The inner flow geometry in MAXI J1820+070 during hard and hard-intermediate states

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Open questions:

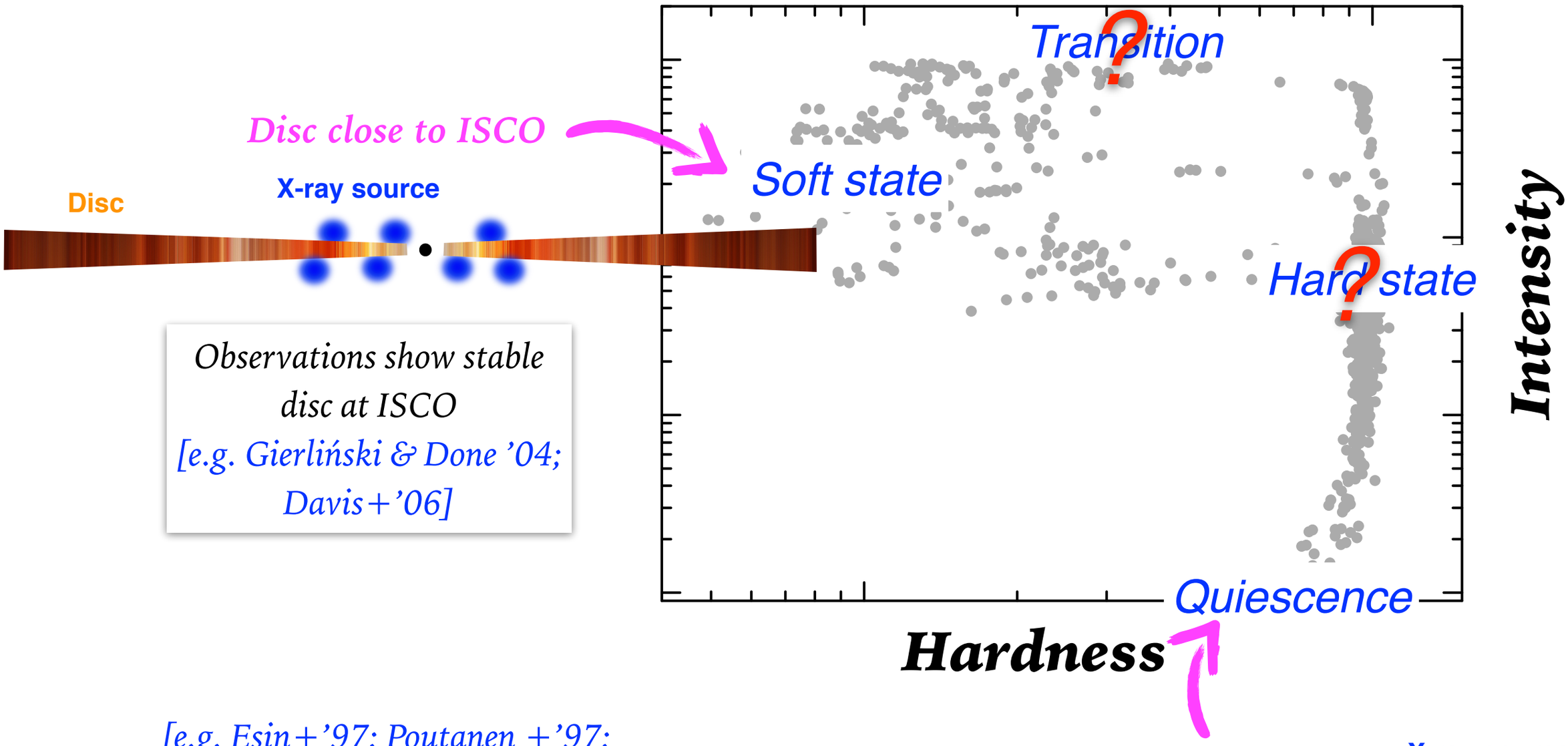
Is the accretion disc truncated in the hard state of BHXRBs?

How does the inner accretion flow evolve at transition?

When does the disc settles at the ISCO?

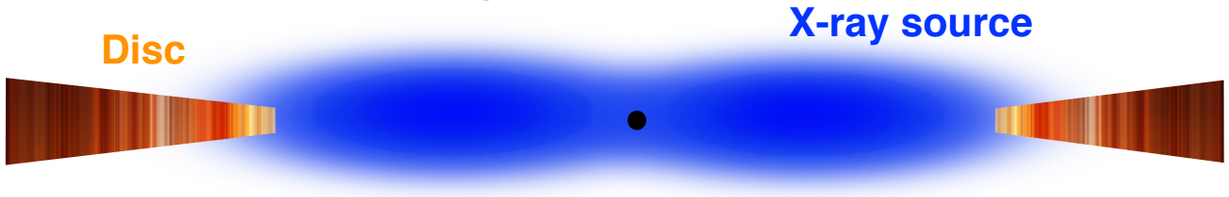
A X-ray spectral-timing analysis of MAXI J1820+070 with NICER

Disc geometry during an outburst



Observations show stable disc at ISCO
[e.g. Gierliński & Done '04; Davis+'06]

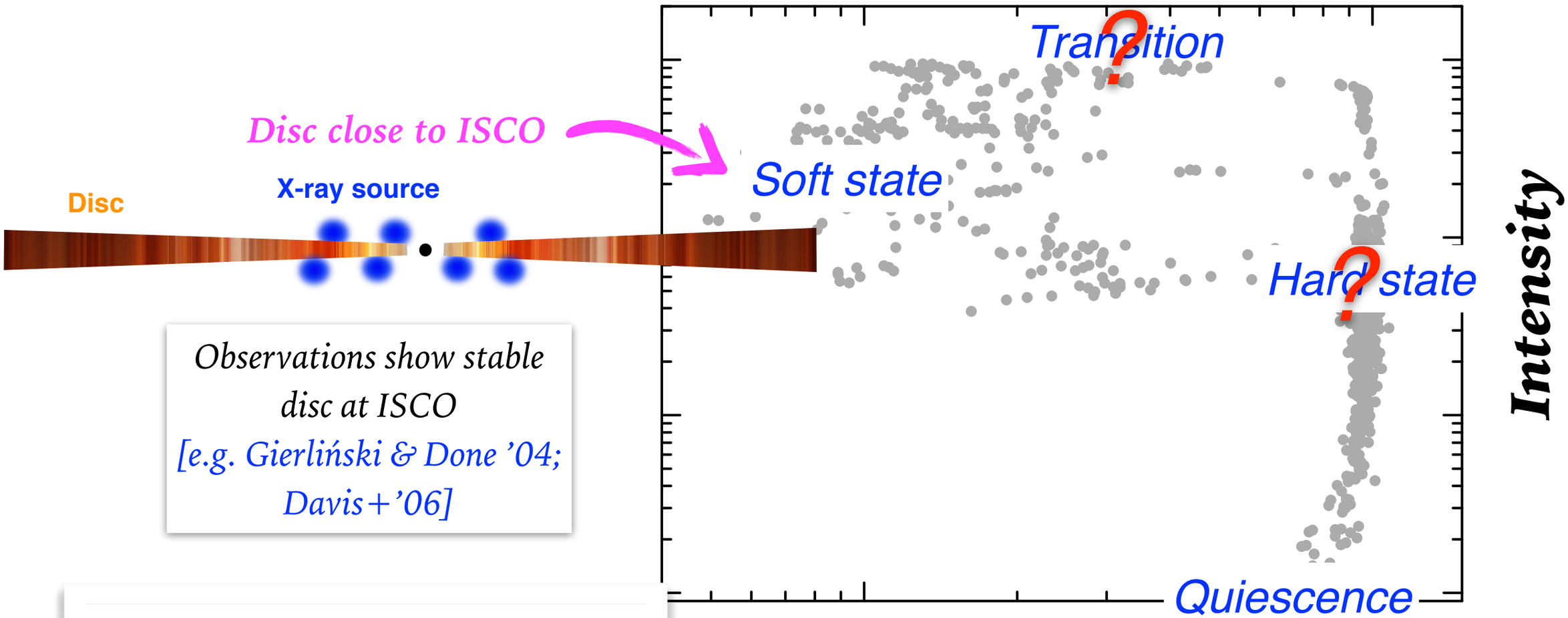
[e.g. Esin+'97; Poutanen +'97; Zdziarski+'99; Meyer+'00; Narayan & McClintock '08; Kylafis & Belloni '15]



Truncated disc+inefficient inner flow

Observations of optical disc lines show truncated disc
[e.g. Bernardini+'16]

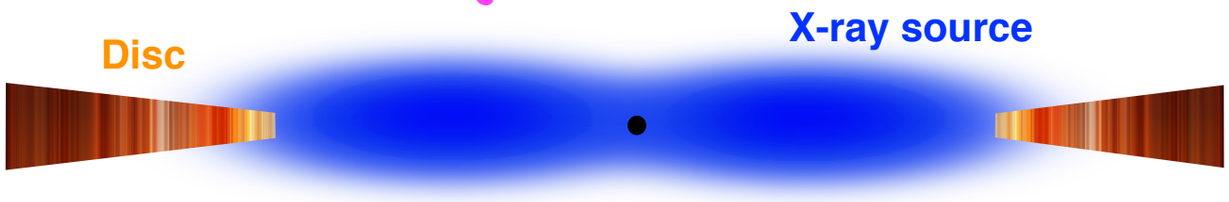
Disc geometry during an outburst



Observations show stable disc at ISCO
[e.g. Gierliński & Done '04; Davis+'06]

Results from spectral analysis of the hard state are controversial
[see Bambi+'21 for a review]

Transition very quick, difficult to observe
[e.g. Dunn+'10]



Truncated disc+inefficient inner flow

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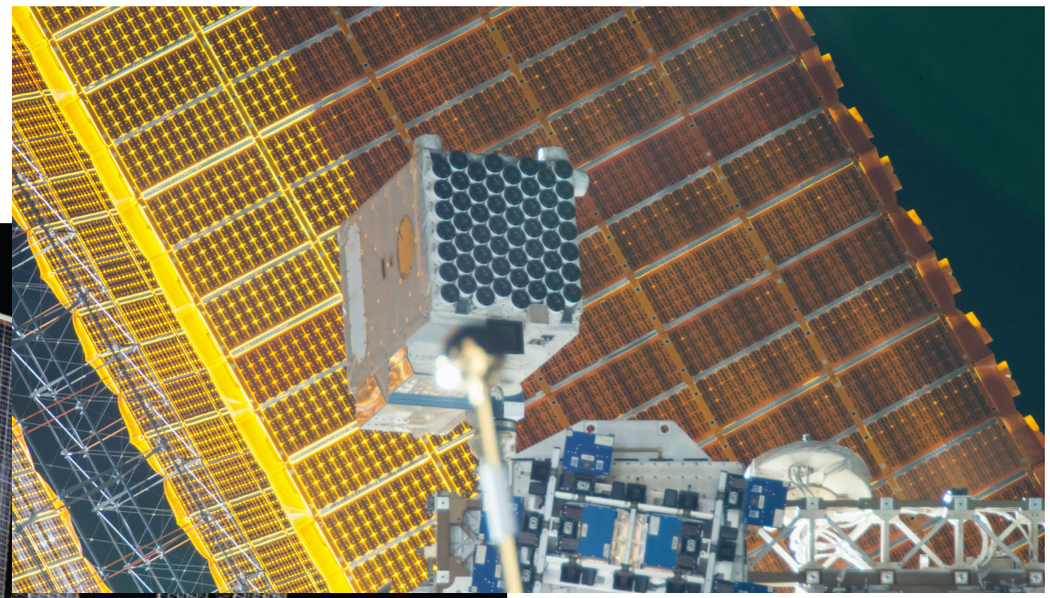
The Neutron star Interior Composition Explorer (NICER)

52 operative X-ray "concentrator" optics (XRC) each paired to a silicon drift detector (SDD)



2022 Bruno Rossi Prize Winner

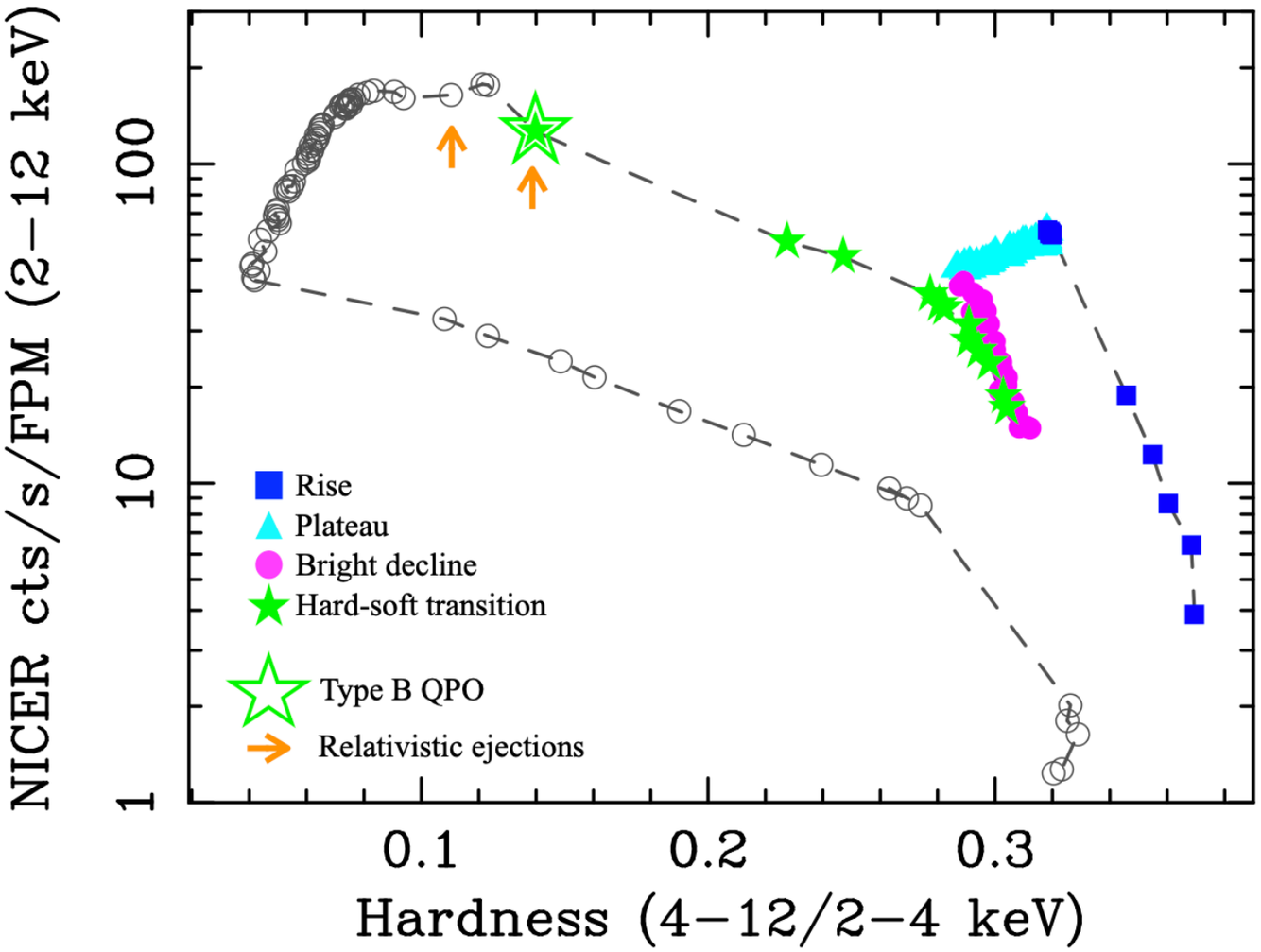
Large collecting area, fast timing capabilities, no limitations to observe very bright source

[Gendreau+'16]

MAXI J1820+070

One of the brightest X-ray binaries ever observed

[e.g. Tucker+'18; Stiele+'19; Buisson+'19; Torres+'19, '20; Atri+'20; Kawamura+'21; Marino+'21]



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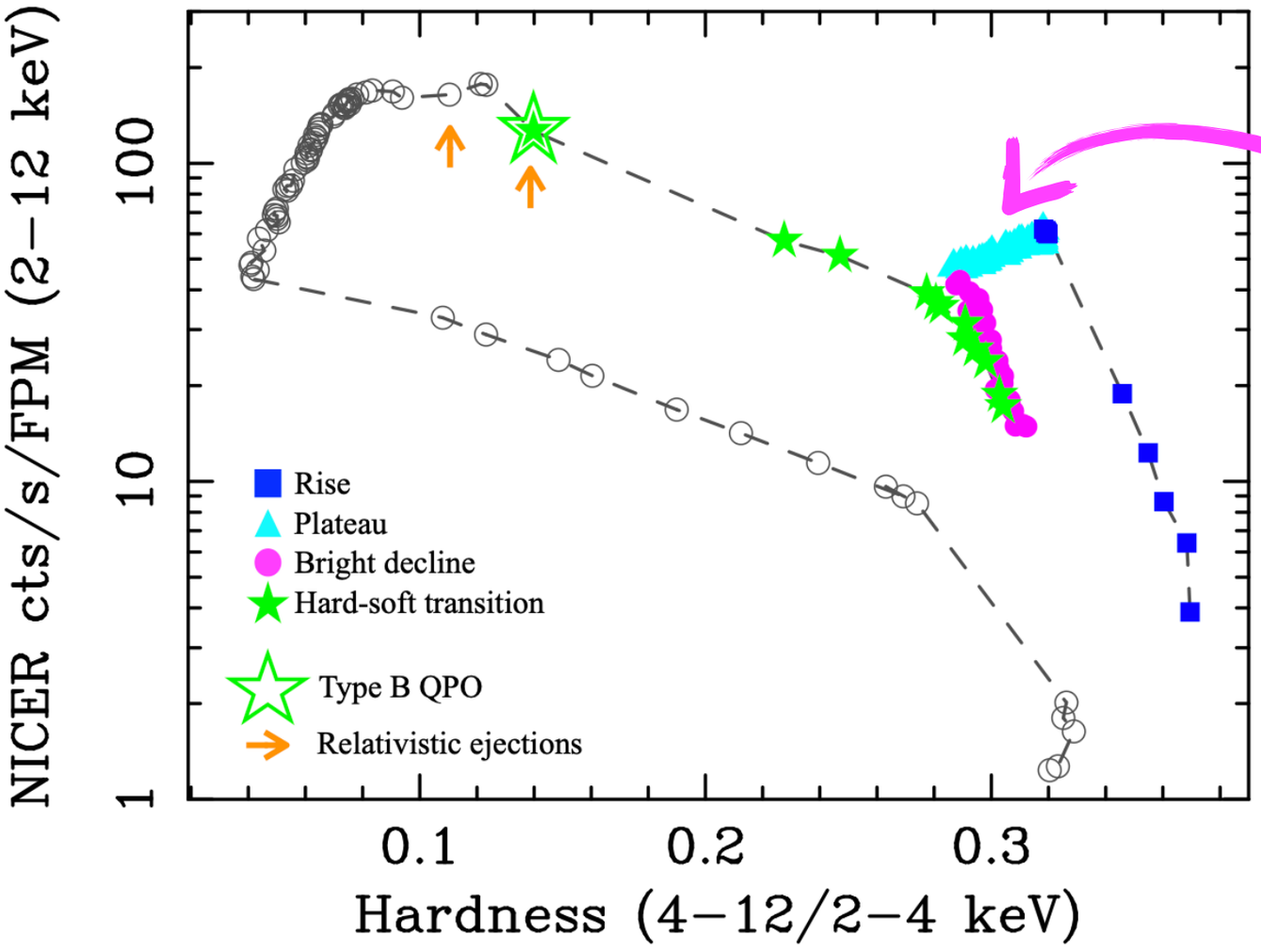

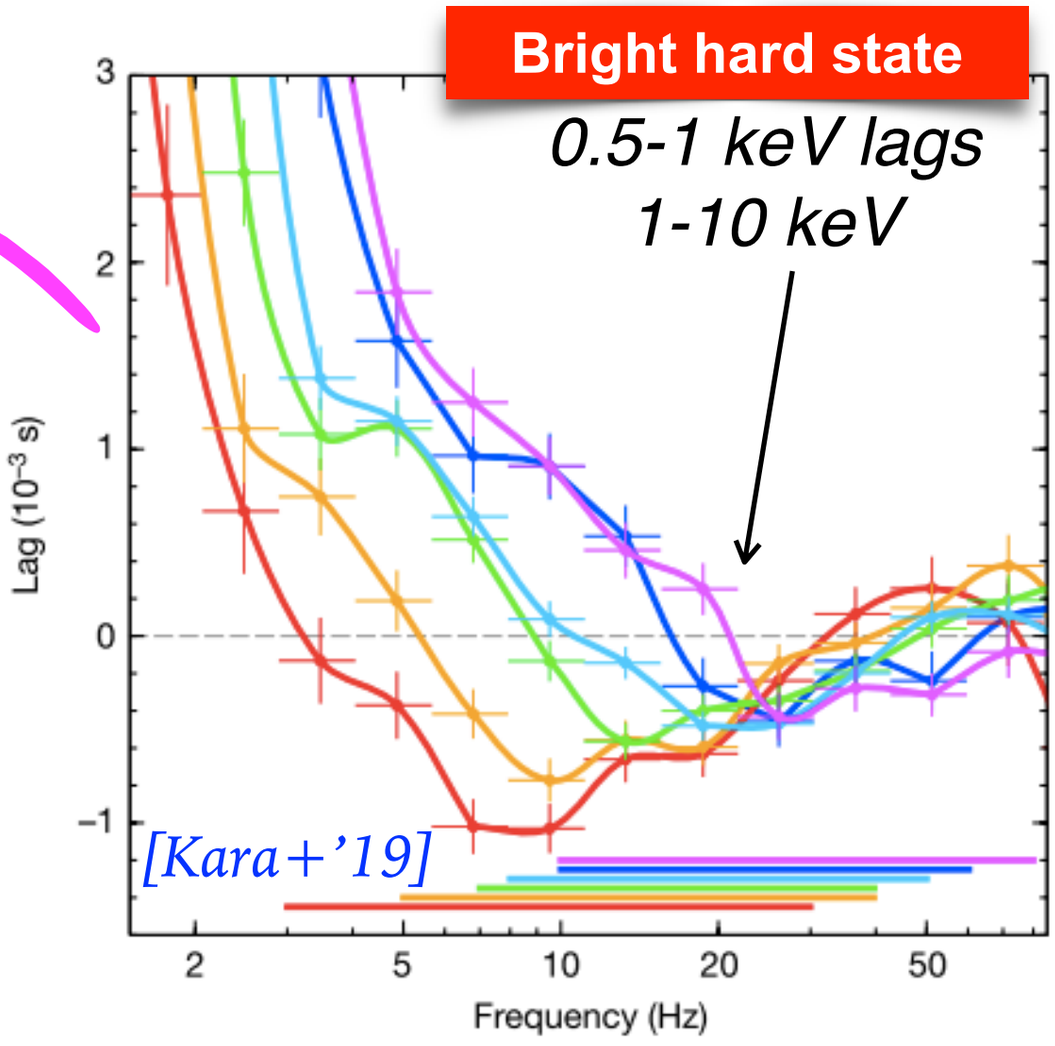

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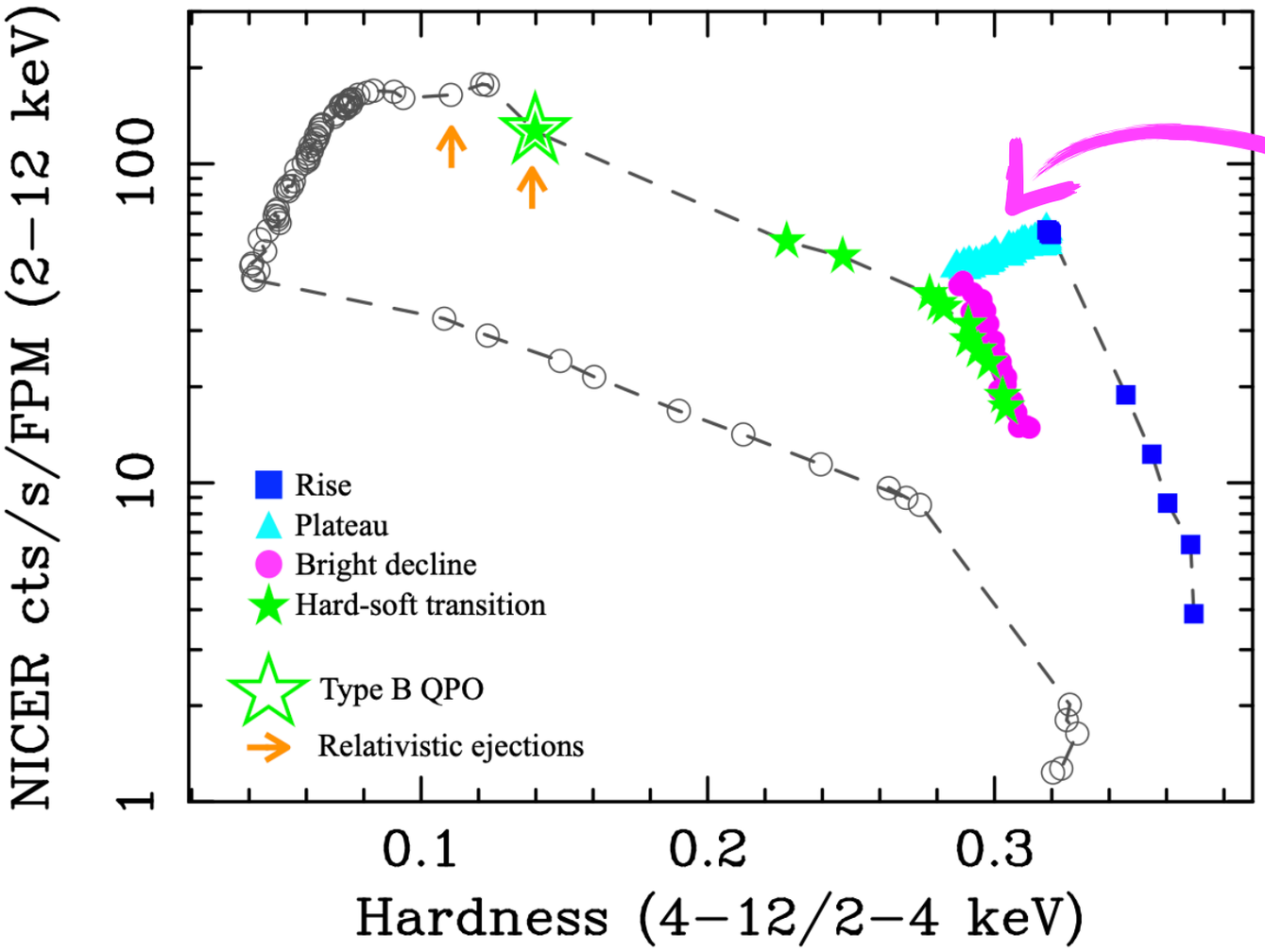
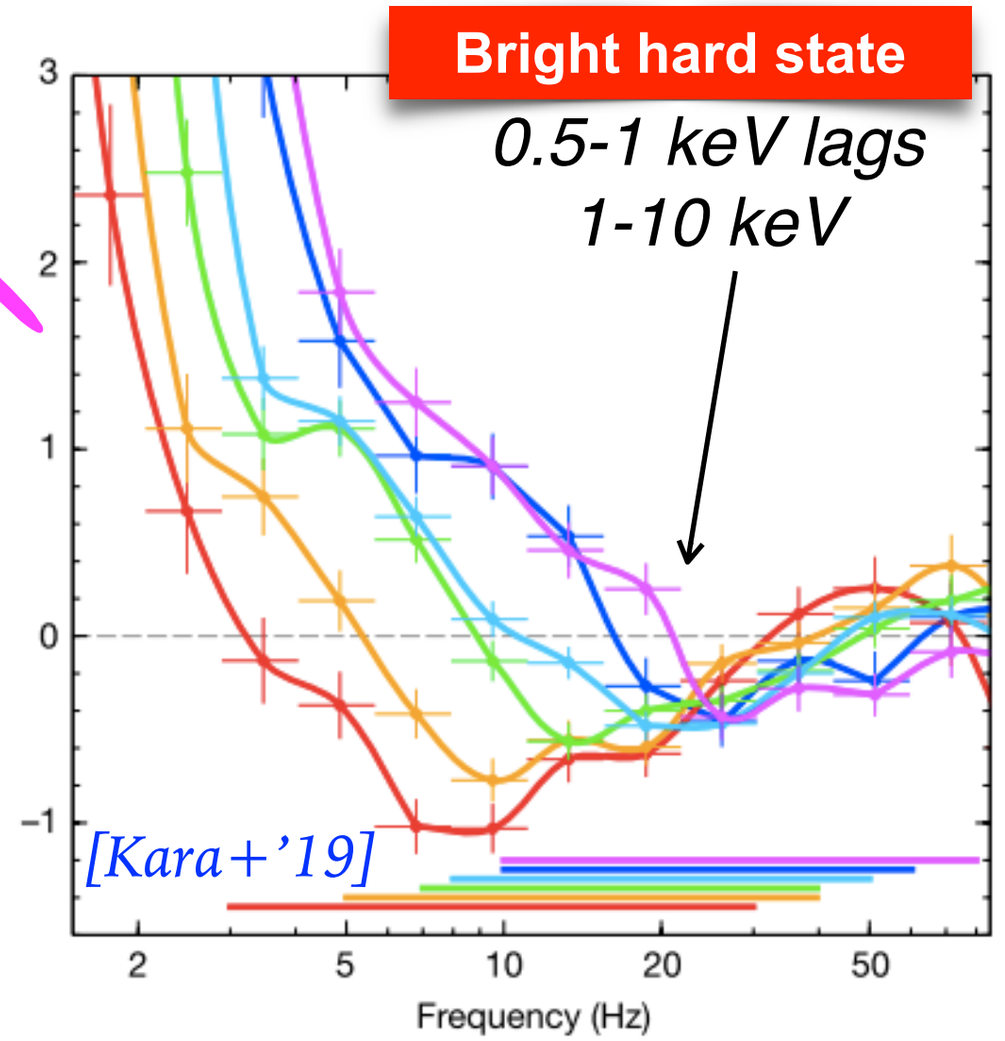
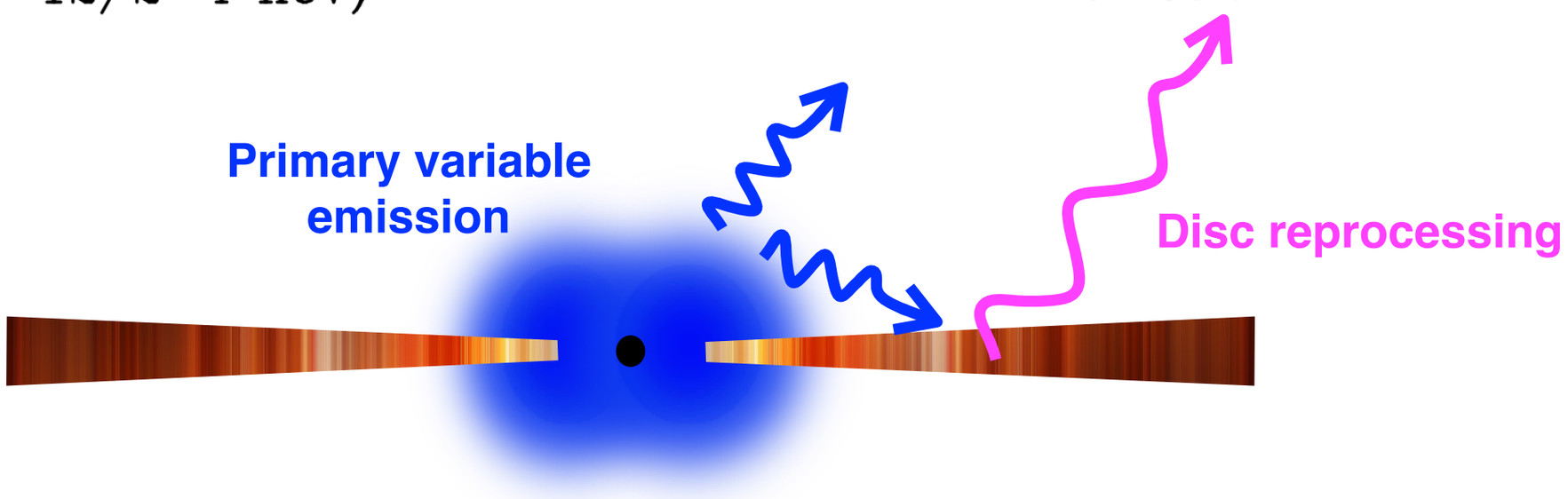


Bright hard state



X-ray reverberation

[e.g. Uttley+'14]



MAXI J1820+070

One of the brightest X-ray binaries ever observed

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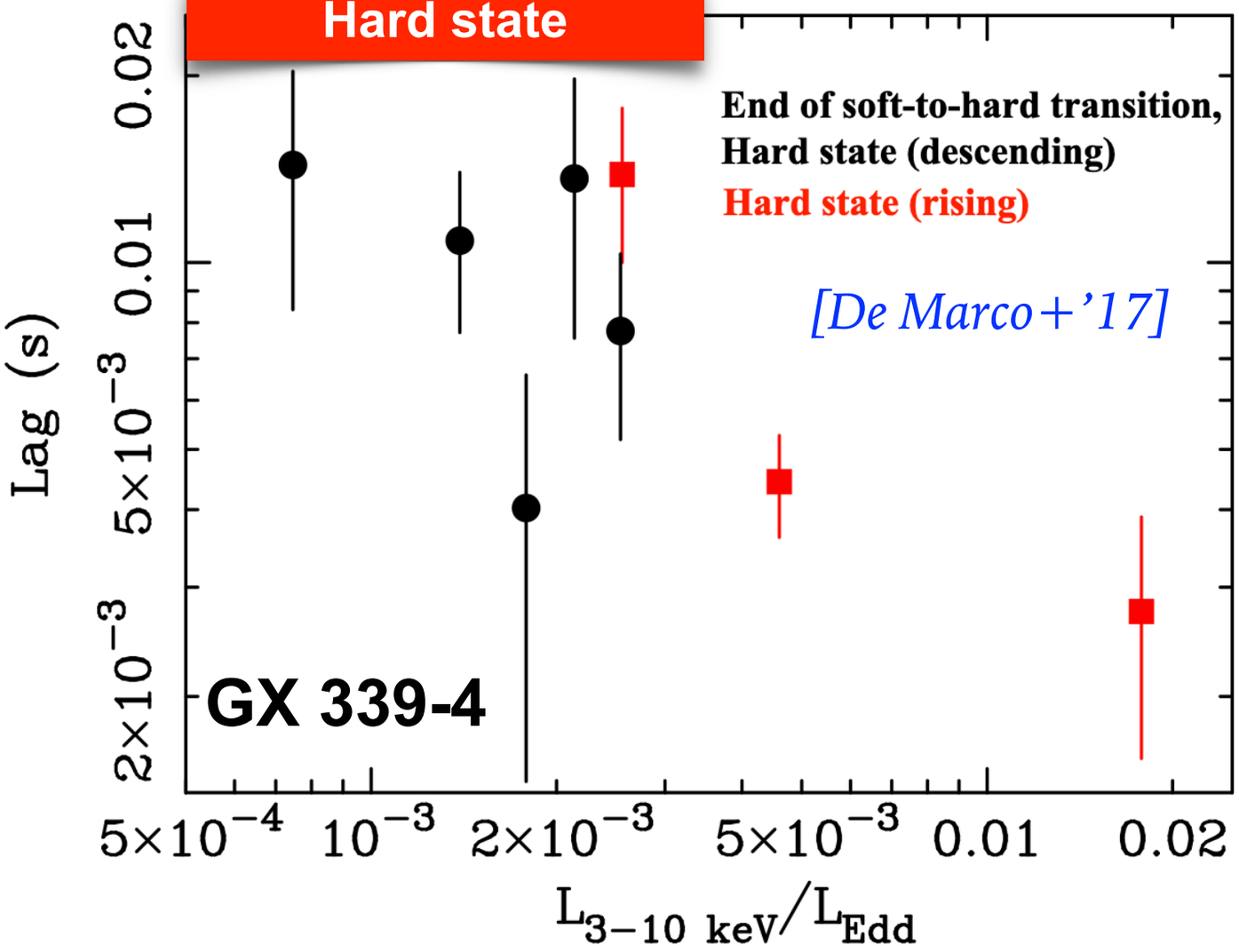
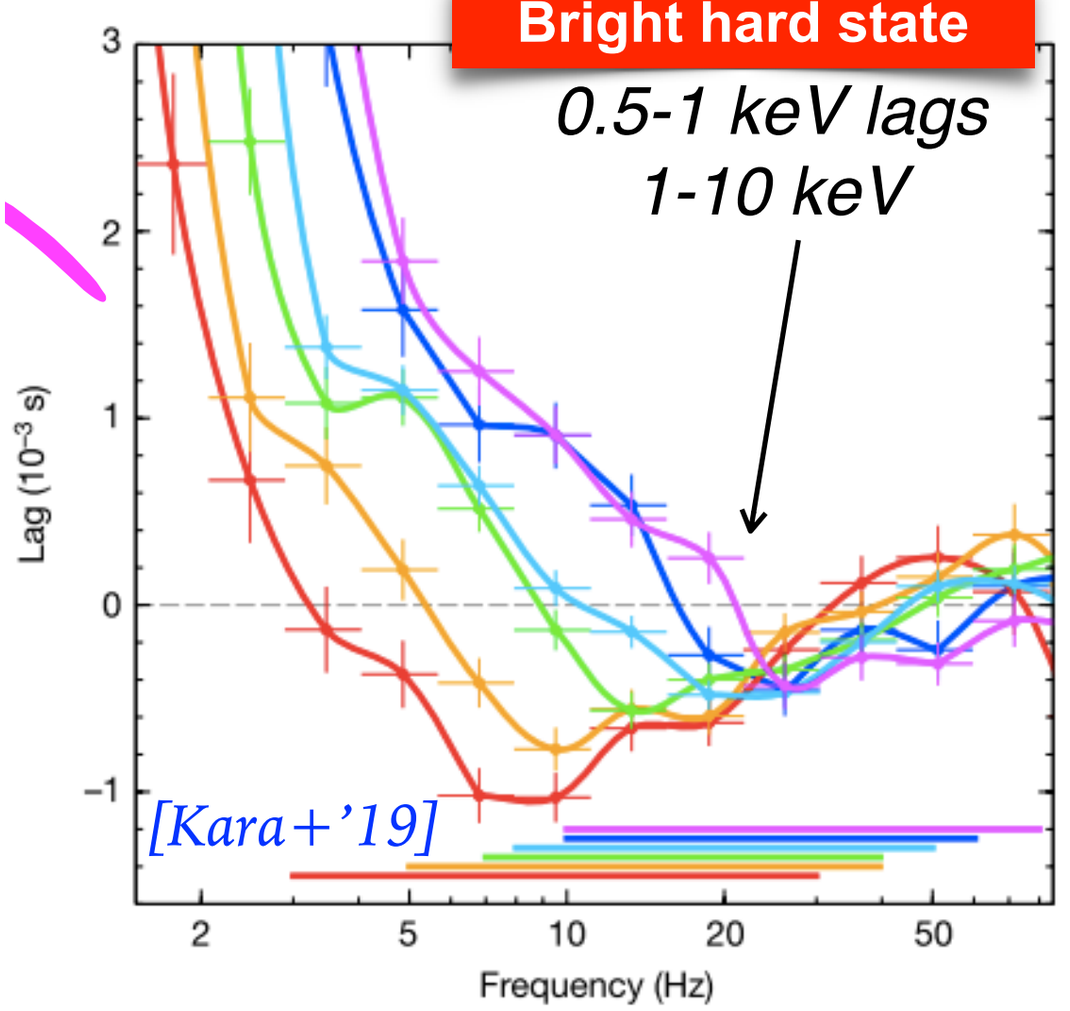
Hard state

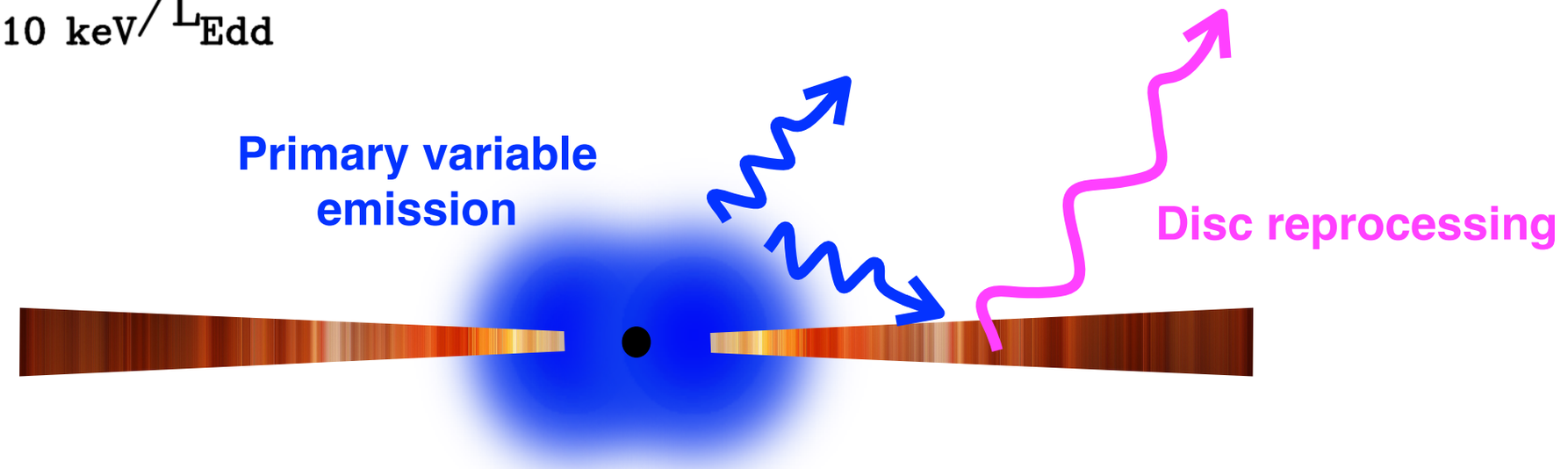


Bright hard state



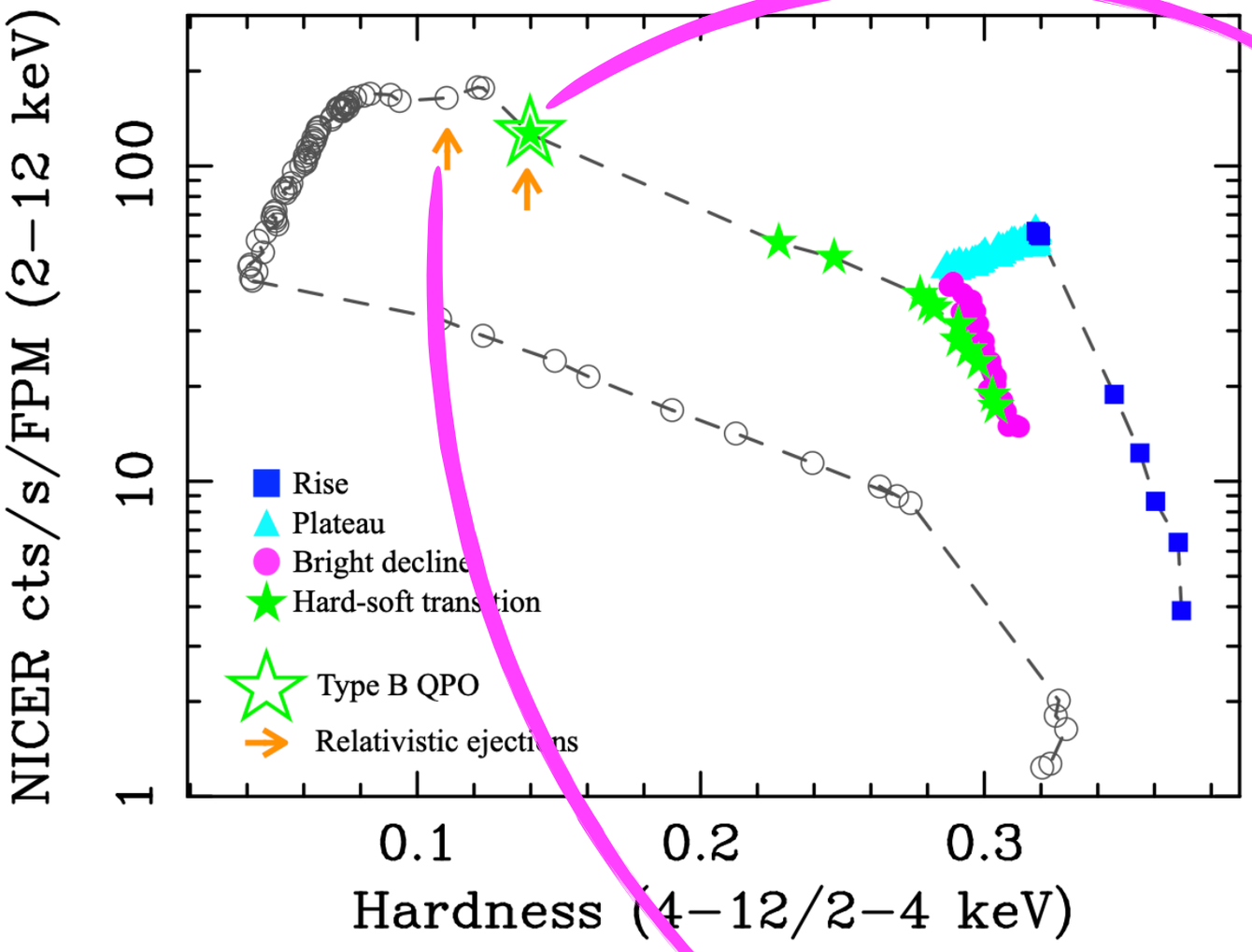
X-ray reverberation

[e.g. Uttley+'14]

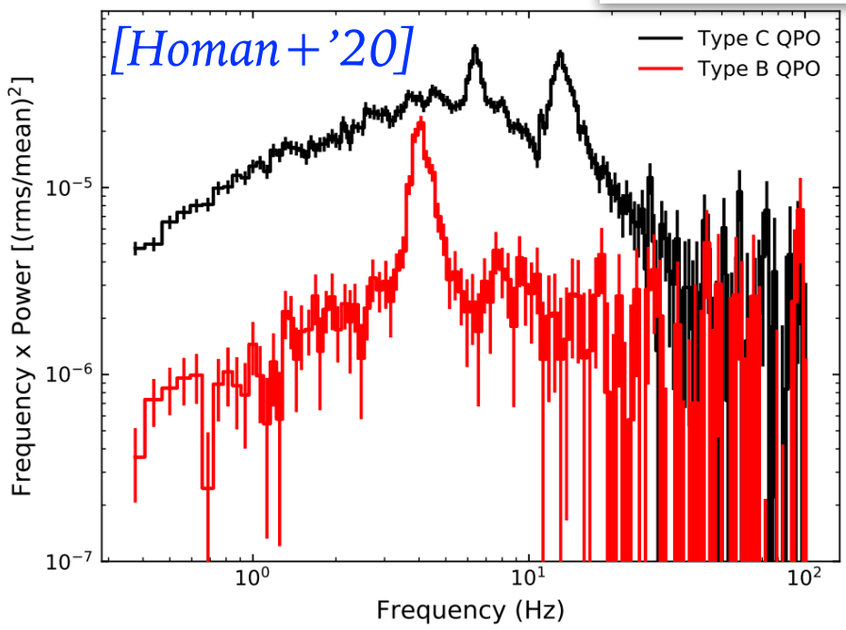


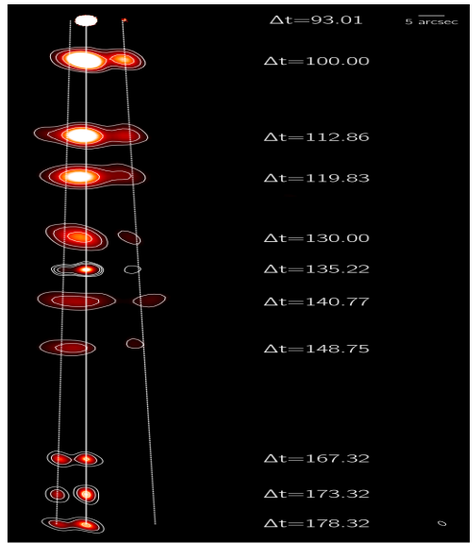
MAXI J1820+070

Simultaneous multiwavelength observations of hard-soft transition

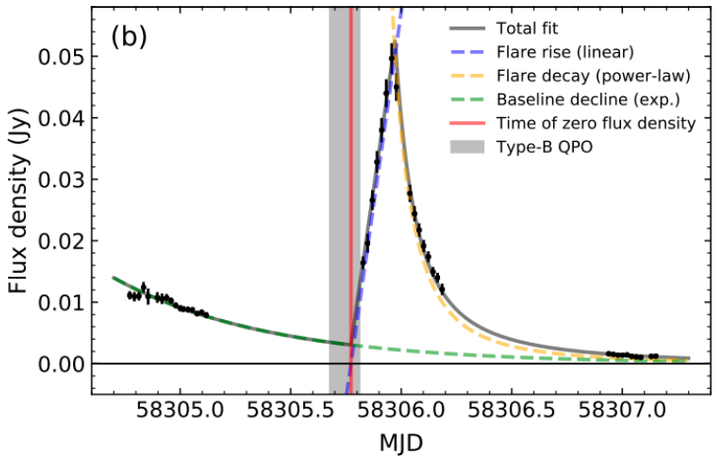


X-ray power spectrum





Radio ejecta



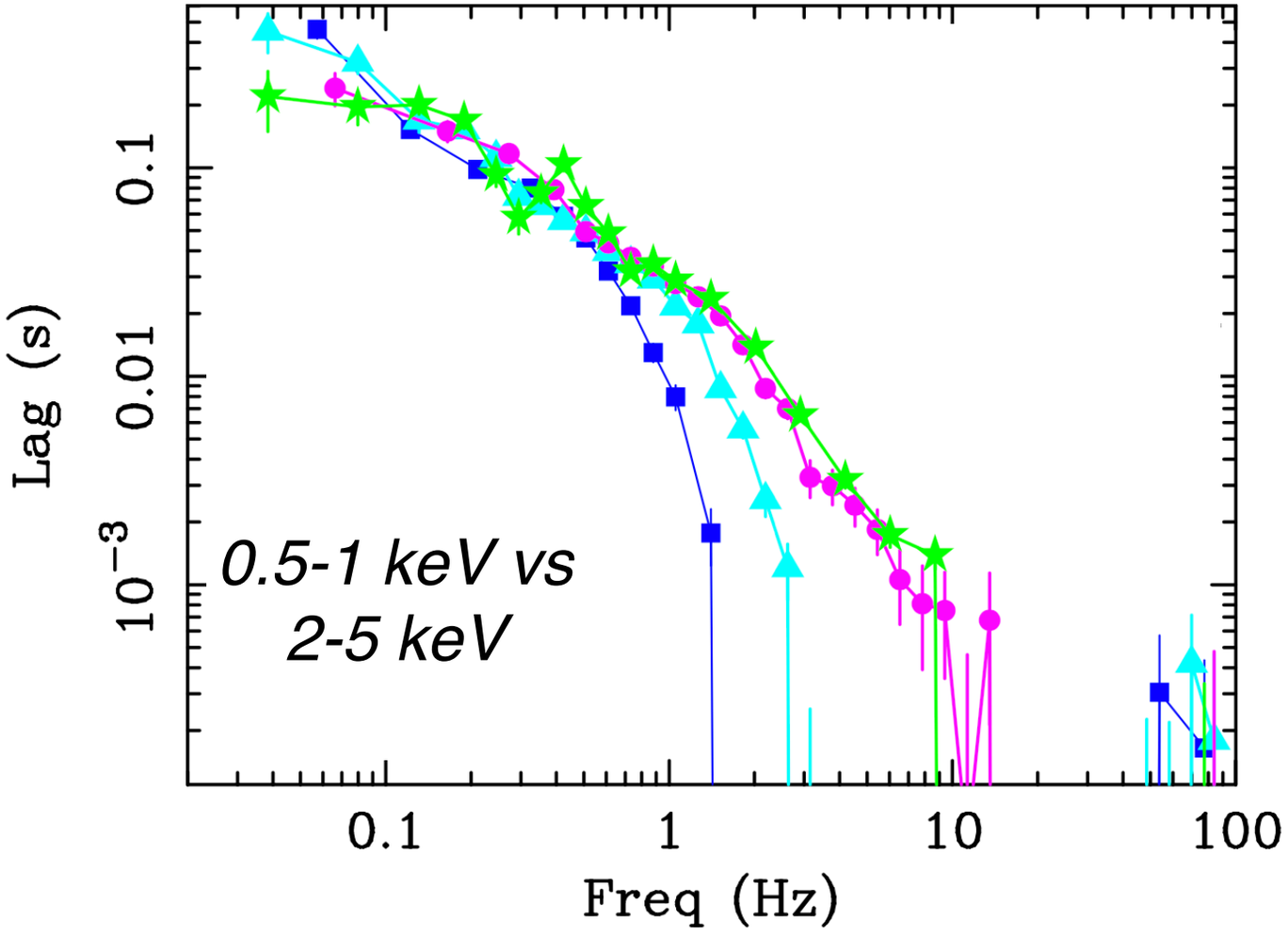
[Bright +'19; Espinasse+'20 Wood+'21]

Radio flare

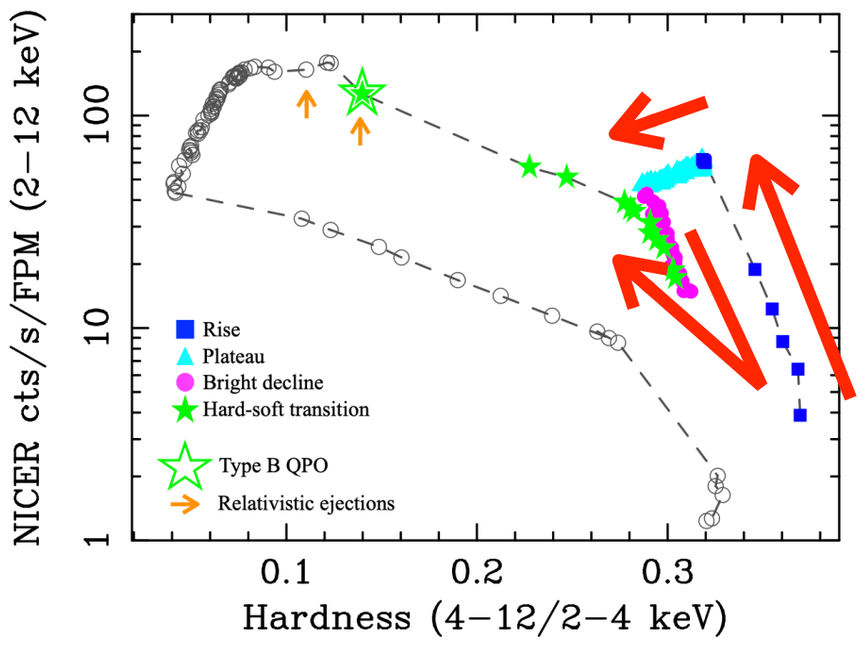
Evolution of geometry in MAXI J1820+070 through hard and intermediate states

Hard X-ray lags

[De Marco+'21]

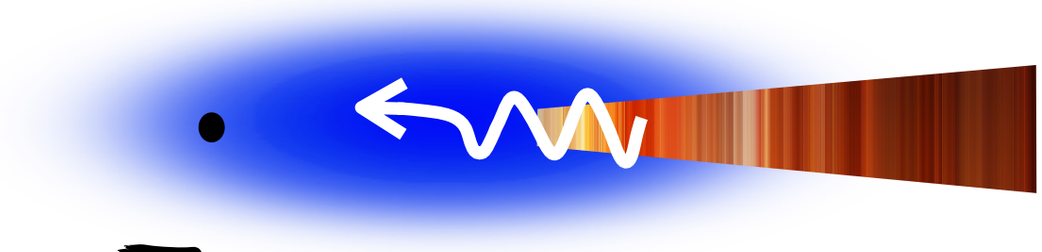


HARD STATE

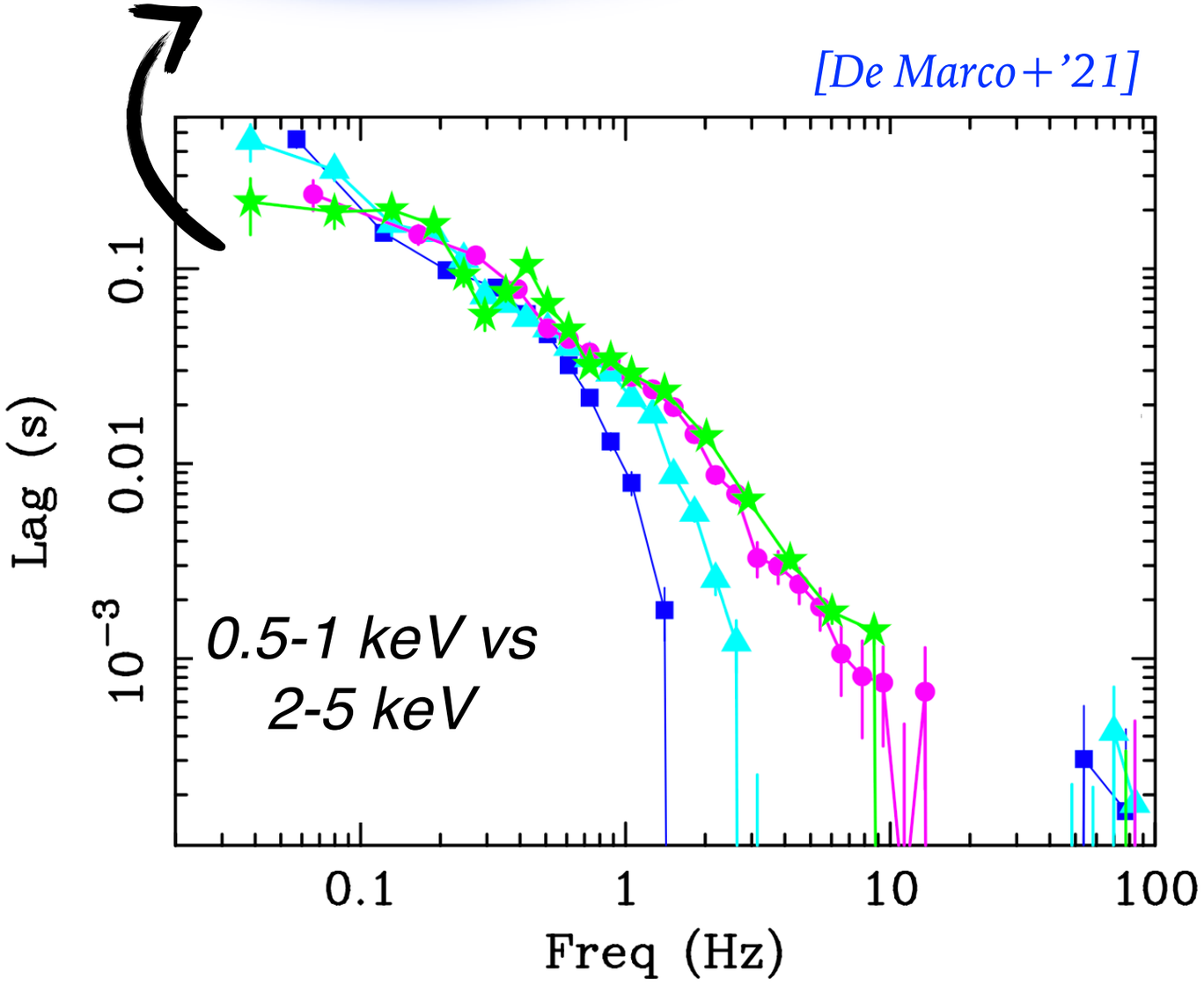


Hard X-ray lags

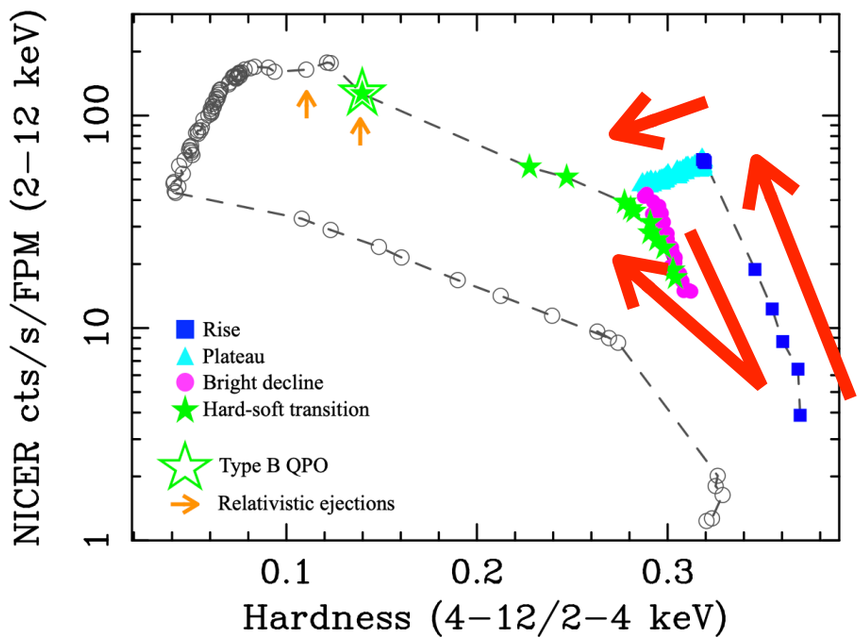
Variability propagates through a spectrally stratified medium
[see also Dziełak, BDM+'21]



[De Marco+'21]

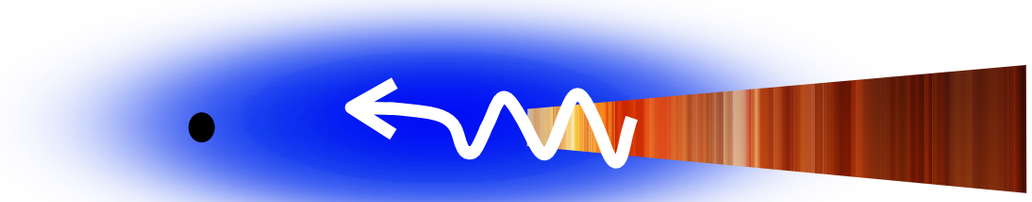


HARD STATE

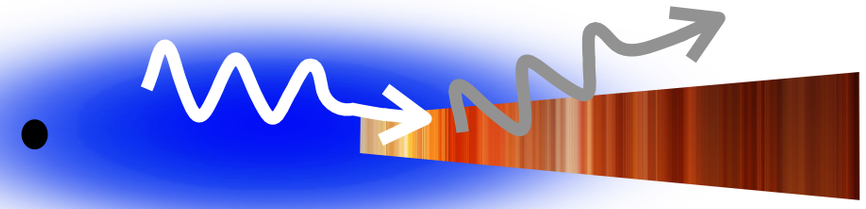


Soft X-ray lags (reverberation)

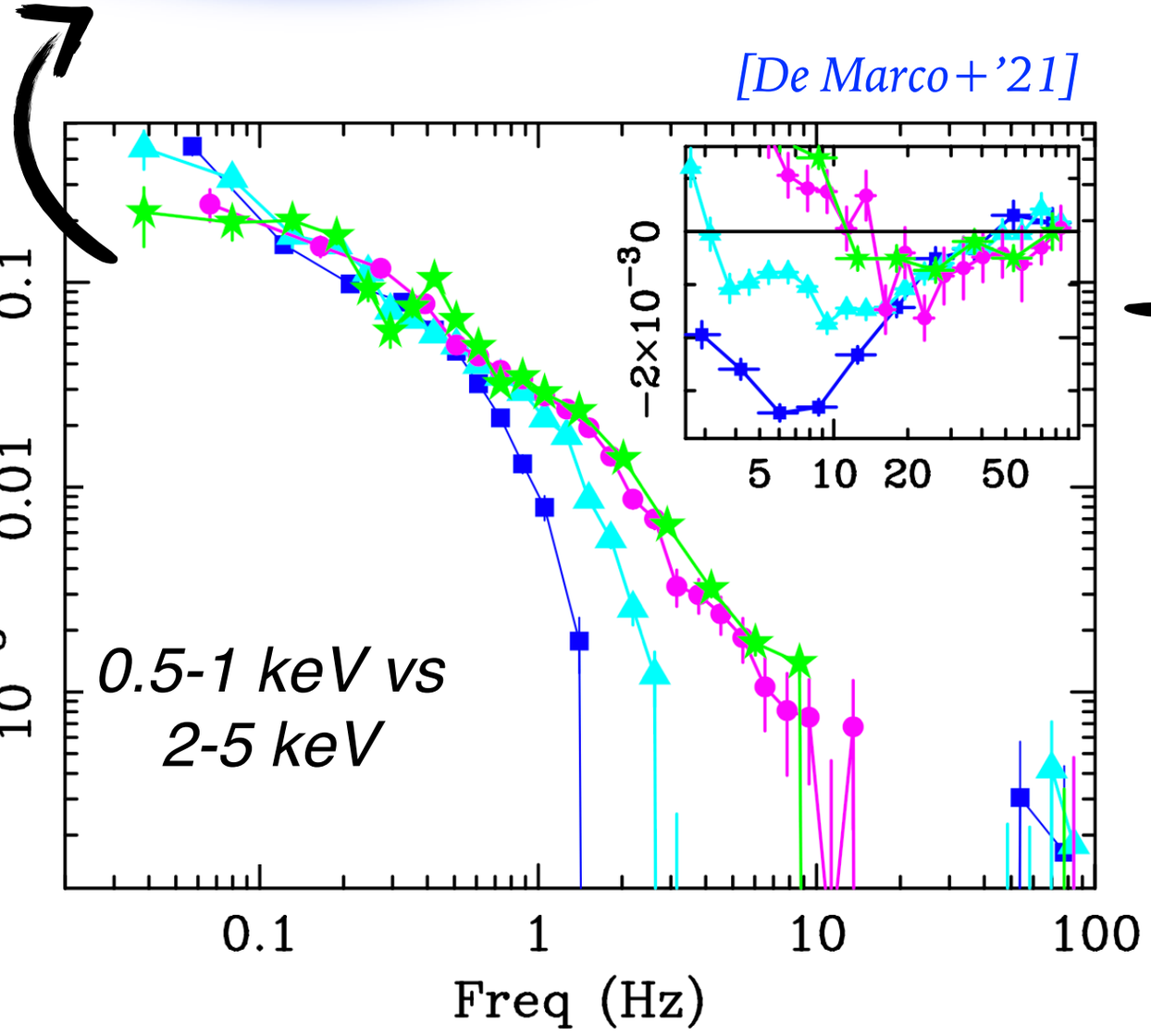
Variability propagates through a spectrally stratified medium
[see also Dziełak, BDM+'21; Kawamura+'21]



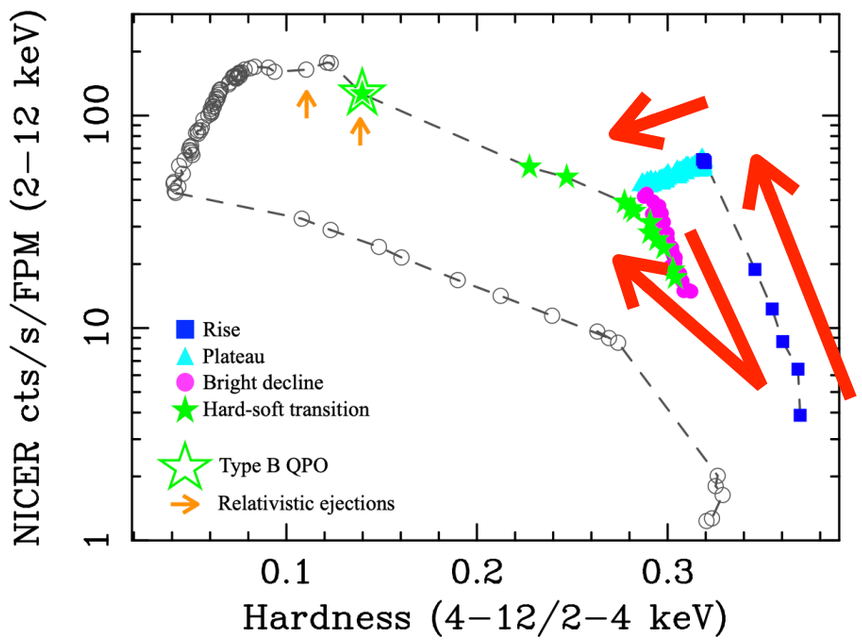
Disc responds to variable hard X-ray irradiation (reverberation)



[De Marco+'21]

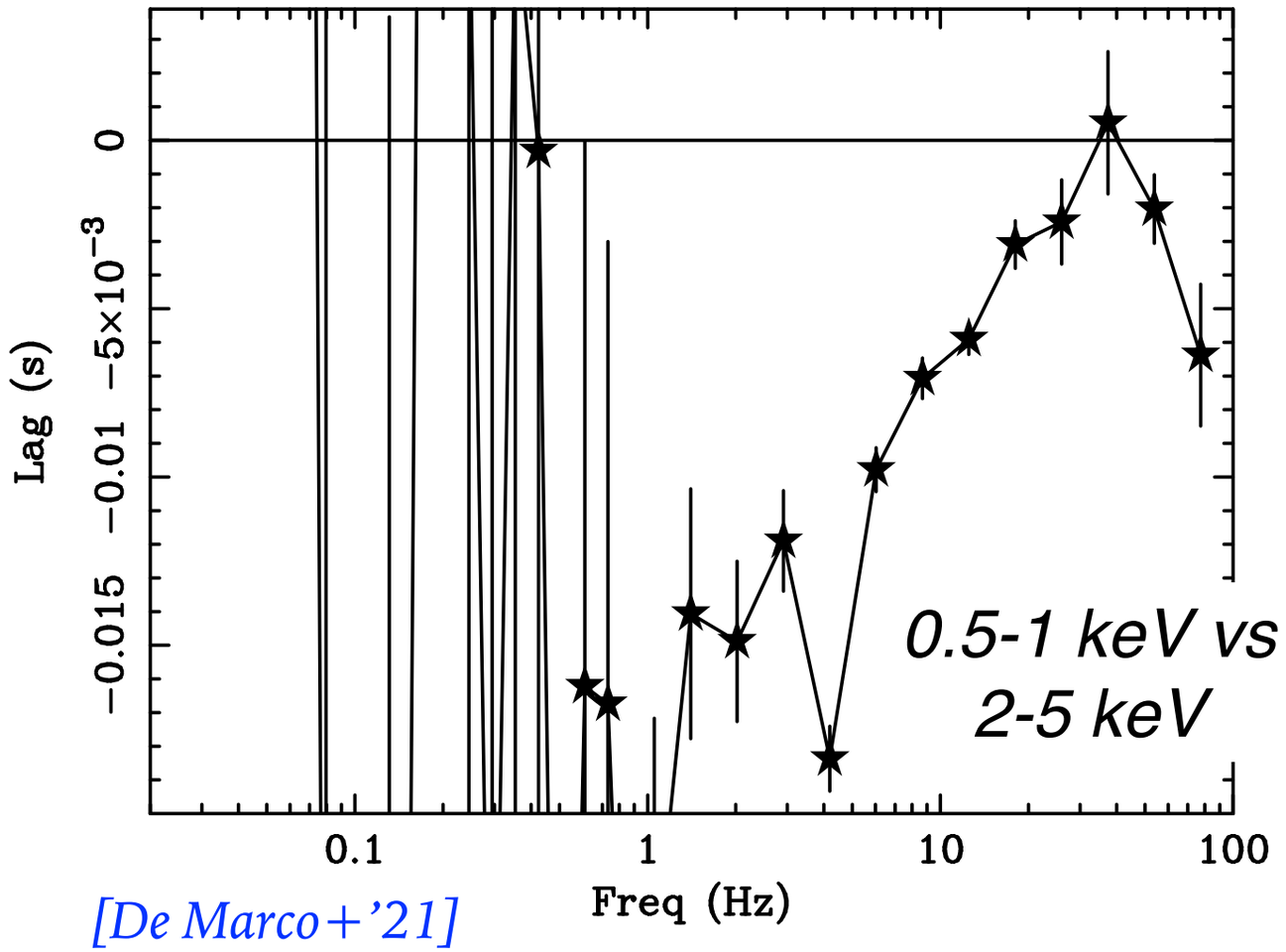


HARD STATE



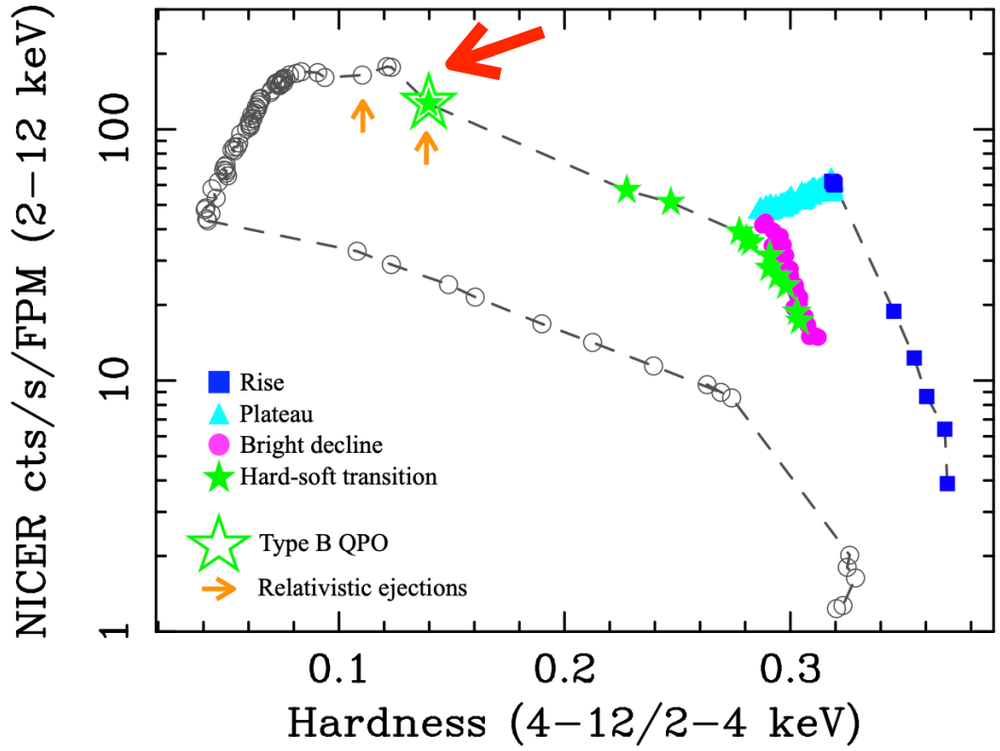
X-ray lags at transition

Continuum low-frequency hard lags disappear, a long reverberation lag dominates



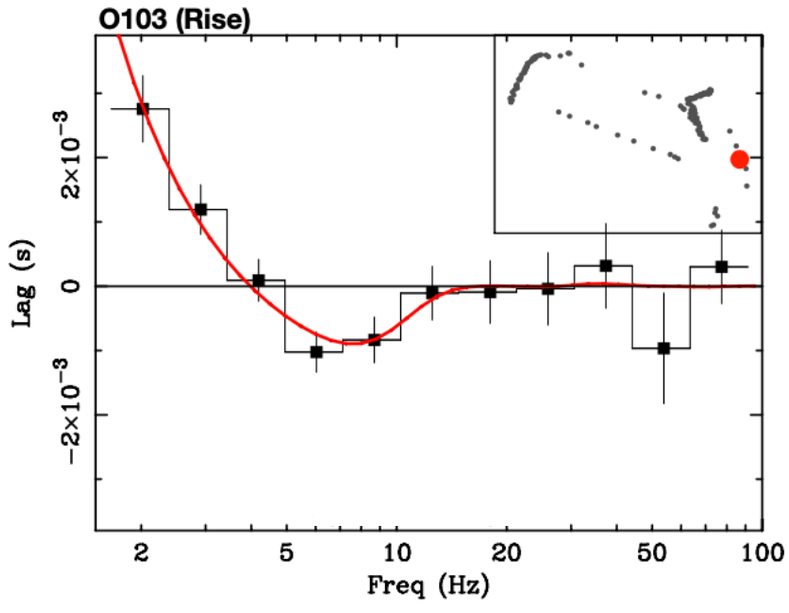
[De Marco+'21]

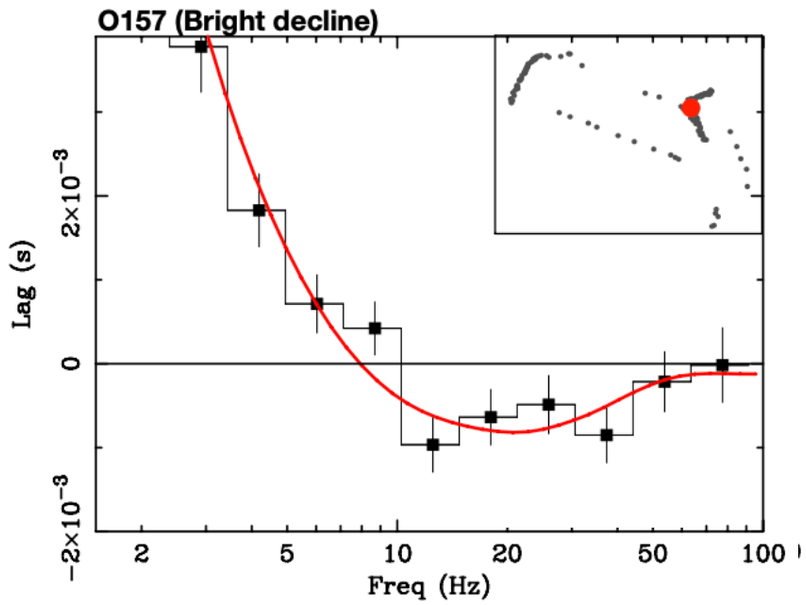
HARD-SOFT TRANSITION

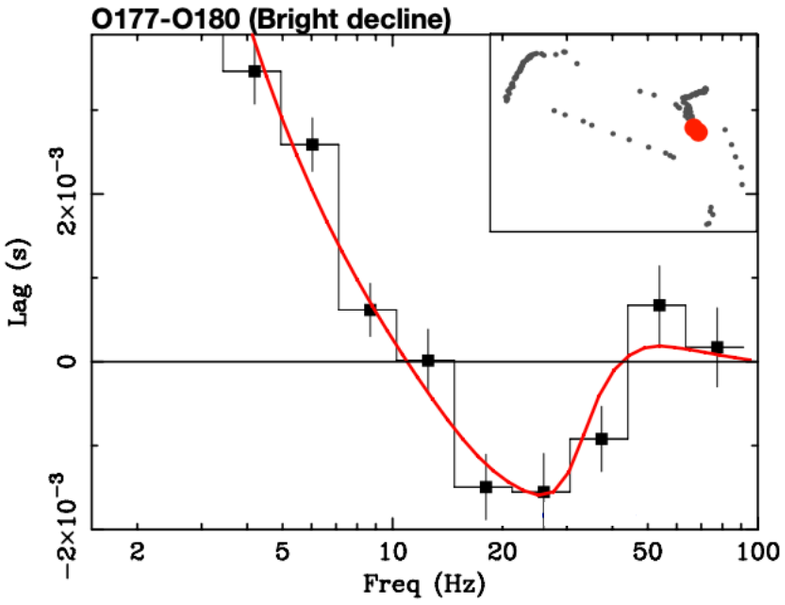


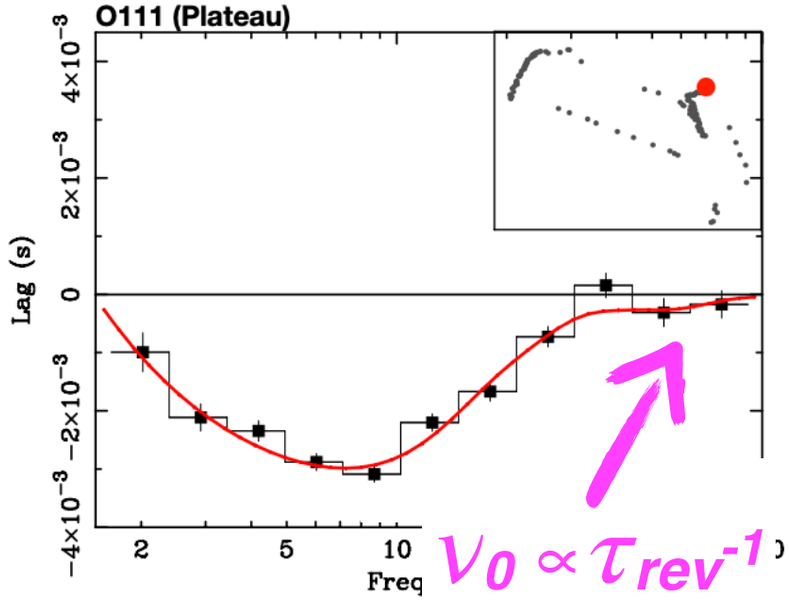
The evolution of X-ray reverberation lags

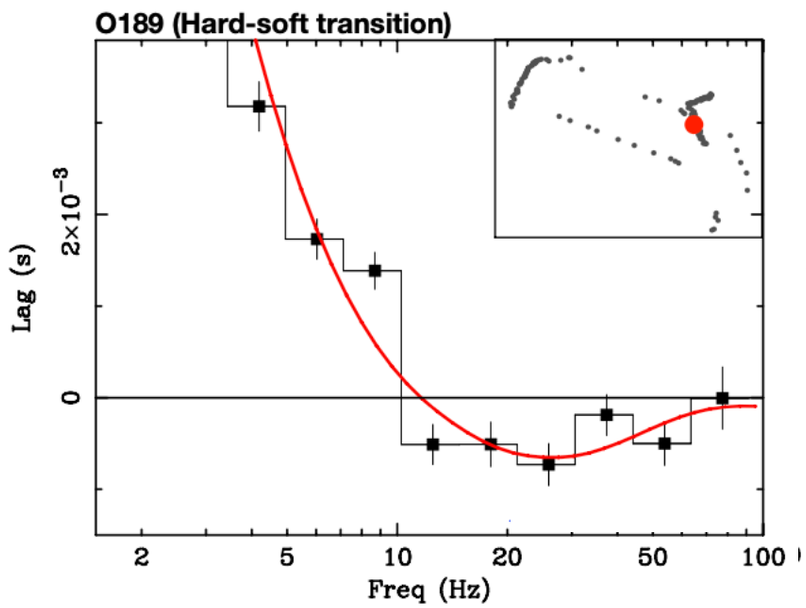
[De Marco+'21]

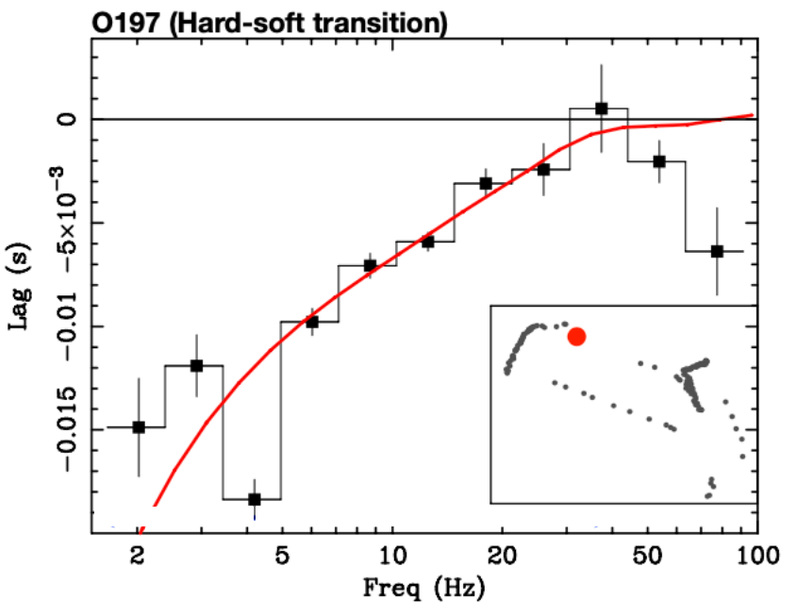










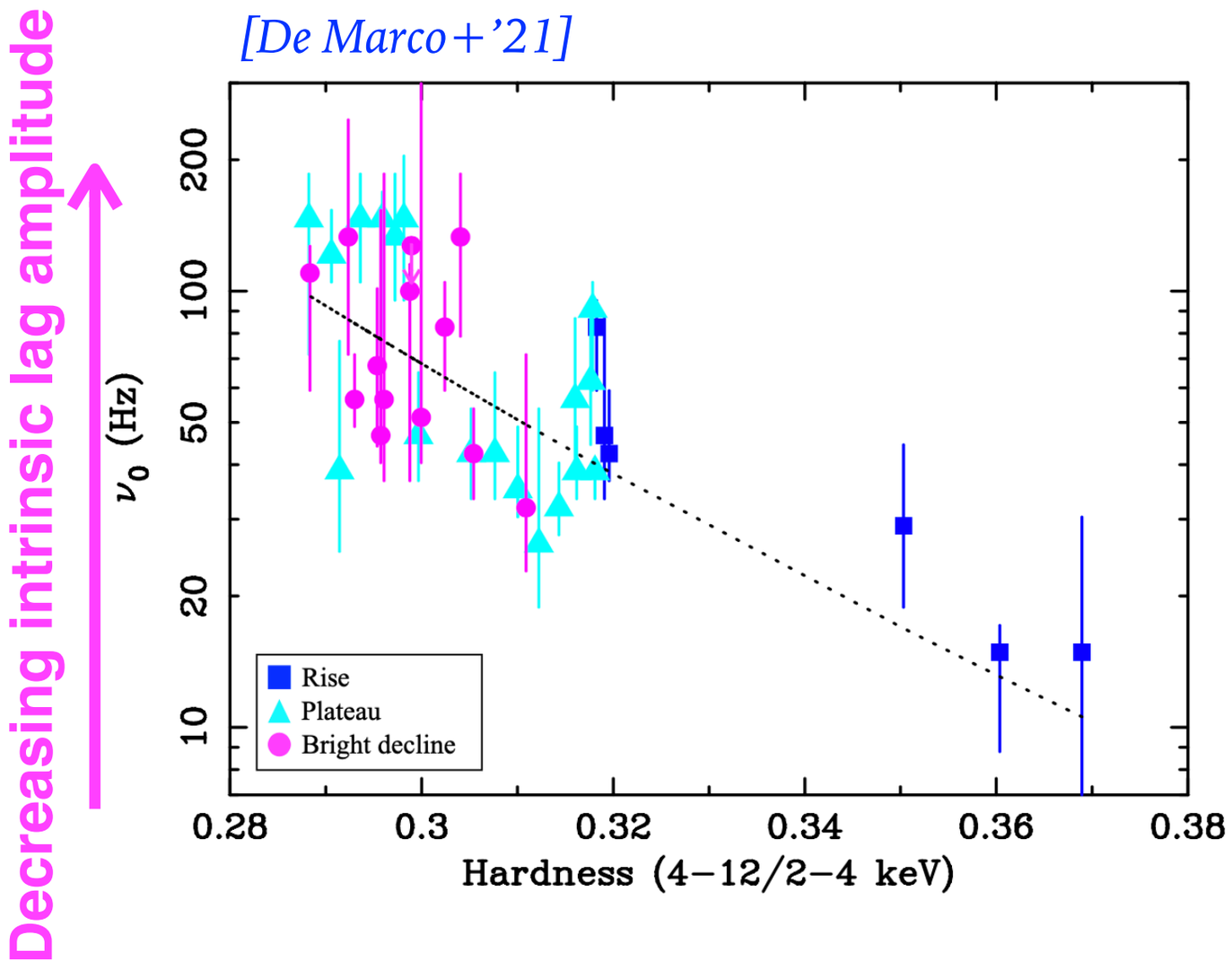


(e.g. Mizumoto+'18)

——— *"Reltrans" spectral-timing model (Ingram+'19; Mastroserio+'19,'20)*

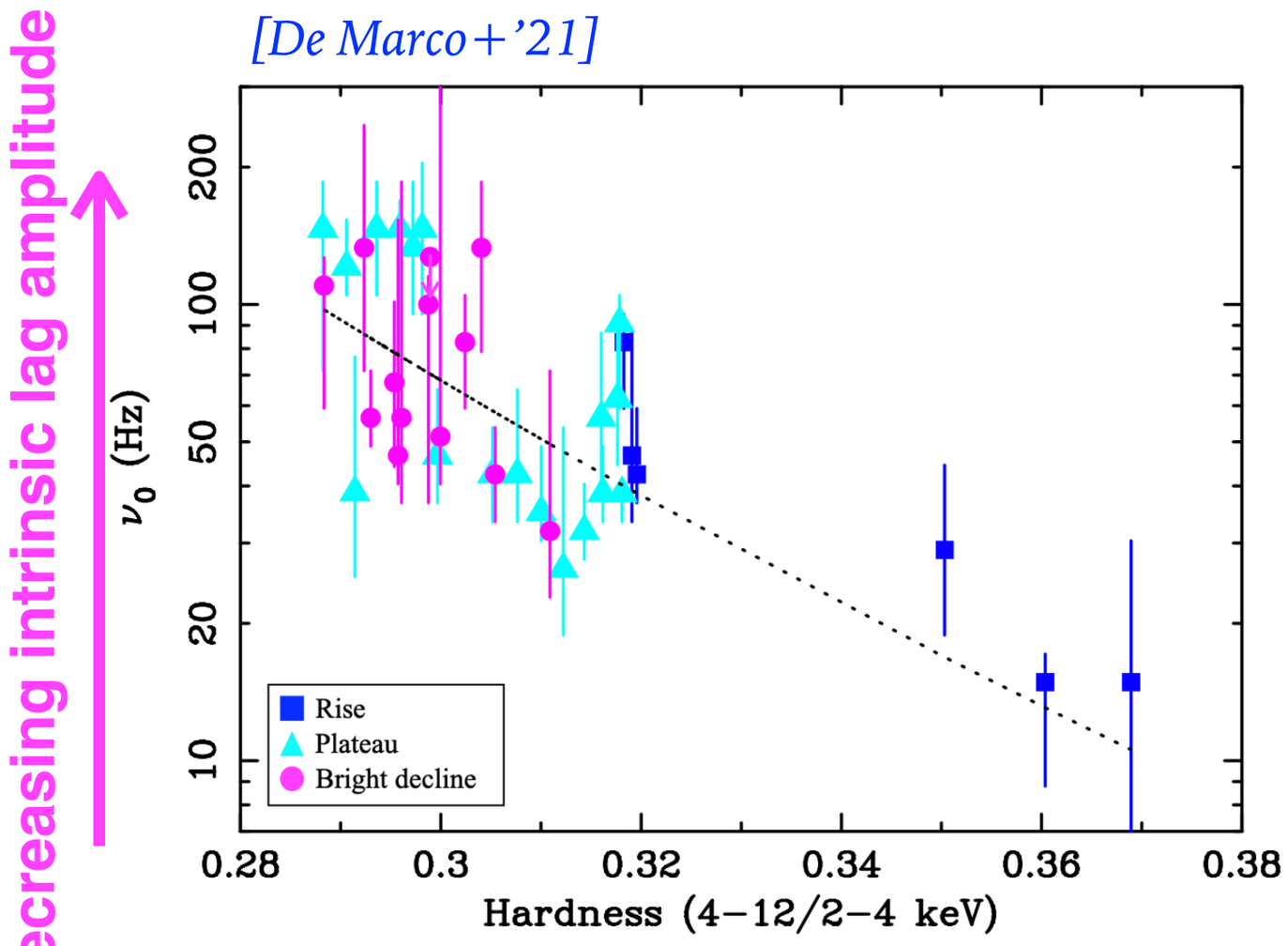
The evolution of X-ray reverberation lags

[De Marco+'21]



The evolution of X-ray reverberation lags

[De Marco+'21]

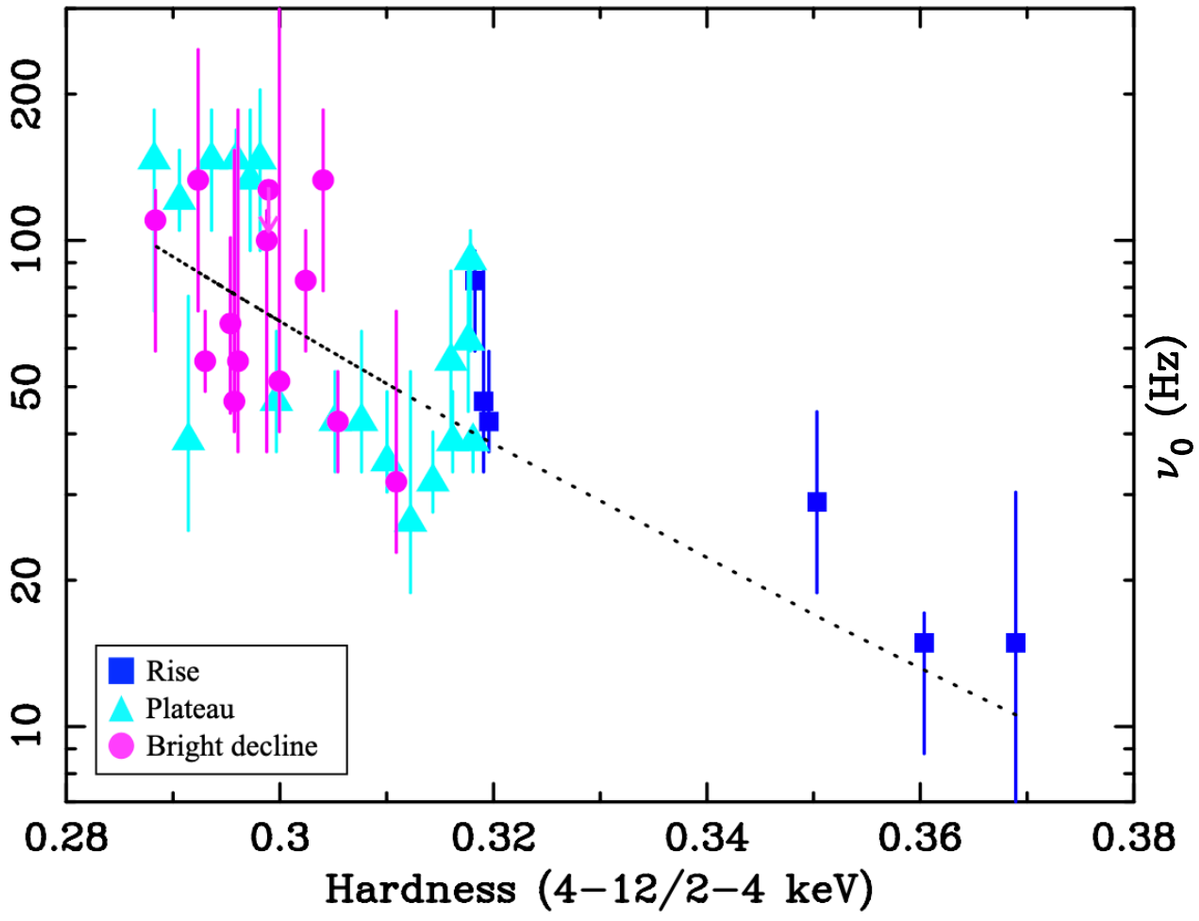


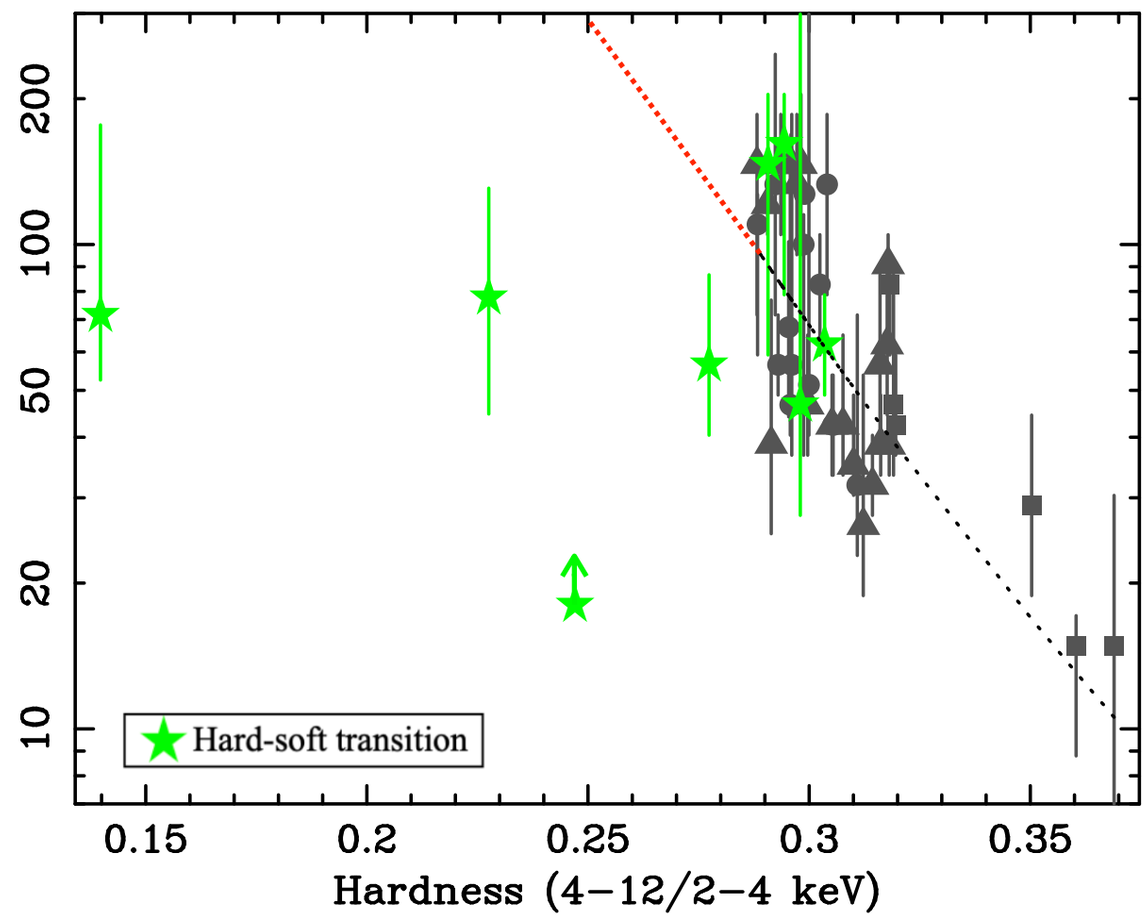
Steady decrease of relative distance between the hard X-ray source and the disc

The evolution of X-ray reverberation lags

Decreasing intrinsic lag amplitude

[De Marco+'21]





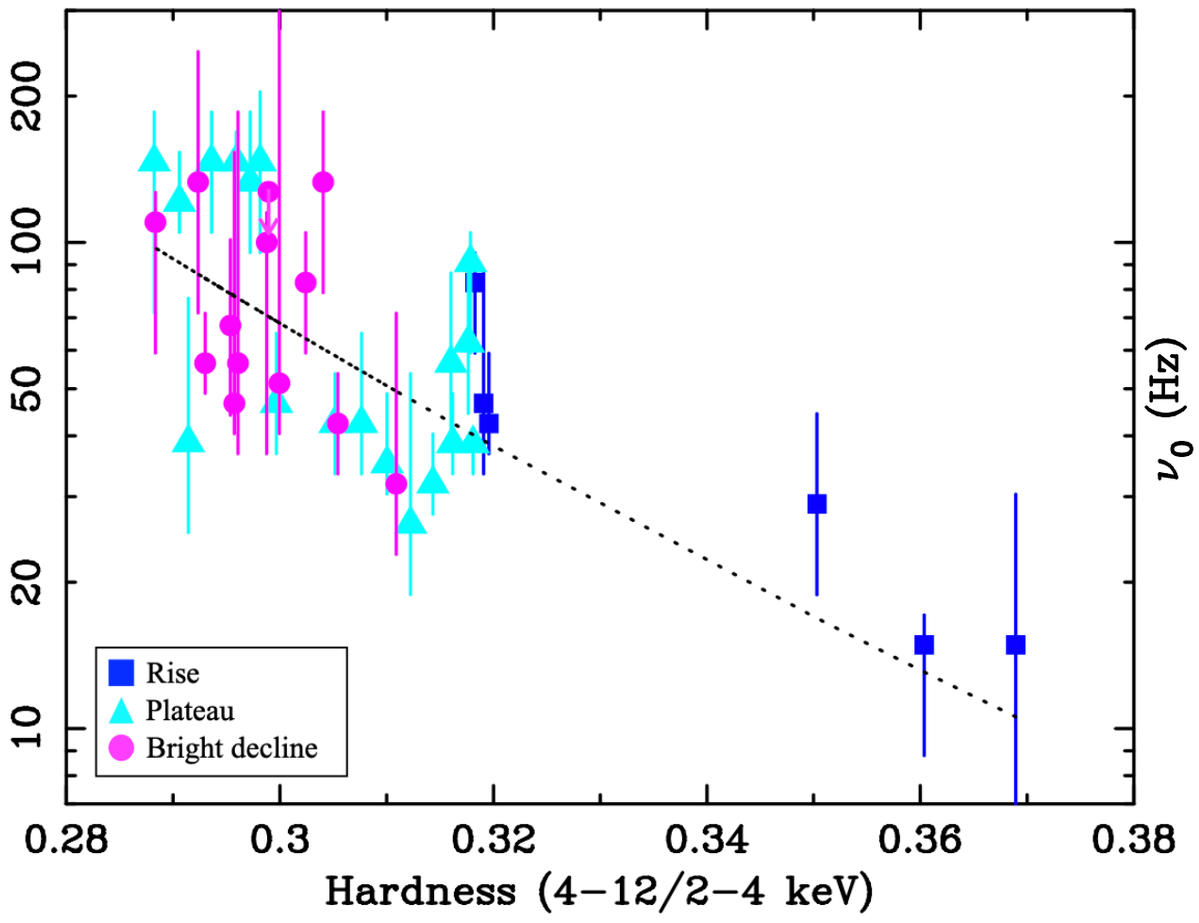
Steady decrease of relative distance between the hard X-ray source and the disc

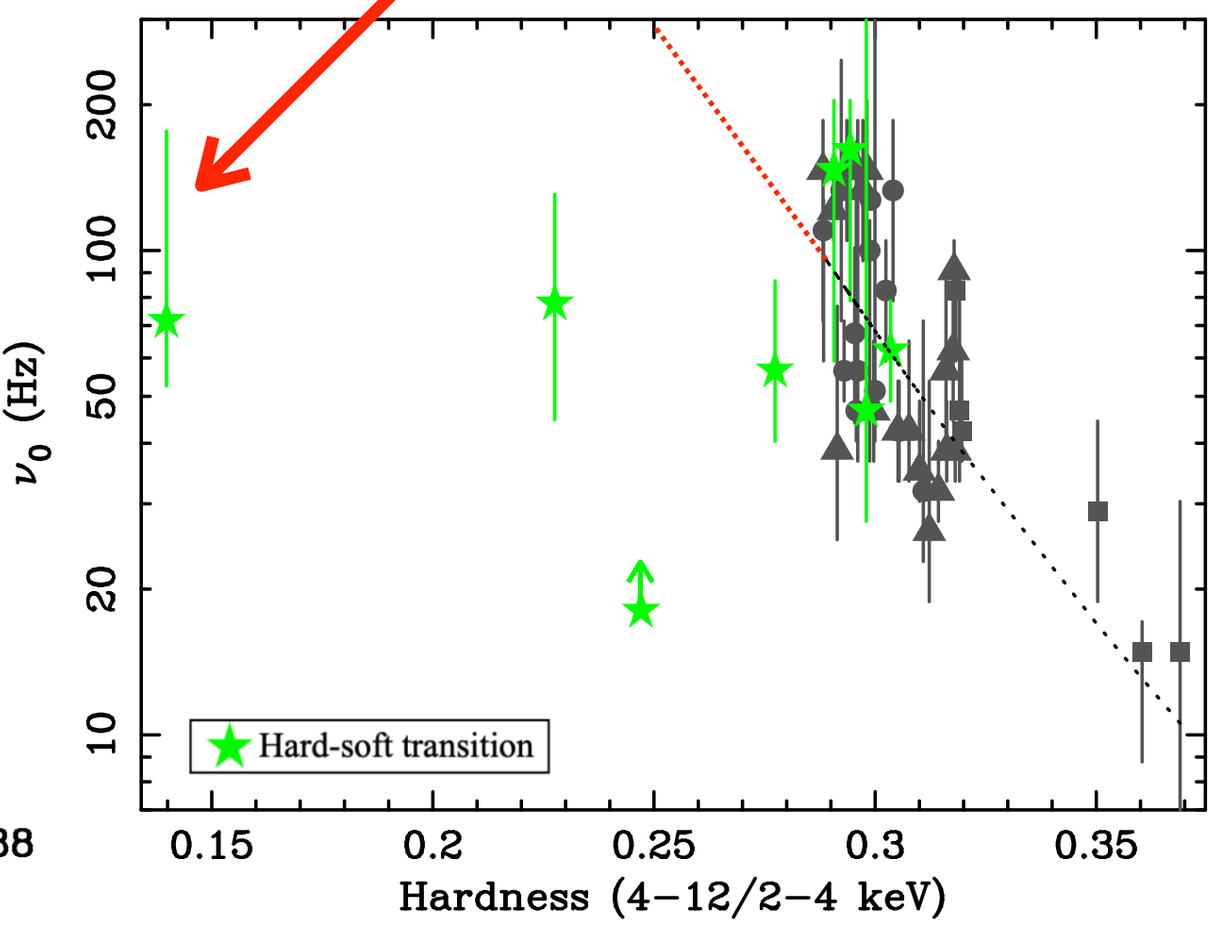
The evolution of X-ray reverberation lags

Estimated date of jet ejections
[Bright+'20; Wood+'21]

Decreasing intrinsic lag amplitude

[De Marco+'21]





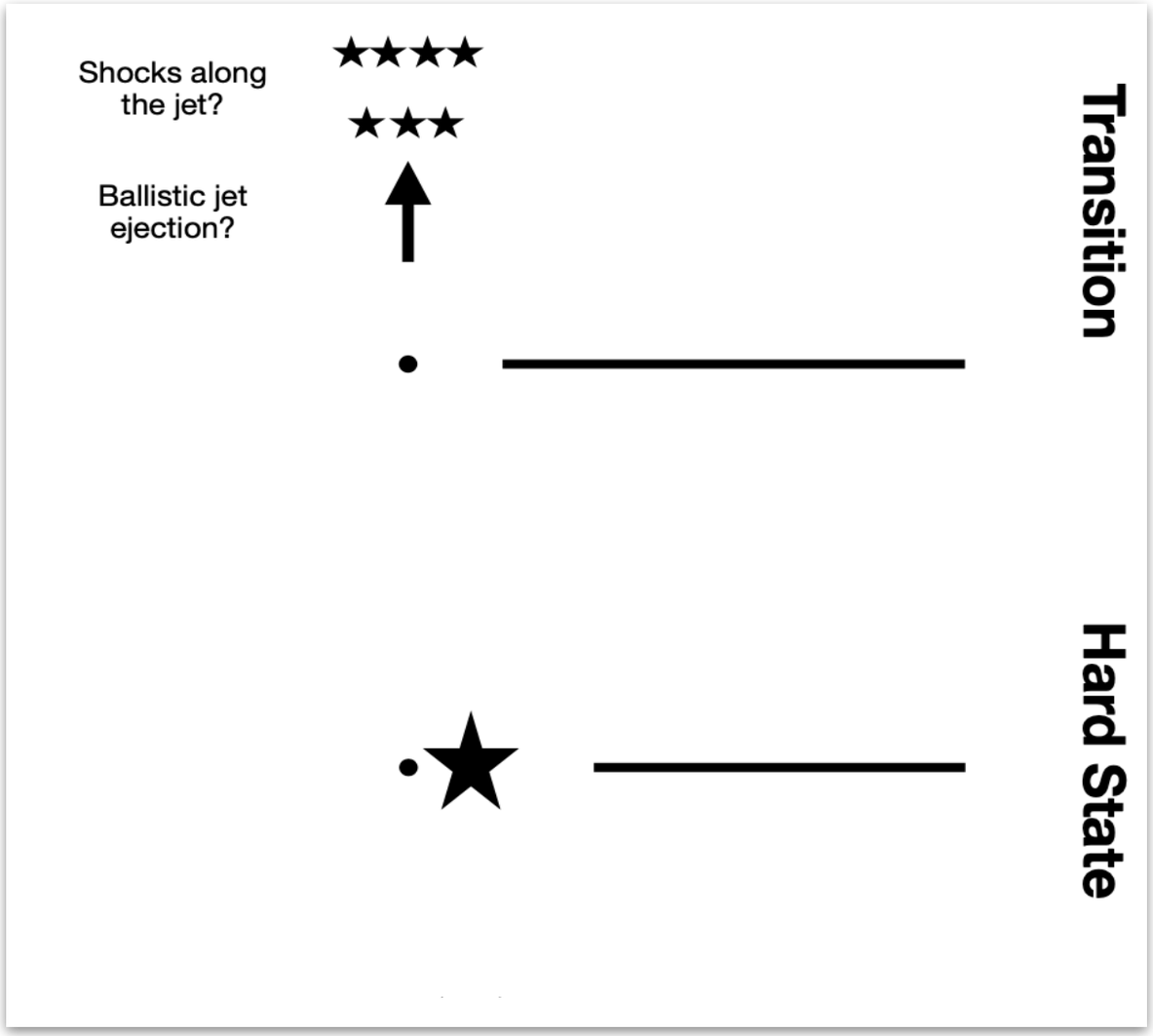
Steady decrease of relative distance between the hard X-ray source and the disc

Sudden increase of distance between the hard X-ray source and the disc

~4 days before jet ejections

The evolution of X-ray reverberation lags

[De Marco+'21]

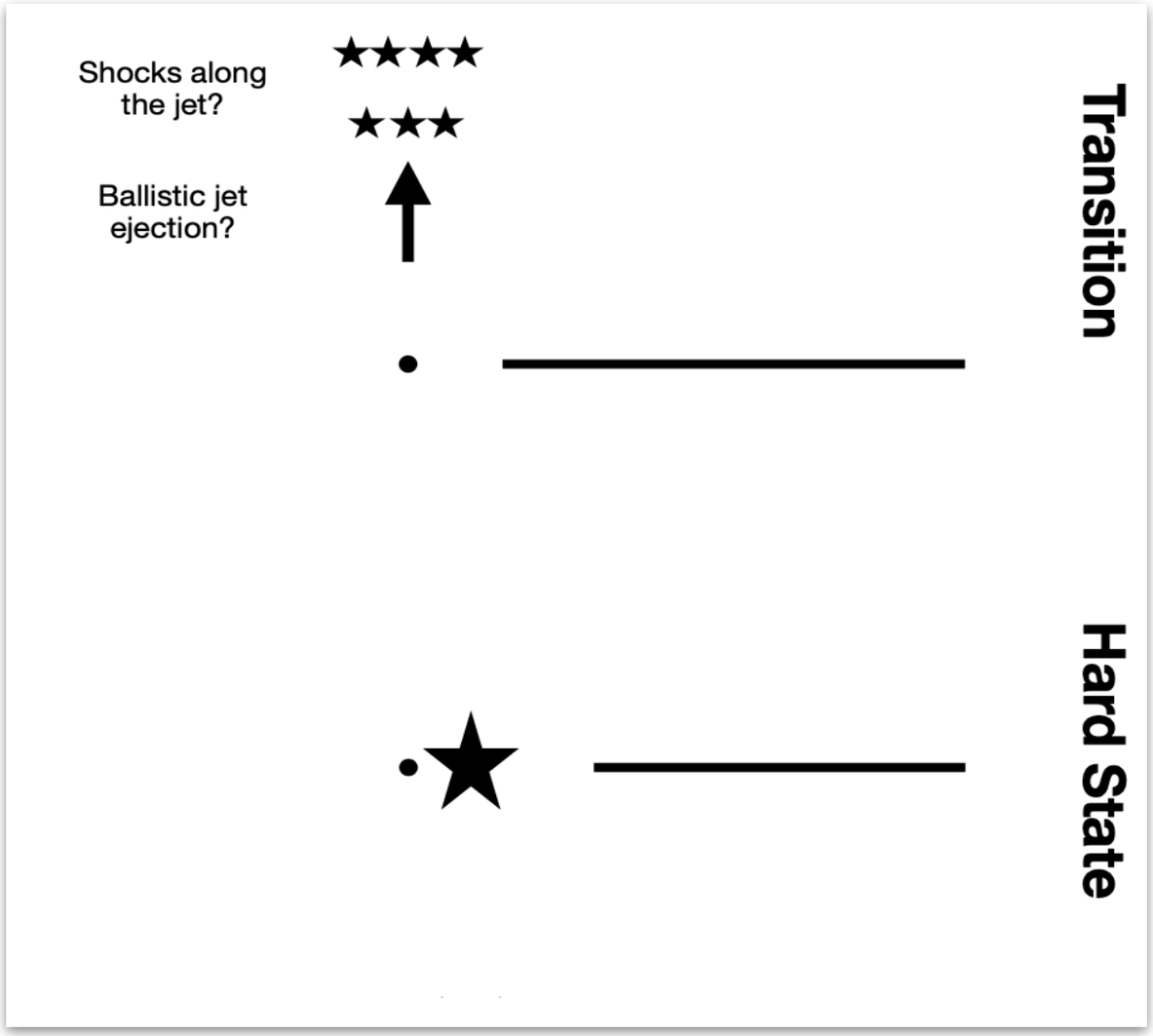


Longer reverberation lags at transition:

dissipation of hard X-rays occurring in a larger or more distant region associated with the jet

The evolution of X-ray reverberation lags

[De Marco+'21]



Longer reverberation lags at transition:

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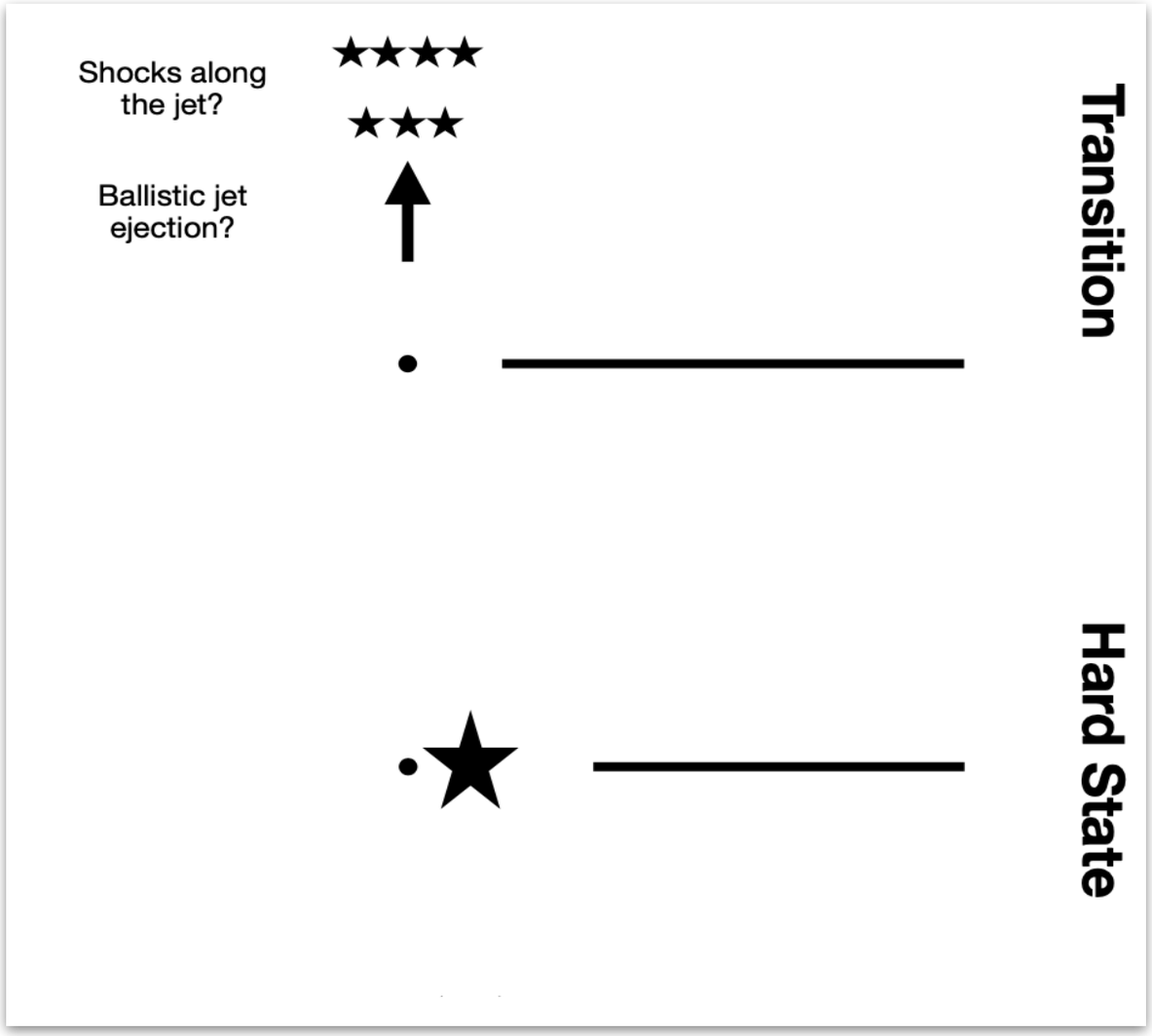
[see also Wang+'21]

The evolution of X-ray reverberation lags

[De Marco+'21]



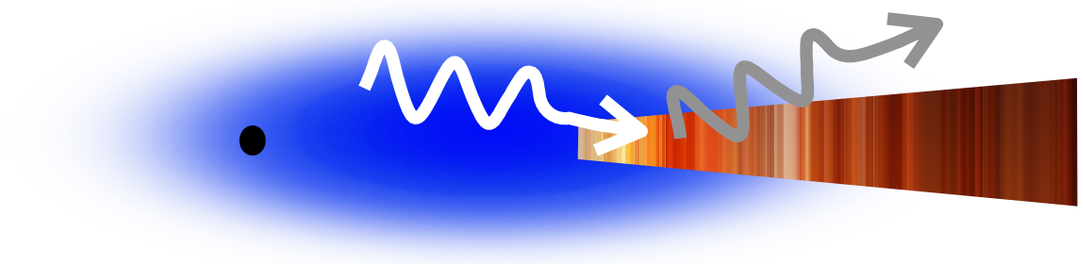
When does the disc reach ISCO?

Longer reverberation lags at transition:

dissipation of hard X-rays occurring in a larger or more distant region associated with the jet

[see also Wang+'21]

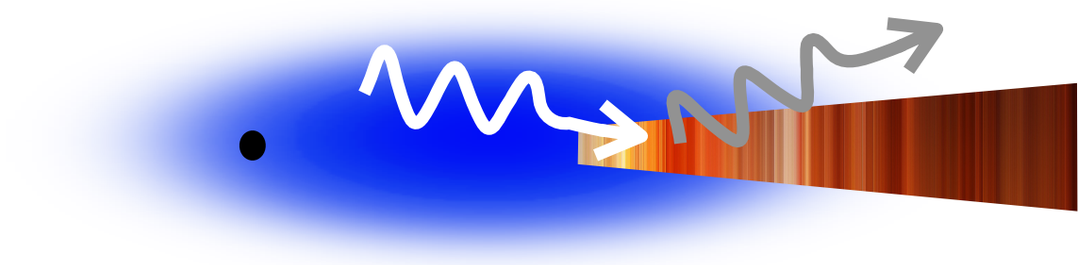
An increasingly hotter disc reprocessing region



Spectrum of linearly correlated variable components (covariance spectra)

[De Marco+'21]

An increasingly hotter disc reprocessing region



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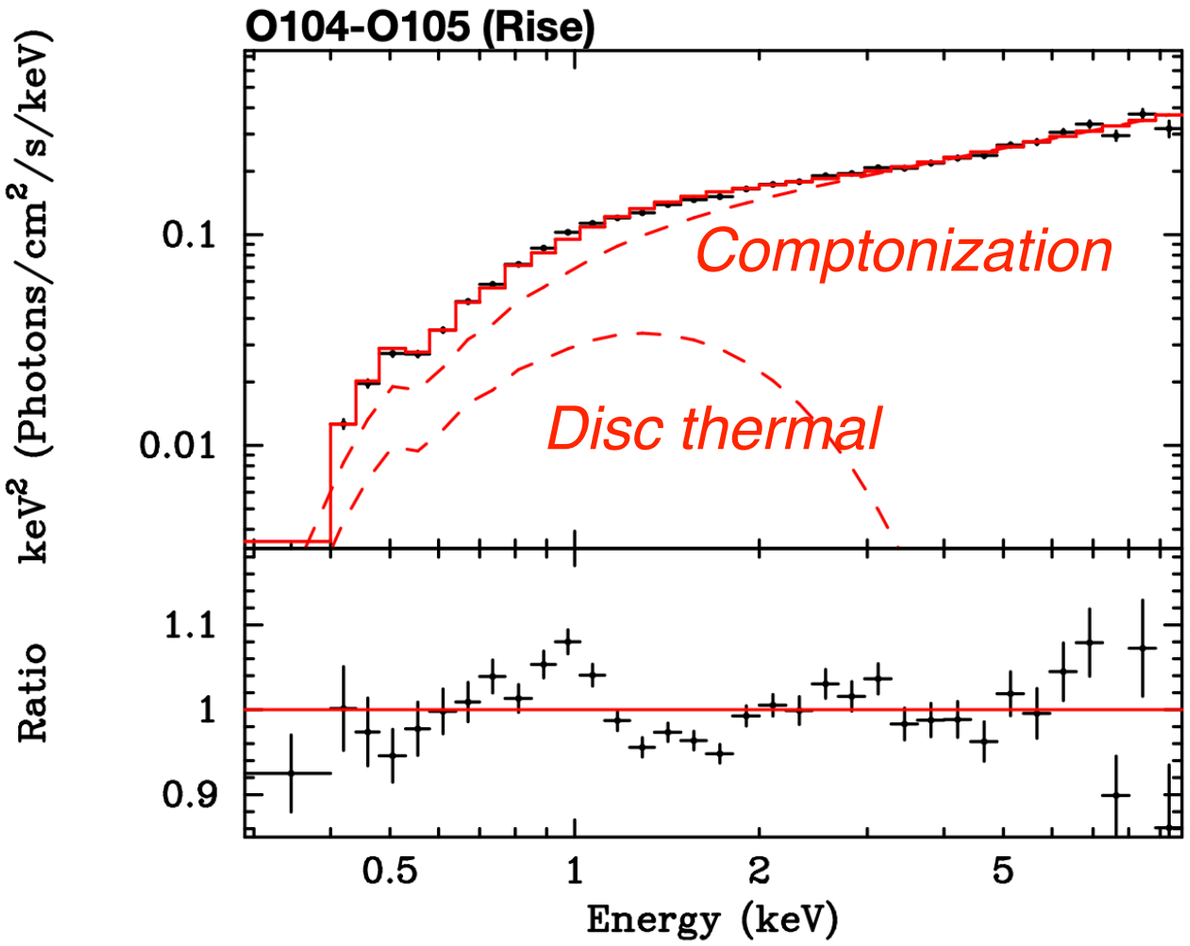

[De Marco+'21]

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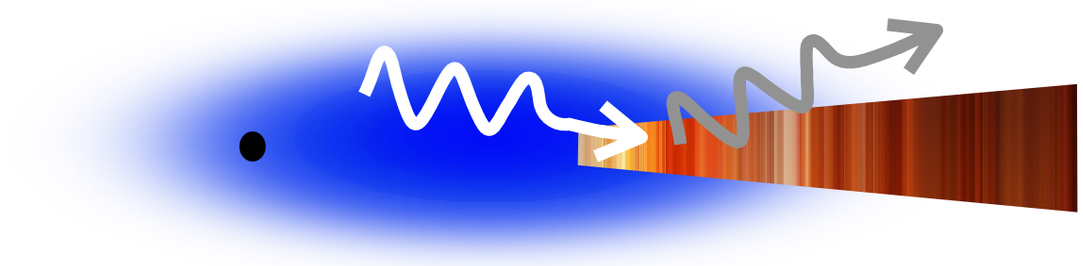

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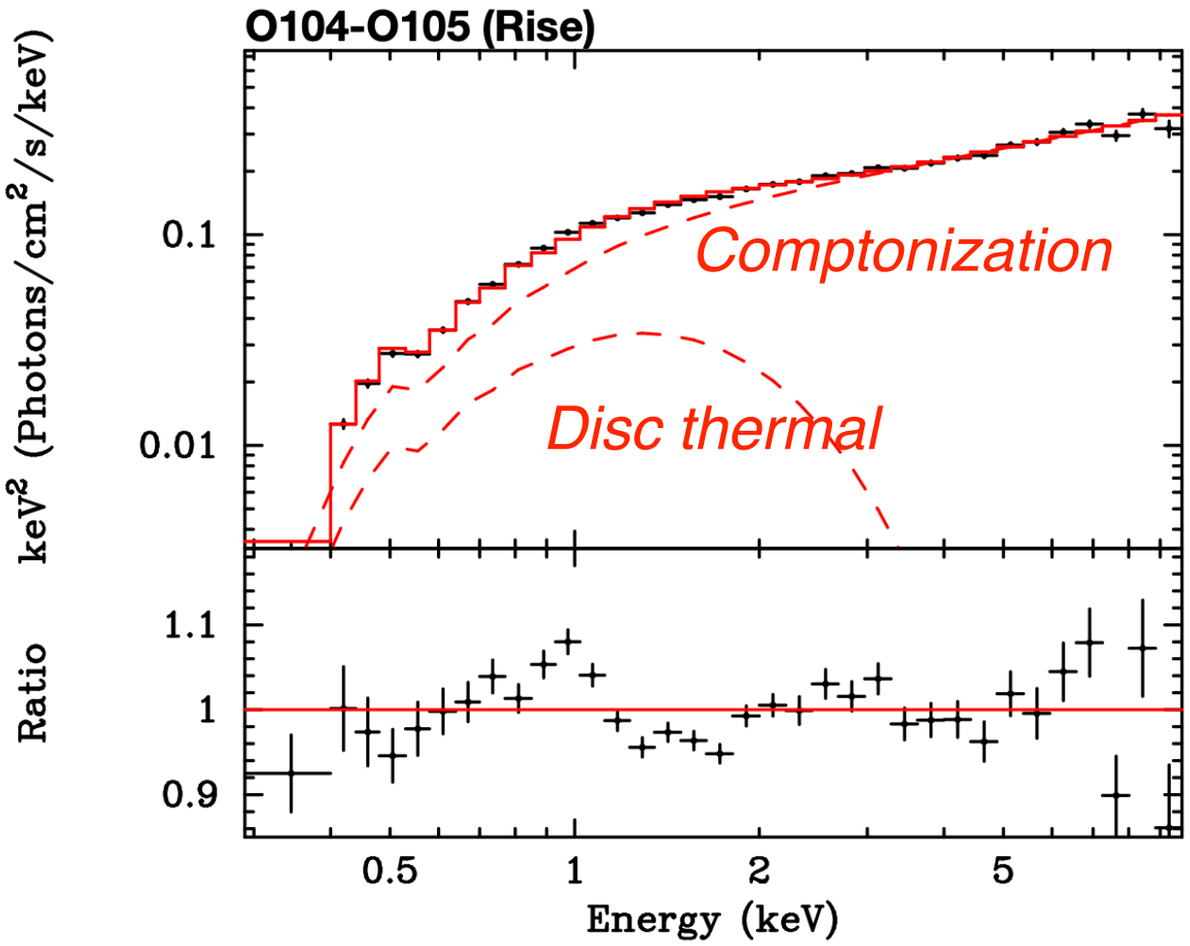
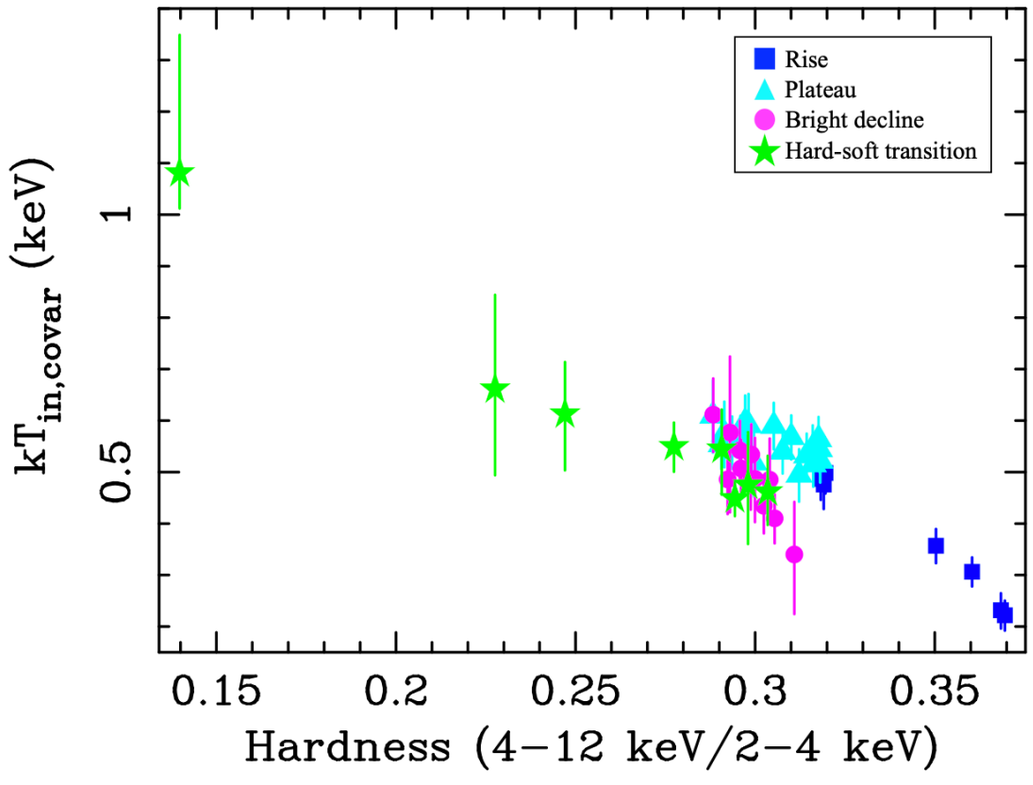
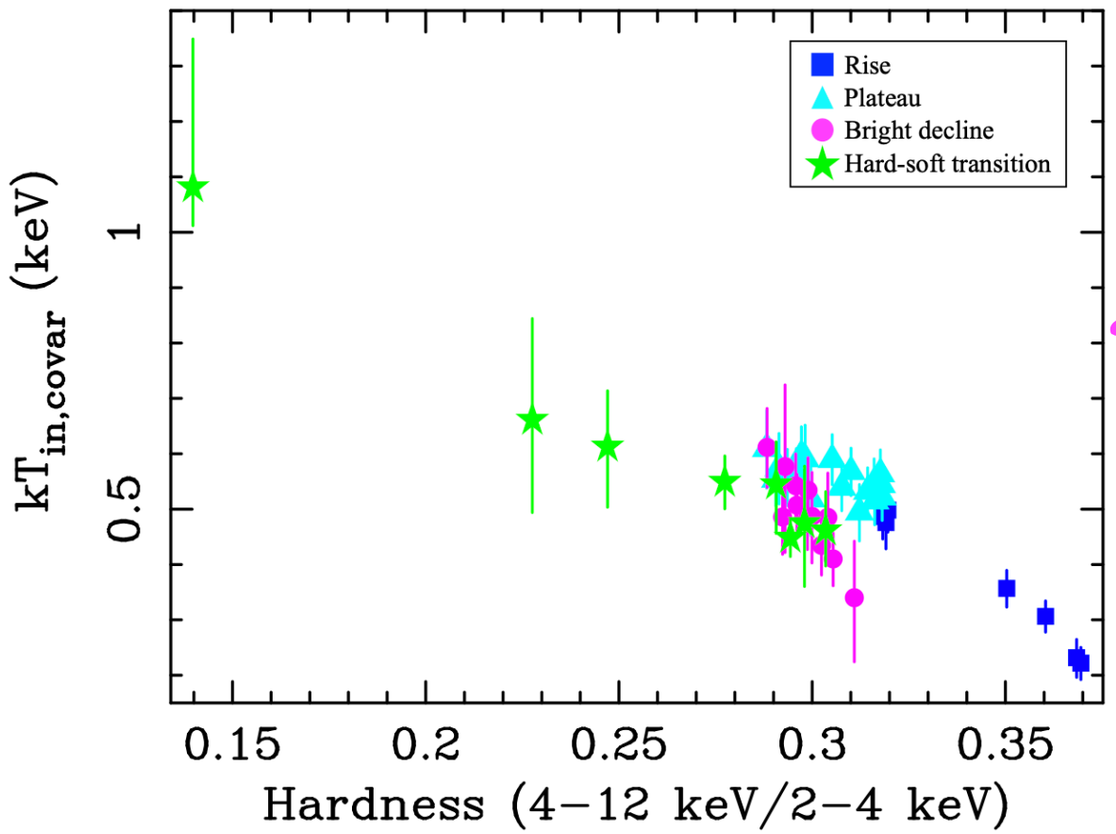




The temperature of the disc region where reprocessing occurs steadily increases (no break at transition!)

[De Marco+'21]

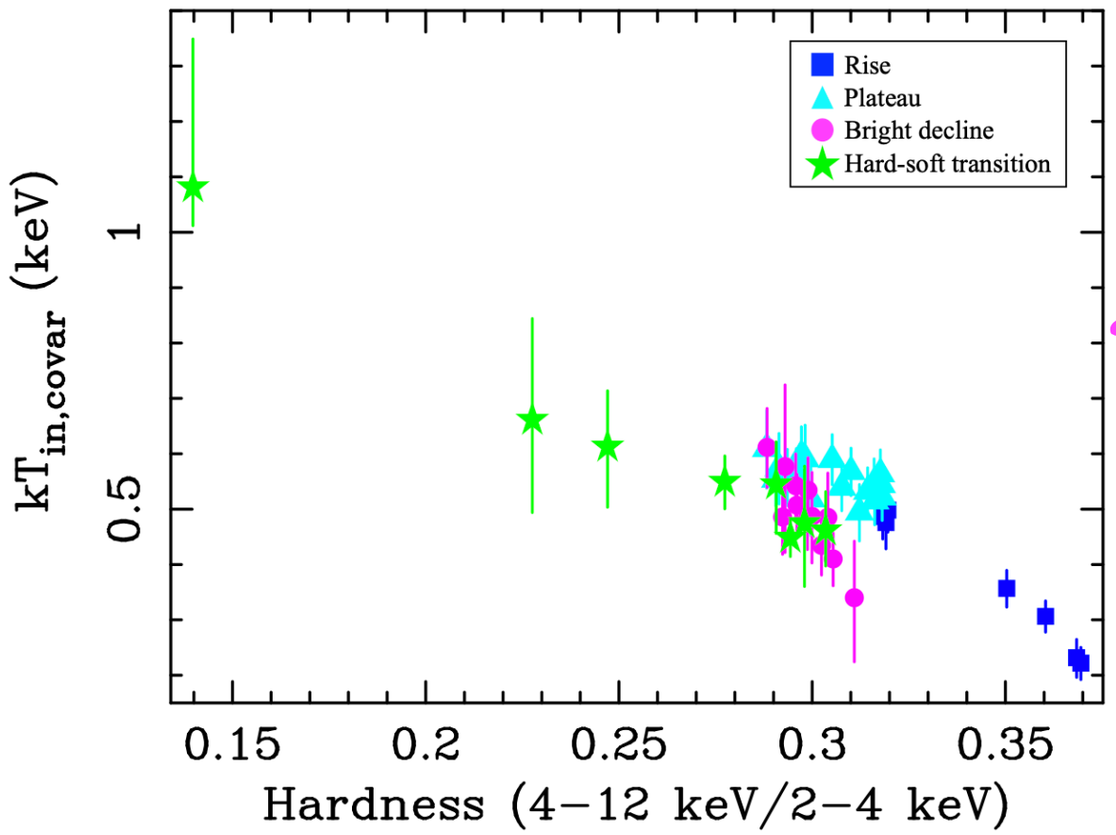
An increasingly hotter disc reprocessing region



$$\frac{R_{\rm in}}{R_{\rm g}} \gtrsim 10 \frac{\mathcal{R}^{1/2}(1-a)^{1/2} l_{\rm irr}^{1/2}}{(kT_{\rm eff}/1\ {\rm keV})^2 (M/10M_\odot)^{1/2}}$$

[Zdziarski & De Marco+'20]

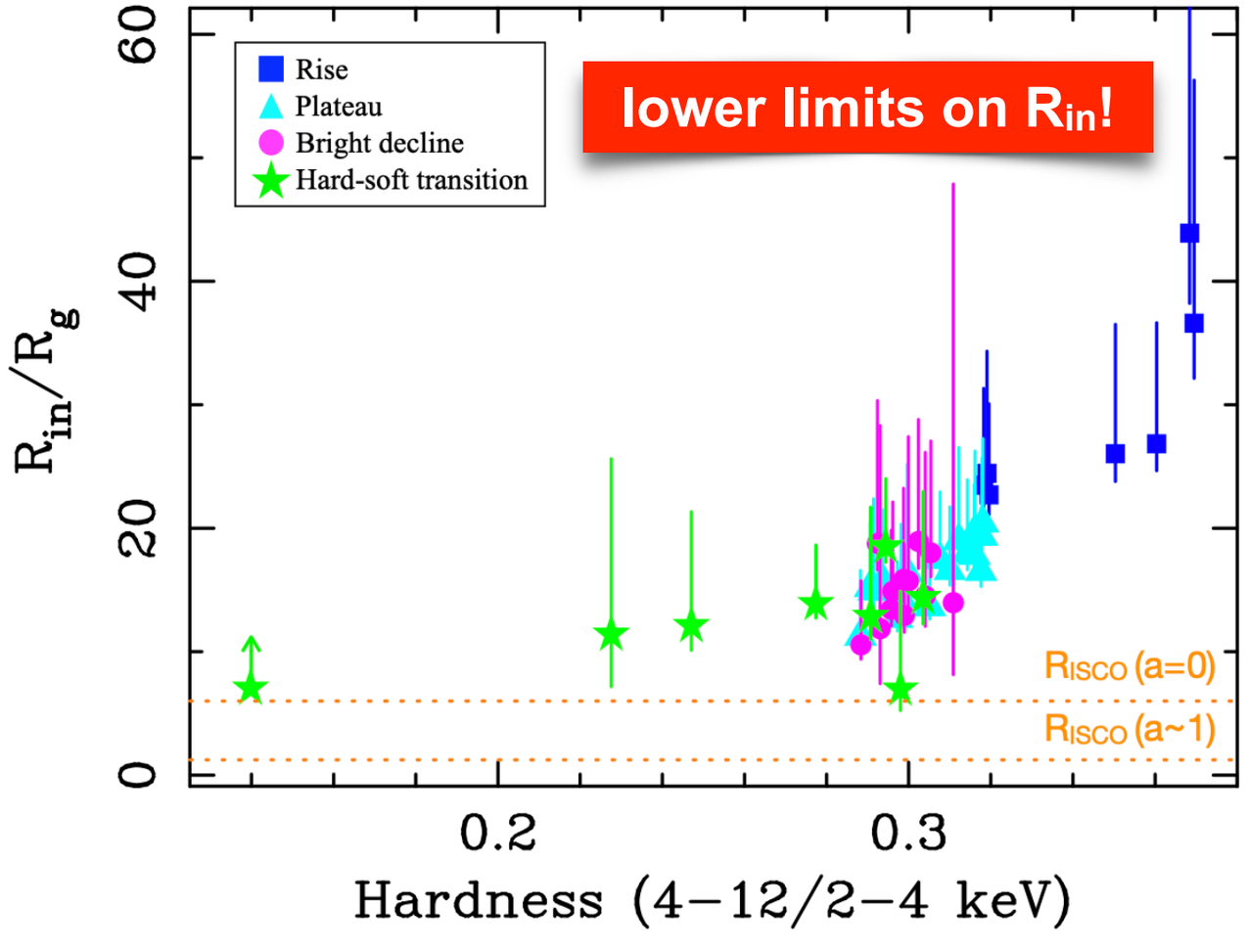
An increasingly hotter disc reprocessing region



$$\frac{R_{\rm in}}{R_{\rm g}} \gtrsim 10 \frac{\mathcal{R}^{1/2}(1-a)^{1/2} l_{\rm irr}^{1/2}}{(kT_{\rm eff}/1\ {\rm keV})^2 (M/10M_\odot)^{1/2}}$$

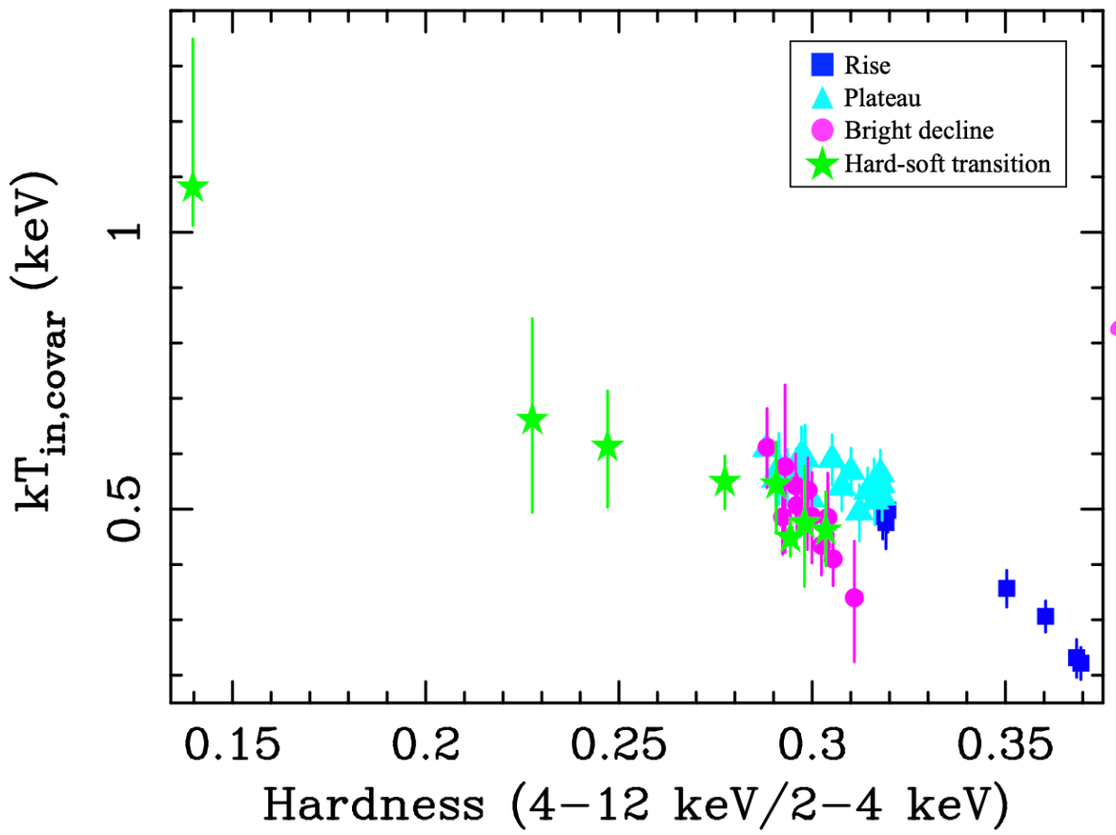
[Zdziarski & De Marco+'20]

[De Marco+'21]



The increase of temperature is consistent with a decrease of inner disc radius

An increasingly hotter disc reprocessing region



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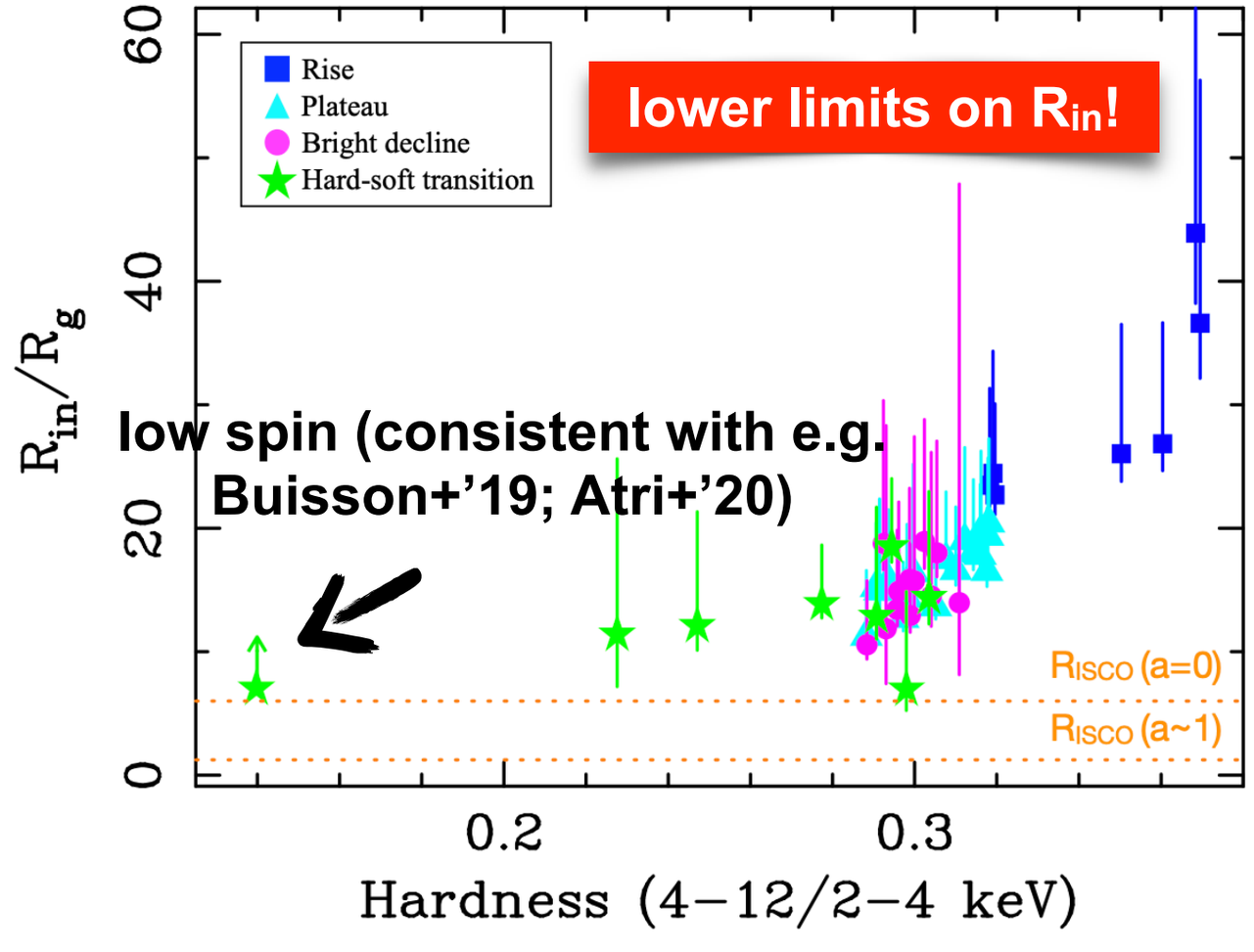

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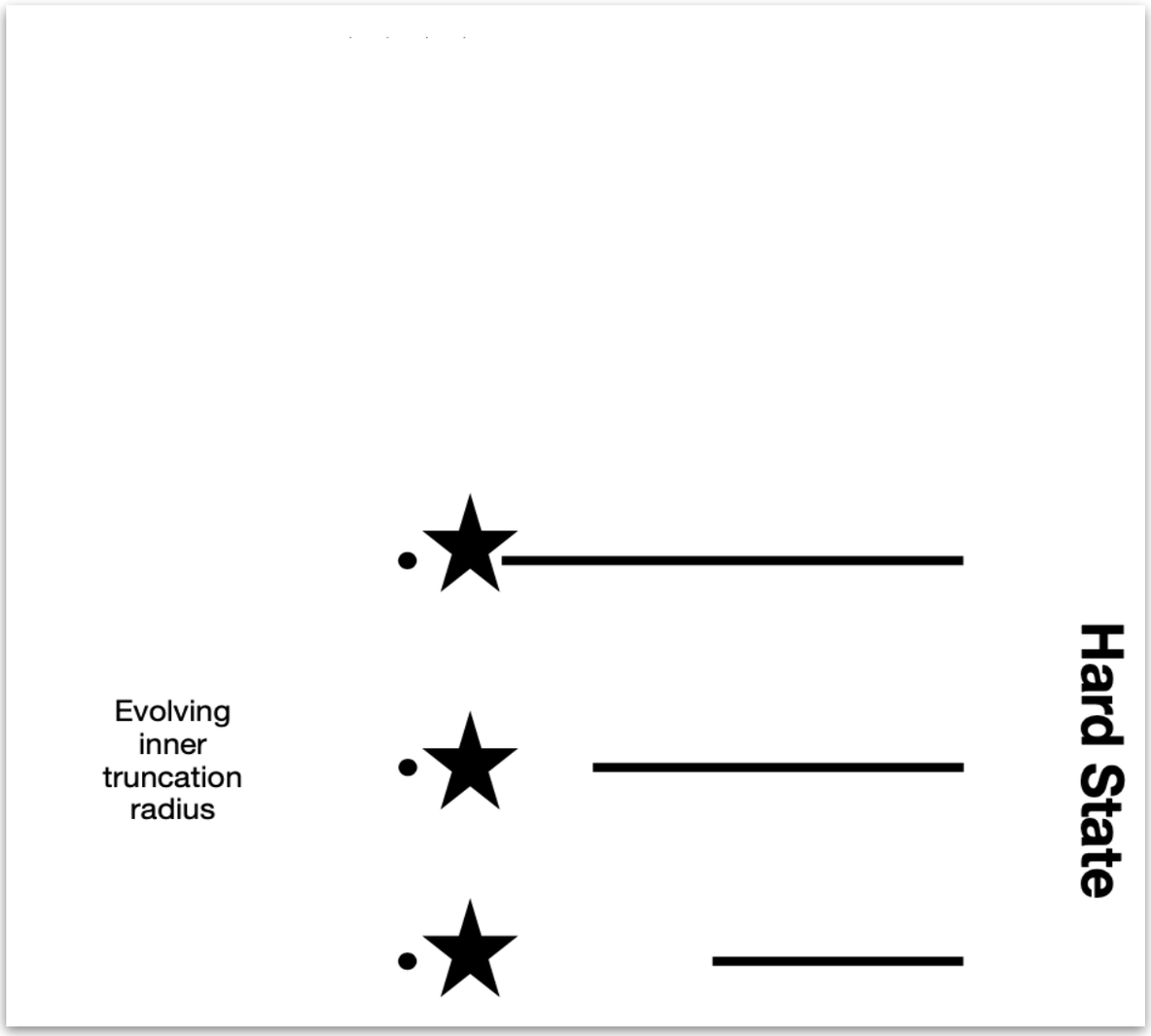
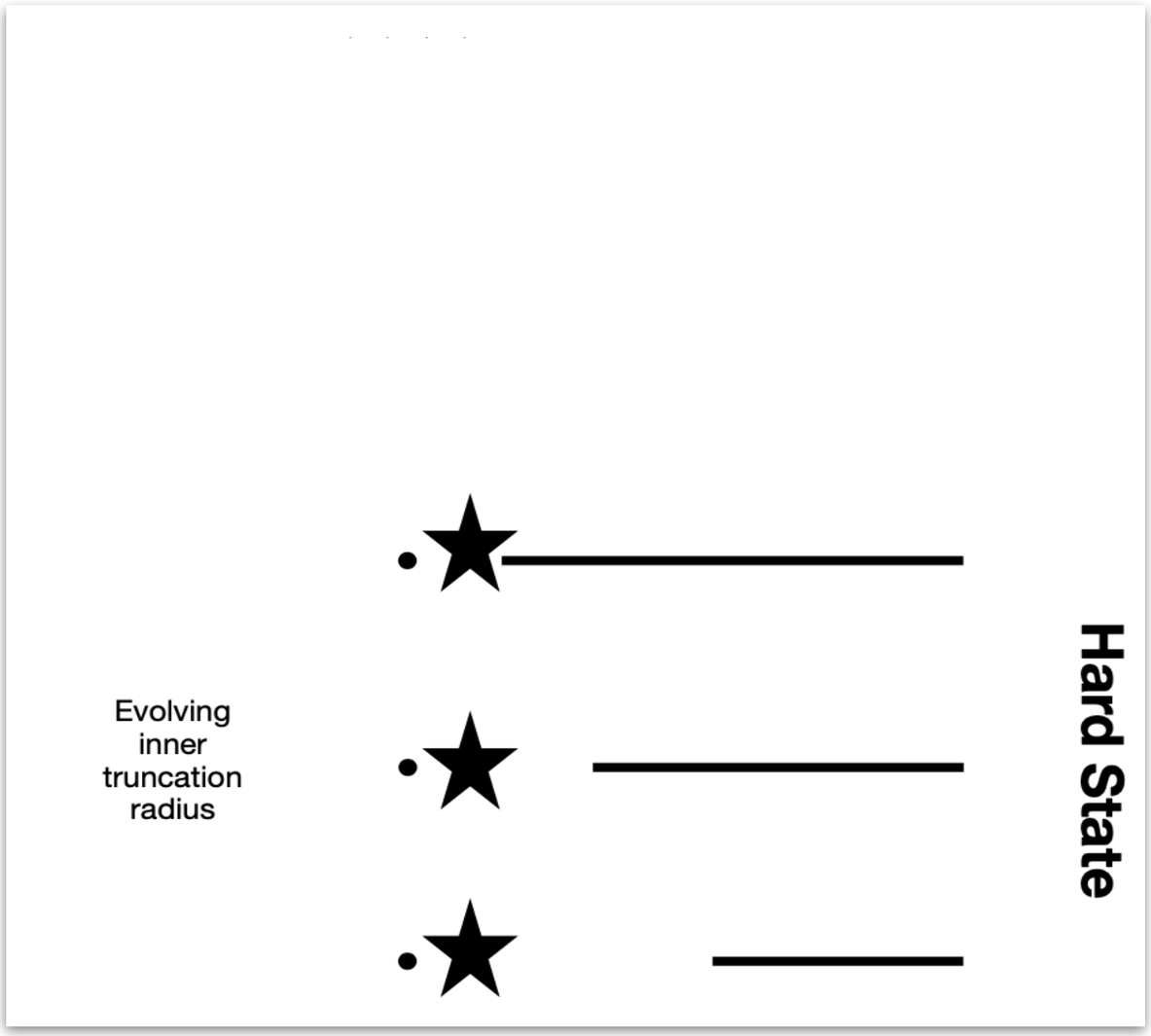
Summary of results



[De Marco+'21]

Summary of results



[De Marco+'21]

Outburst starts with long reverberation lags, cold truncated disc

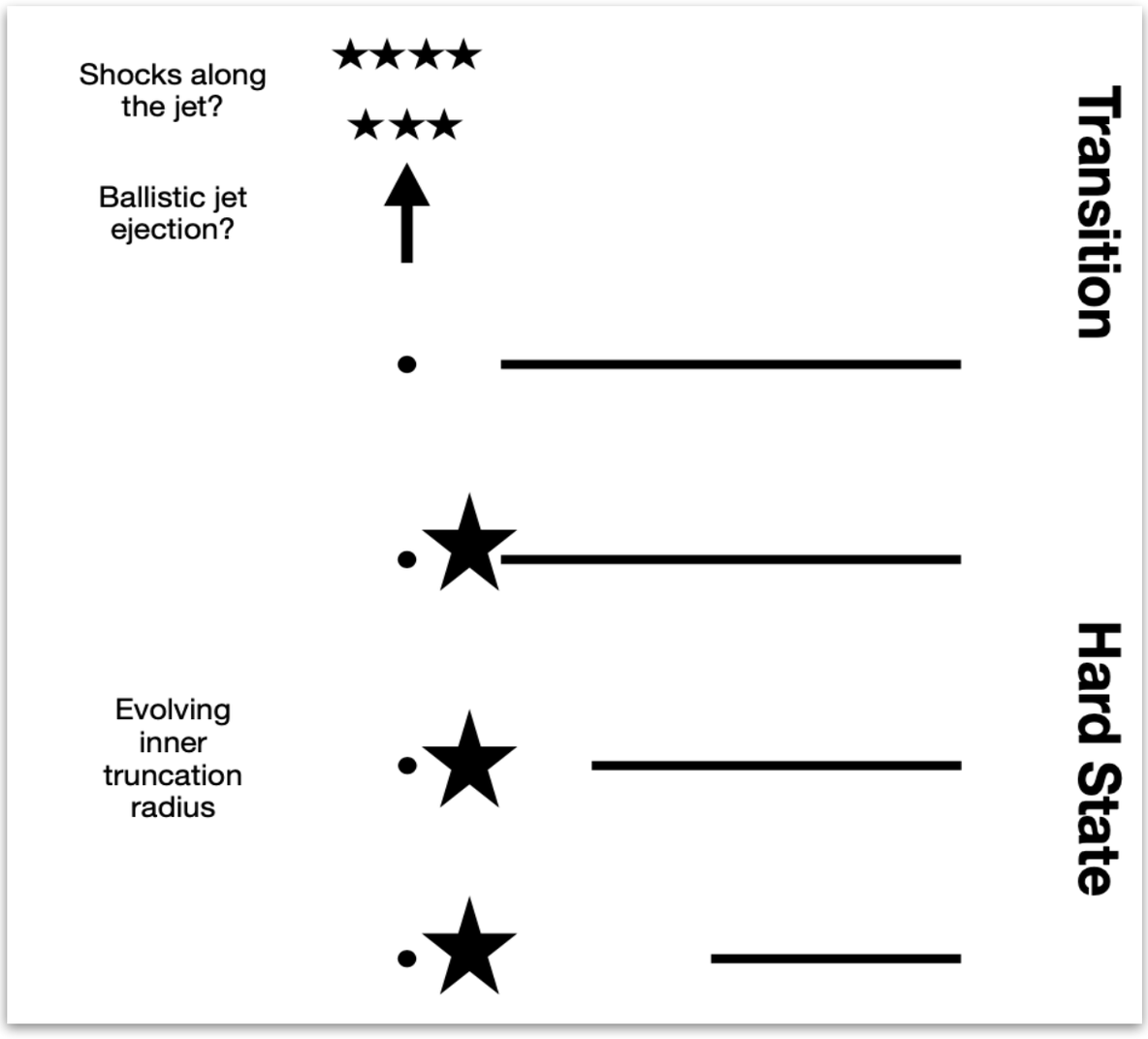
Increasingly shorter reverberation lags, increasingly hotter and less truncated disc (Rev lag and $kT_{in,covar}$ follow the same trend)

Inner radius moving inwards
Hard X-rays dissipated close to the BH

Summary of results

Very hot disc, Small/no truncation
BUT
Very long reverberation lags, No continuum hard lags, Relativistic ejections
(Rev lag and $kT_{in,covar}$ stop following the same trend)

Inner radius reaching (close to) ISCO of a non-spinning BH
Hard X-rays dissipated in the jet



[De Marco+'21]

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Thank you!