

X-ray reverberation in accreting black hole systems

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Plan of the talk

What is the aim of X-ray reverberation?

What are the evidences for X-ray reverberation in AGN?

Can we use reverberation to constrain the (evolving) accretion flow geometry in BHXRBs?

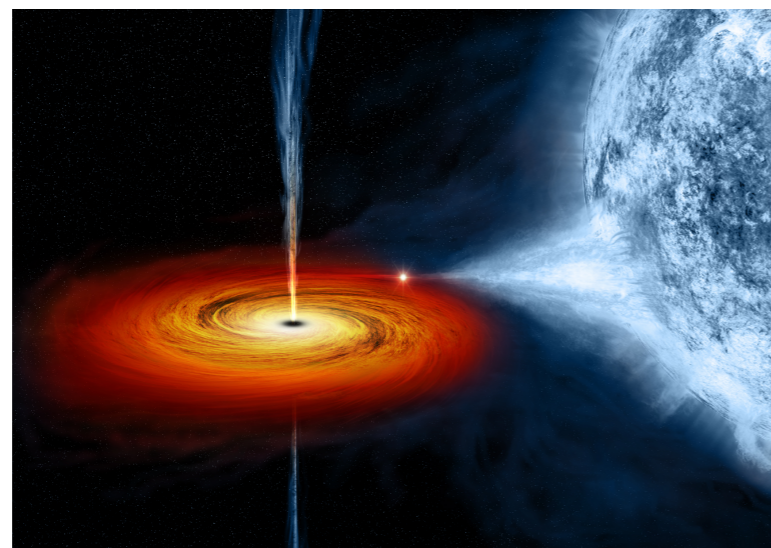
Astrophysical BHs across the mass scale



M_{BH}



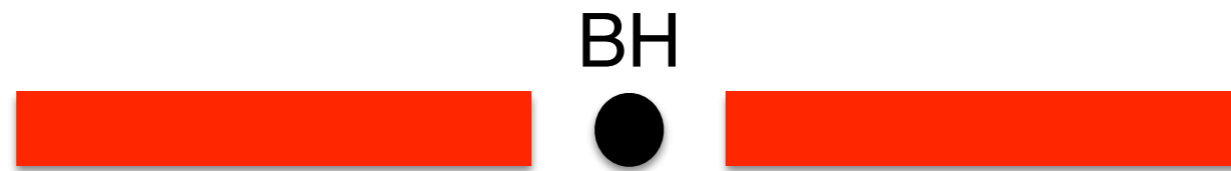
AGN
 $10^5\text{-}10^6 M_{\odot}$



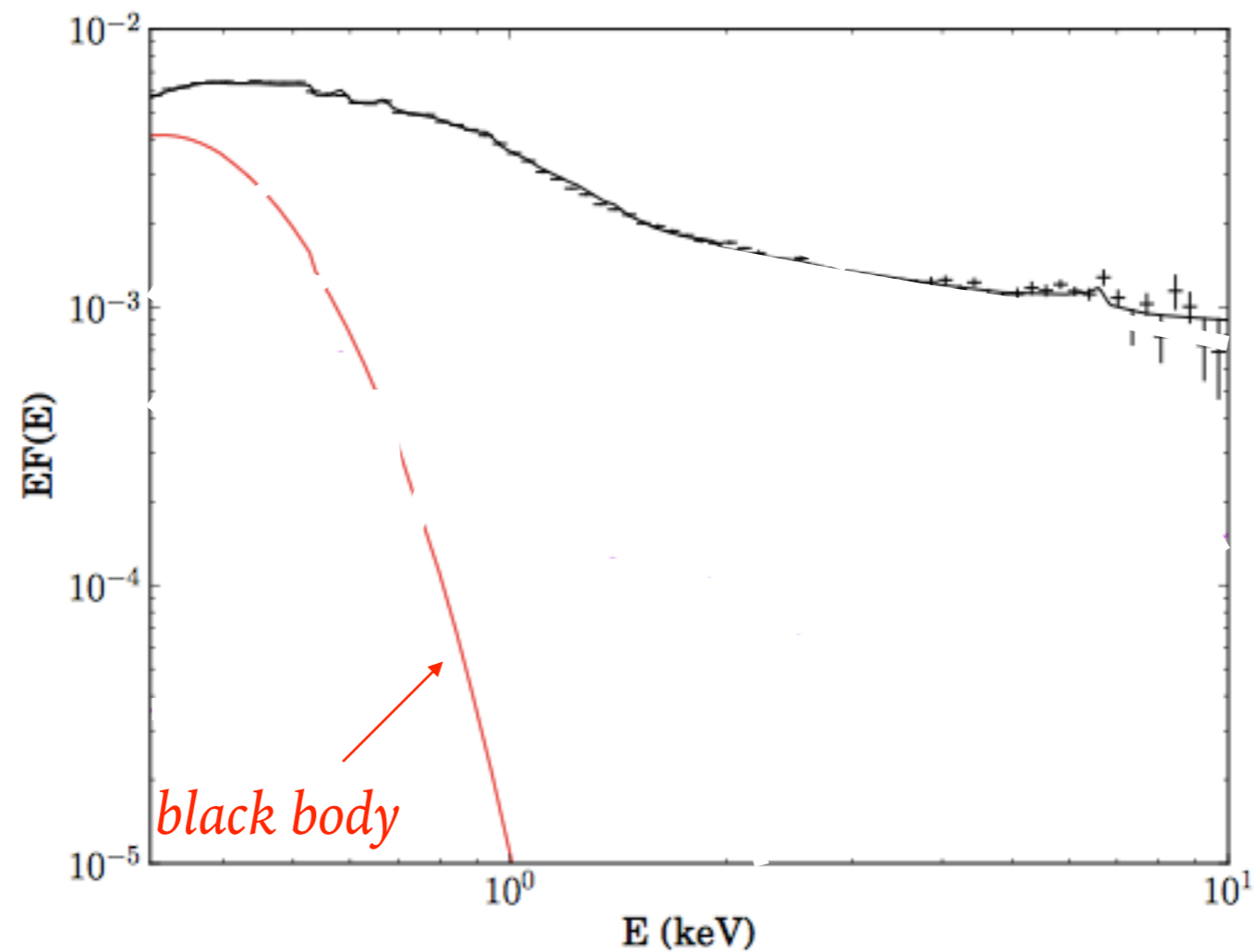
BHXR
 $5\text{-}15 M_{\odot}$

Different scales
Same accretion mechanism

The X-ray spectrum



Standard disc/thermal
[e.g. Shakura & Sunyaev '73
Novikov & Thorne '73]



The X-ray spectrum

Corona/Inner comptonizing region

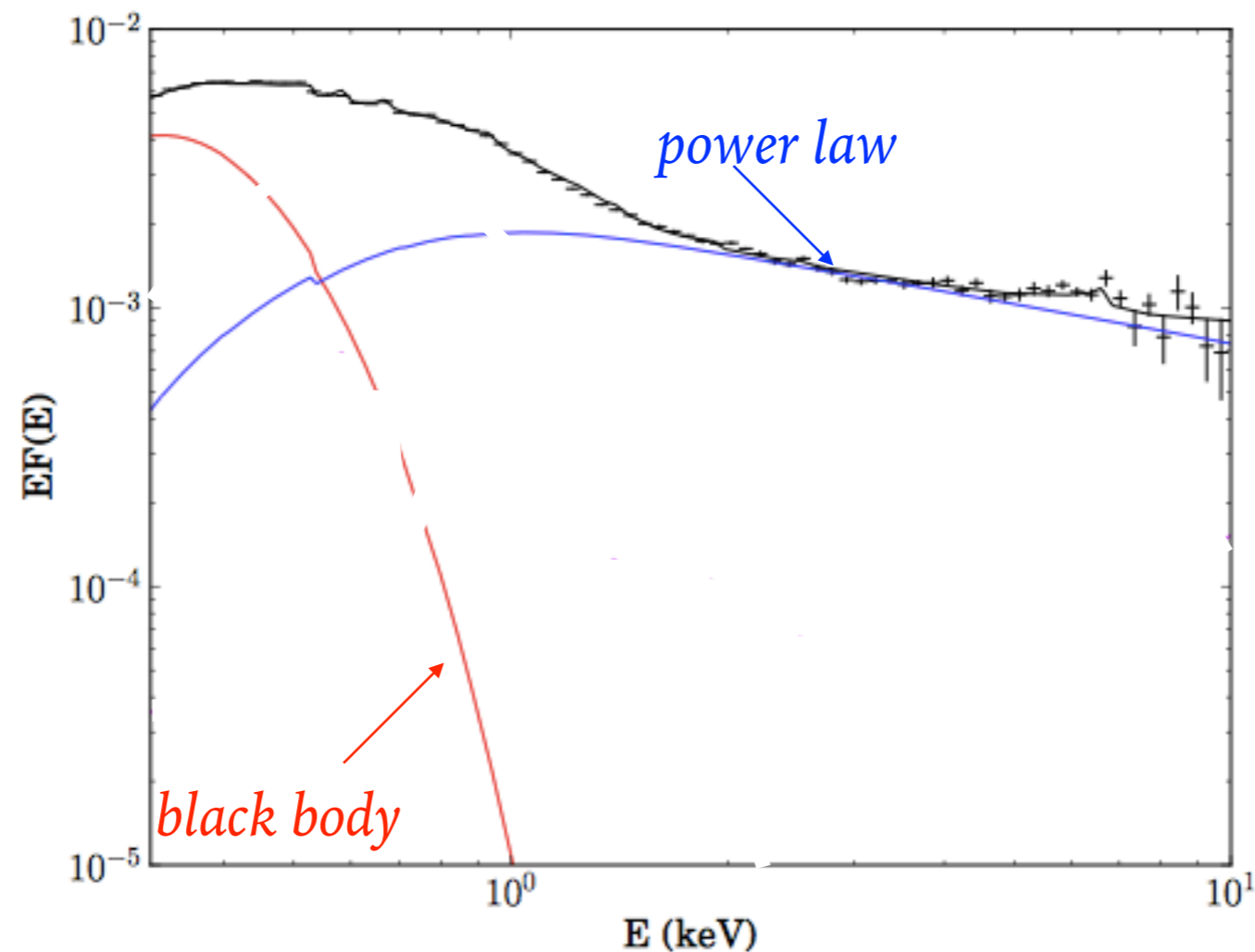
[e.g. Sunyaev & Trümper '79;
Haardt & Maraschi '91]



BH



Standard disc/thermal
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Novikov & Thorne '73]



The X-ray spectrum

Corona/Inner comptonizing region

[e.g. Sunyaev & Trümper '79;
Haardt & Maraschi '91]

Disc reprocessing/Reflection

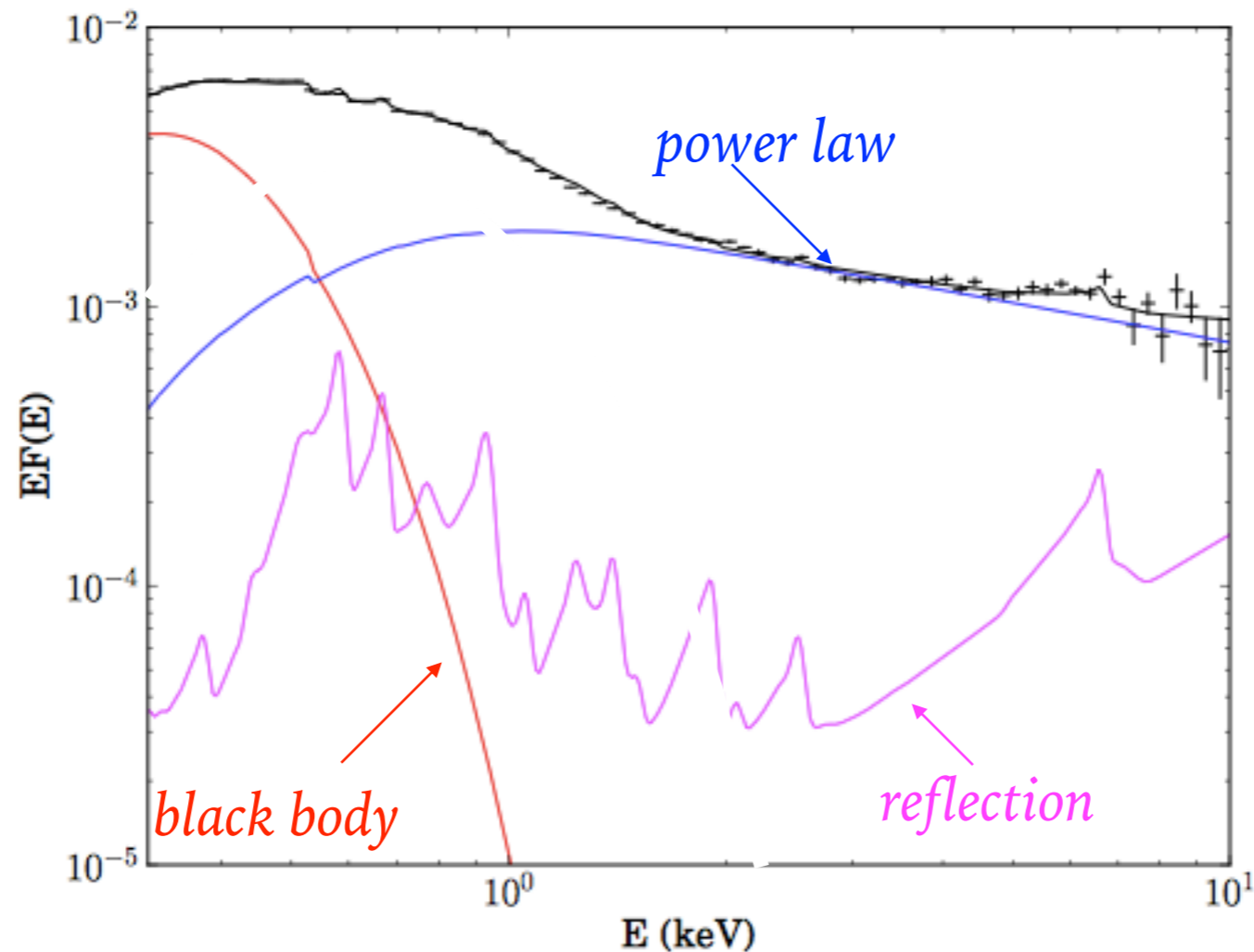
[e.g. Guilbert & Rees '89;
Ross & Fabian '05]



BH



Standard disc/thermal
[e.g. Shakura & Sunyaev '73
Novikov & Thorne '73]

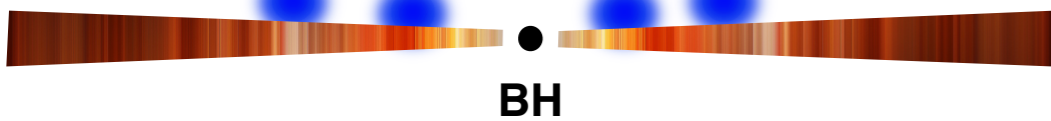


What is the aim of X-ray reverberation?

Open questions: what's the geometrical distribution of the accreting gas?

X-ray source

compact comptonizing regions?



BH

base of a jet?



BH

extended?

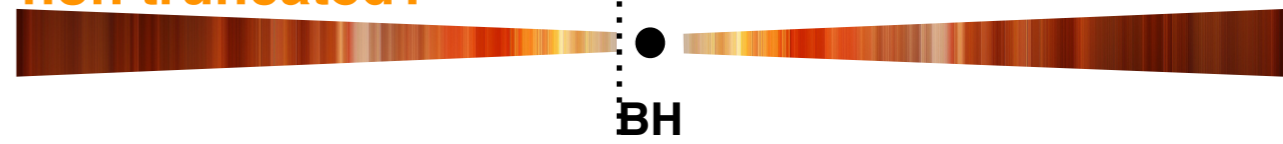


BH

some hybrid structure?

Disc truncation

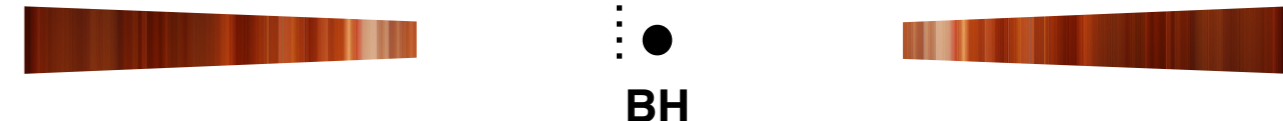
non truncated?



ISCO

BH

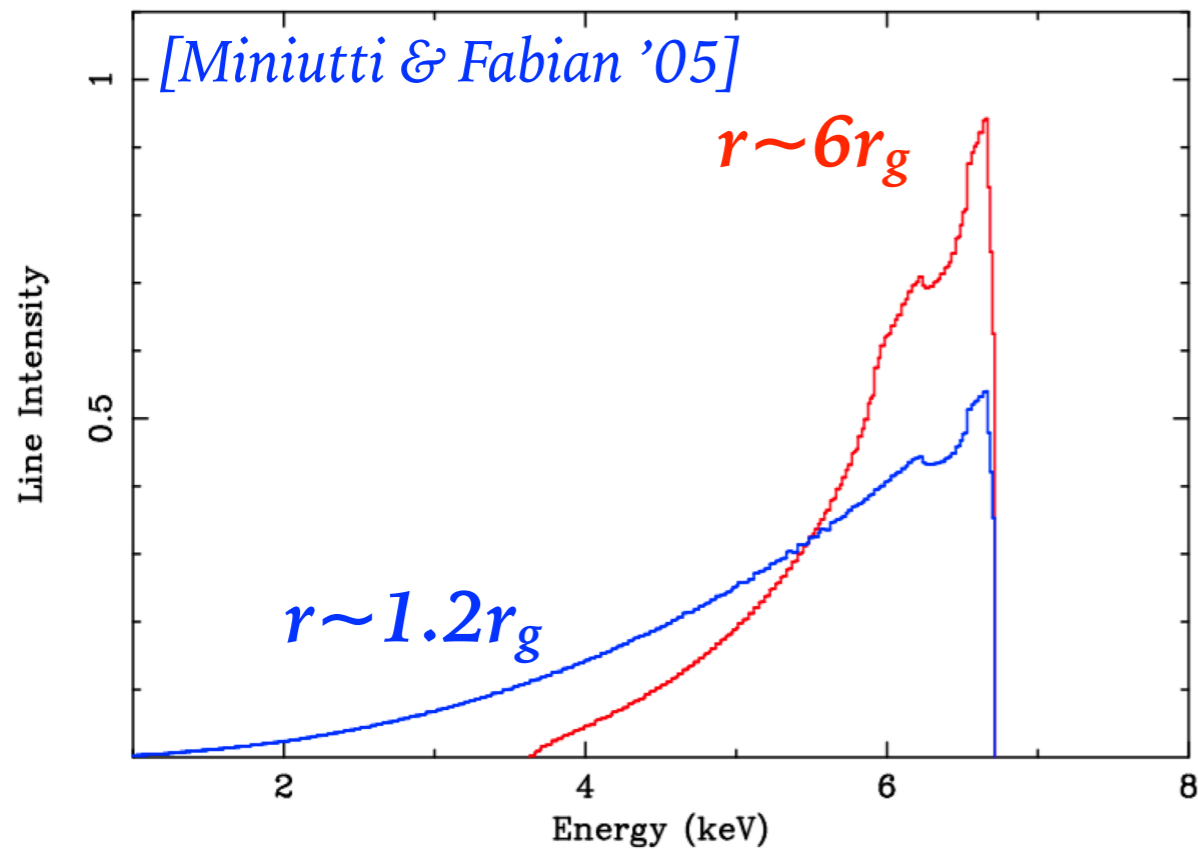
truncated?



BH

*Relevant for reliable
BH spin estimate!*

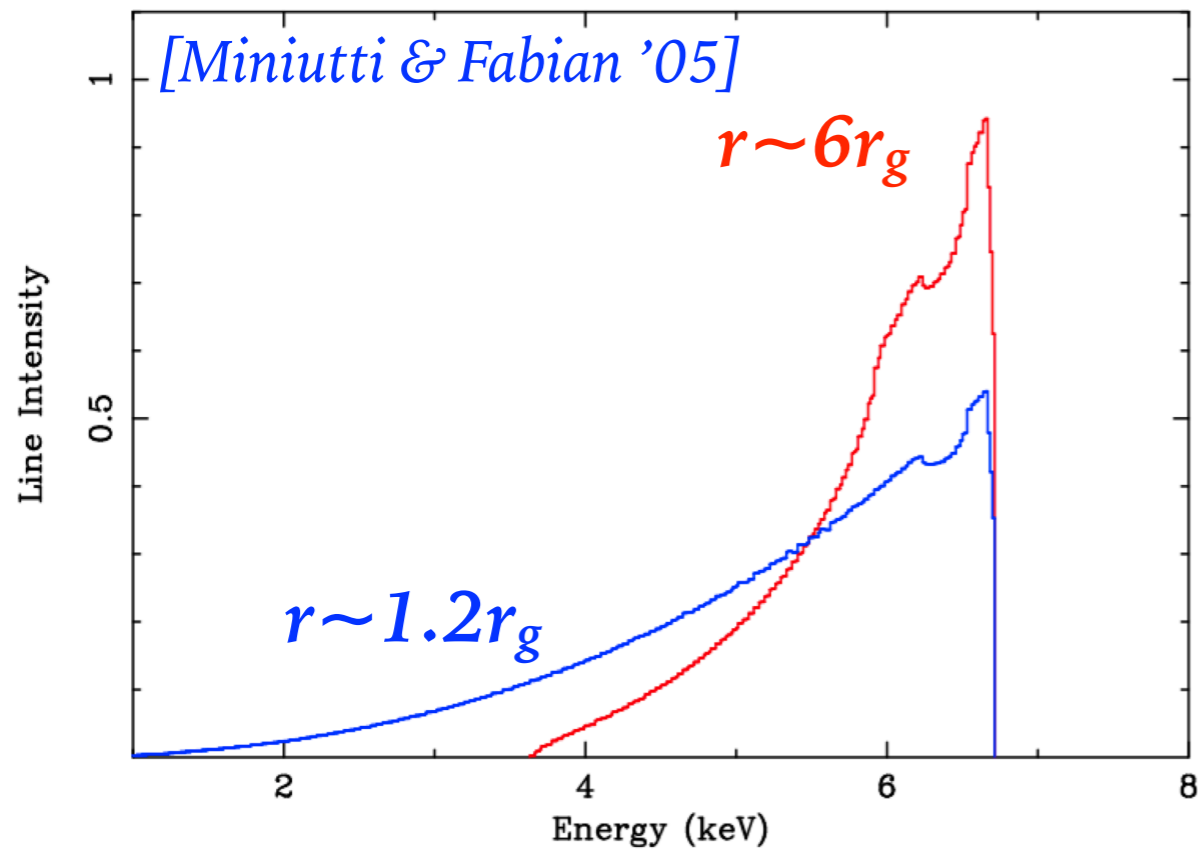
Geometry from Fe line spectroscopy



Line profile sensitive to disc radius and coronal illumination

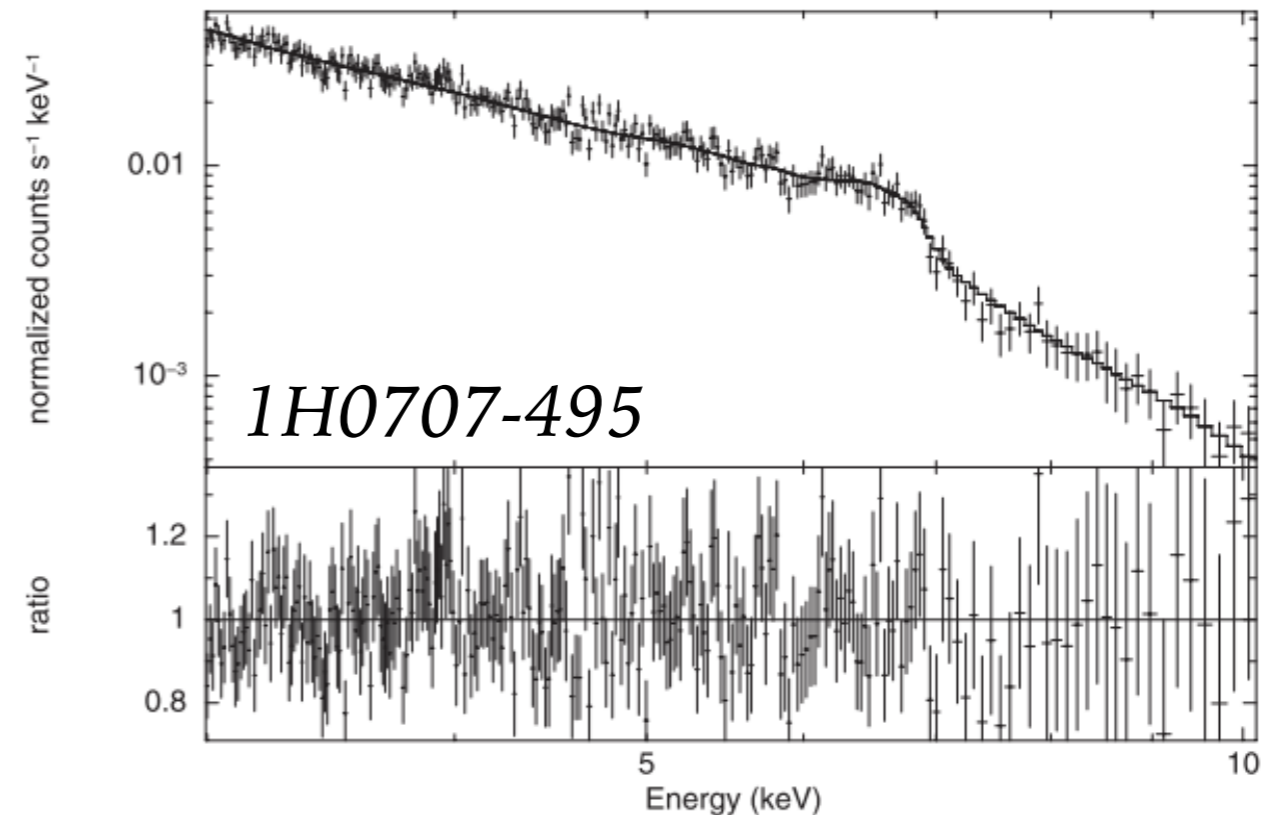
[e.g. Fabian+ '89; Wilkins & Fabian '11]

Geometry from Fe line spectroscopy



Line profile sensitive to disc radius and coronal illumination

[e.g. Fabian+ '89; Wilkins & Fabian '11]

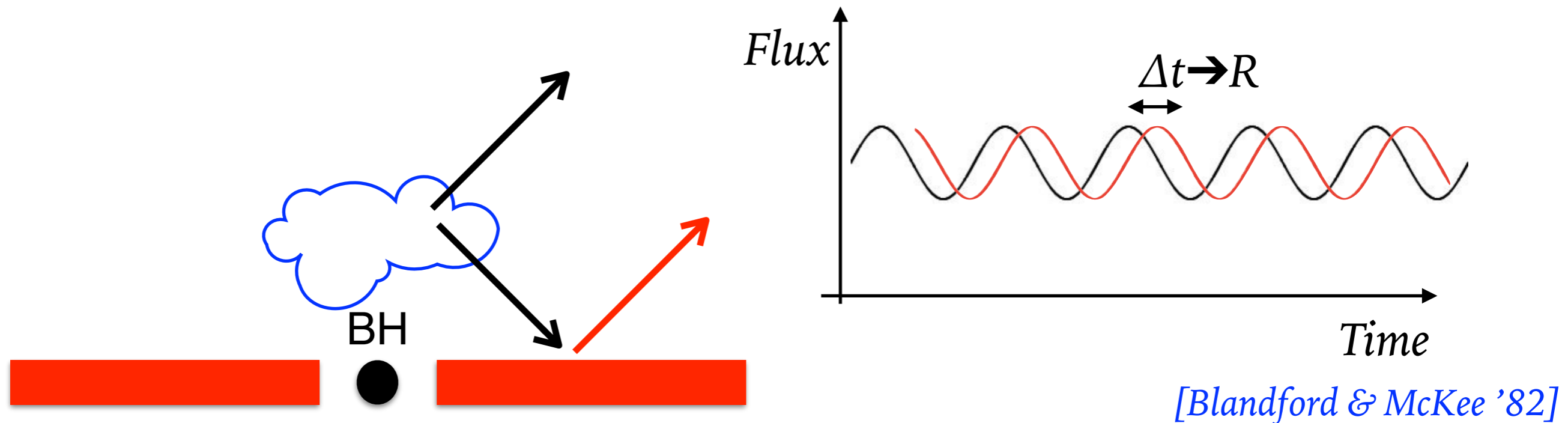


Difficulties in disentangling broad features from the continuum

[e.g. Bhayany & Nandra '11; Mantovani+ '16]

Reverberation:

independent method to constrain geometry



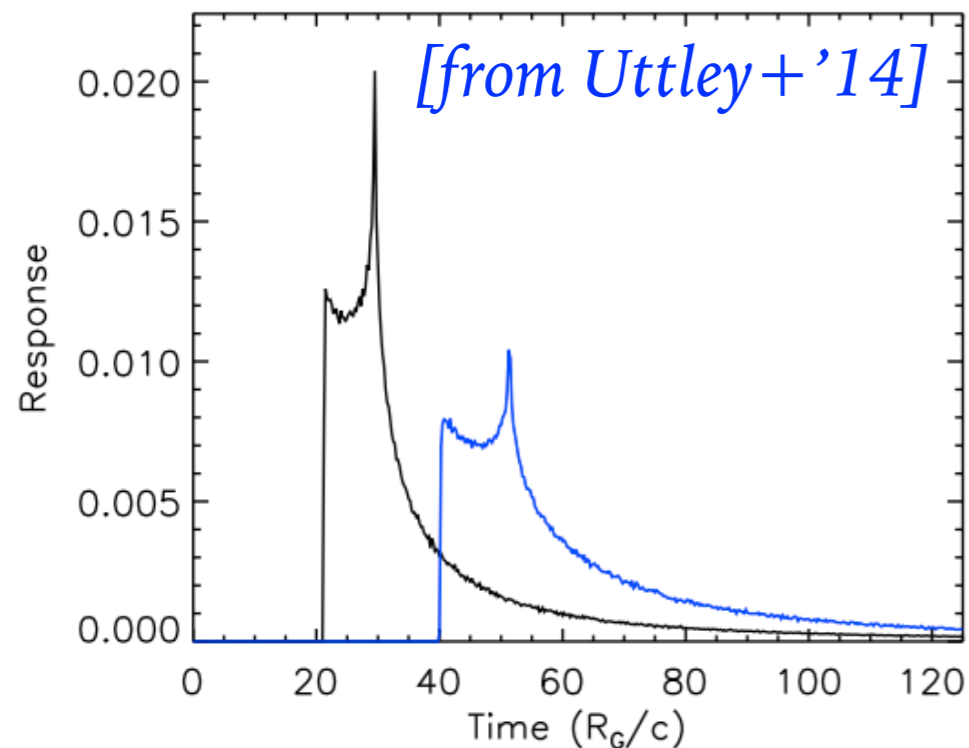
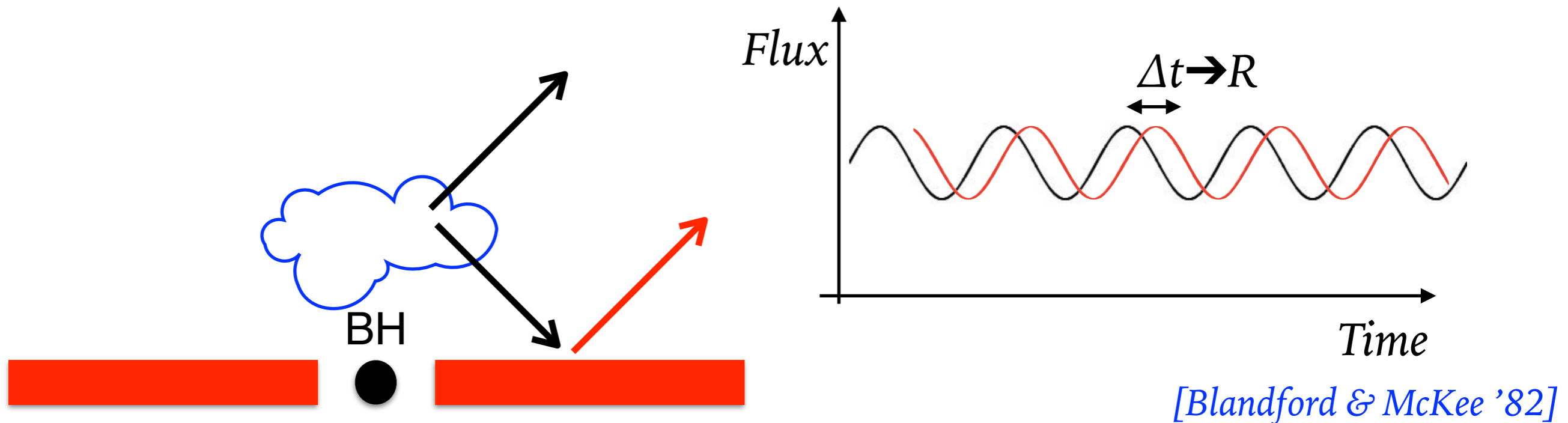
Commonly used in the UV/optical/IR to map BLR and outer disc in AGN

[e.g. Peterson + '04; Edelson + '15; Shappee + '14]

*Reverberation in the X-ray band can be used to **map the geometry** of the corona and of the inner accretion flow [review Uttley + '14]*

Reverberation:

independent method to constrain geometry

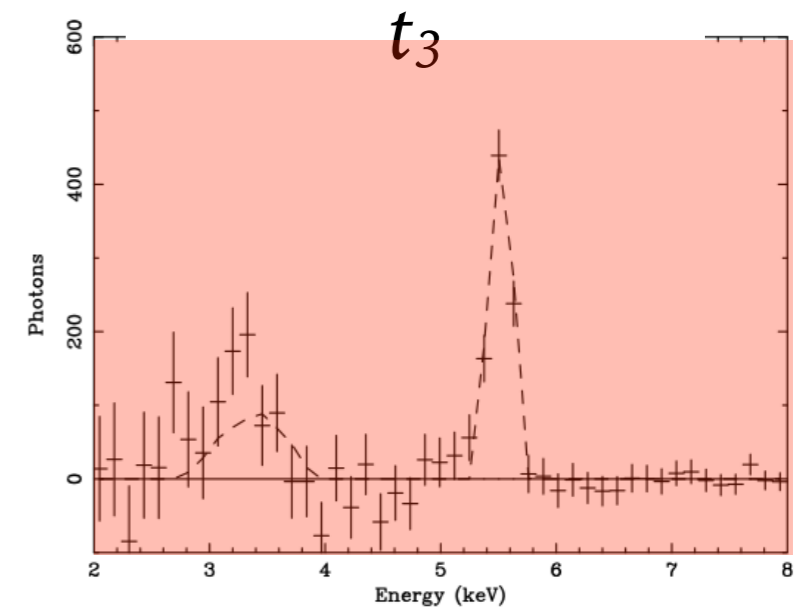
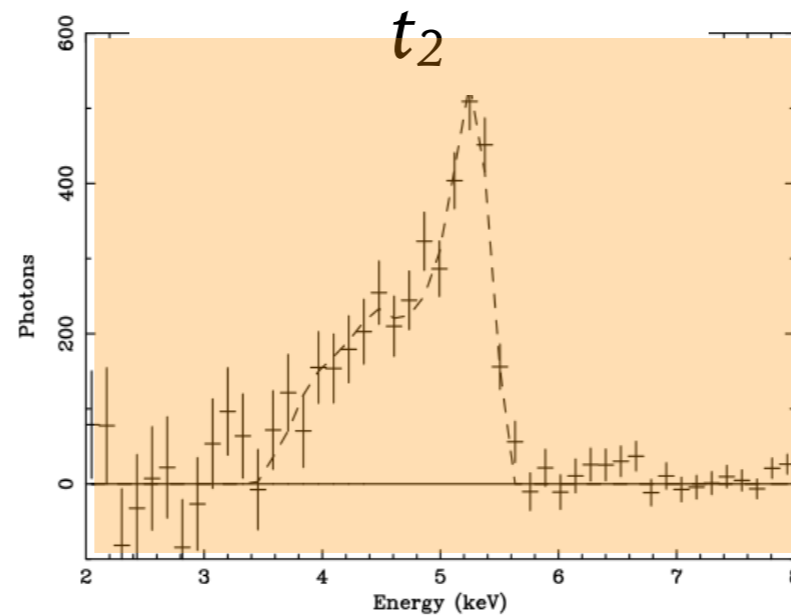
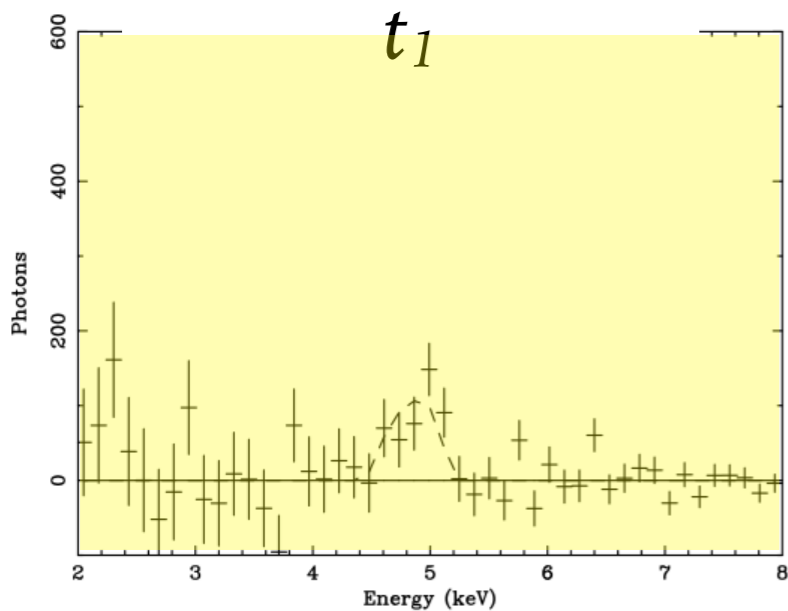
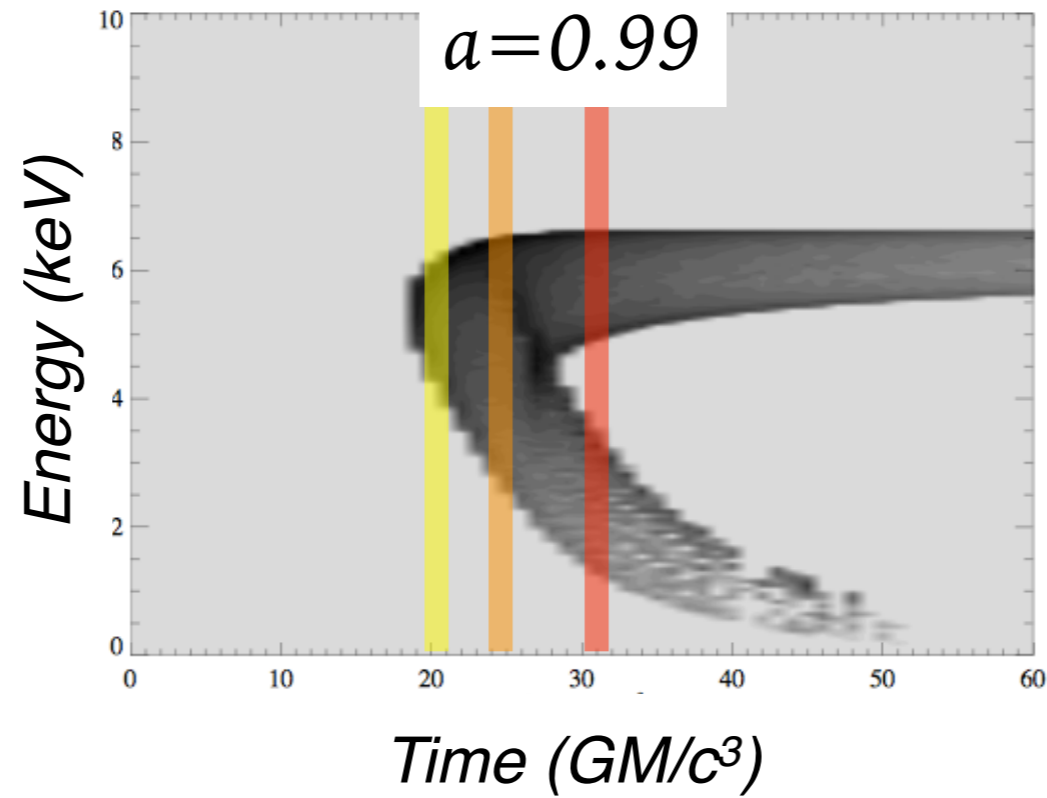


Goal: determine the transfer function of the system \rightarrow encodes information about the geometry

***What are the evidences for X-ray
reverberation in AGN?***

FeK line reverberation: predictions

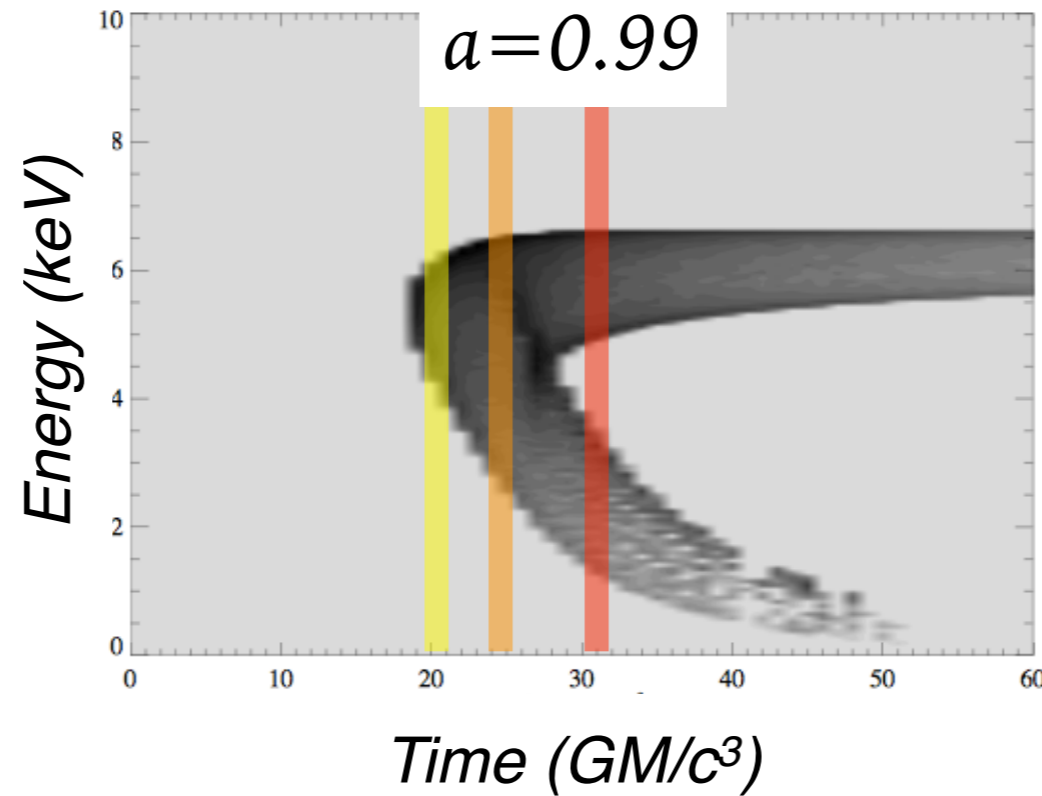
Fabian+'89; Stella '90; Matt & Perola '92; Campana & Stella '93



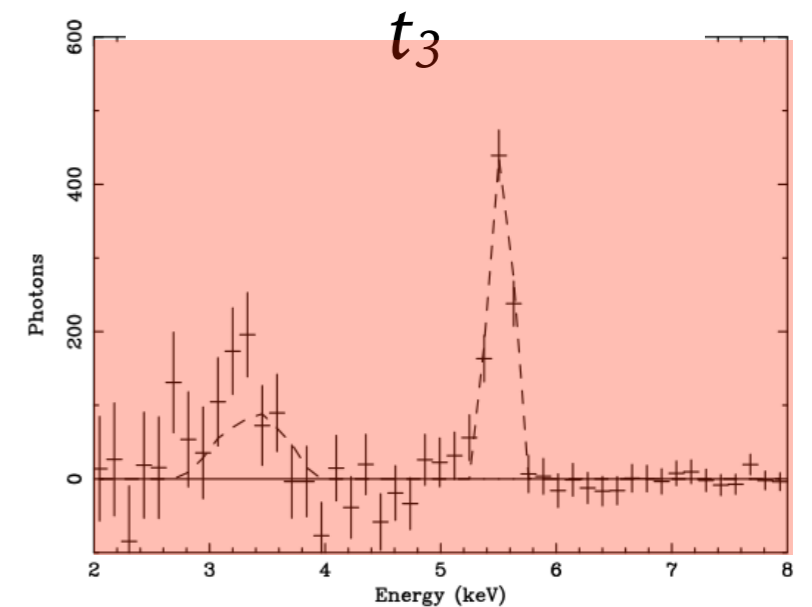
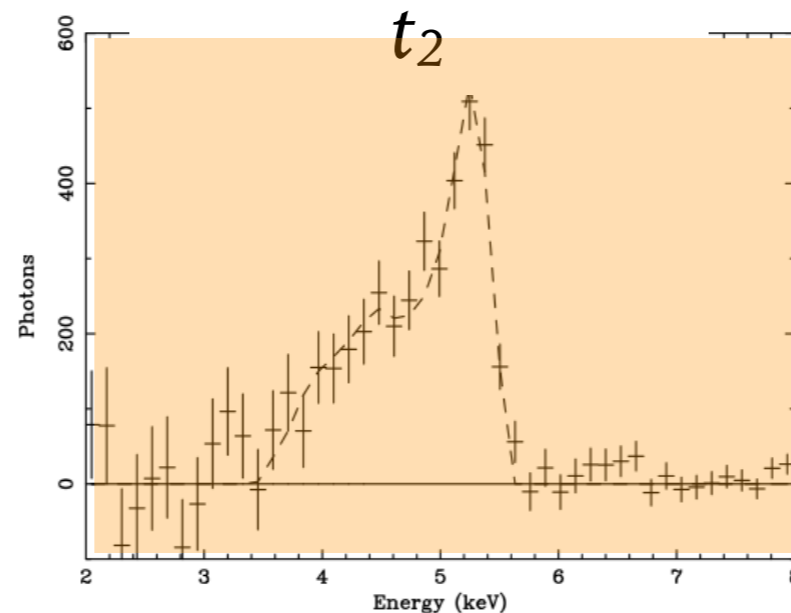
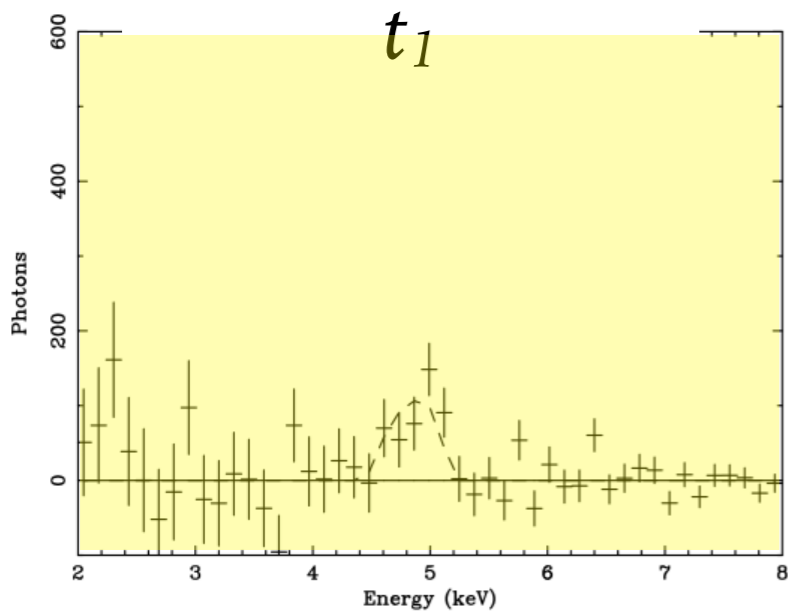
[Reynolds+'99, Young & Reynolds '00]

FeK line reverberation: predictions

Fabian + '89; Stella '90; Matt & Perola '92; Campana & Stella '93

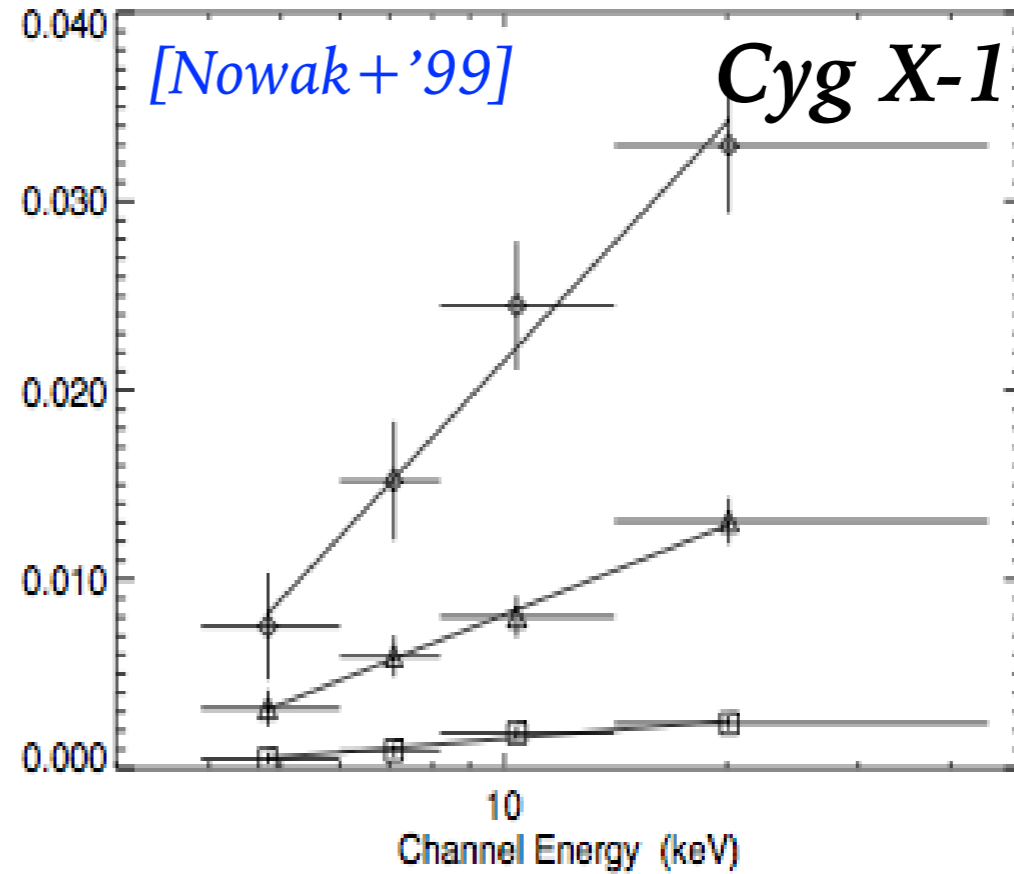
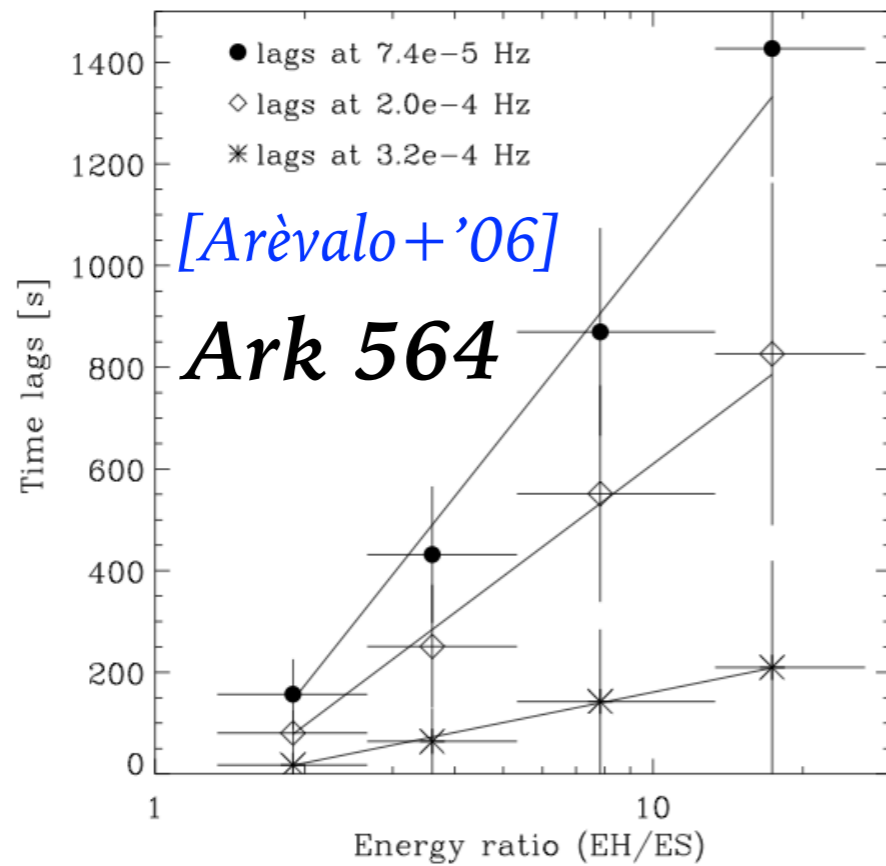


Early attempts to observe X-ray reverberation failed e.g. Reynolds + '00; Vaughan & Edelson '01



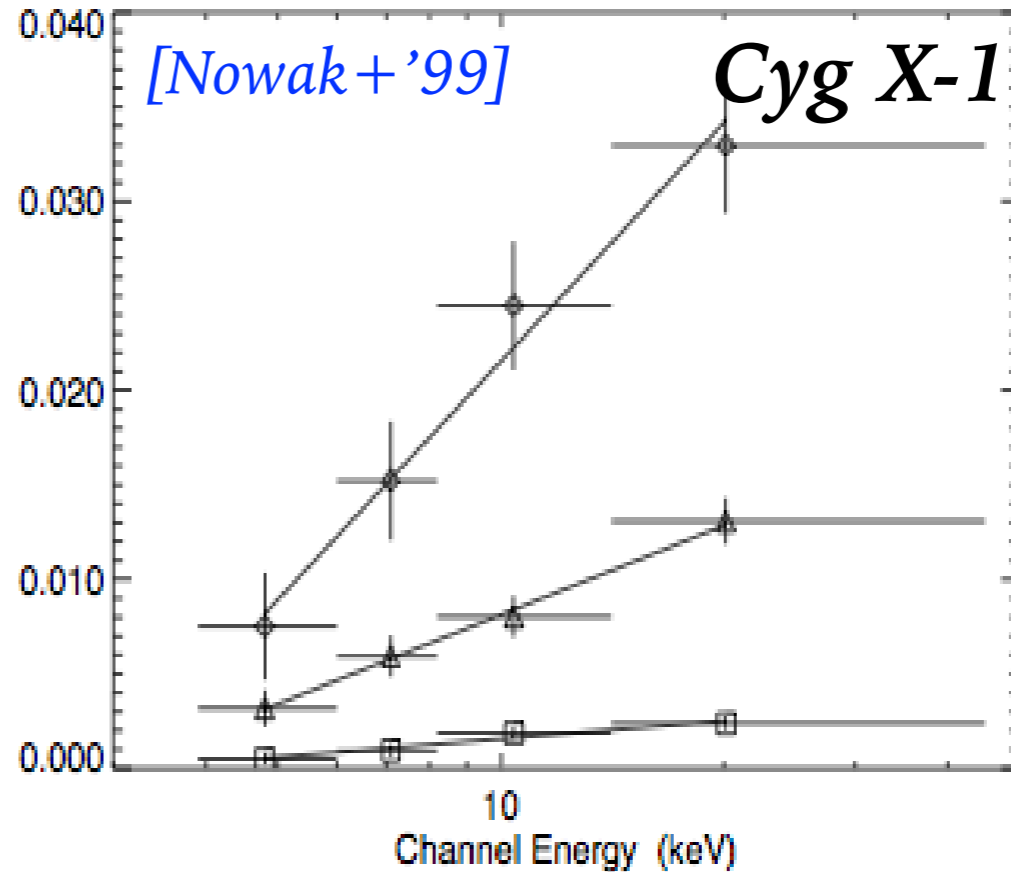
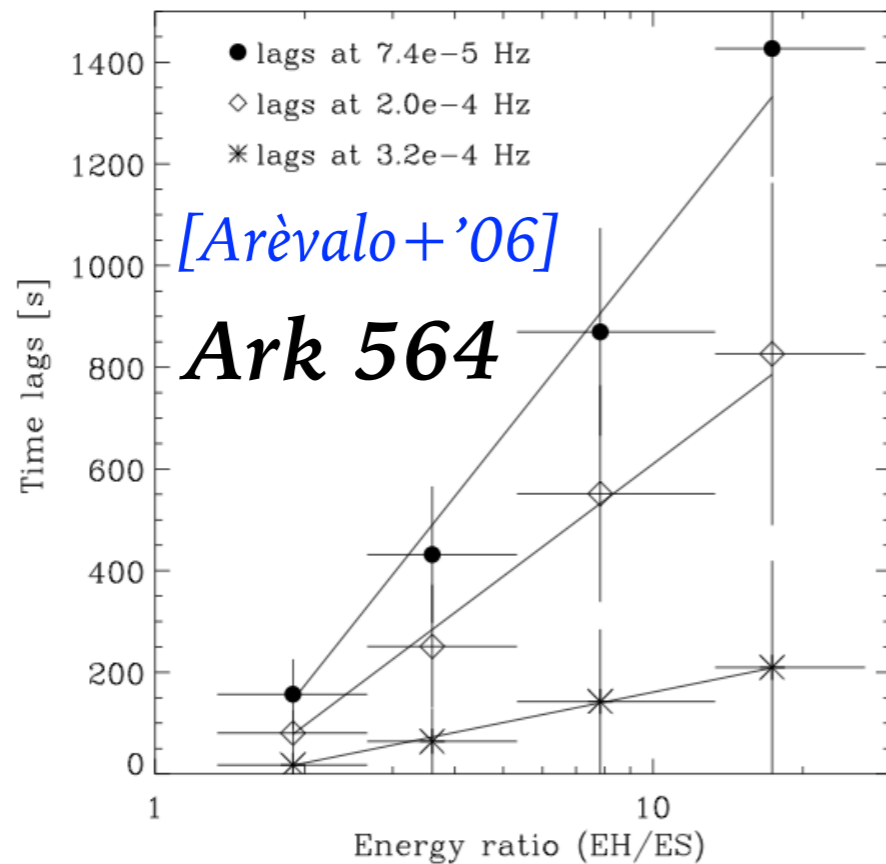
[Reynolds + '99, Young & Reynolds '00]

Hard lags common to AGN and BHXRBs



Kotov + '01 showed hard lags in BHXRBs suggest inward propagation of \dot{M} perturbations [Lyubarskii '97]

Hard lags common to AGN and BHXRBs



Kotov + '01 showed hard lags in BHXRBs suggest inward propagation of \dot{M} perturbations [Lyubarskii '97]

And AGN?

Problems related to requirement of extended corona

Alternative scenarios:

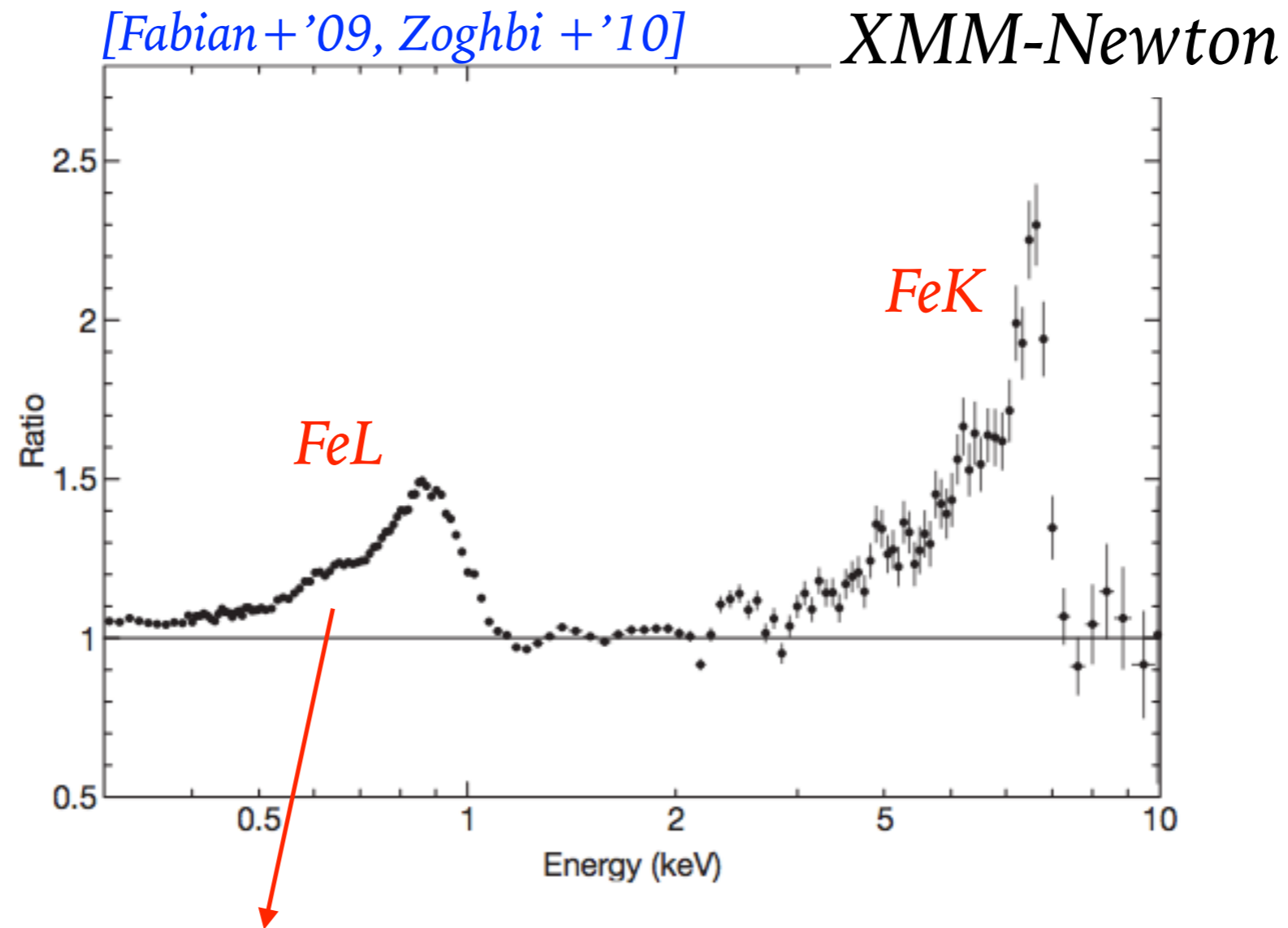
large scale scatterer

[e.g. Miller + '11; Turner + '16; Miller's talk]

or large hard lags from compact corona

[Uttley & Malzac in preparation]

First robust detection: 1H0707-495

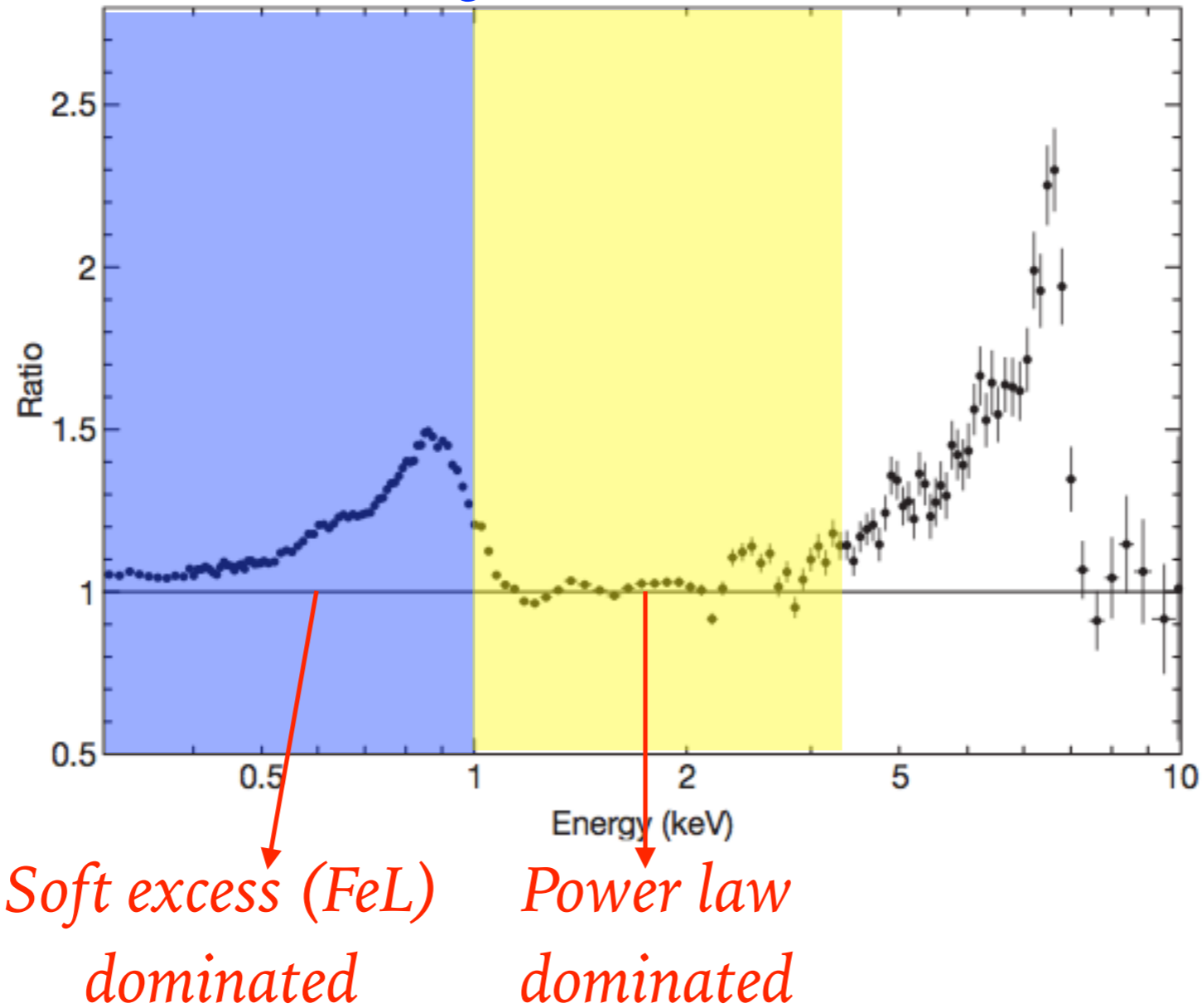


Prominent when Fe abundance is high

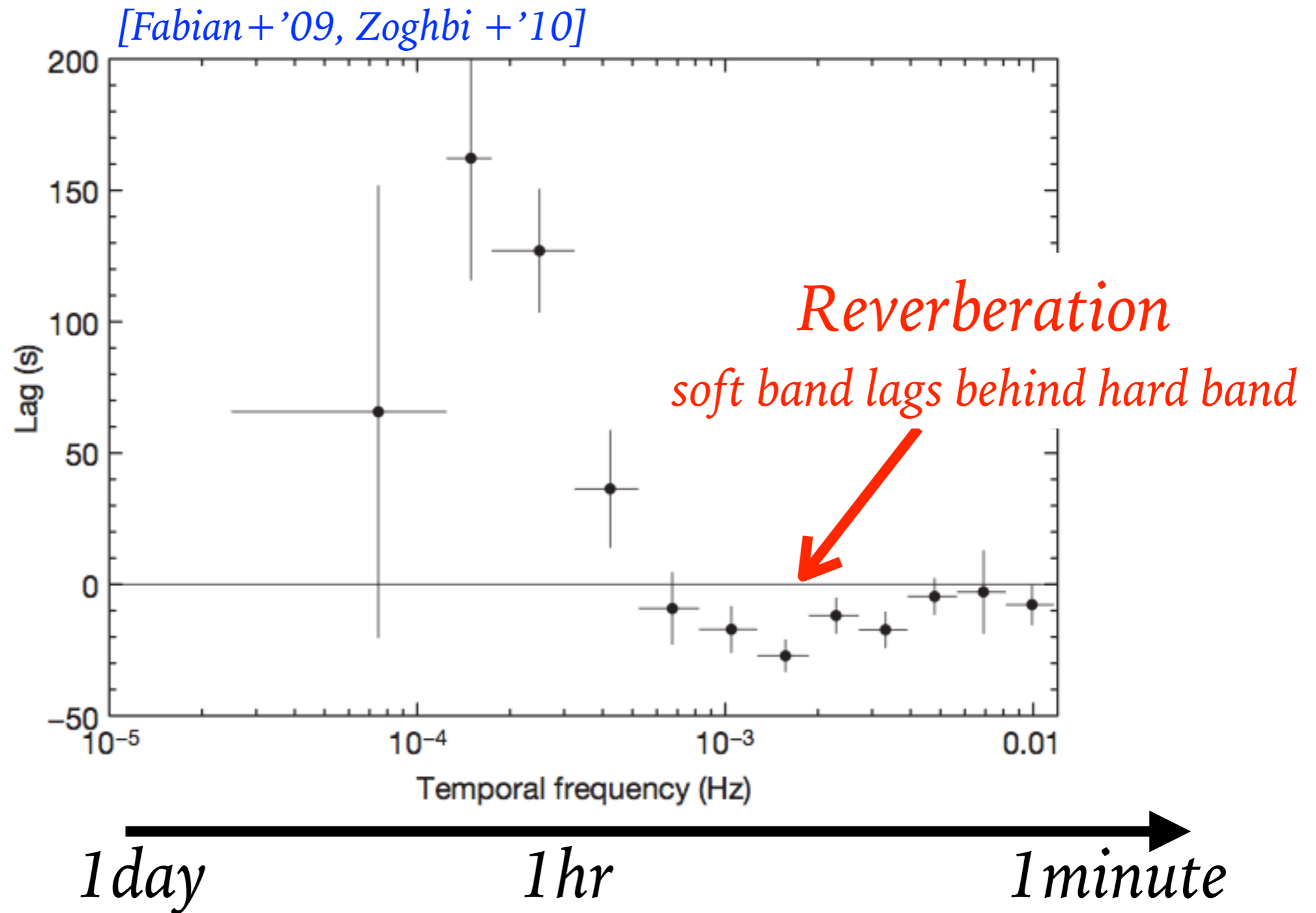
(first tentative detection in Ark 564 [McHardy+'07])

First robust detection: 1H0707-495

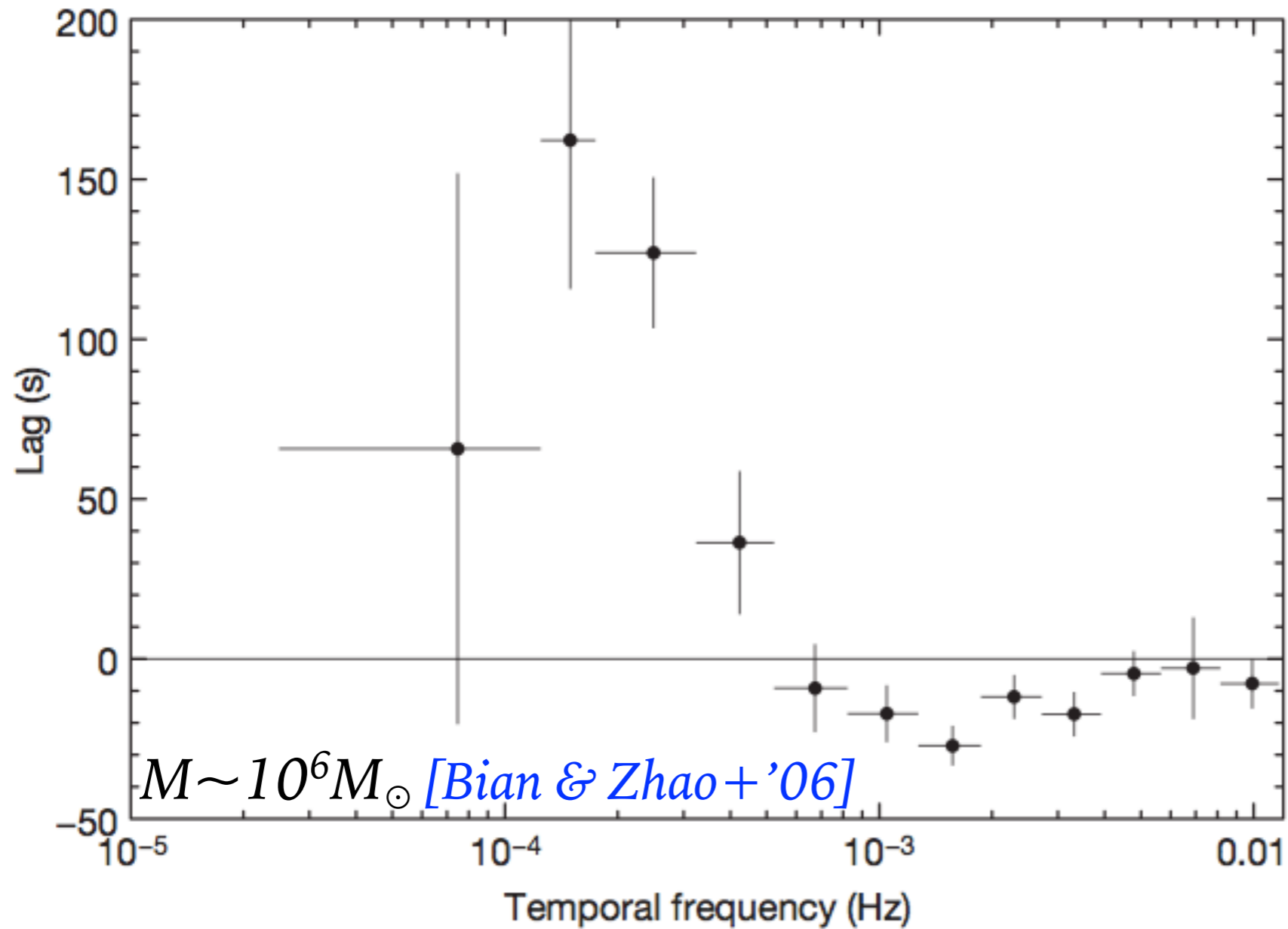
[Fabian+'09, Zoghbi+'10]



First robust detection: 1H0707-495

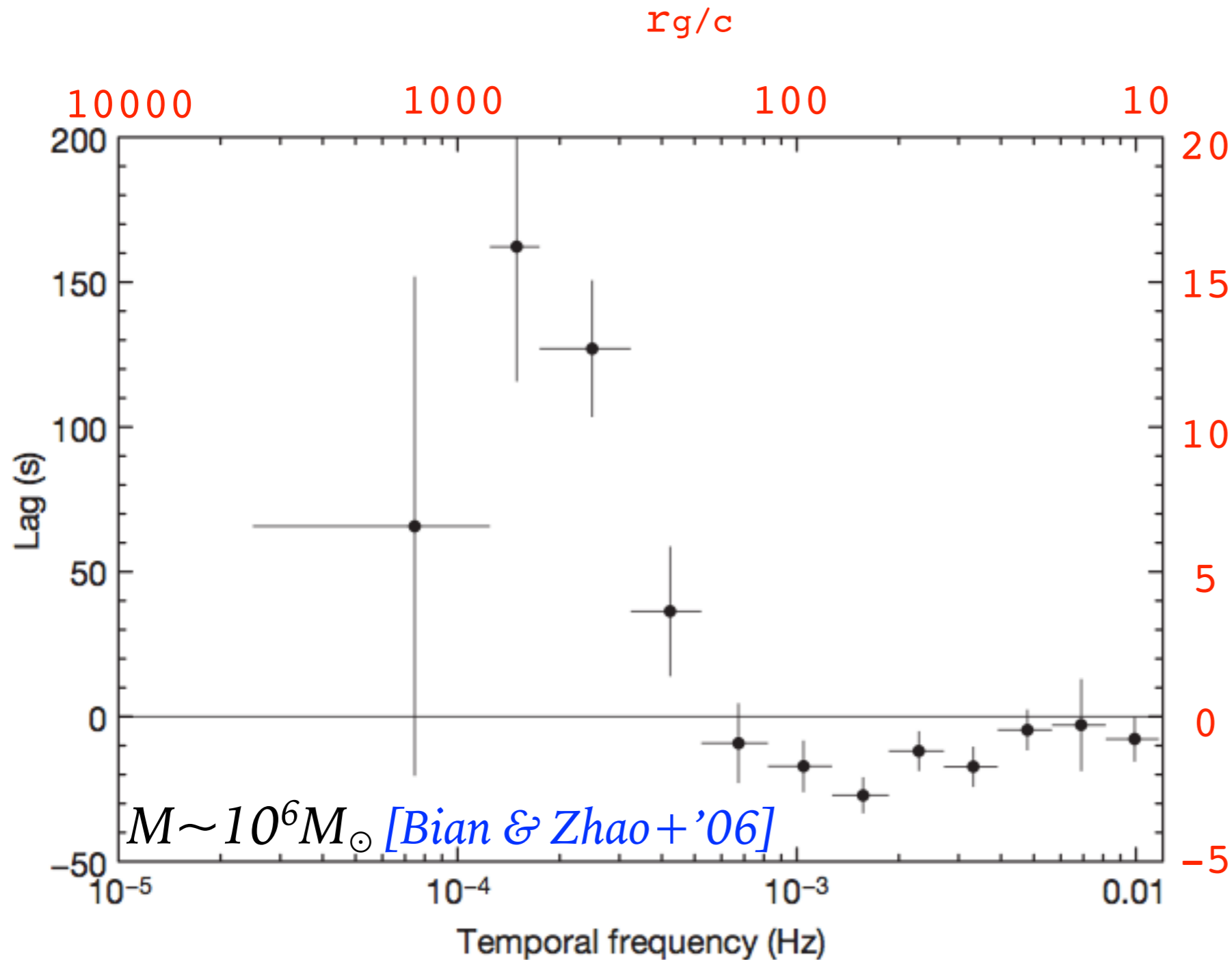


First robust detection: 1H0707-495



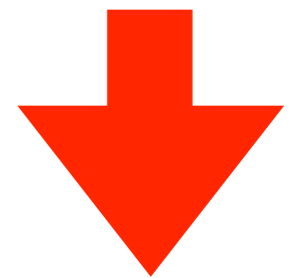
$$t = r_g/c = GM/c^3$$

First robust detection: 1H0707-495



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

*The time scales
imply short distances
and compact
reprocessing regions*



*As expected from
disc reverberation!*

X-ray reverberation common in AGN?

XMM archival data of Radio quiet, X-ray unobscured, variable AGN, with known BH mass (CAIXAvar sample [\[Ponti+'12\]](#))

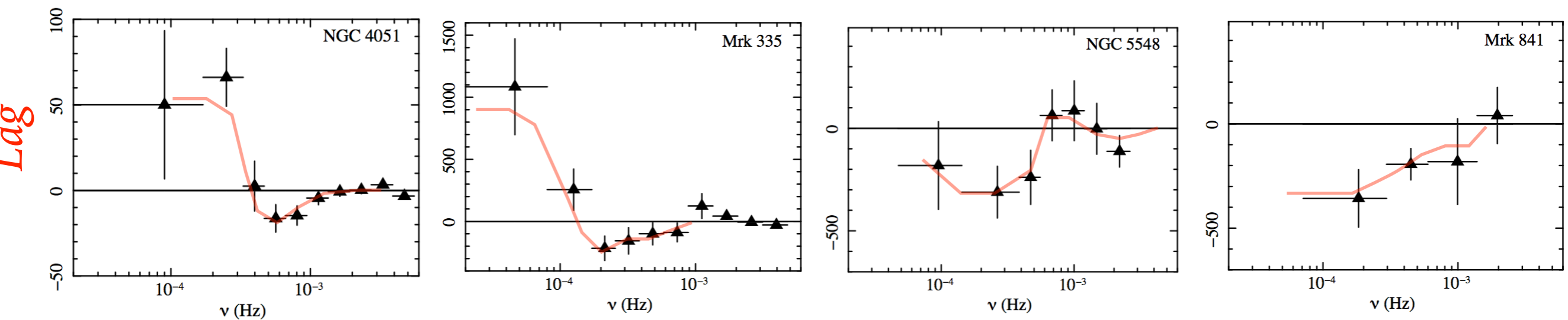
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BH Mass

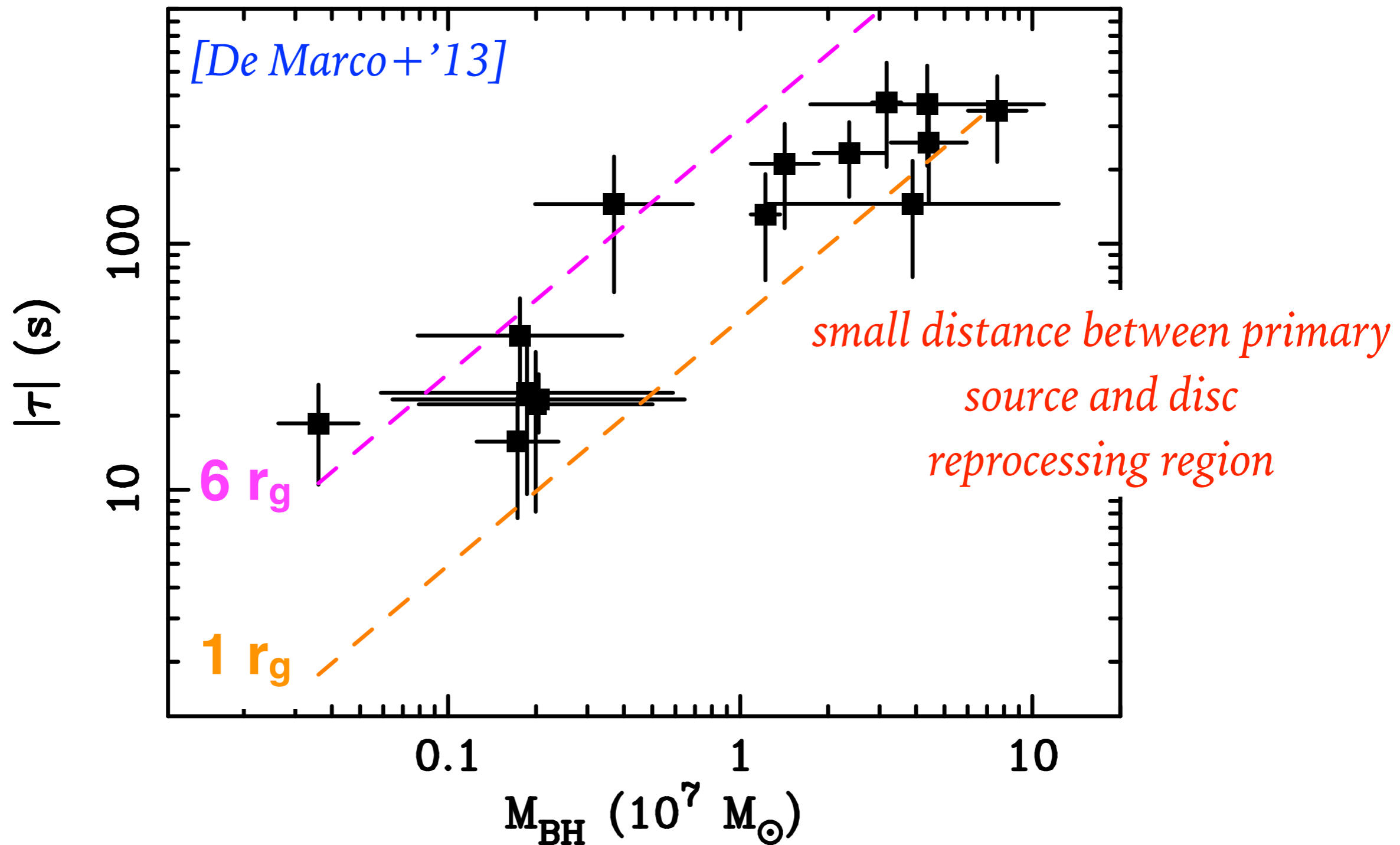
10^6

10^8



[De Marco+'13]

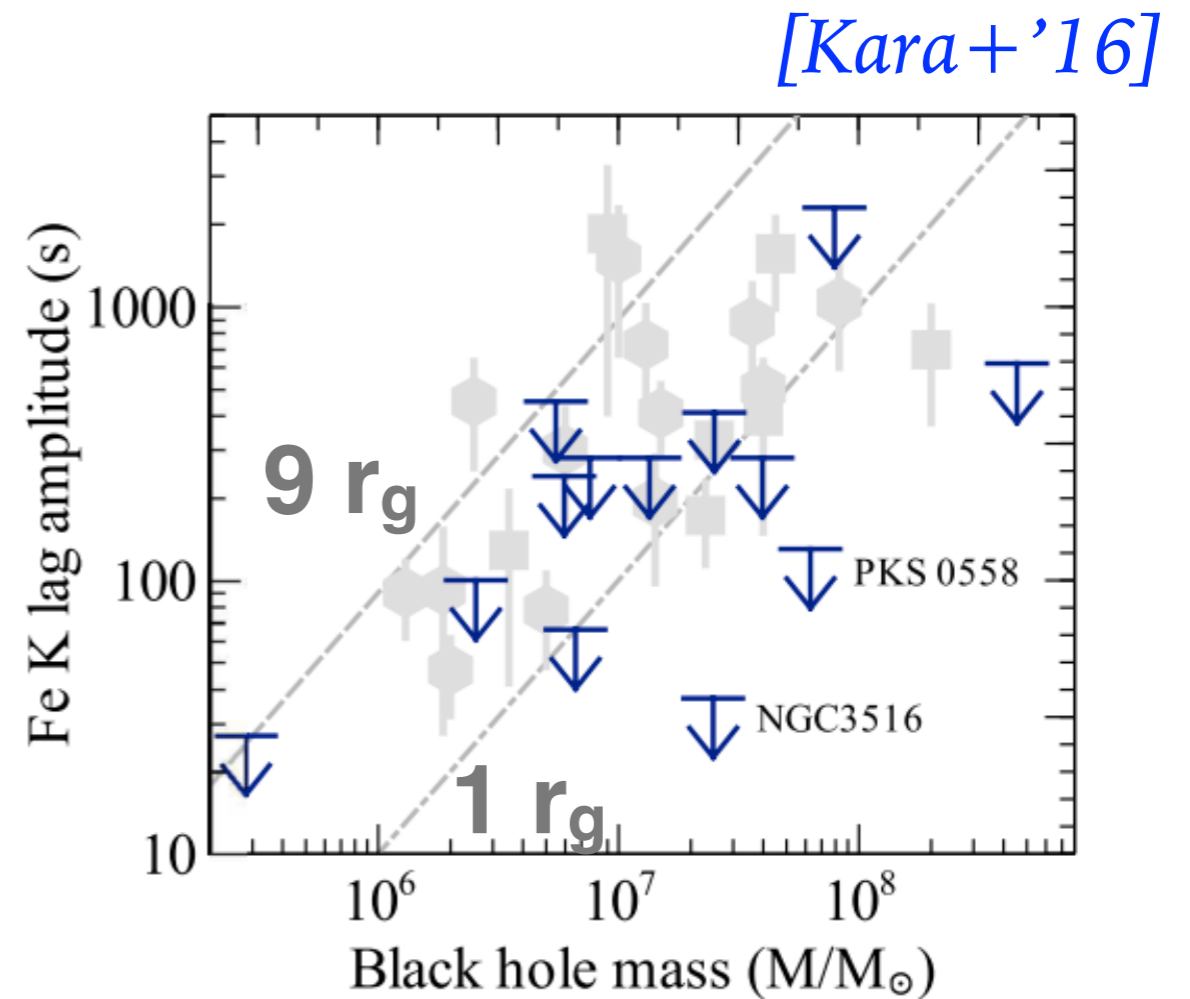
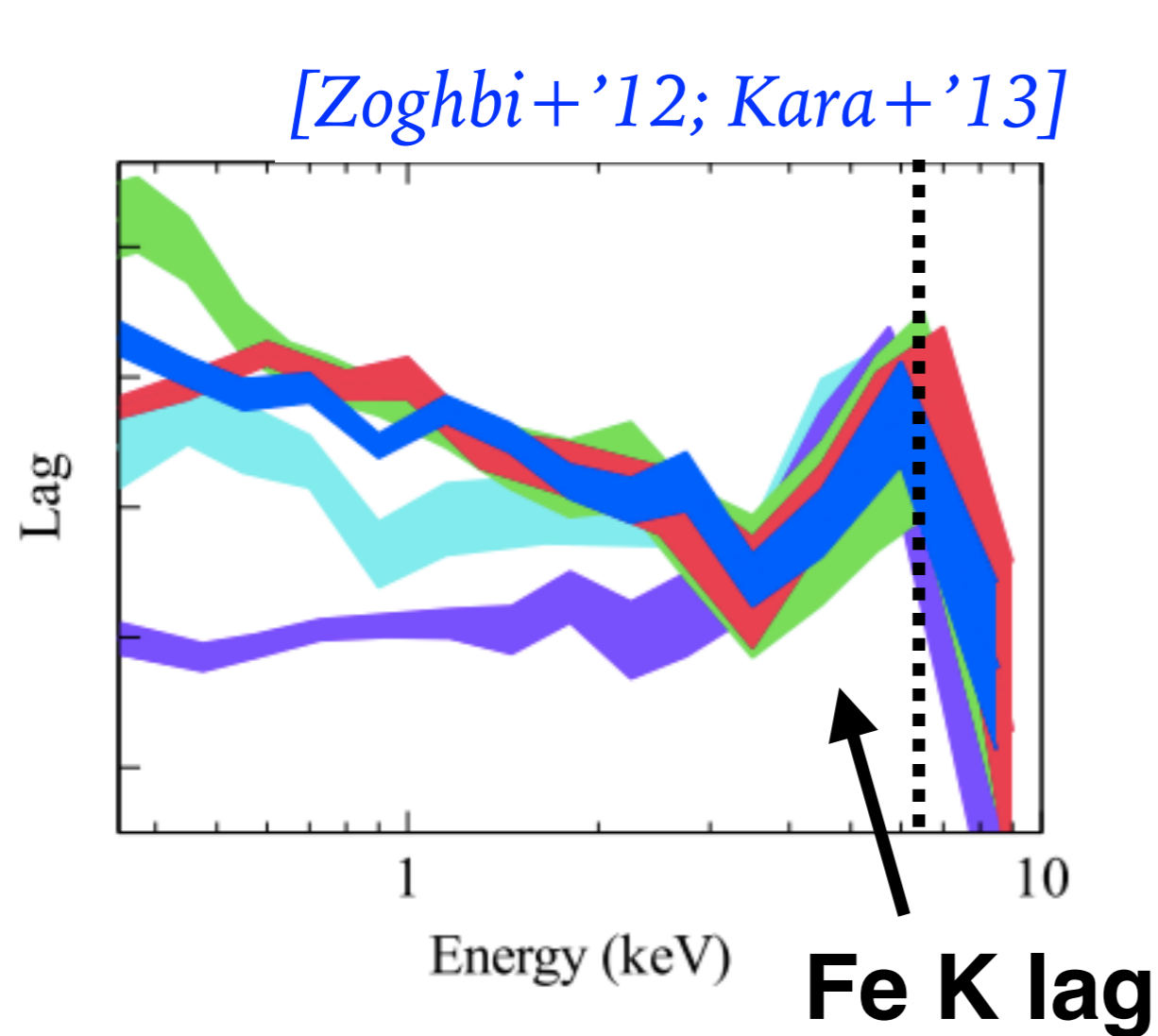
Reverberation lag vs BH mass correlation in AGN



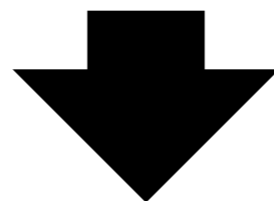
Corona is compact and the disc likely extends down to the ISCO

[consistent with microlensing results e.g. Chartas+'08]

Reverberation in the Fe K band



Inferred distances consistent with constraints from soft lags



reprocessing from the same regions of the disc

Wrap-up

Global studies of X-ray reverberation suggest disc-corona geometry similar in radio quiet AGN, favouring a compact corona and a disc extending down to small orbits

Future

Building self consistent models [e.g. Wilkins + '16; Chainakun + '16; Mastroserio's talk]

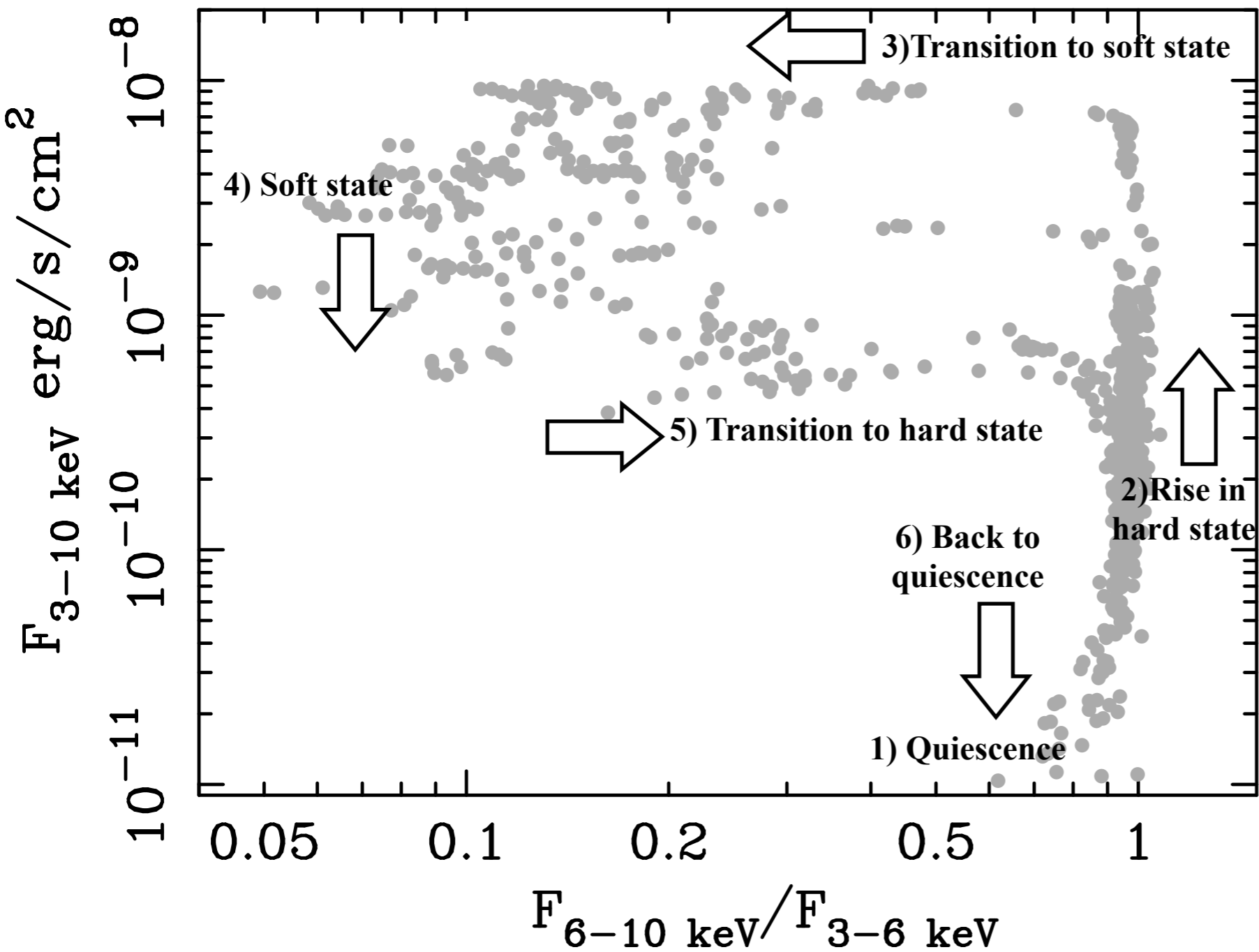
Understanding role of additional components [e.g. warm absorber, Silva + '16, large scale scatterer, Turner & Miller '16; Miller's talk]

Studying lag phenomenology [e.g. flux-dependence? Kara + 13]

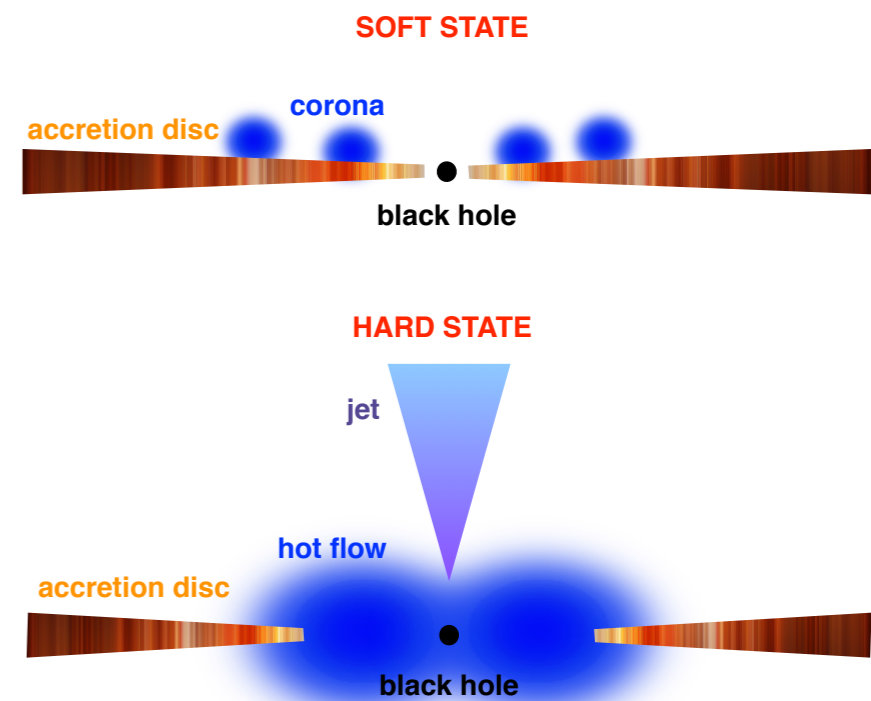
Can we use reverberation to constrain the (evolving) accretion flow geometry in BHXRBSs?

Changes of inner flow geometry during outburst evolution

GX 339-4

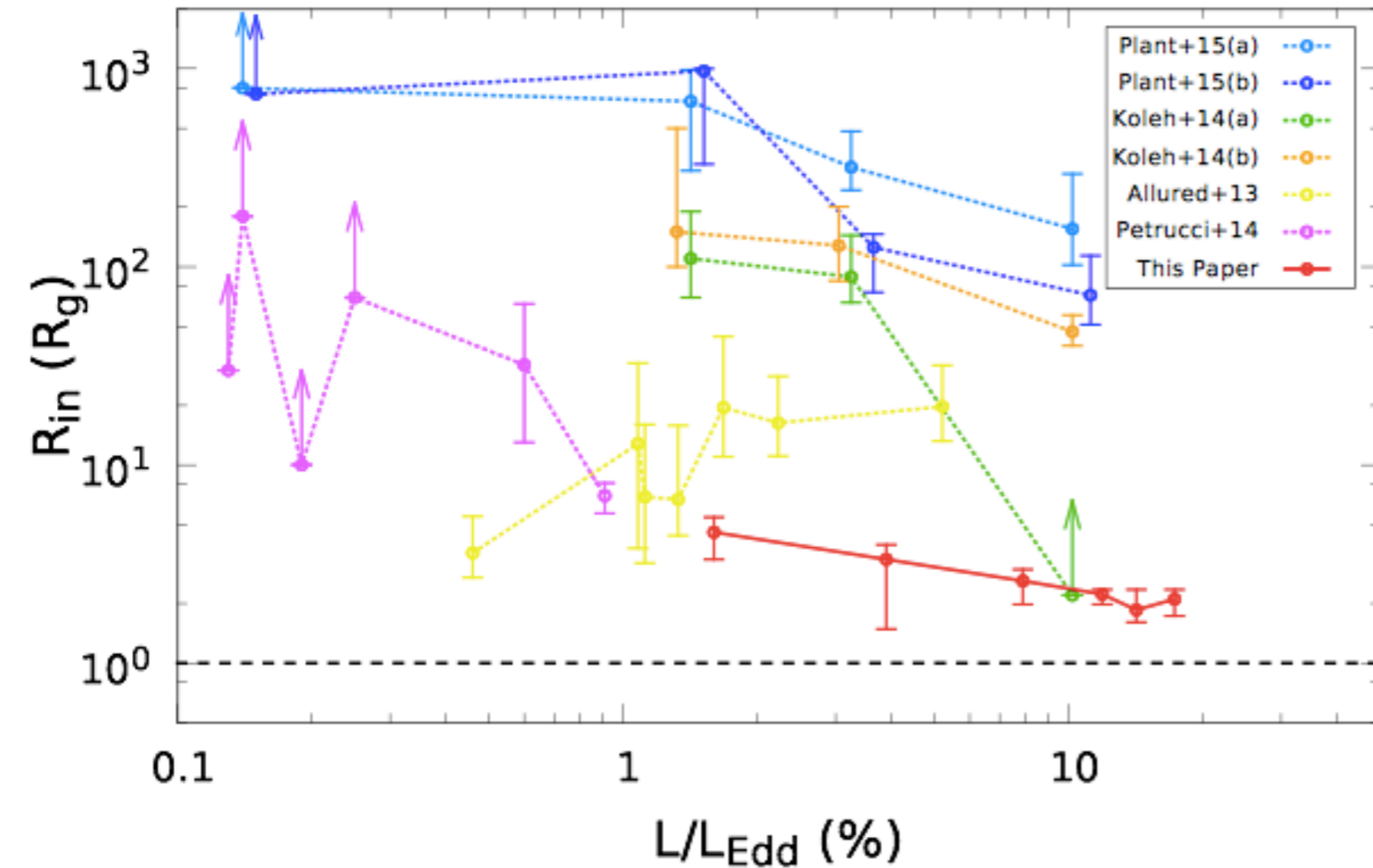


Disc truncated at large radii when accretion rate is low [e.g. Esin+'97; Poutanen+'97; Zdziarski+'99; Narayan & McClintock '08; Veledina's talk]



Results from FeK fit are controversial

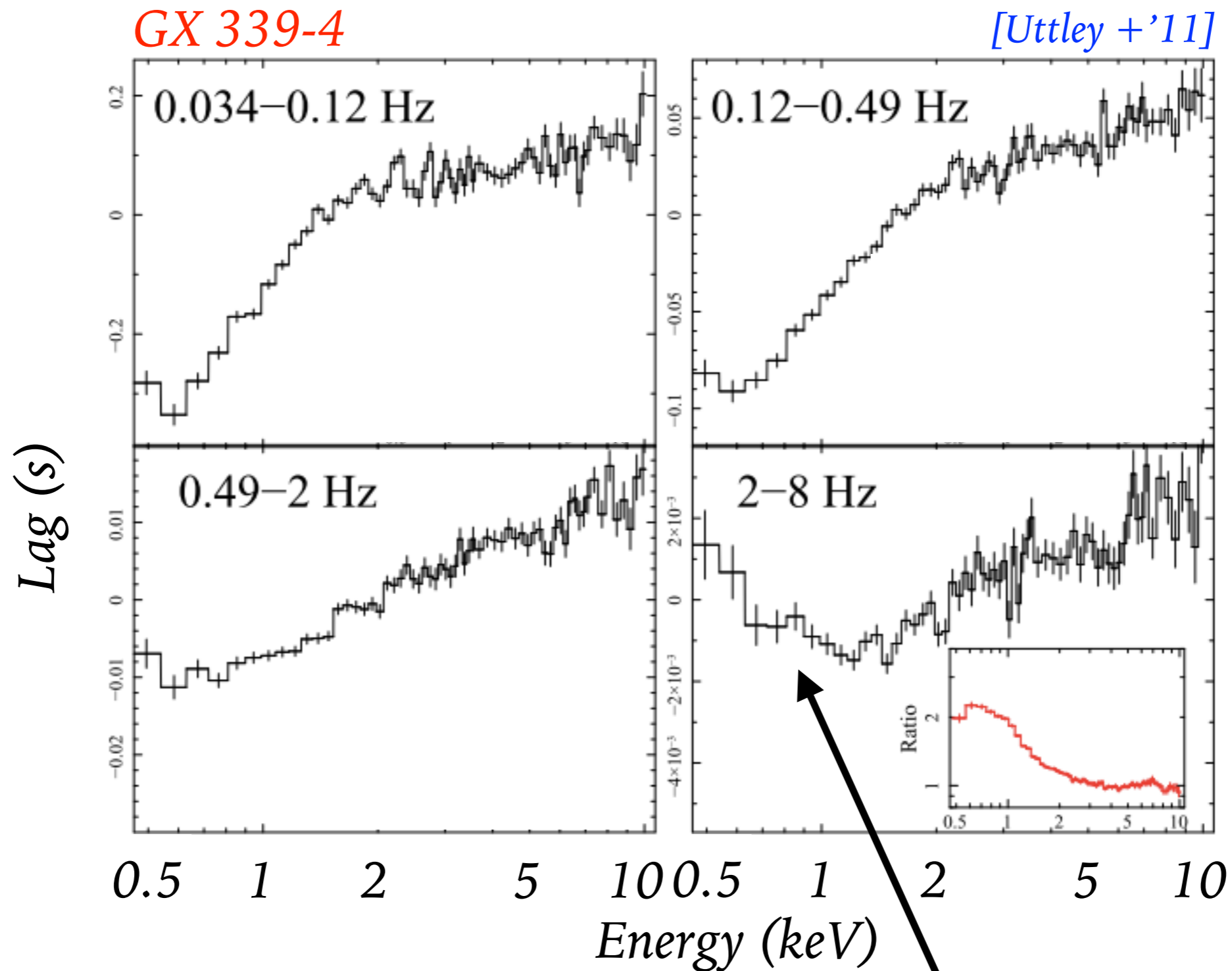
[Garcia+'15]



Widely different estimates of R_{in}
and no consensus

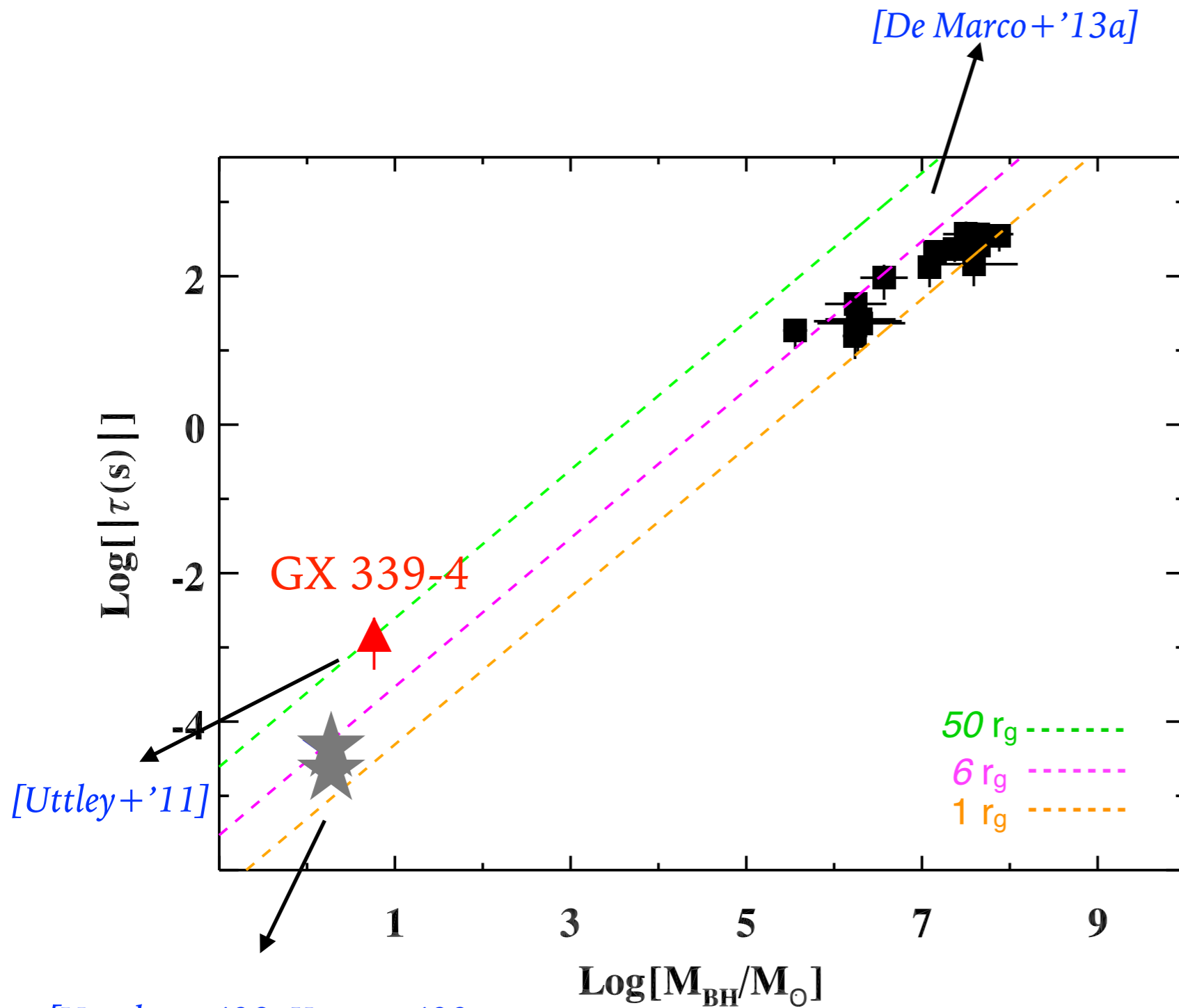
[e.g. Reis+'08; Plant+'15; Garcia+'15;
Basak & Zdziarski '16; Zdziarski's talk]

First detection of reverberation in a BHXRBB



Disc thermal reverberation

Reverberation across mass scale

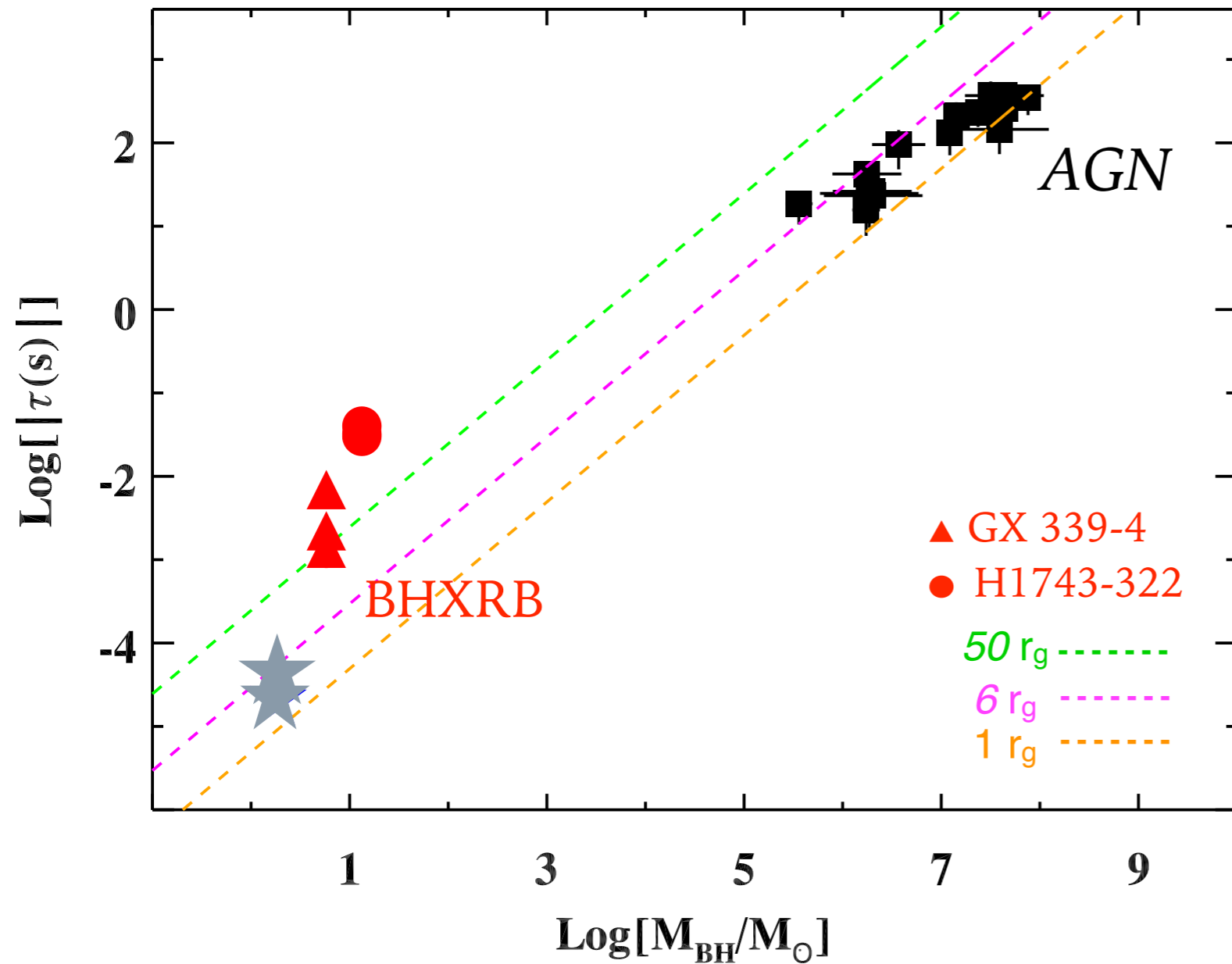


GX 339: lag a factor ~ 10 longer than extrapolation of AGN sample

[Vaughan+'98, Kaaret+'99, deAvellar+'13, Barret+'13, Cackett+'16]

New detections of reverberation lags in BHXRBs

[De Marco + '15, '16]



Sample: 10 sources (about 60 observations)

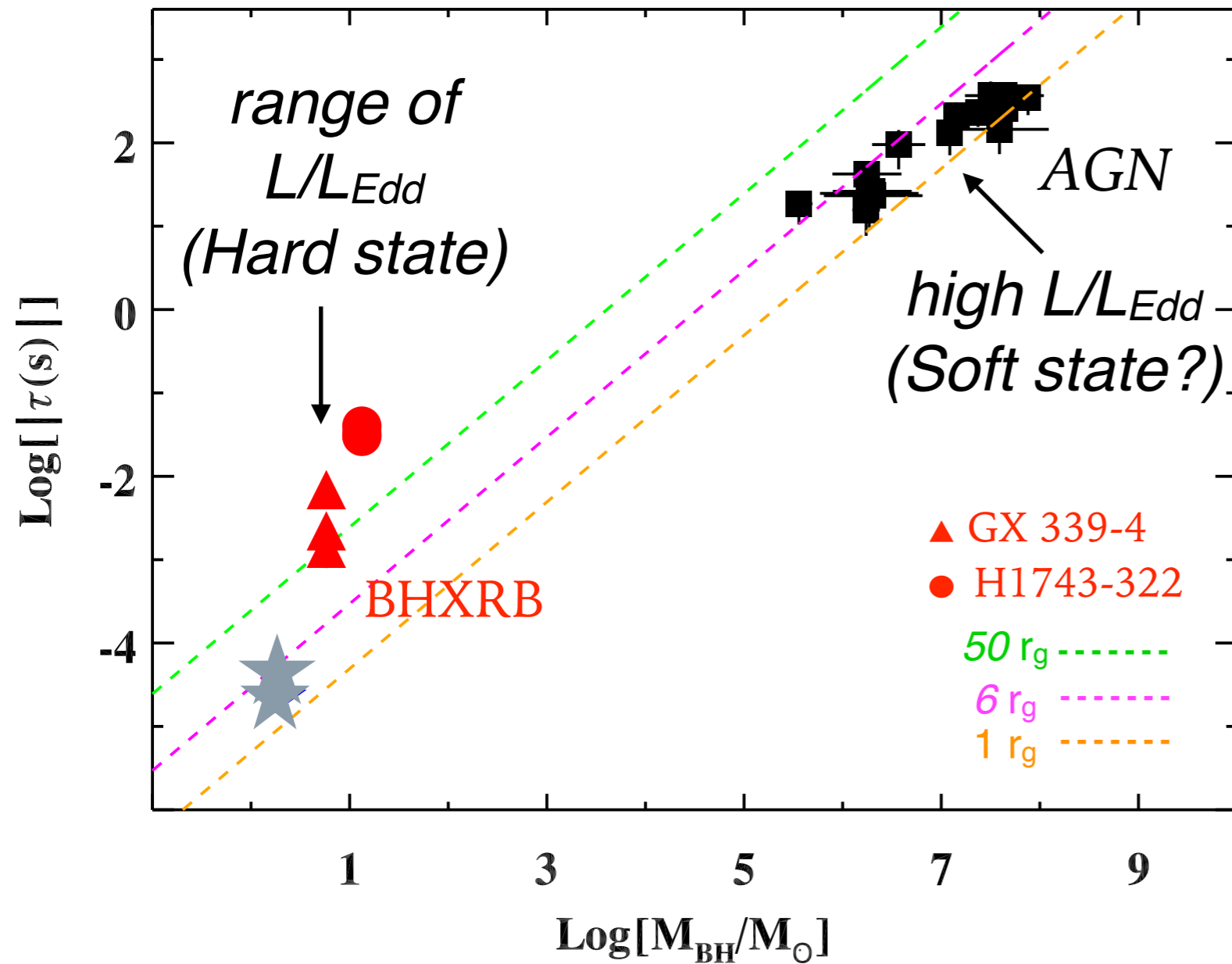
New detections (2 for GX 339-4, 4 for H1743-322)

- ▲ GX 339-4
- H1743-322
- $50 r_g$
- $6 r_g$
- $1 r_g$

Offset between BHXRBs and the AGN sample

New detections of reverberation lags in BHXRBs

[De Marco + '15, '16]



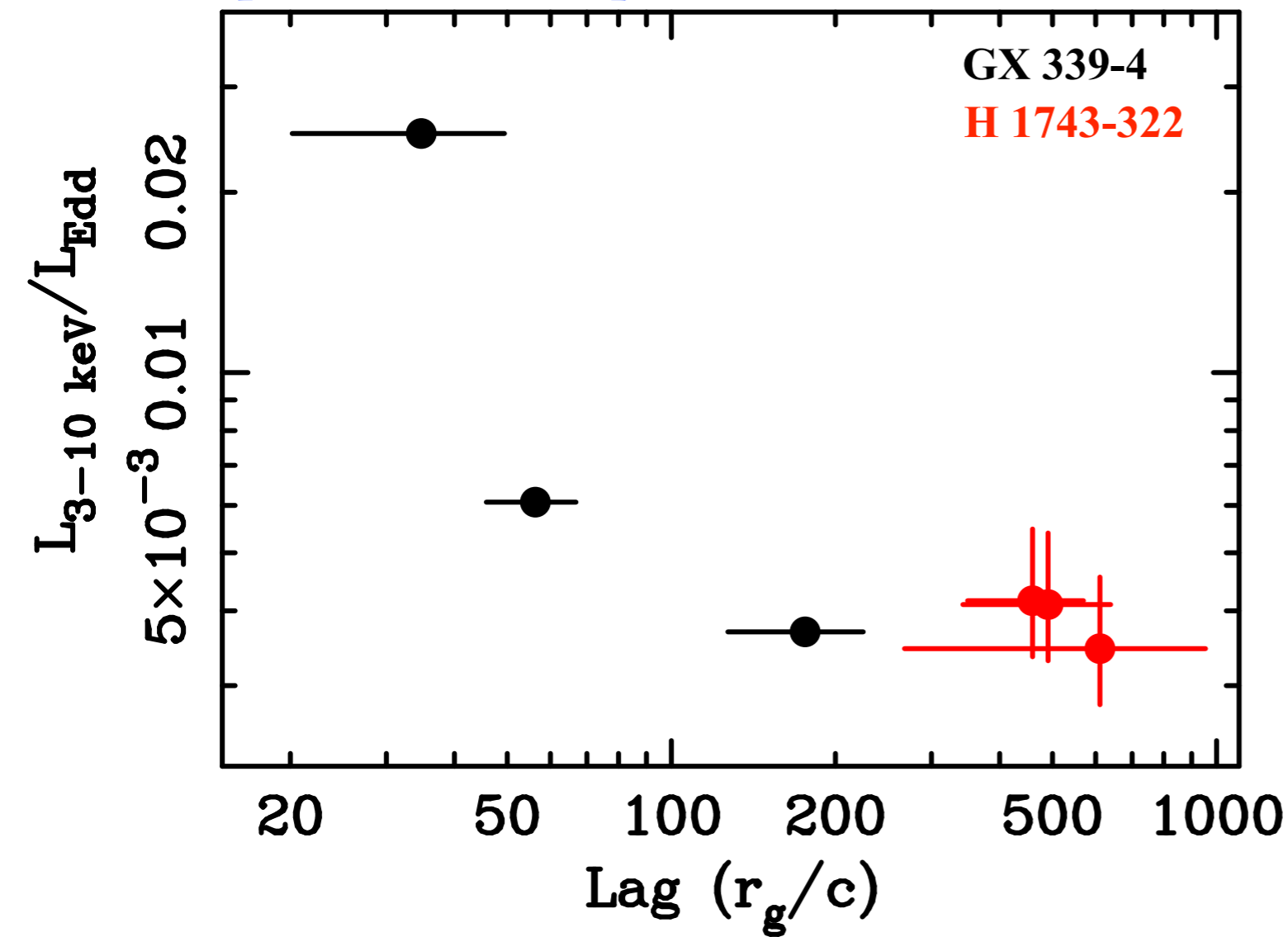
Sample: 10 sources (about 60 observations)

New detections (2 for GX 339-4, 4 for H1743-322)

Offset between BHXRBs and the AGN sample → different disc-corona geometry?

Lag amplitude varying with luminosity

[De Marco + '16]

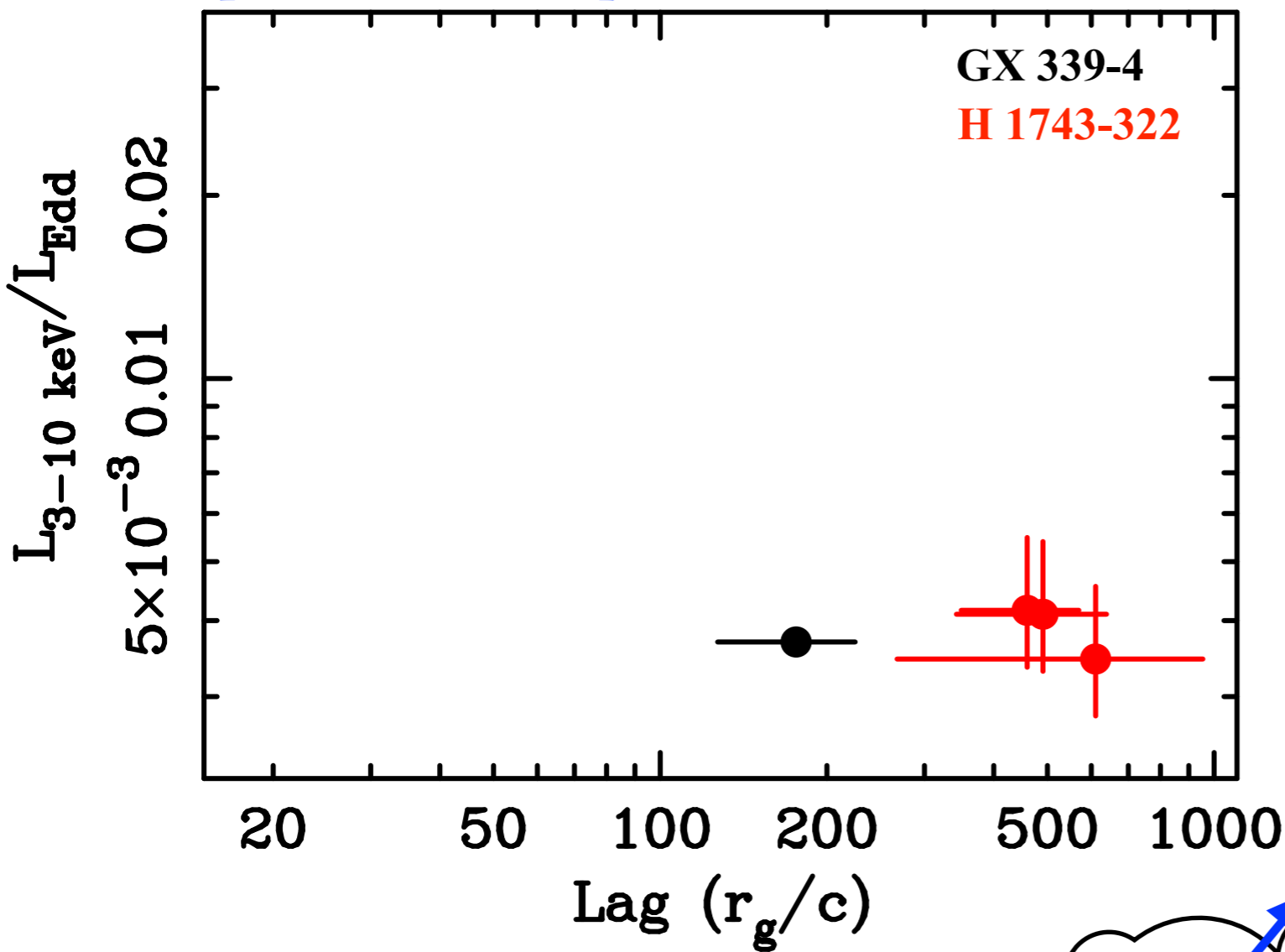


The reverberation lag decreases as the source rises in luminosity

Evolving disc-corona geometry in BHXRBs

Lag amplitude varying with luminosity

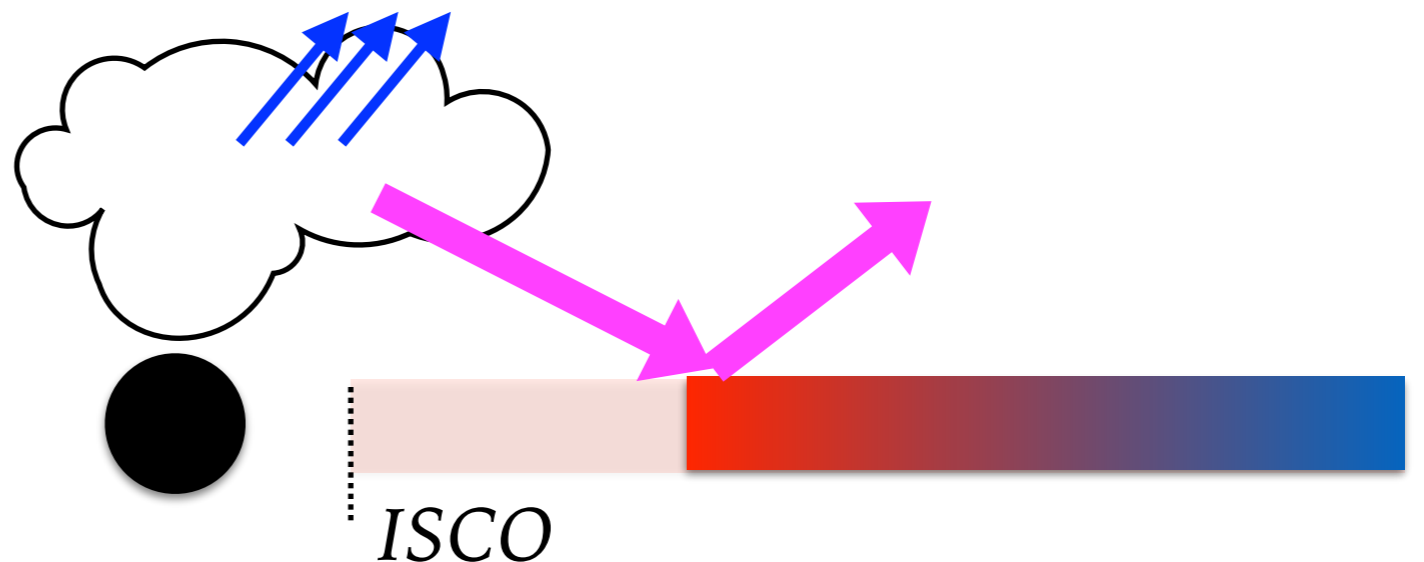
[De Marco + '16]



The reverberation lag decreases as the source rises in luminosity

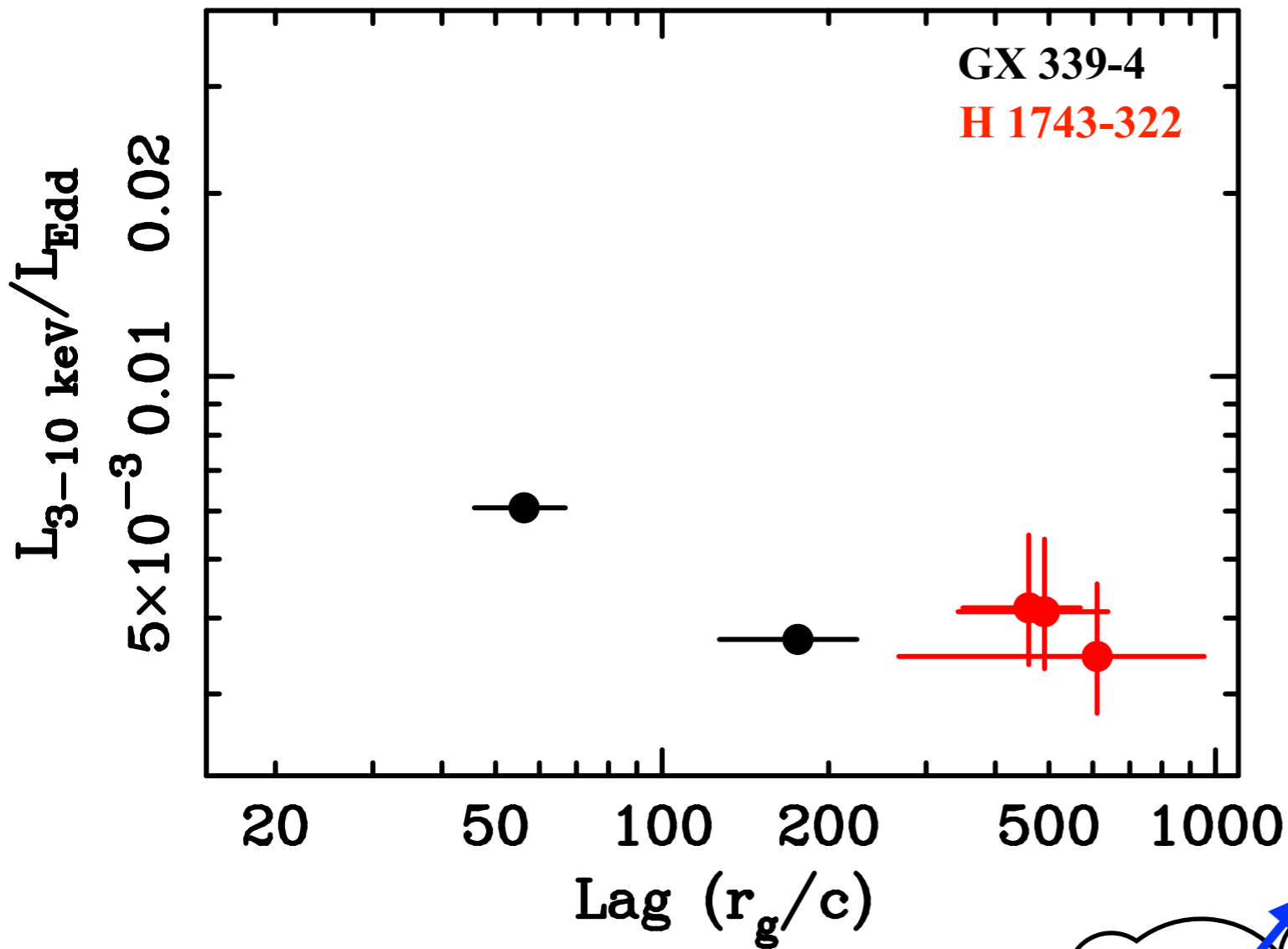
Evolving disc-corona geometry in BHXRBs

Results consistent with disc truncation radius moving in



Lag amplitude varying with luminosity

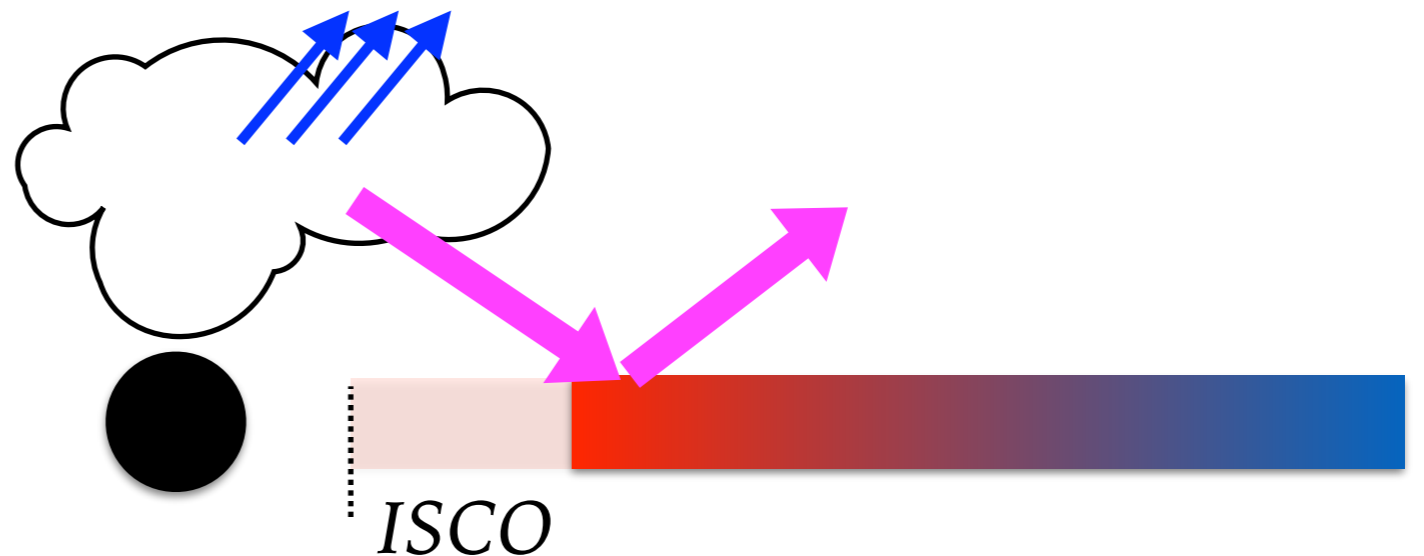
[De Marco + '16]



The reverberation lag decreases as the source rises in luminosity

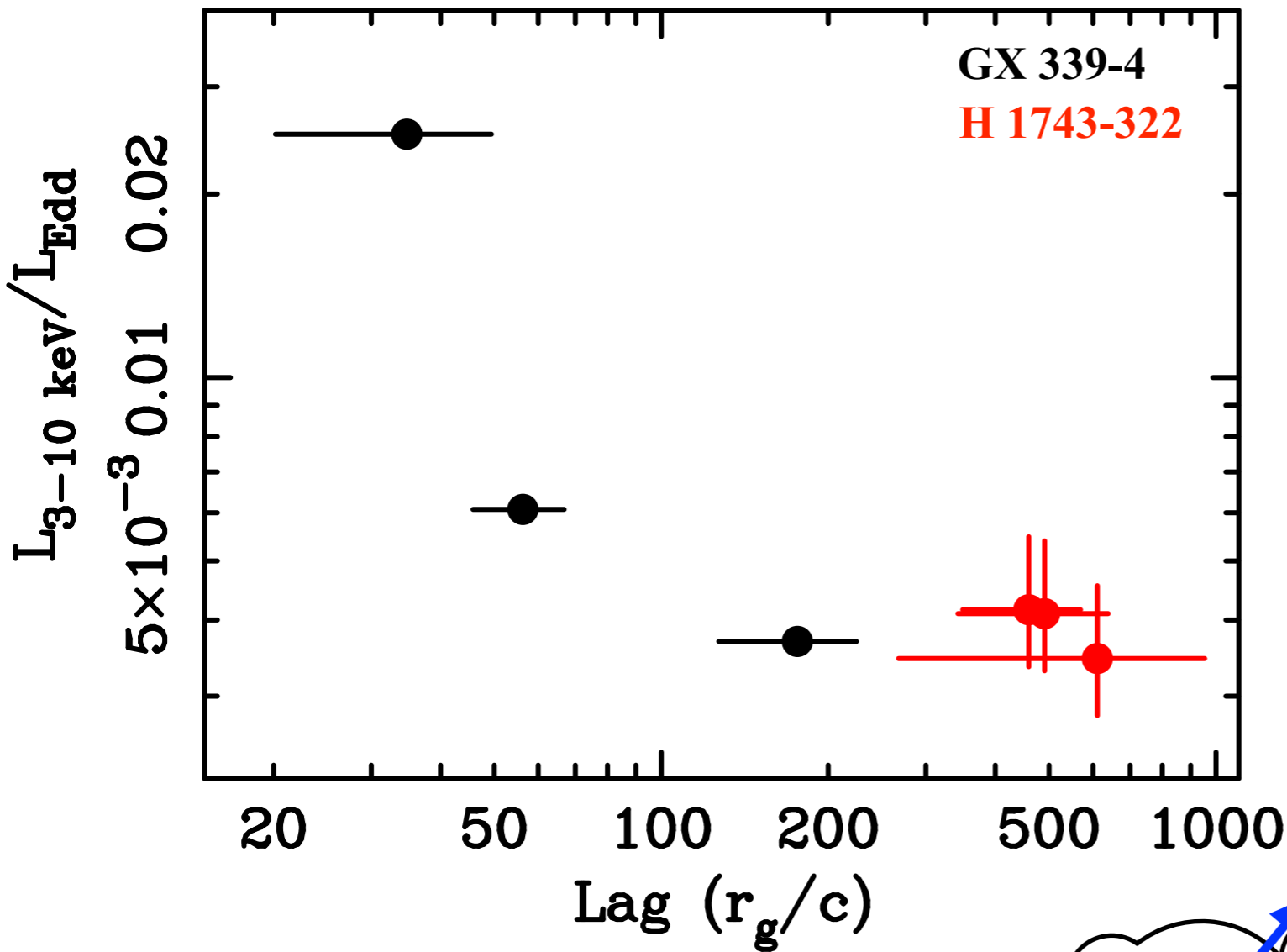
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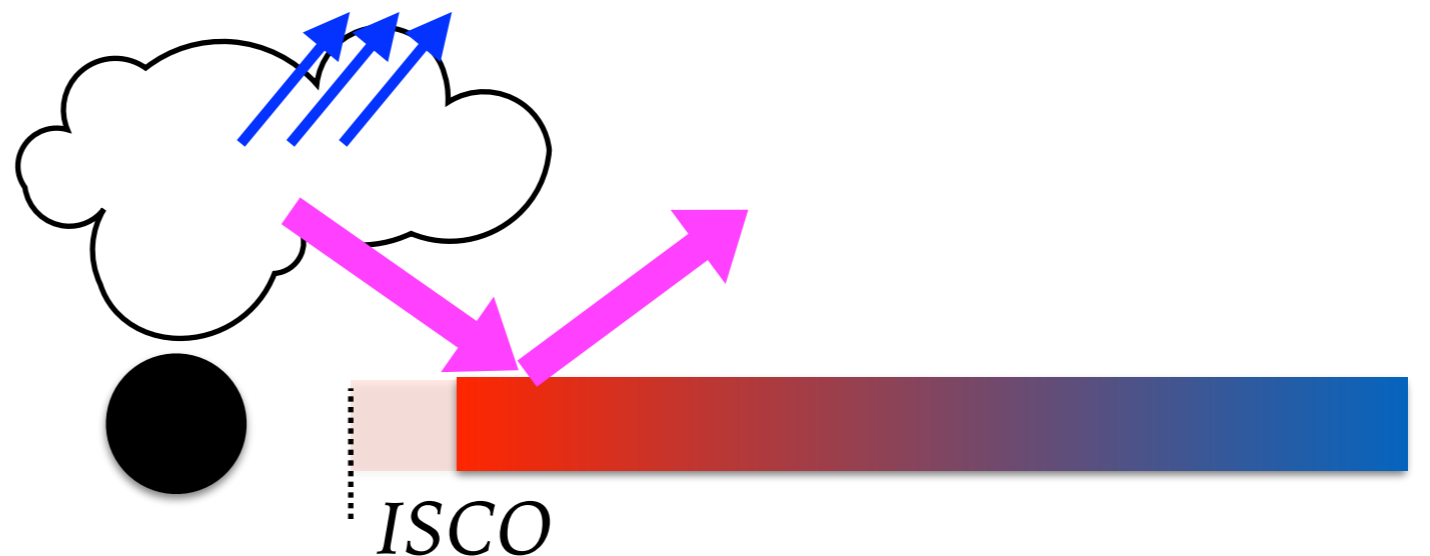
[De Marco + '16]



The reverberation lag decreases as the source rises in luminosity

Evolving disc-corona geometry in BHXRBs

Results consistent with disc truncation radius moving in



Wrap-up

The reverberation lag decreases with luminosity in the hard state, consistent with an evolving inner disc radius

Future

Detailed modelling of lag spectra with self-consistent models to derive disc inner radius

Disentangle contribution of lags associated with QPOs [[Stevens + '16](#); [Ingram + '16a](#); '16b; [van den Eijnden + '16](#); see also [Ingram's talk](#)]

More data! To study more sources and to sample more accretion states

Thanks!