Accretion physics
(a X-ray spectral-timing perspective for Athena)

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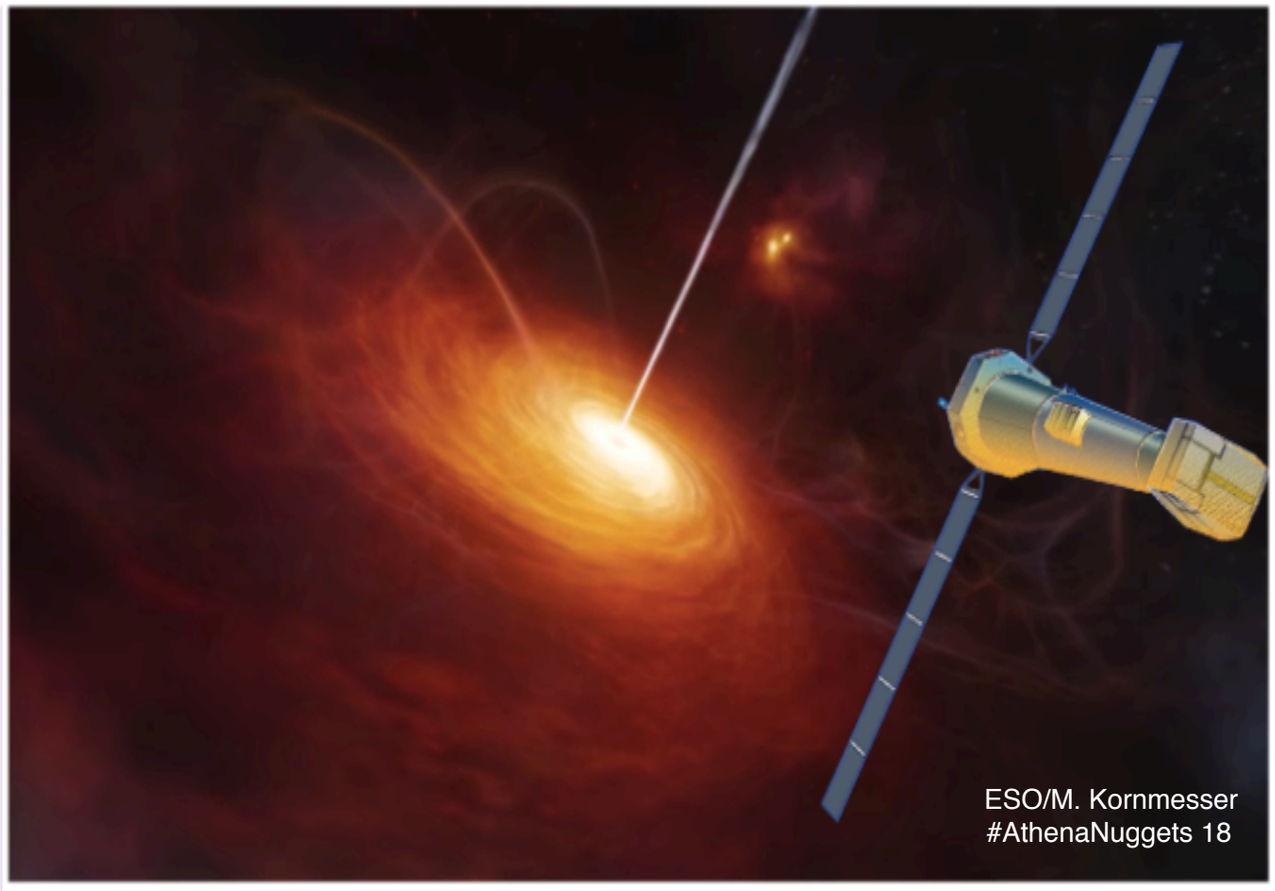
Outstanding problems

Constraining parameters of the BH (Mass and Spin)

Determining physical conditions of the gas in the innermost regions around a BH



How do BHs grow? … How do BHs influence the host galaxy? … How are jets accelerated? … How do variations of the accretion flow are related to the jet? …What is the nature of the hard X-ray source? … How does the inner flow evolve? …What does produce the observed flux variability? …

Aim of the talk

Advances obtained with X-ray spectral-timing techniques

How Athena will boost this field

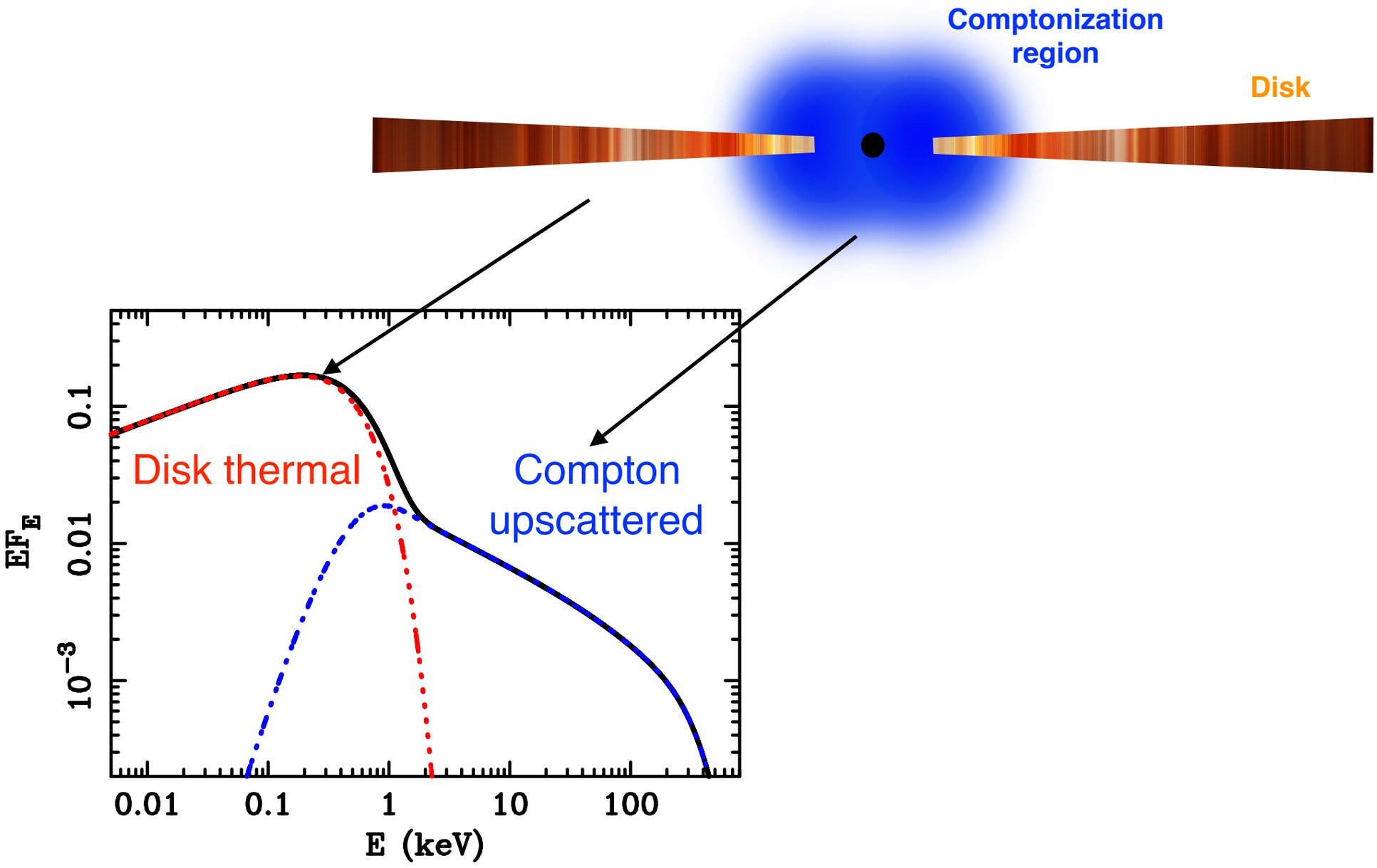
Aim of the talk

Advances obtained with X-ray spectral-timing techniques

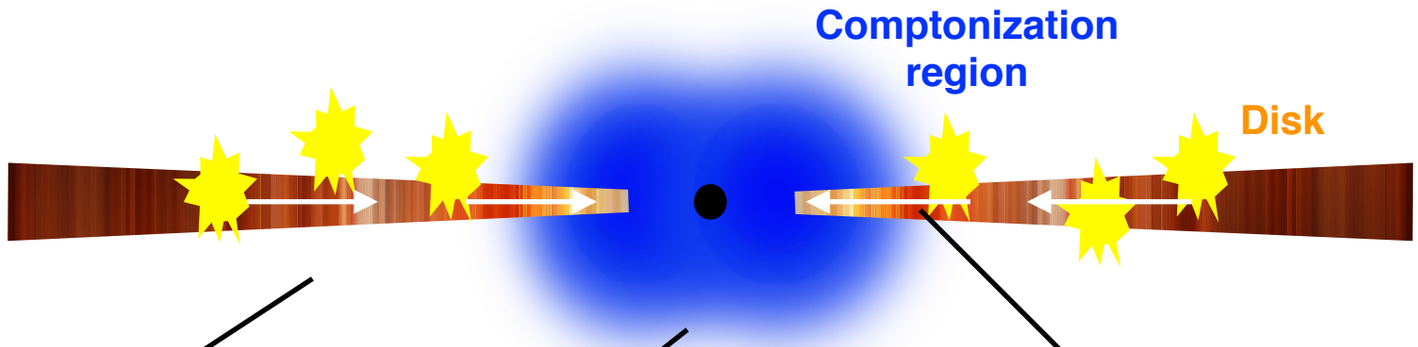
Broad band E coverage (down to soft X-rays),
Large effective area, Fast timing capabilities

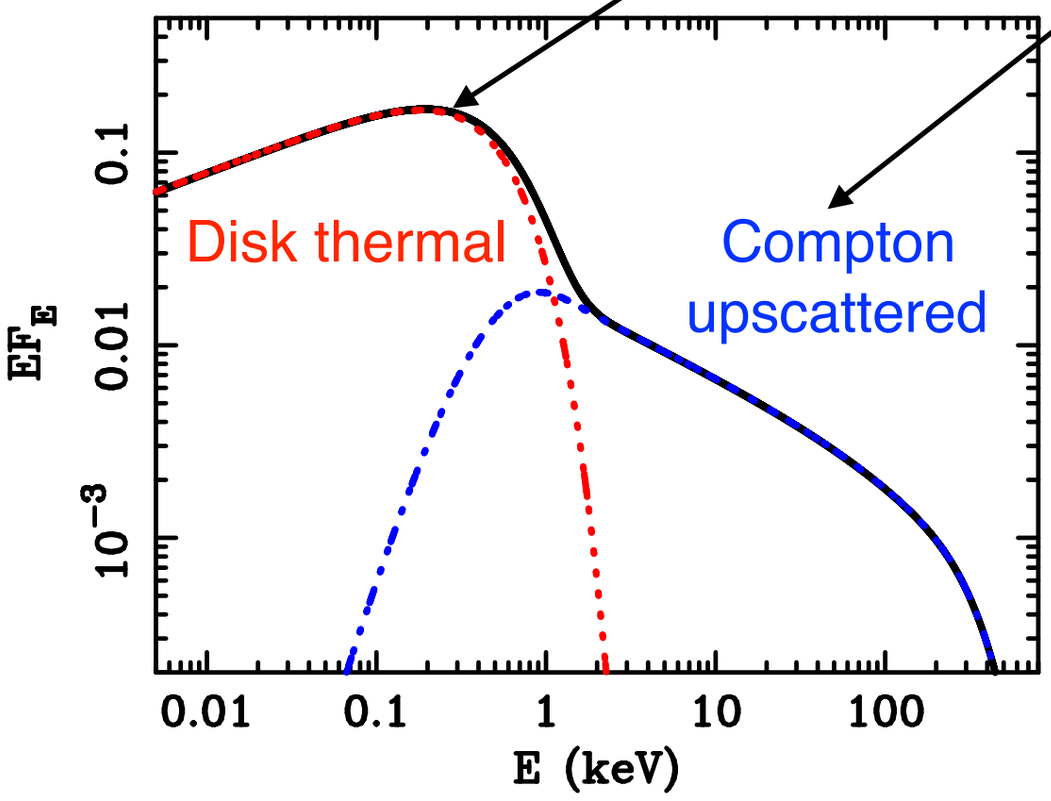
How Athena will boost this field

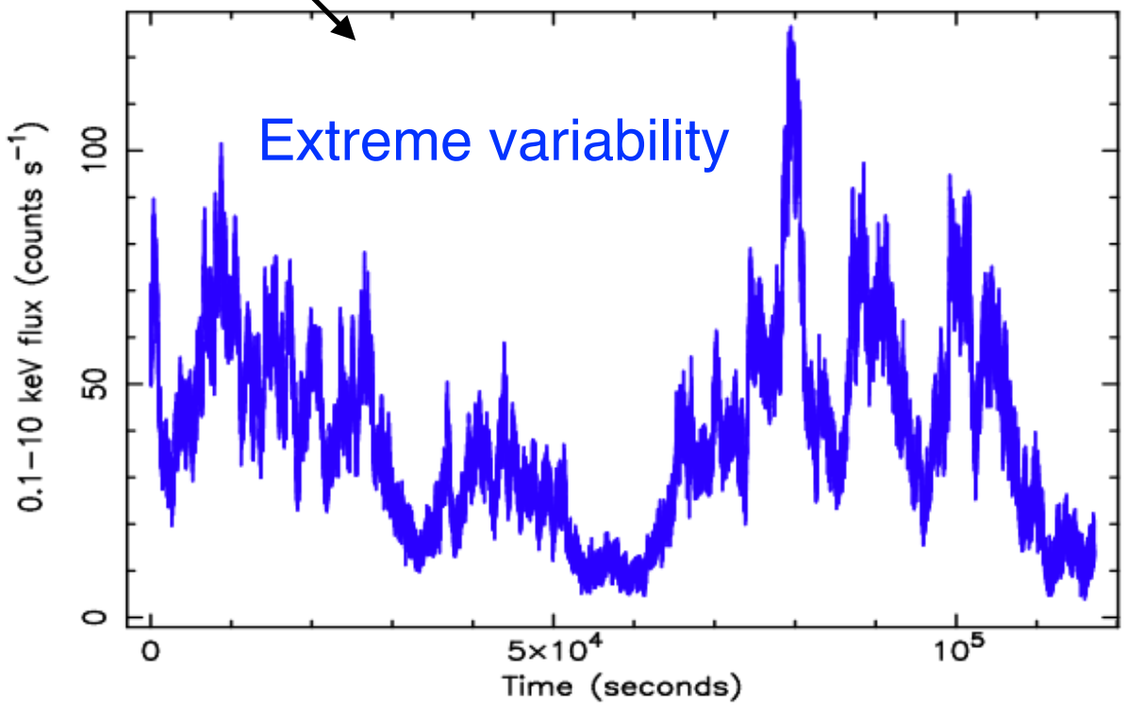
Spectral and timing signatures of BH accretion



Spectral and timing signatures of BH accretion







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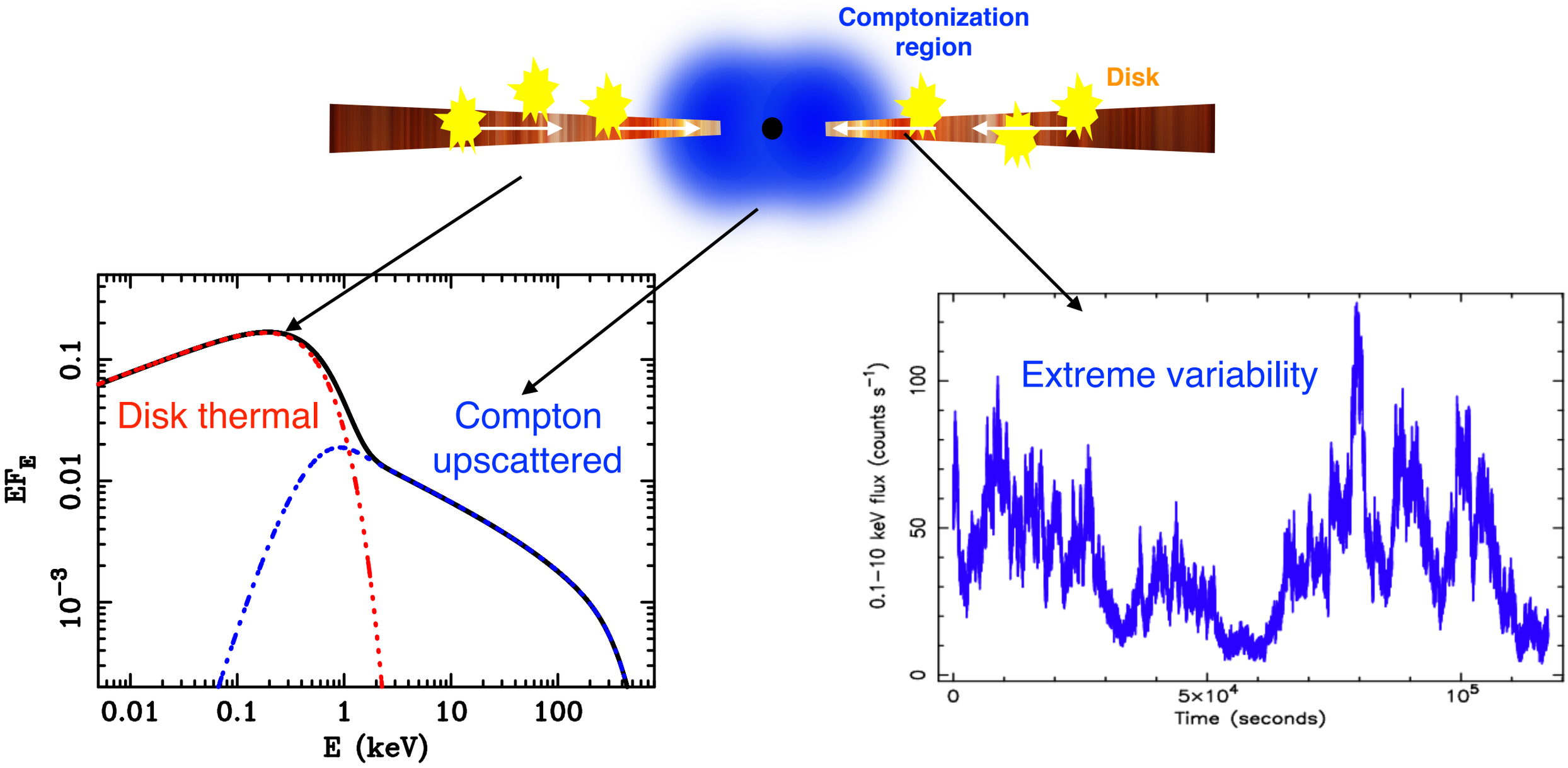
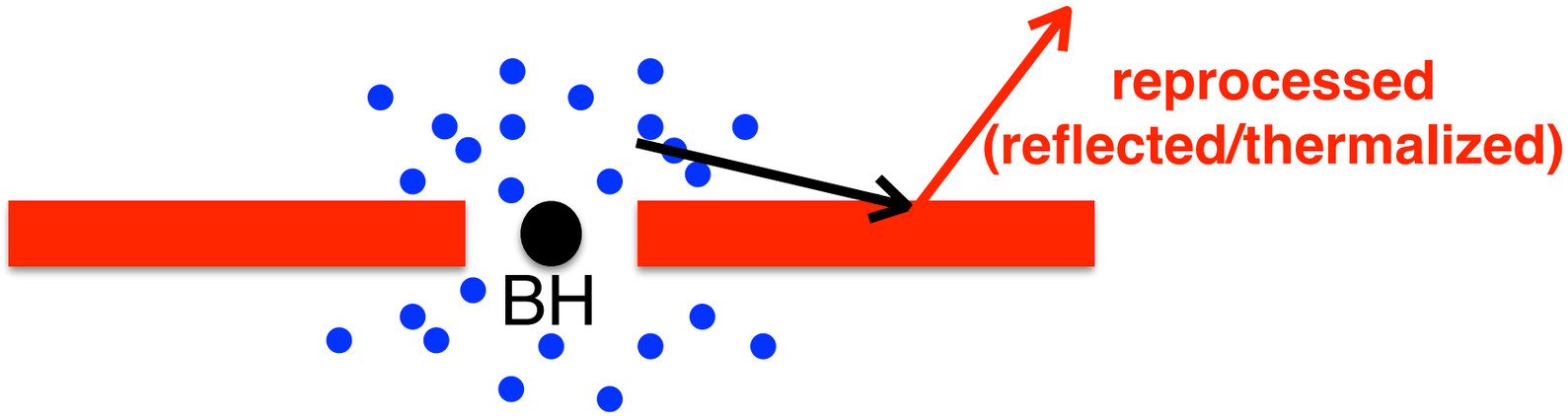
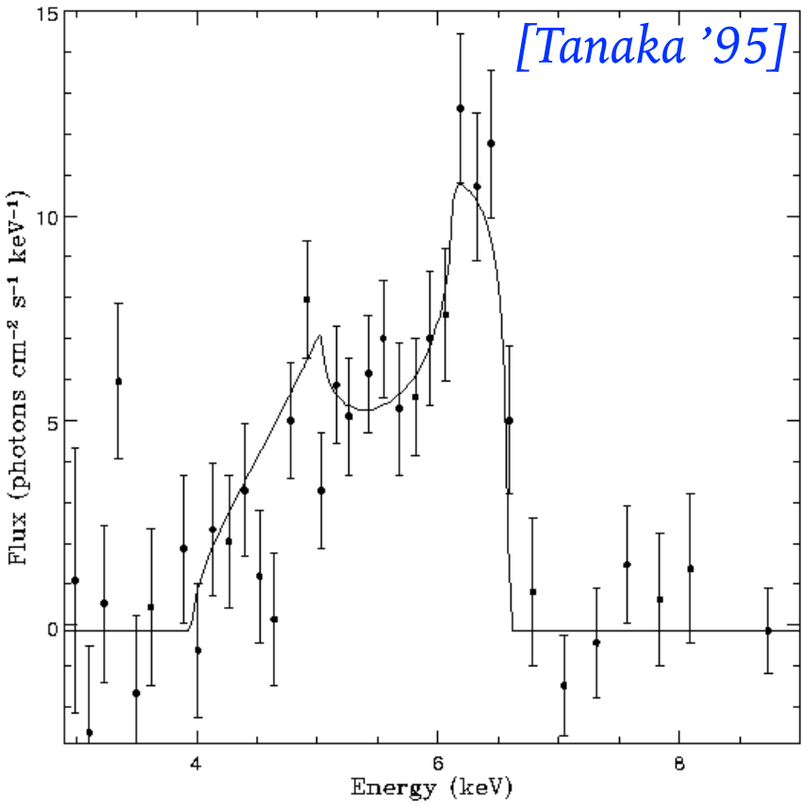


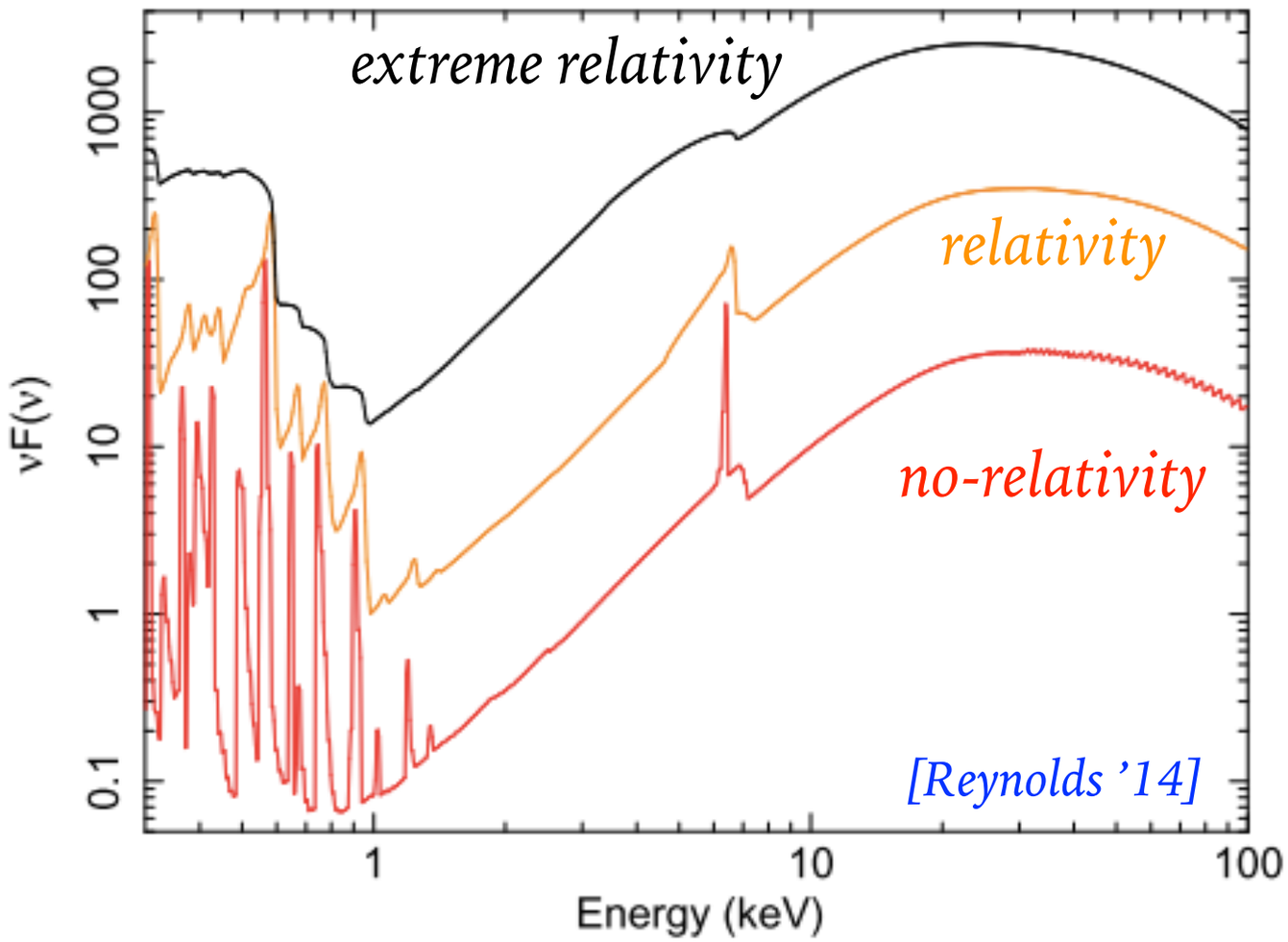
X-ray spectral-timing: novel approach to separate the emission from in the innermost radii

Probing the innermost accretion flow



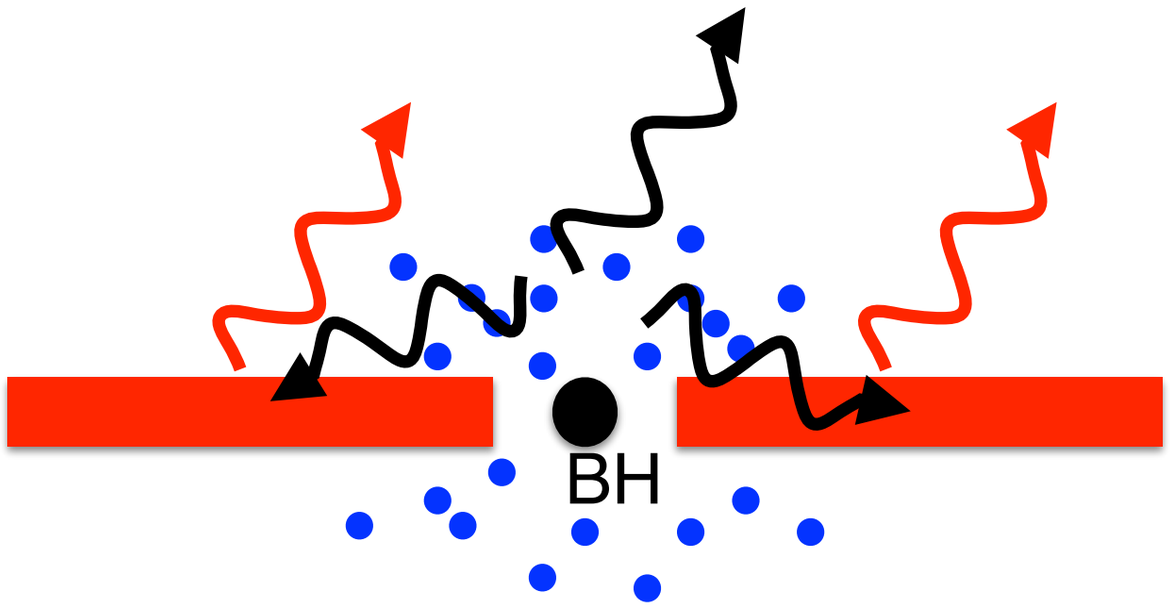
MCG -6-30-15





Profile/intensity depend on disc-corona geometry, BH spin, disc ionization, Fe abundance…

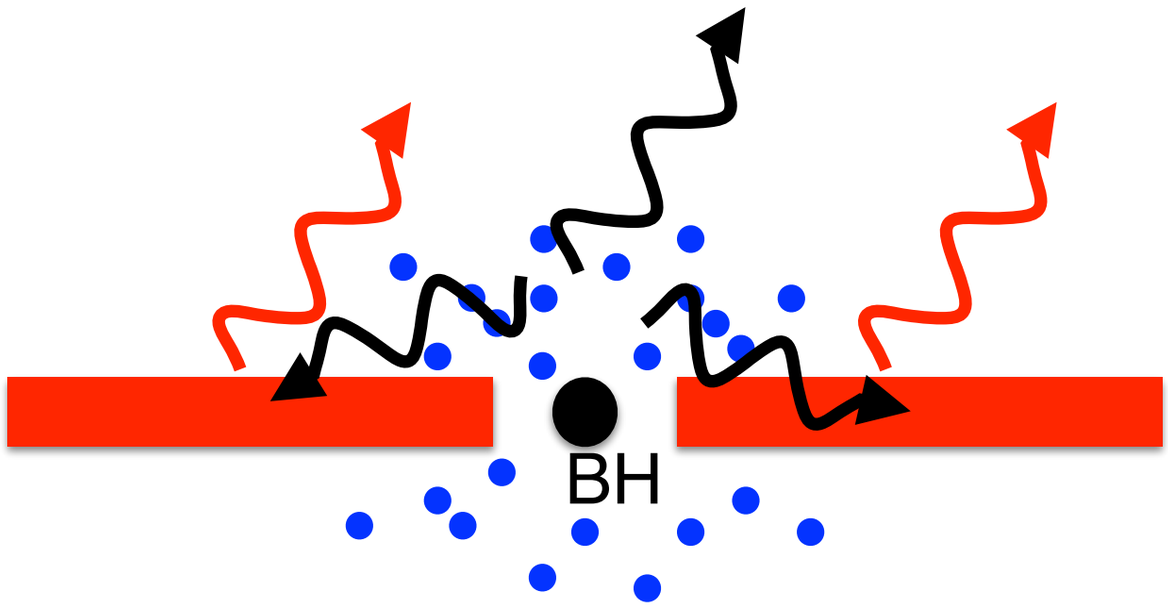
X-ray reverberation



Reprocessed emission time-delayed due to additional light travel time

[e.g. Blandford & McKee ’82; Stella ’90; Campana & Stella ’95; Reynolds +’99; Young & Reynolds ’00; Poutanen ’02; Fabian+’09; Uttley+’14]

X-ray reverberation



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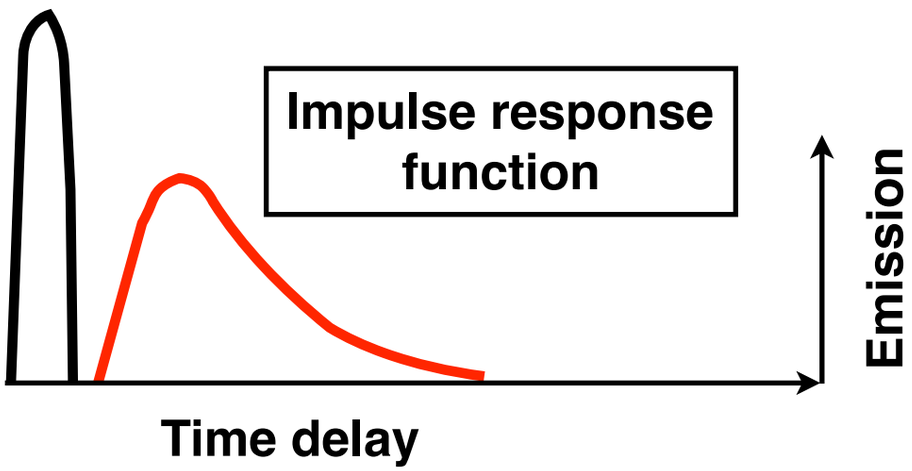
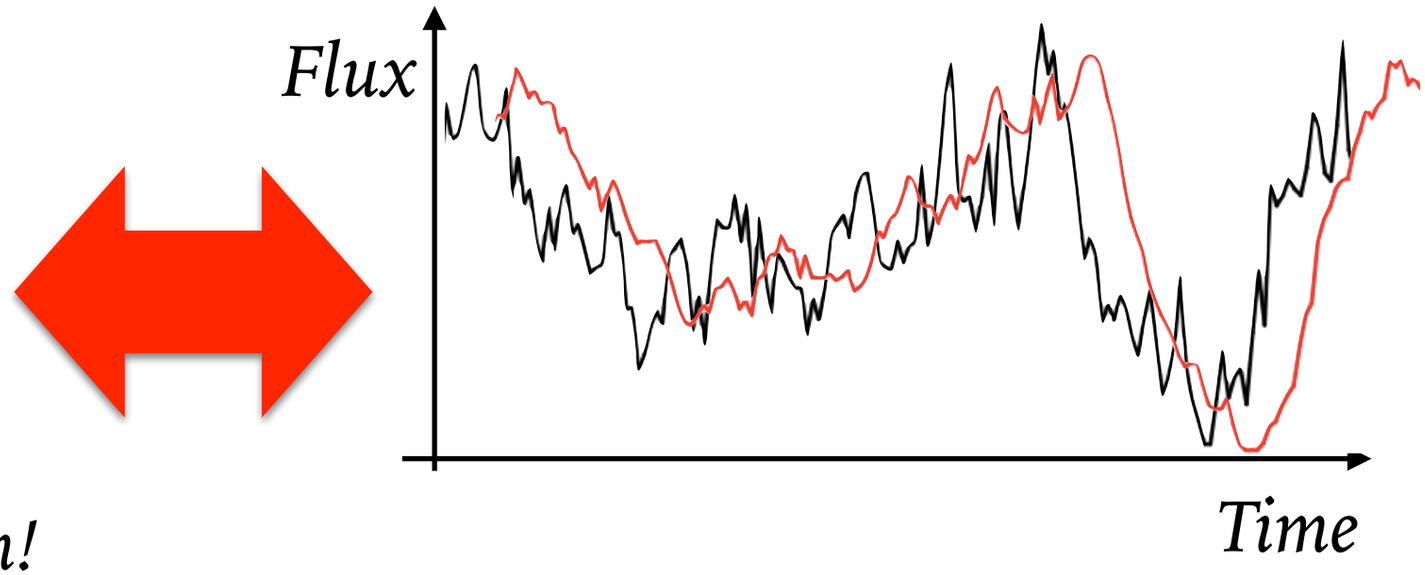
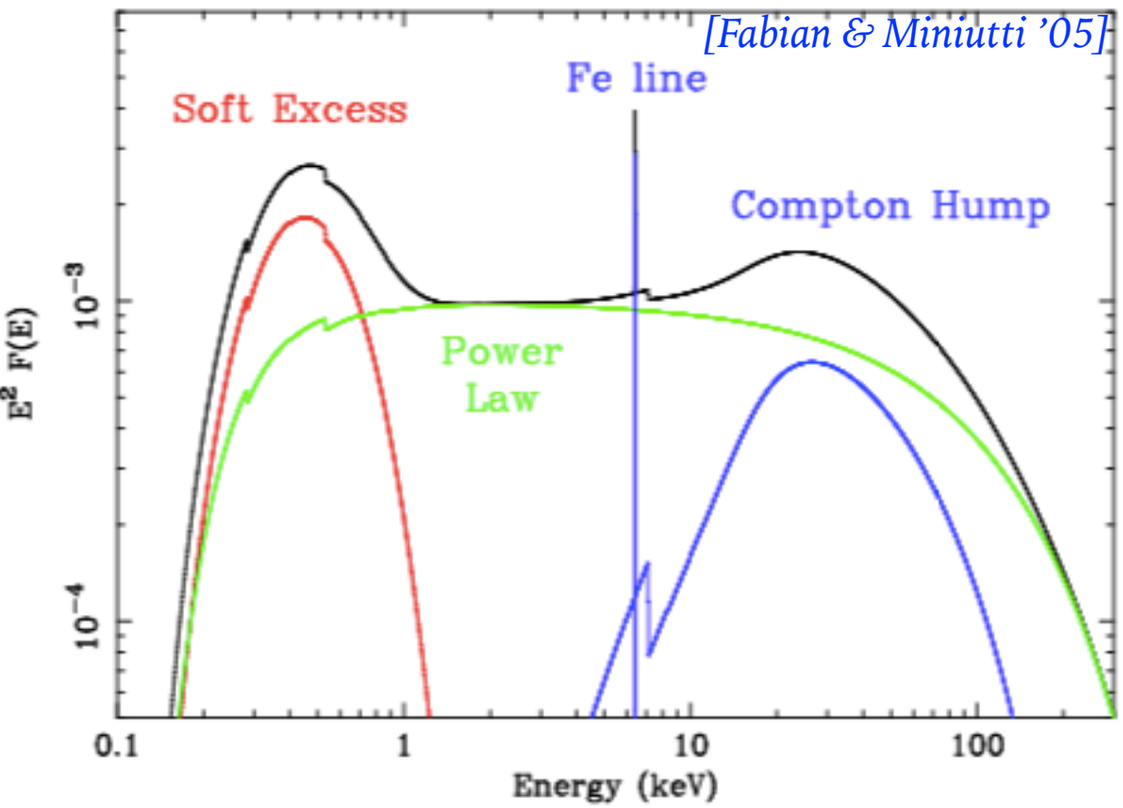




Encodes the geometry of the system!

[e.g. Blandford & McKee '82; Stella '90; Campana & Stella '95; Reynolds +'99; Young & Reynolds '00; Poutanen '02; Fabian+'09; Uttley+'14]

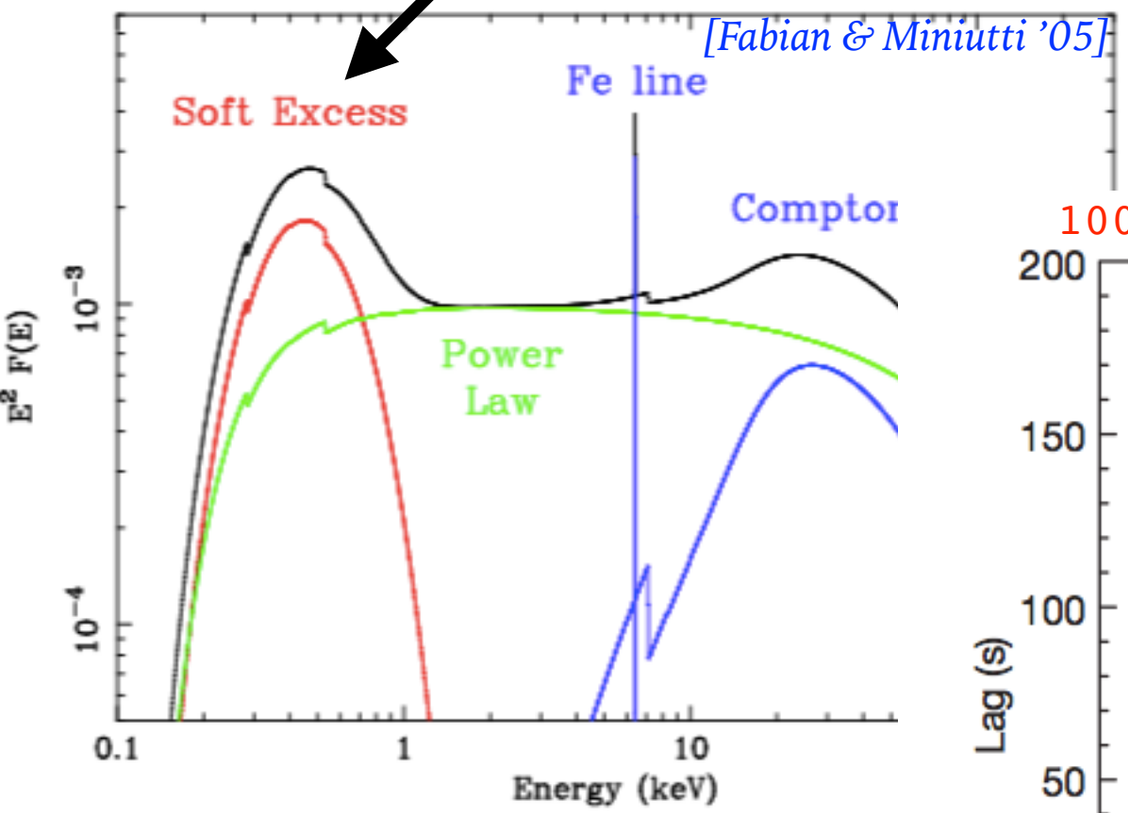
X-ray reverberation in AGN

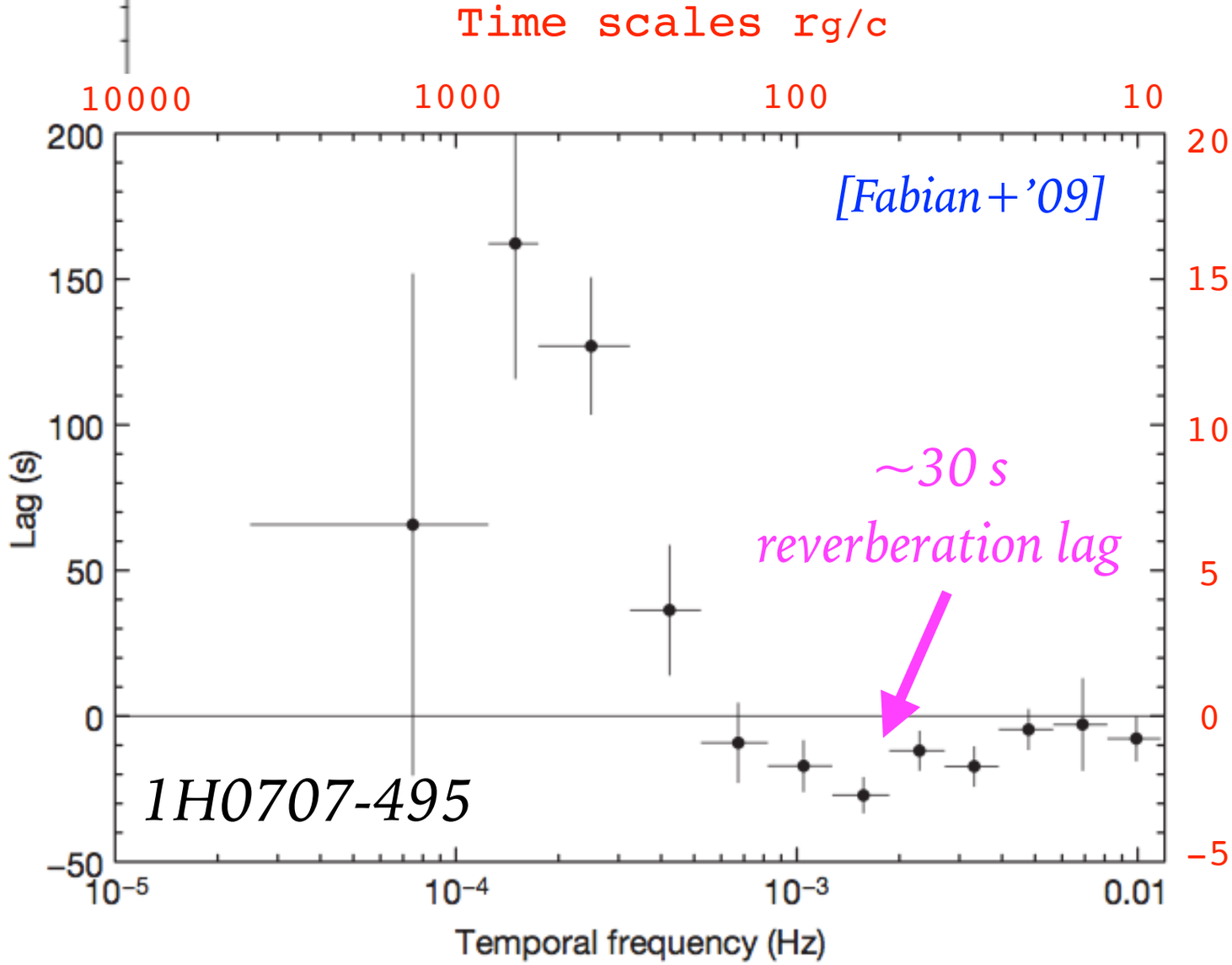


[Fabian & Miniutti '05]

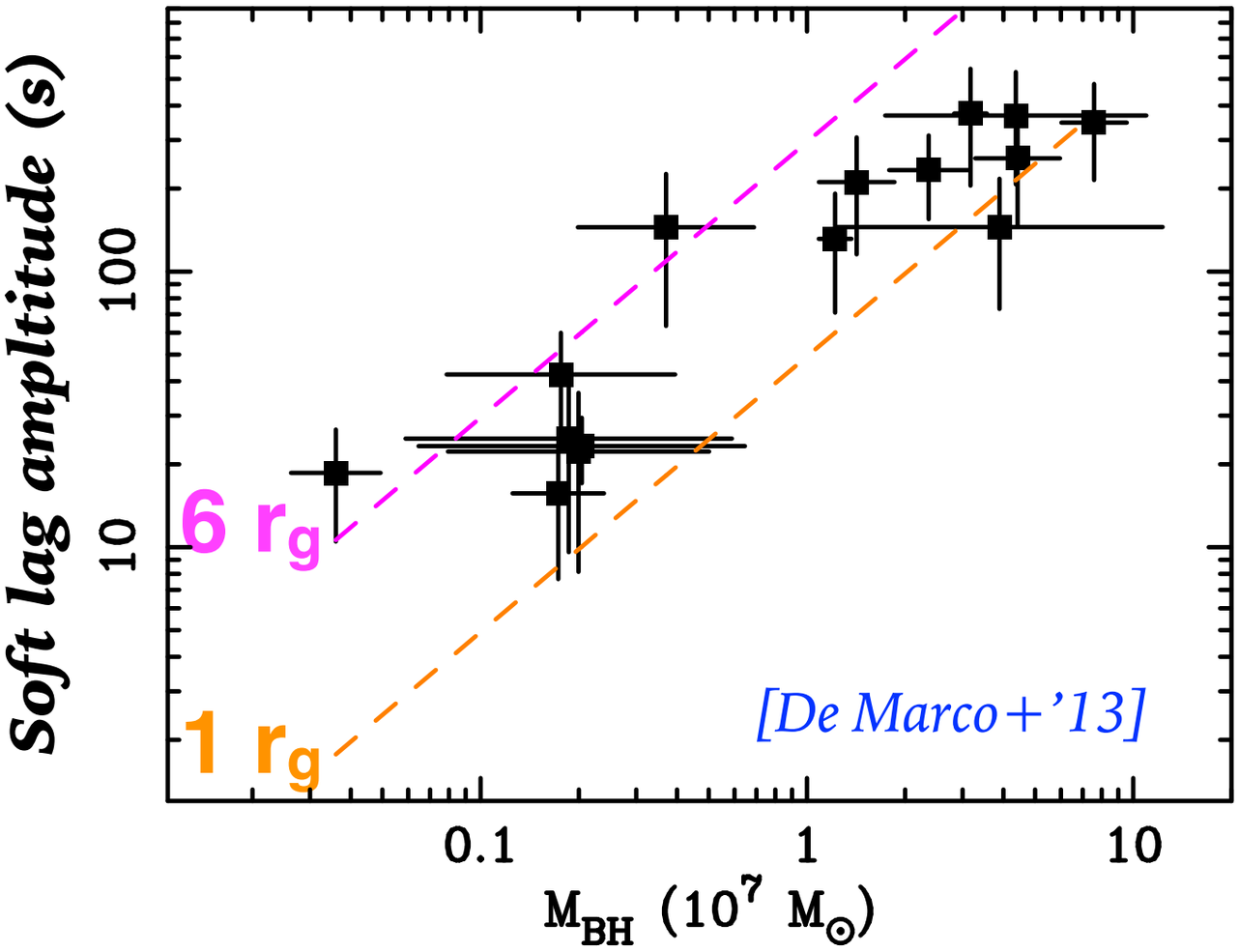
X-ray reverberation in AGN

Soft excess responding to variability of hard X-ray photons





Correlation with BH mass



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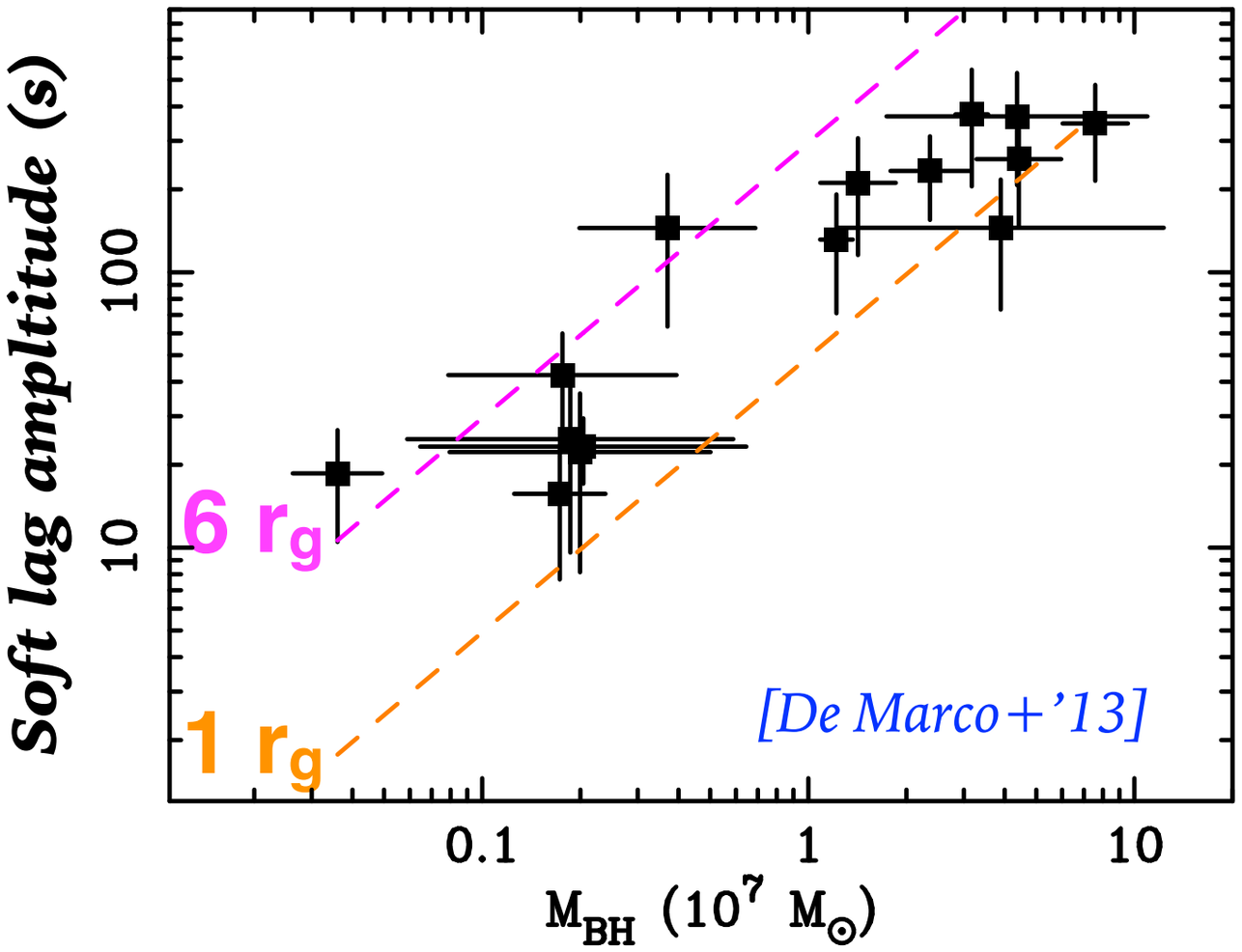


What does this tell us?

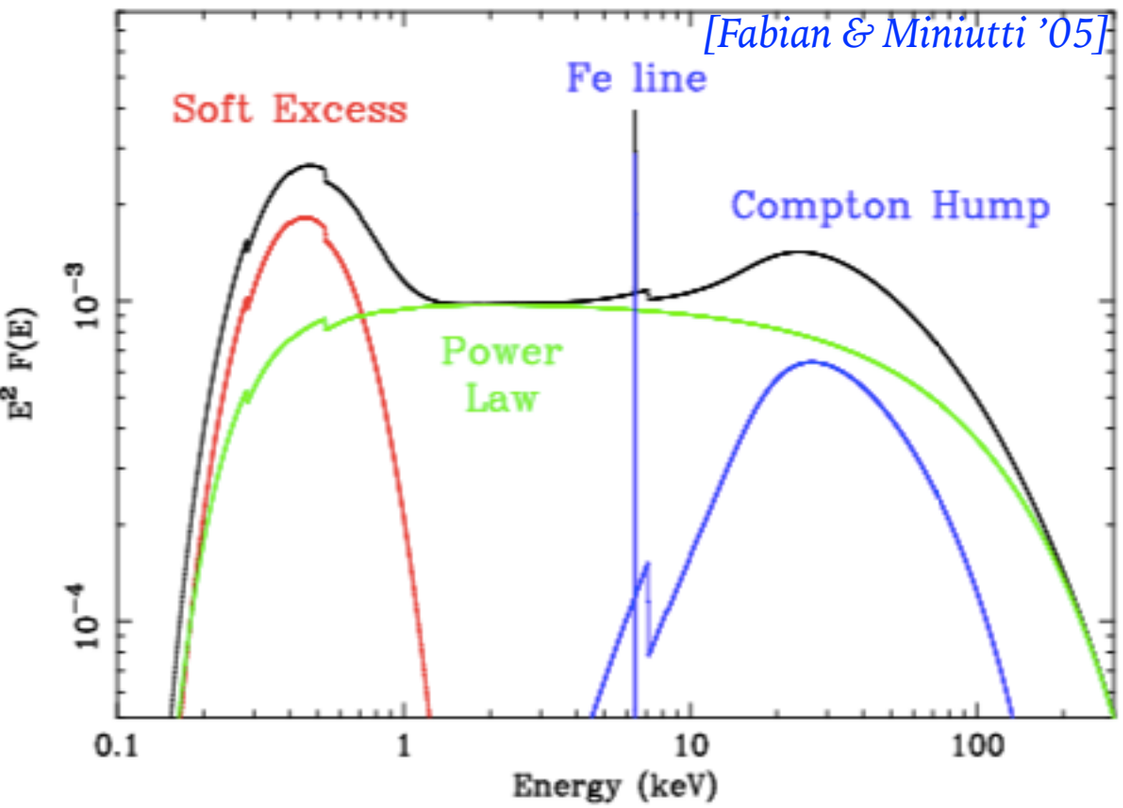
- Soft excess due to reprocessing in the inner regions of the disc

- Same inner flow geometry in RQ AGN

- Any scatter introduced by dilution small

Compact corona, disc extending down to the ISCO

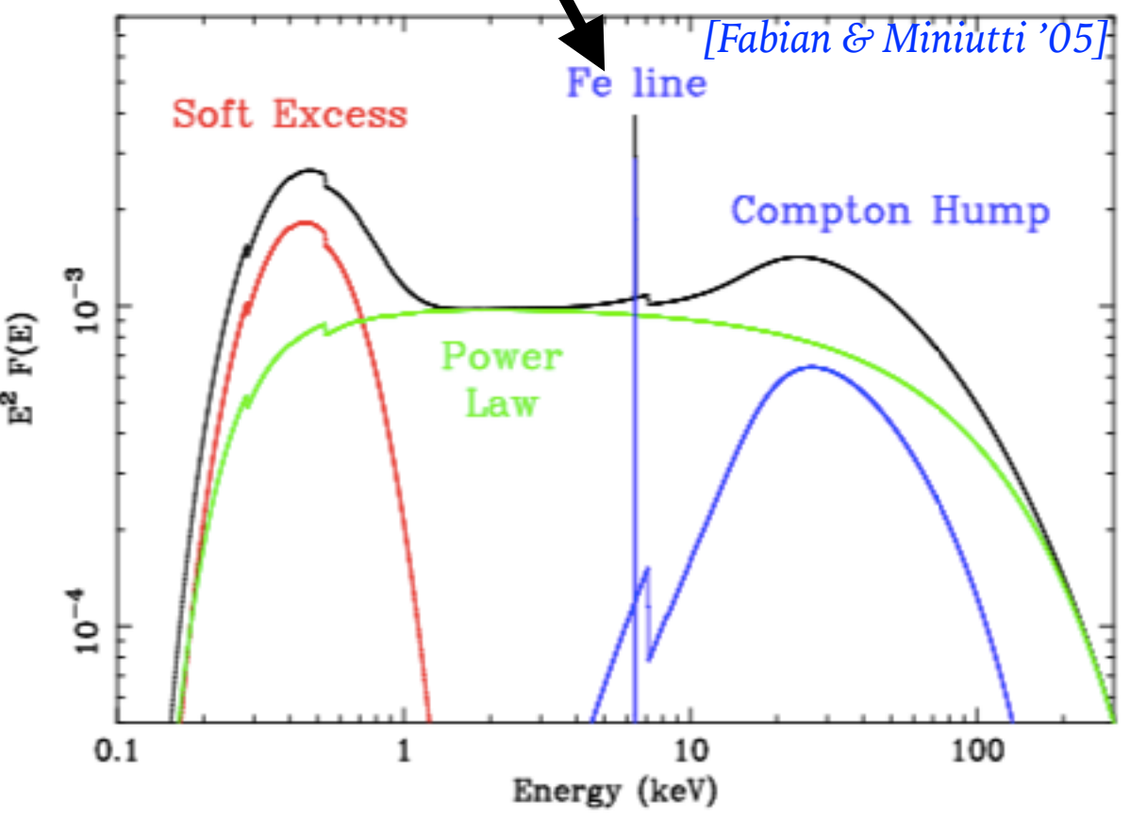
X-ray reverberation in AGN

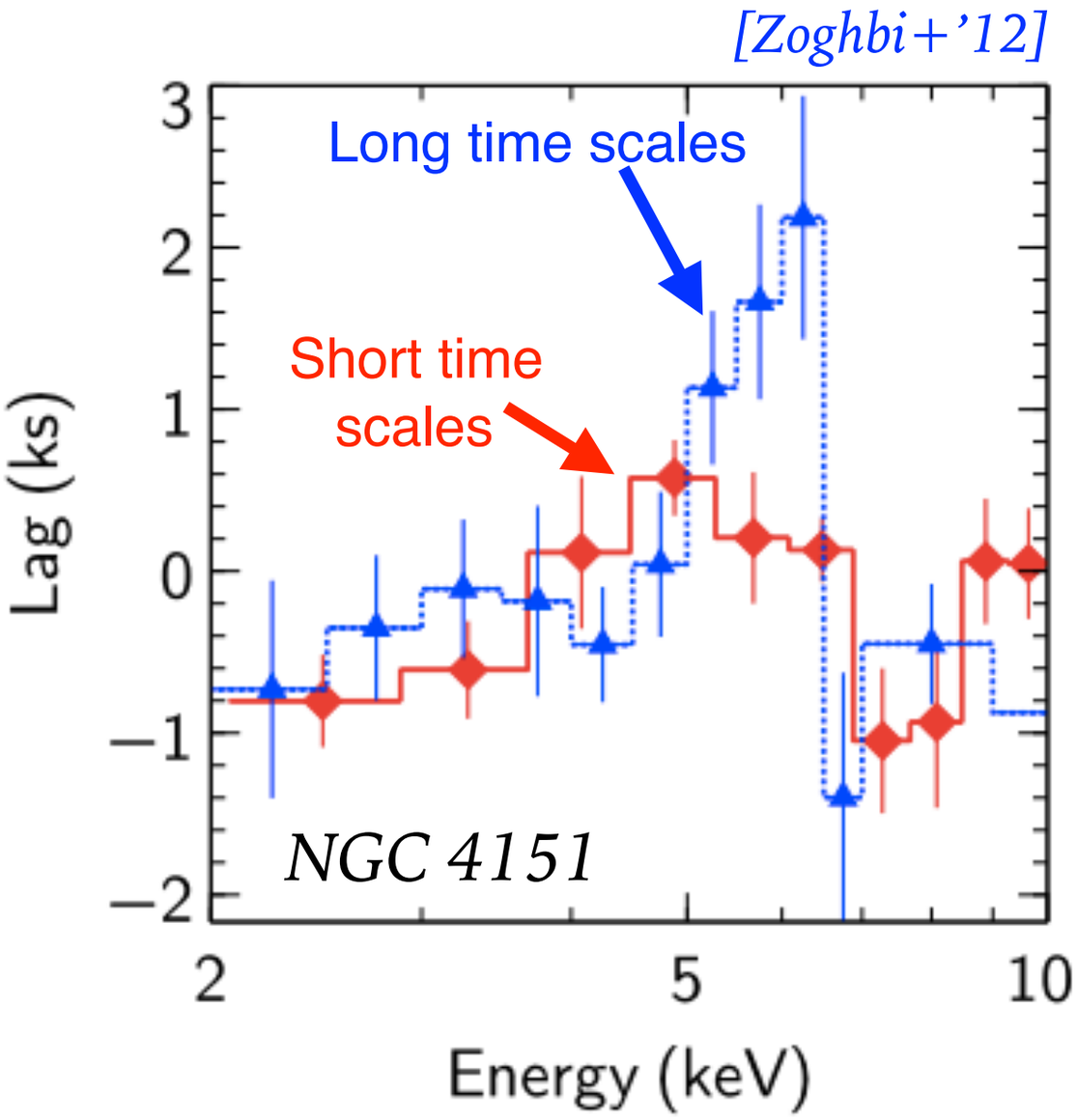


[Fabian & Miniutti '05]

X-ray reverberation in AGN

Fe K line responding to variability of hard X-ray photons





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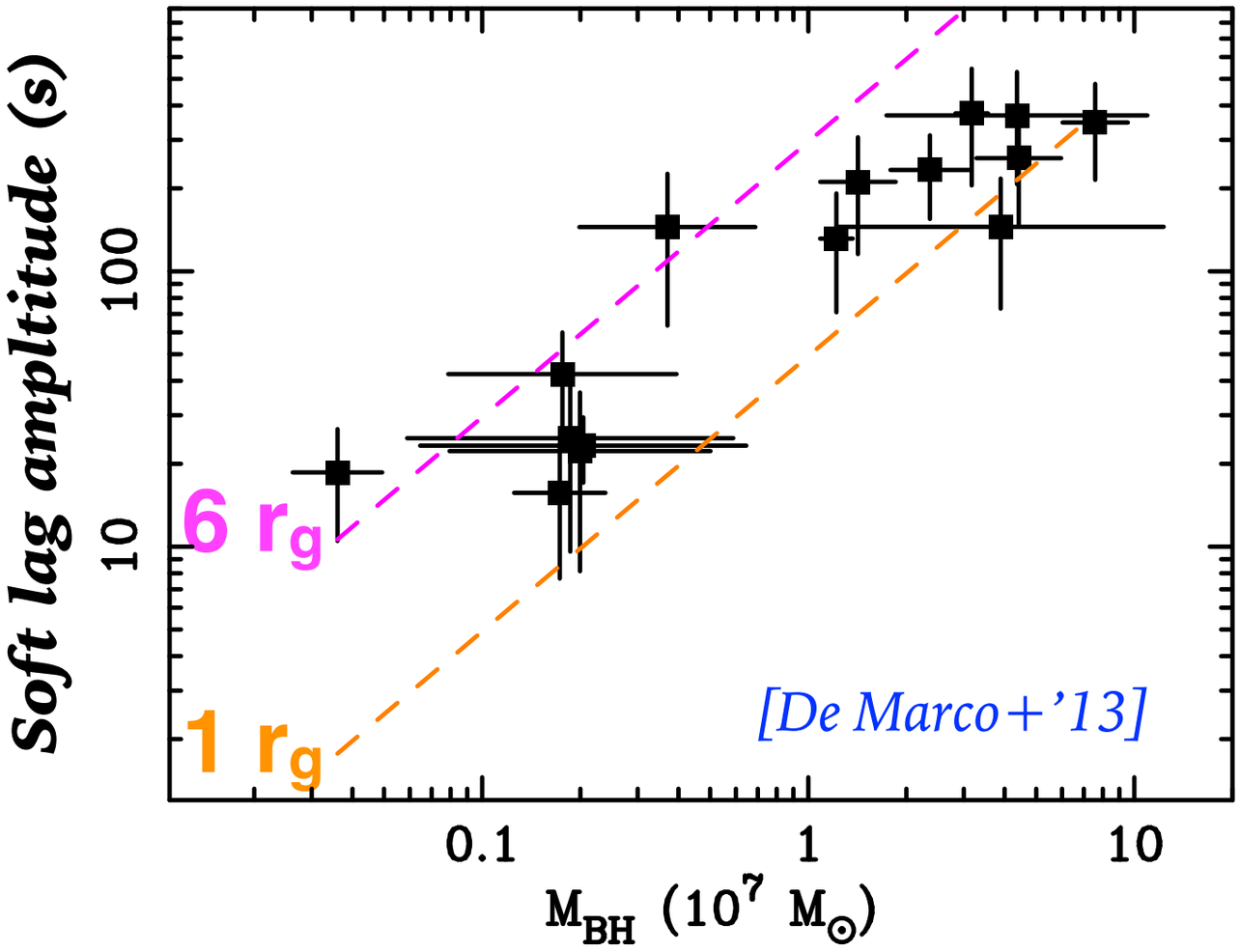
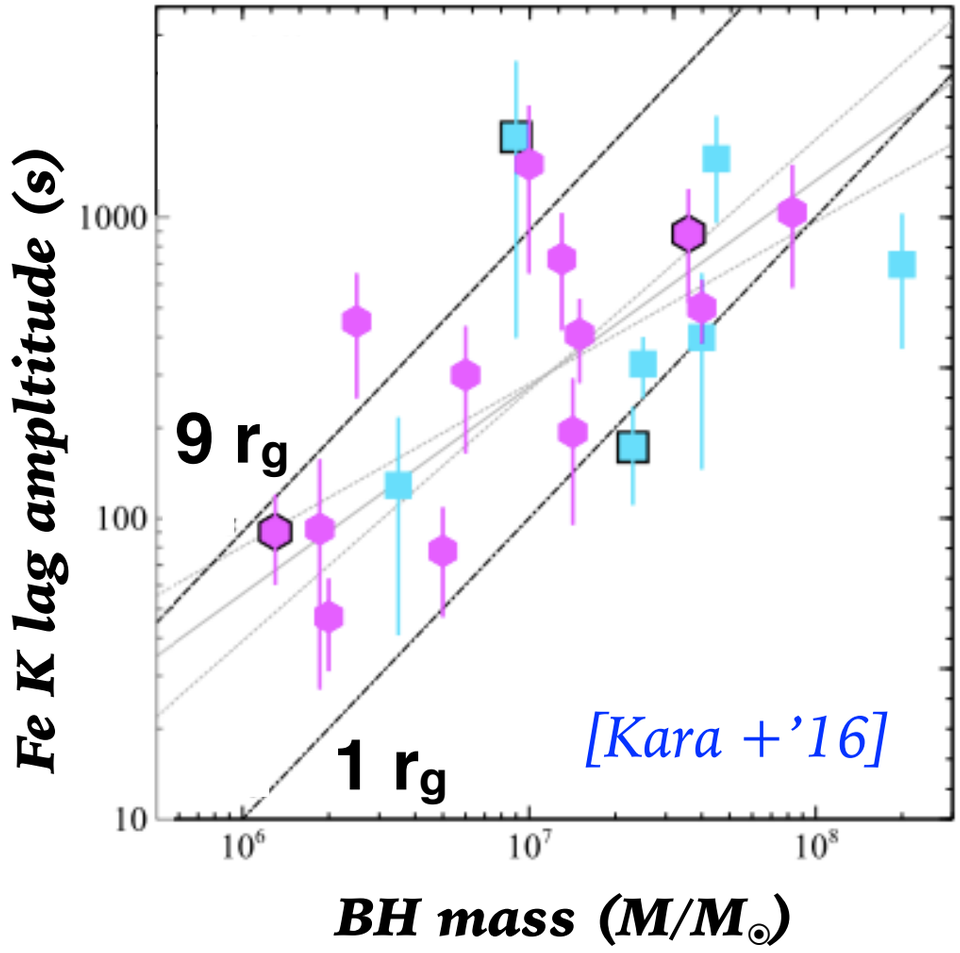




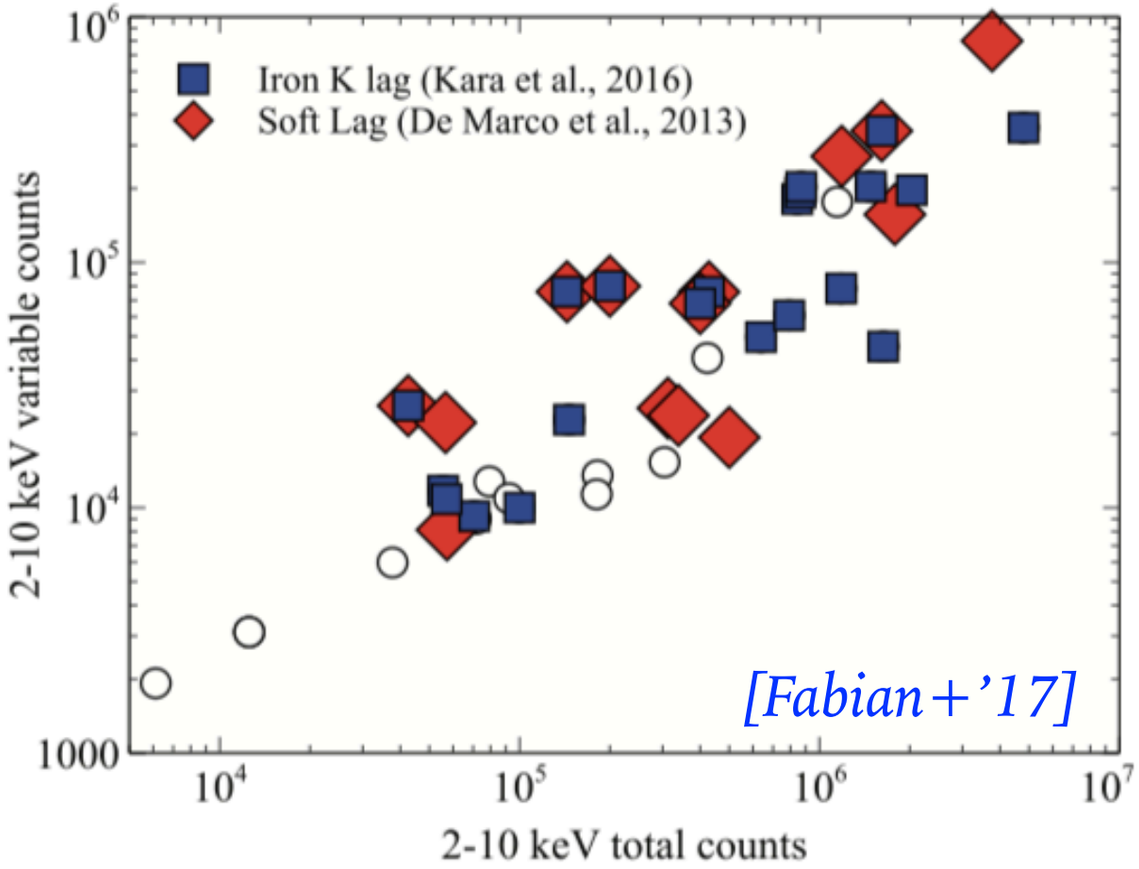
Point to same reprocessing mechanism/region:

Reflection [Fabian+'09]

Soft band thermal reprocessing in a warm corona [Gardner & Done '14]

X-ray reverberation with Athena

Increasing the number of detections



Currently, detections of reverberation in ~30 sources (mostly XMM, but also NuSTAR)

[see also most recent studies: e.g. Chiang+'17 Lobban+'18; Mallick+'18; Frederick+'18]

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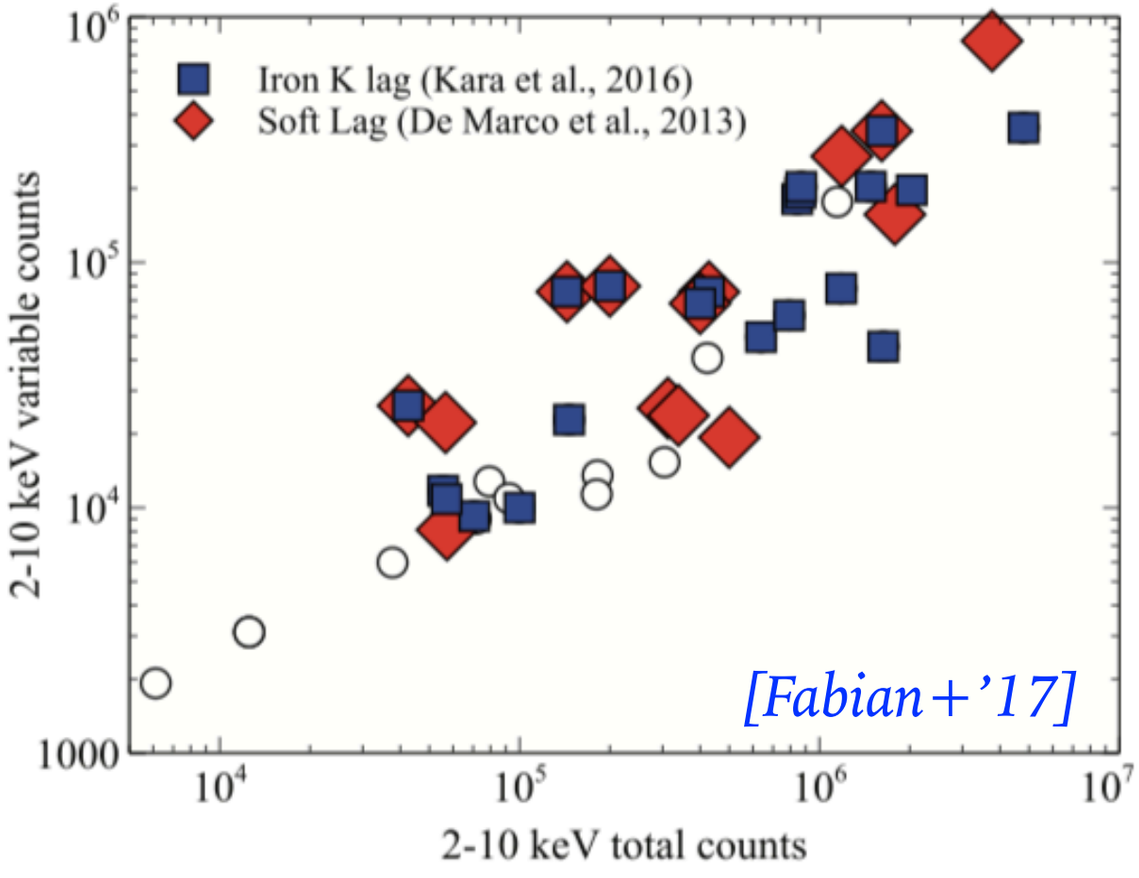

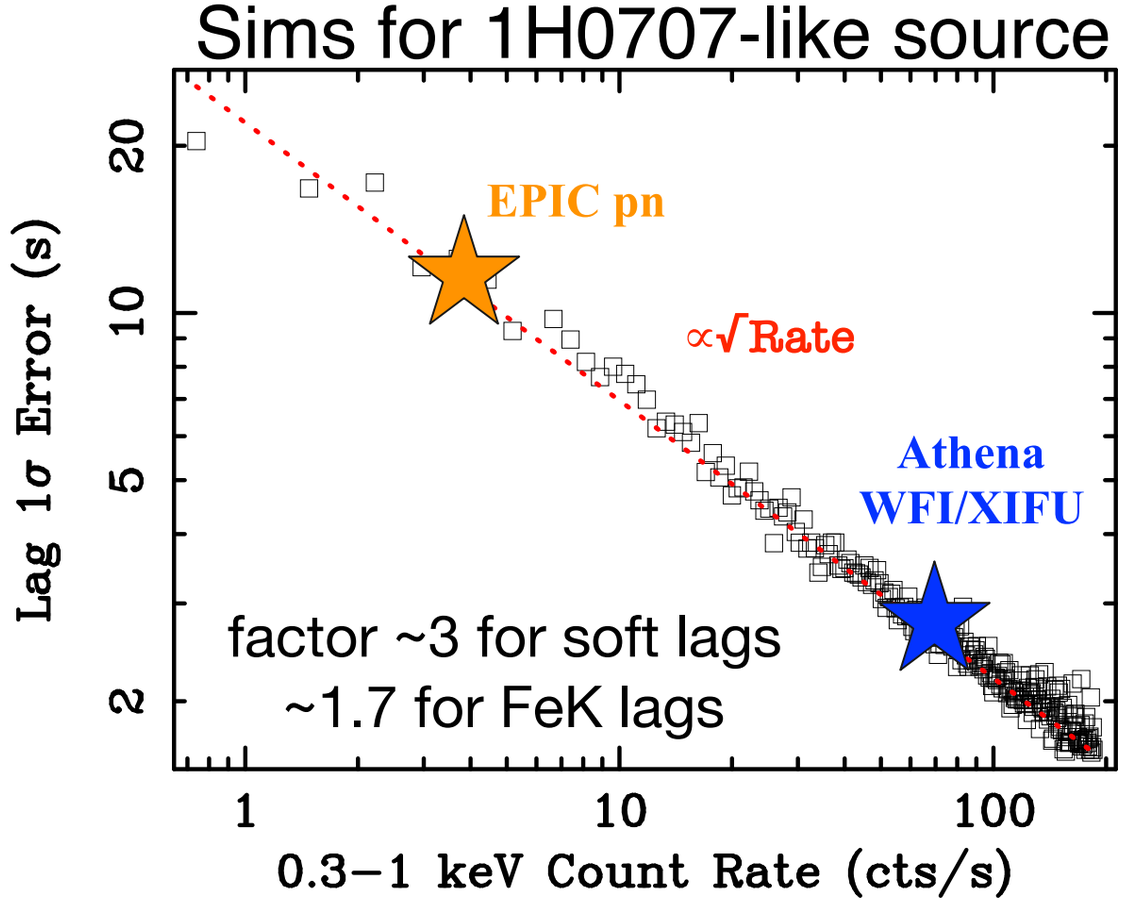

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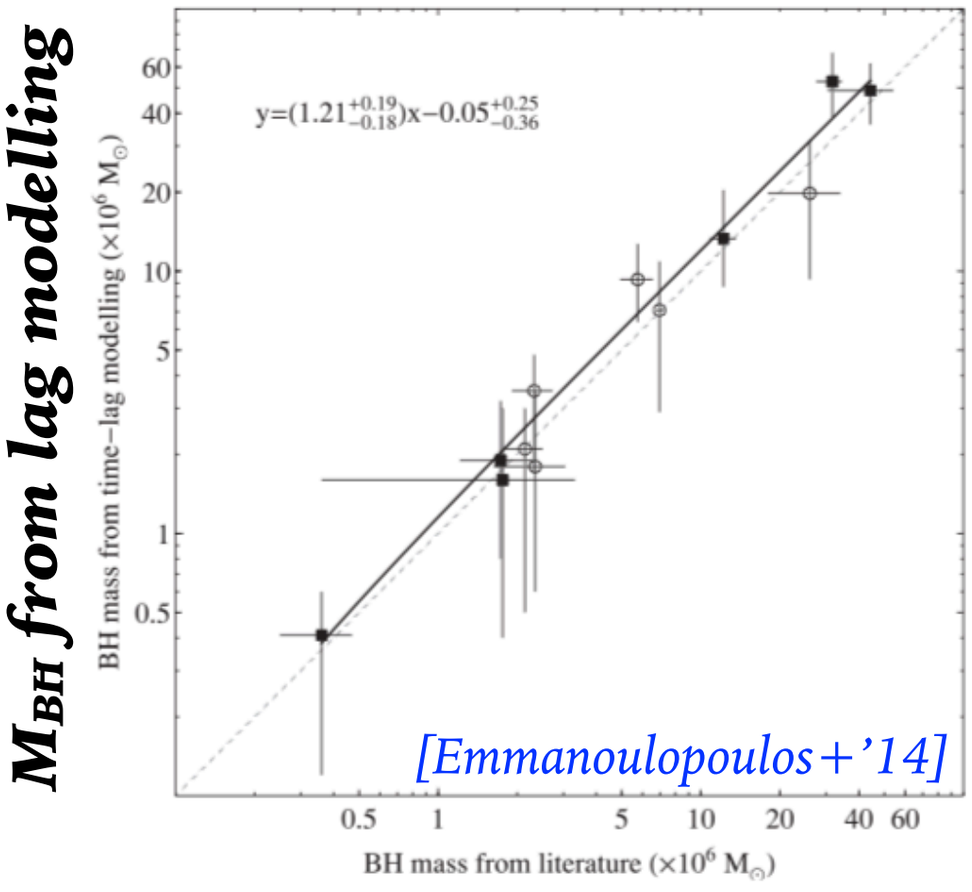
about 3x more detections

X-ray reverberation with Athena

Constraining the BH mass

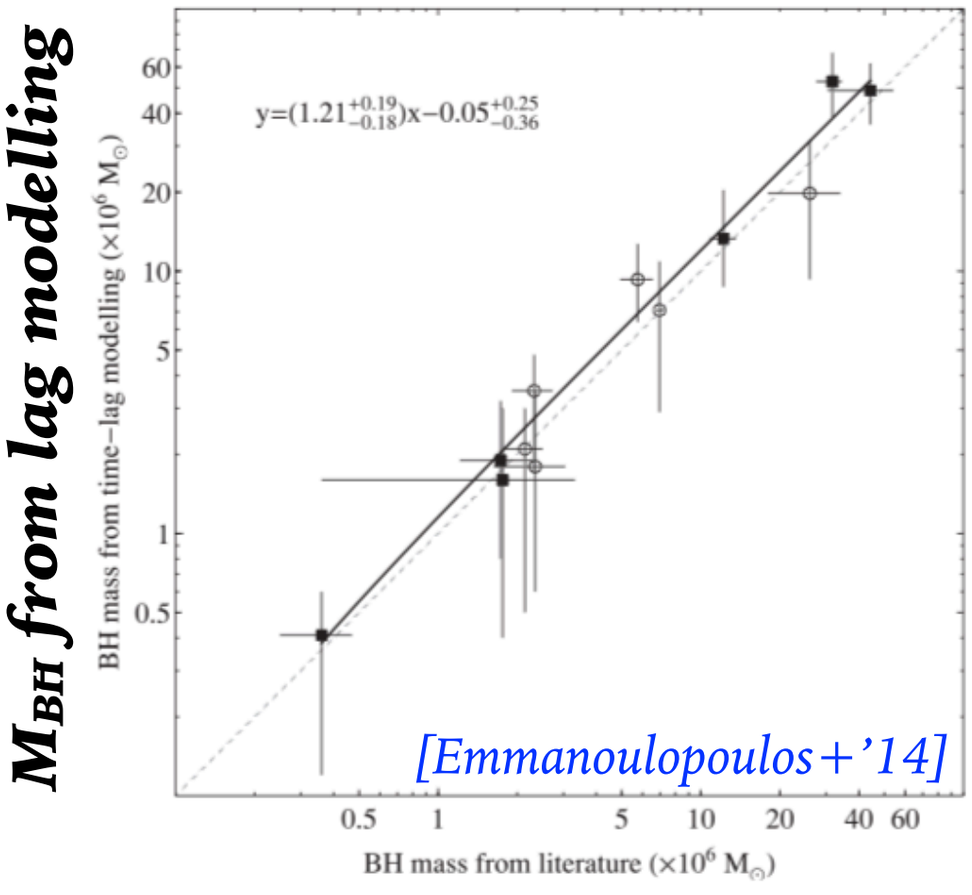


M_{BH} *from lag modelling*

M_{BH} *from optical/UV*

X-ray reverberation with Athena

Constraining the BH mass



M_{BH} from optical/UV

Reverberation lag

+

high-resolution Fe line spectroscopy

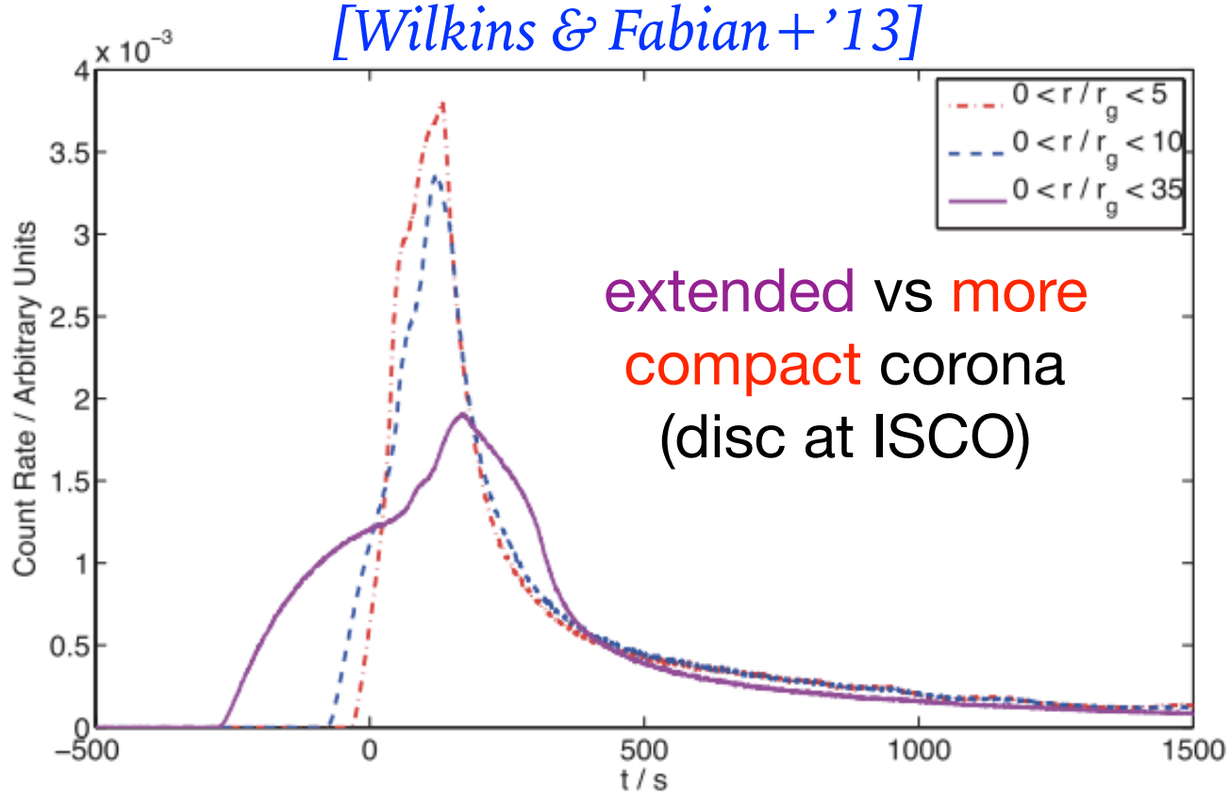
Goal: obtain measurements as accurate as from optical/UV reverberation

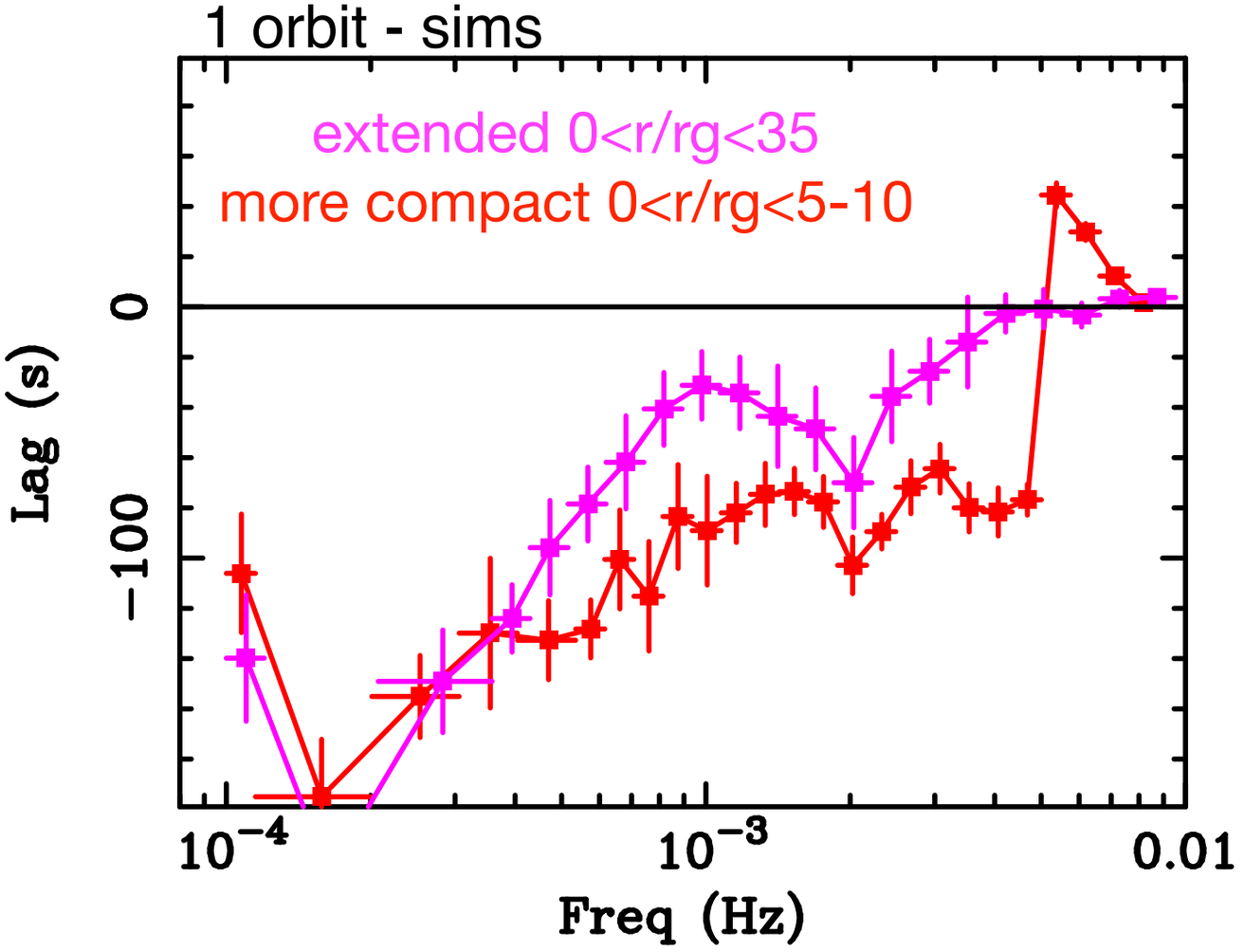
X-ray reverberation with Athena

Independent constraints on the accretion flow geometry

plus possible variations of the geometry!!!! [Kara +'13; Frederick +'18]

[Wilkins & Fabian+'13]





X-ray reverberation with Athena

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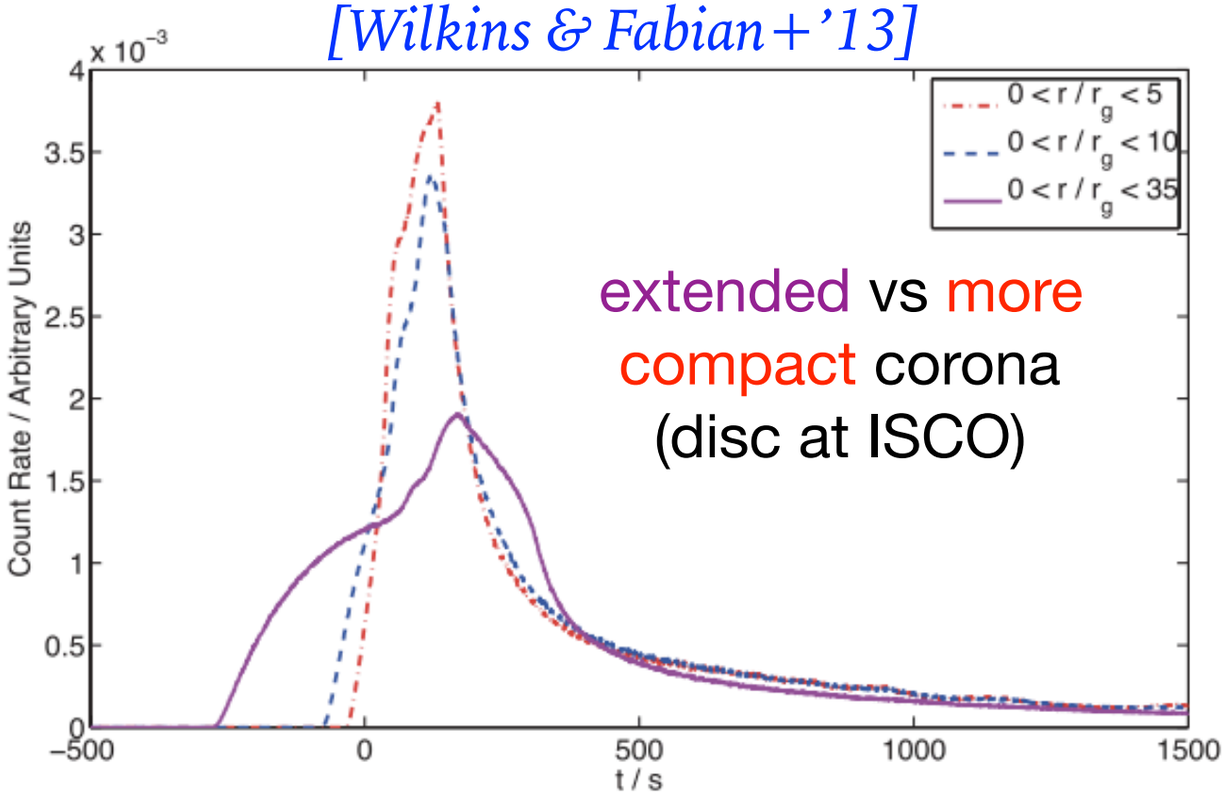

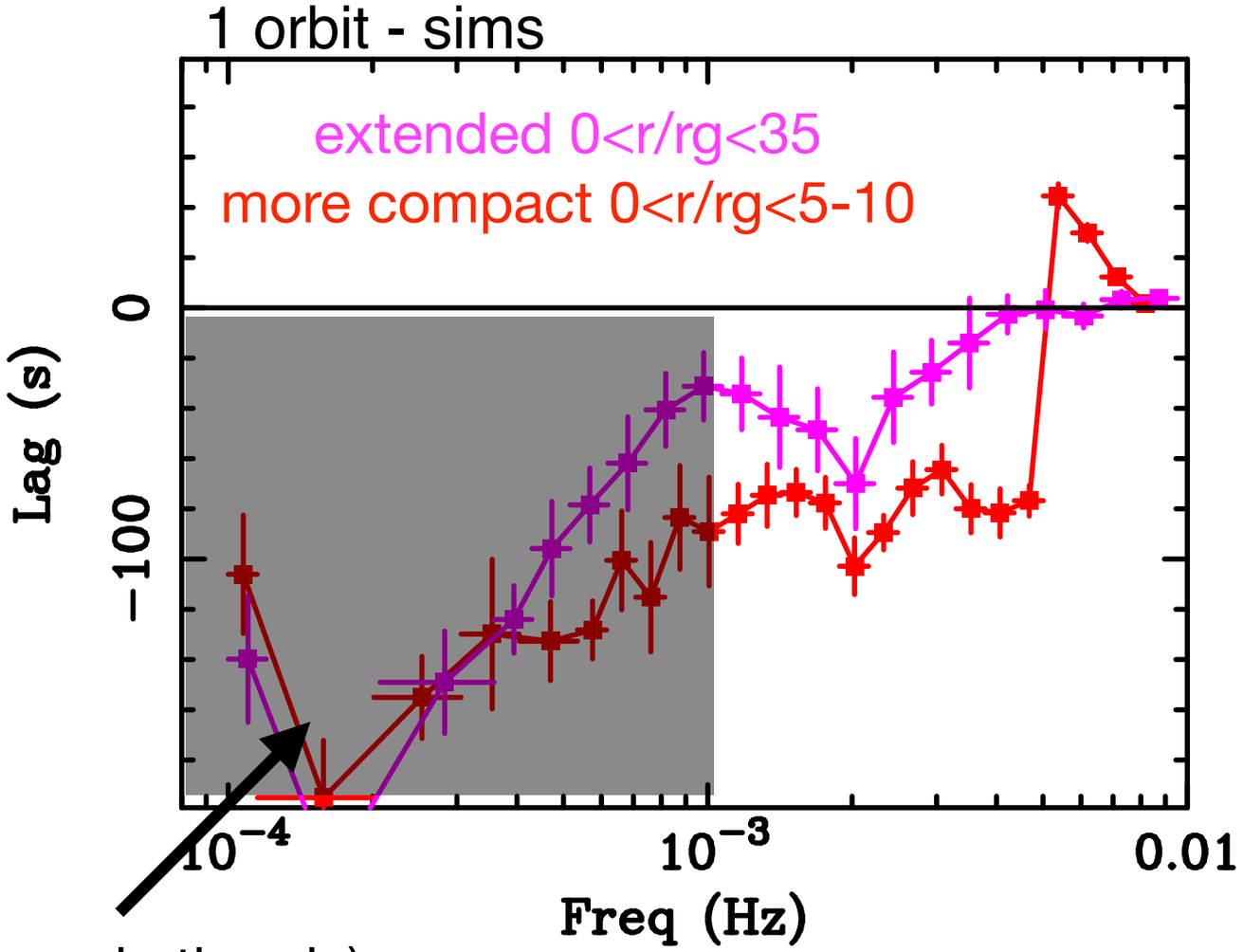

dominated by hard lags (not shown in the pic):
not associated with light travel

X-ray reverberation with Athena

Independent constraints on the accretion flow geometry

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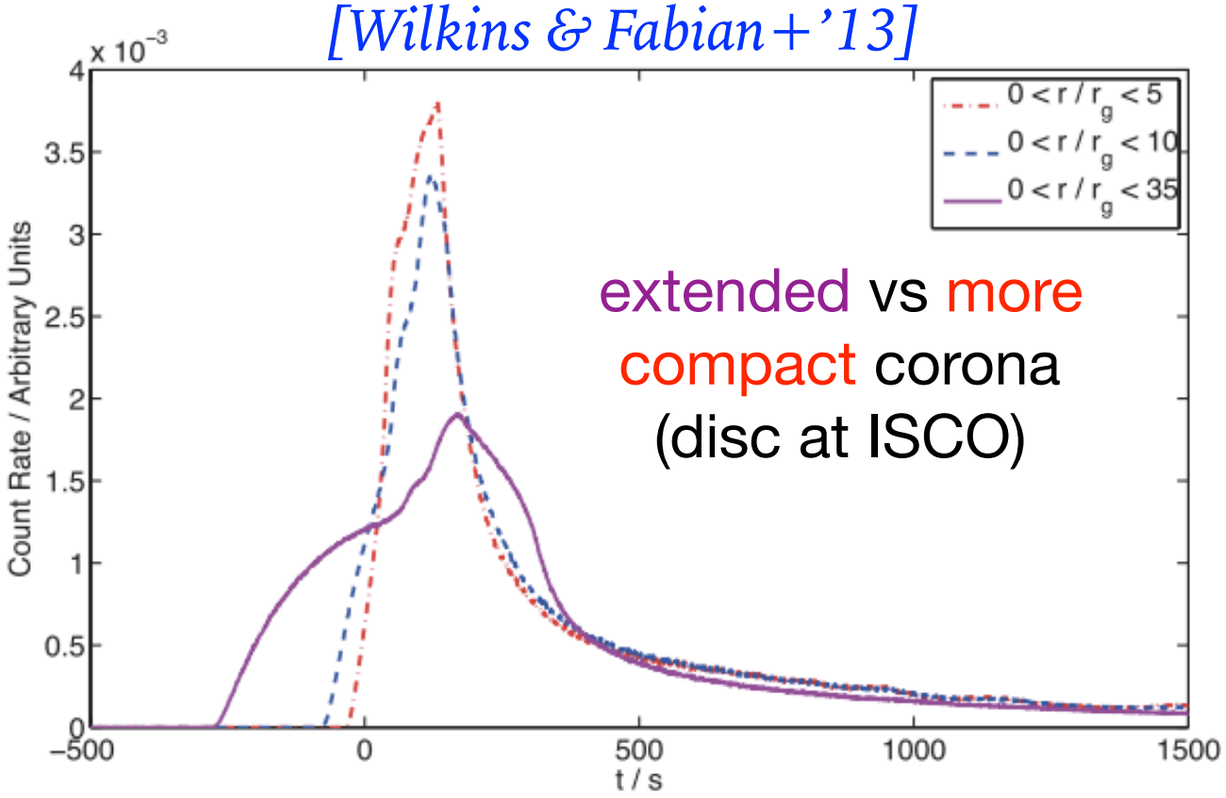
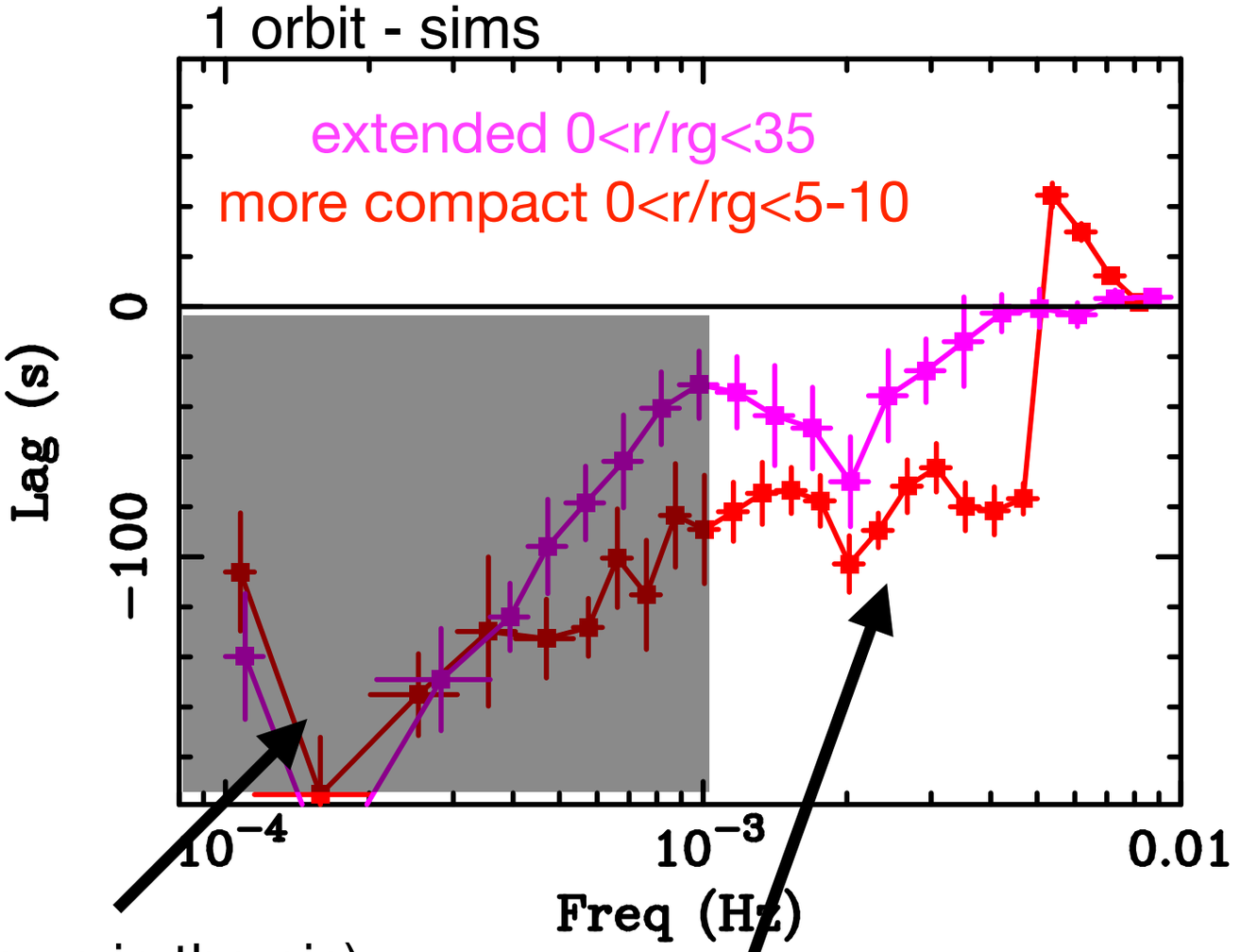


extended vs more compact corona (disc at ISCO)



dominated by hard lags (not shown in the pic): not associated with light travel

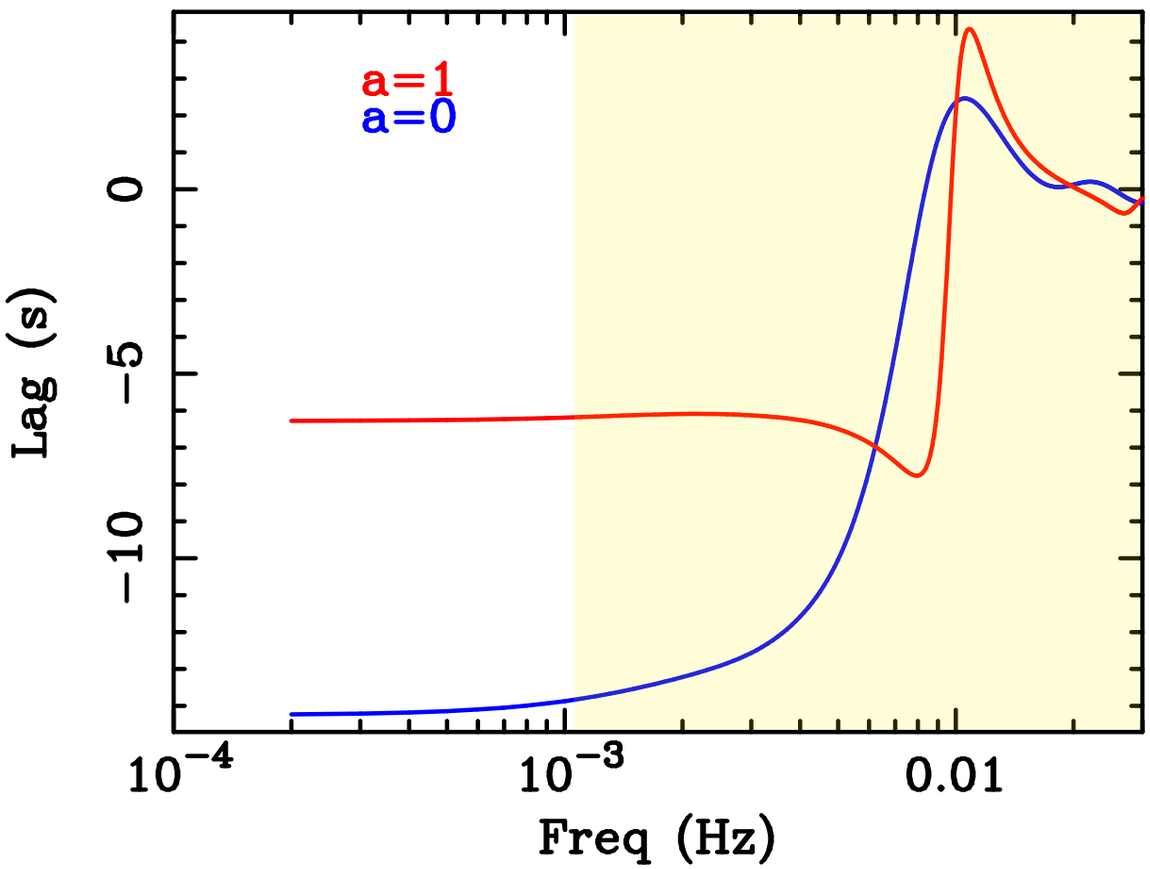
no hard lags, less dilution

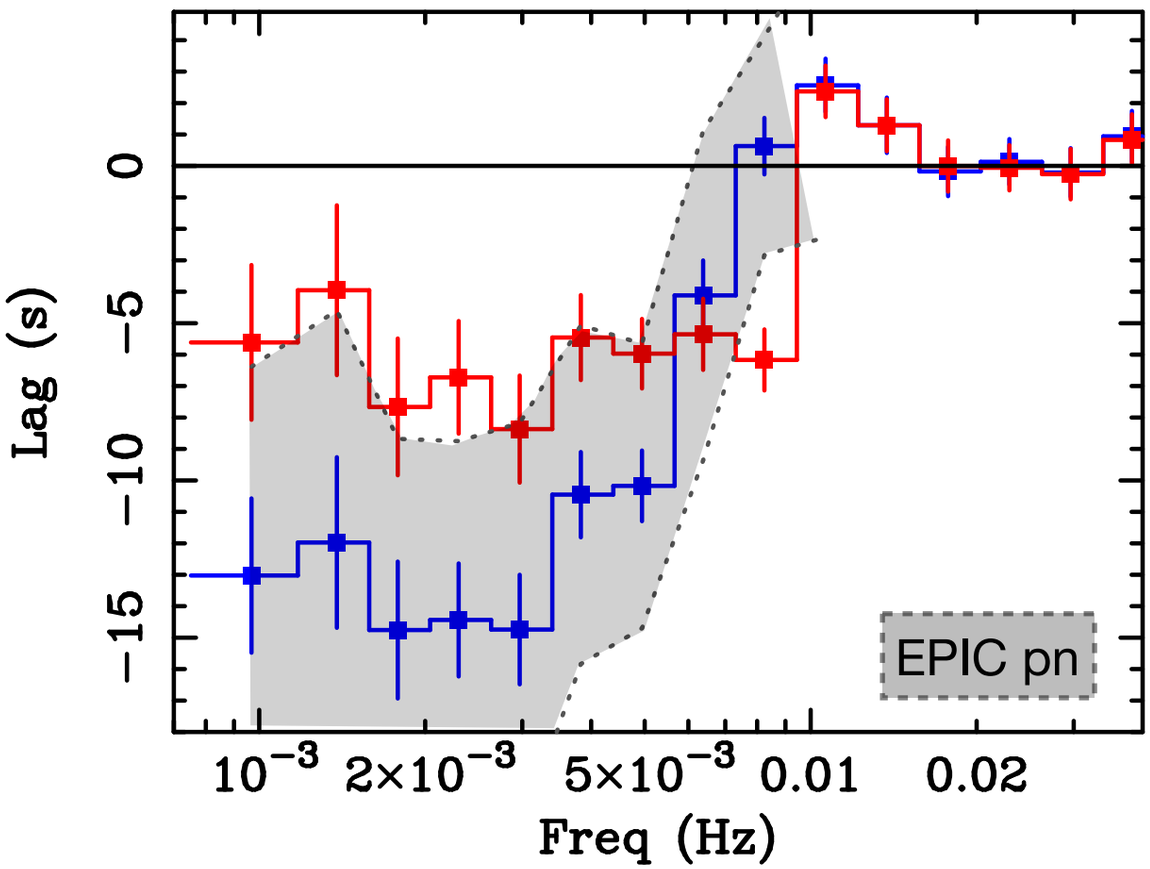
subtle differences in the shape of the response

X-ray reverberation with Athena

Constraining the BH spin

[credits: M. Dovčiak]

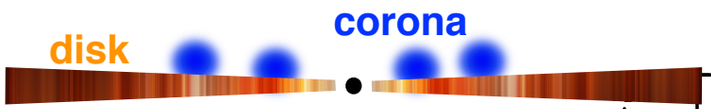




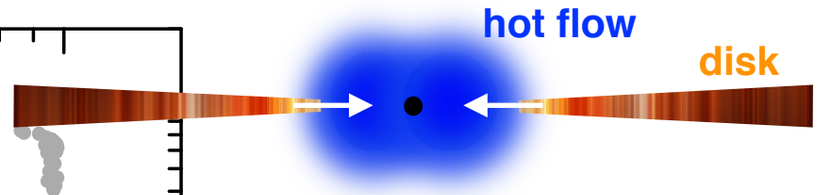
Soft lags due to inner disc reverberation in a lamp post geometry ($h\sim2r_g$)

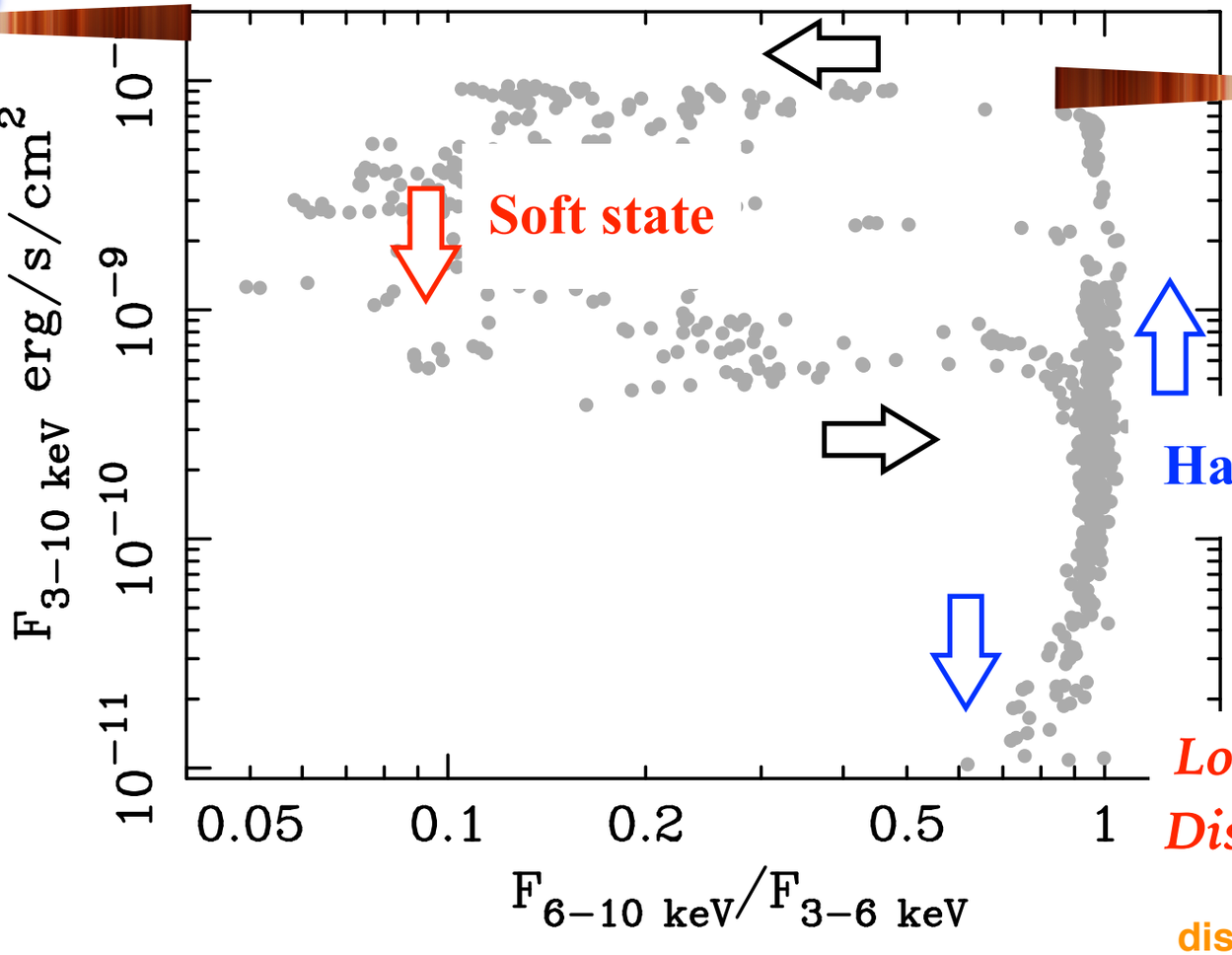
Testing different accretion modes: BH binaries

Soft state: Disc close to ISCO

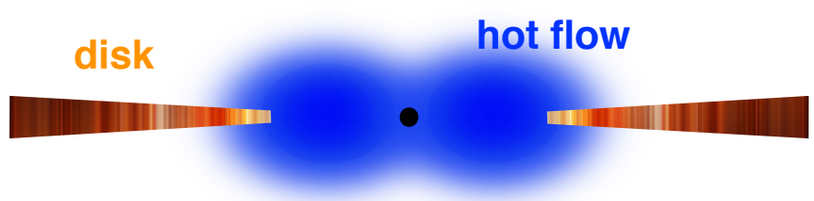


Disc inner radius moving inwards





Low L hard/quiescent state:
Disc truncated at large radii



[e.g. Chakrabarti & Titarchuk '95; Esin+'97; Poutanen +'97; Zdziarski+'99; Meyer+'00; Narayan & McClintock '08; Kylafis & Belloni '15]

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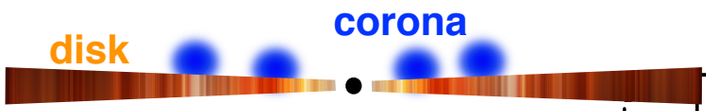

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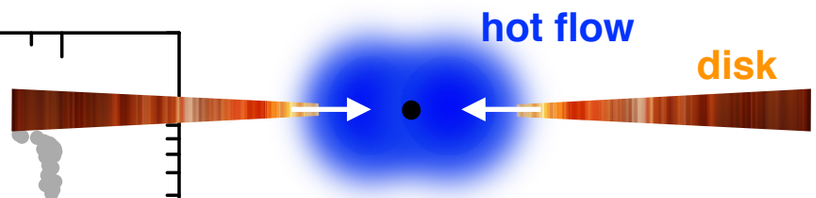
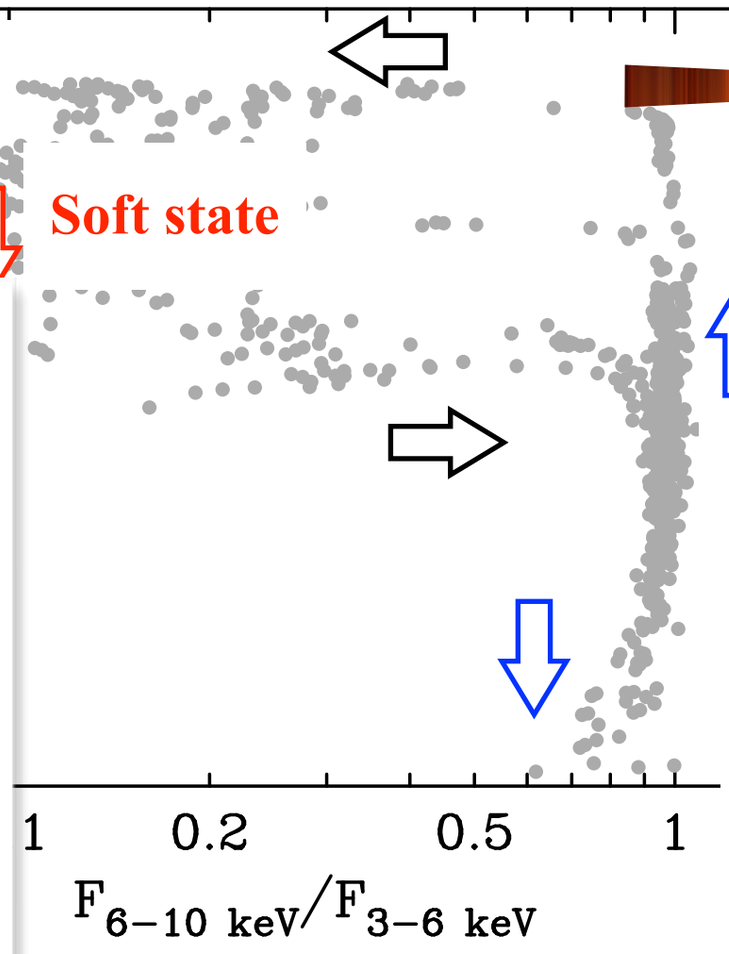


✔ *Spectral evolution*

✔ *Low freq QPOs*

✔ *Evolution of power spectrum*

[e.g. Done +'07]



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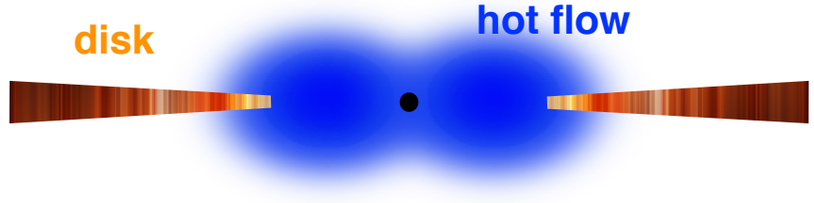
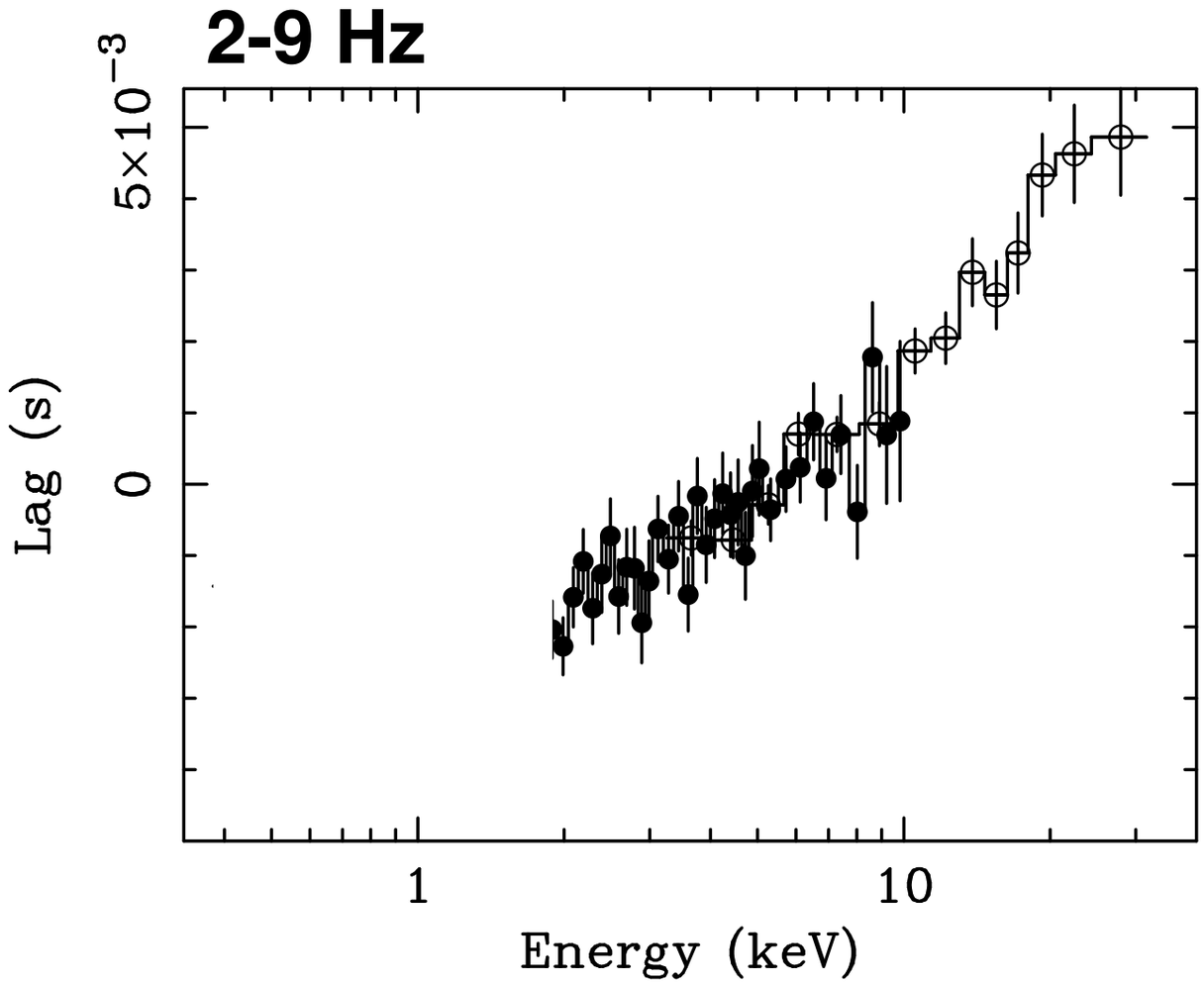


[e.g. Chakrabarti & Titarchuk '95; Esin+'97; Poutanen +'97; Zdziarski+'99; Meyer+'00; Narayan & McClintock '08; Kylafis & Belloni '15]

X-ray reverberation in BH binaries



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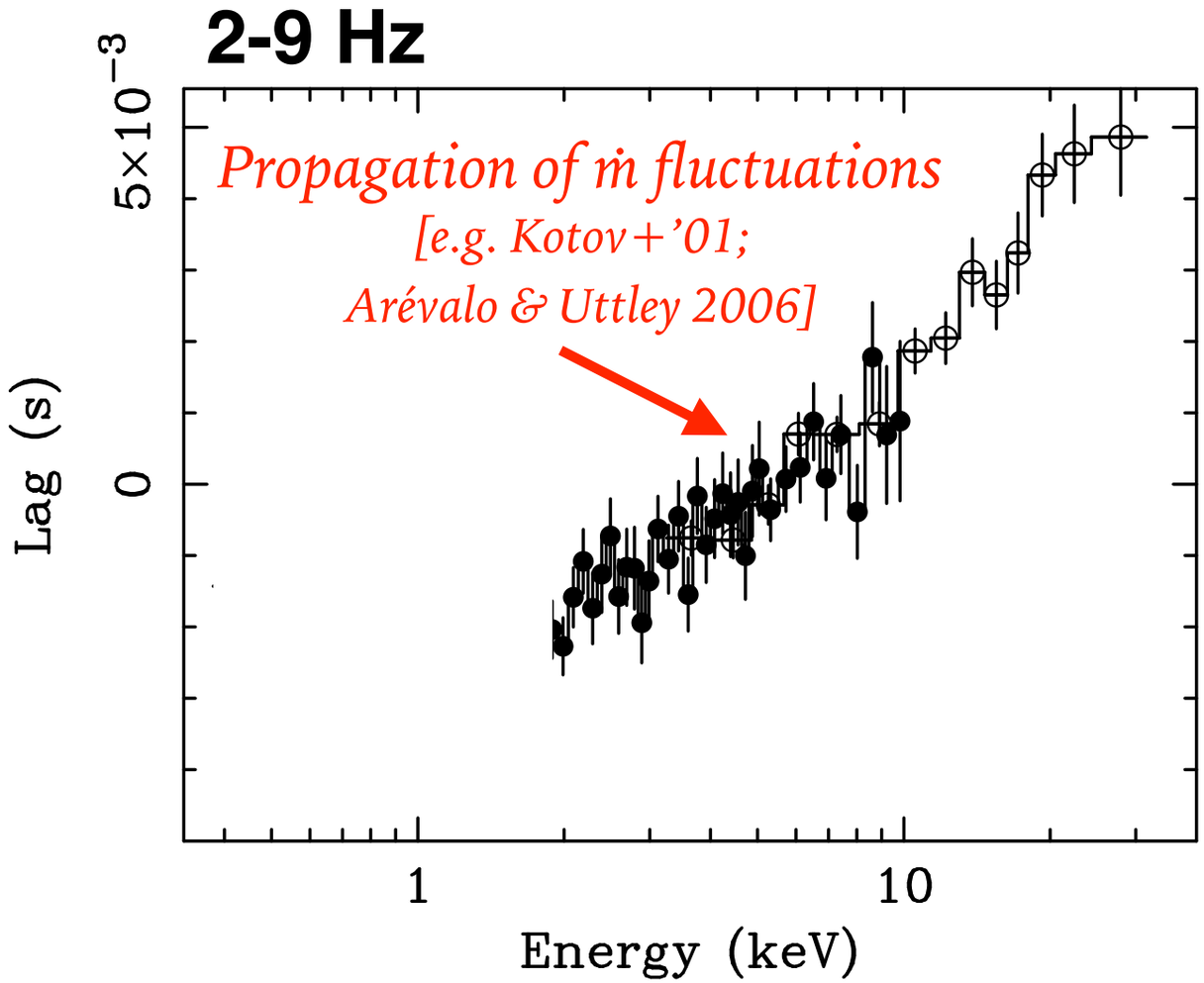

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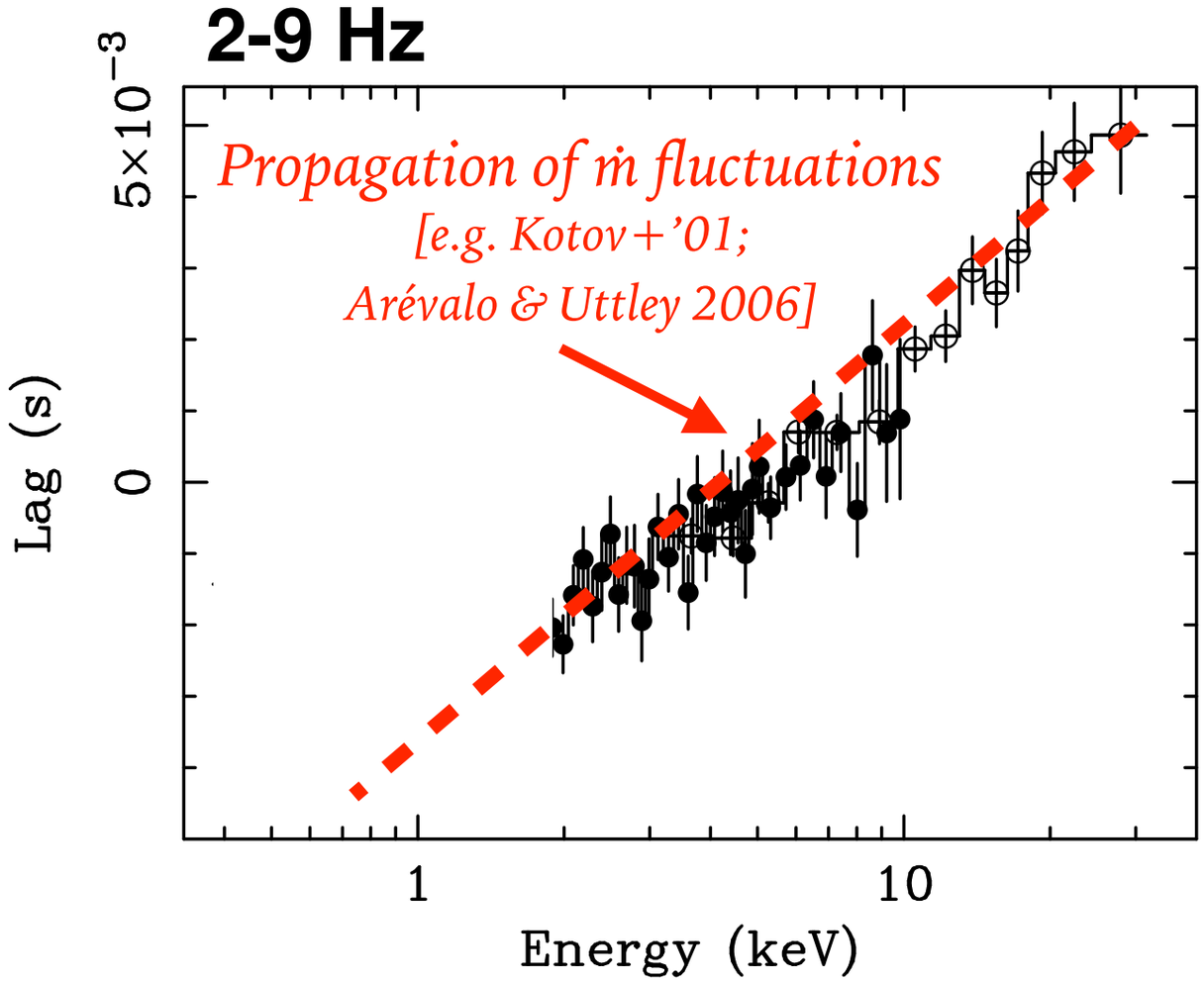
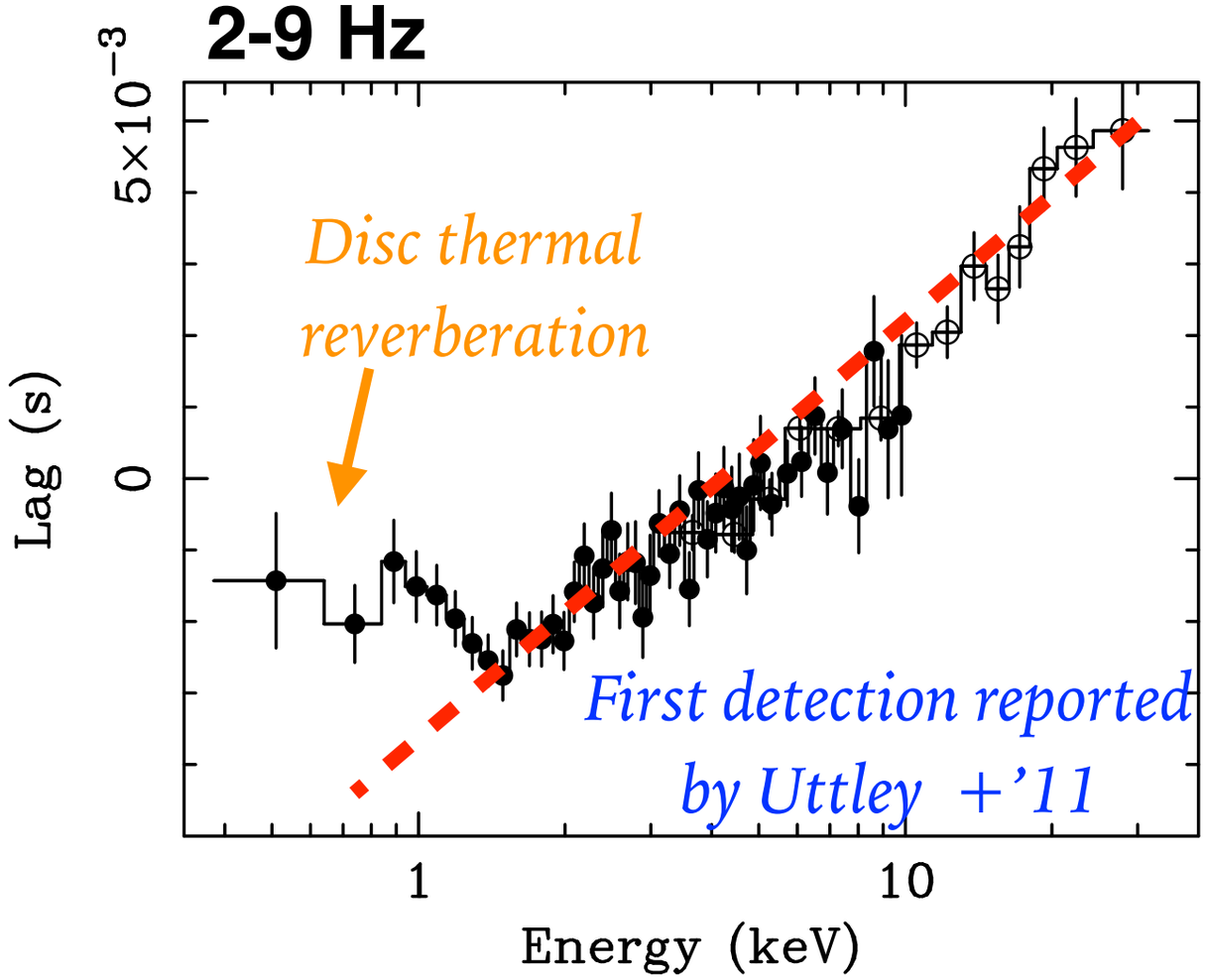


X-ray reverberation in BH binaries

Sensitivity in the soft band allows studying the disc in the hard state



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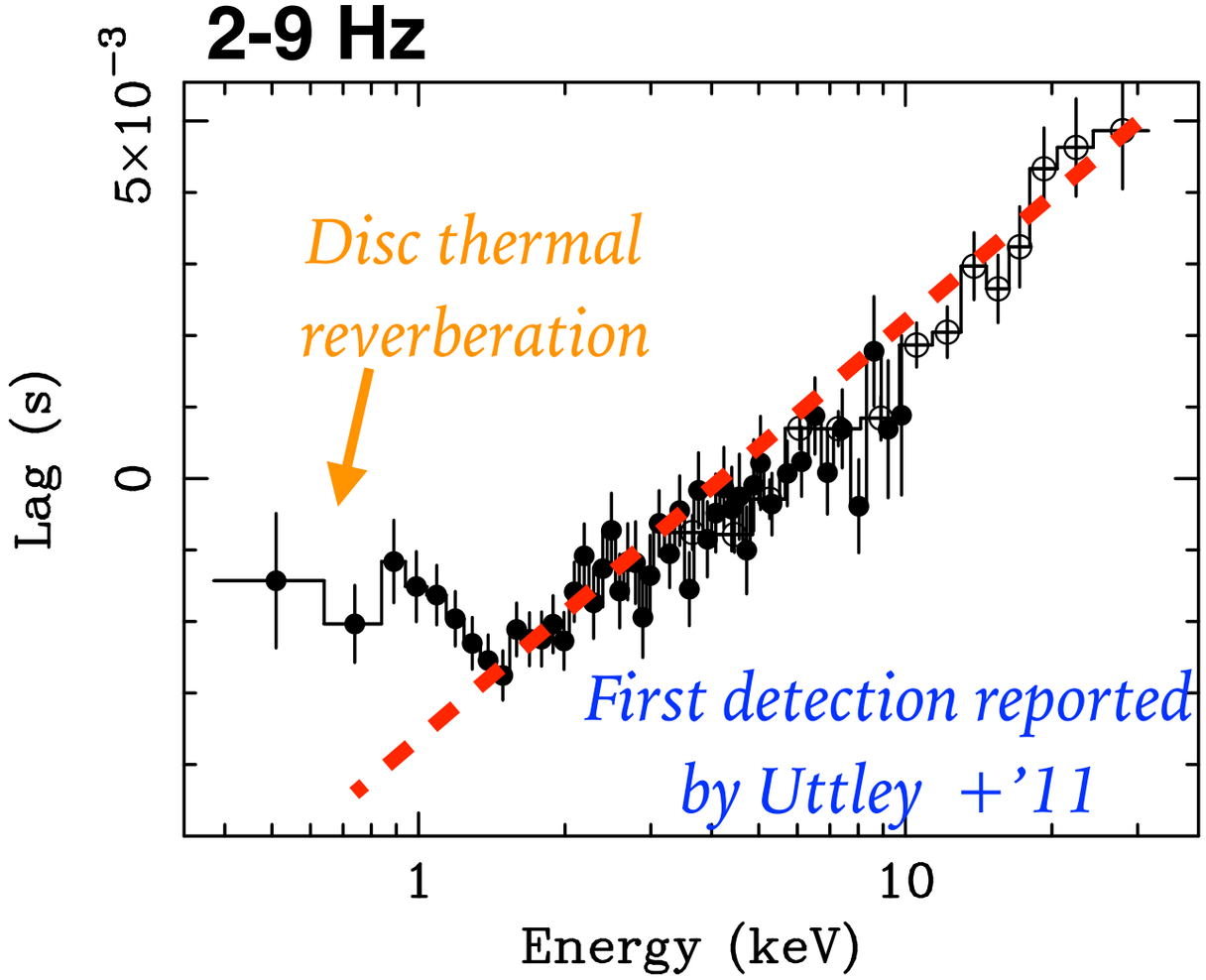
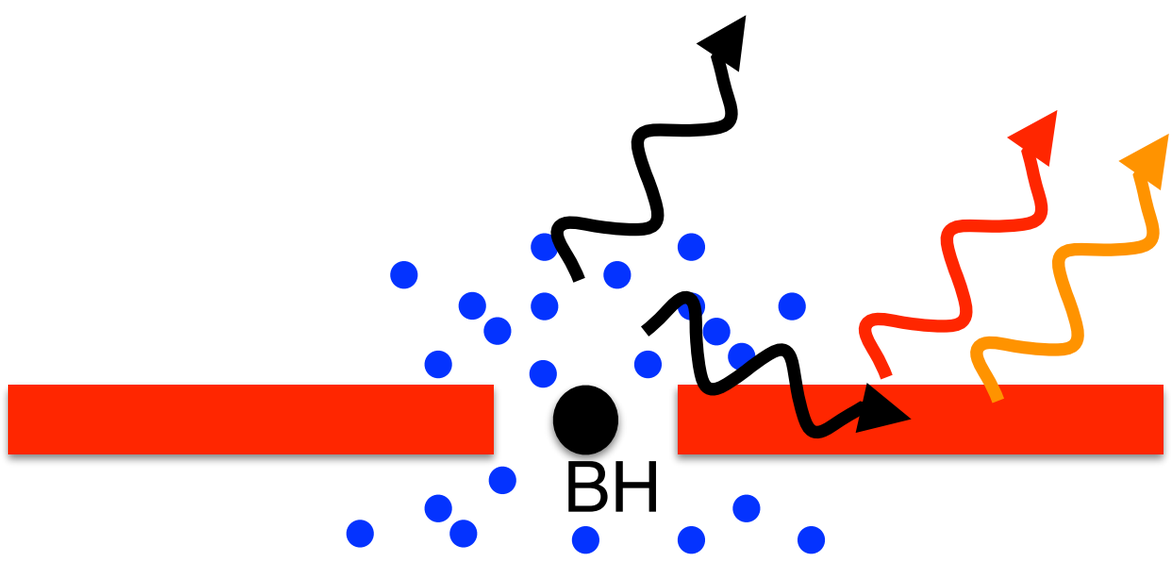
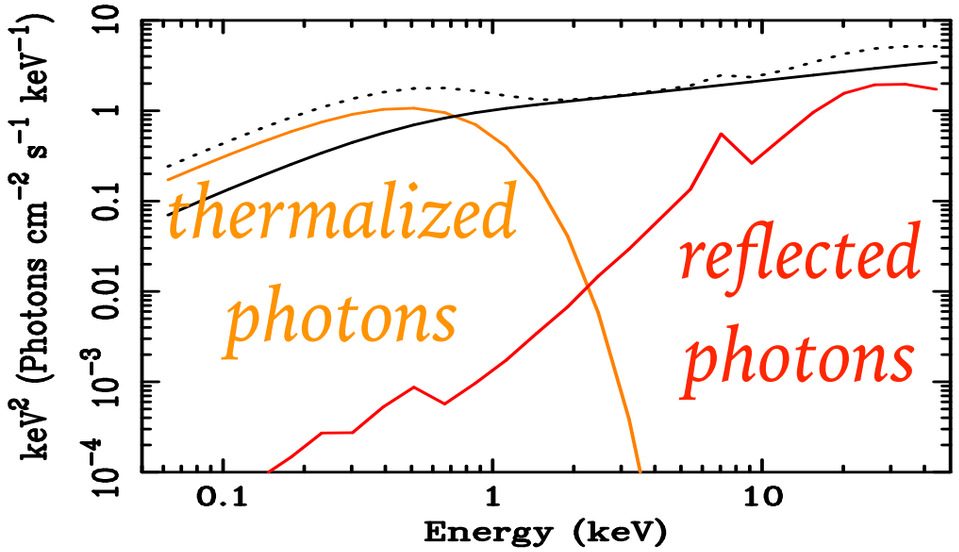


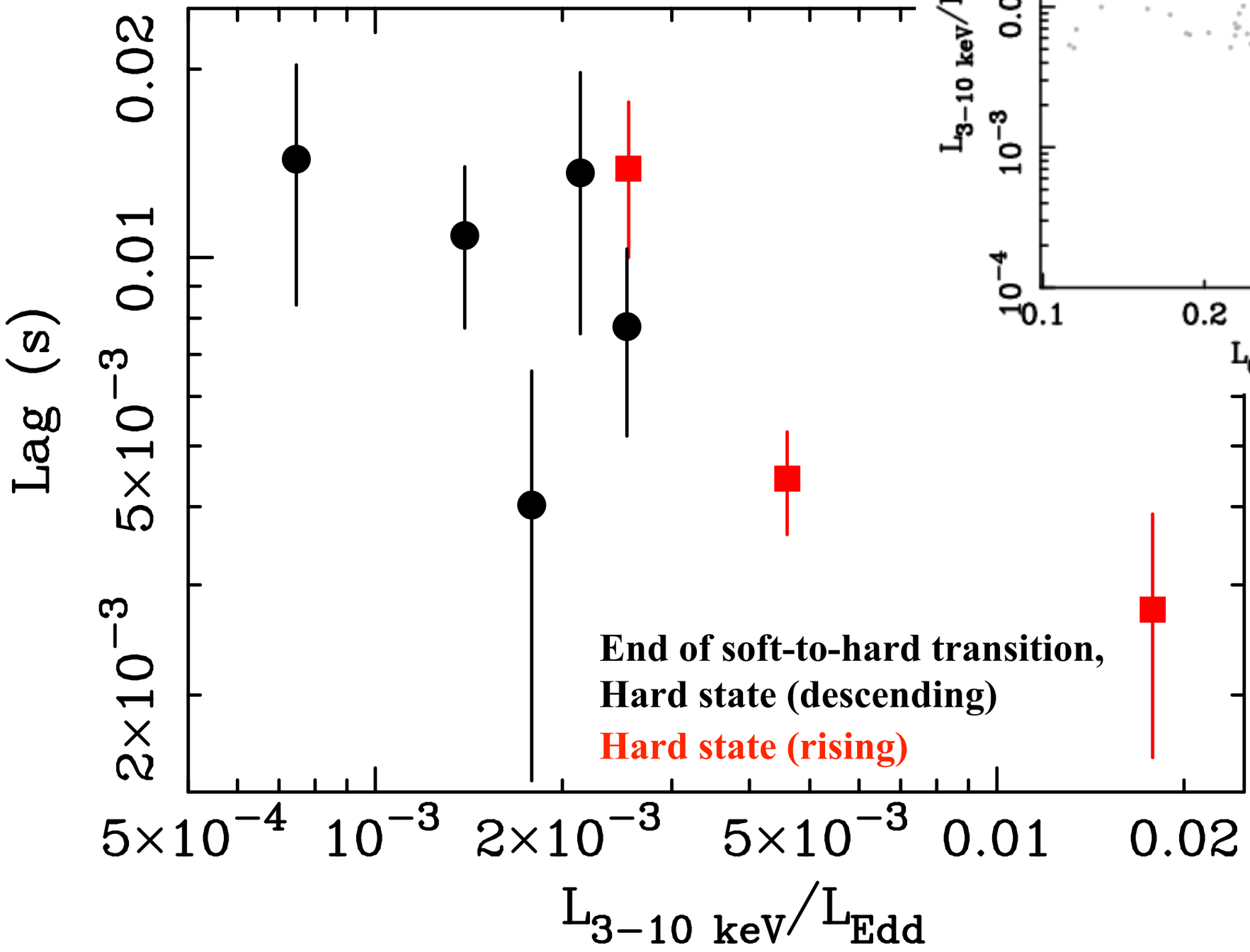


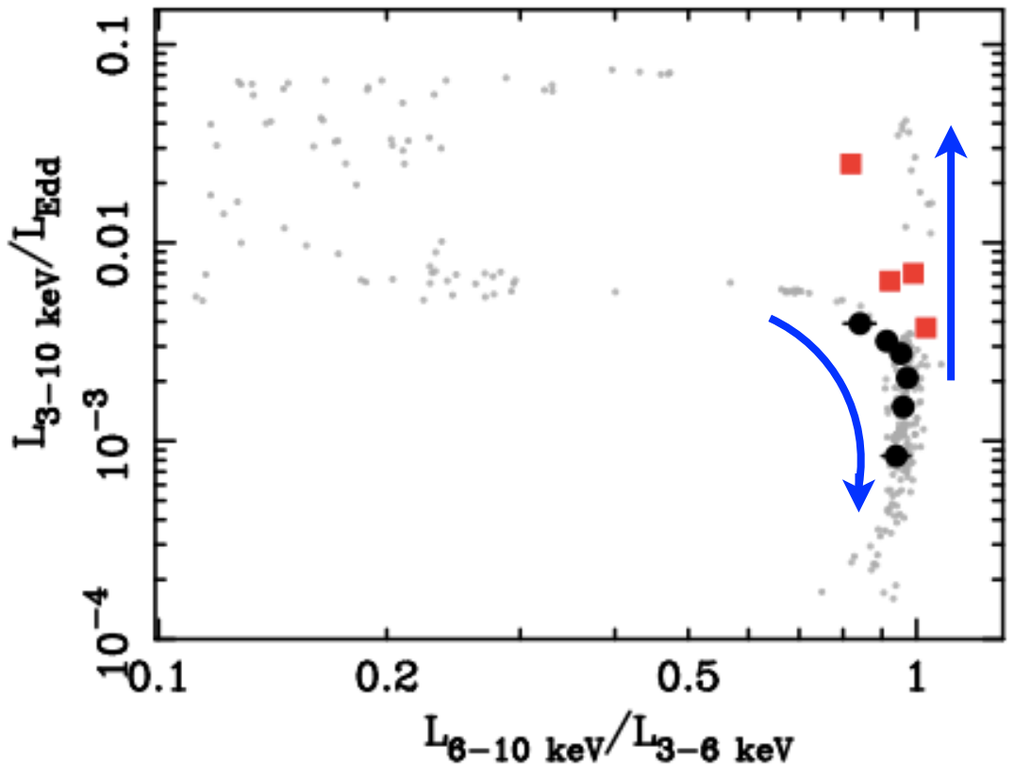


X-ray reverberation during an outburst

Distance mapped by the lag decreases towards luminous hard states

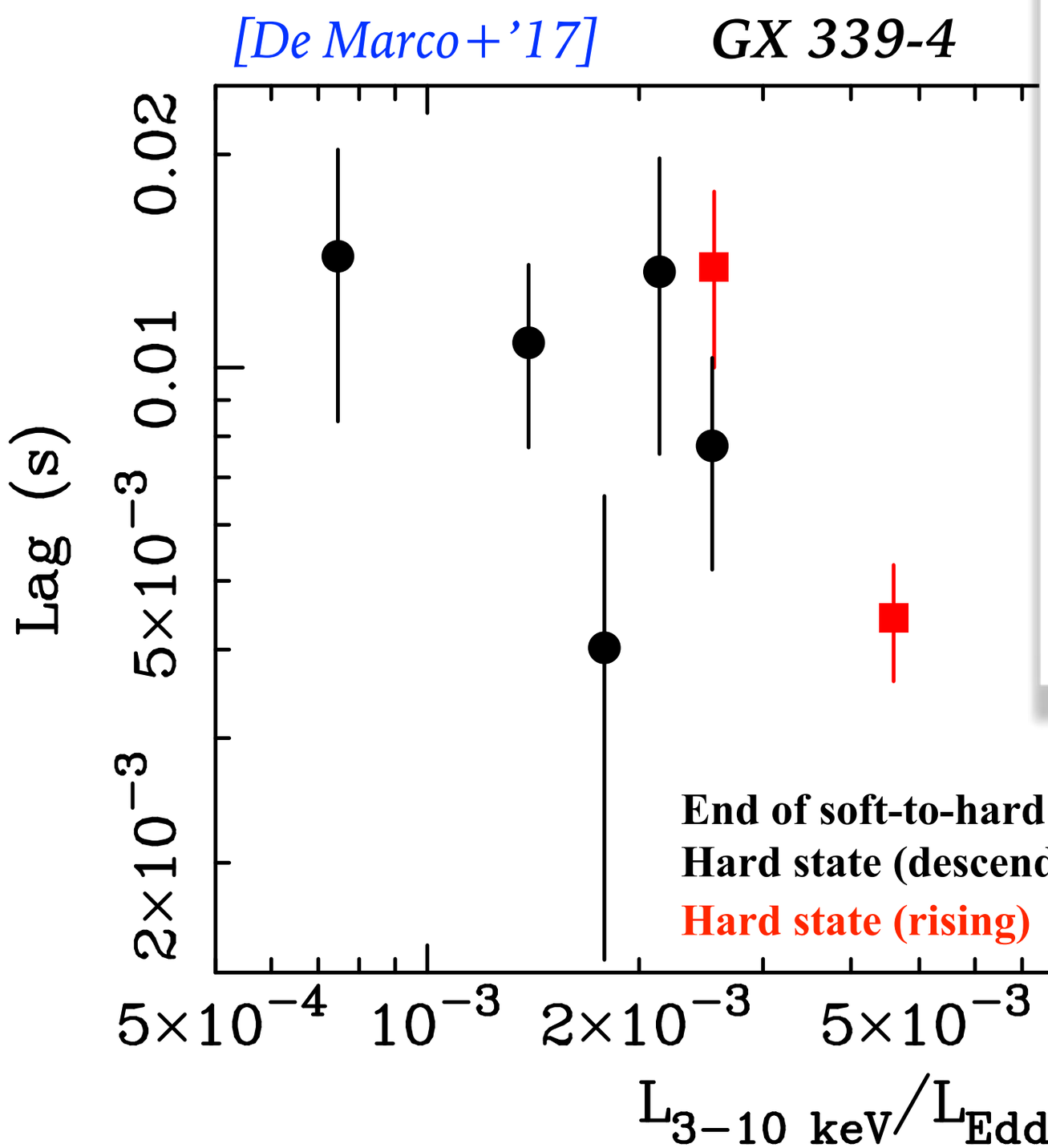
[De Marco+'17] **GX 339-4**





X-ray reverberation during an outburst

Distance mapped by the lag decreases towards luminous hard states



What does this tell us?

- The geometry of the inner flow changes in the hard state

- Expected if disc inner radius not fixed at ISCO in the hard state

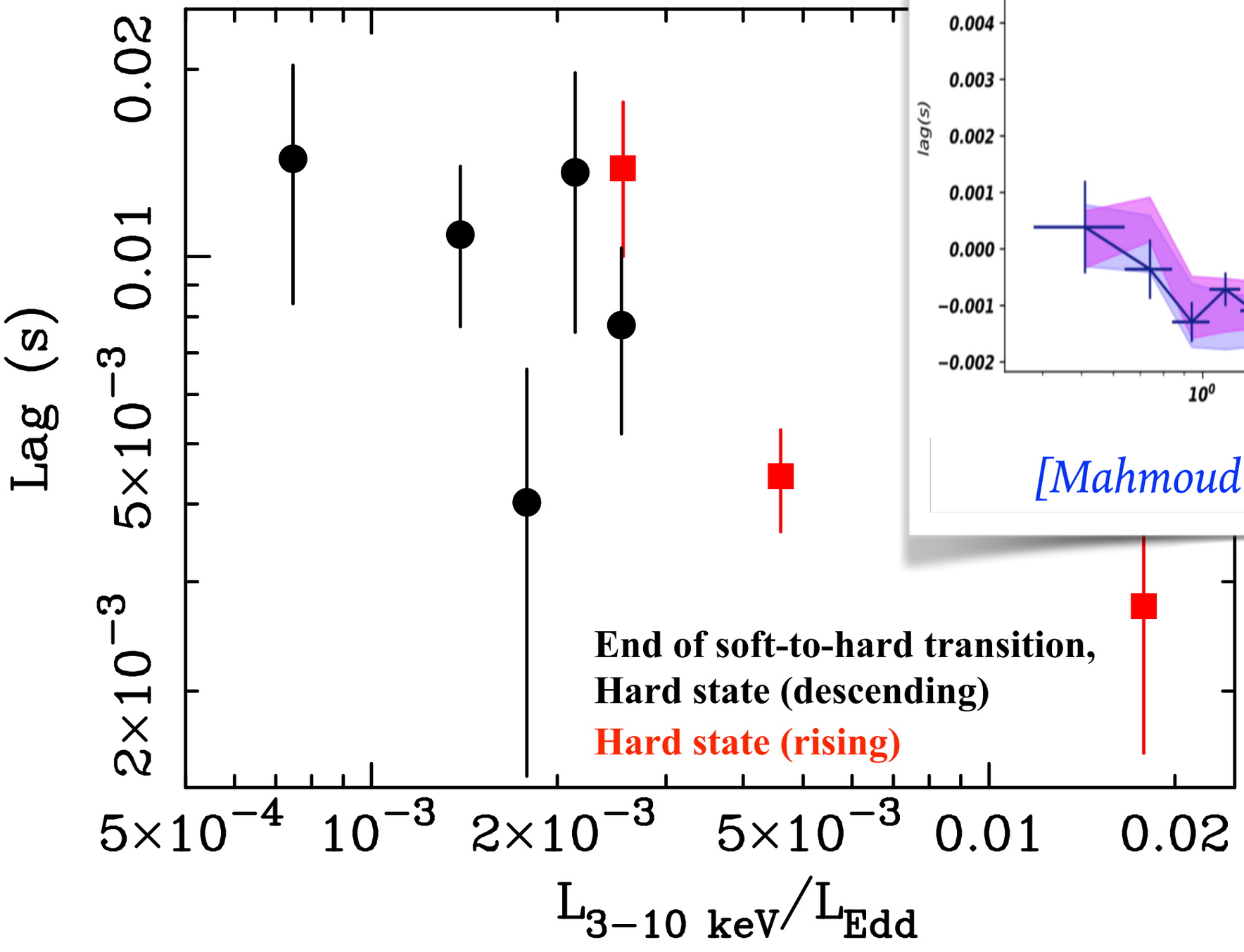
In agreement with truncated-disc models

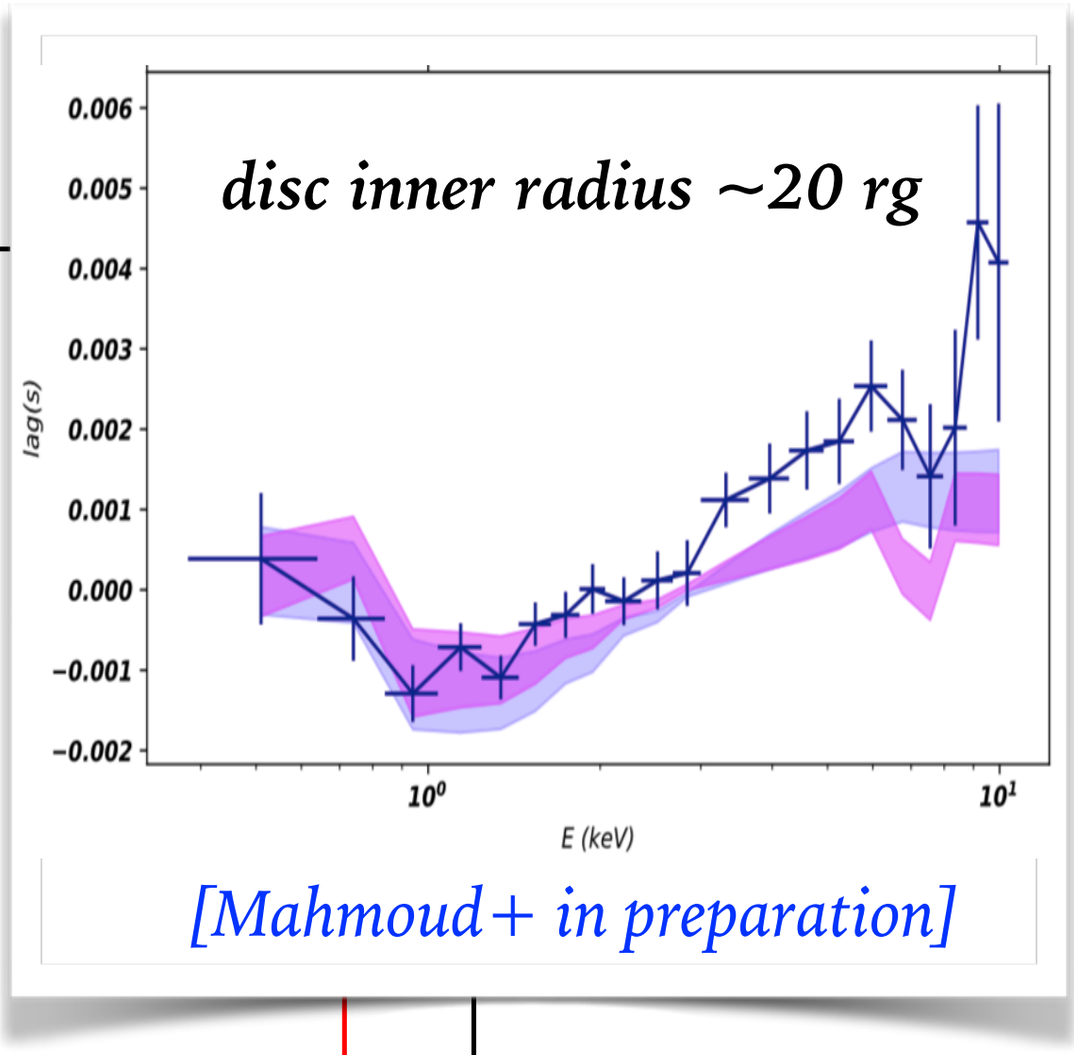
X-ray reverberation during an outburst

Distance mapped by the lag decreases towards luminous hard states

[De Marco+'17]

GX 339-4

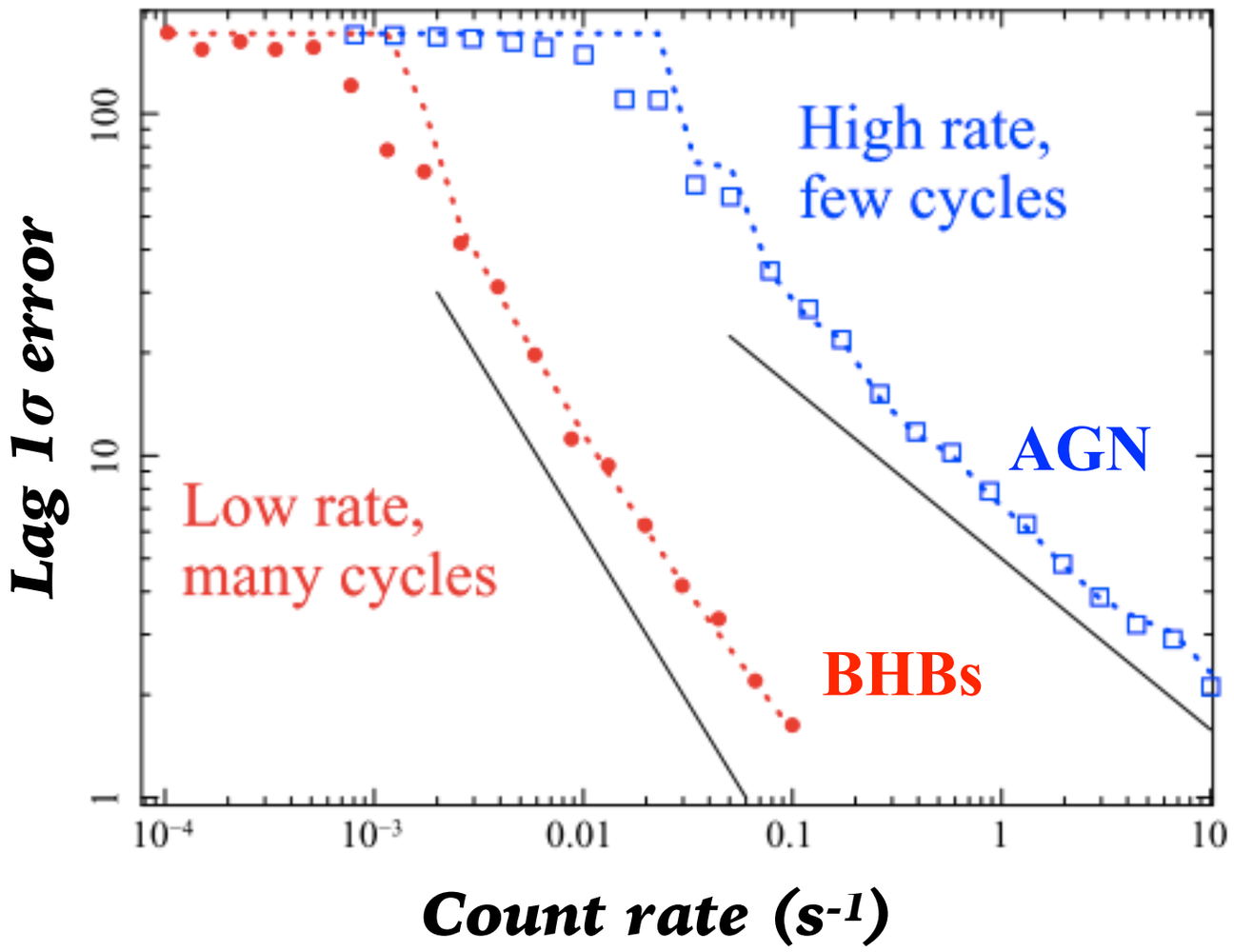




[Mahmoud+ in preparation]

X-ray reverberation with Athena

[Uttley+'14]

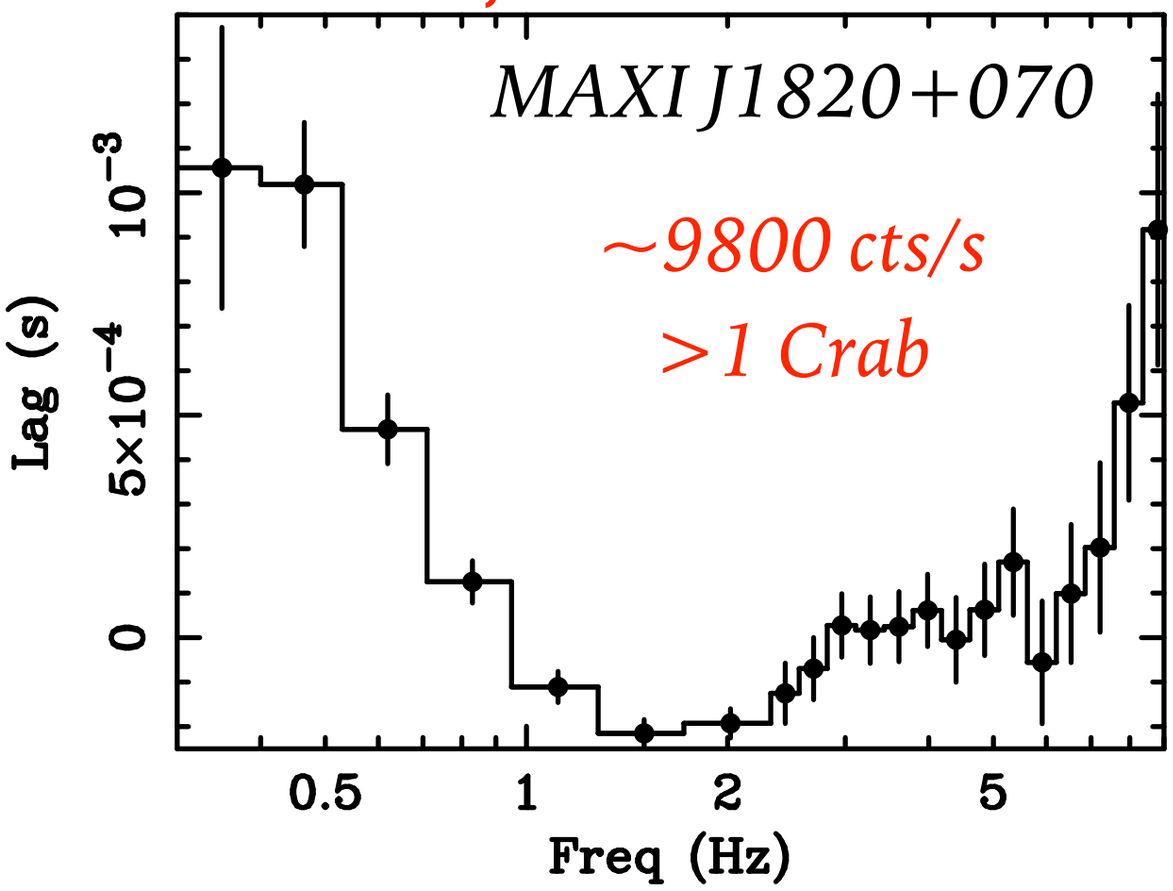


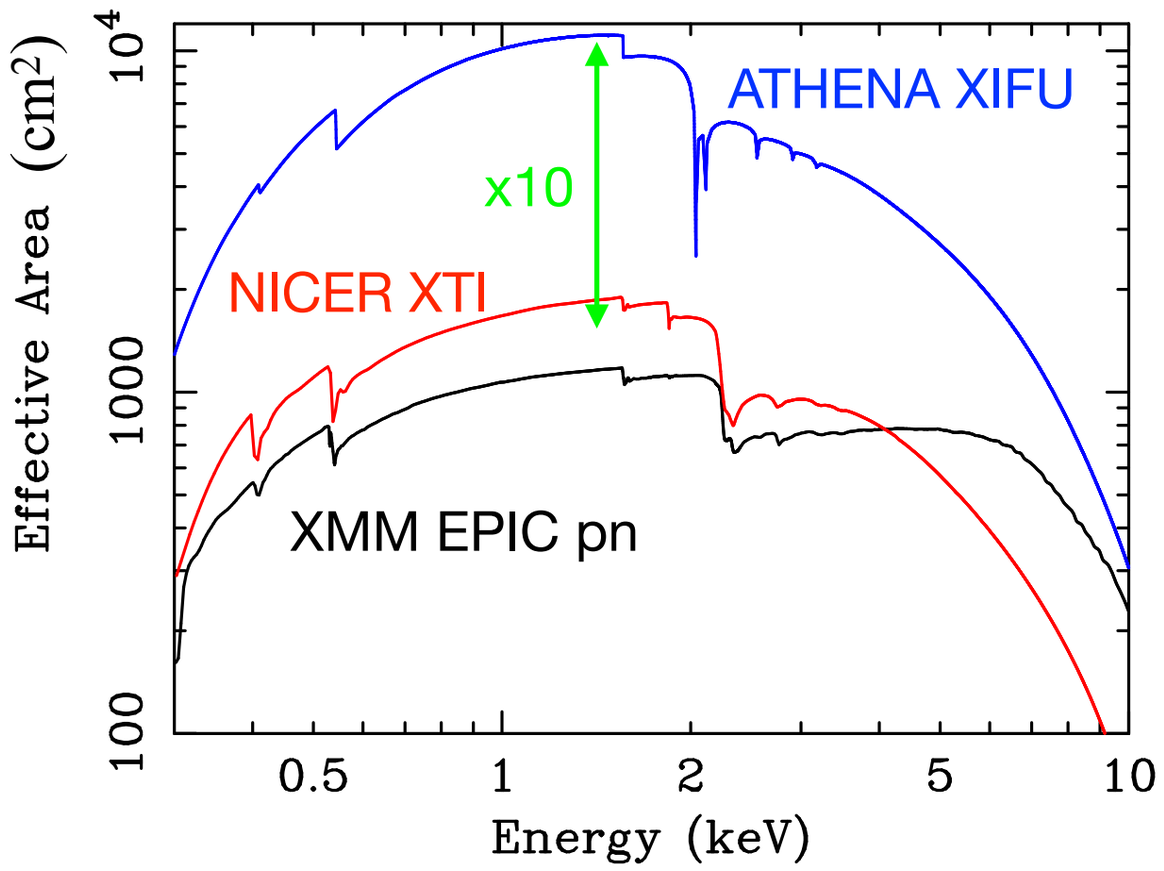
Biggest improvements foreseen for BHB studies!!

Caveat: BHBs can get VERY bright…

A NICER preview of X-ray reverberation with ATHENA

10-60 Hz, ~5ks





ATHENA will provide similar high S/N, high frequency lag spectra for sources a factor of 10 less luminous

+ unprecedented spectral resolution!

Conclusions

X-ray reverberation: independent method to study the inner accretion flow

X-ray reverberation measurements consistent with reprocessing occurring in the inner disc in RQ AGN, and evolving disc geometry in BHXRBs

To make a comparison with detailed models and infer precise constraints on disc-corona geometry we need high S/N and spectral resolution measurements over a broad E range combined with good timing capabilities

X-ray spectral-timing with Athena will allow us to independently constrain the parameters of the BH and the physical properties of the innermost accretion flow

Thanks!