X-ray reverberation in accreting black hole systems

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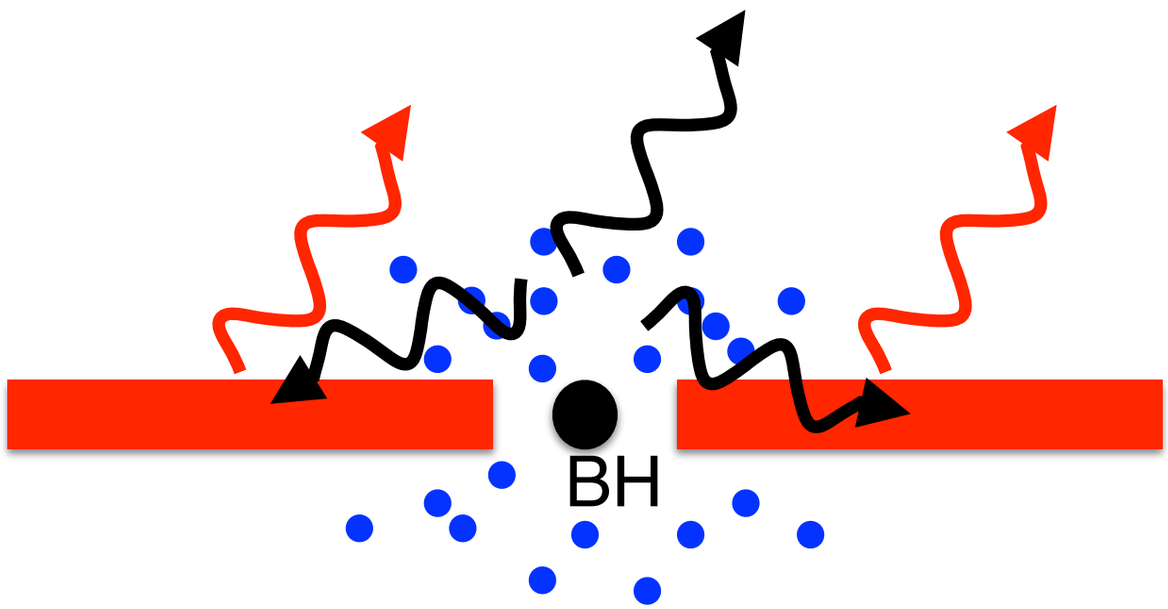
Focus of the talk

Observations of X-ray reverberation

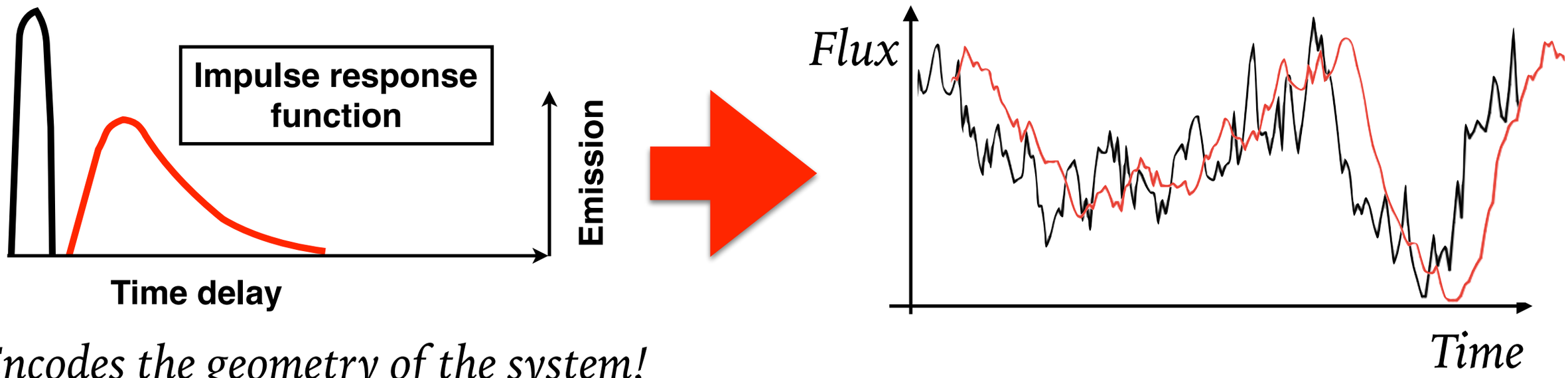
Current models

Probing disc geometry: X-ray reverberation

Independent method to constrain geometry of the inner accretion flow



Reprocessed emission time-delayed due to additional light travel time

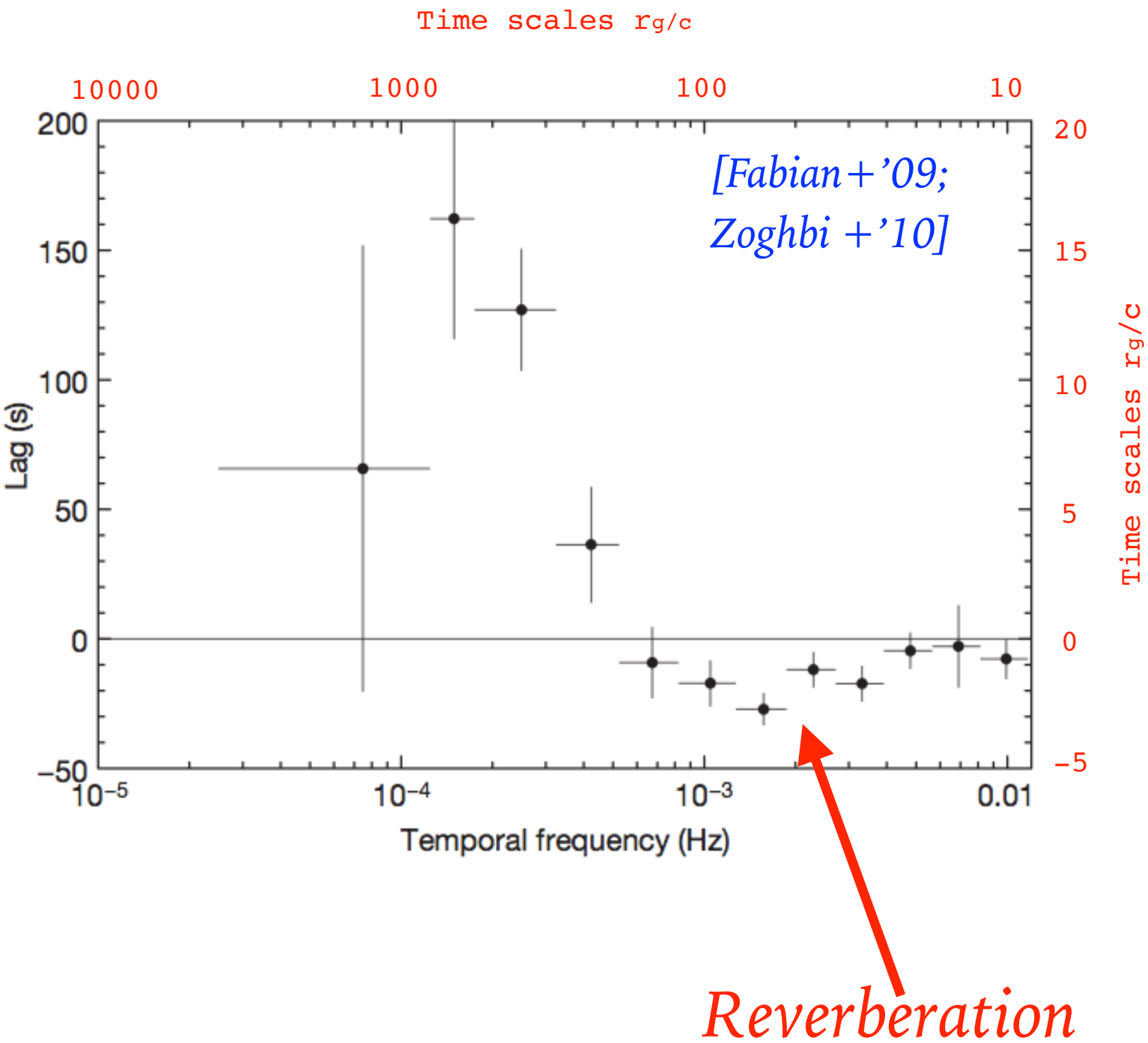


Encodes the geometry of the system!

[e.g. Blandford & McKee '82; Stella '90; Campana & Stella '95; Reynolds +'99; Young & Reynolds '00; Poutanen '02; Fabian+'09; Zoghbi+'11; Kara+13; Uttley+'14]

X-ray reverberation in AGN: 1H0707-495

Reprocessed soft X-ray emission responding to hard X-ray illumination



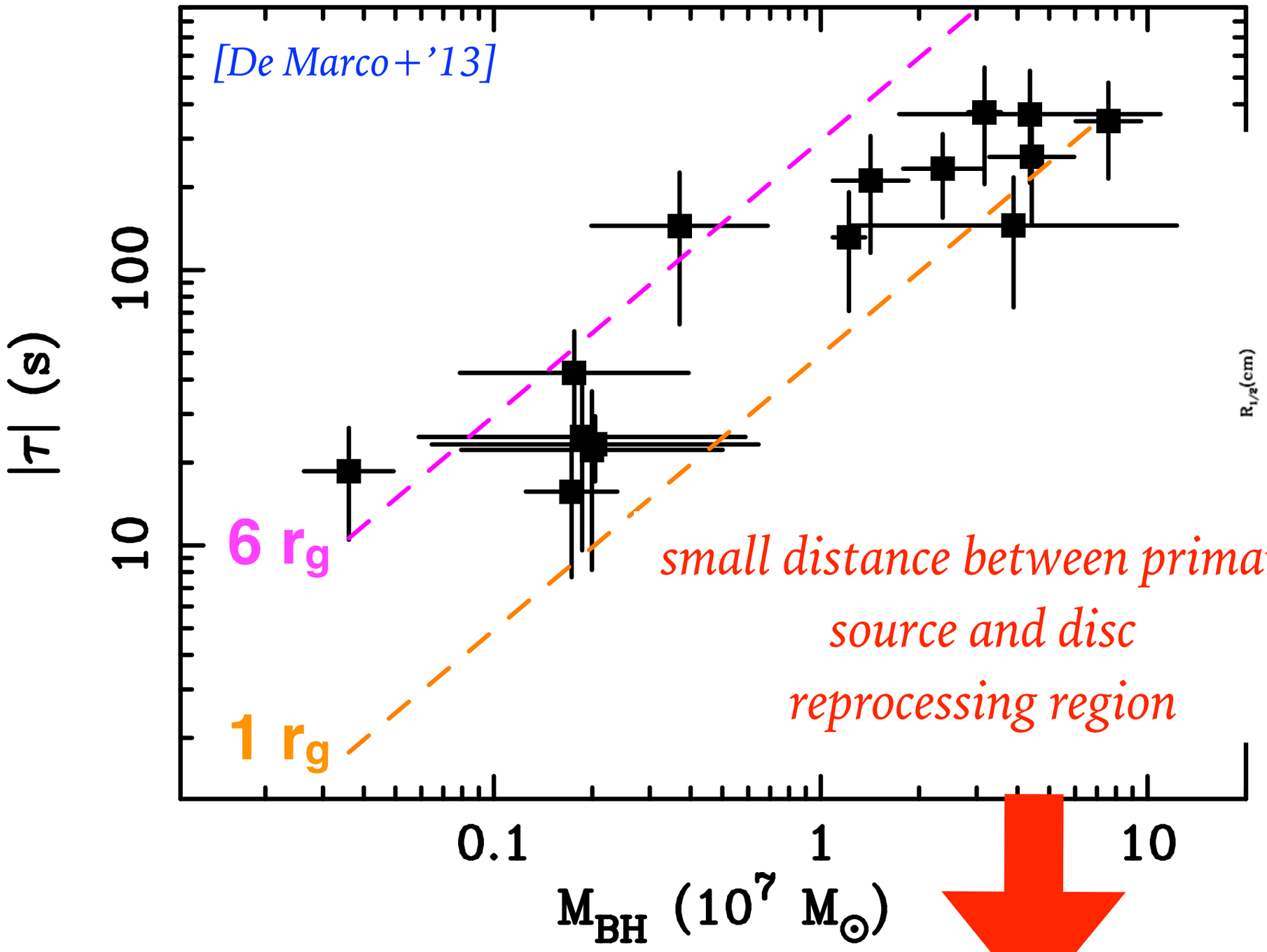
$t = r_g/c = GM/c^3$

The time scales imply short distances and compact reprocessing regions

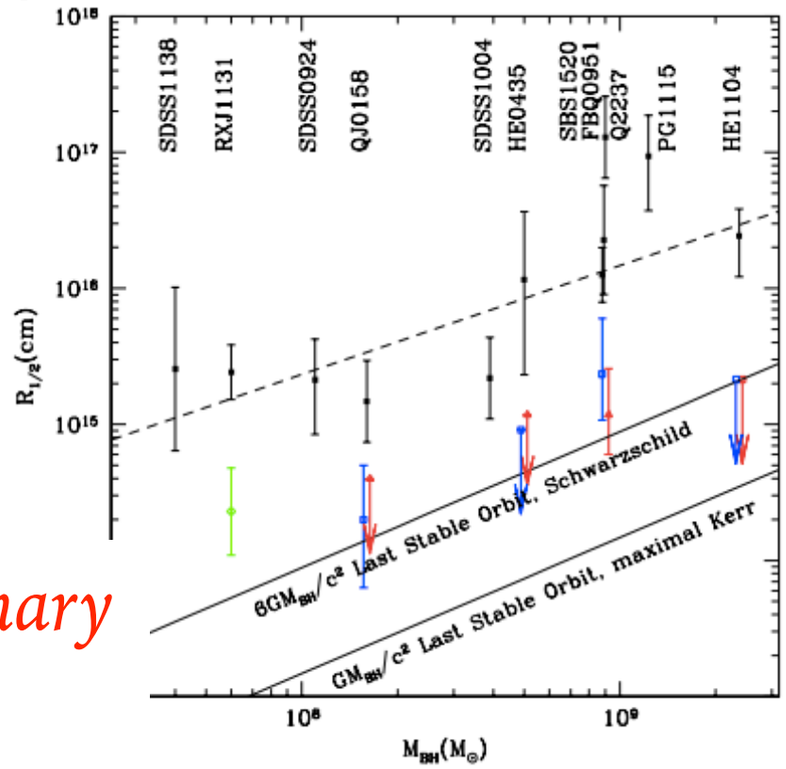
As expected from disc reverberation!

Soft X-ray reverberation lag in AGN

Lag correlates with BH mass



small distance between primary source and disc reprocessing region



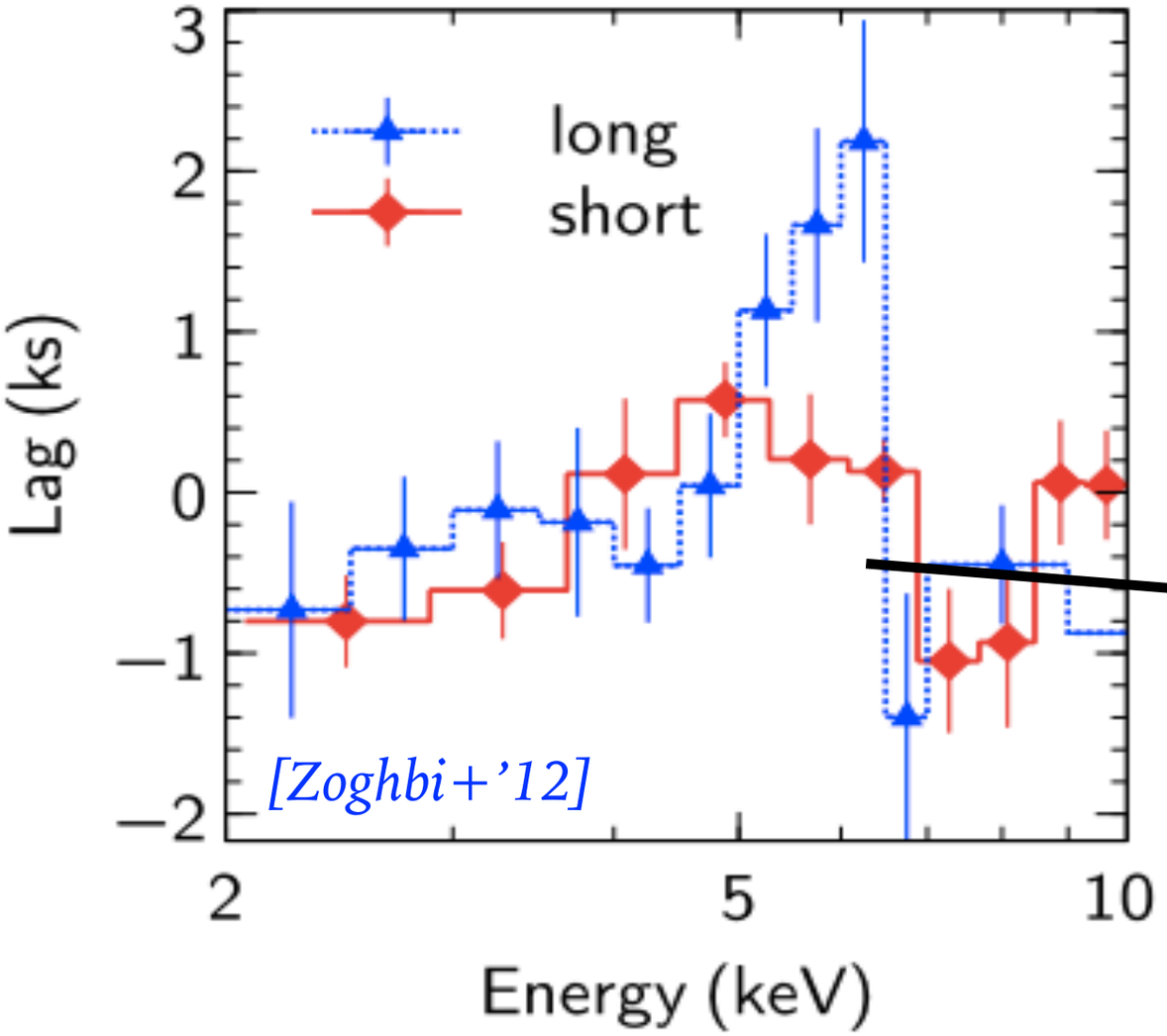
Consistent with microlensing results

[e.g. Morgan+'10; Mosquera+'13]

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

Fe K reverberation lag in AGN

Self consistency of inner disc reverberation interpretation



Redshifted, broad component shows shorter lags and responds to short time scale X-ray flux variability

[e.g. Zoghbi+'12; '13; '14; Kara +'13a; '13b; '14; '16]

Fe K reverberation lag in AGN

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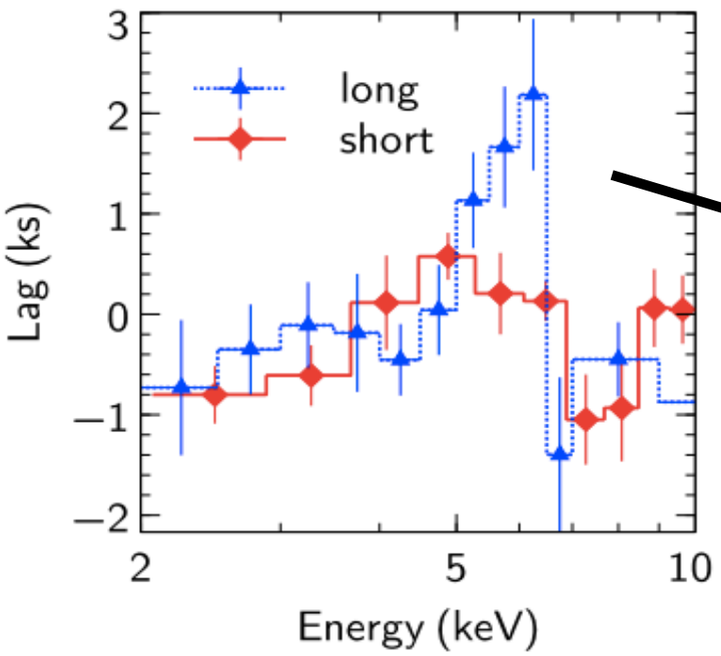
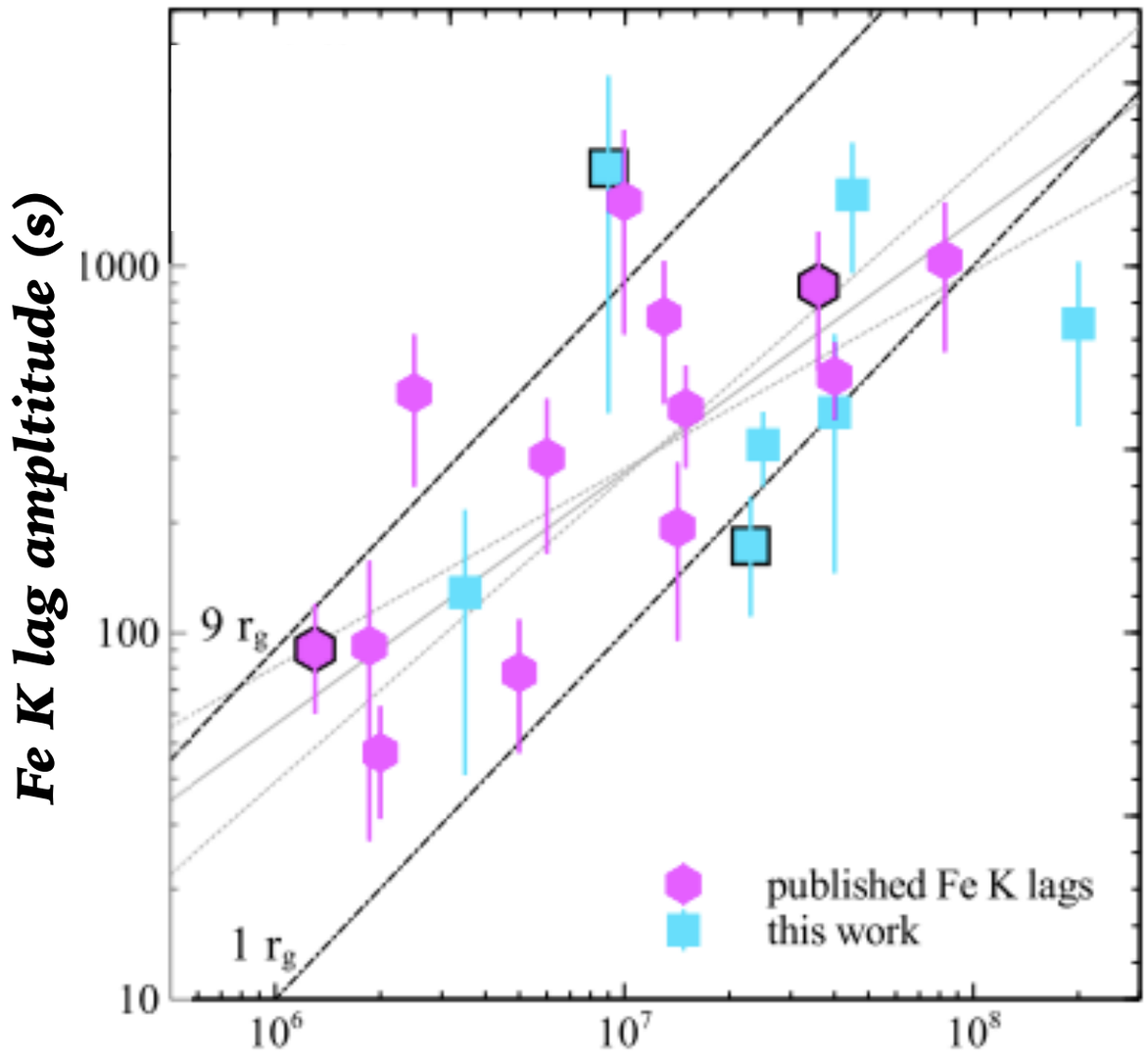


[Zoghbi+'12]



Soft and reflection component produced in the same regions of the disc

Distances consistent with constraints from soft lags

[e.g. Zoghbi+'12; '13; '14; Kara +'13a; '13b; '14; '16]

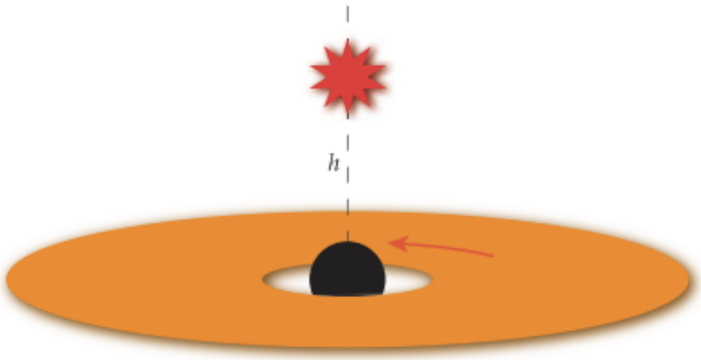
Modeling X-ray reverberation

To infer the intrinsic lag amplitude

To properly account for effects due to, e.g. dilution, ionization, reflection fraction

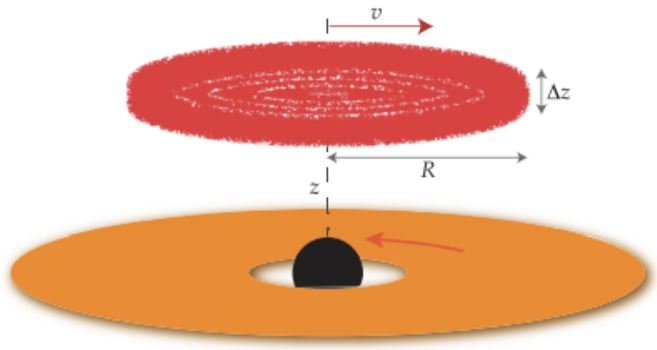
[figures from Wilkins+'16]

lamp-post



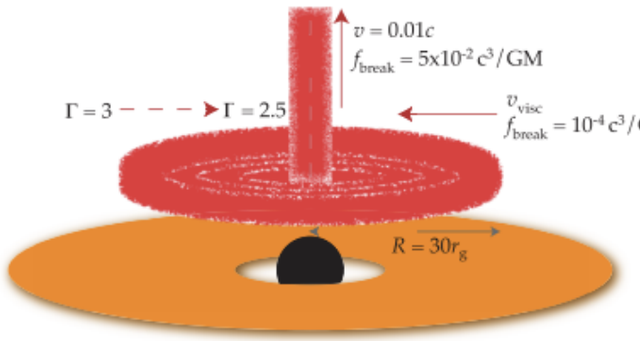
[Cackett+'14; Dovciak+'14; Emmanoulopoulus+'14; Epitropakis+'16; Chainakun+'16]

extended



[Wilkins & Fabian '13; Chainakun & Young '17]

composite

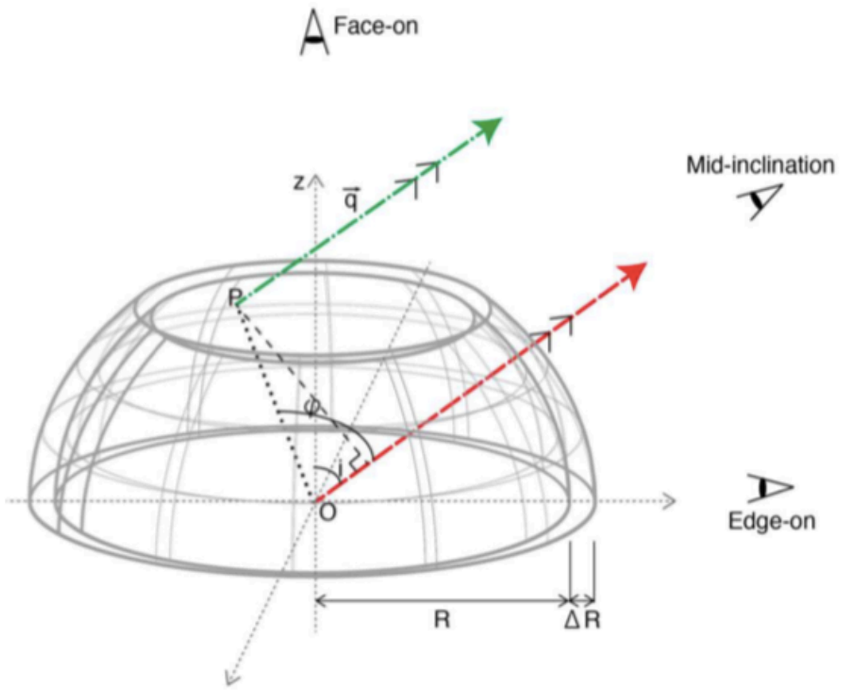


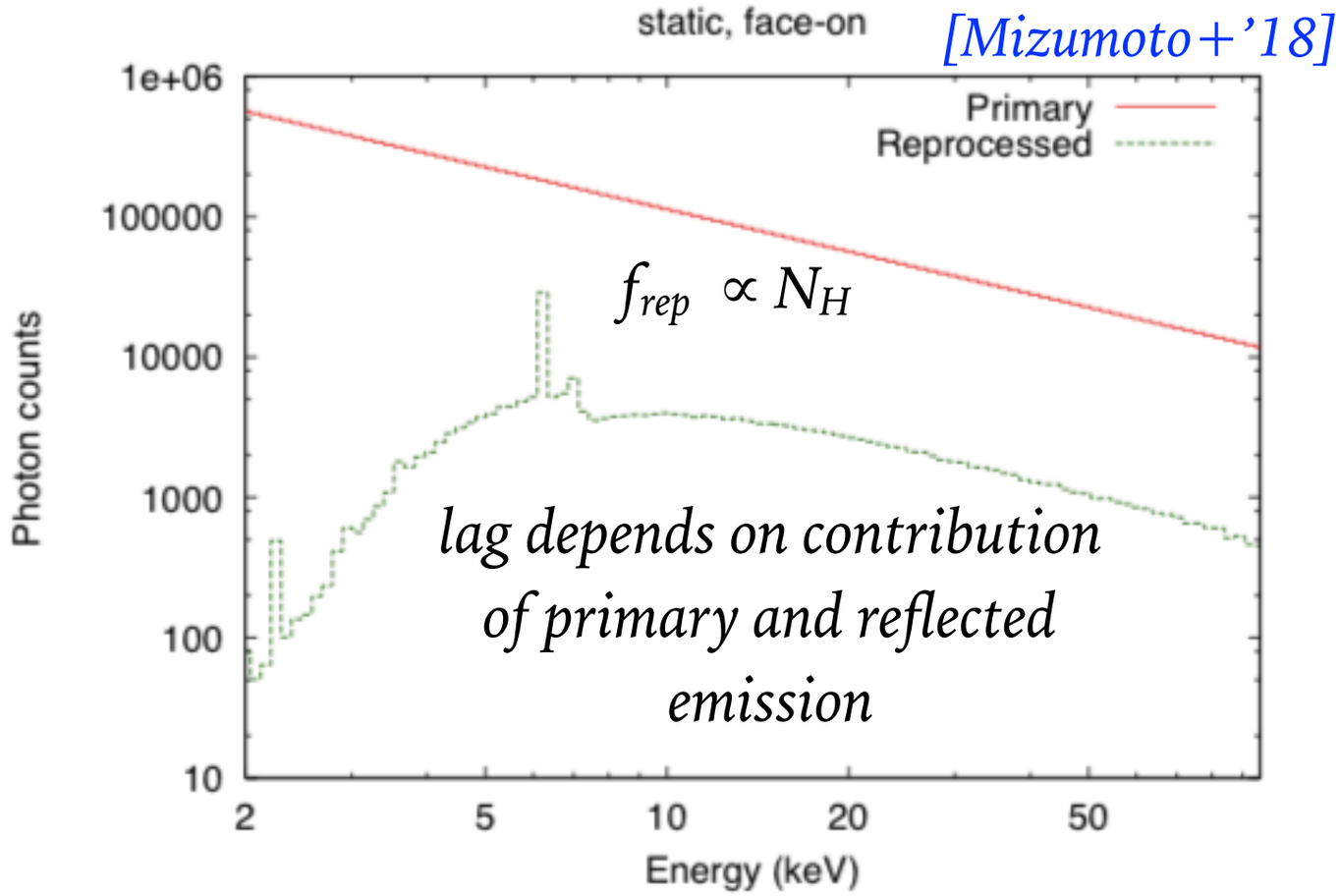
[Wilkins+'16]

Derived disk-corona distances within ~10 r_g (consistent with raw estimates)

Any contribution from winds?

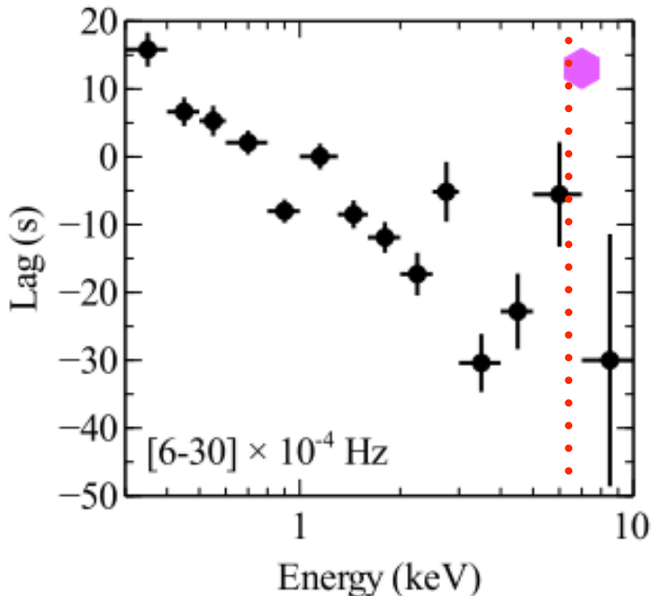
Diluted reflection from distant material produces small lags





[Mizumoto+'18]

To produce enough reprocessed fraction $N_H \sim 10^{23}$ cm^{-2} → *Much longer lags in the soft band*



[see also Miller+'10; Turner+'17]

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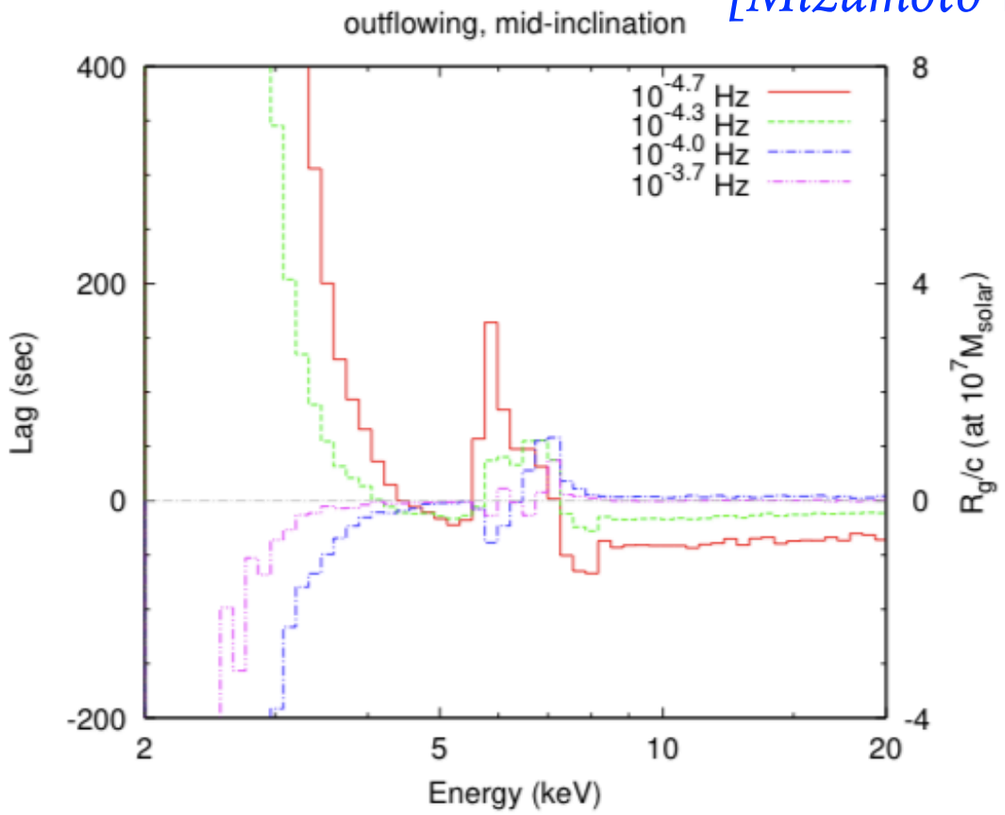

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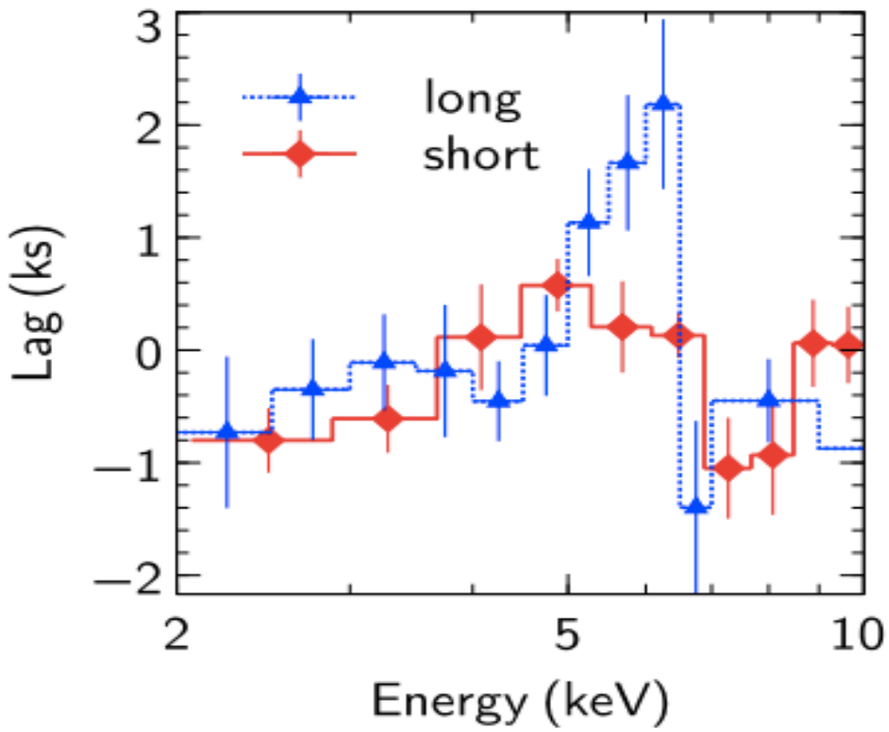

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Long time scales, more redshifted features → *Opposite observed in one source*

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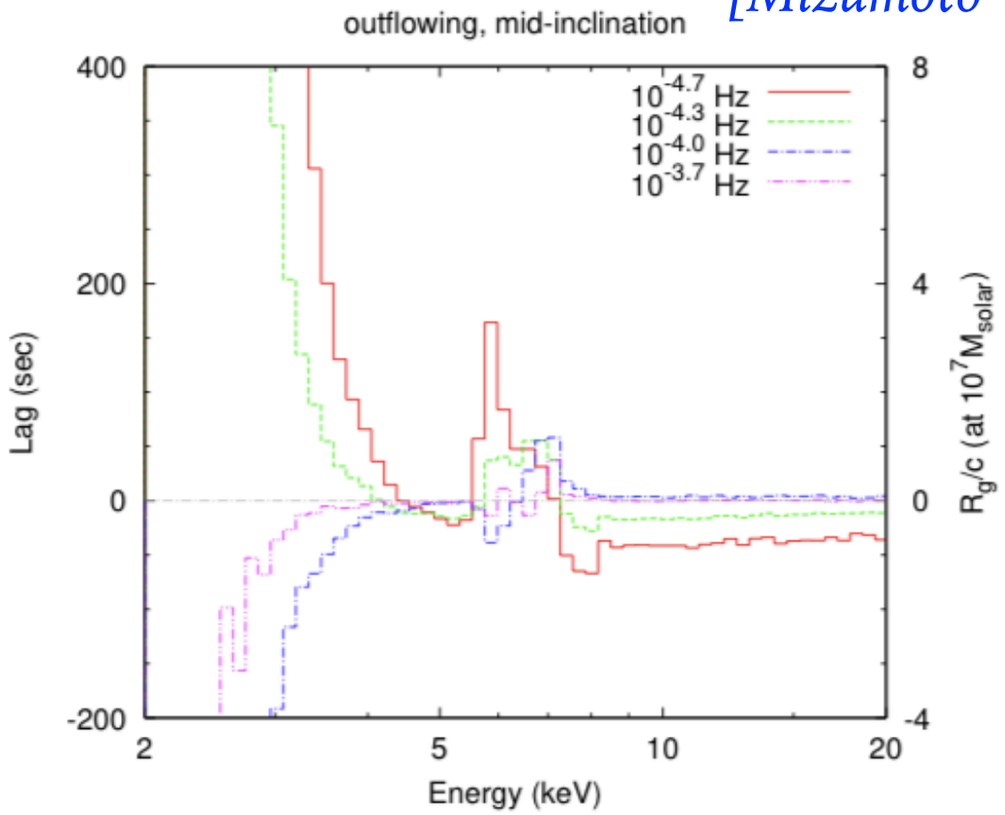

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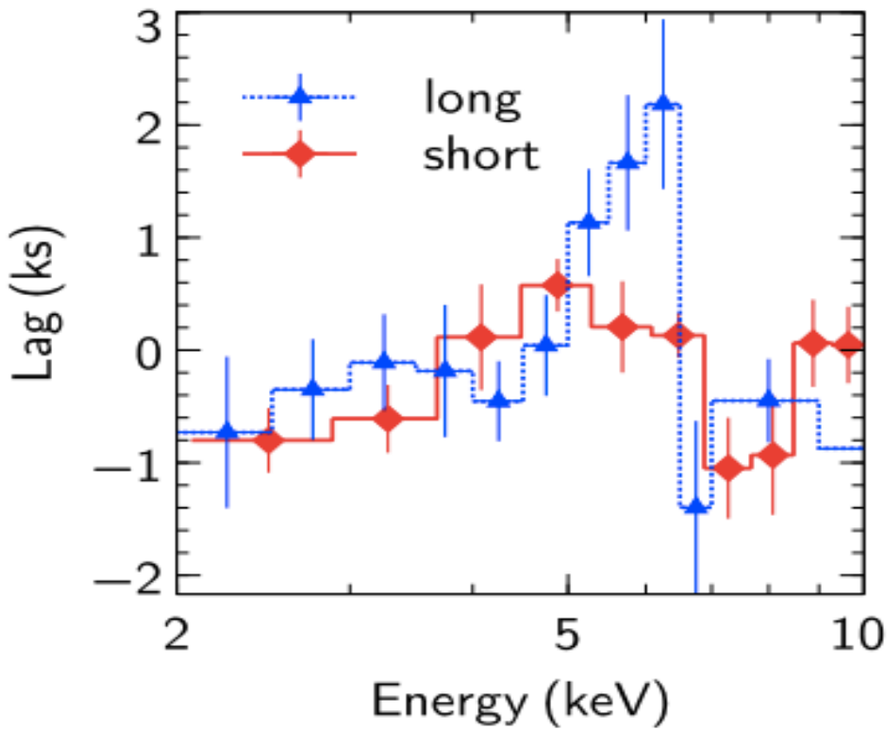

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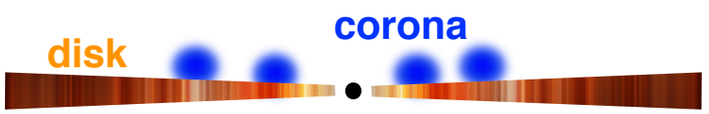
In 1H0707 inferred upper limit on the size scale is $\sim 14 r_g$ (launching radius of a super-Edd wind) → *Also this solution requires a close reflecting medium*

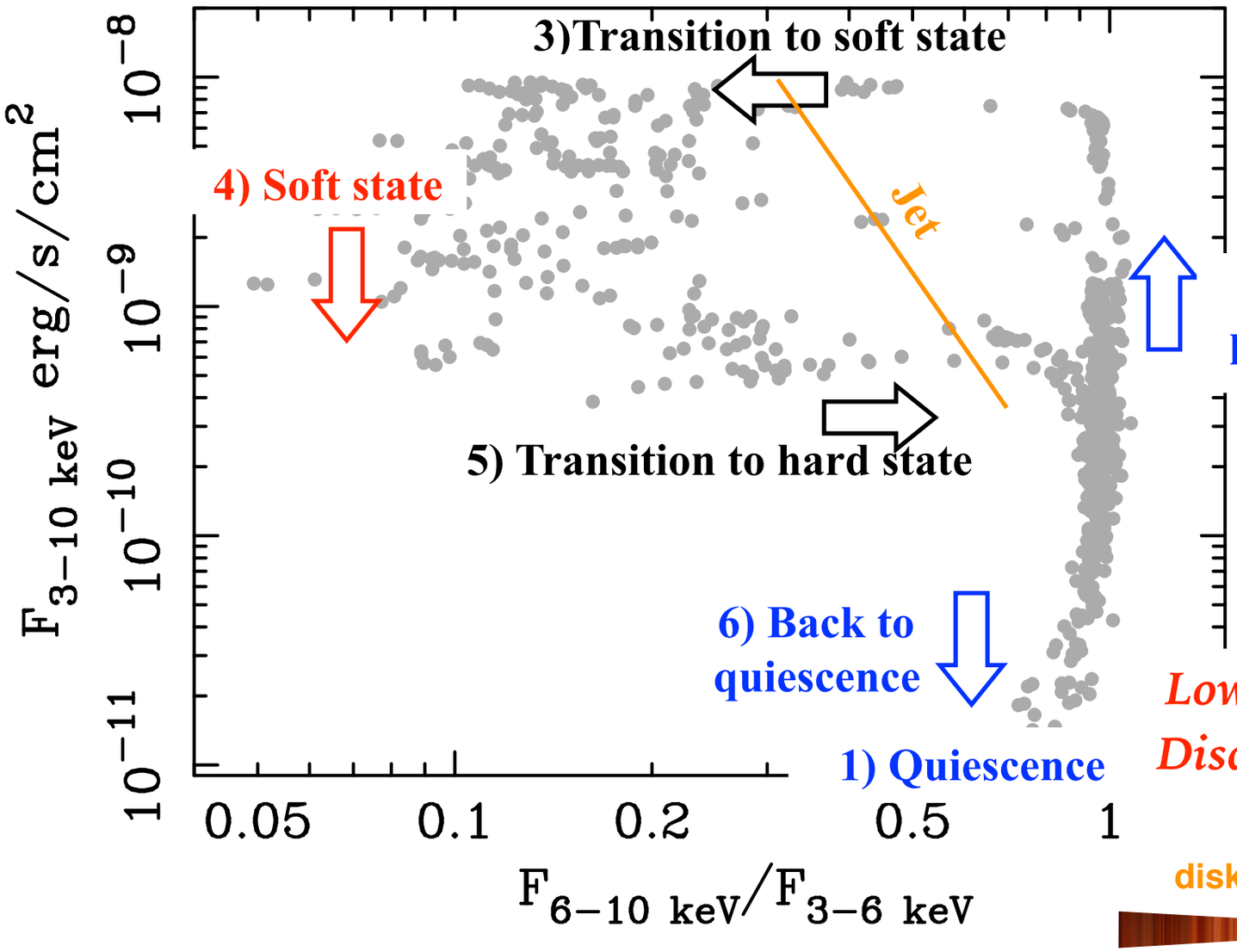
[see also Miller+'10; Turner+'17]

Accretion states in BHXRBs: variations of inner flow geometry?

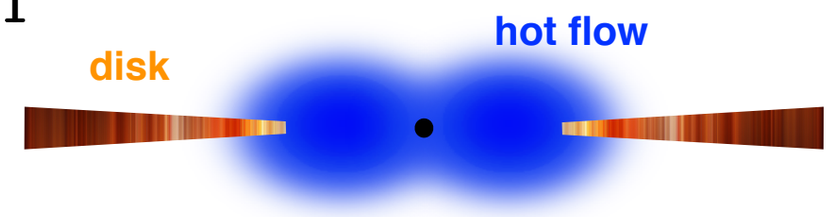
A plausible scenario to explain the outburst evolution of XRBs

Soft state: Disc close to ISCO





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



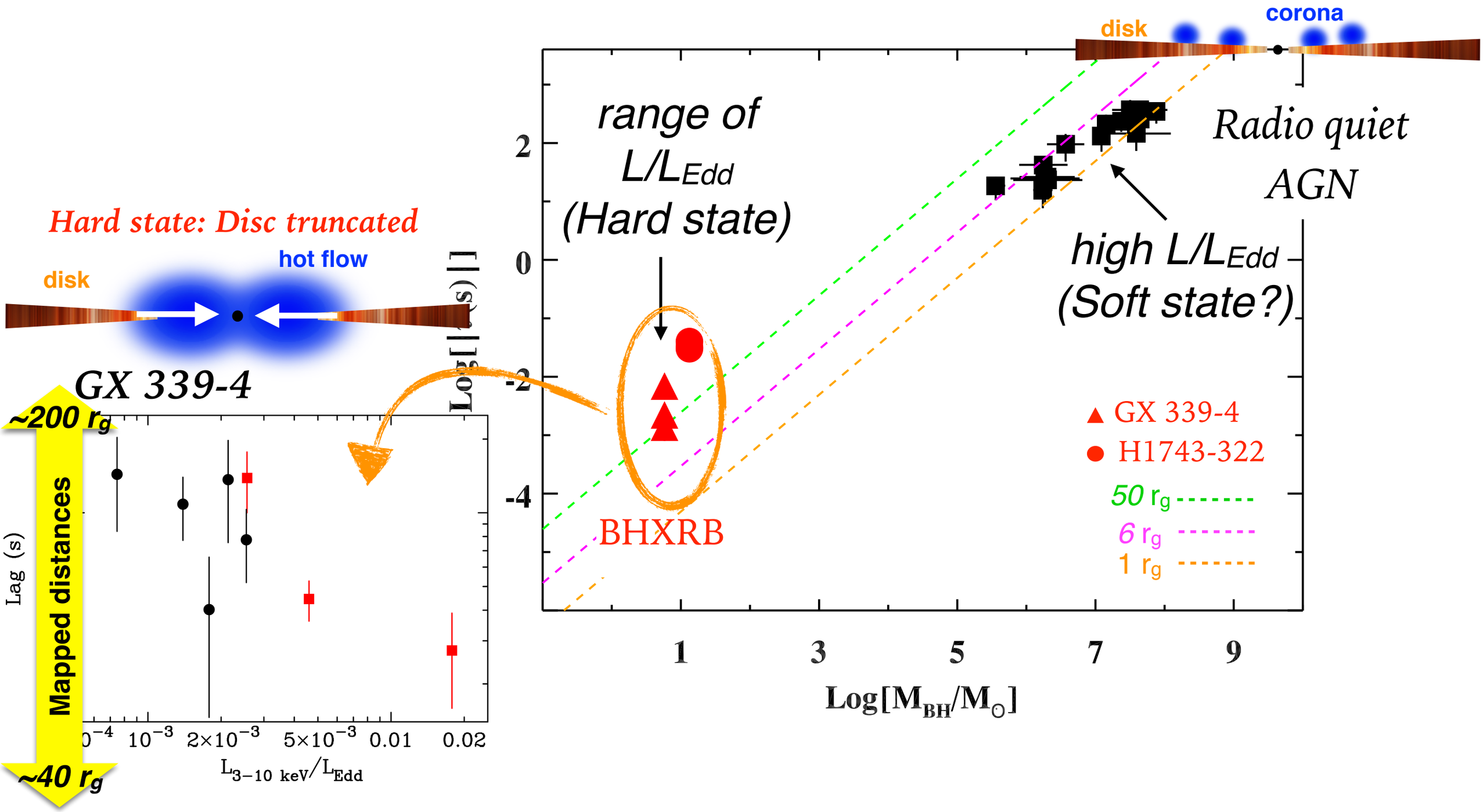
[e.g. Esin+'97; Poutanen +'97; Zdziarski+'99; Meyer+'00; Narayan & McClintock '08; Kylafis & Belloni '15]

Reverberation lags in BHXRBs

Longer lags in hard state BHXRBs than in AGN

[De Marco+'15a, De Marco & Ponti'16; De Marco+'17]

Soft state: Disc close to ISCO



Hard state: Disc truncated

Different inner flow geometry associated with different accretion states

Continuum hard lags: propagation of $\dot{M}$ fluctuations

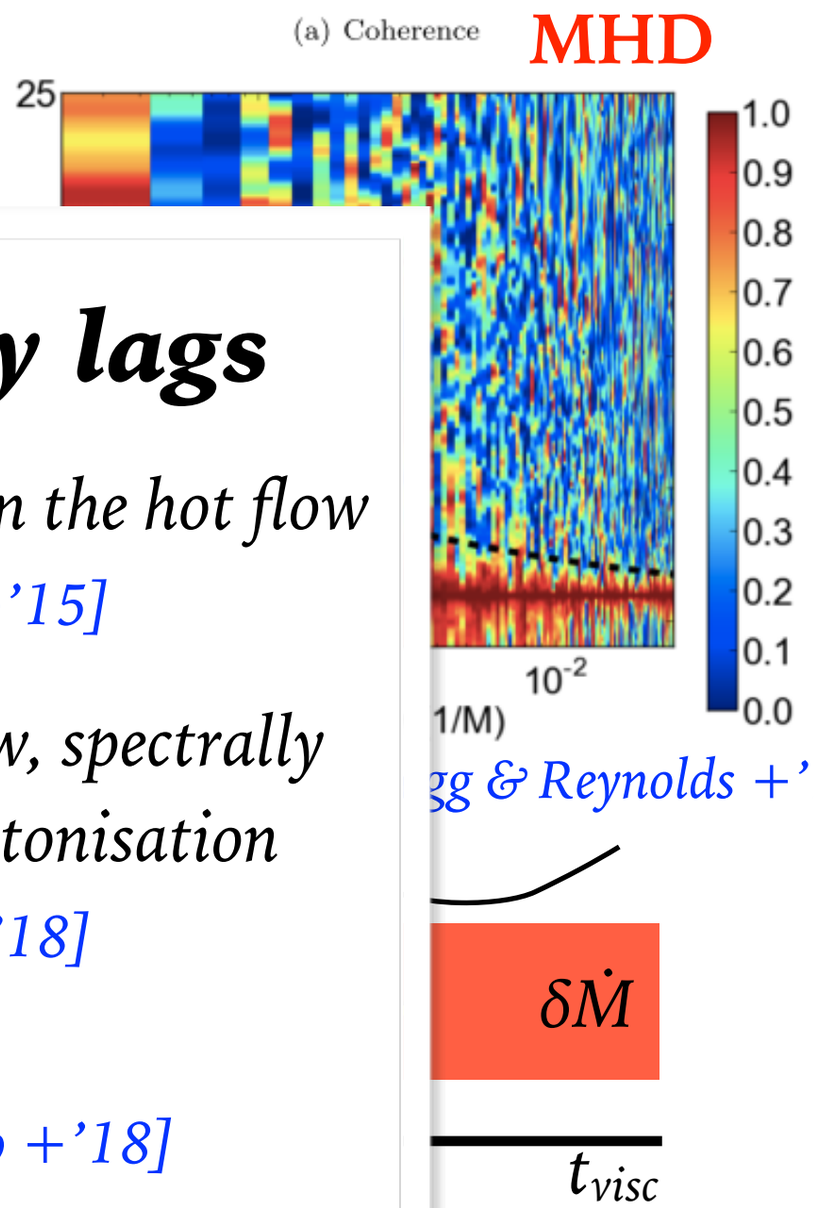
These models can reproduce the observed properties of X-ray variability

Modeling hard X-ray lags

ṁ fluctuations both in the disc and in the hot flow (PROPFLUC) [Rapisarda+'15]

Variability produced in the hot flow, spectrally distinct regions within the Comptonisation zone [Mahmoud & Done '17'18]

Pivoting power law [Mastroserio +'18]



Slow variability ... *ced in inner radii*

[Lyubarskii '97, Kotov +'01, Arévalo & Uttley +'06, Ingram & van der Klis'13; Rapisarda+'15; Mastroserio+'18; Mahmoud & Done '17'18]

Summarizing…

X-ray reverberation is an independent method to study the geometry of the inner evolution

Disc reverberation can self-consistently explain observed soft and FeK lags in AGN

Which constraints on geometry have we inferred so far?

Disc-corona geometry similar in bright radio-quiet AGN: compact corona illuminating a disc likely extending to innermost orbit

Reverberation lags in BHXRBs map distances larger than in radio quiet AGN, consistent with truncated disc during hard and hard-intermediate states

X-ray reverberation lags in BHXRBs scale with luminosity, consistent with an evolving disk geometry (inner radius moving in as the outburst proceeds)