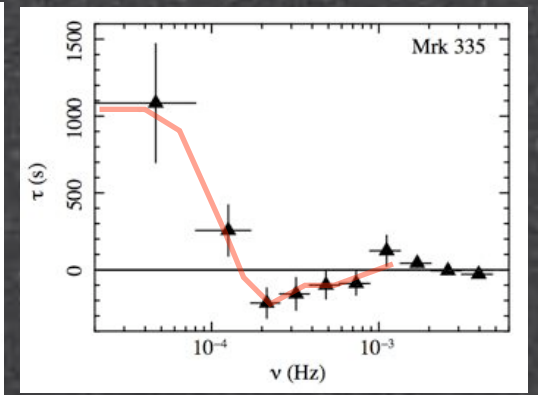
[CAIXA, Ponti +12]

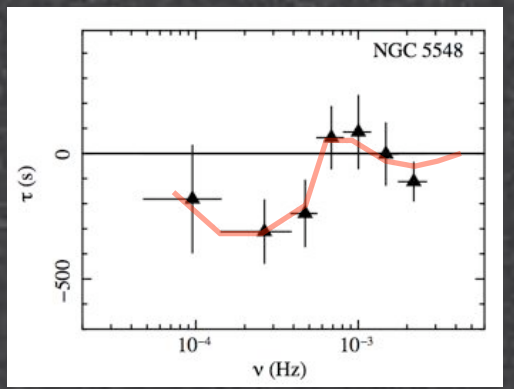
15 detections

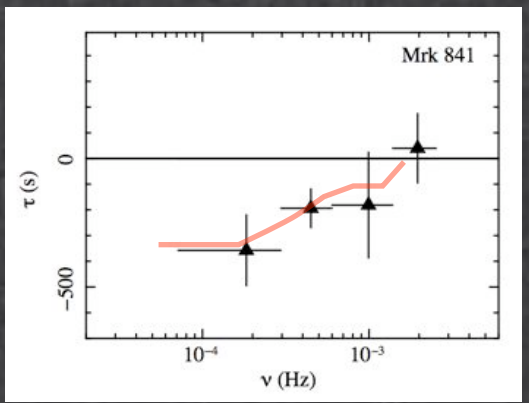
possibly present in all
AGN of the sample

10^6 **Mass** 10^8





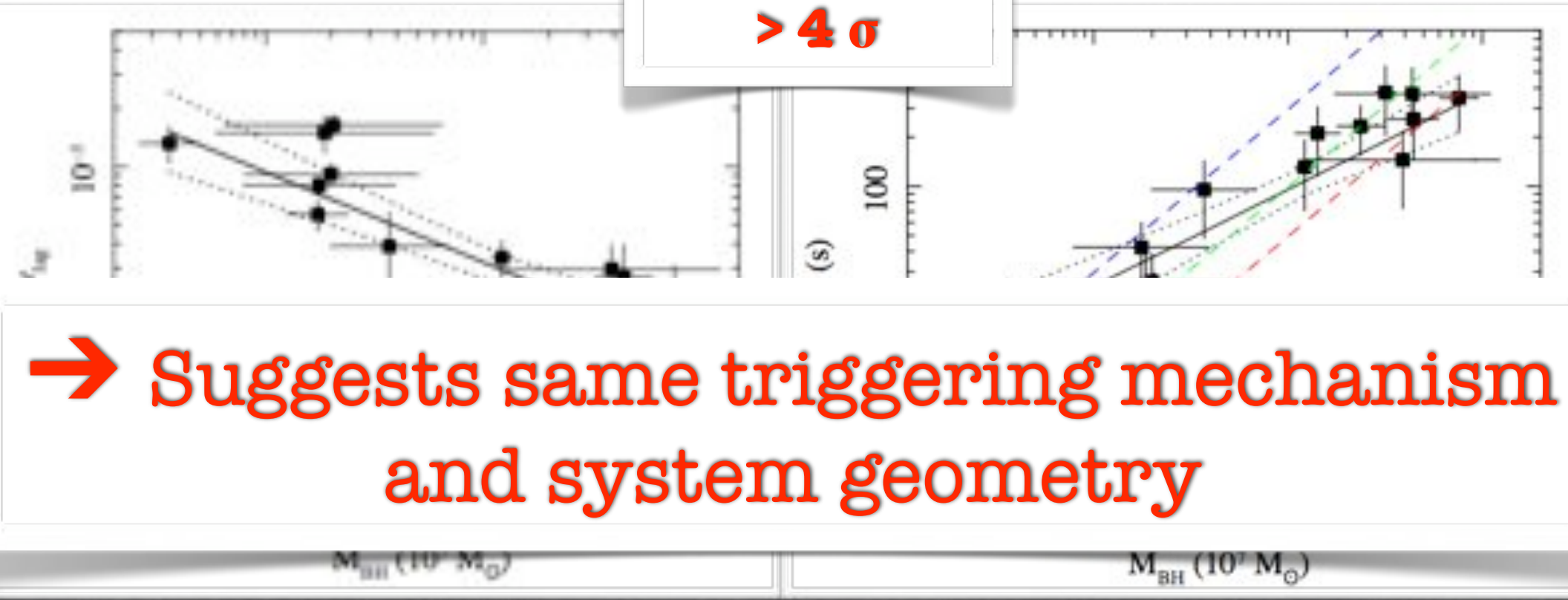




Mass-scaling of soft lags

[De Marco +13]

significance > 4 σ

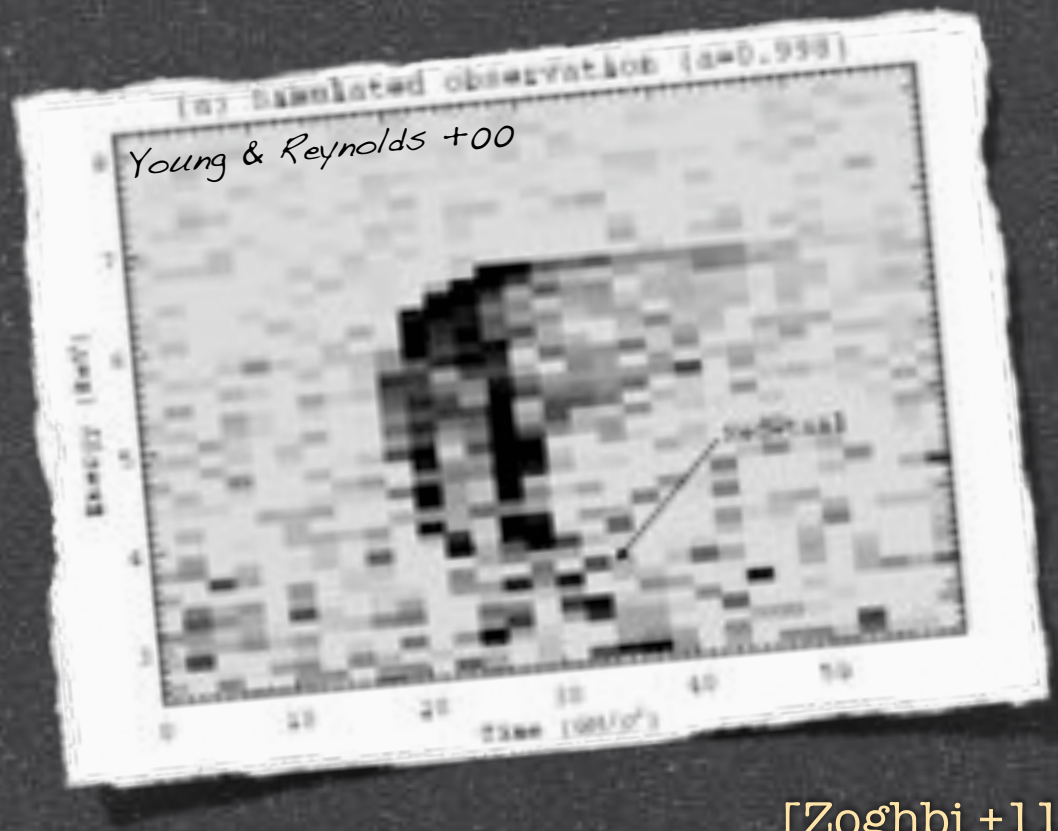


➔ Suggests same triggering mechanism and system geometry

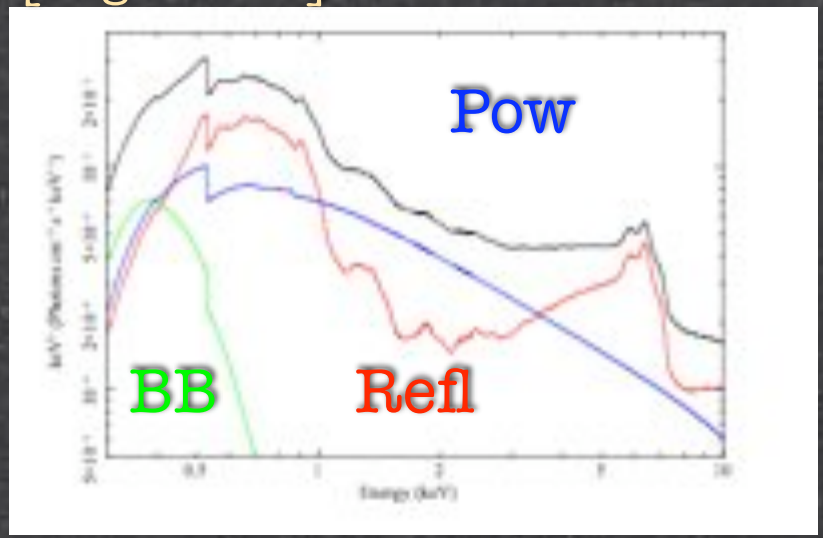
* Soft lags shift to lower frequencies/larger amplitudes as the BH mass increases

* Observed lag amplitudes ➔ very short distances

FeK band lags



[Zoghbi +11]

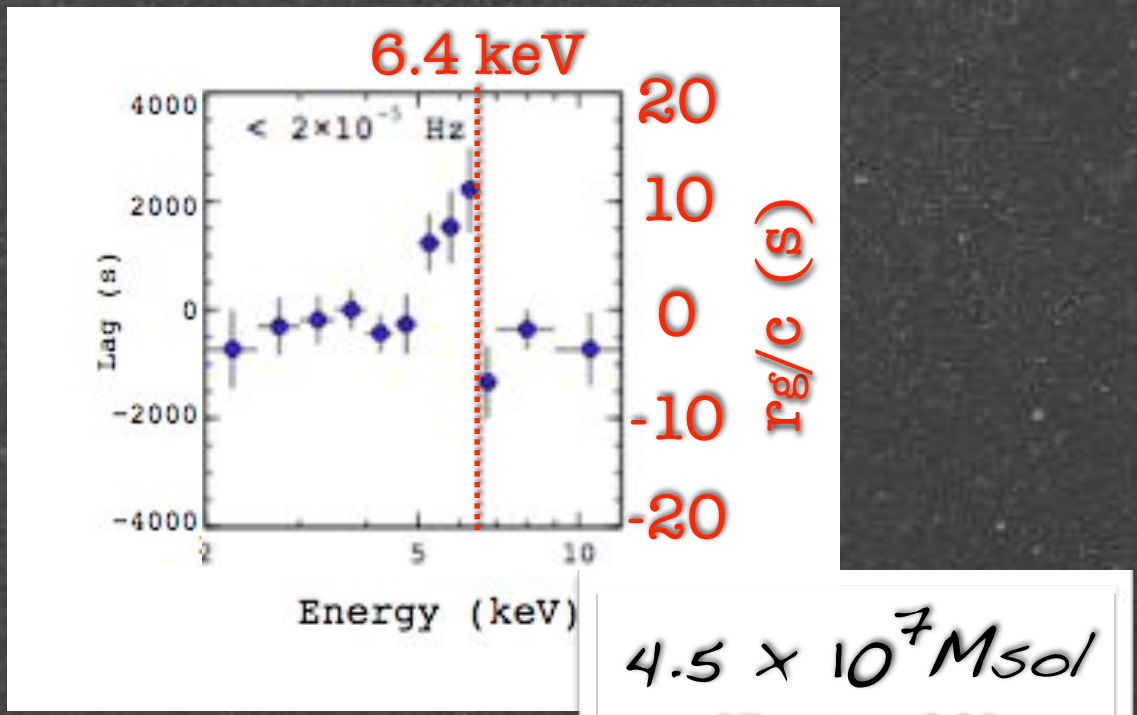


*Expected in a reverberation scenario

*Limited by low statistics

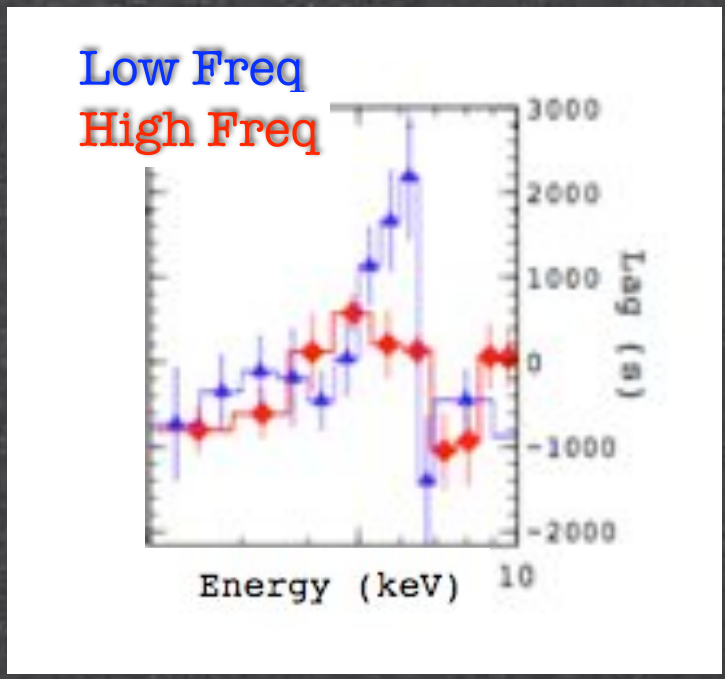
NGC 4151: first FeK lag

[Zoghbi +12]



$4.5 \times 10^7 M_{sol}$

[Bentz +06]



*Peak shifted below 6.4 keV

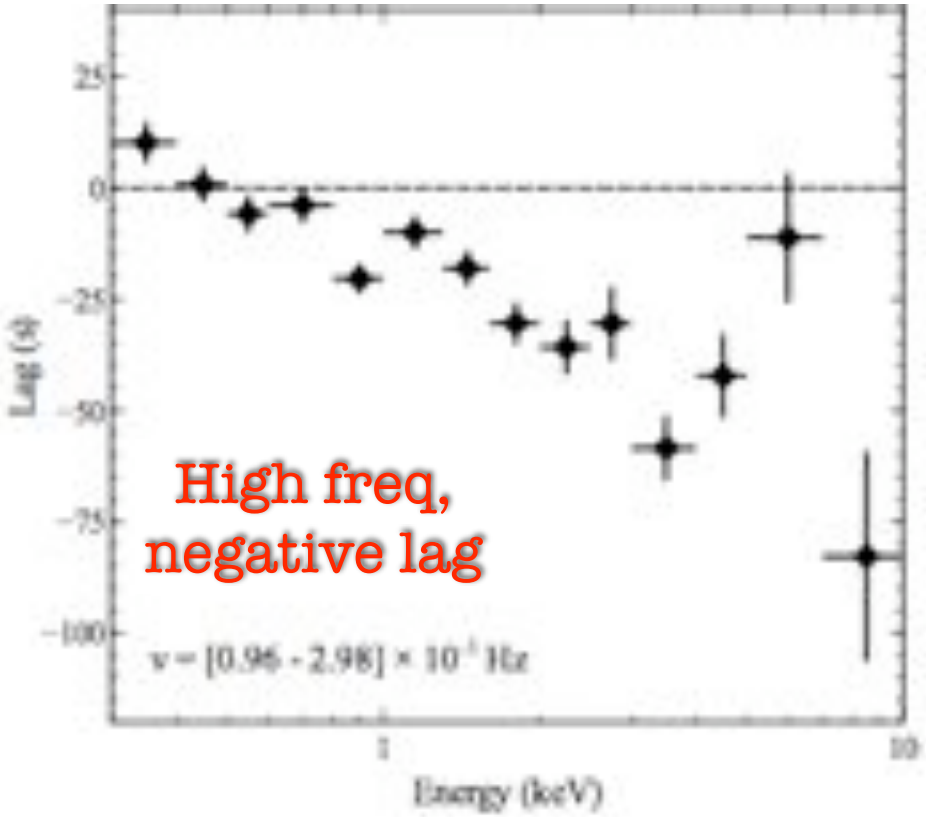
*Peak shifts to lower energies when high frequencies are probed

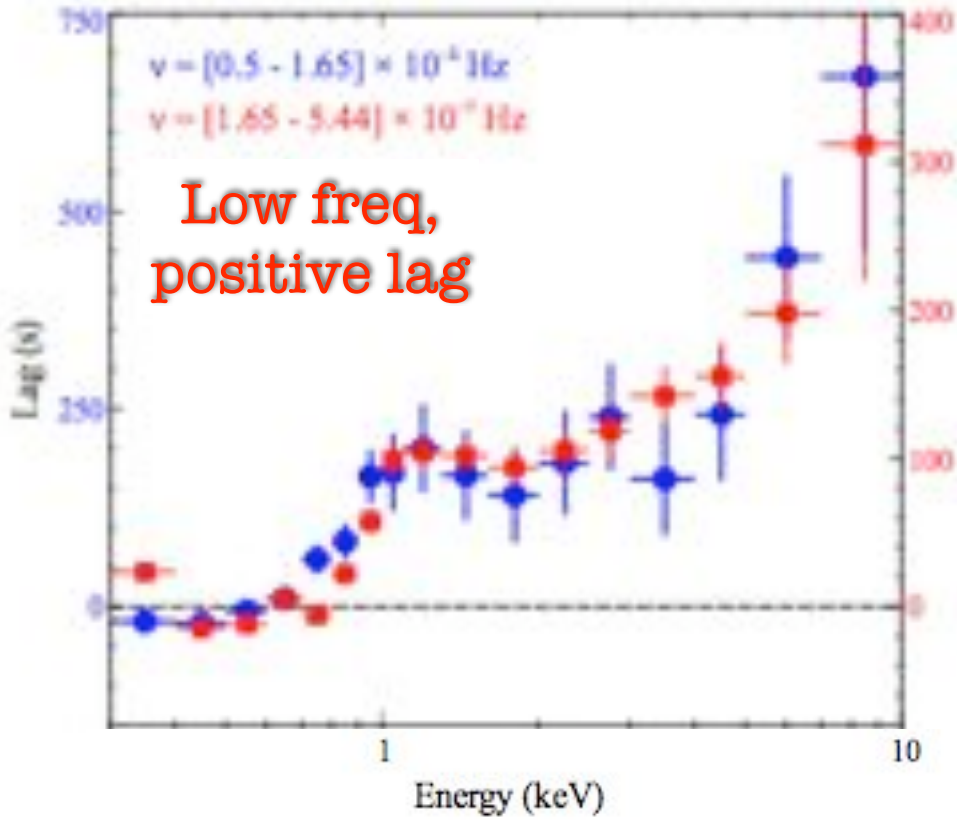
Red tail of the line originating at smaller radii

See also:
Zoghbi +13 (NGC7314, and MCG-5-23-16)

FeK lag in 1H0707-495

[Kara +13a]



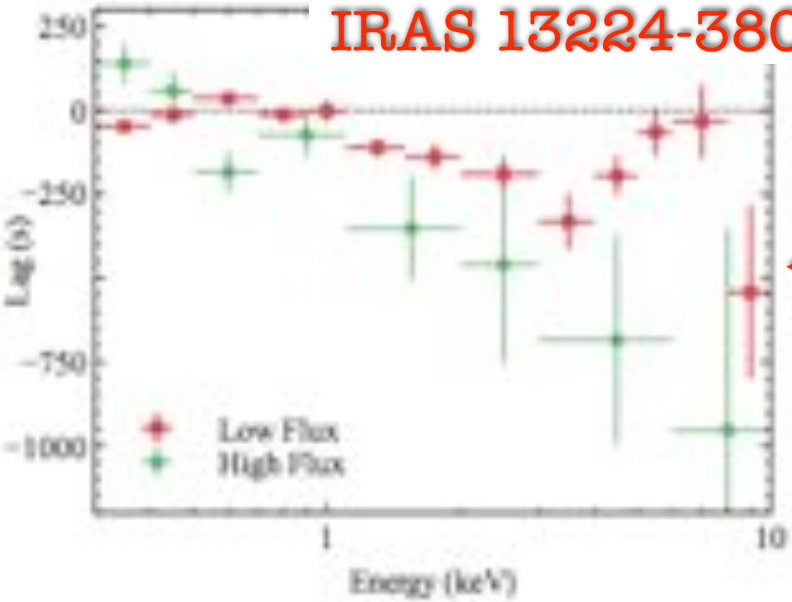


* 1.3 Ms data set of archived XMM Newton observations

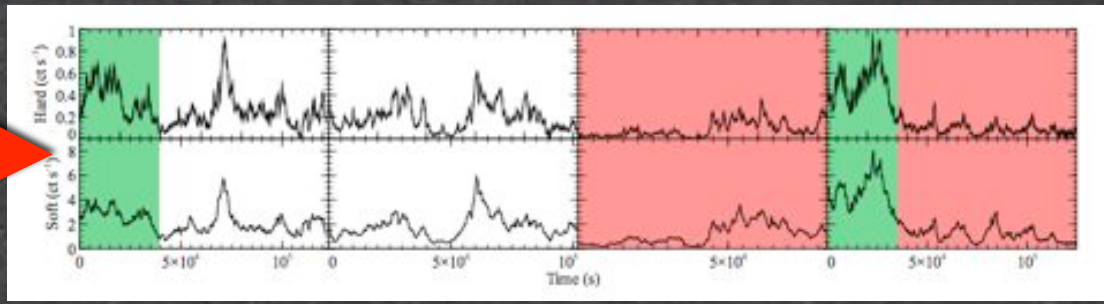
Lags varying with flux

*In sources with drastic flux changes (see talks by E. Kara and W. Alston)

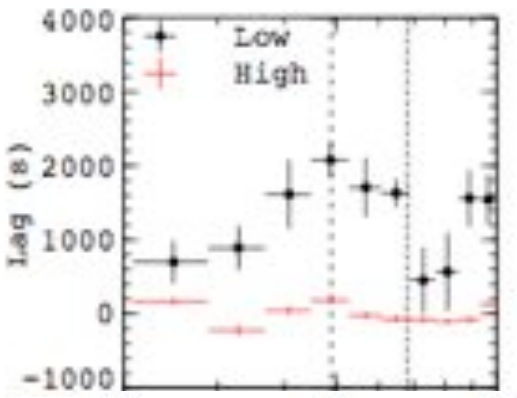
IRAS 13224-3809



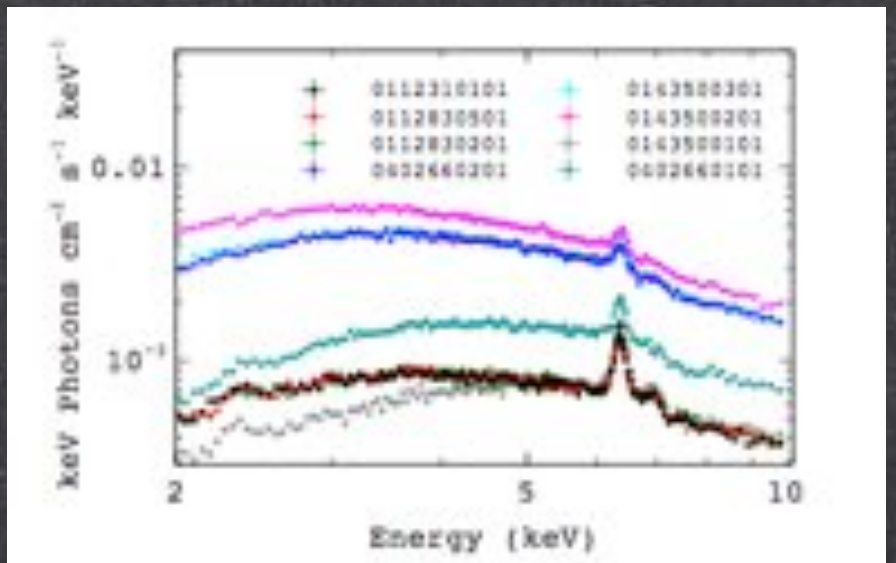
[Kara +13b]



NGC 4151



[Zoghbi +12]



Modeling X-ray lags

* What geometry can reproduce the observed variability properties and lags?

* Final aim: derive the transfer function
[Wilkins & Fabian 13, Legg +13,
see talk by E. Legg]

Summary

* **AGN show both (low frequency) hard and (high frequency) soft lags**

* **The hard lags have properties similar to those in XRBs**

* **Two models have been proposed for soft lags: inner disc reverberation, reverberation from a distant reflector**

* **The amplitude and frequency of soft lags show significant scaling with BH mass → similar triggering process and geometry in all radio quiet AGN**

* **Lags in the Fe K band have been observed in a few sources, where it has been possible to study them**

* **For those sources showing drastic flux variations, the lag varies with flux**