

X-ray reverberation: a tool to constrain the (evolving) disc geometry in BHXBs

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G. Henri, J. Malzac, J. Rodriguez, J. A. Tomsick, F. Ursini, A. A. Zdziarski*



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via the Polish National Science Center grant Polonez*

Plan of the talk and main questions

- 1. Motivations: Why constraining disc geometry in BHXRBS?
Why using X-ray reverberation?***

Plan of the talk and main questions

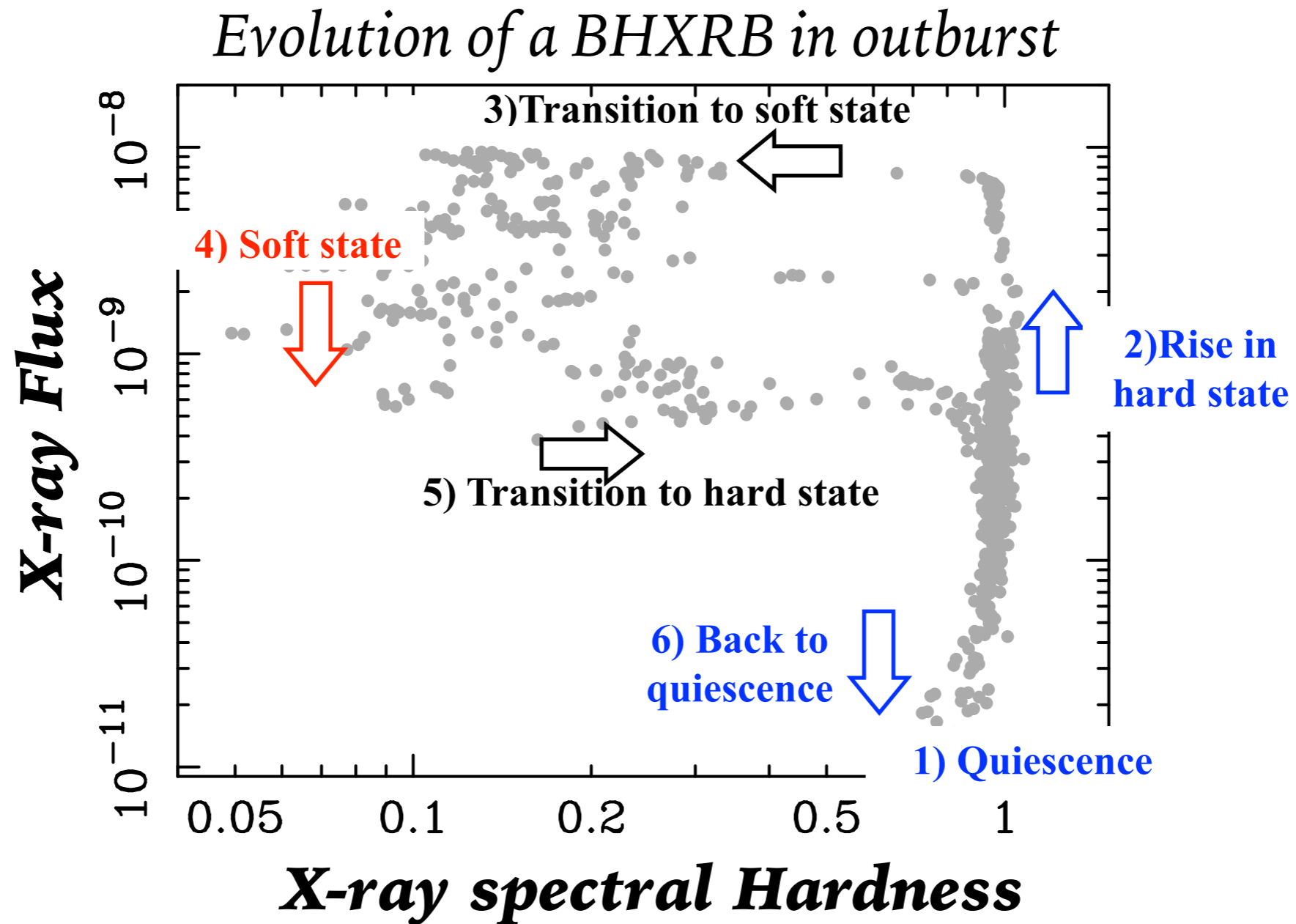
- 1. Motivations: Why constraining disc geometry in BHXRBS?
Why using X-ray reverberation?***
- 2. Goal: How do X-ray reverberation lags evolve through different accretion states?***

Plan of the talk and main questions

- 1. Motivations: Why constraining disc geometry in BHXRBS?
Why using X-ray reverberation?***
- 2. Goal: How do X-ray reverberation lags evolve through different accretion states?***
- 3. Conclusions: What do observations of X-ray reverberation in BHXRBS tell us?***

Manifestations of accretion: a rich phenomenology

Changes in the contribution from optically thick and thin plasma



Spectral evolution

+

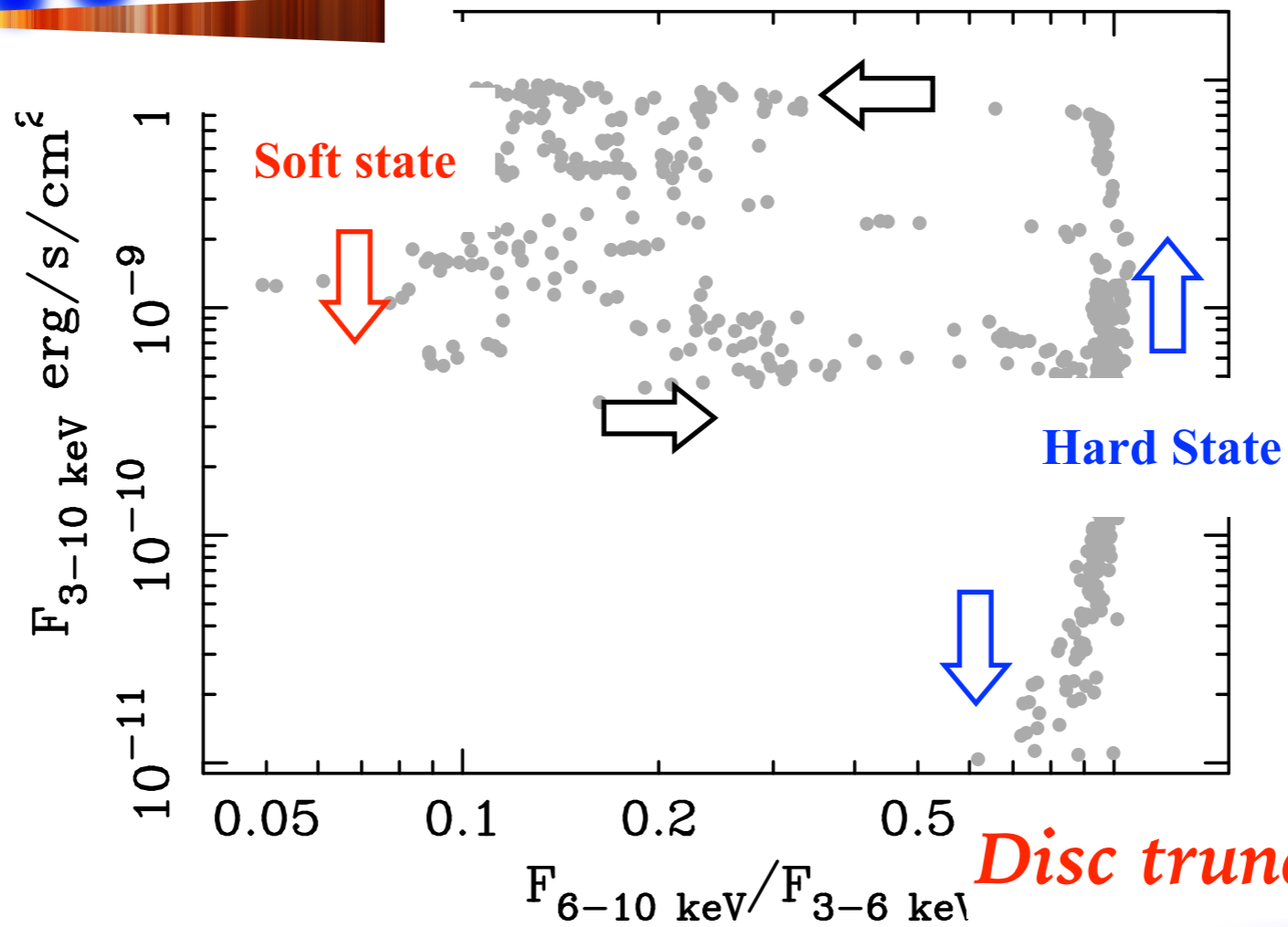
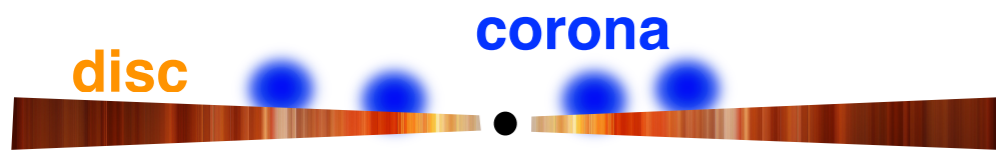
Timing evolution

[e.g. Fender + '04; Belloni + '05;
Dunn + '10; Muñoz-Darias + '11]

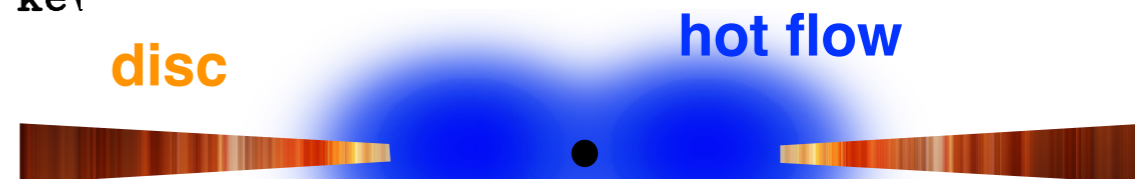
Variations of inner flow geometry

A plausible scenario to explain the outburst evolution

Disc close to ISCO



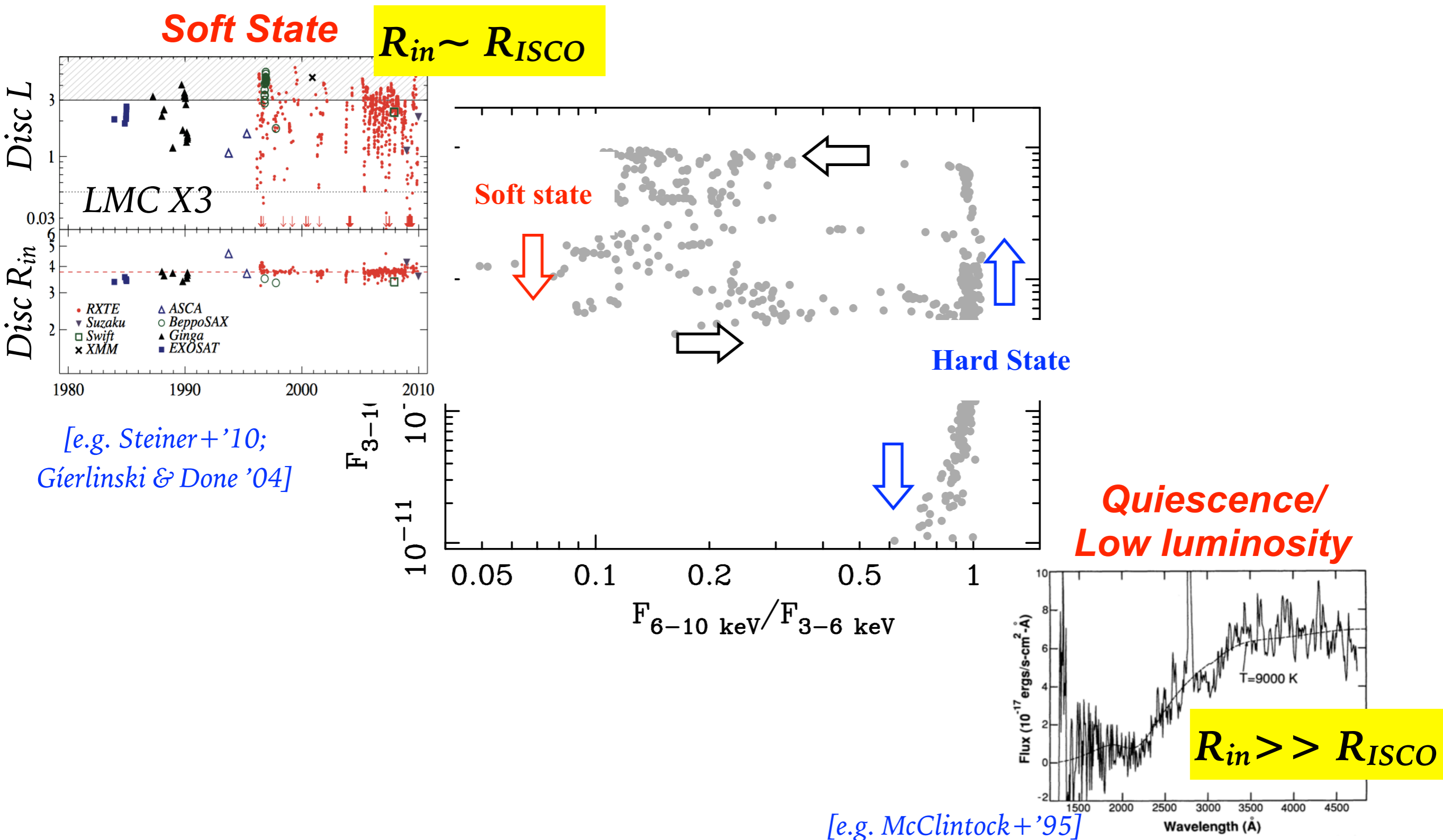
Disc truncated at large radii



[e.g. Esin + '97; Poutanen + '97; Zdziarski + '99; Meyer + '00; Narayan & McClintock '08]

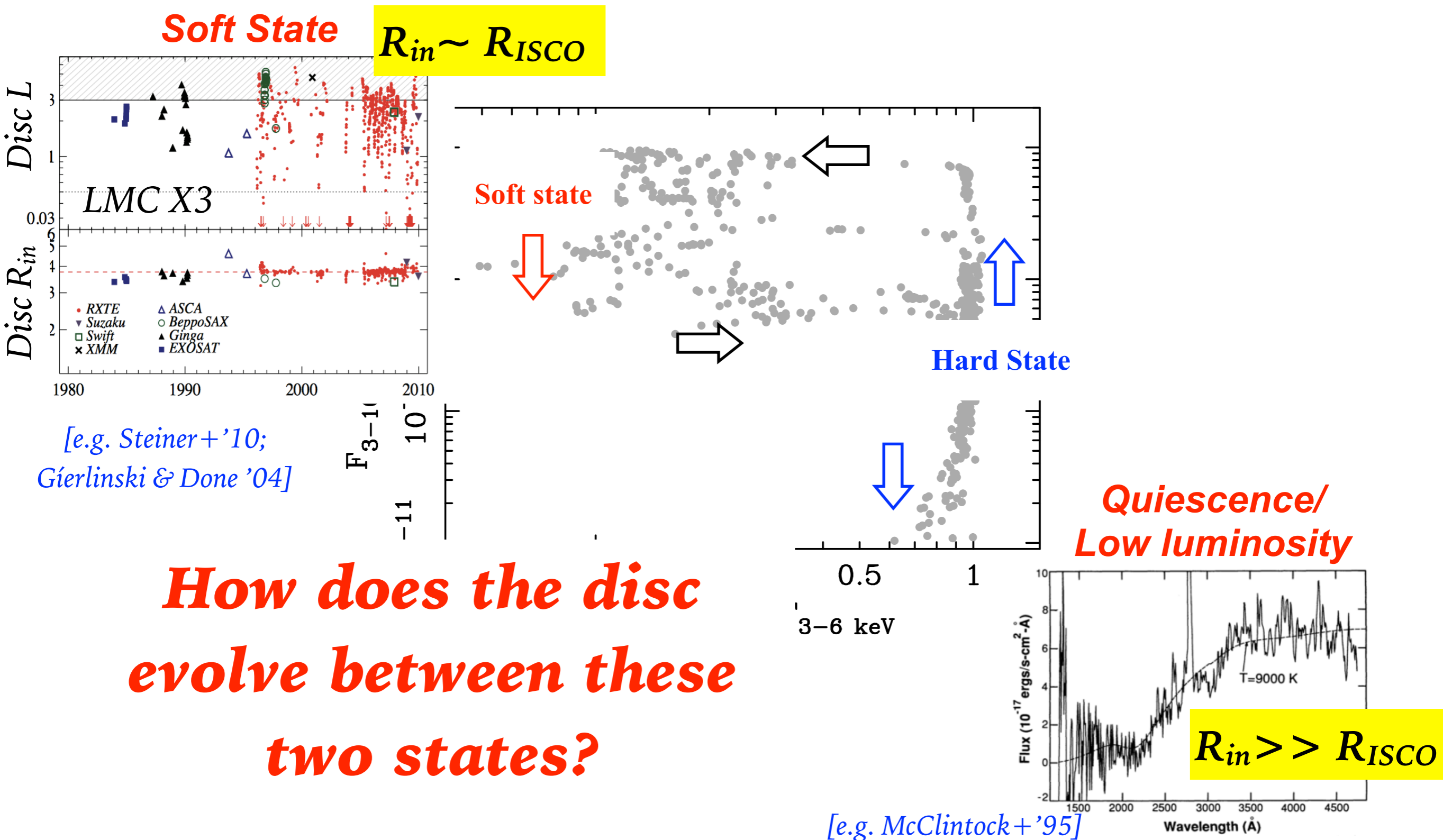
Evolving disc geometry: observational evidences

Disc non-truncated during soft state, highly-truncated during quiescence



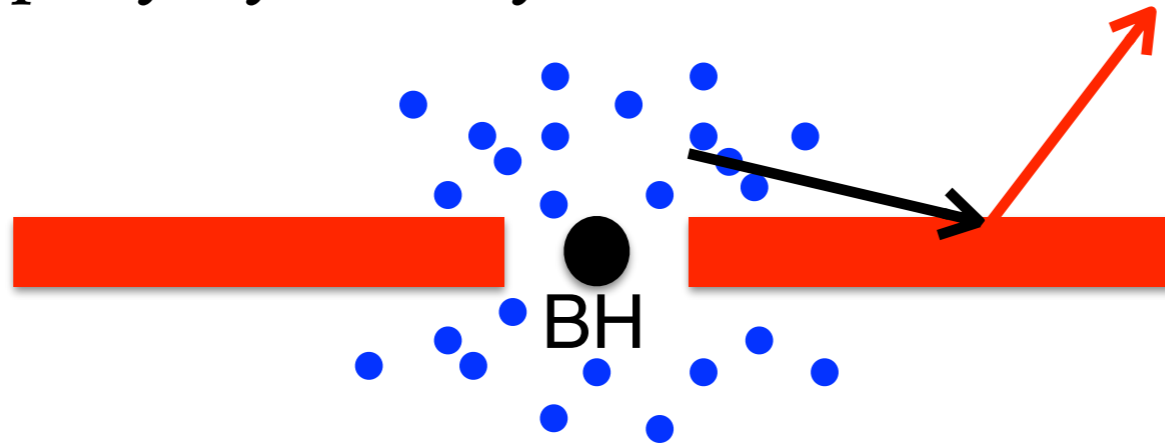
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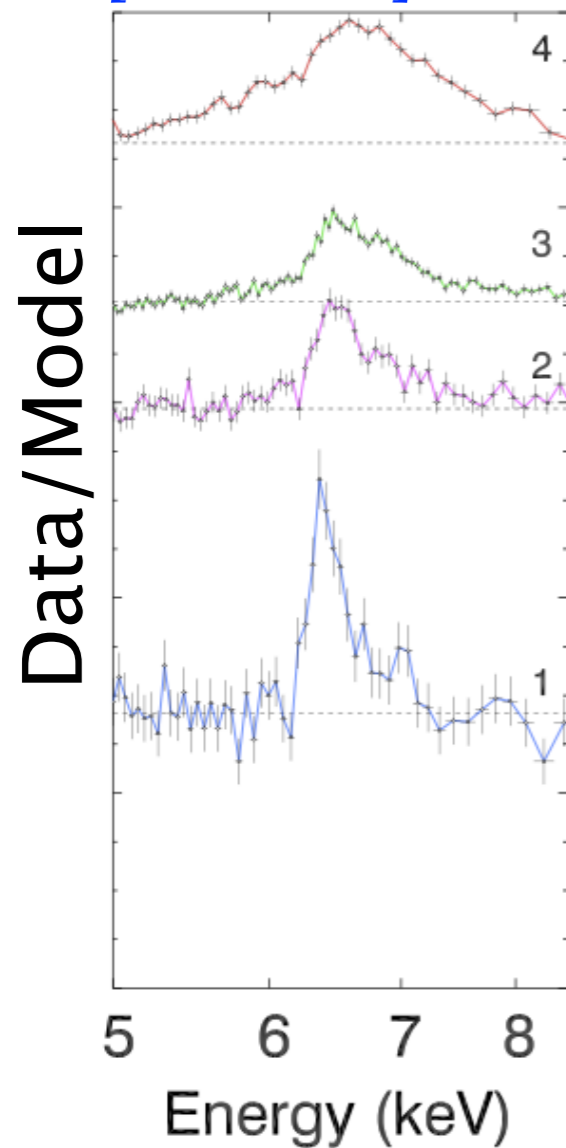


Reflected component

Intensity/shape of reflection features used to constrain geometry



[Plant+'15]

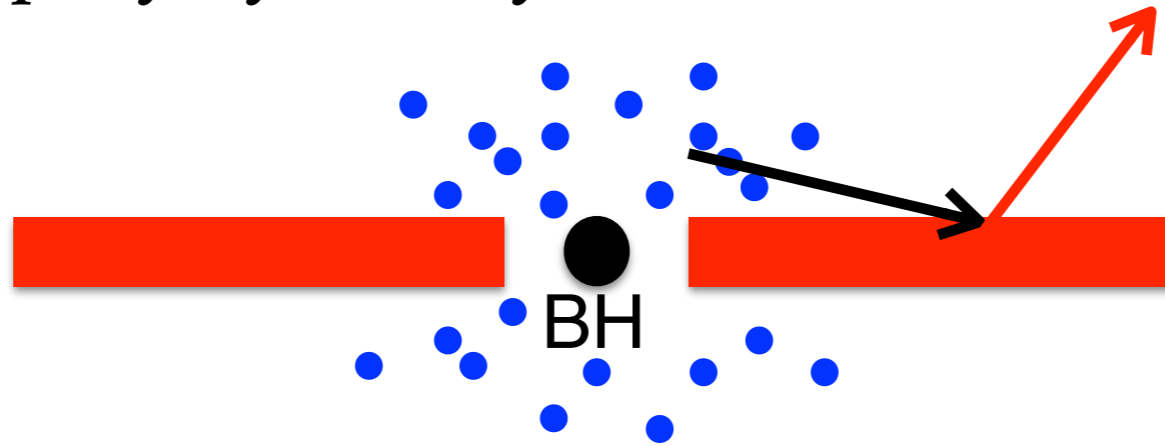


Hard State
Luminosity

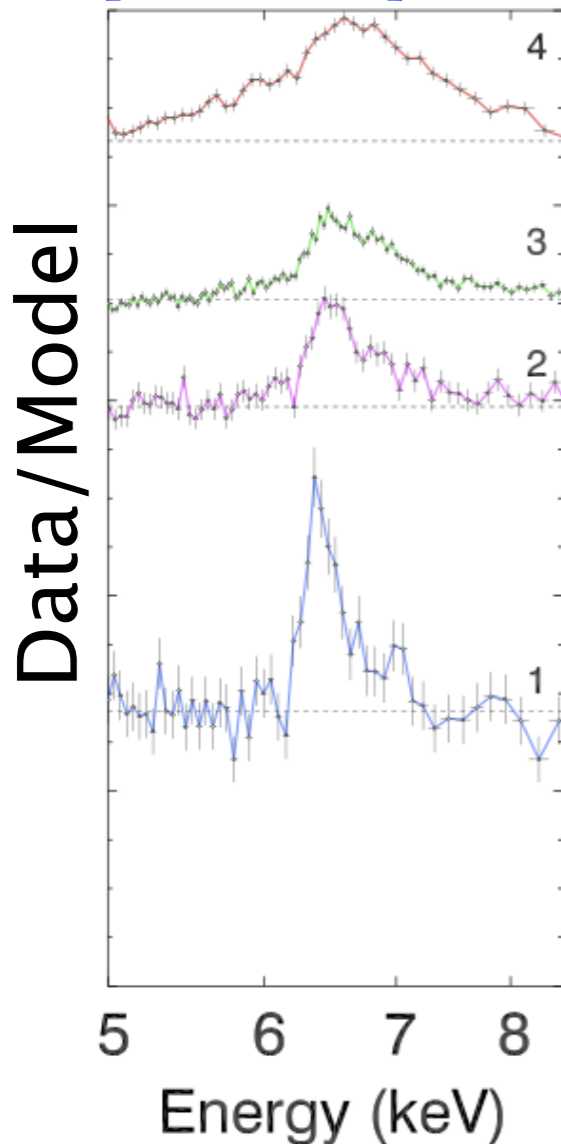


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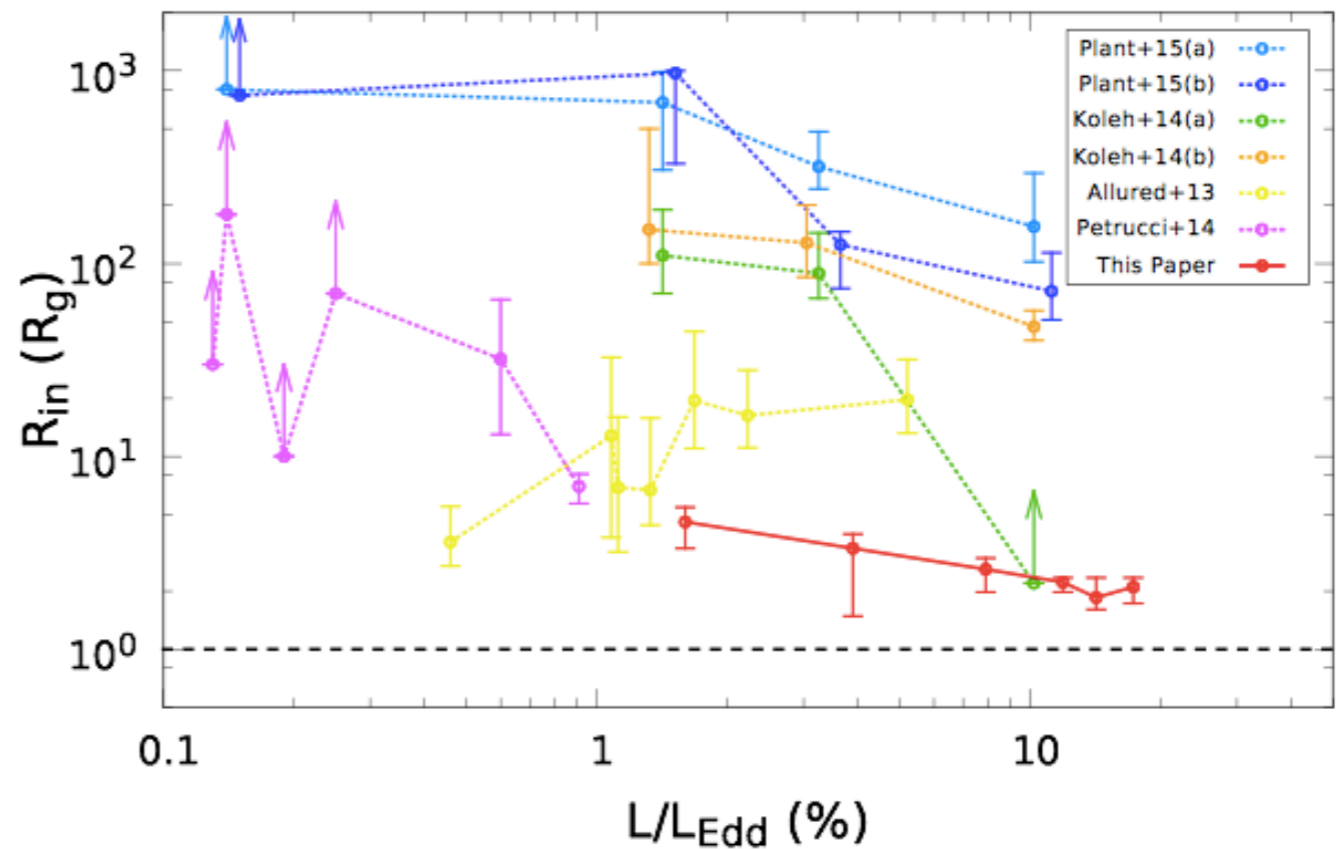
[Plant+'15]



Hard State
Luminosity

[García+'15; García's talk]

GX 339-4 (hard state)



No general agreement

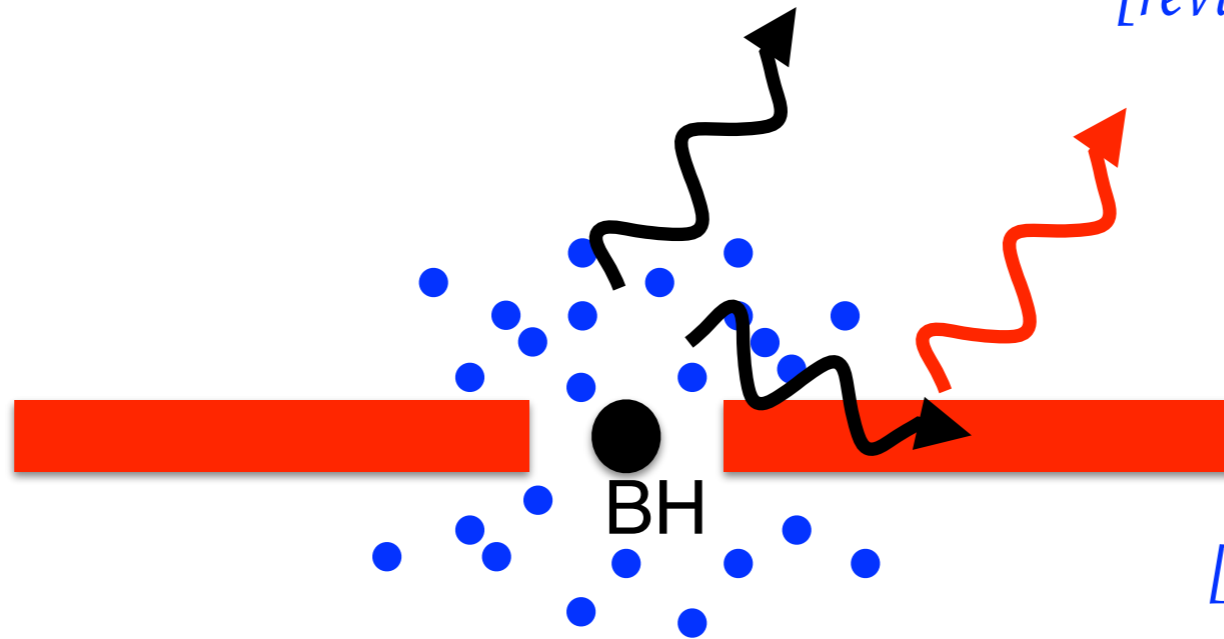
[e.g. Miller+'04, '06; Reis+'08; Plant+'15; García+'15;

Basak & Zdziarski '16; Basak+'17]

X-ray reverberation

Independent method to constrain geometry of the inner accretion flow

[review: Uttley+ '14; E. Kara's talk]

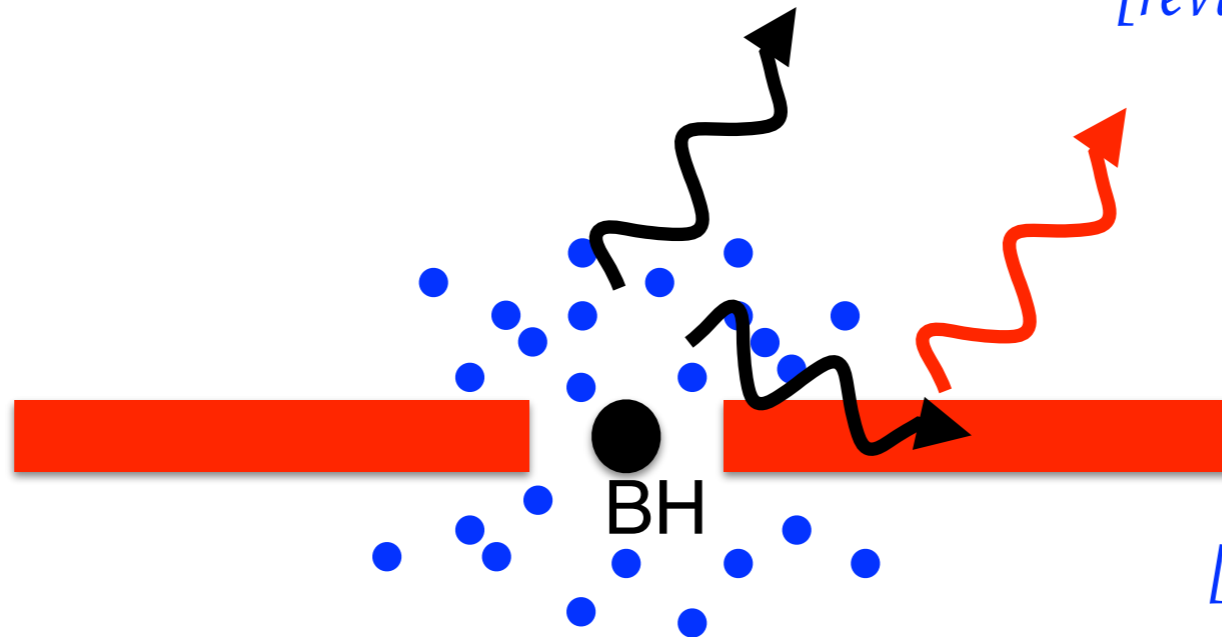


[Blandford & McKee '82]

X-ray reverberation

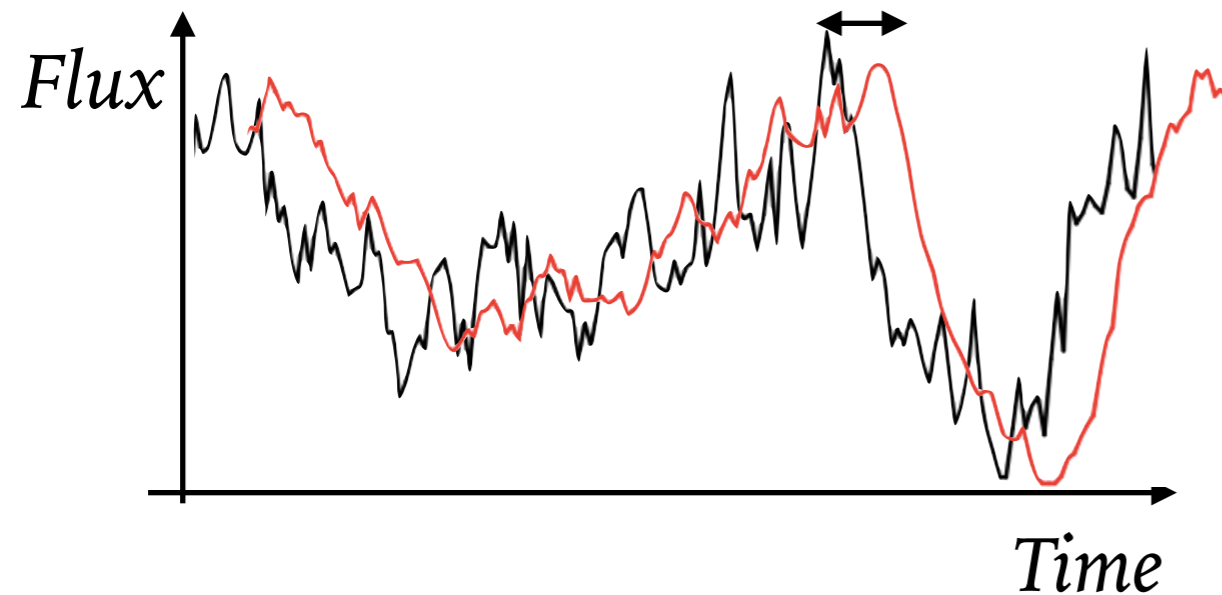
Independent method to constrain geometry of the inner accretion flow

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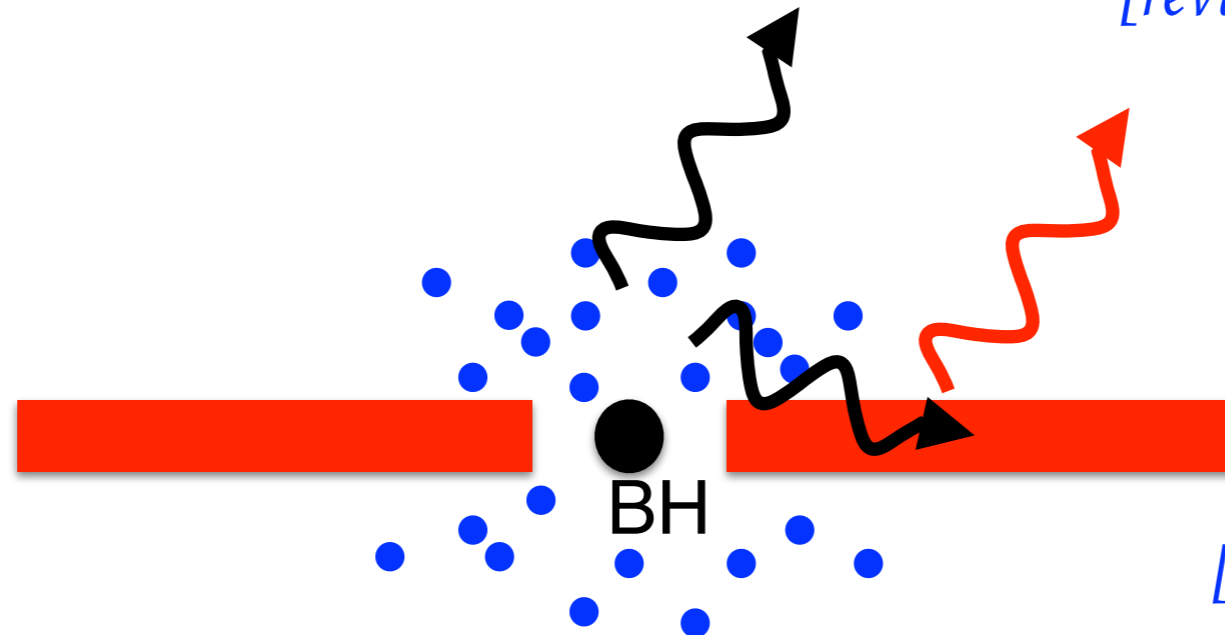
time delay maps physical distances



X-ray reverberation

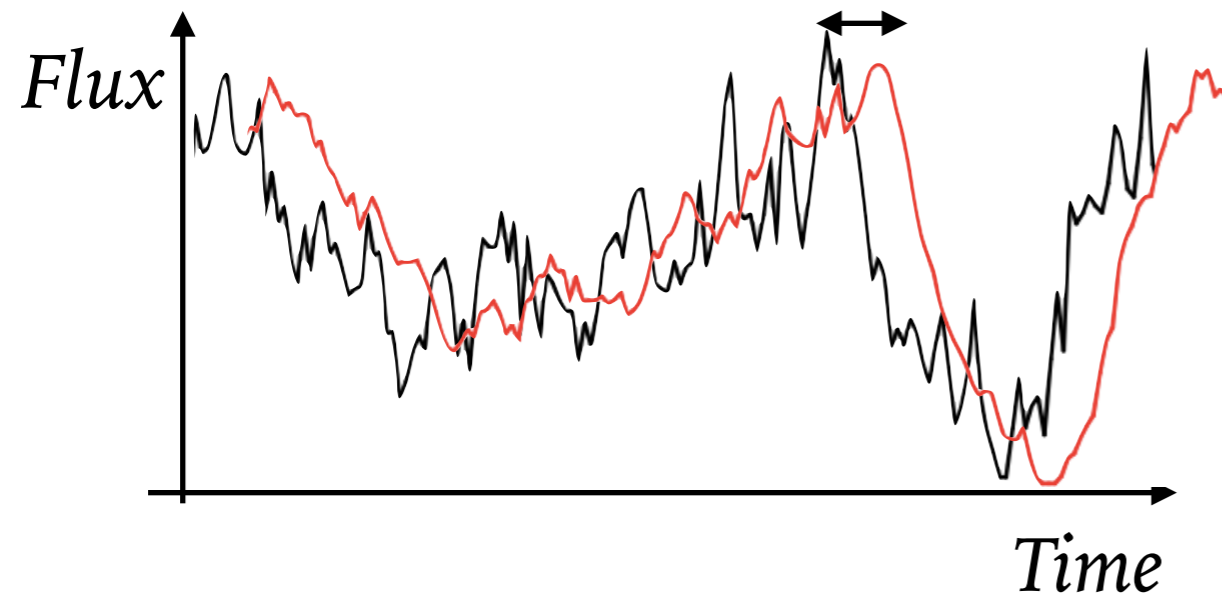
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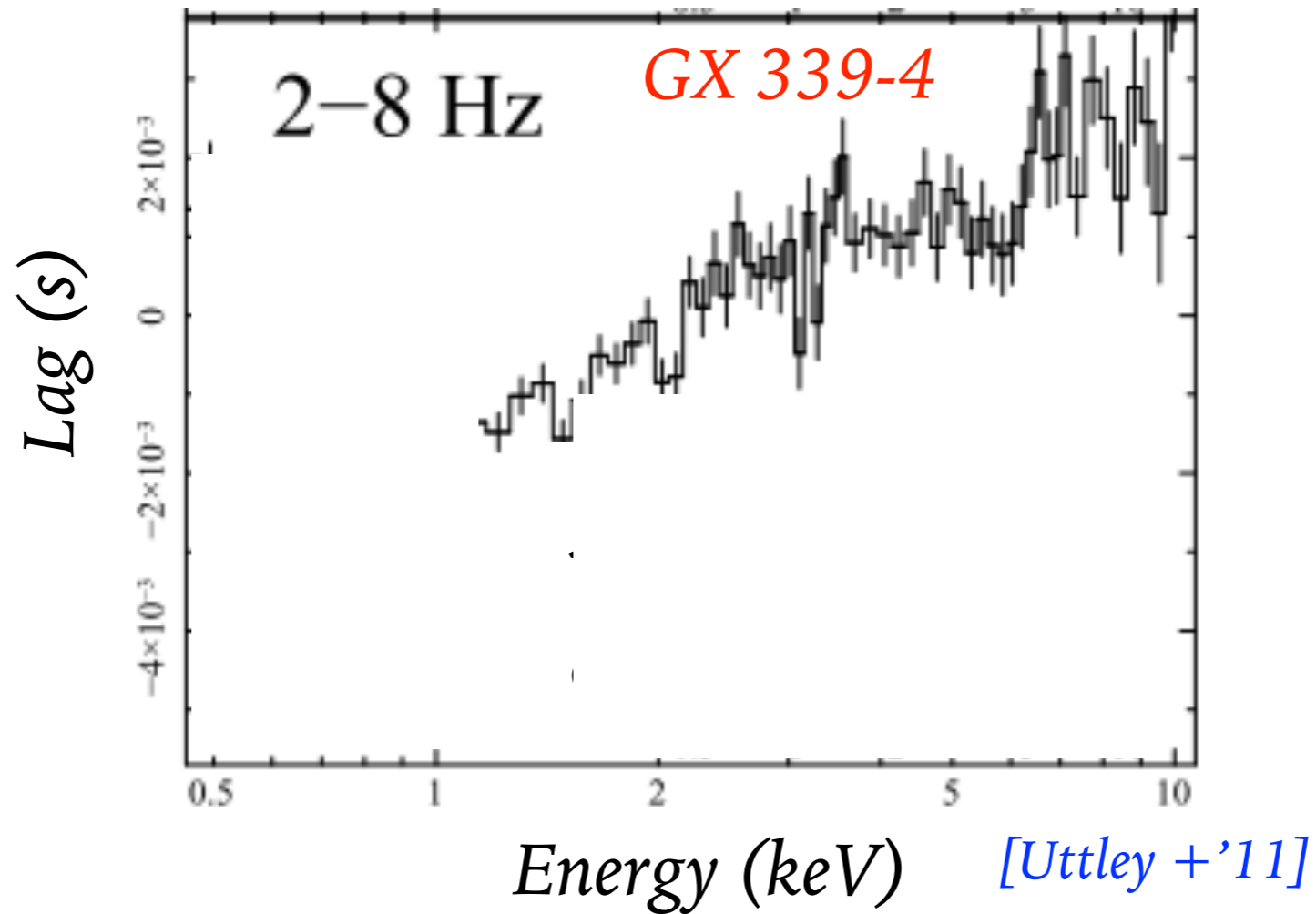
time delay maps physical distances



Can be used to constrain geometry!

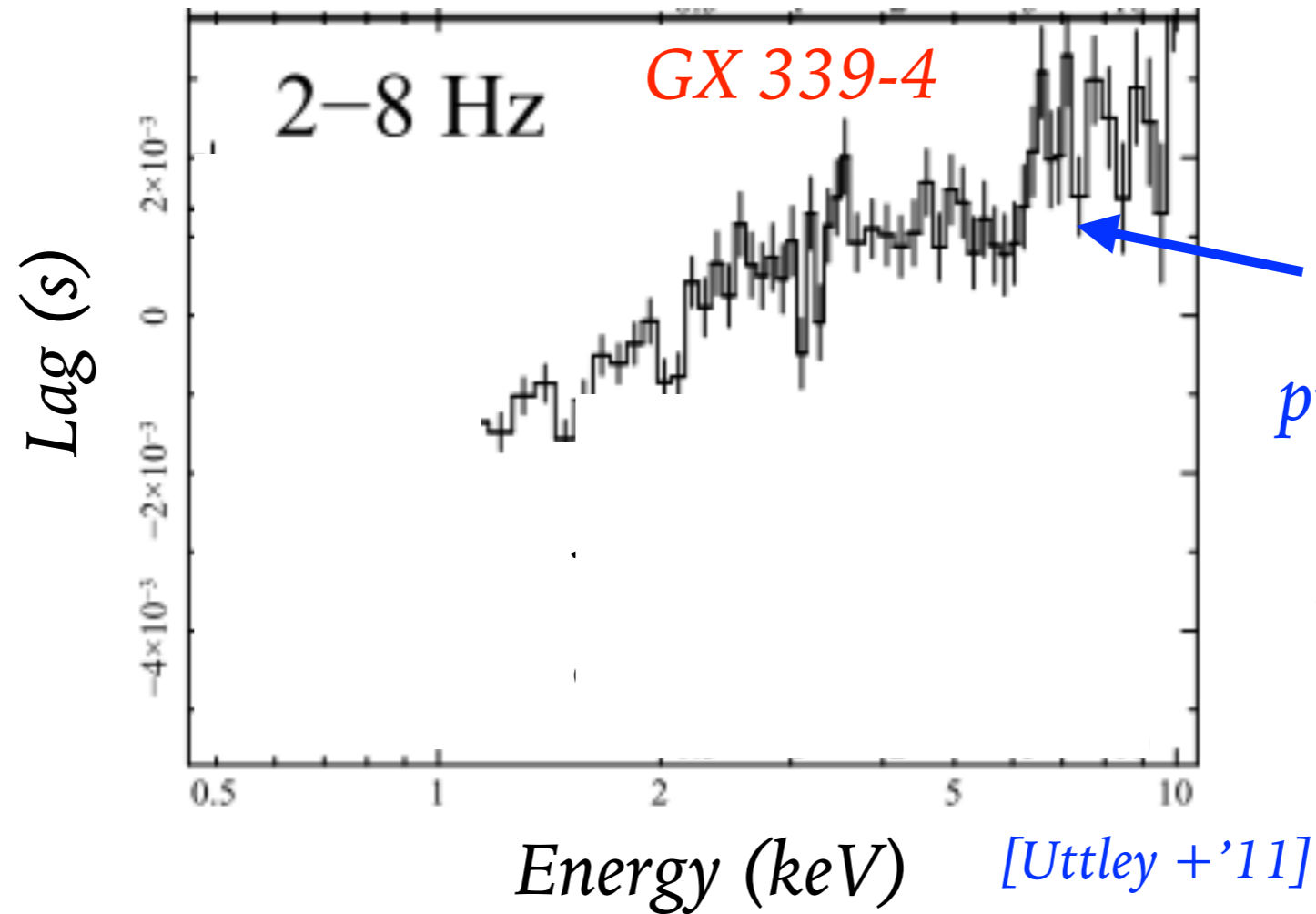
Disc reverberation in GX 339-4

XMM soft band sensitivity allows observing the disc during the hard state



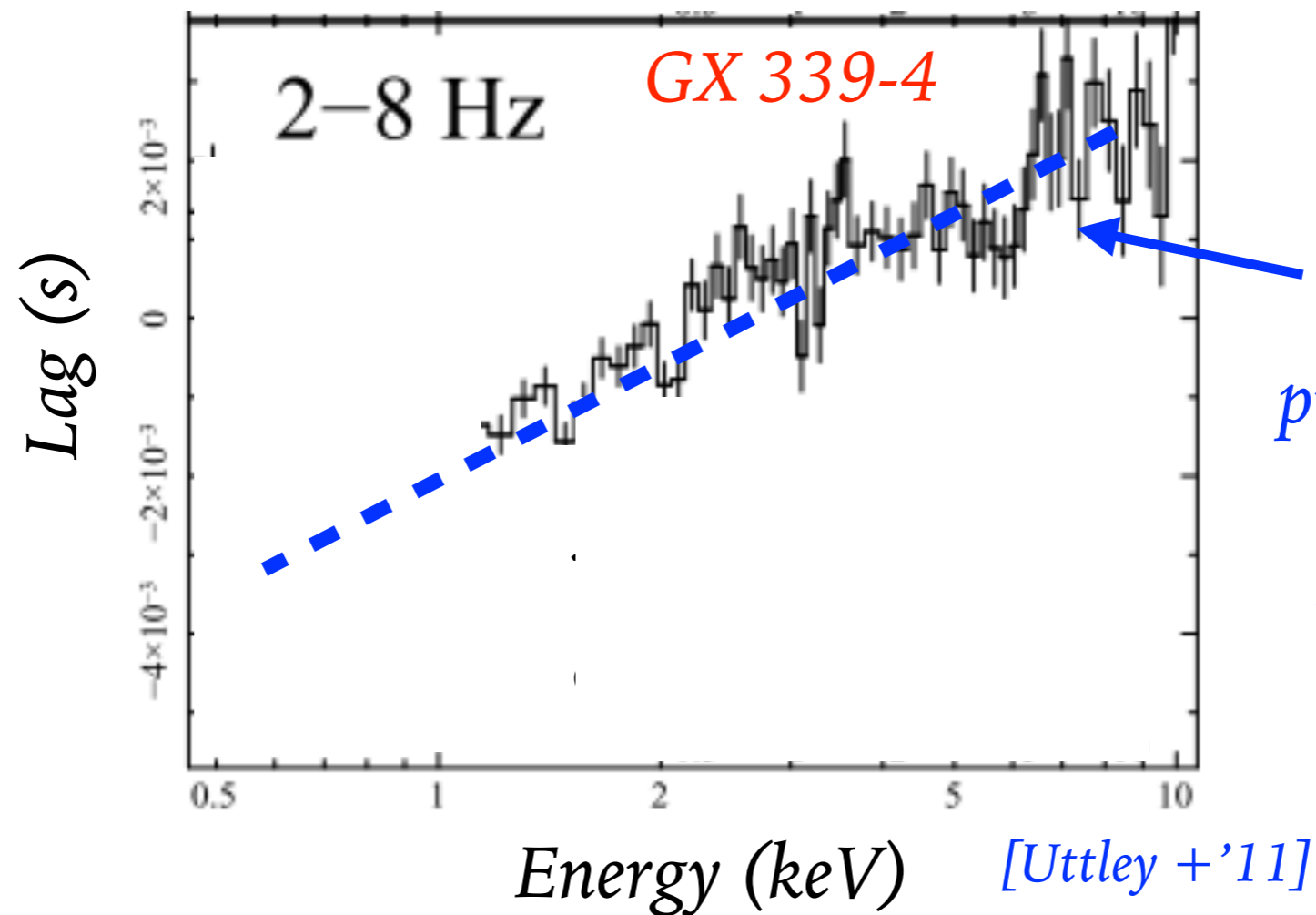
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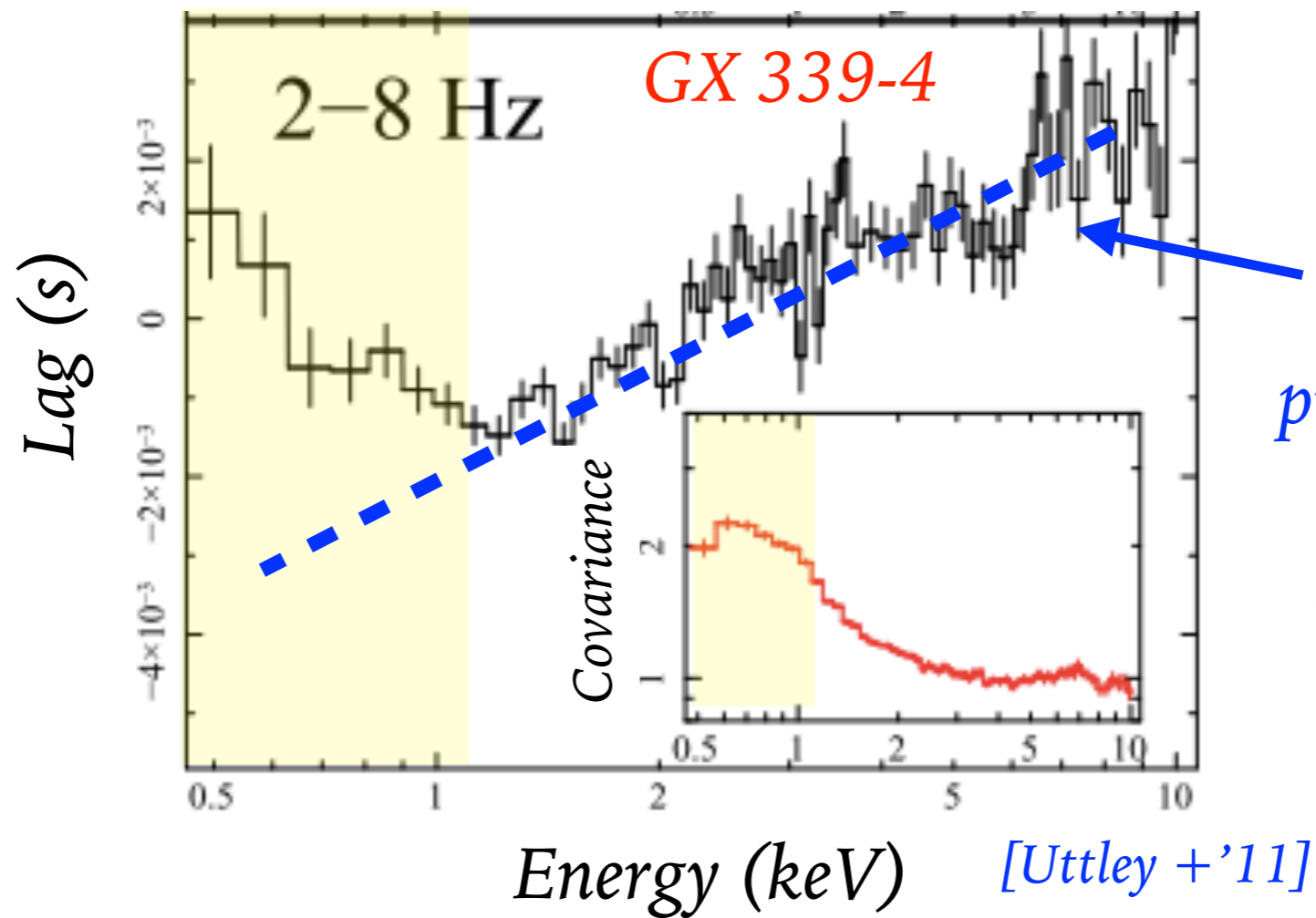
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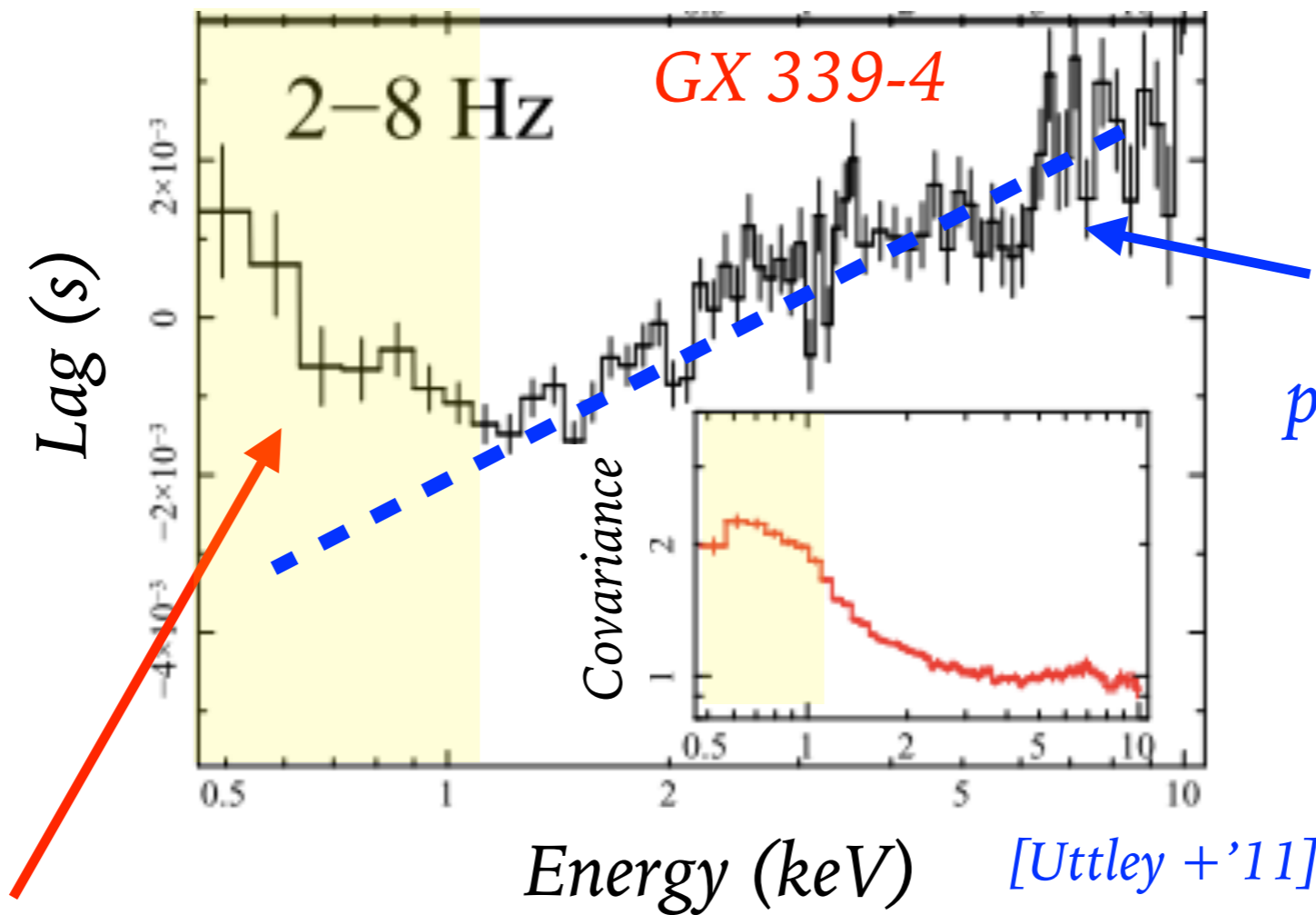
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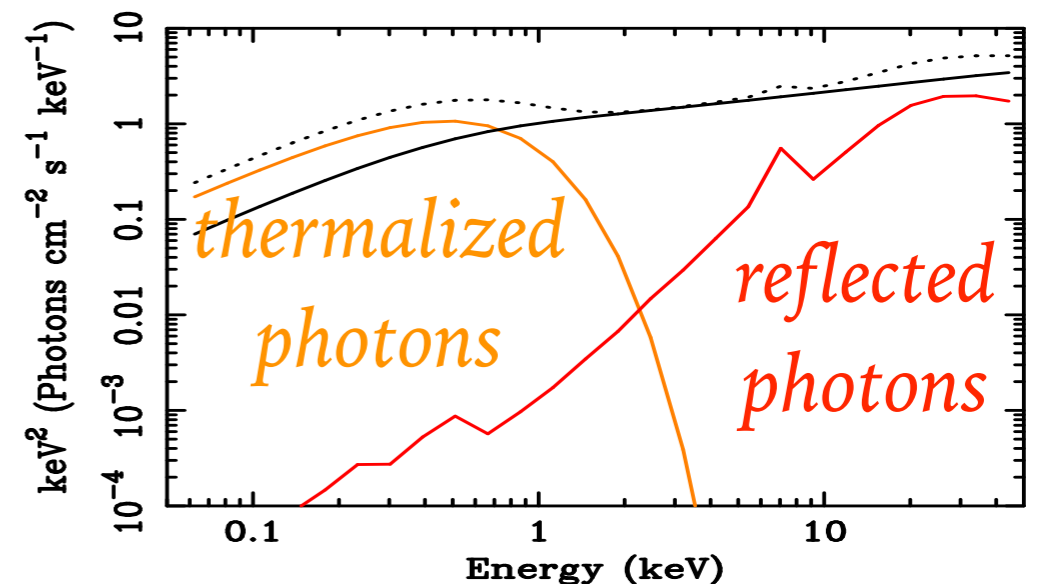
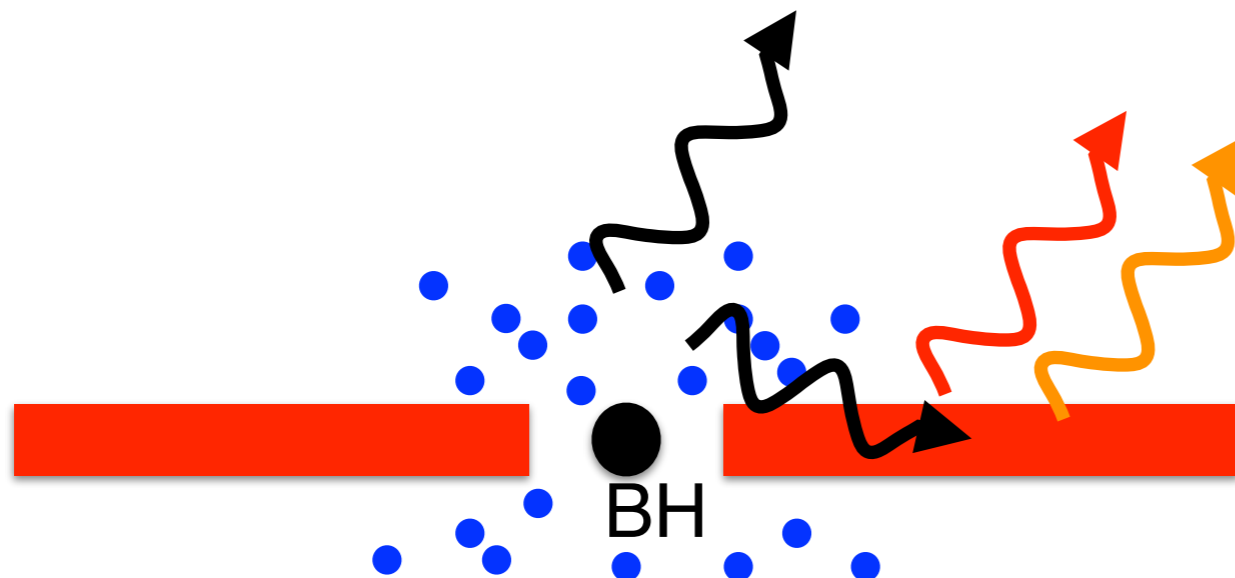
XMM soft band sensitivity allows observing the disc during the hard state



Hard lags associated with primary continuum
[e.g. Kotov+'01; see also Mastroserio's talk]

Energy (keV) [Uttley +'11]

Disc thermal reverberation



Reverberation lags vs accretion state

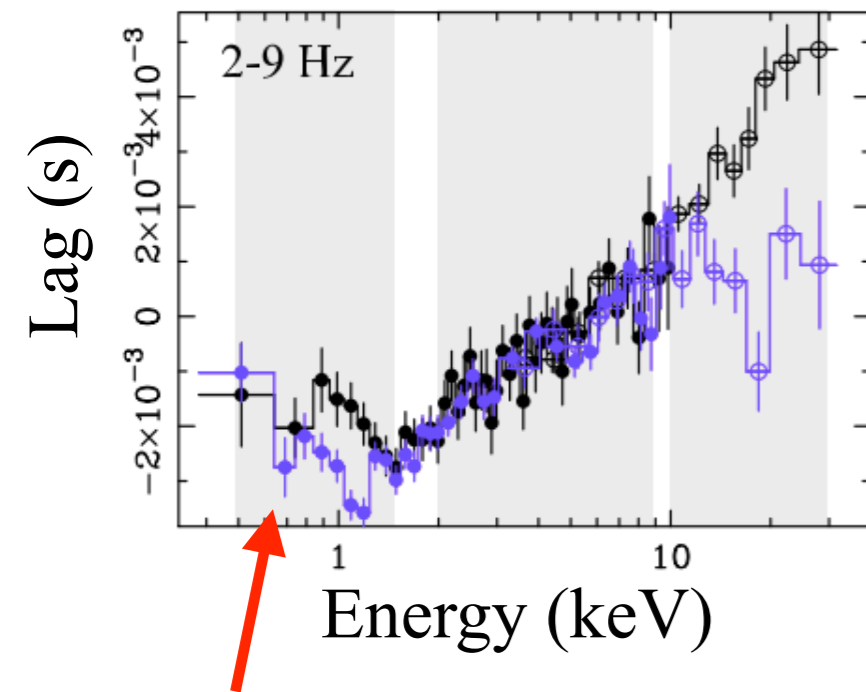
Sample: 10 sources observed with XMM

[De Marco + '15, De Marco & Ponti'16]

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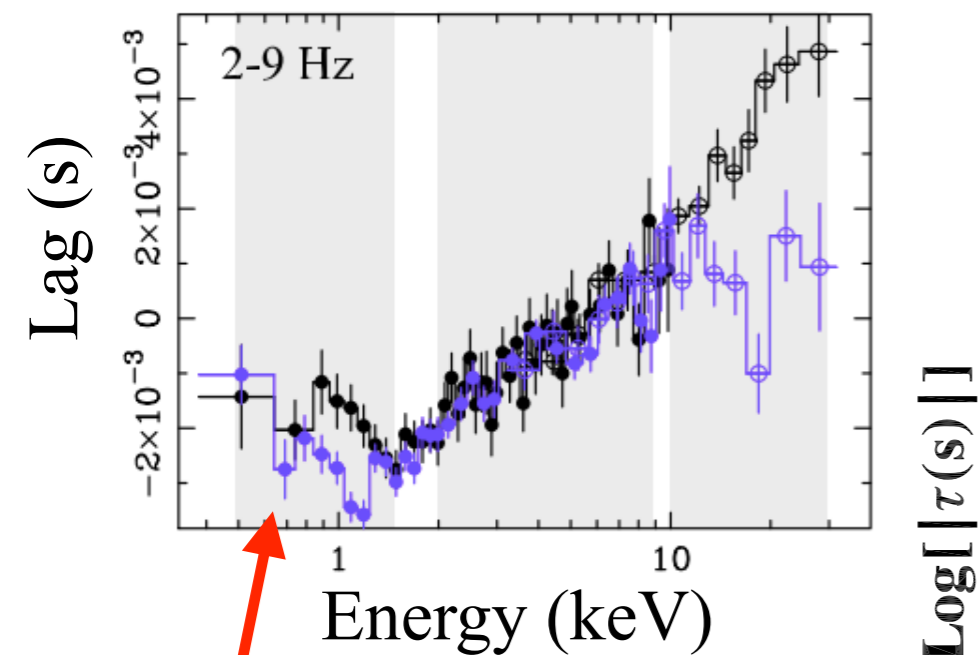
New detections

*(GX 339-4,
H1743-322)*

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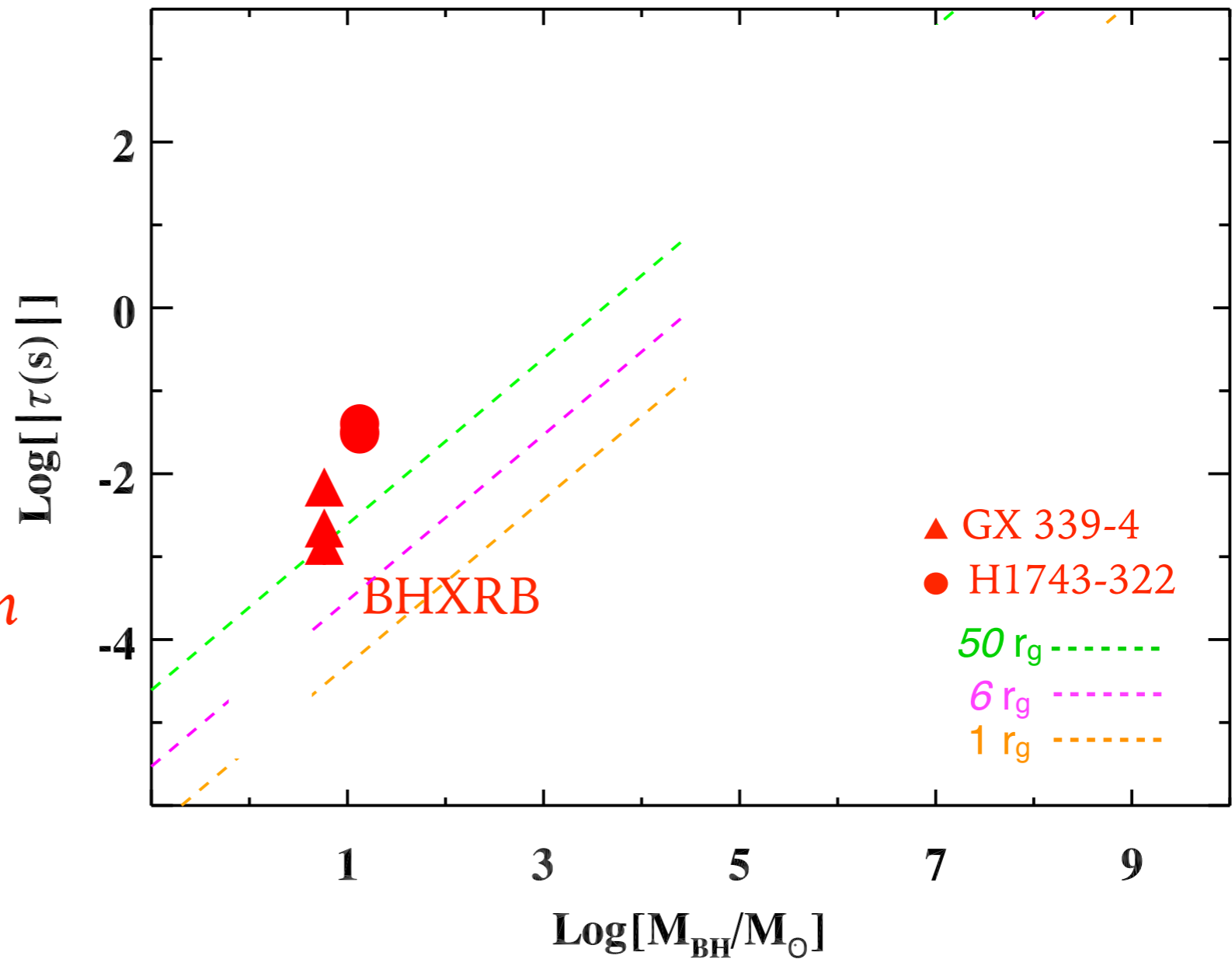
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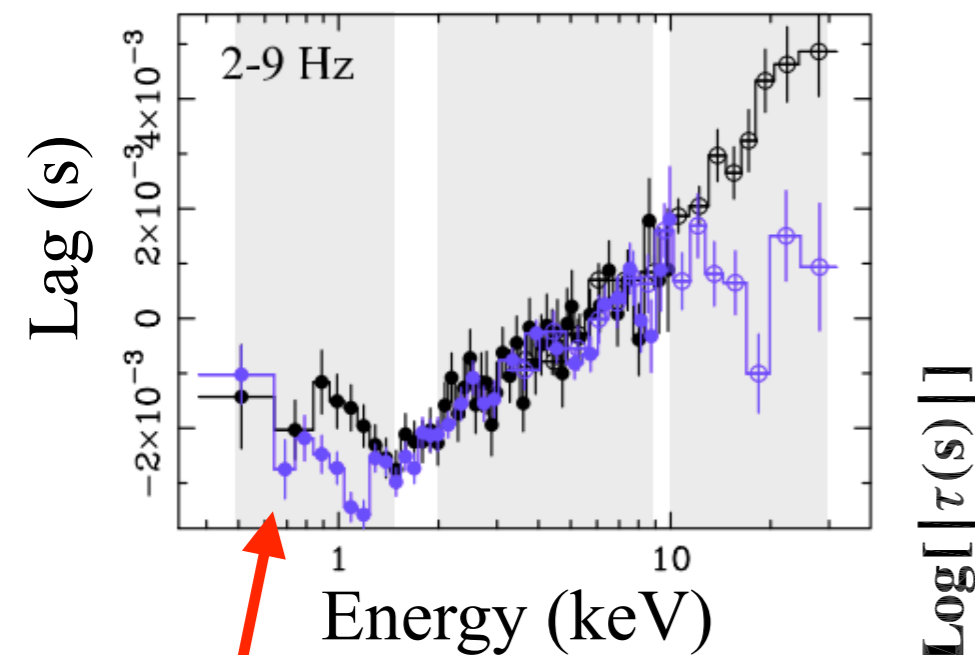
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[De Marco + '13

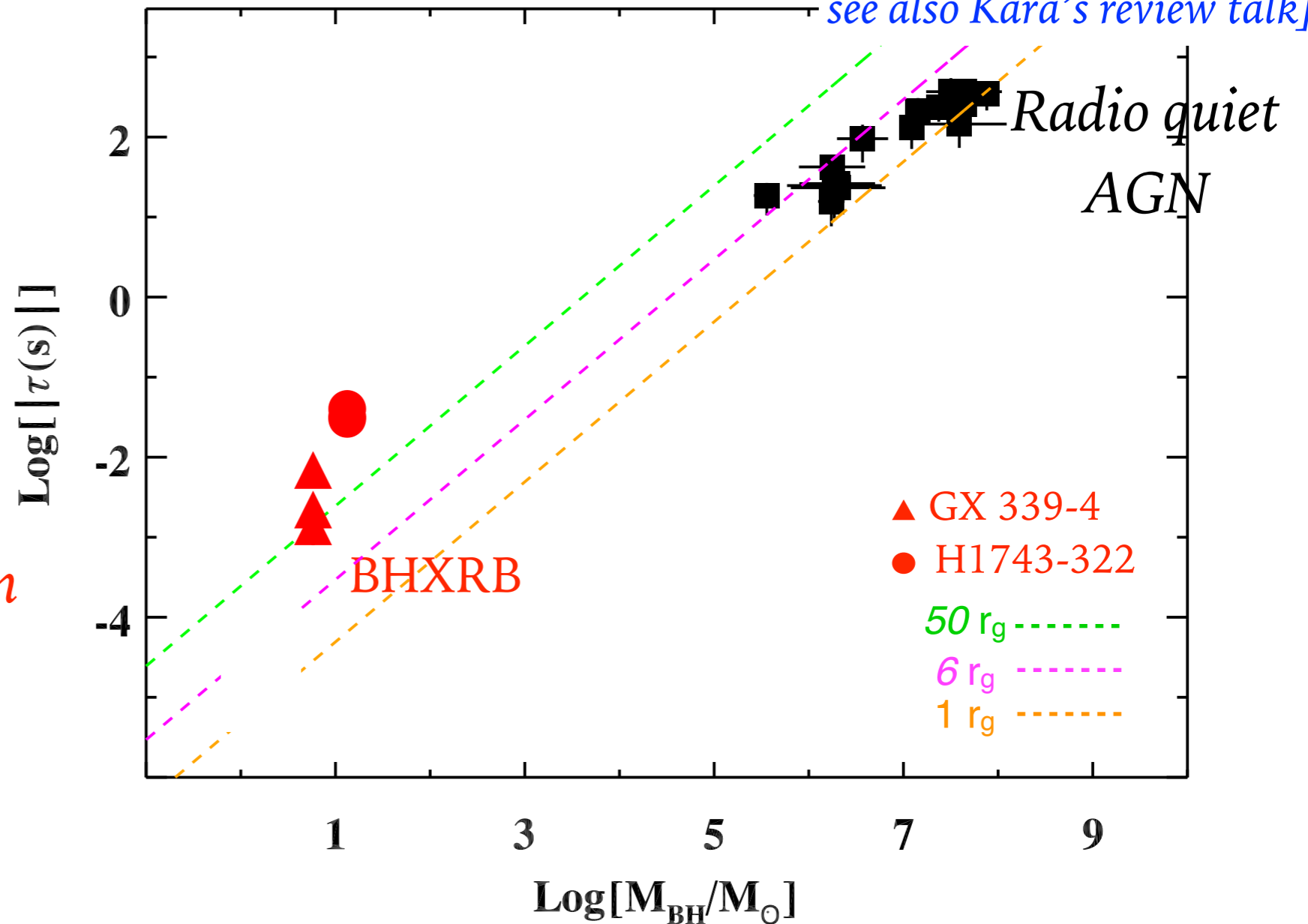
see also Kara's review talk]



Disc thermal reverberation

New detections

(GX 339-4,
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Offset between BHXR Bs and the AGN sample

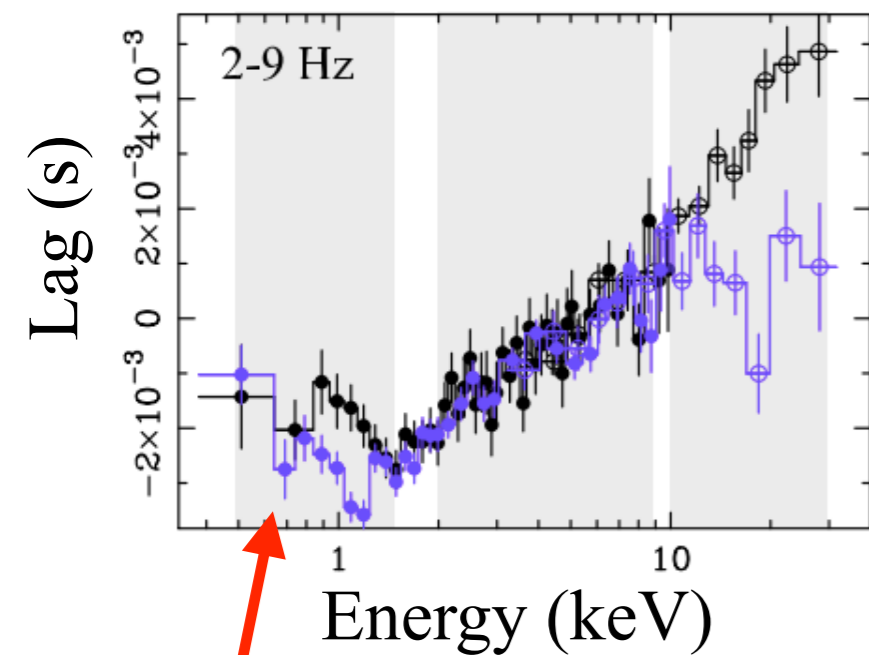
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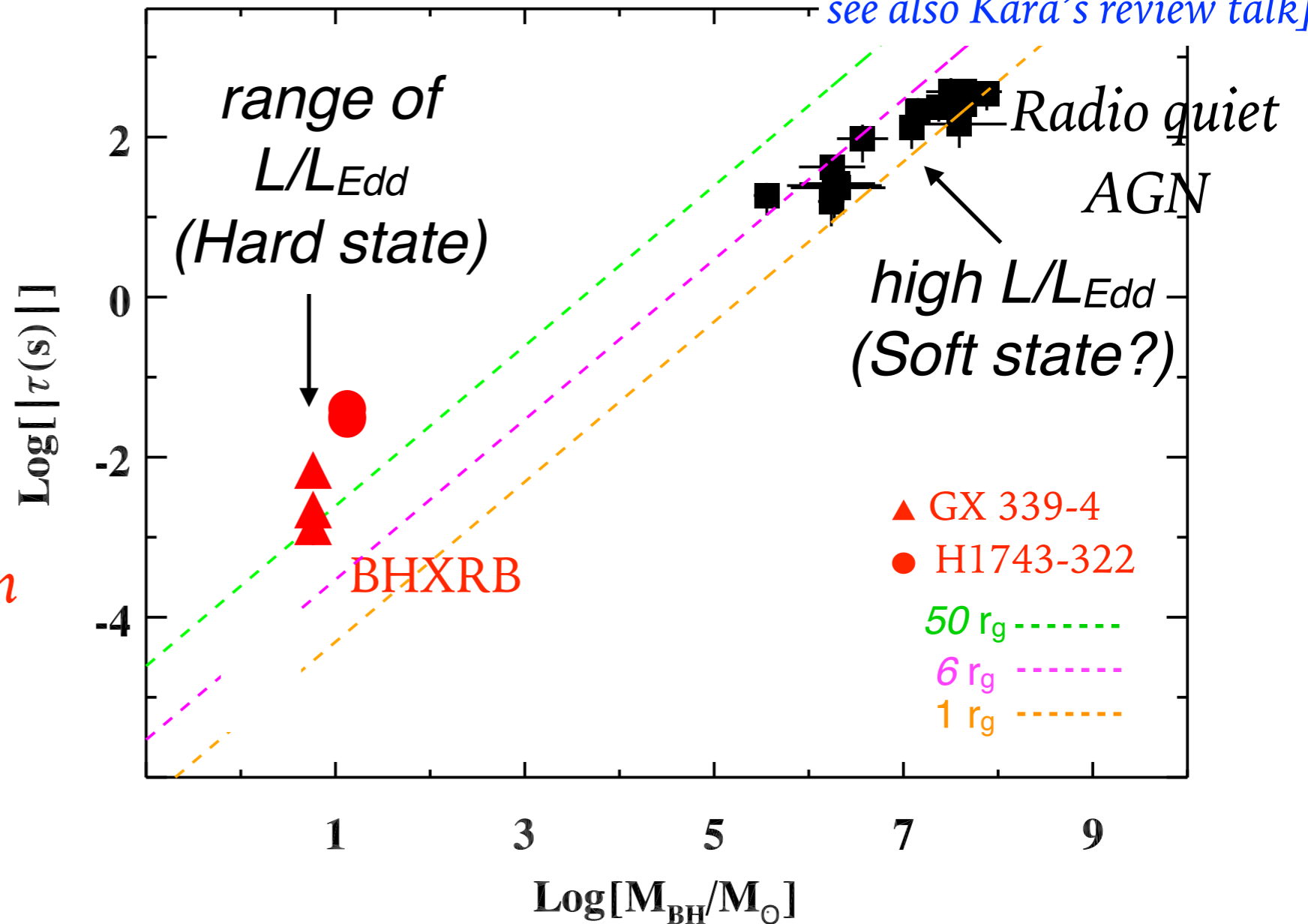
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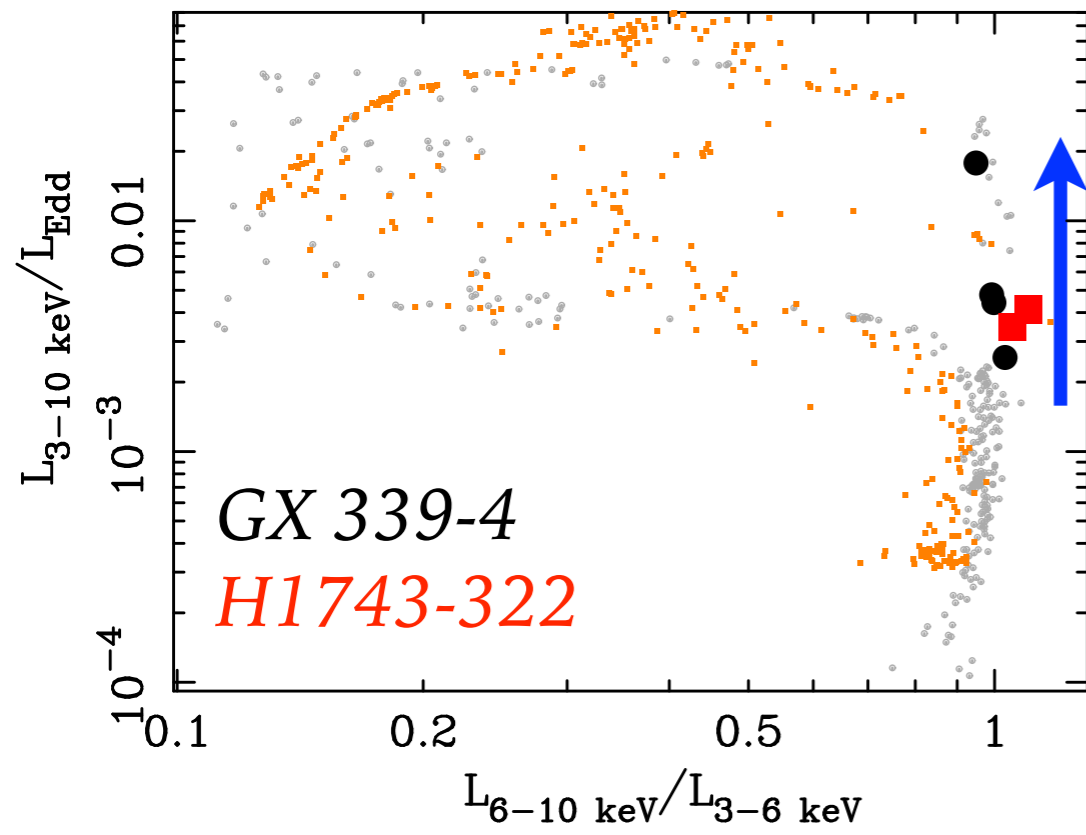
(GX 339-4,
H1743-322)



Offset between BHXRBs and the AGN sample \rightarrow different inner flow geometry

Evolution of reverberation lag during outburst

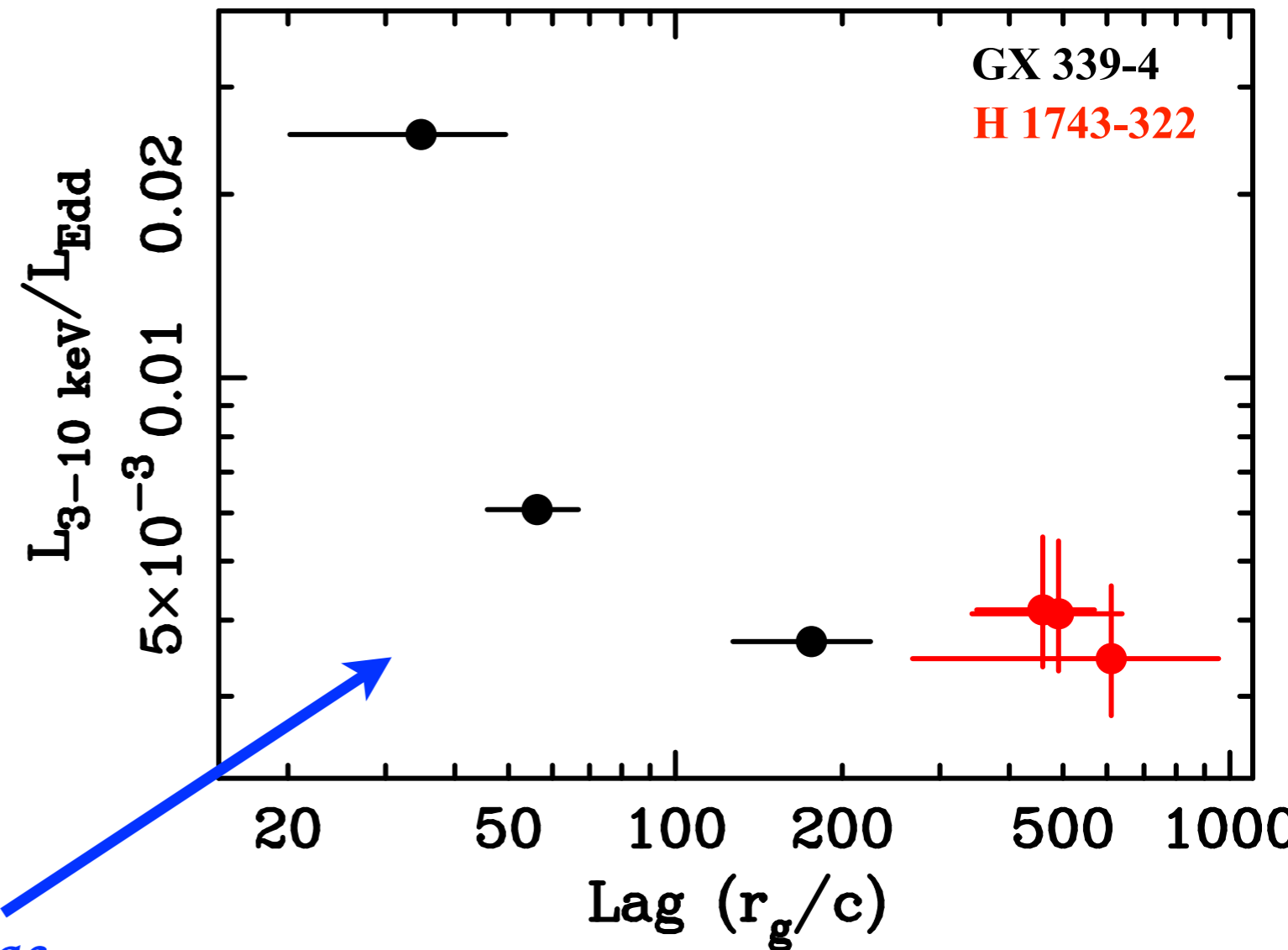
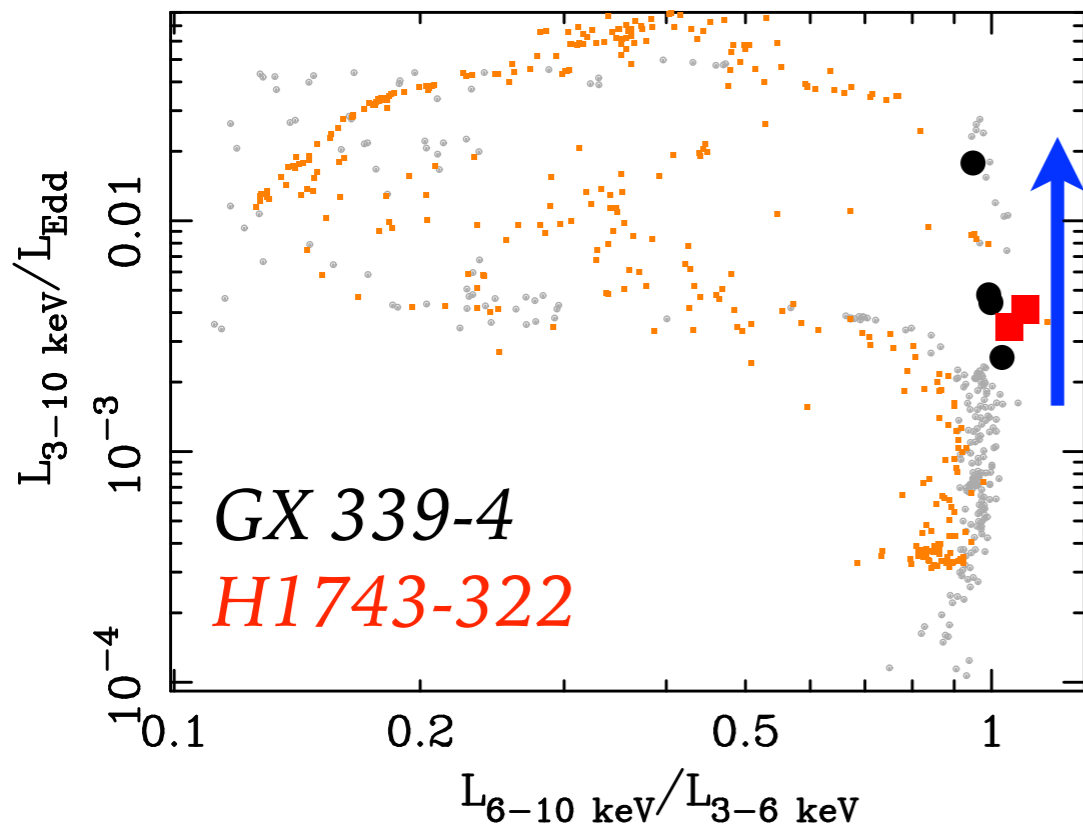
Variations of lag amplitude as a function of luminosity in the hard state



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Variations of lag amplitude as a function of luminosity in the hard state

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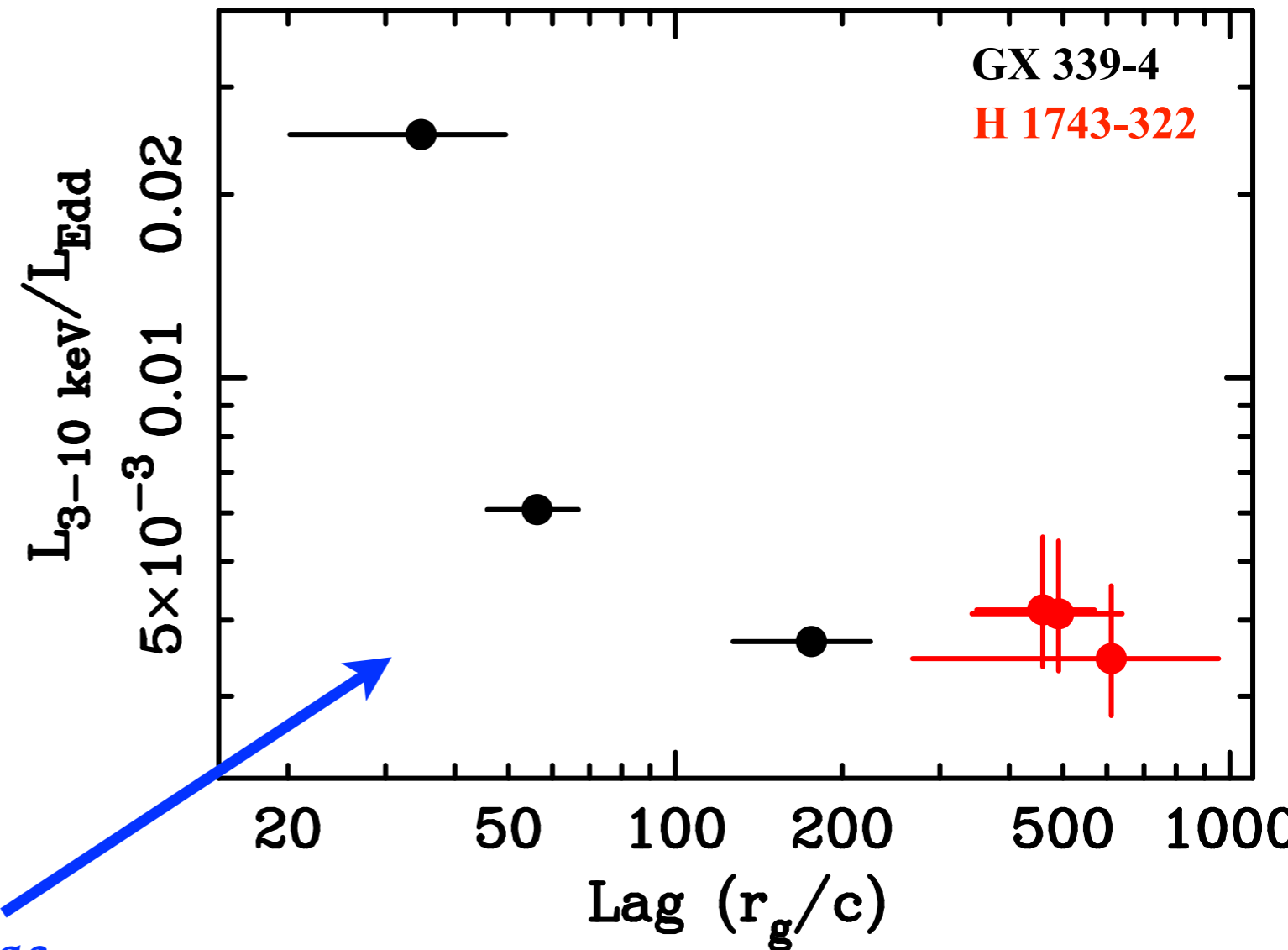
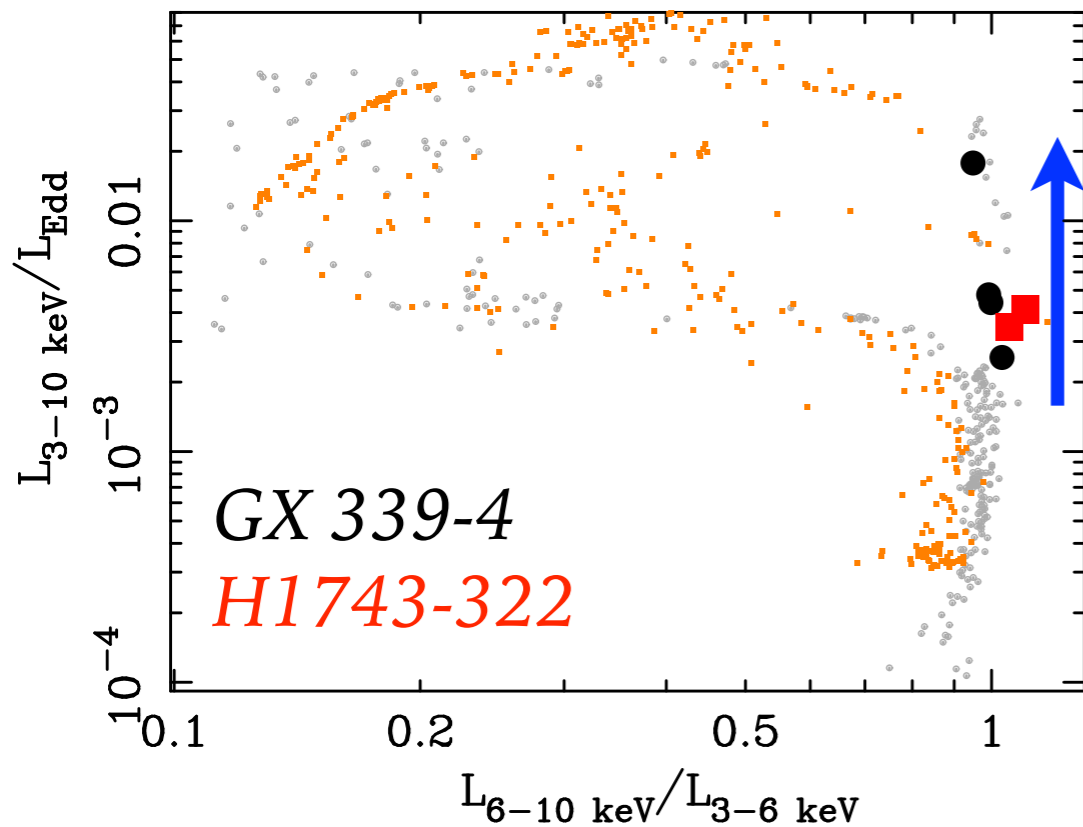


The reverberation lag decreases as the source rises in luminosity through the hard state

Evolution of reverberation lag during outburst

Variations of lag amplitude as a function of luminosity in the hard state

[De Marco + '15; De Marco & Ponti '16]



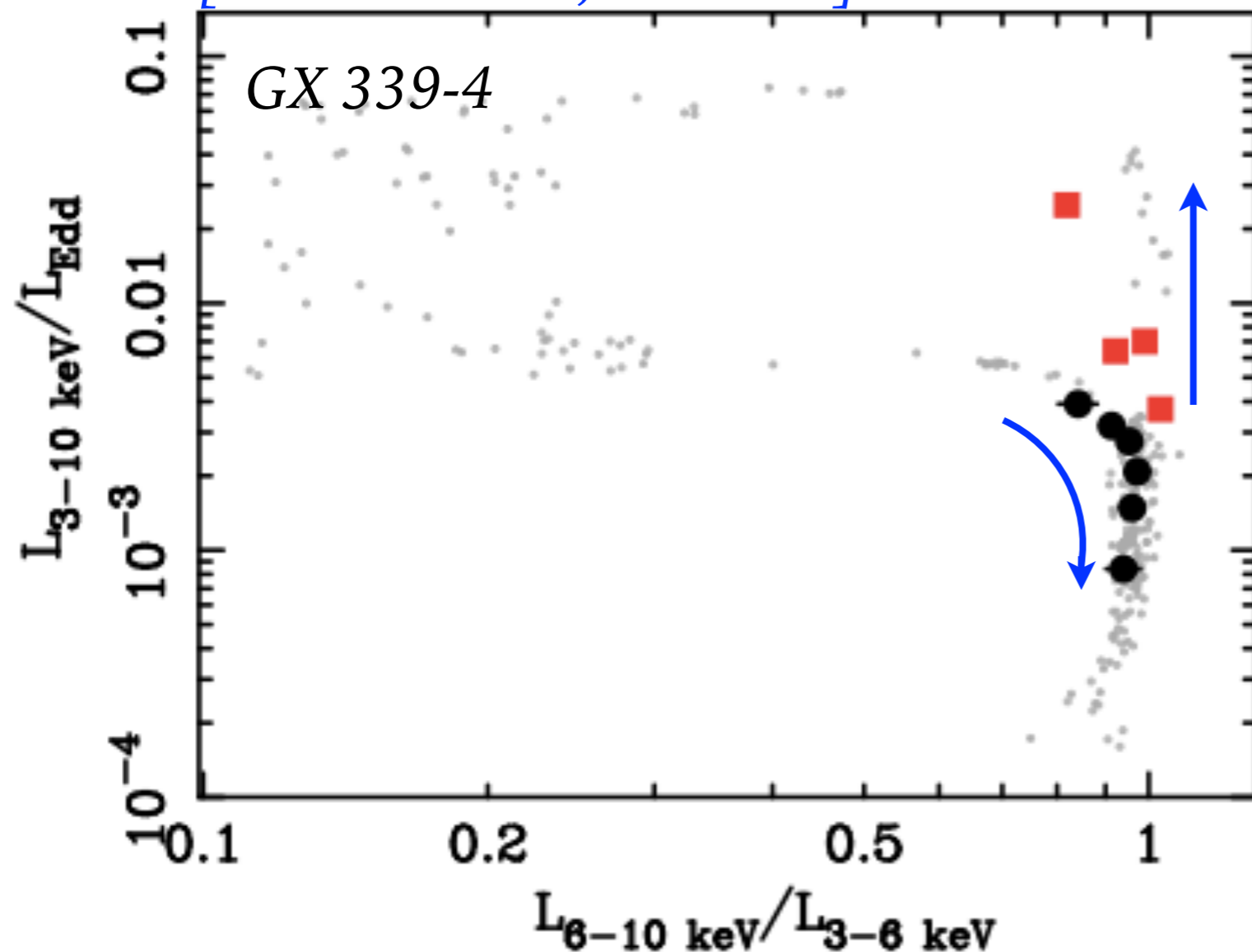
The reverberation lag decreases as the source rises in luminosity through the hard state

Decreasing distance of primary X ray-to-disc reprocessing sites

Aim: mapping the reverberation lag during an entire outburst

End of soft-to-hard state transition and return to quiescence

[De Marco + '17, submitted]



RXTE 2009-2010

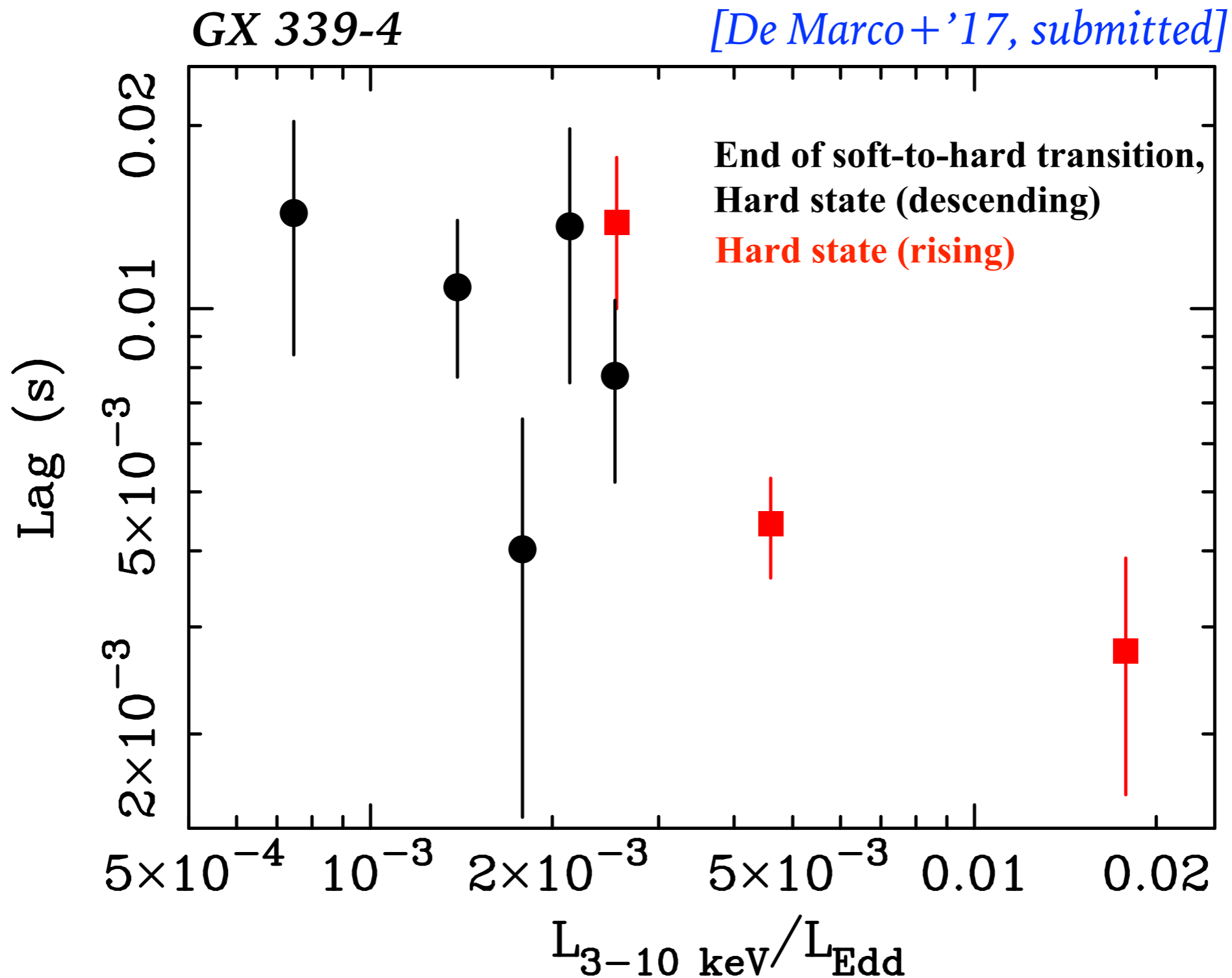
XMM archival

XMM 2015 monitoring

[See Petrucci's poster E03]

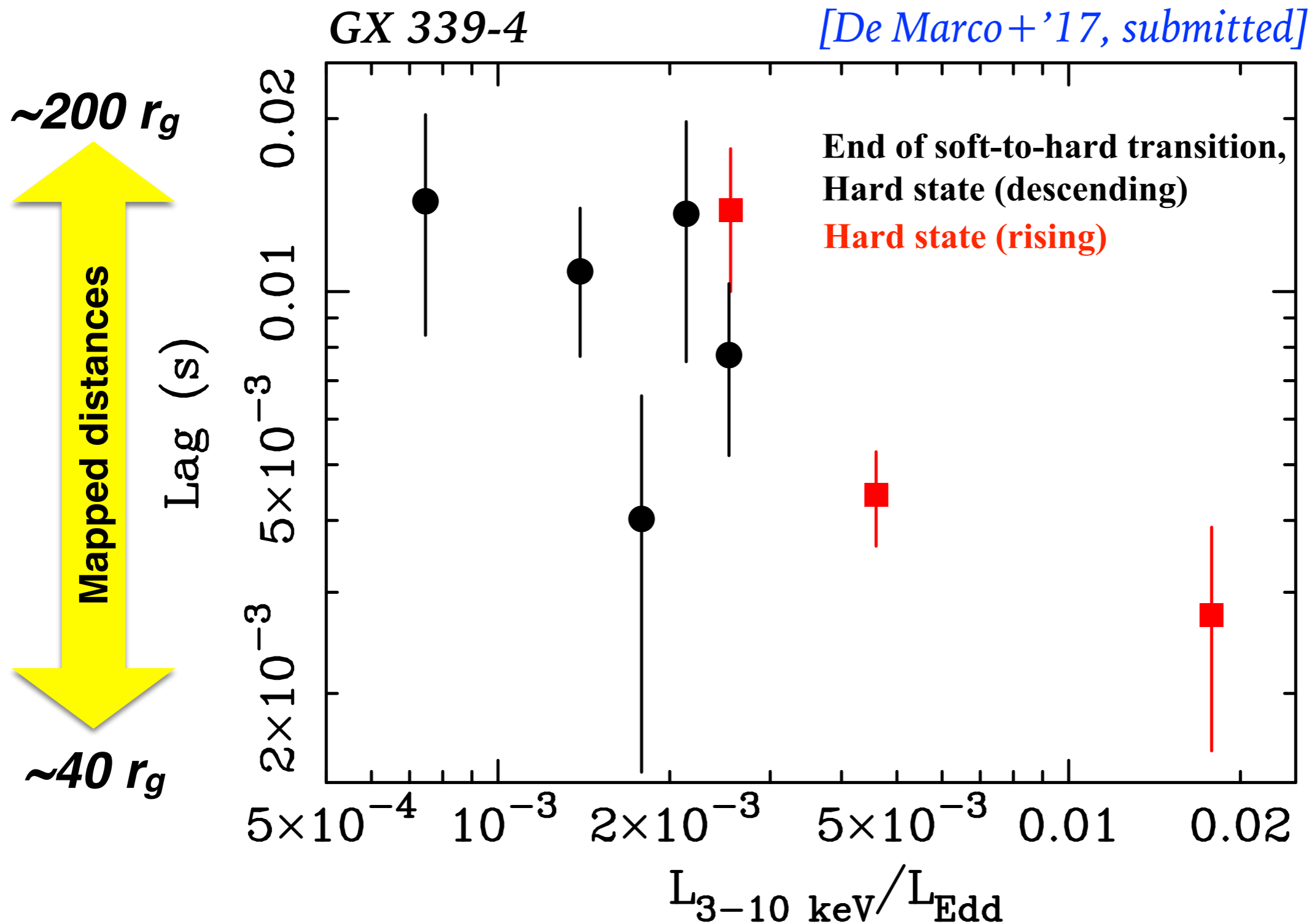
Aim: mapping the reverberation lag during an entire outburst

Overall results



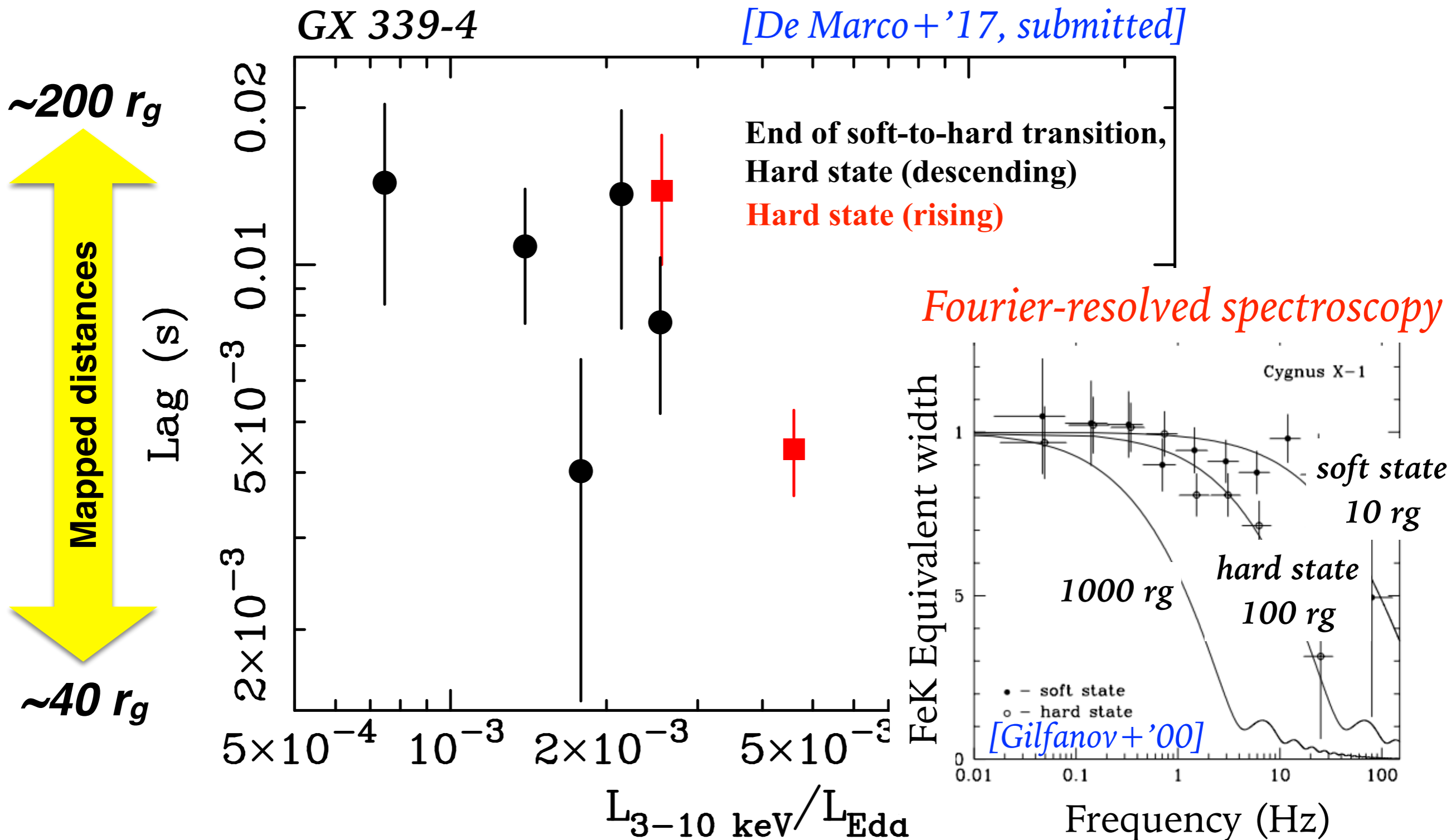
Aim: mapping the reverberation lag during an entire outburst

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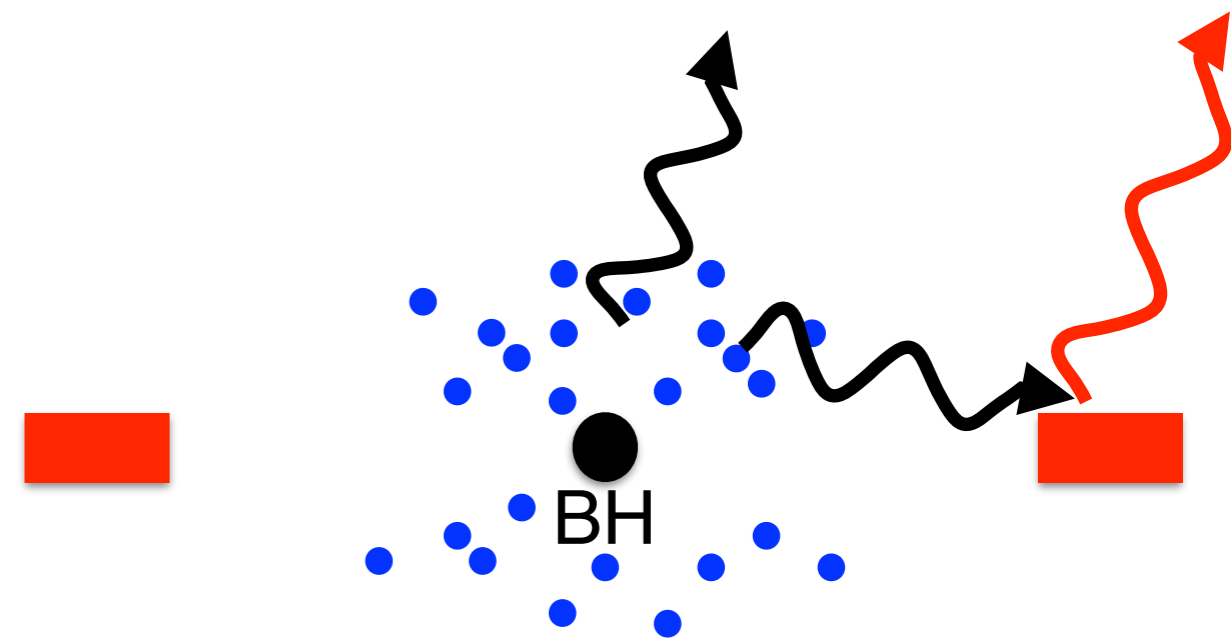
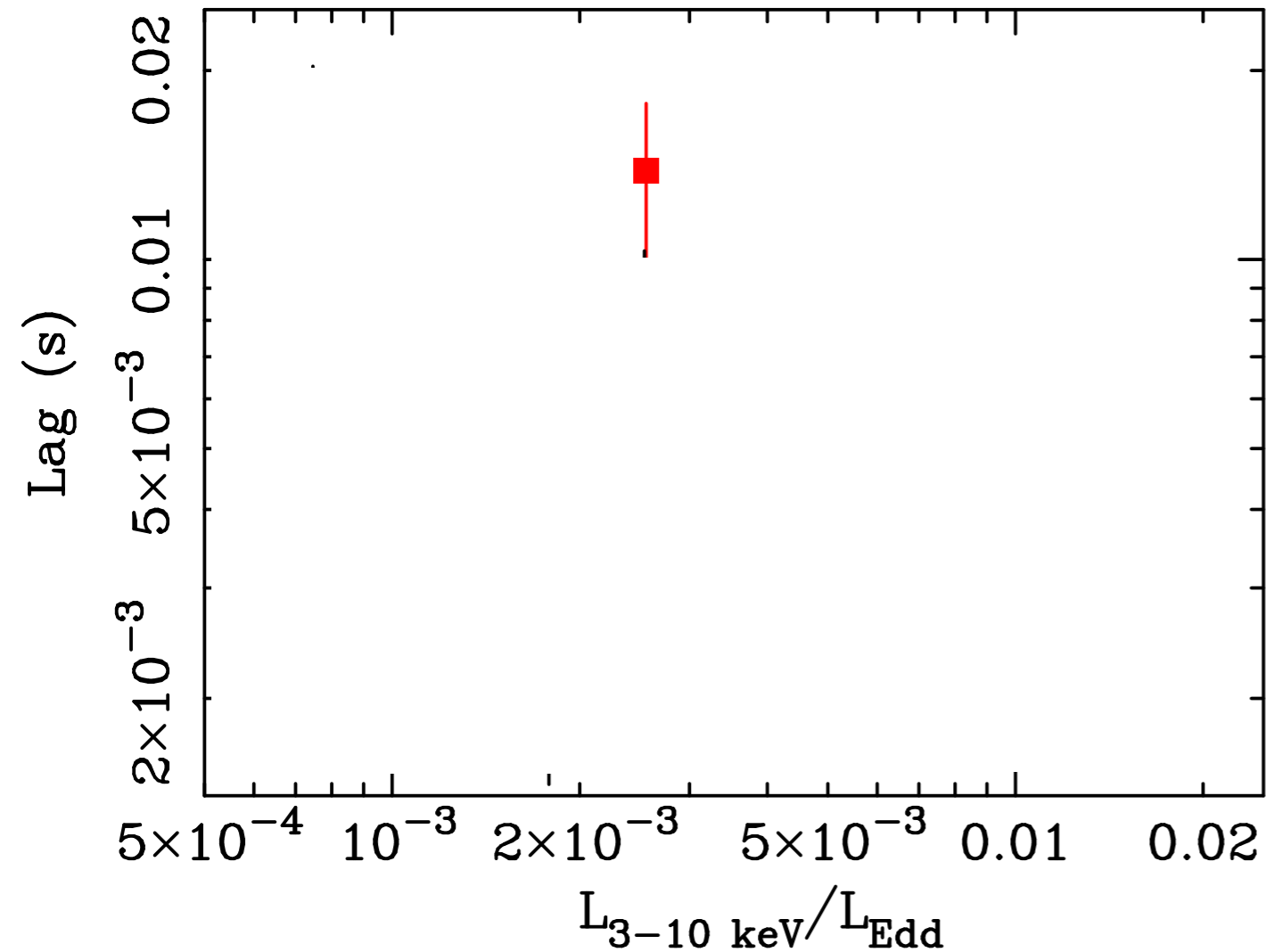


Mapping the reverberation lag during outburst

Evidences of evolving disc geometry throughout hard/hard-intermediate states

[De Marco + '17, submitted]

GX 339-4

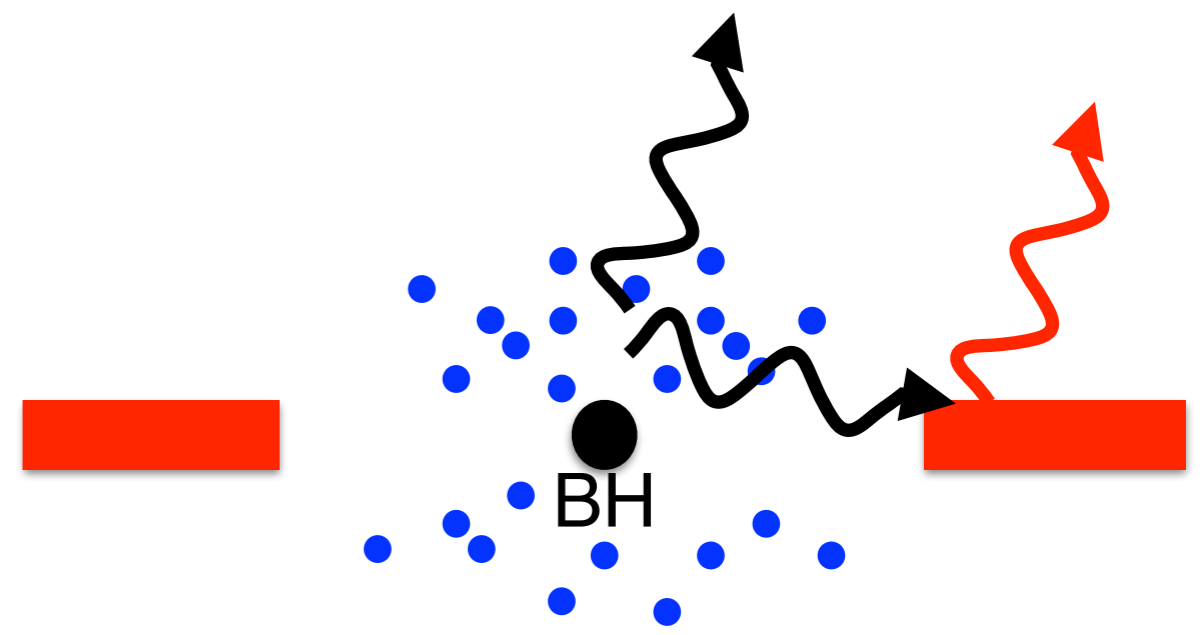
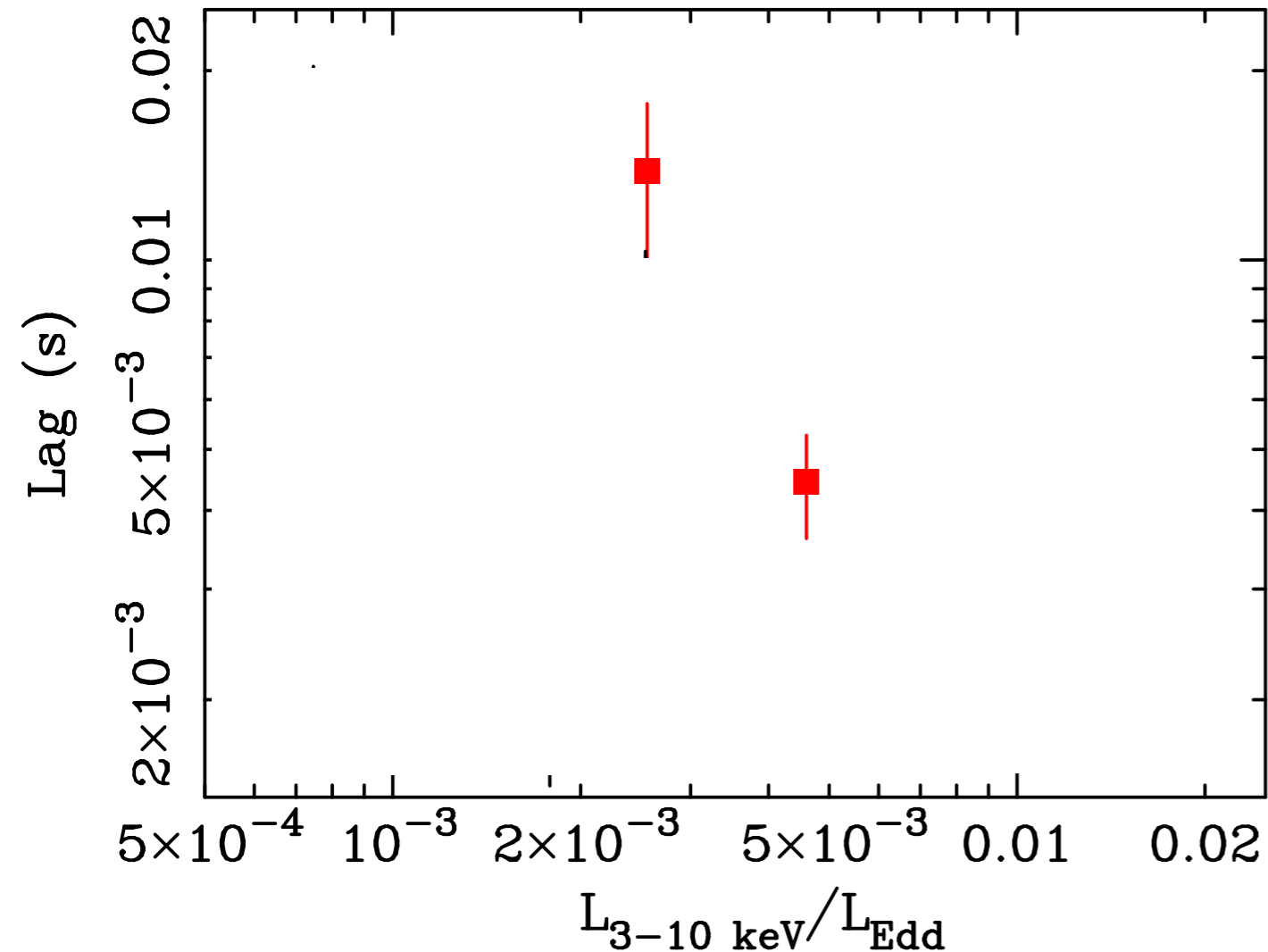


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GX 339-4



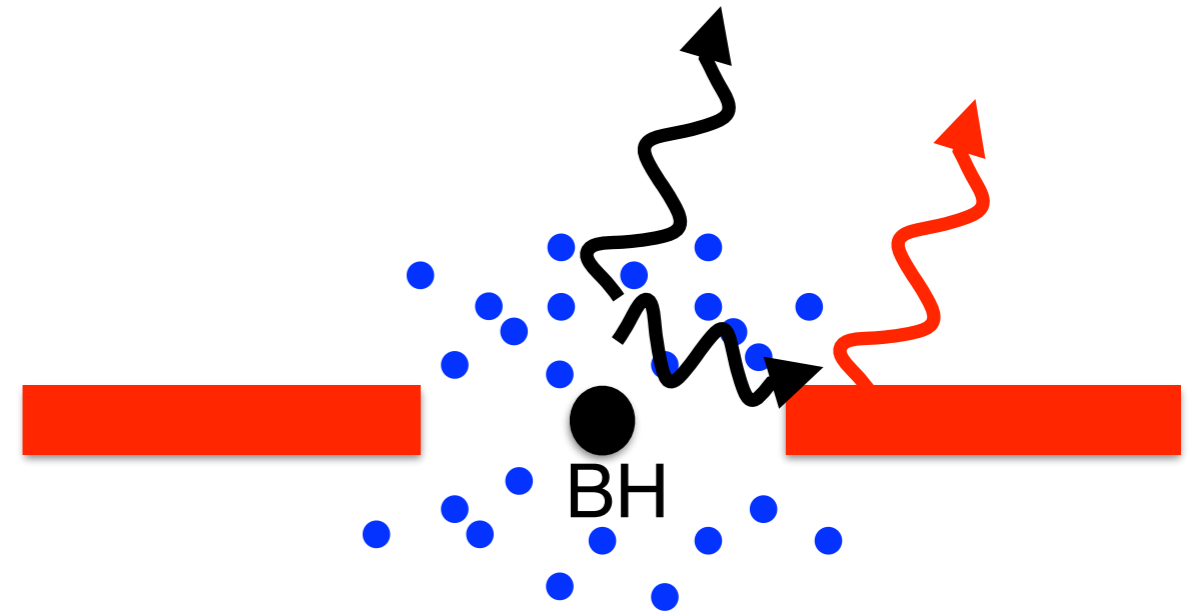
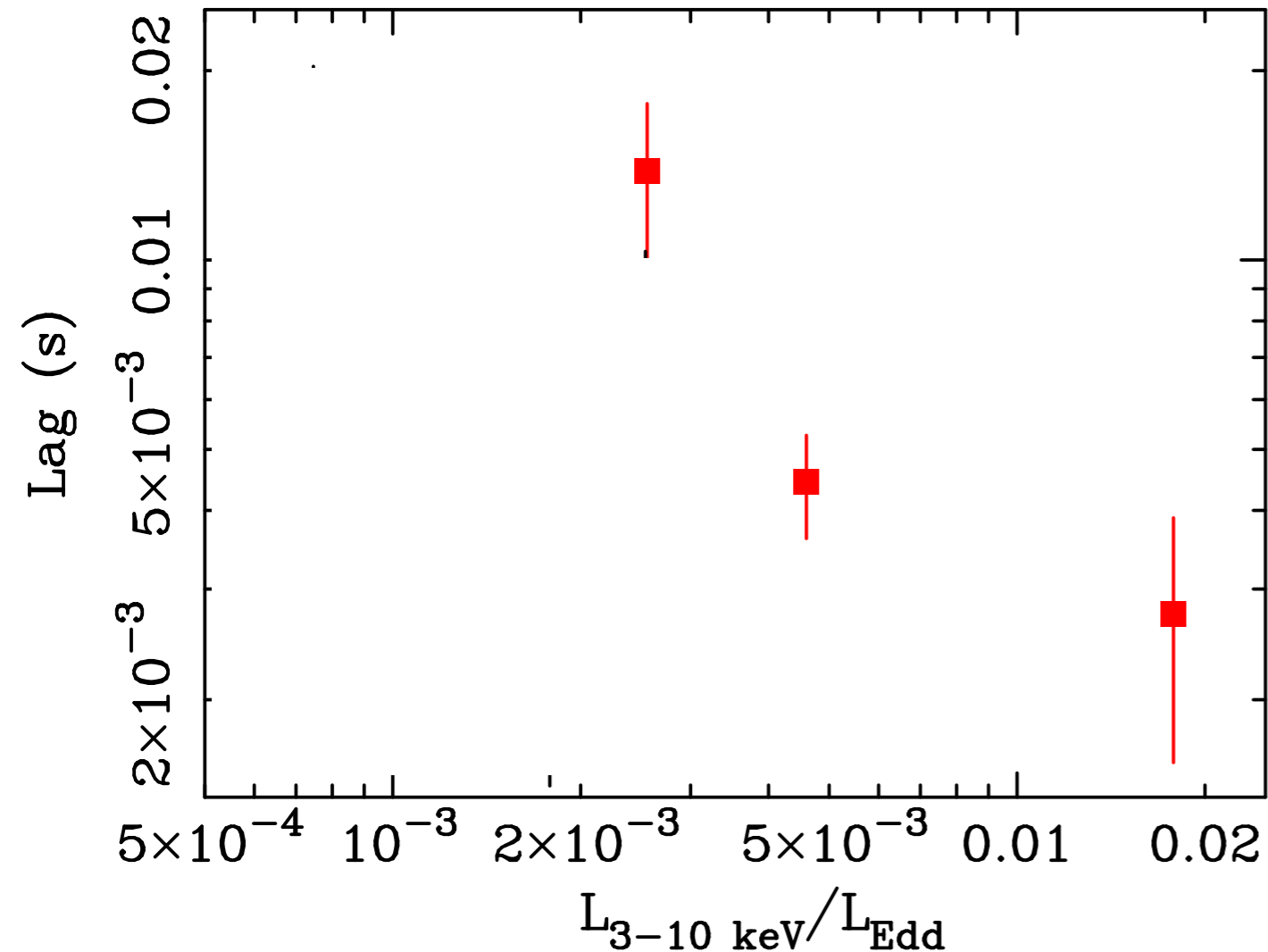
1. Hard state (rising) \rightarrow disc truncation radius moving in

Mapping the reverberation lag during outburst

Evidences of evolving disc geometry throughout hard/hard-intermediate states

[De Marco + '17, submitted]

GX 339-4



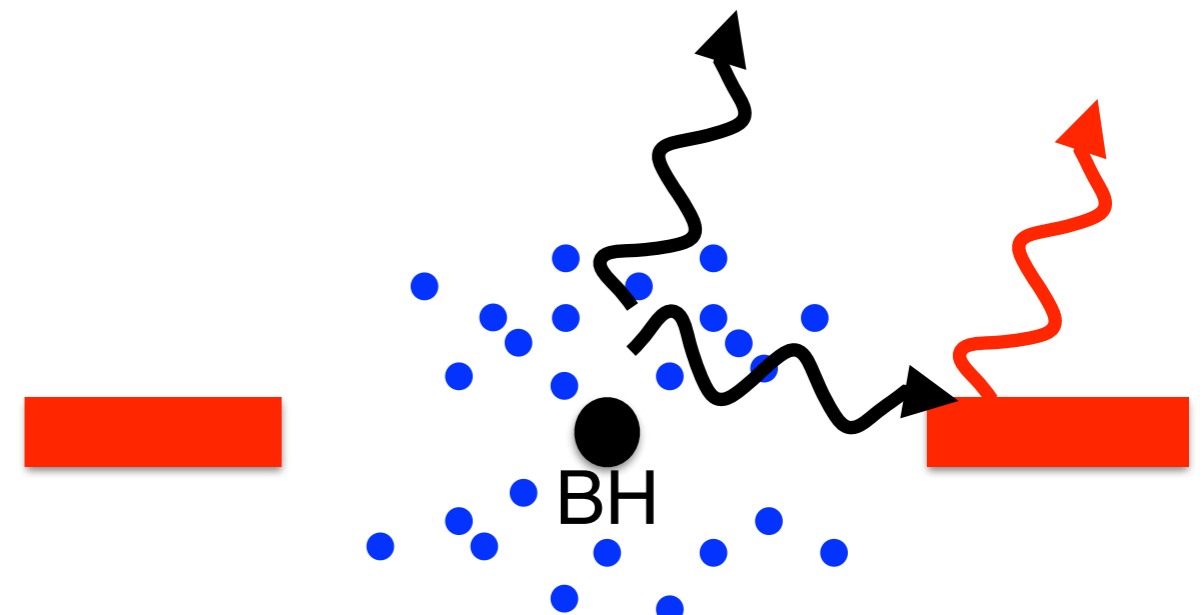
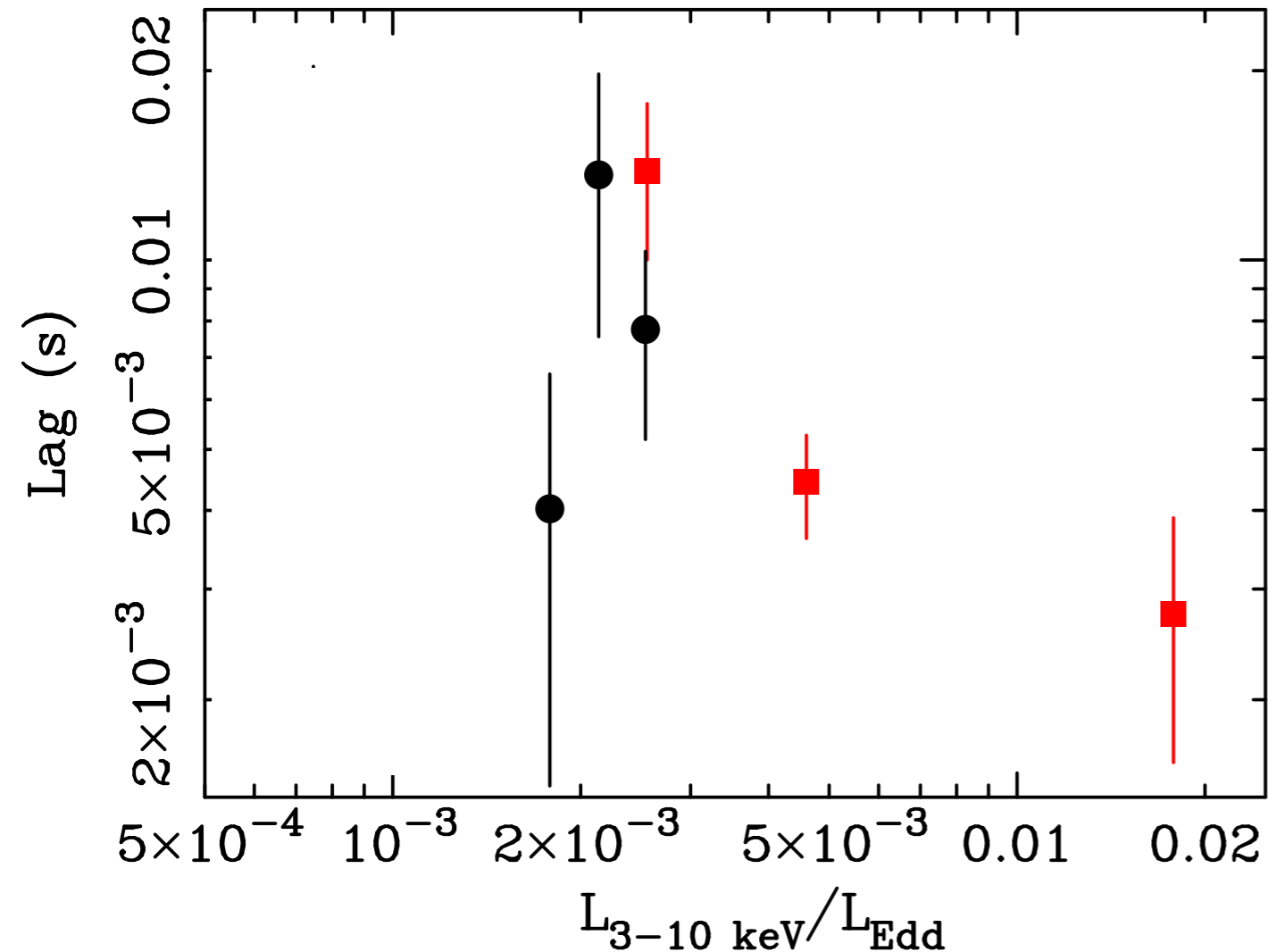
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GX 339-4



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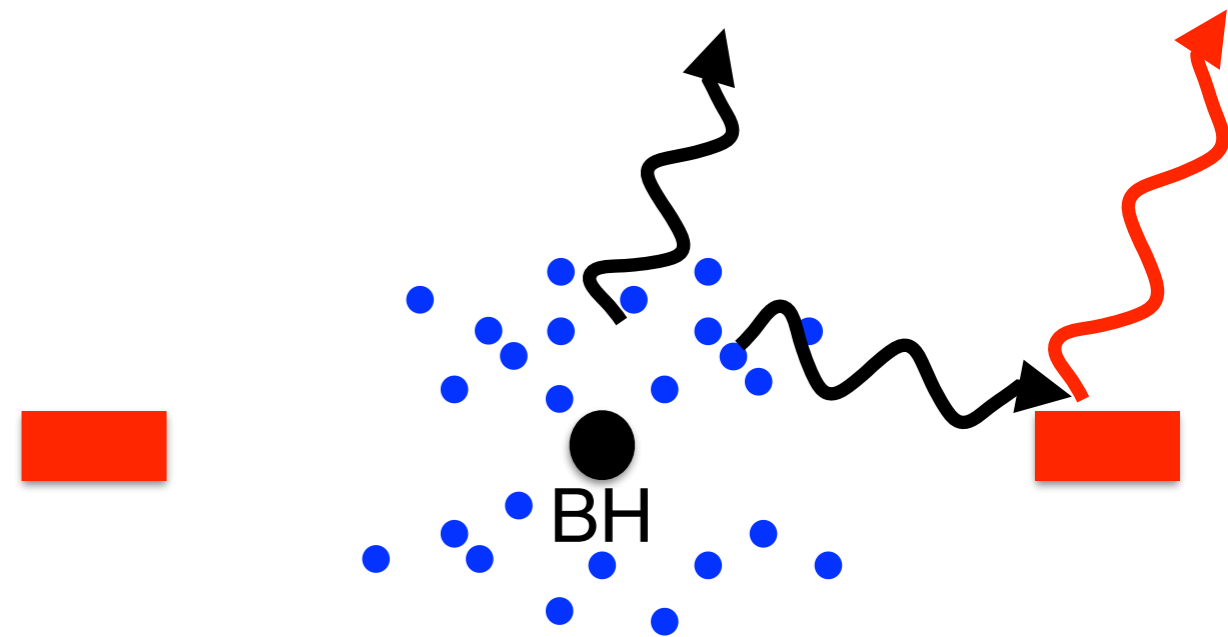
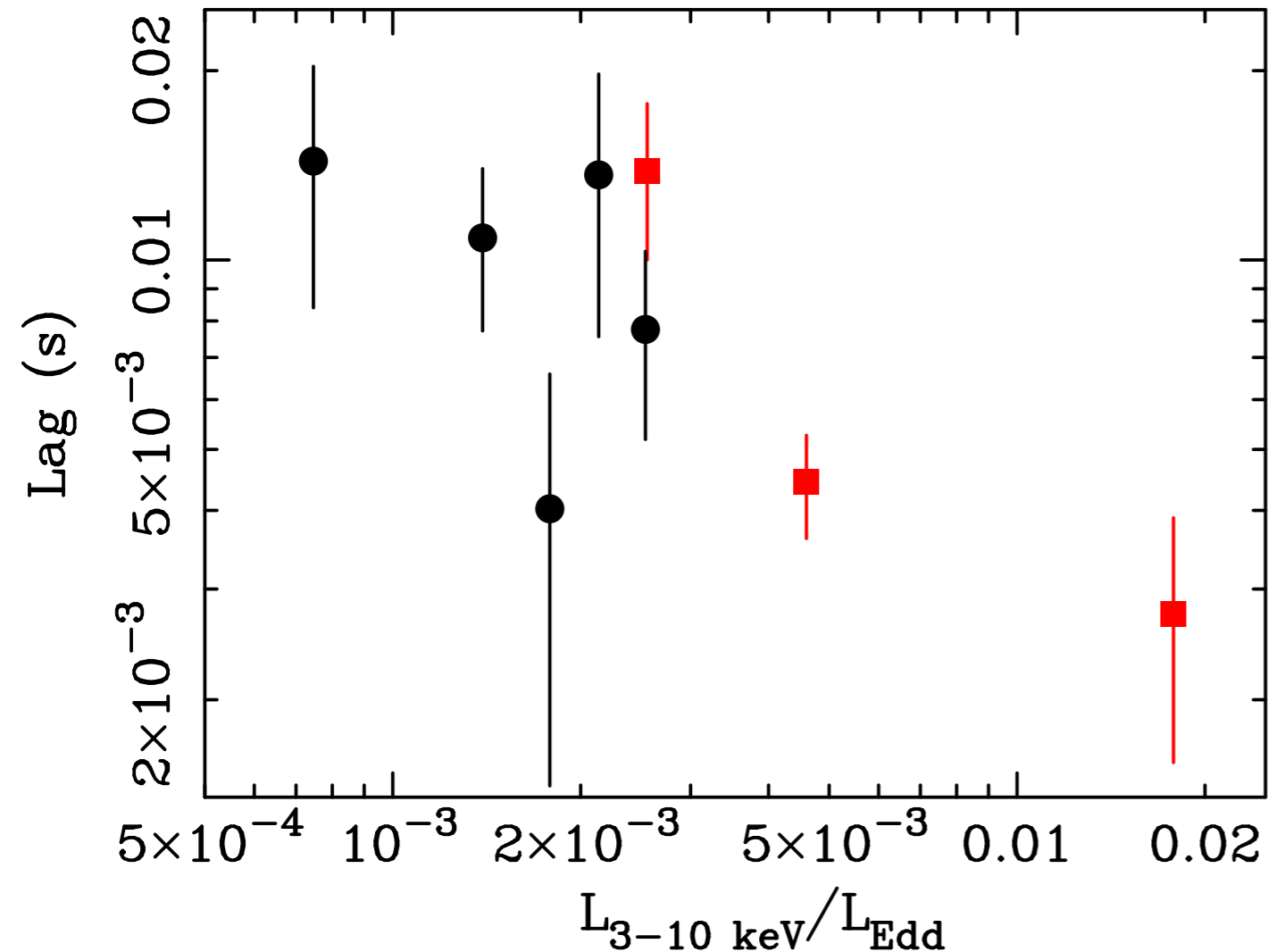
2. *End of soft-to-hard transition → disc highly truncated*

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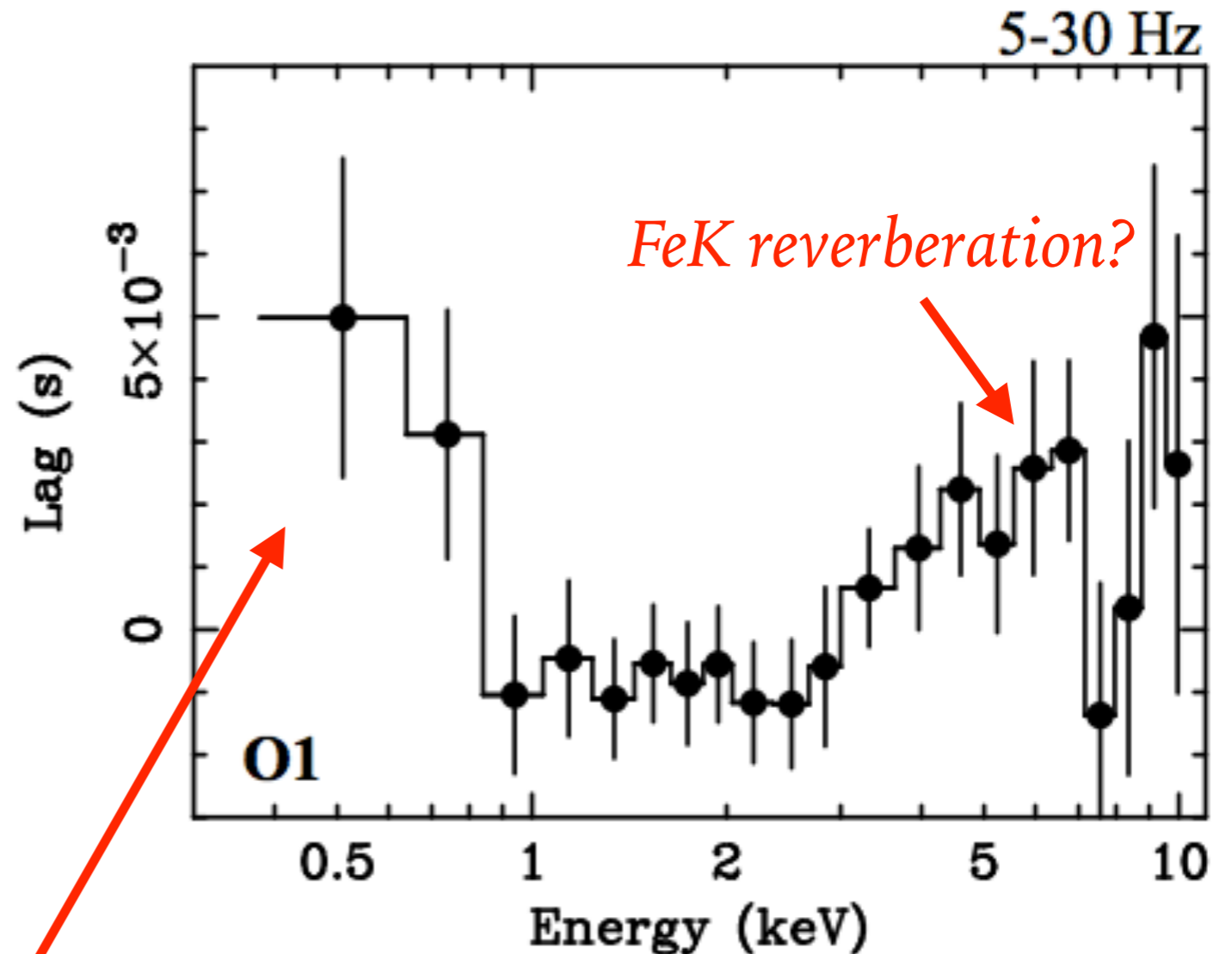
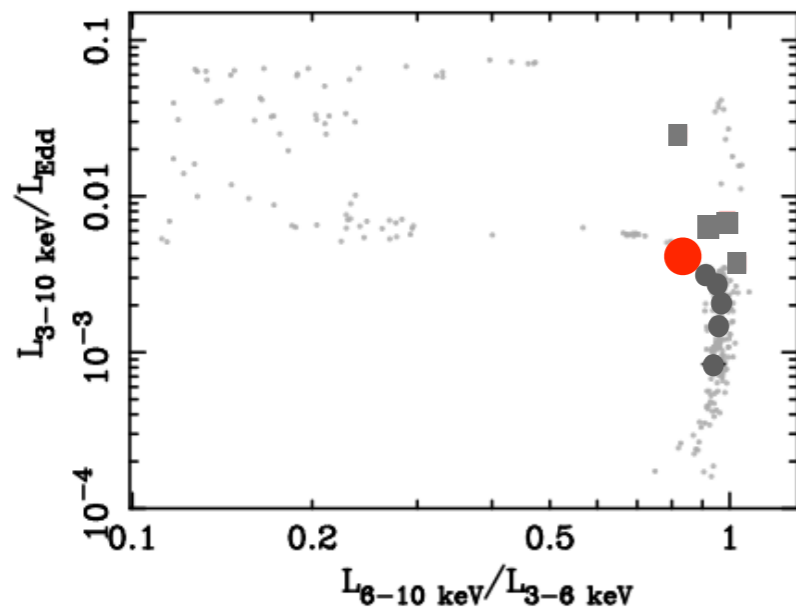
GX 339-4



1. *Hard state (rising) → disc truncation radius moving in*
2. *End of soft-to-hard transition → disc highly truncated*
3. *Hard state (descending) → disc truncation radius receding*

FeK reverberation?

Prominent feature at FeK energy in lag-energy spectra



Disc thermal reverberation

[De Marco + '17, submitted]

Thermal and FeK lag consistent with reprocessing occurring in the same region of the disc

Conclusions

- 1. Motivations: *Why constraining disc geometry in BHXRBS?*
*Why using X-ray reverberation?***

Conclusions

1. **Motivations:** *Why constraining disc geometry in BHXRBSs?*

Why using X-ray reverberation?

✓ *Understand origin of observed phenomenology in BHXRBSs*

✓ *X-ray reverberation offers an independent method to constrain geometry*

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2. **Goal:** *How do X-ray reverberation lags evolve through different accretion states?*

- ✓ *During hard-intermediate/hard state reverberation lag maps distances ranging between ~ 40 - $200 r_g$*
- ✓ *Reverberation lag amplitude decreases as luminosity increases*
- ✓ *Possible detection of FeK reverberation*

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3. Conclusions: *What do observations of X-ray reverberation in BHXRBs tell us?*

- ✓ Variations of inner flow geometry characterize hard/hard-intermediate states
- ✓ Results consistent with a truncated and evolving accretion disc

Thanks!