Soft X-ray lags

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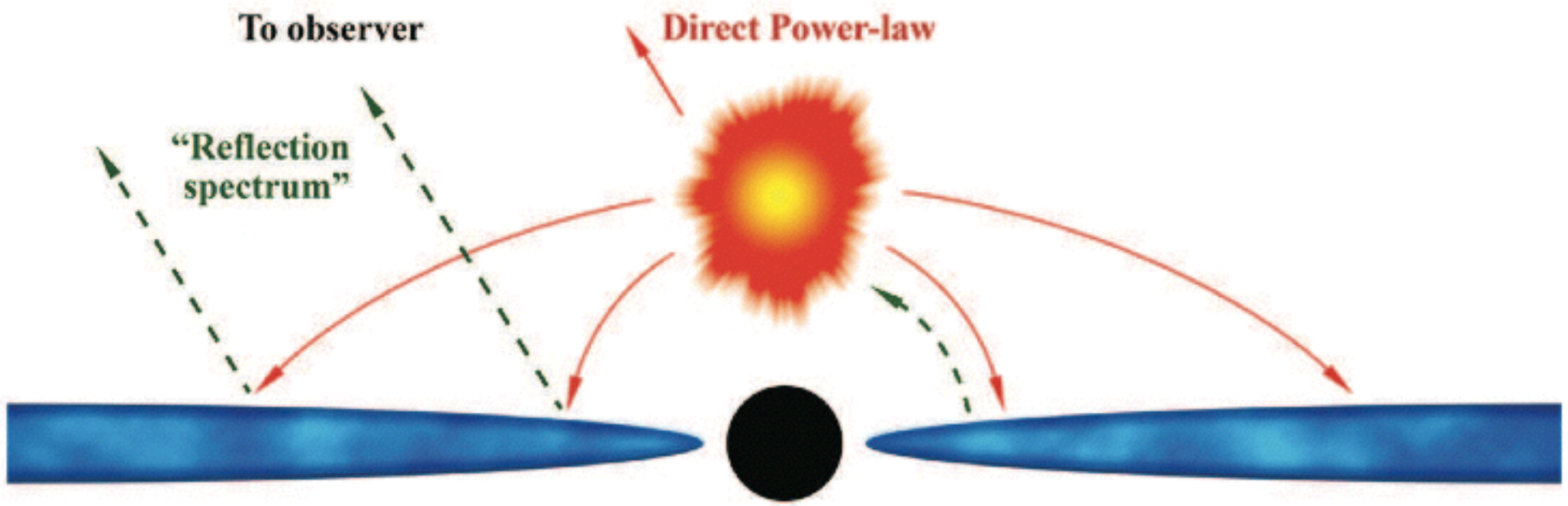
Overview

- *Scientific background and first detections*
- *Observational properties*
- *Interpretation*

Scientific background

X-ray time lags

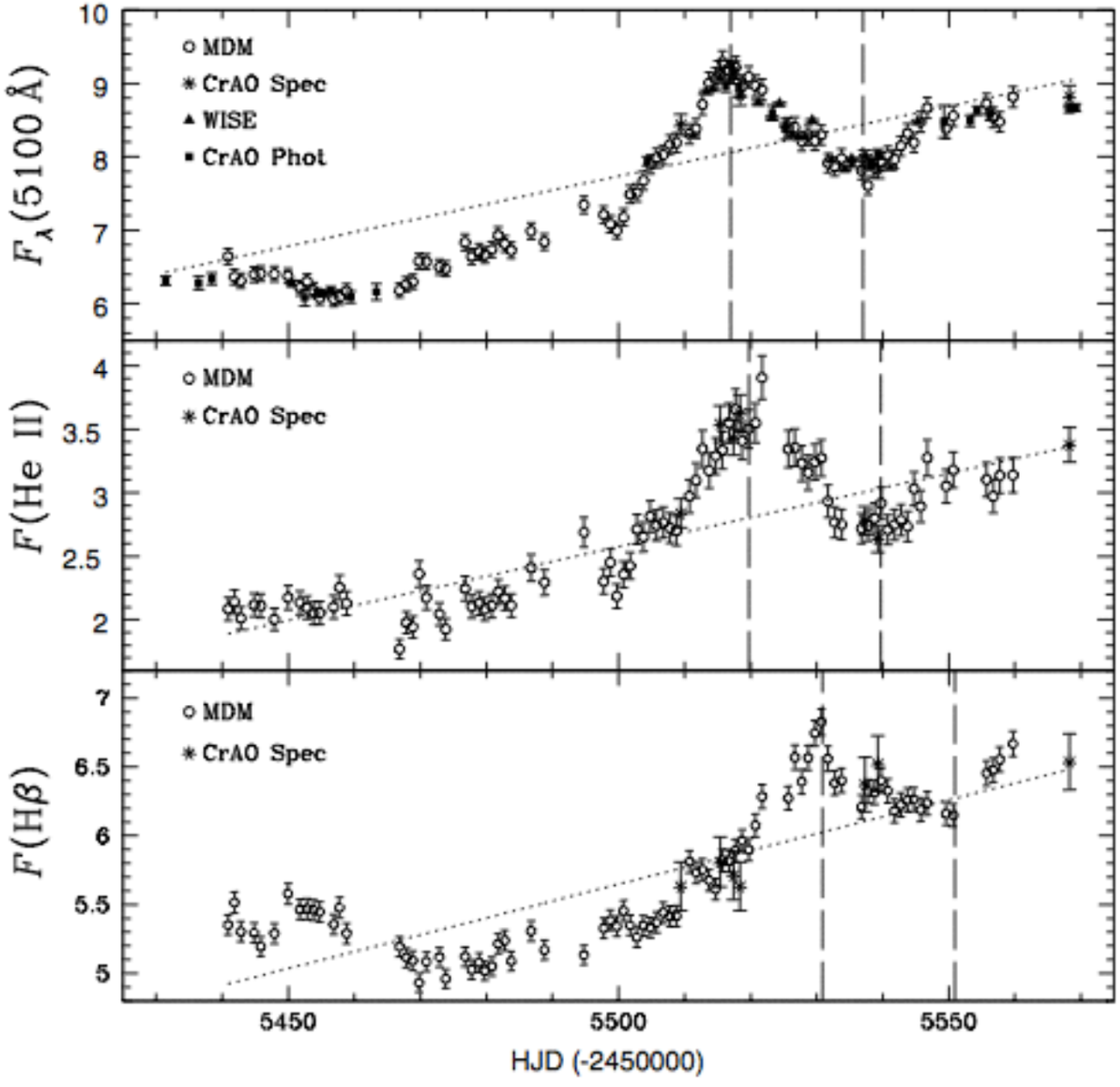


[from Uttley et al. 2014]

Time lags imply the presence of coherent variations in two different energy bands, with (a fraction of) the emission in one band delayed by a given amount of time (as a consequence of reprocessing/scattering).

Time lags and geometry

Mrk 335



[Grier et al. 2012]

Emission line response to continuum variations is used to infer the kinematics and geometry of the BLR

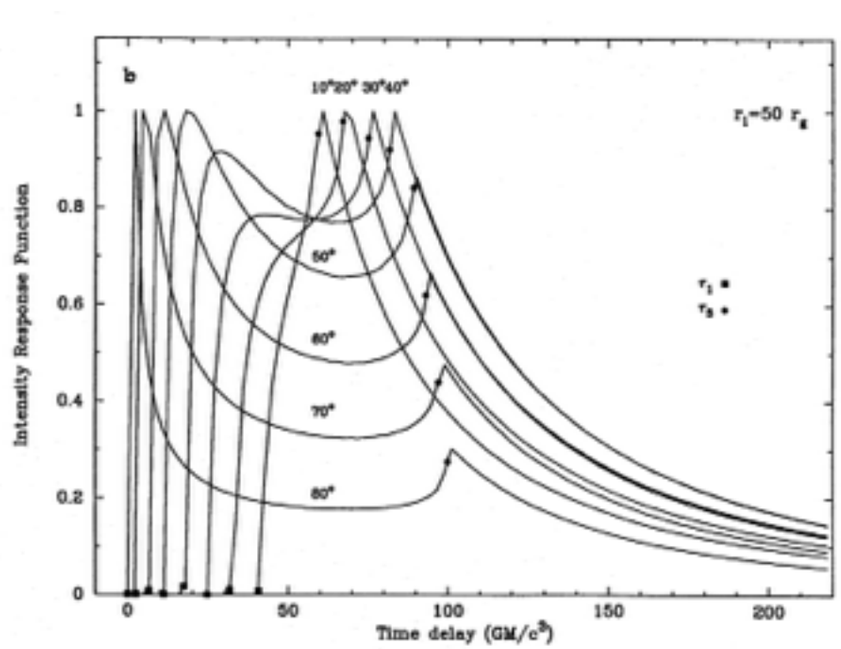
Reverberation mapping

time scales~ several days

Information we can get…

Transfer function ➔ *response of the reprocessing medium to an instantaneous flash of light*

1. ***Distance***
2. ***Geometry***
3. ***Origin of secondary emission***

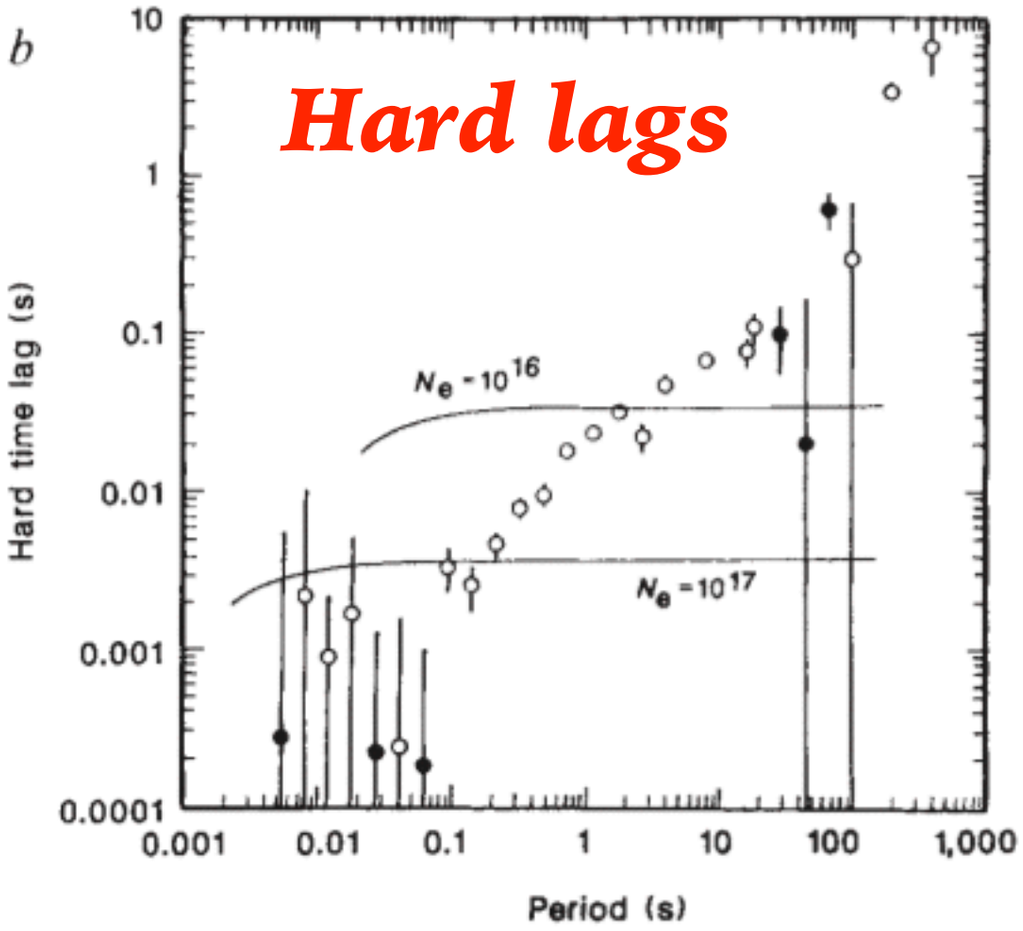


[Campana & Stella 1995]

First detections

Time lags in accreting BHs

First detection: Cygnus X-1 *[Miyamoto et al. 1988]*



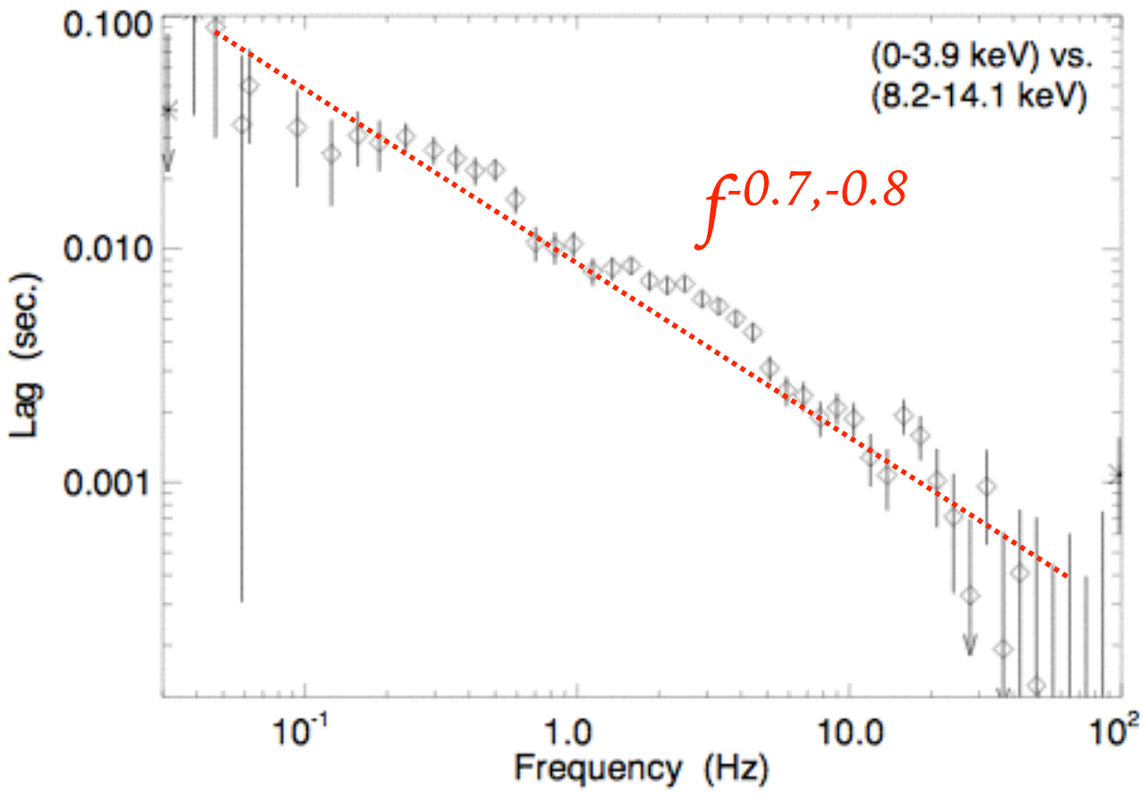
and 1.2–5.7 keV are in the range 0.01–1.0 radian. (2) The hard X-ray delay time between 15.8–24.4-keV and 1.2–5.7-keV X-rays is ~2 ms for a period of ~0.1 s, and the delay time increases almost linearly up to several seconds for a period of ~300 s.

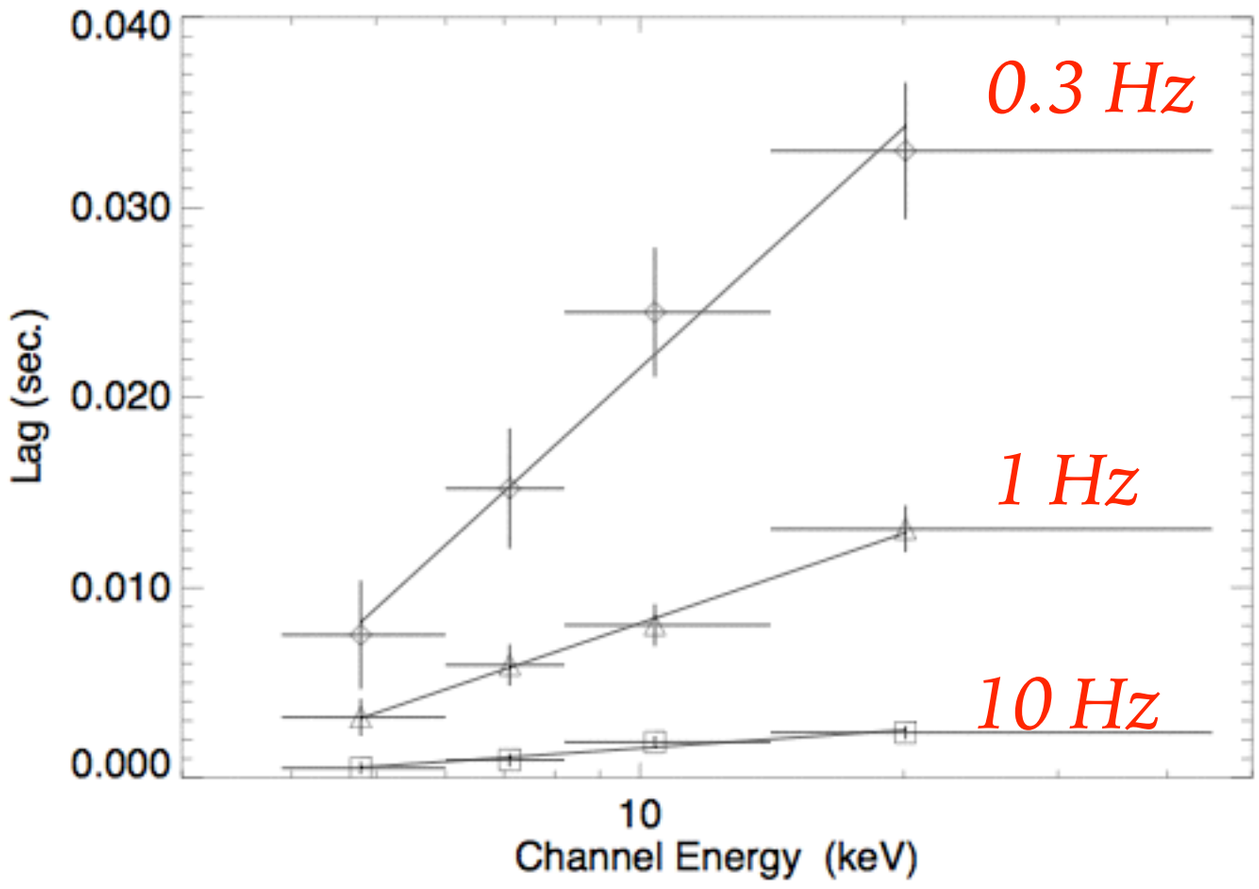
passed by the observations. As the energy separation of the two bands increases the hard X-ray lag increases. On average, the

Time lags in BHBs

Hard lags are common in BHBs

[e.g. Miyamoto et al. 1992, Nowak et al. 1999, Pottschmidt et al. 2000]

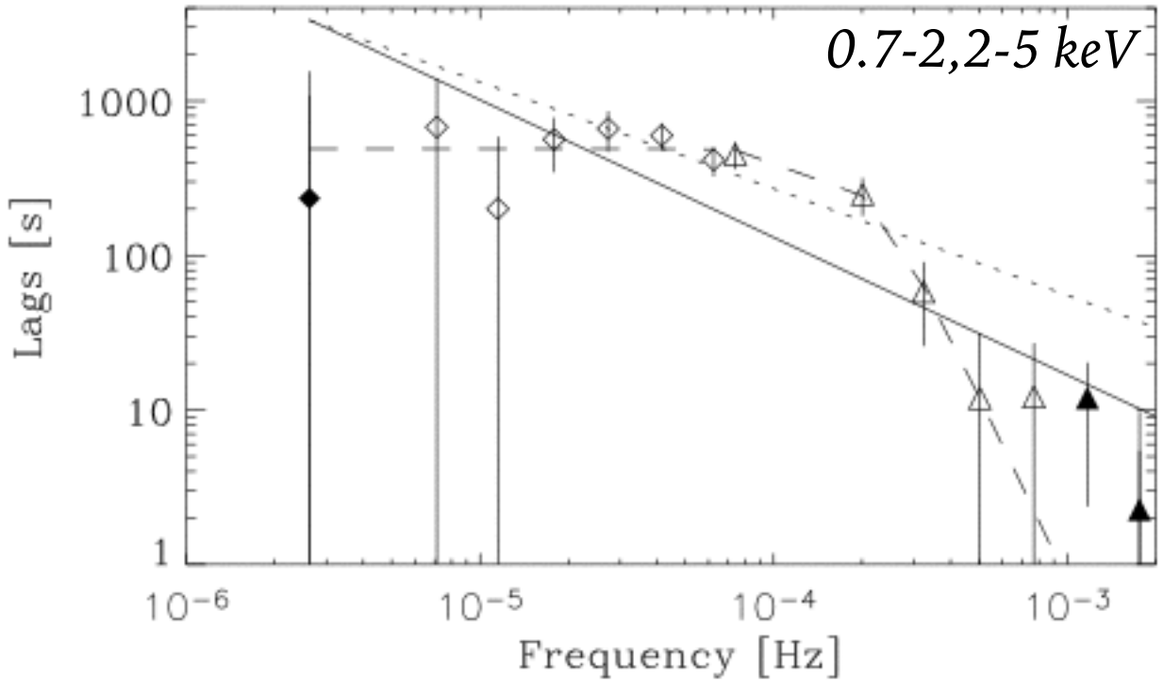




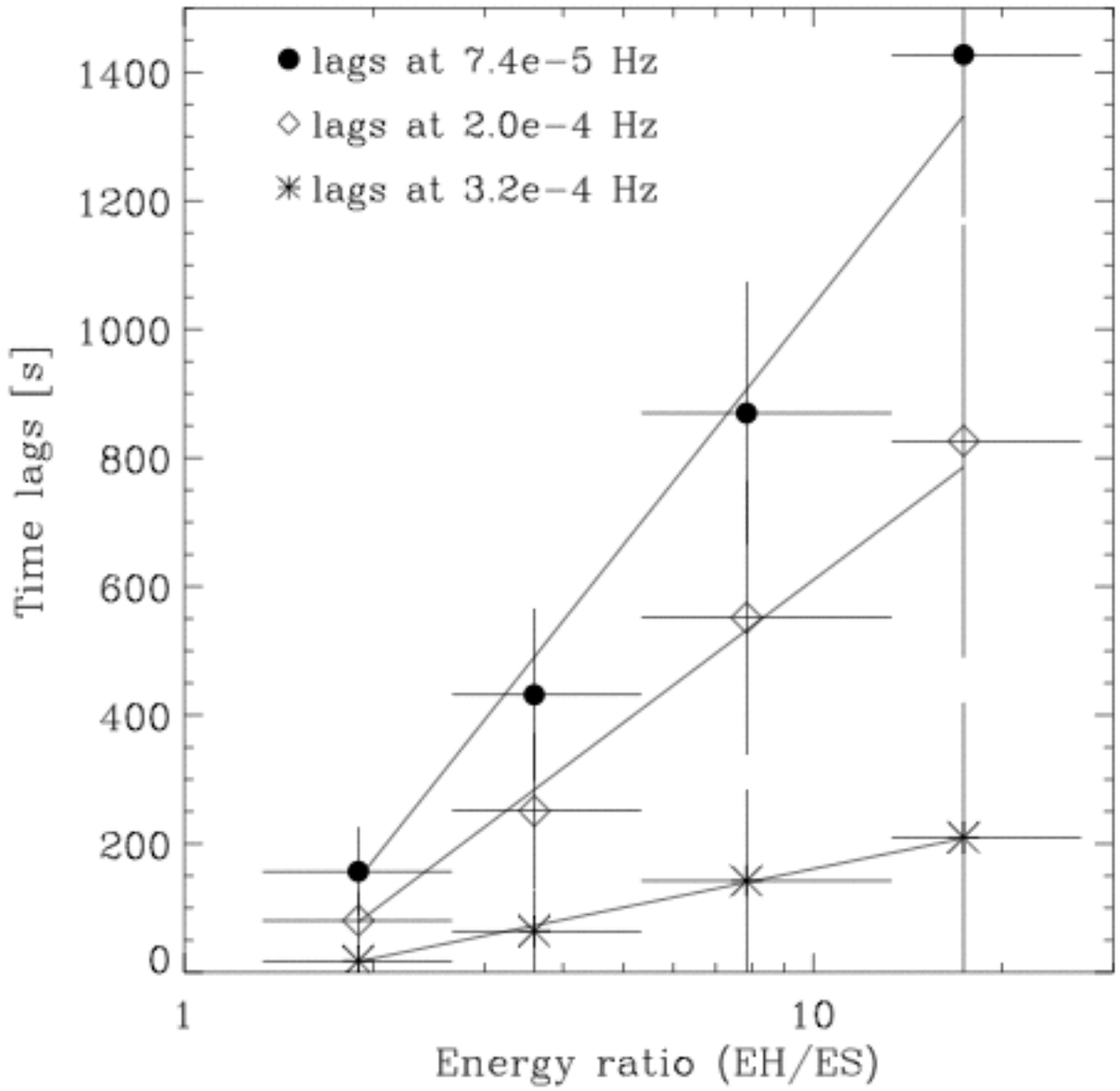
Time lags in AGN

First detection: NGC 7469 *[Papadakis et al. 2001]*

Ark 564



[Arevalo et al. 2006]



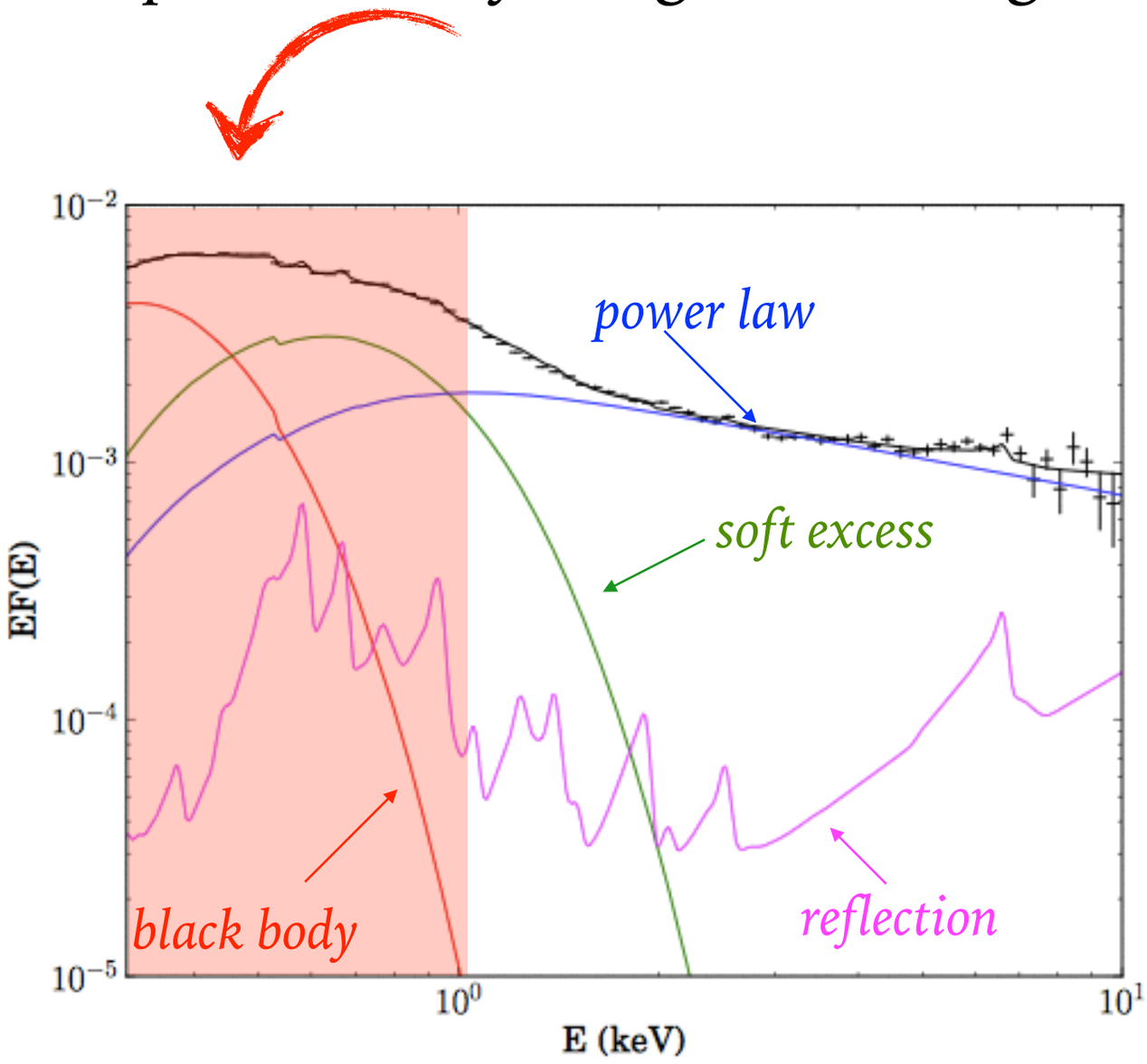
Similar physical origin, but longer time scales (as expected)

e.g. inward propagation of mass accretion rate fluctuations

[Lyubarski 1997, Kotov et al. 2001, Arevalo & Uttley 2006]

Note!

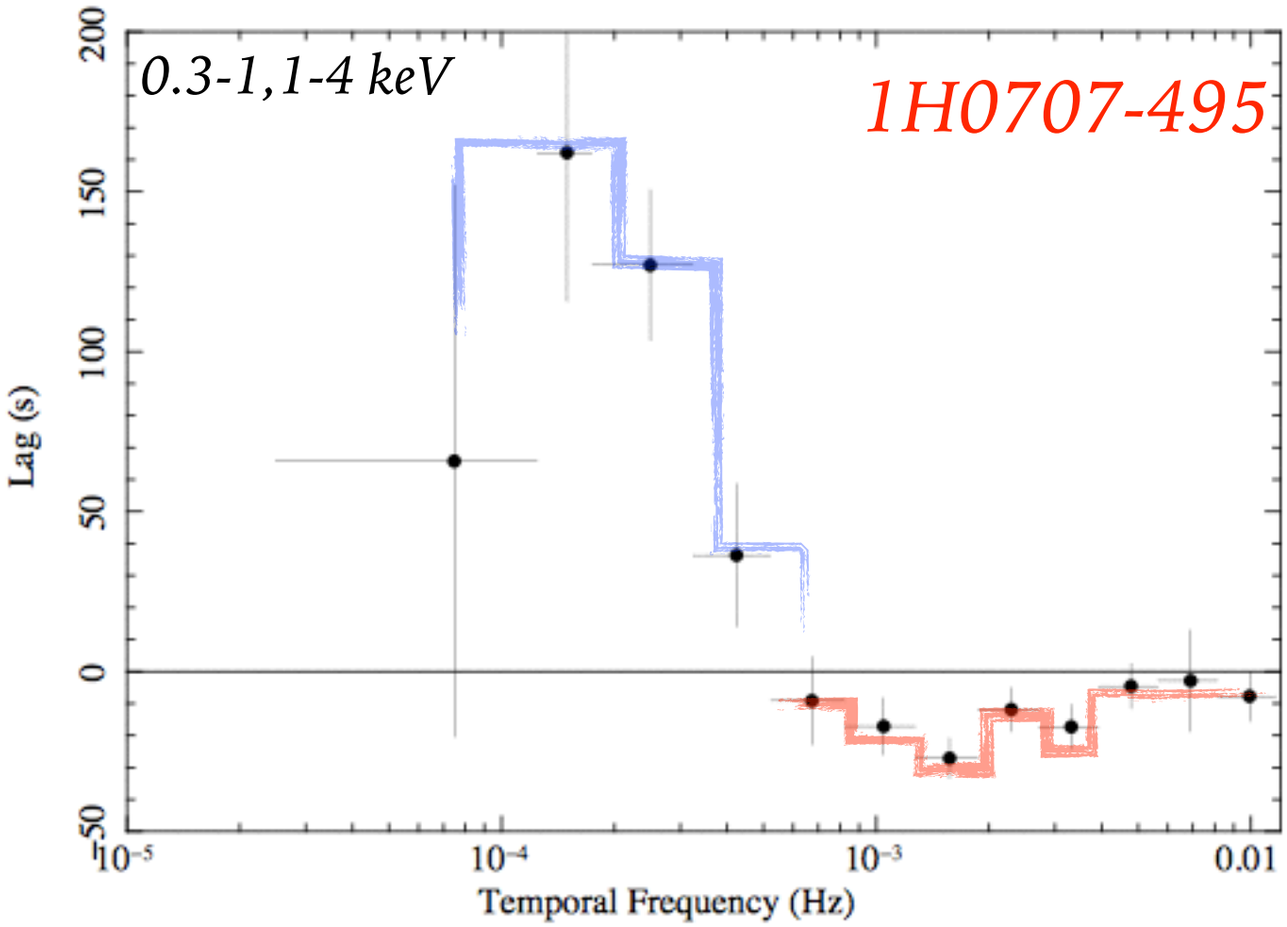
XMM-Newton opened the way to high S/N timing studies in the soft band

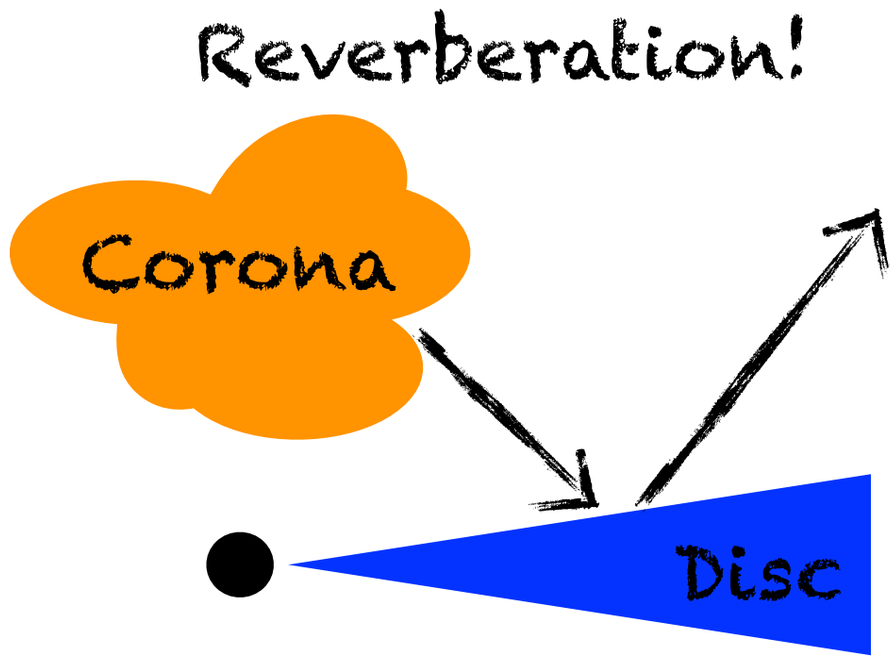


High frequency soft lags - first detections

McHardy et al. 2007 *tentative detection in Ark 564*

Fabian et al. 2009 *>5σ detection in 1H0707-495*

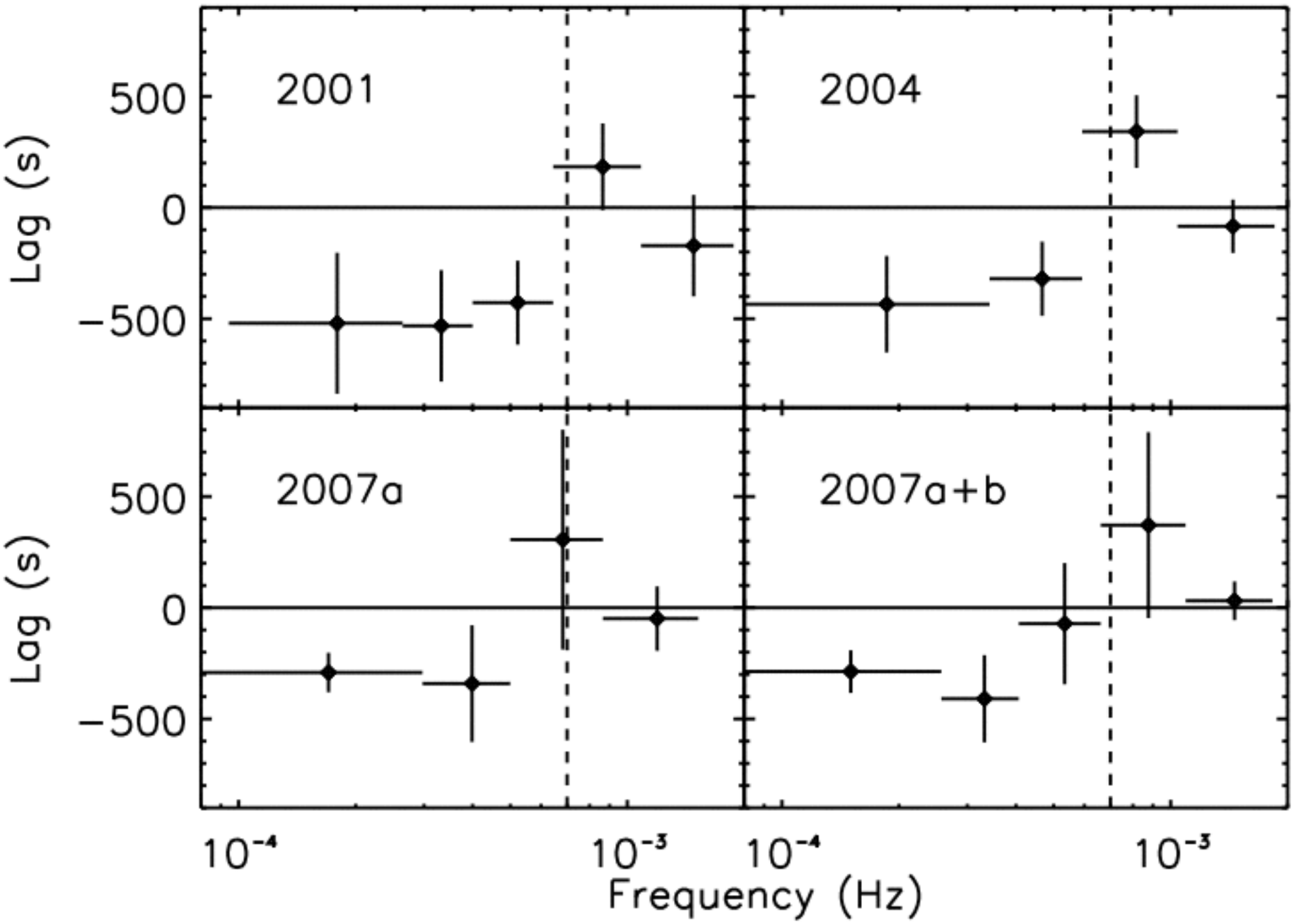




Emmanoulopoulos et al. 2011 *soft lag in MCG-6-30-15 and Mrk 766*

Observational properties

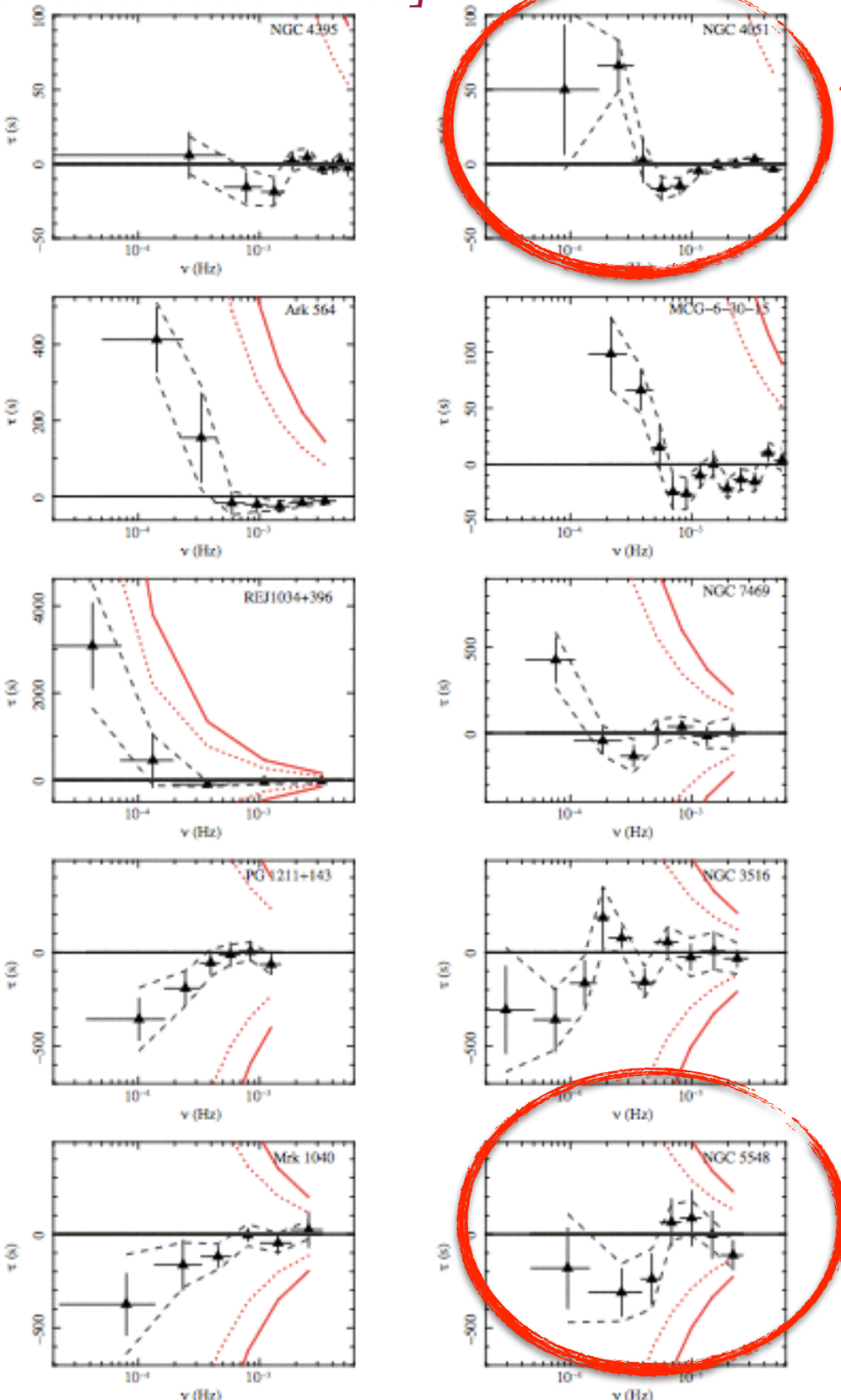
PG 1211+143



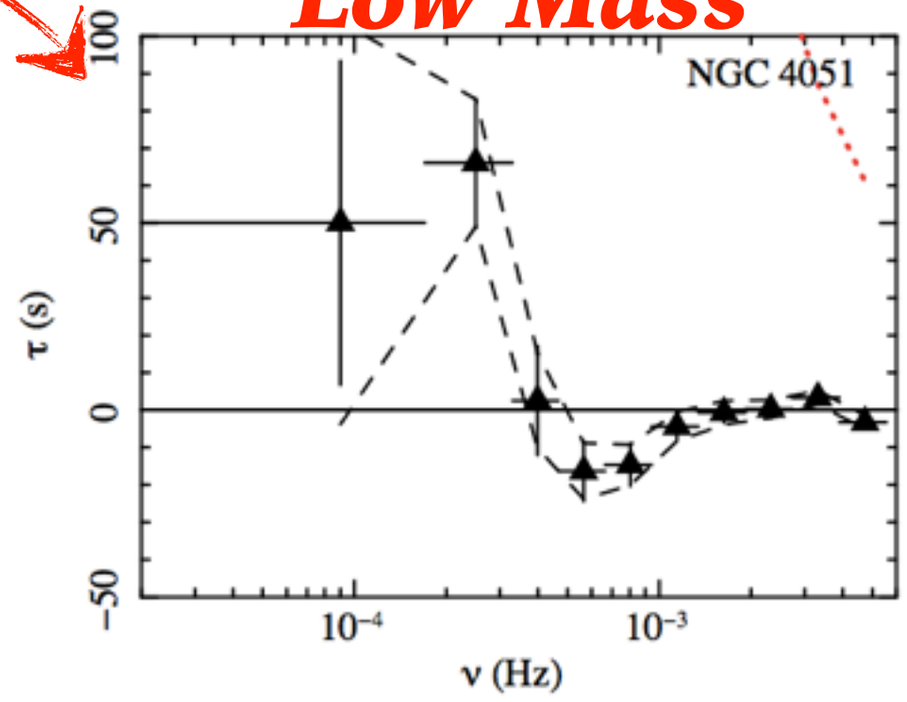
[De Marco et al. 2011]

Soft lags - systematic detections

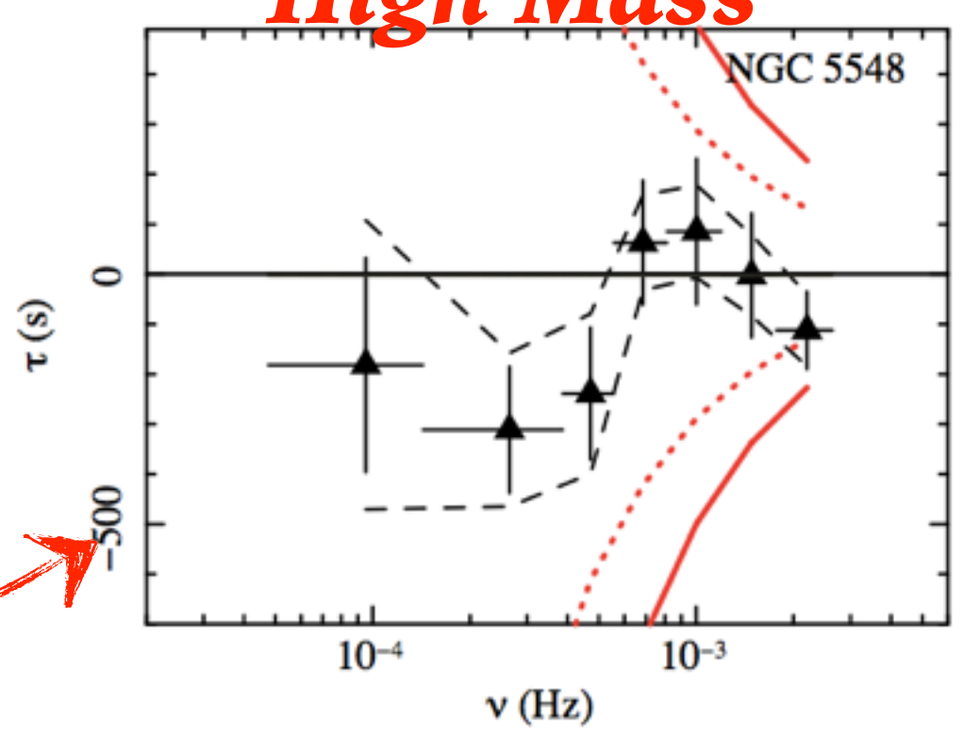
[De Marco et al. 2013a]



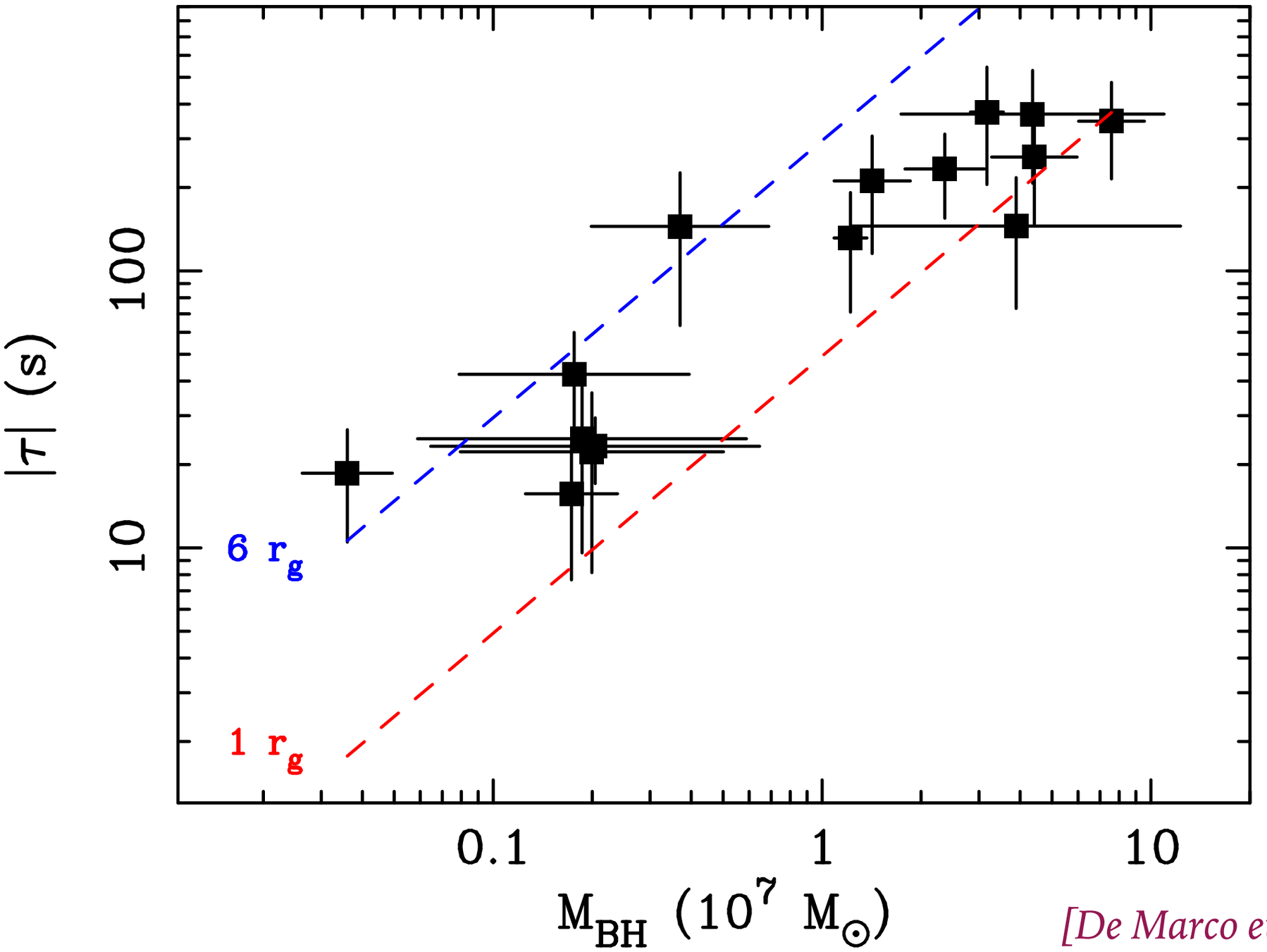
Low Mass



High Mass



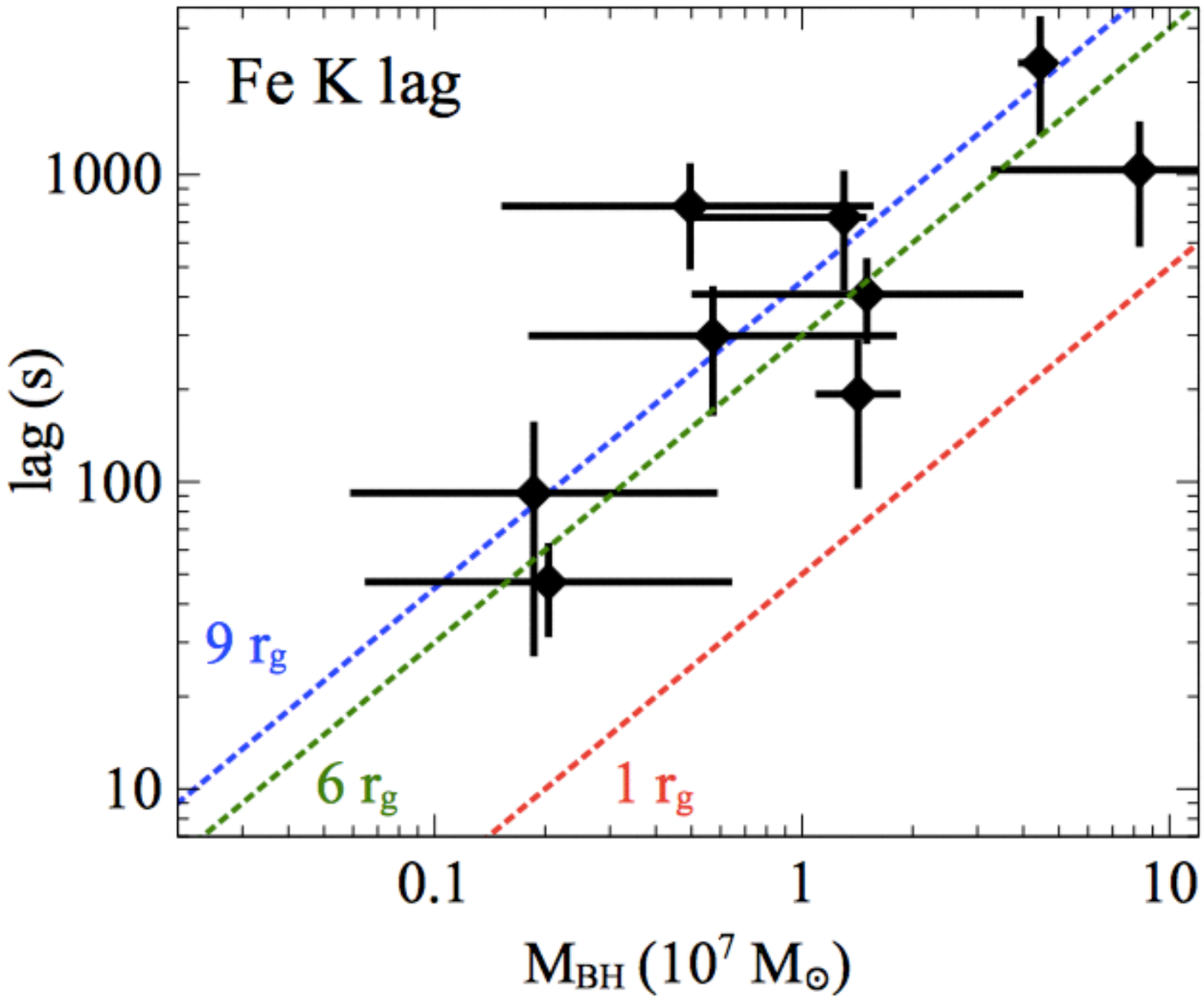
Soft lags - correlation with mass



[De Marco et al. 2013a]

…same correlation between lag frequency and mass

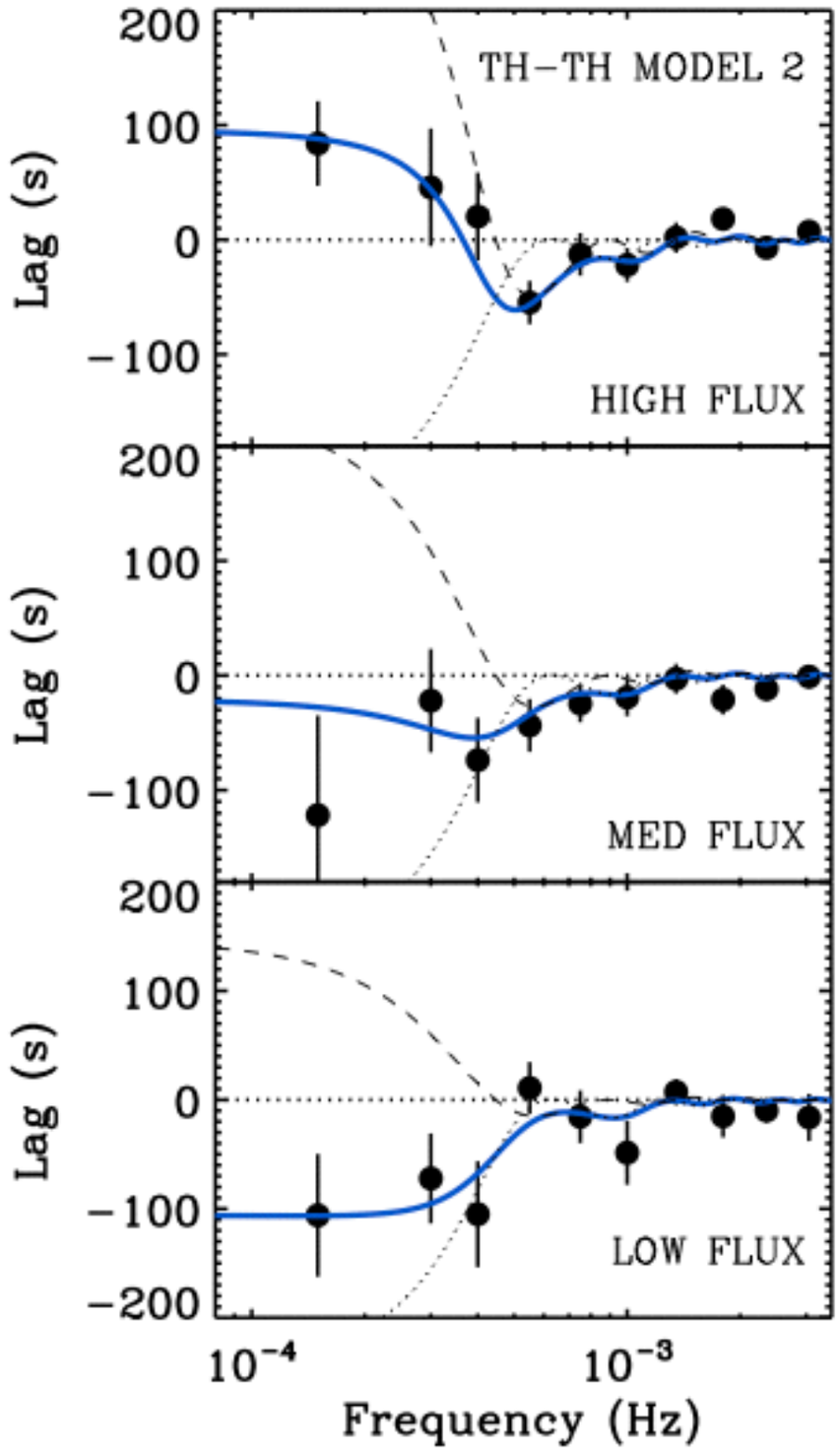
Fe K lags - correlation with mass

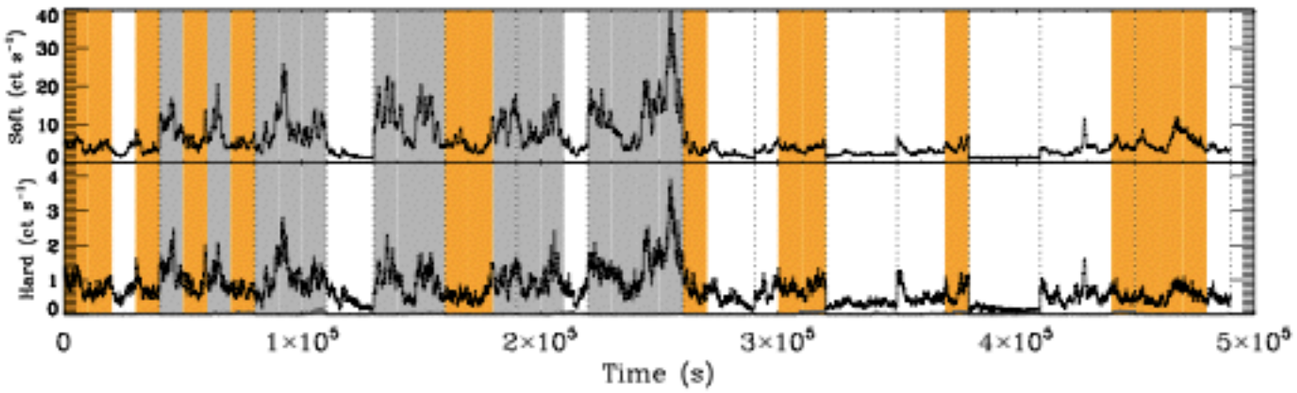


[Zoghbi et al. 2012, Kara et al. 2013a,b]

Soft lags - flux dependence

NGC 4051





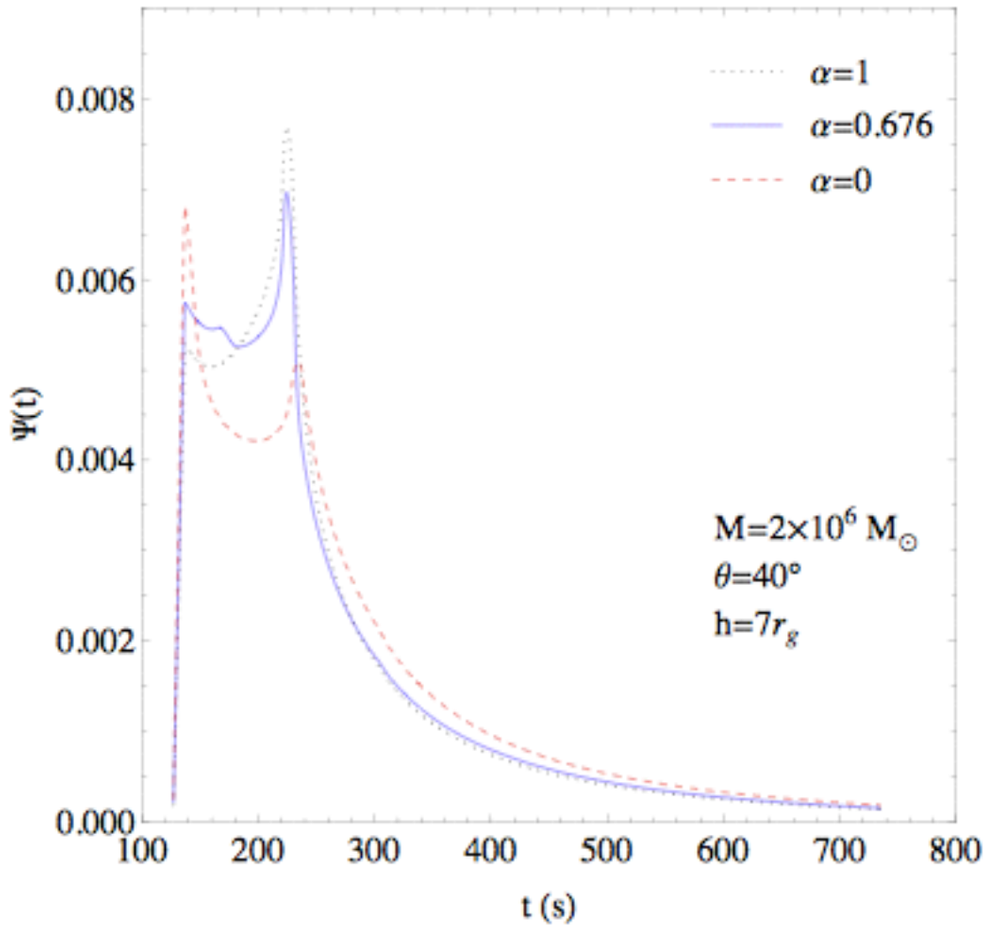
[Alston et al. 2013, see also Kara et al. 2013c + Kara's and Alston's talks]

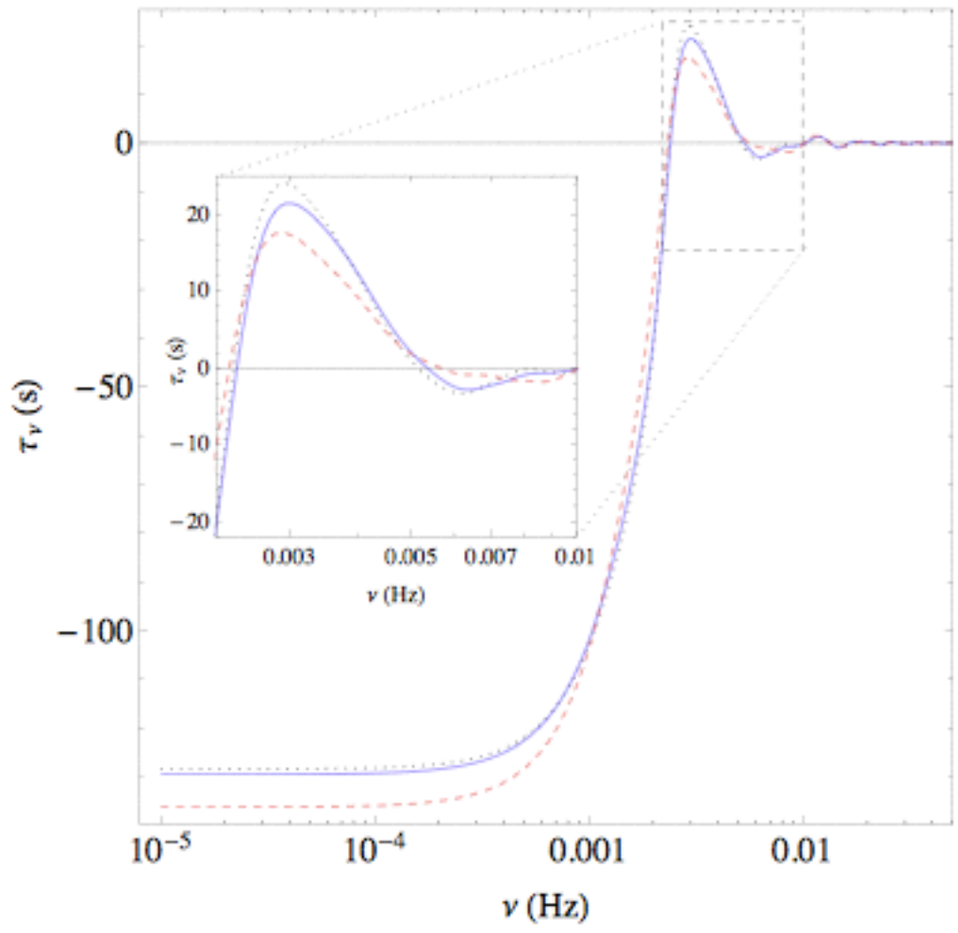
Interpretation

Modelling

[Miller et al. 2010, Legg et al. 2012, Chainakun & Young 2012, Wilkins & Fabian 2013, Cackett et al. 2014, Emmanoulopoulos et al. 2014, Gardner & Done 2014, + Dovciak's talk]

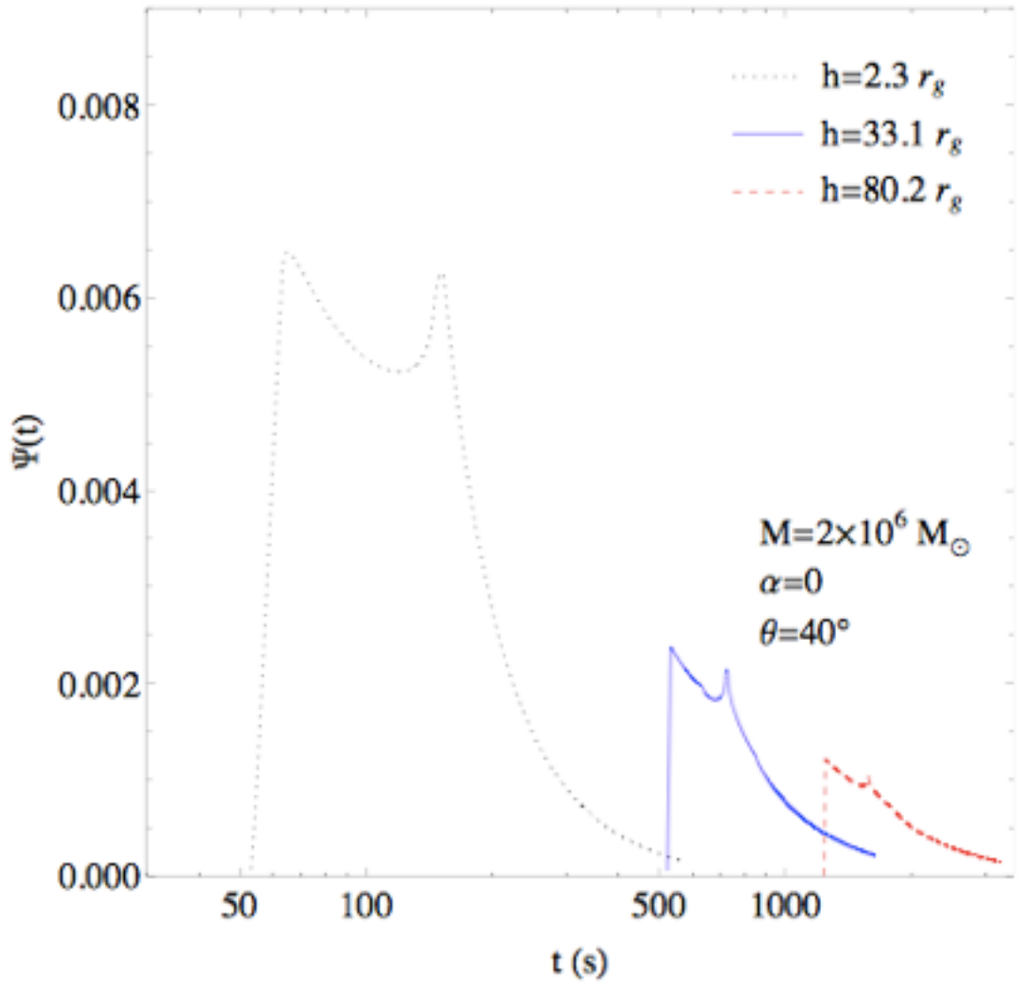
Spin

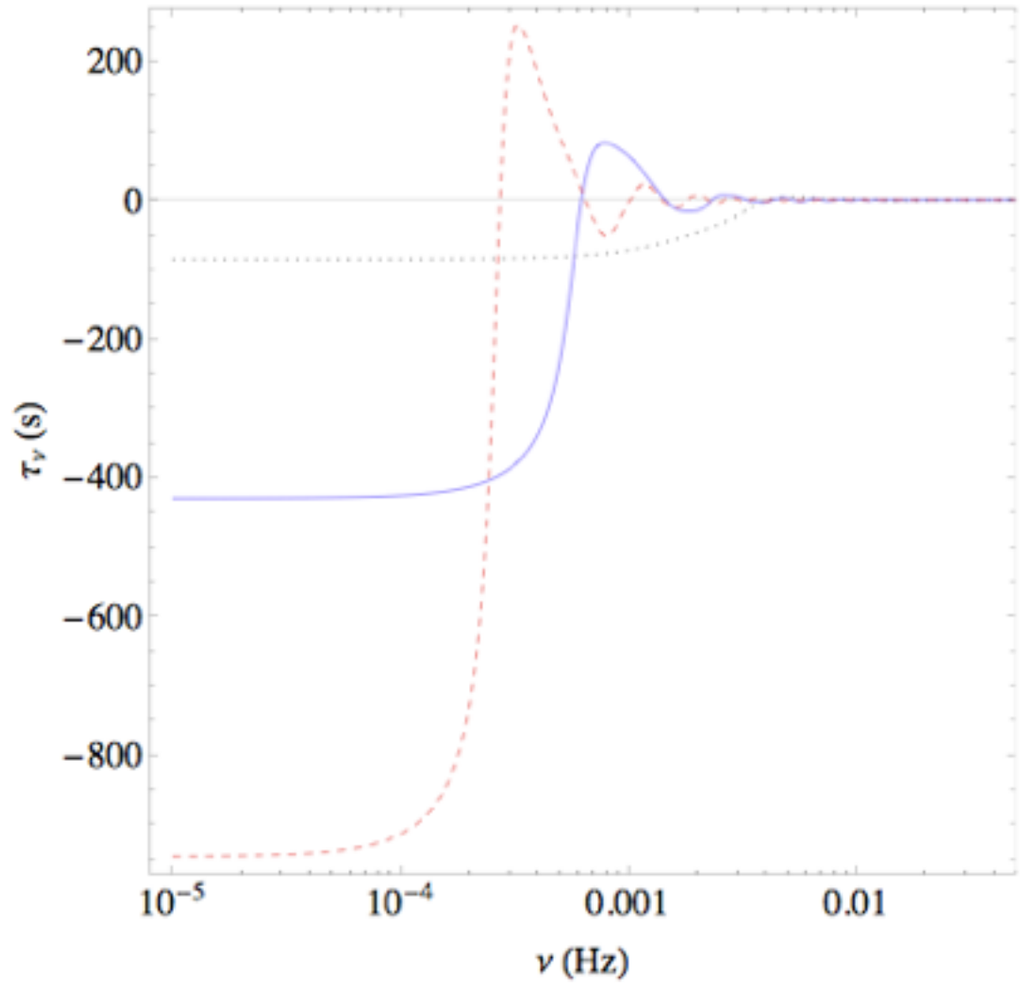




[Emmanoulopoulos et al. 2014]

Height

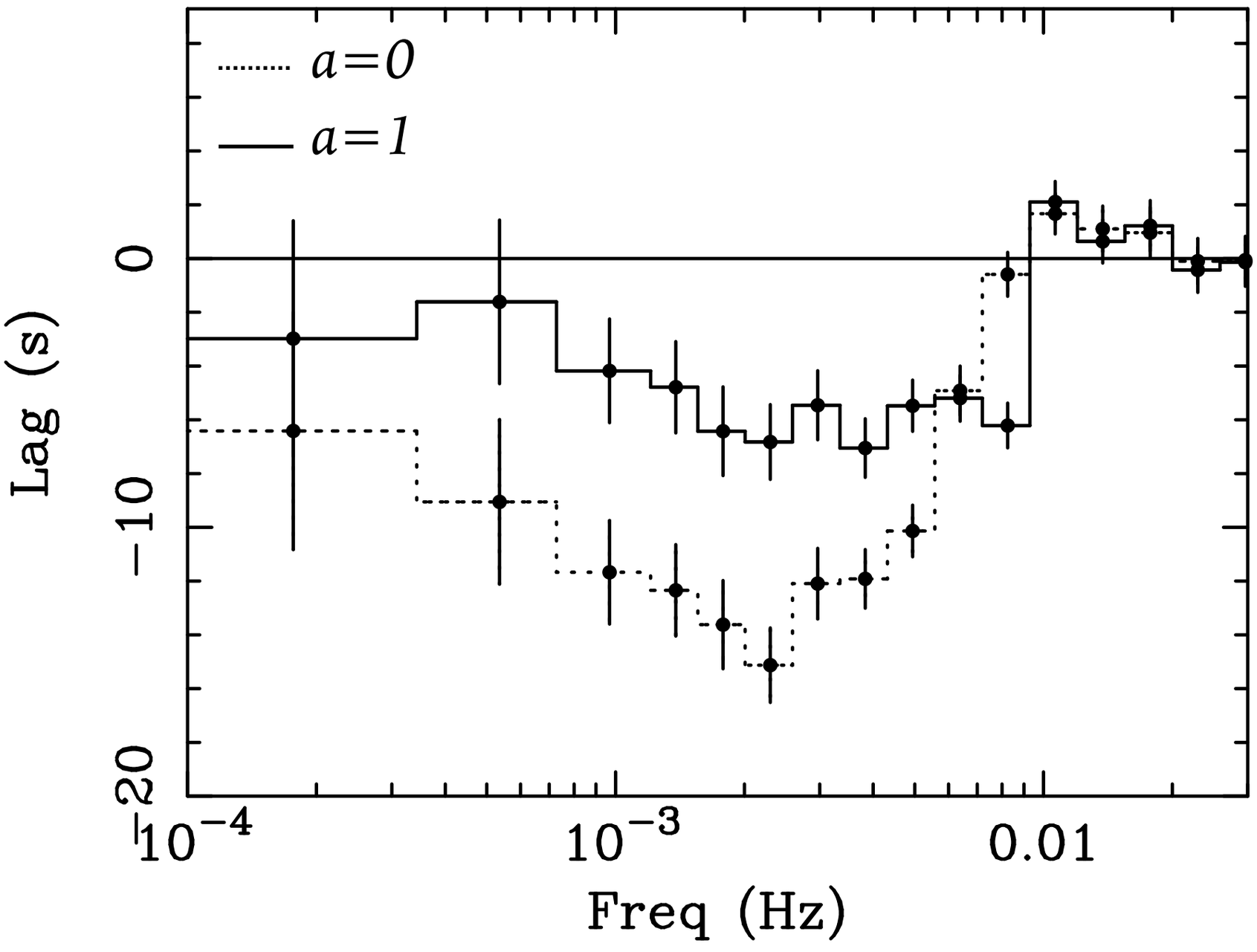




best fit ➔ 4 rg

[Emmanoulopoulos et al. 2014]

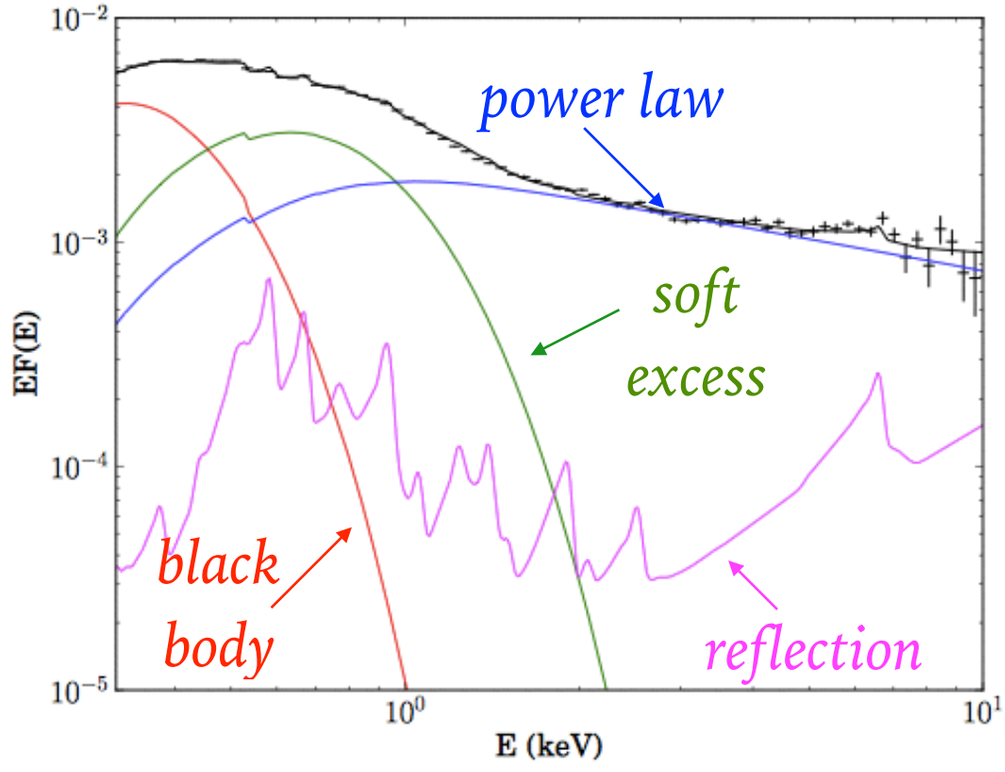
Athena



Soft vs FeK lags: same or different origin?

Reflection ➔ both lags correlate with BH mass, and map the similar time scales

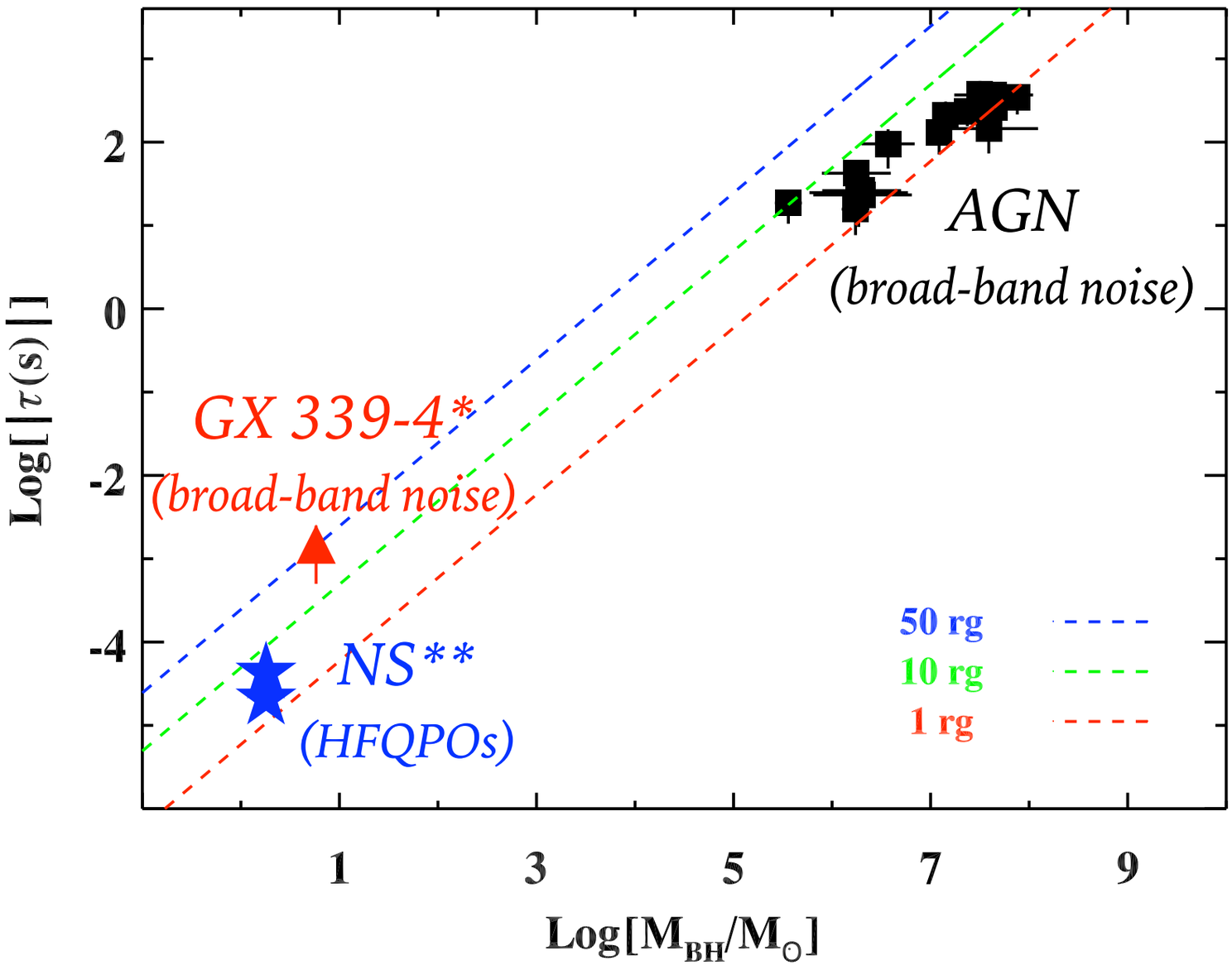
However, the soft band spectrum is very complex…



Comptonisation/thermal reverberation *[PG1244+026 Gardner & Done 2014]*

Absorption *[early attempts by Miller et al. 2010, Legg et al. 2012, new studies by Silva, Uttley & Costantini]*

Soft lags in AGN vs stellar mass sources

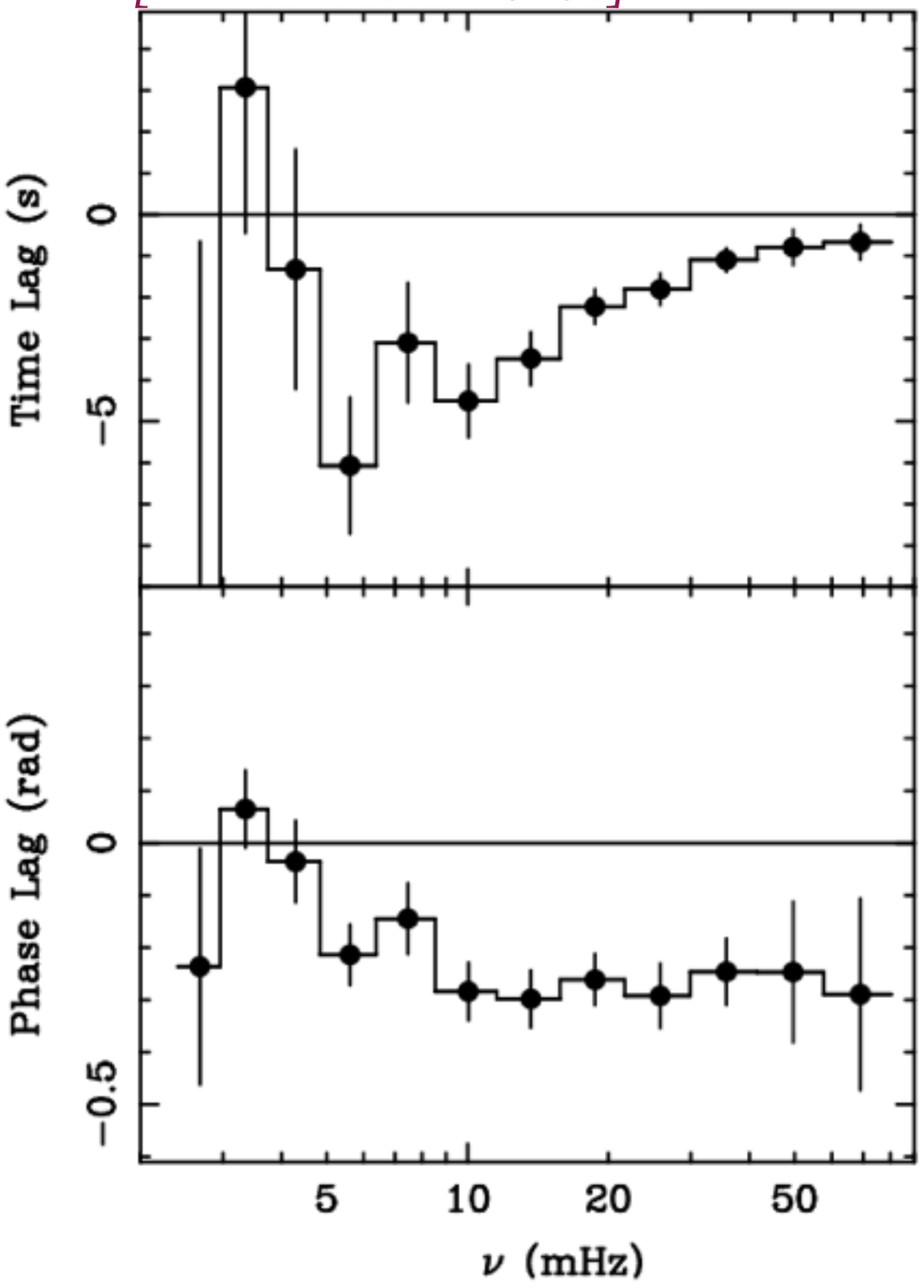


* *[Uttley et al. 2011]*

** *[Vaughan et al. 1998, Kaaret et al. 1999, deAvellar et al. 2013, Barret et al. 2013]*

ULXs: NGC 5408 X-1

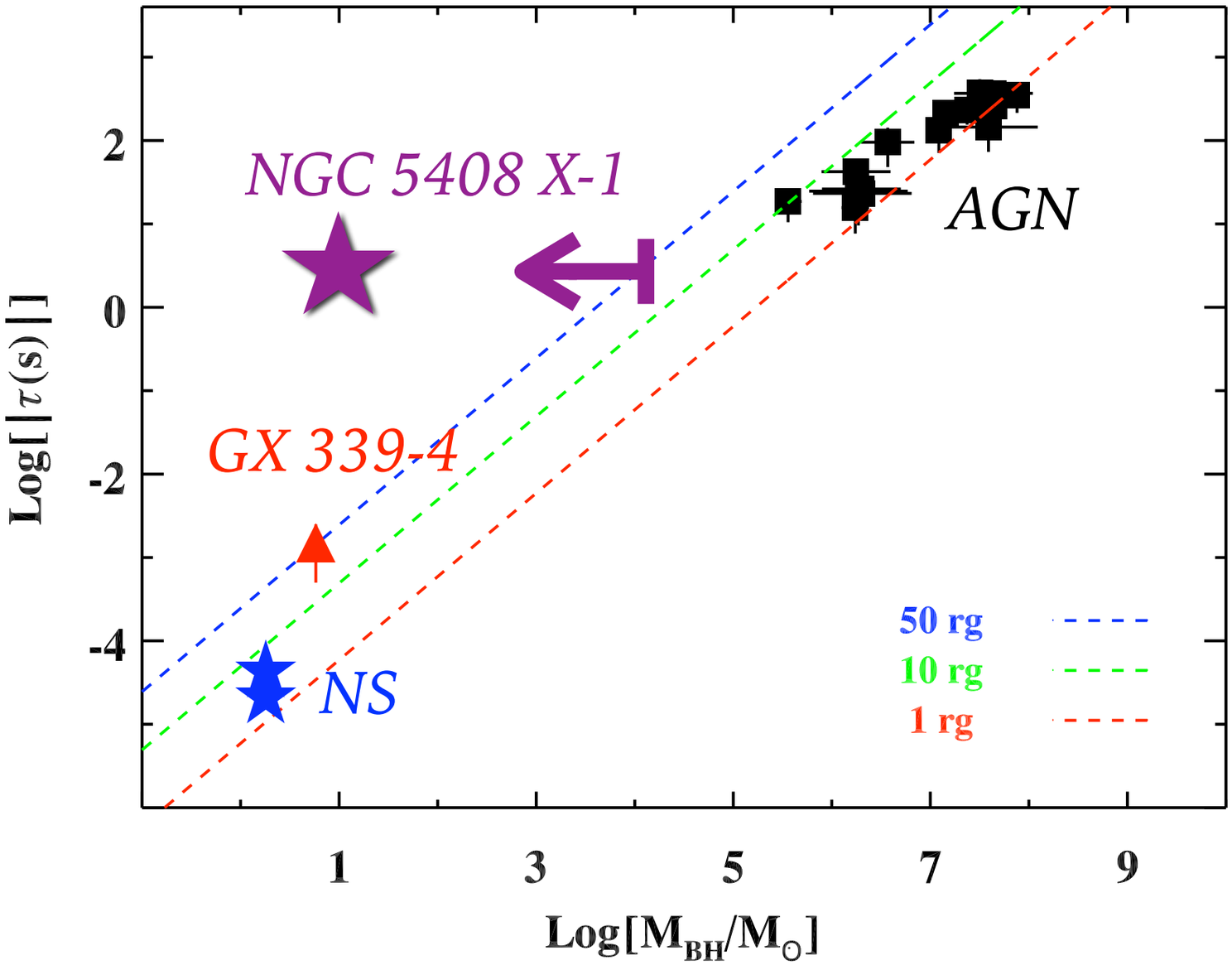
[De Marco et al. 2013b]



0.3-1 keV vs 1-7 keV

»99.9% significant soft lag!

Soft lags in AGN vs stellar mass sources



IMBH: *the lag fits in the correlation (may require truncated disc)*

Stellar mass: *the lag is too long to be due to reverberation*

[e.g. Gladstone et al. 2009, Middleton et al. 2011,]

Summary

1. *Soft lags appear to be an ubiquitous feature of variable AGN*
2. *Soft lags map small distances*
3. *Correlation with mass implies a common length scale*
4. *Fe K lags map similar distances*
5. *Flux-dependent analyses unveil a complex phenomenology*
6. *Soft lags are observed also in other accreting sources, but the existence of a link with AGN is yet to be established*