FERO Meeting
Krakow, Poland
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X-ray reverberation lags in AGN

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Collaborators:
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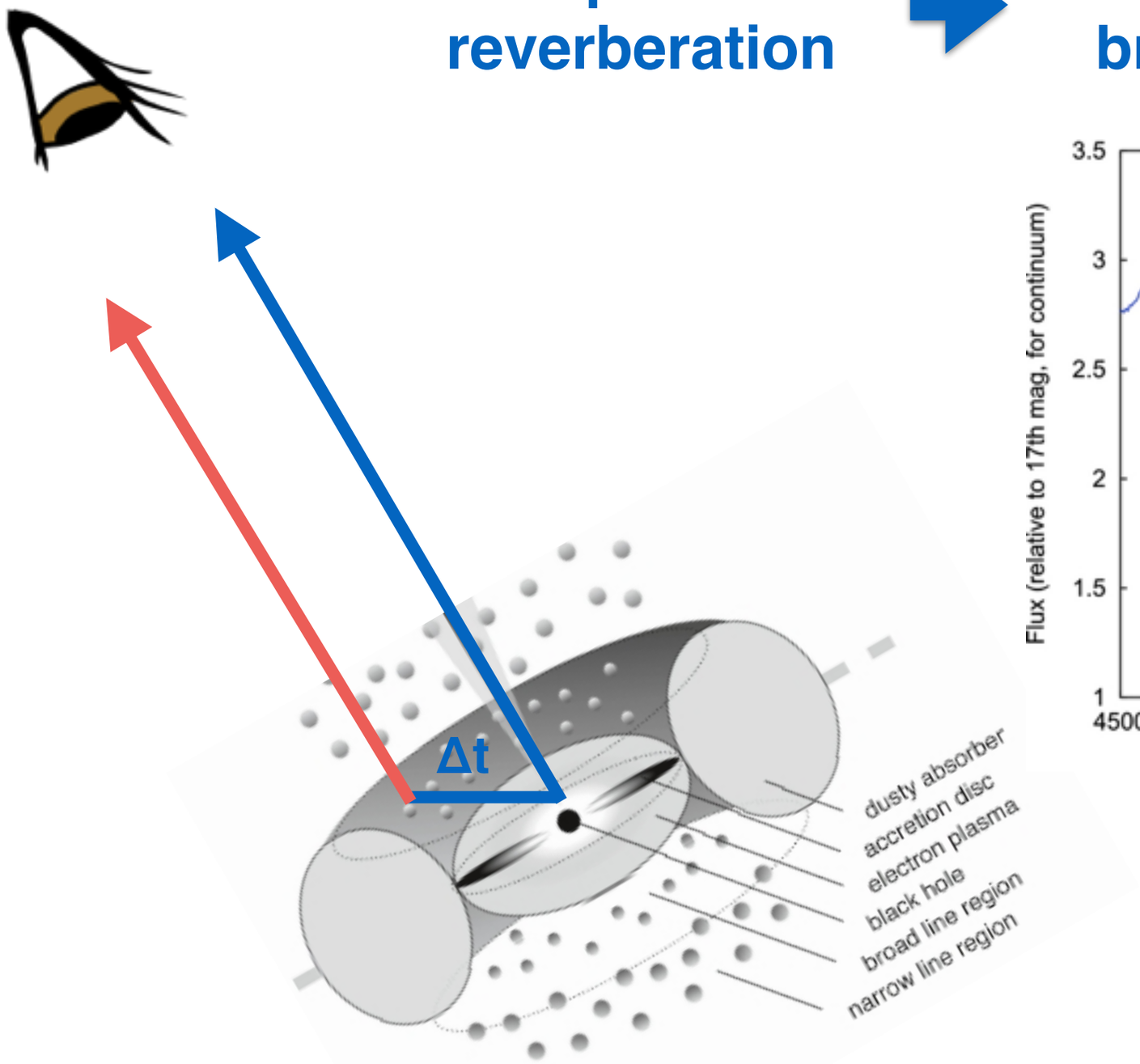
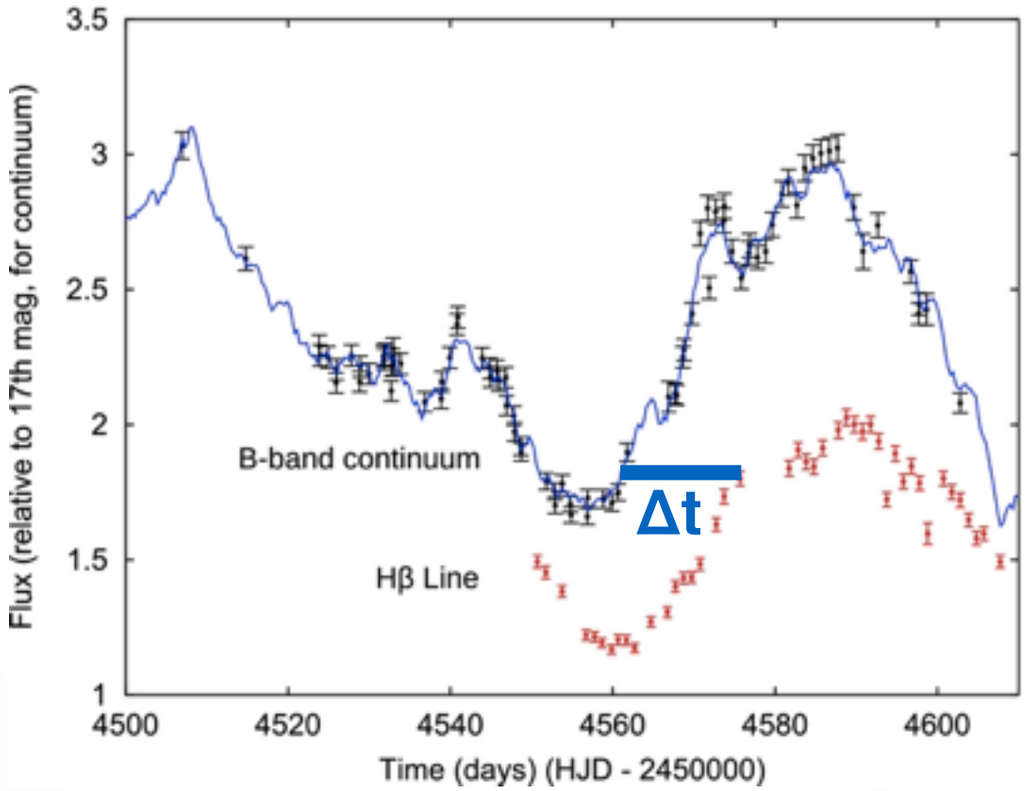
Giorgio Matt, Andrea Marinucci, Dom Walton, Fiona Harrison
Michael Parker, Will Alston, Giovanni Miniutti

Reverberation mapping

Optical reverberation → **mapping the broad line region**





Peterson+

Δt ~ days

Reverberation mapping

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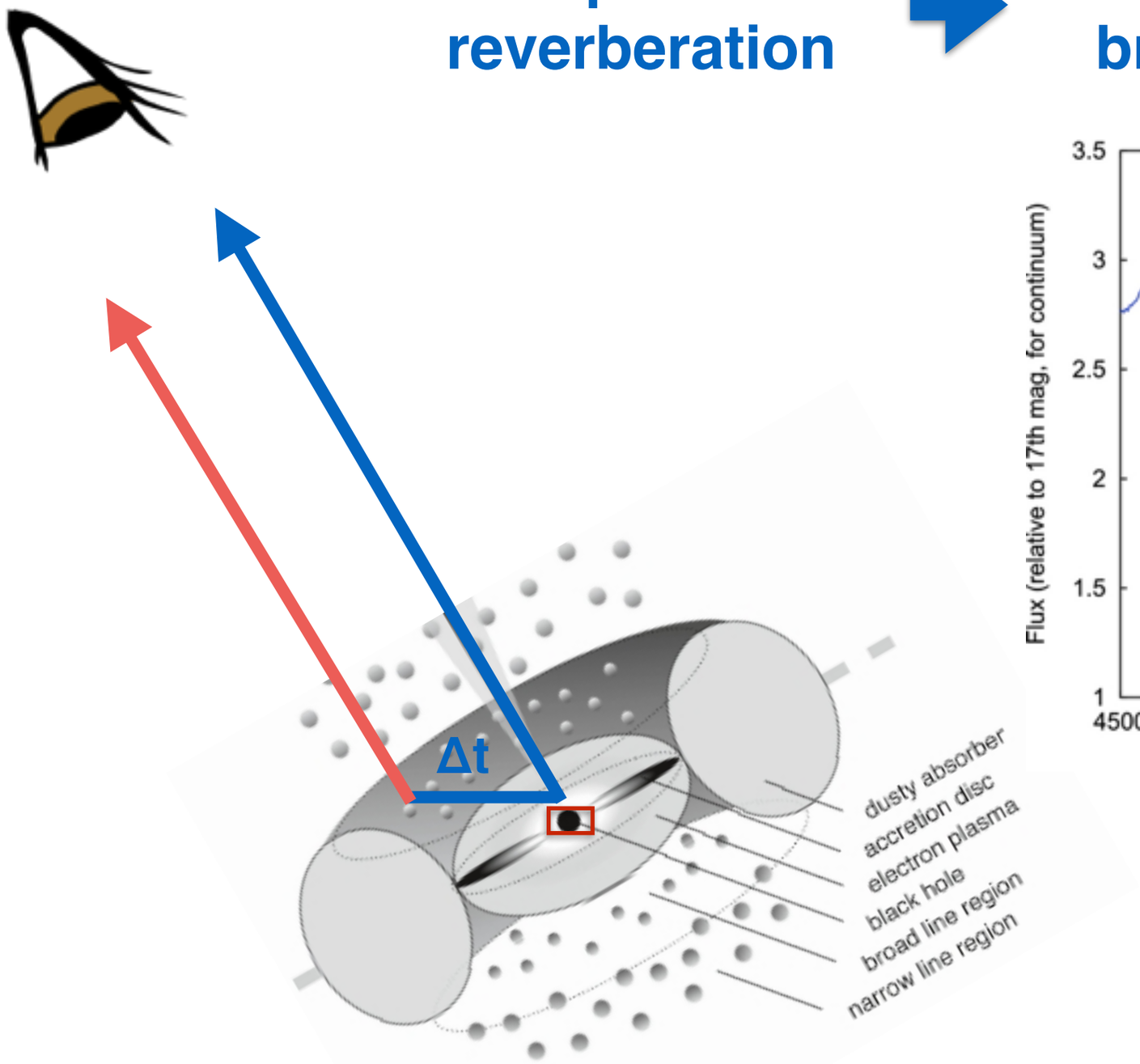

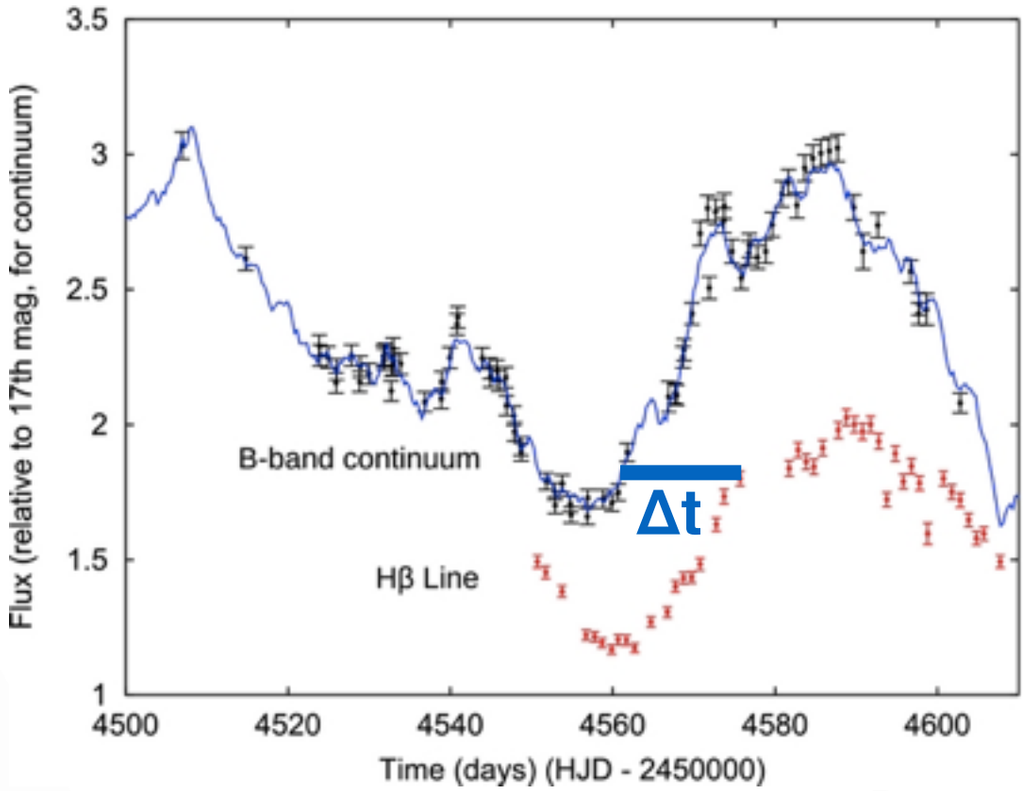

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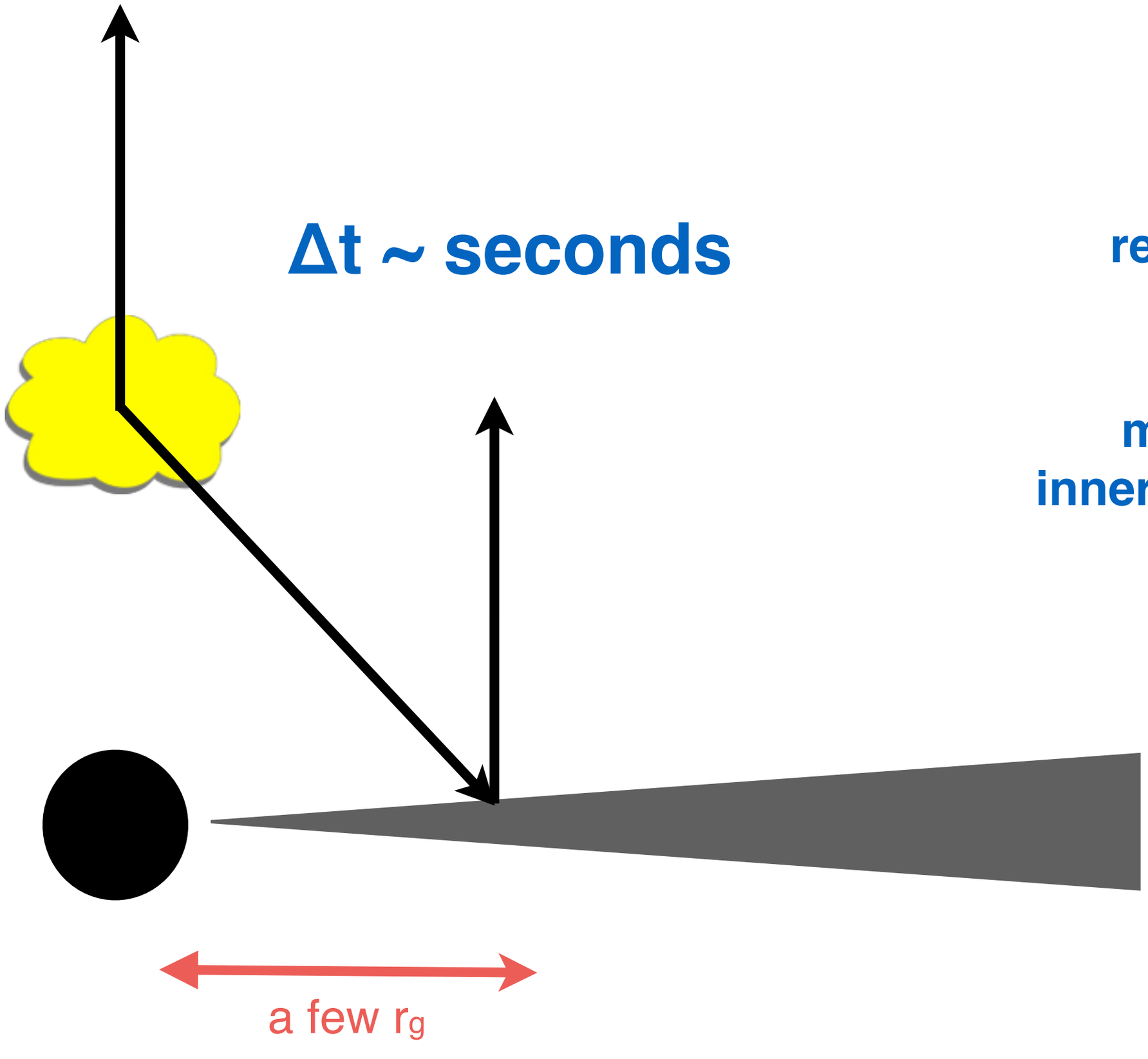
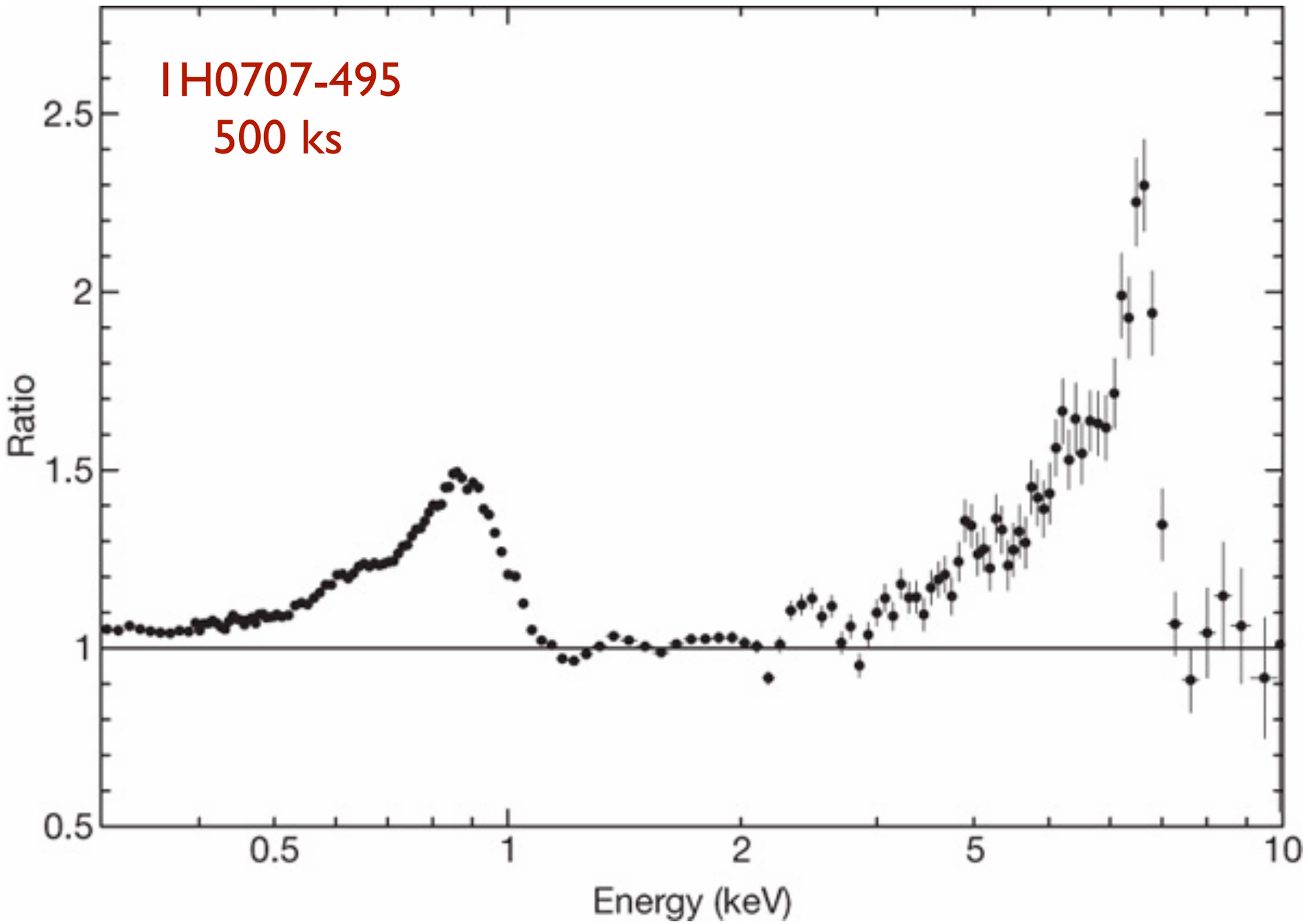


X-ray reverberation

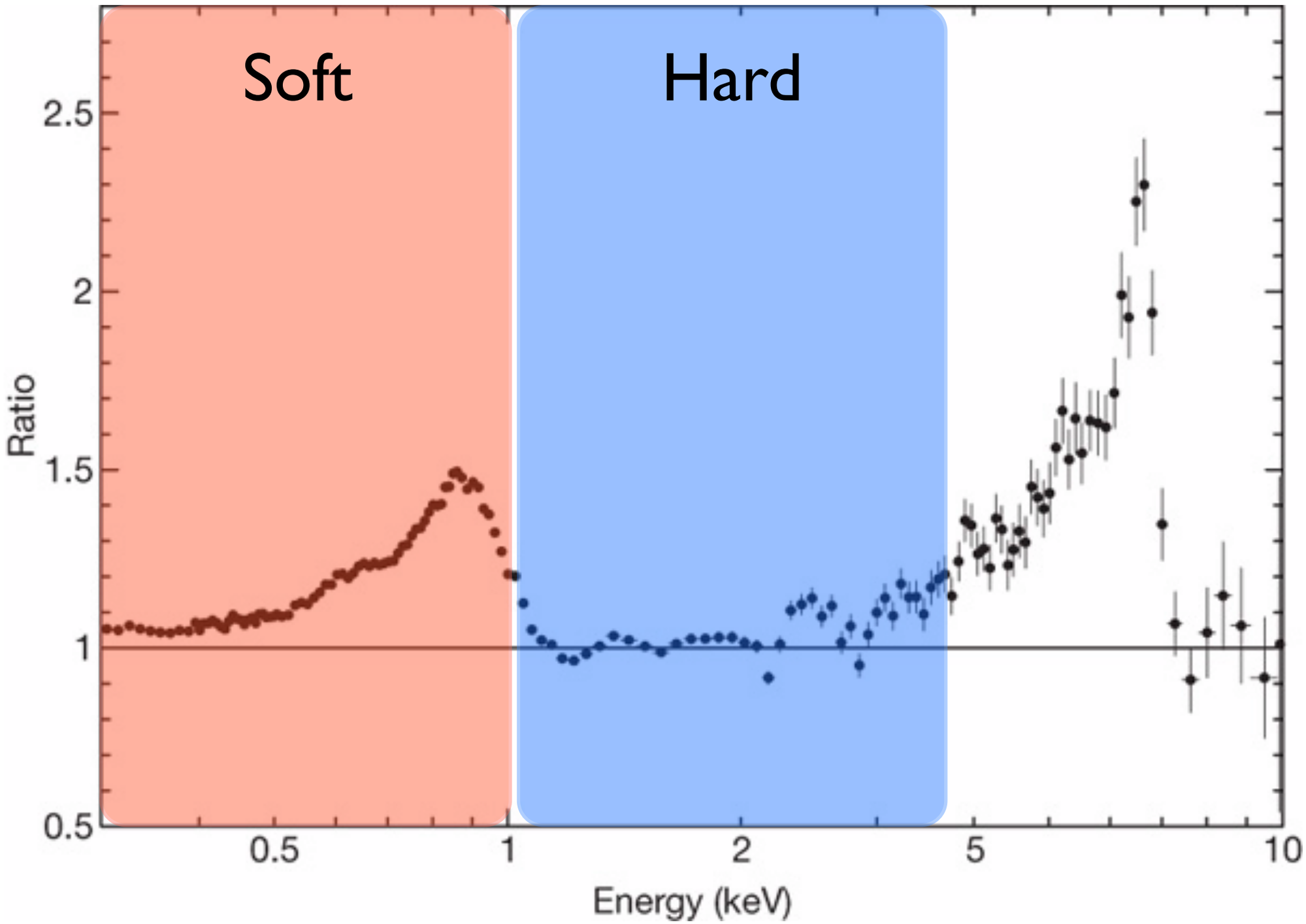
mapping the inner accretion flow

Broad Iron Lines in 1H0707-495



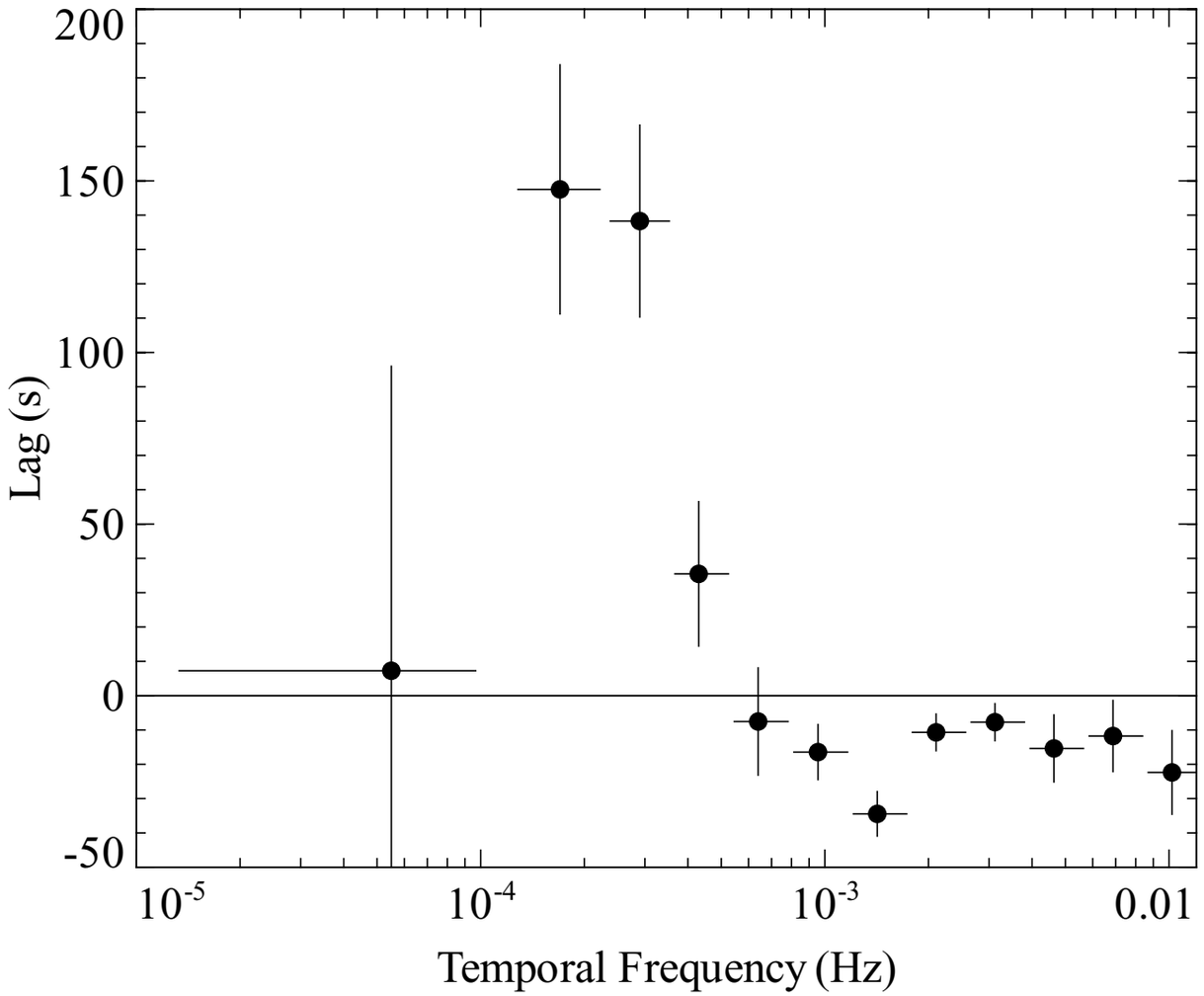
Fabian et al. 2009

Relativistic reflection in 1H0707-495



Fabian et al. 2009

The soft lag

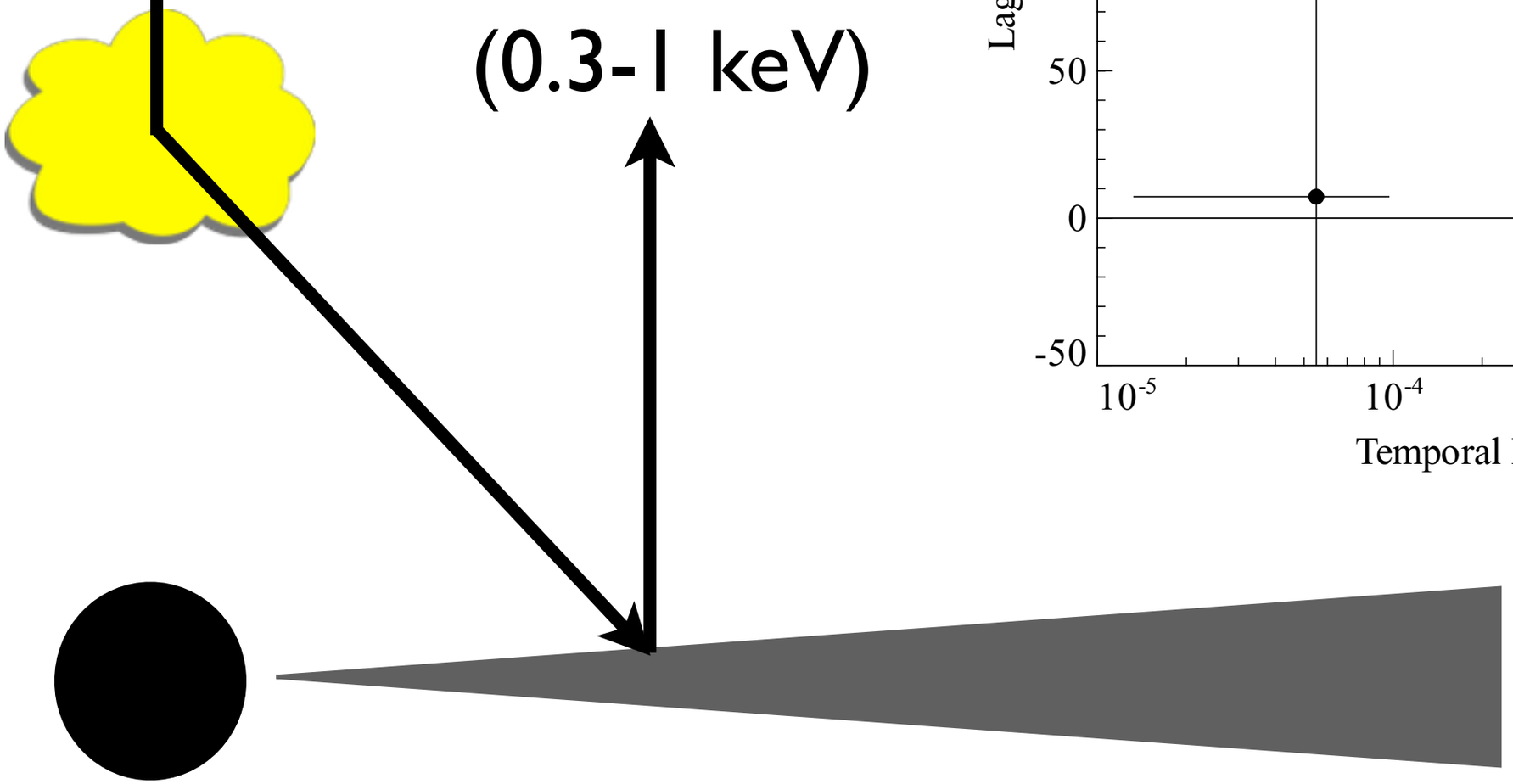


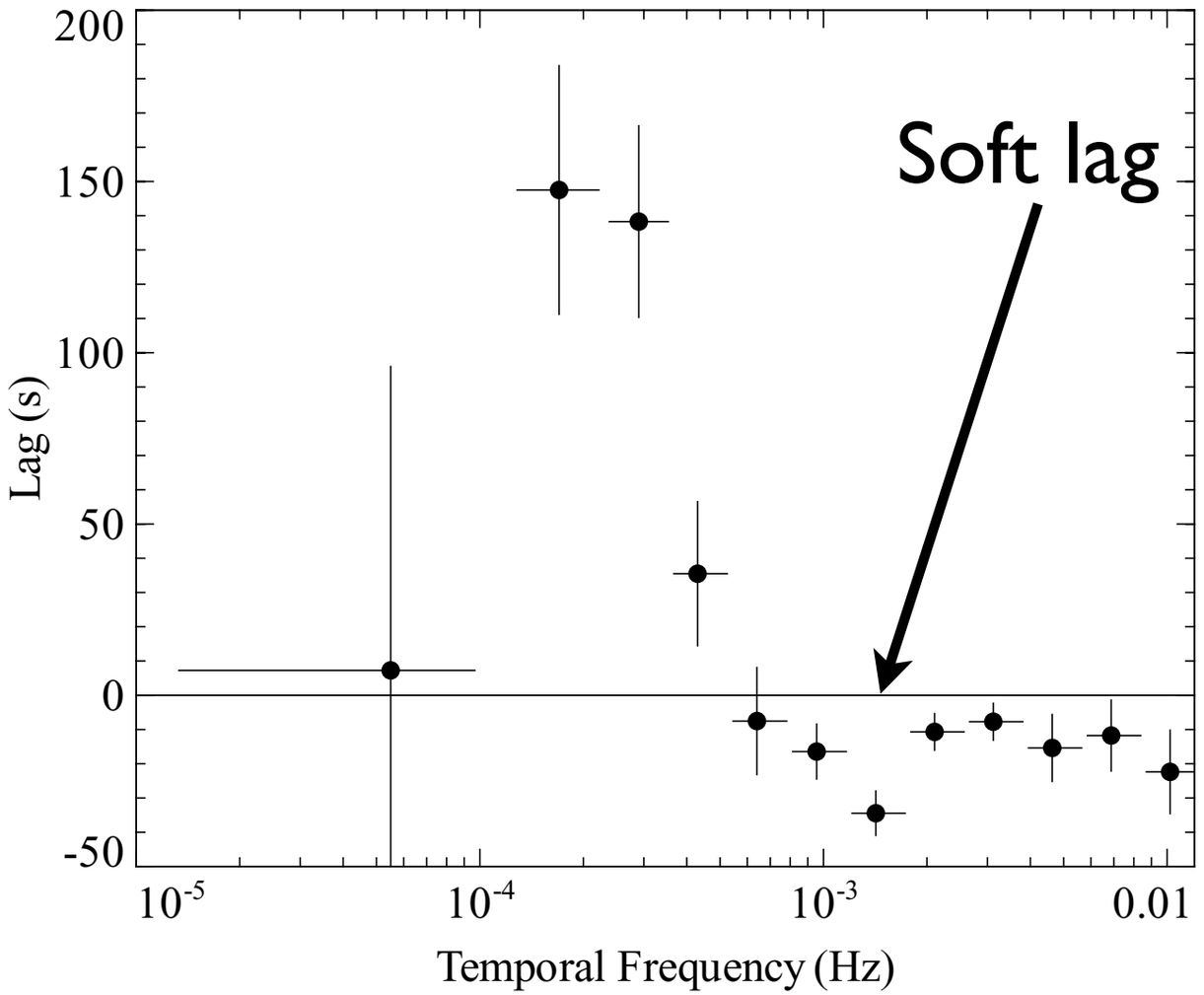
Fabian et al. 2009
Zoghbi et al. 2010

The soft lag

❶ Continuum
(1-4 keV)

❷ Reflection
(0.3-1 keV)





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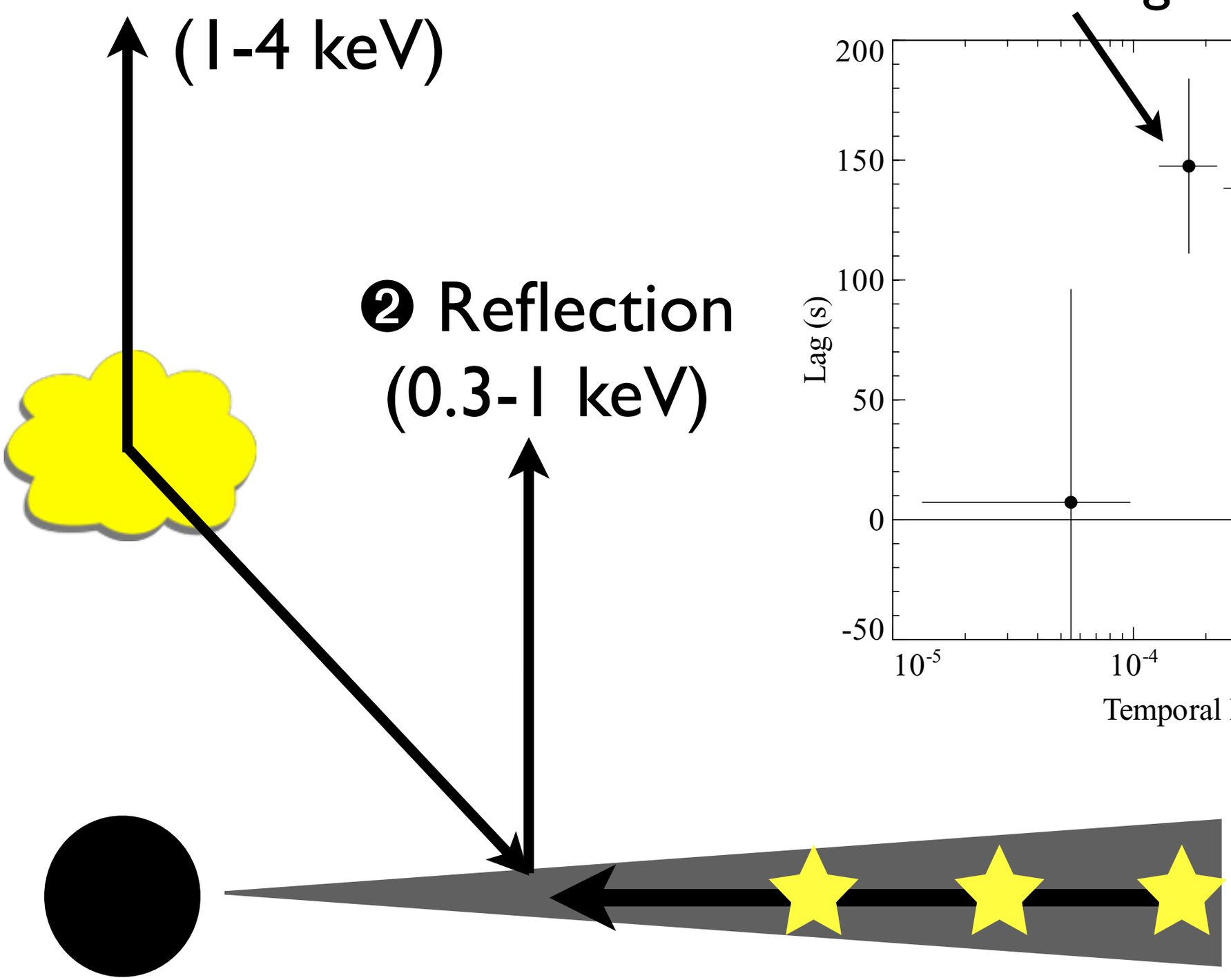

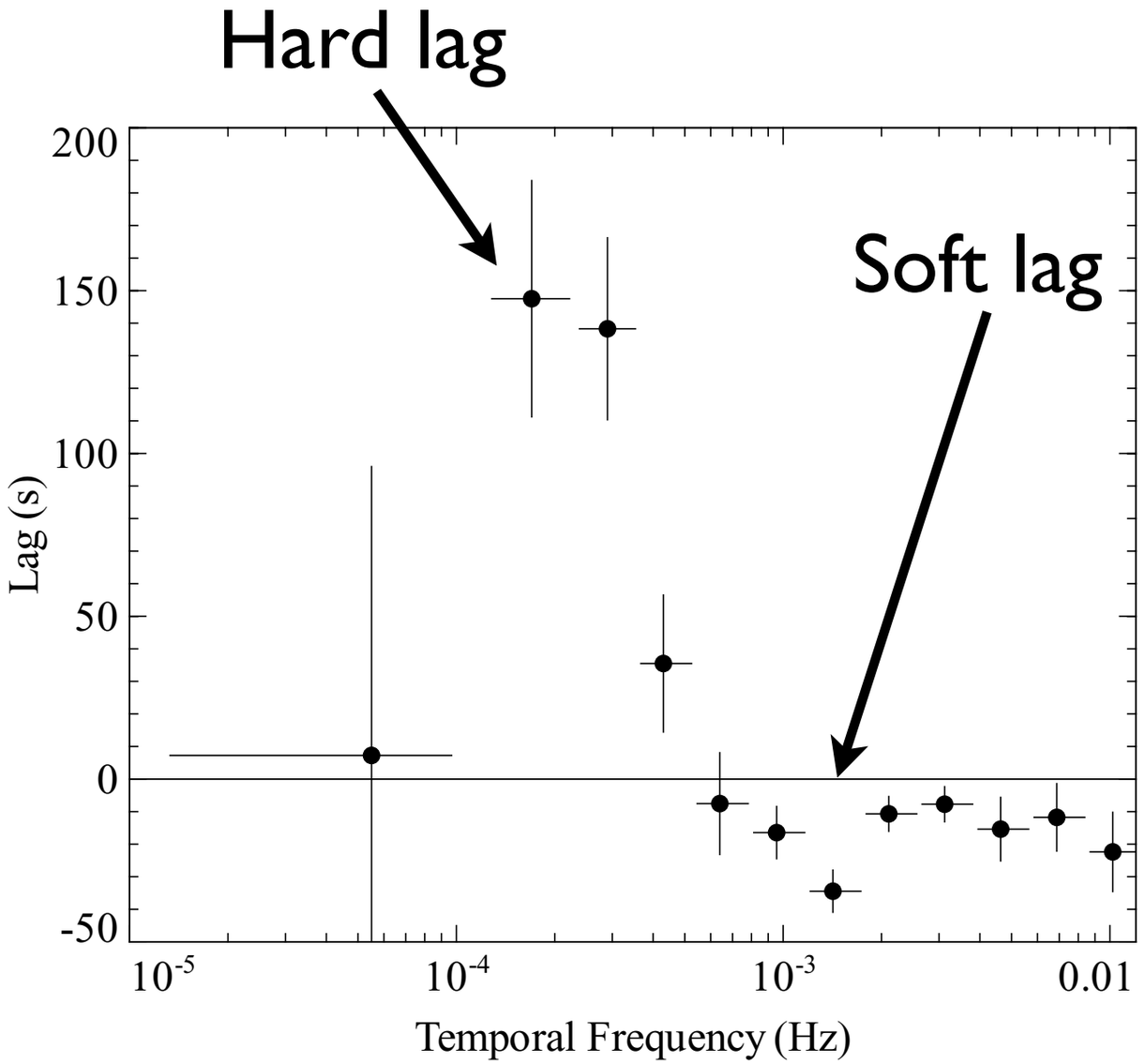

Arevalo & Uttley 2006

Fabian et al. 2009
Zoghbi et al. 2010

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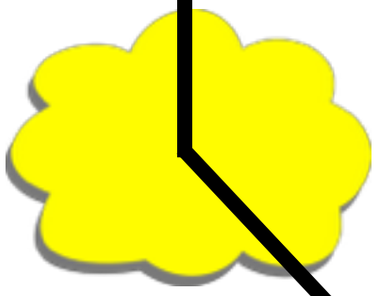
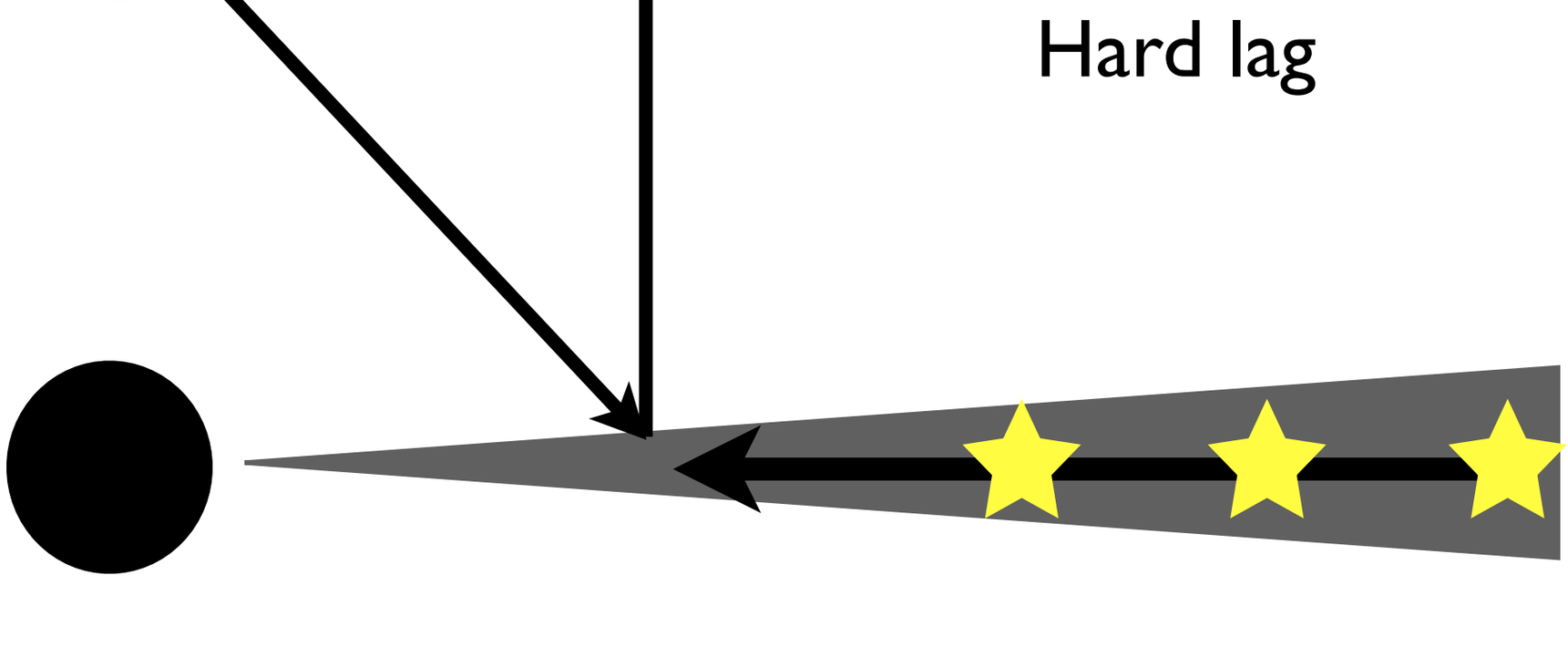
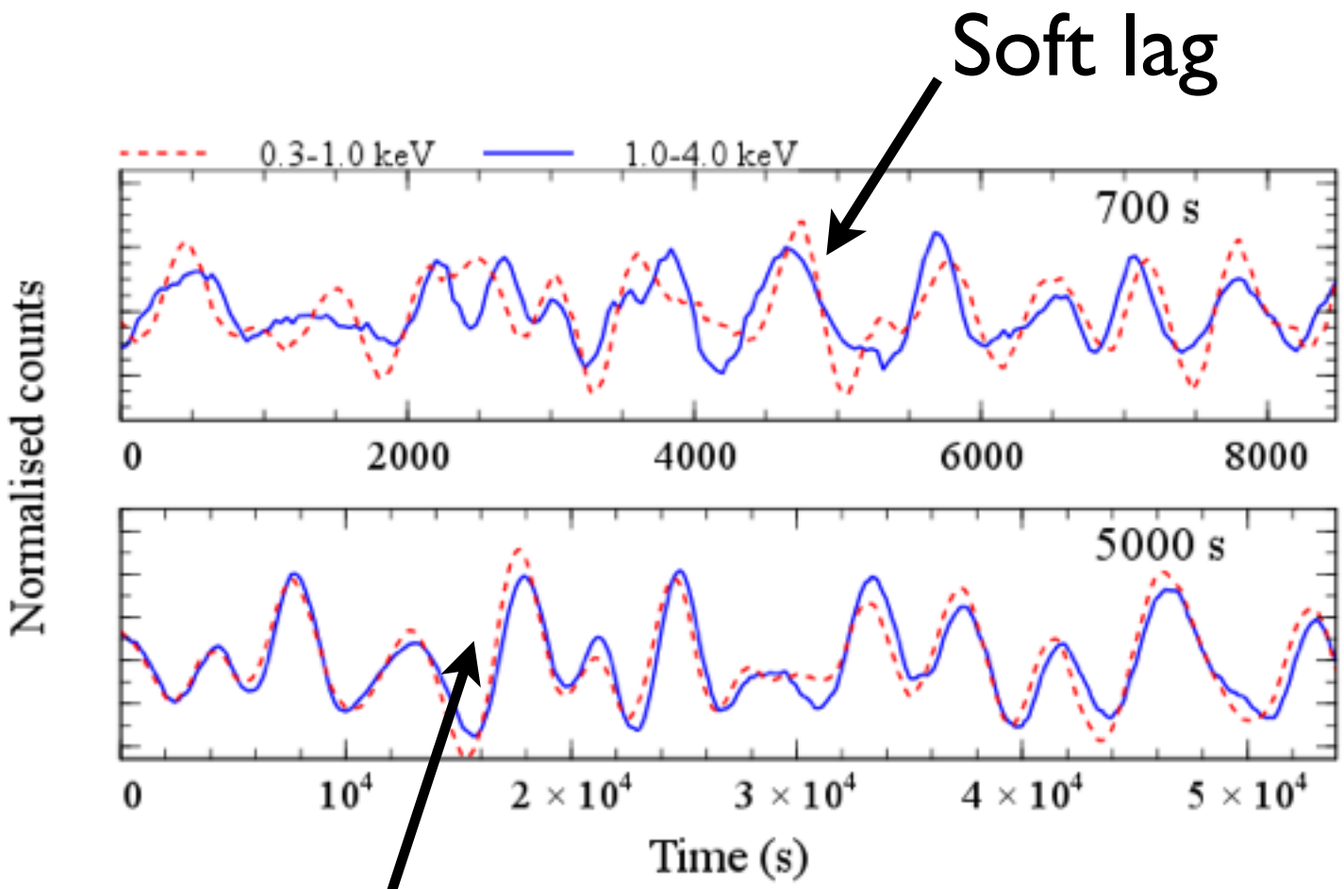






Zoghbi et al. 2010

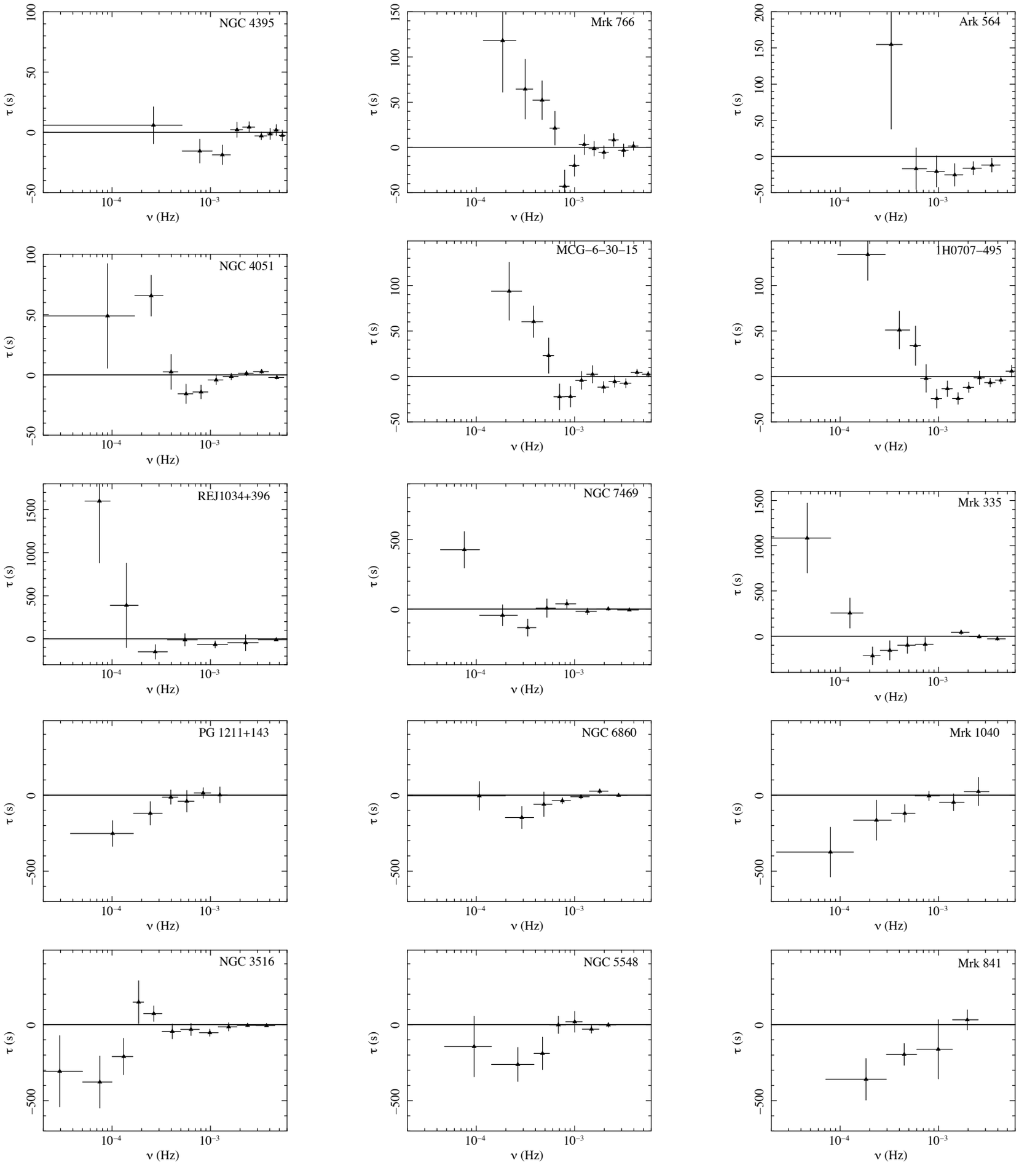
Arevalo & Uttley 2006

Fabian et al. 2009

The soft lag

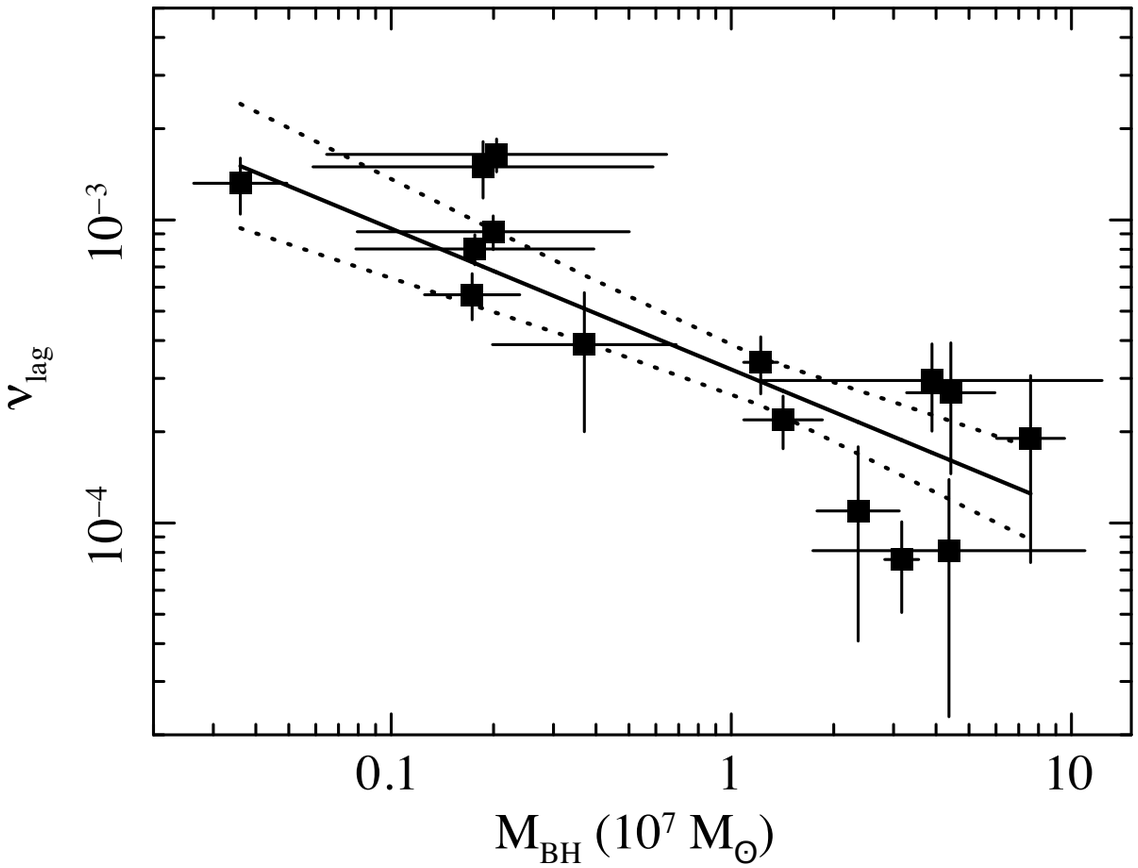
- Now found in over 20 sources

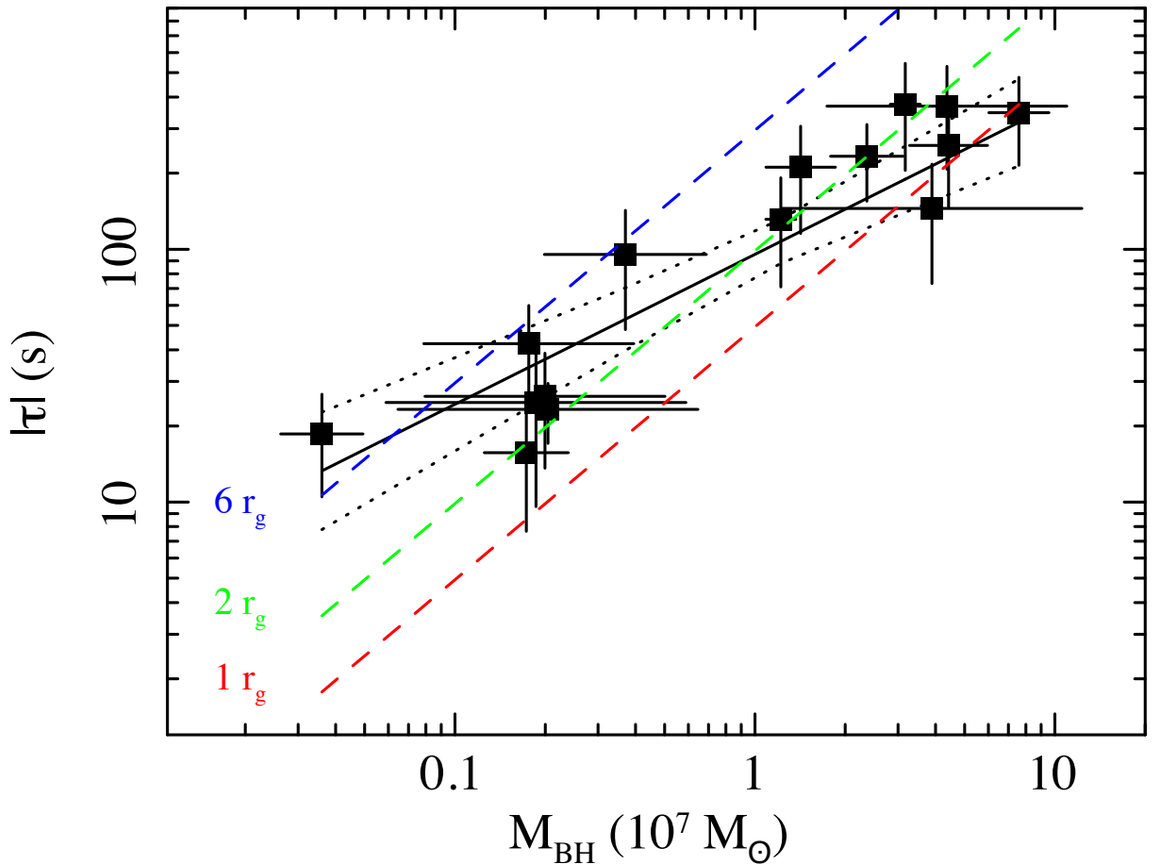
mass



De Marco+2013

The soft lag

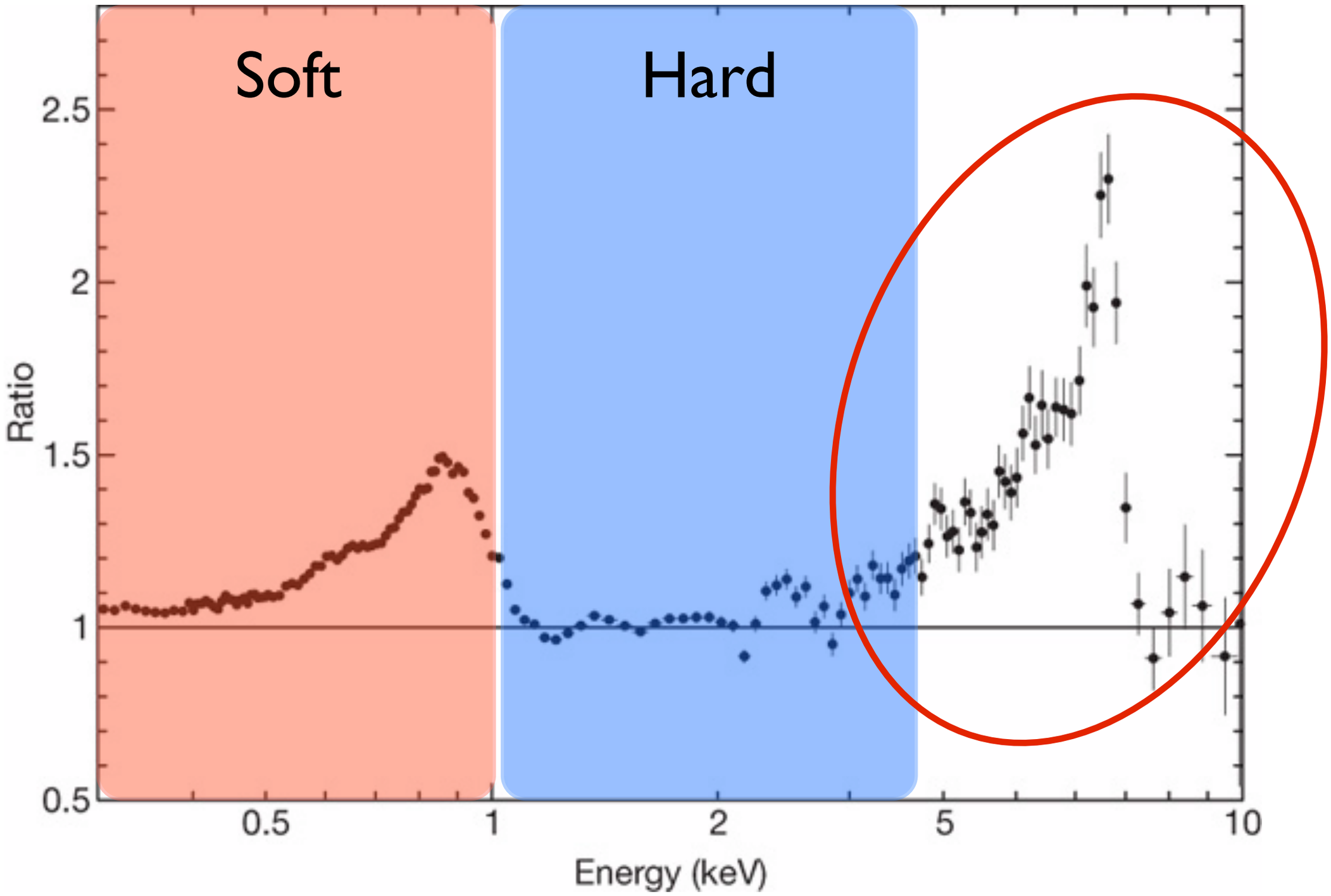




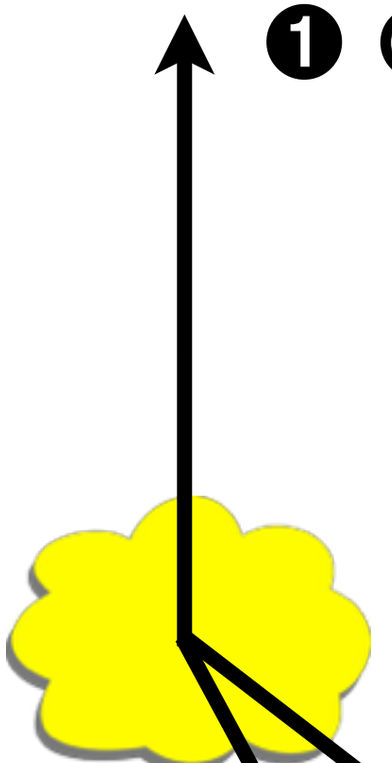
Time lag amplitude indicating that soft excess is emitted from compact region

De Marco+2013

Fe K Lags?



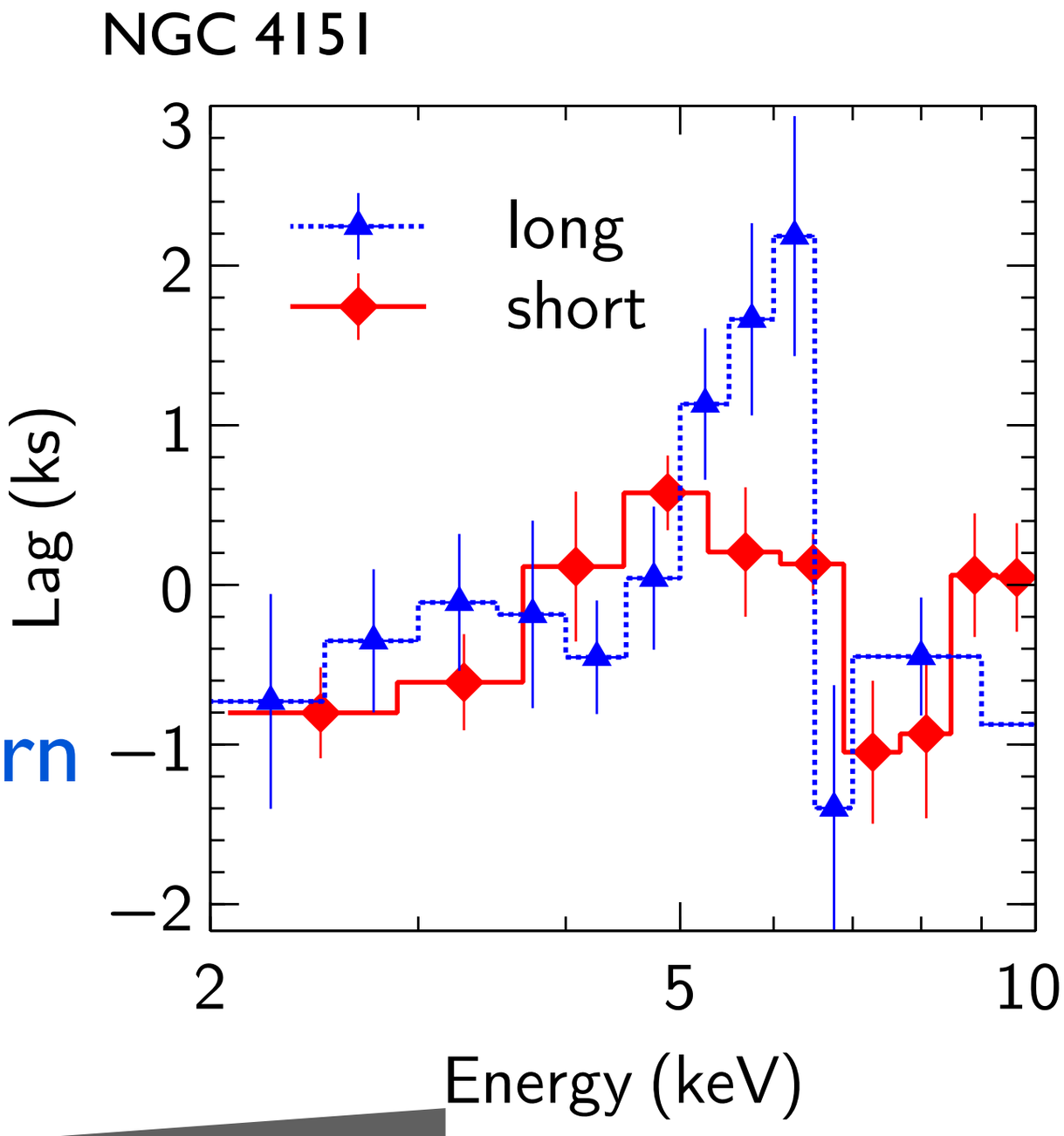
High frequency iron K lags



❶ Continuum

❷ Red wing

❸ Blue Horn



Zoghbi et al 2012

High frequency iron K lags

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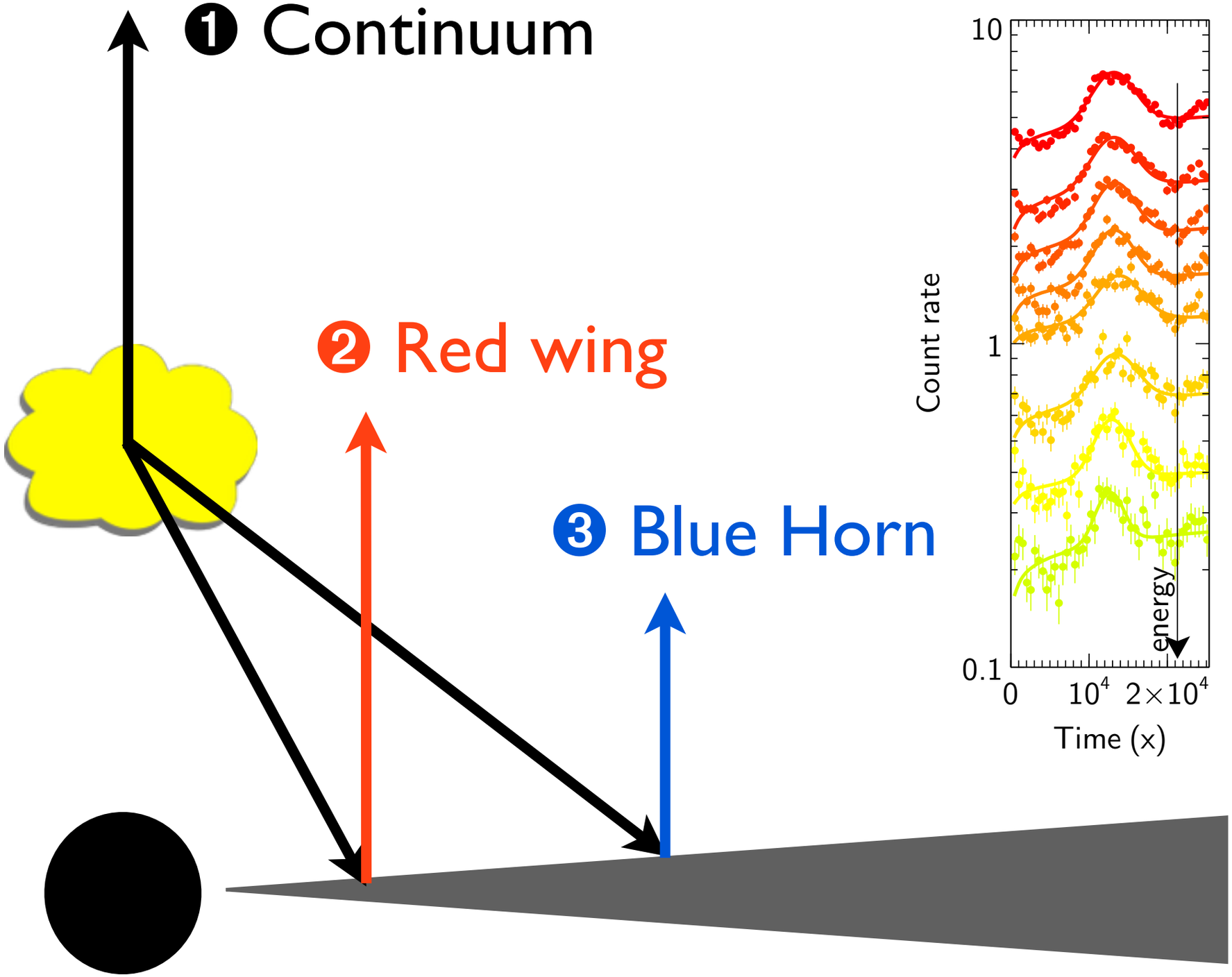
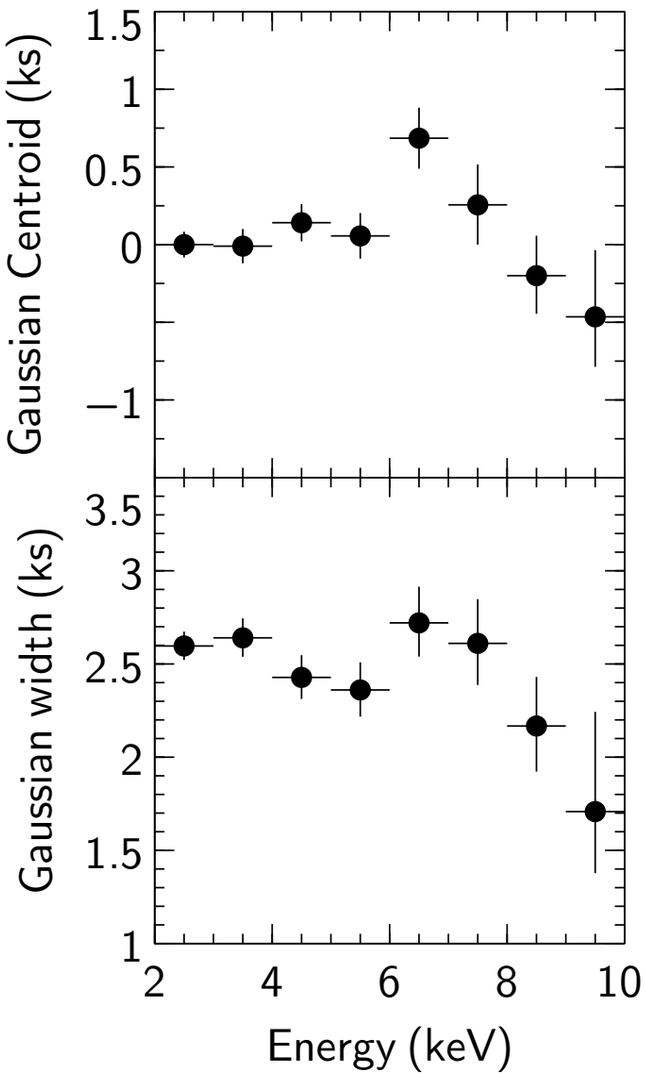
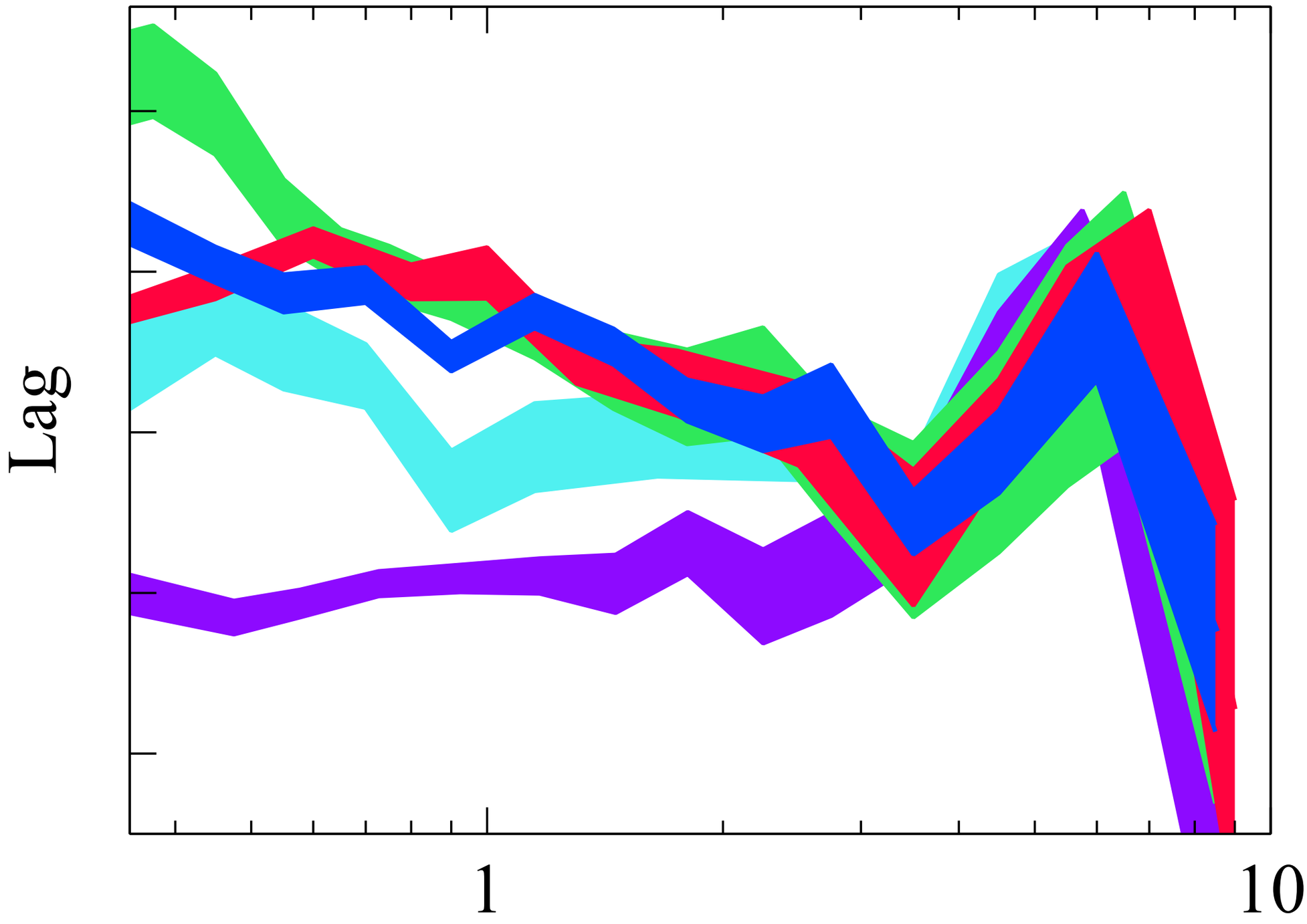


MCG-5-23-16



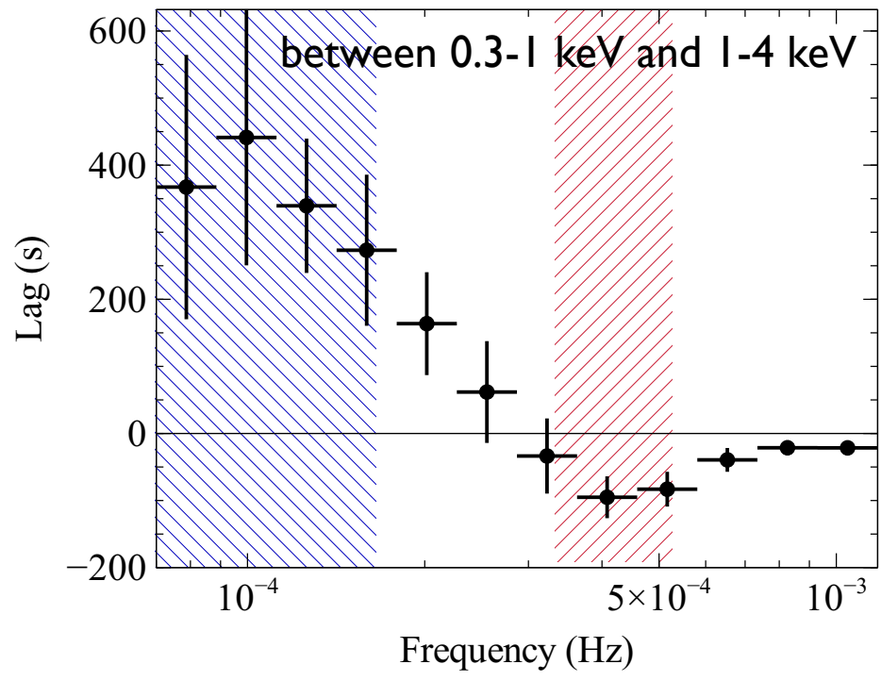
Zoghbi et al 2014

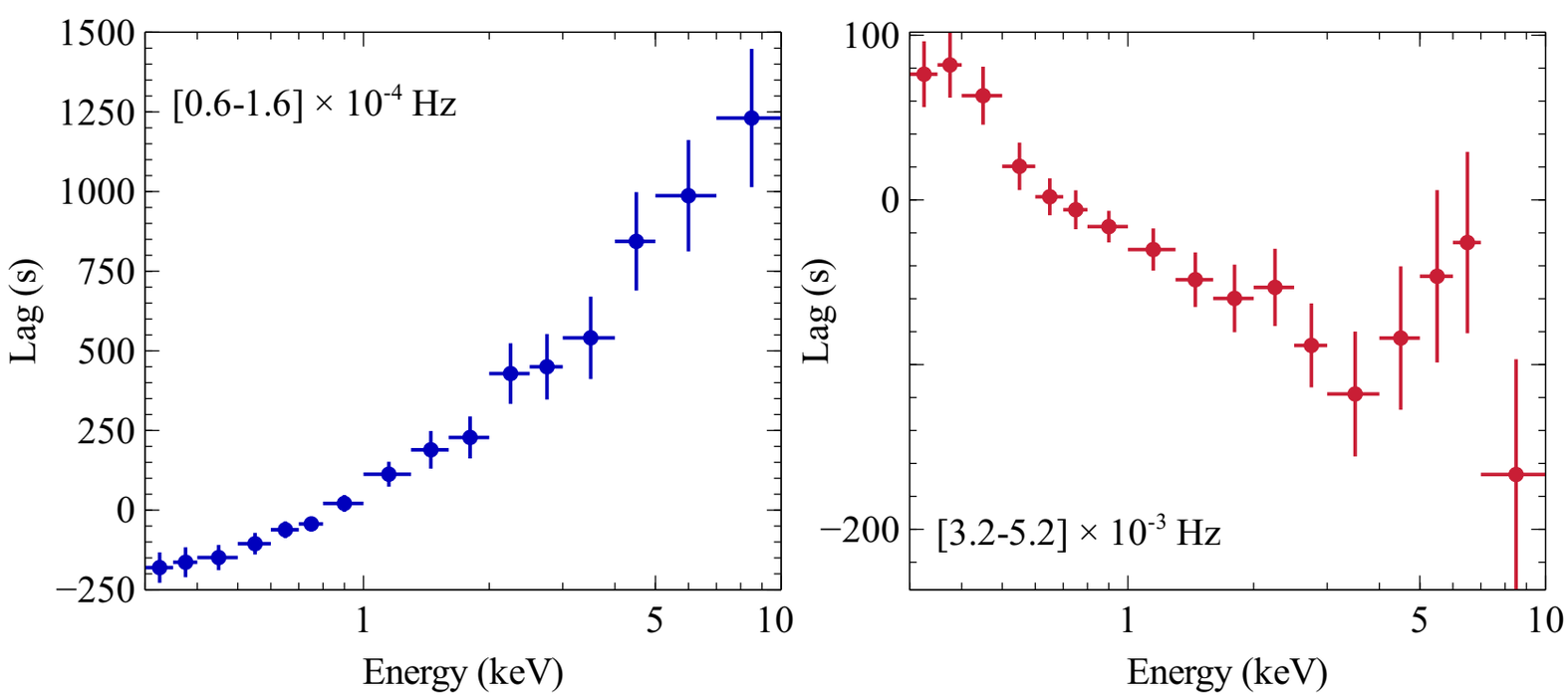
High frequency iron K lags



Uttley+14, adapted from EK+13

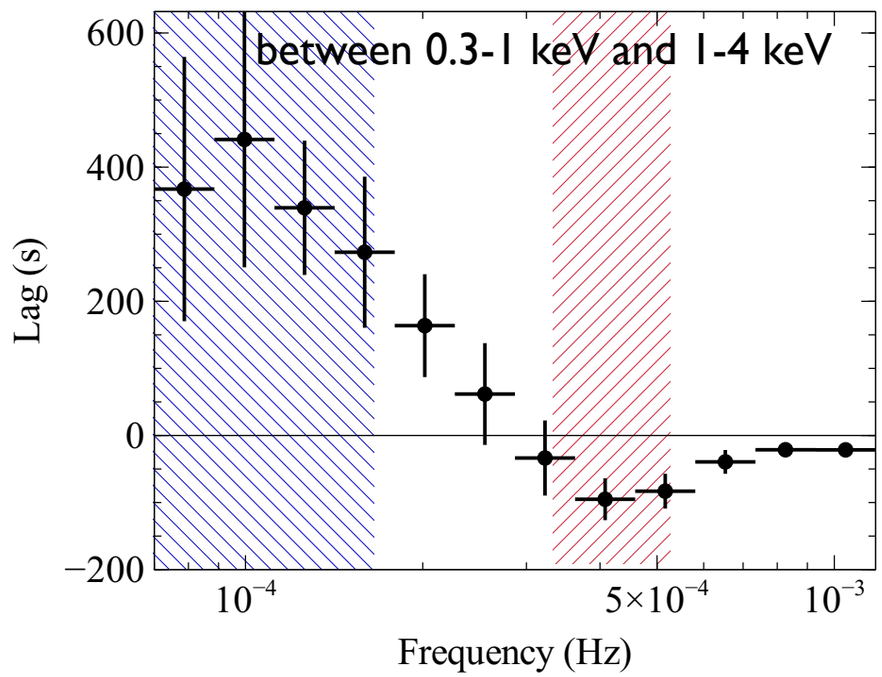
Low-frequency lags

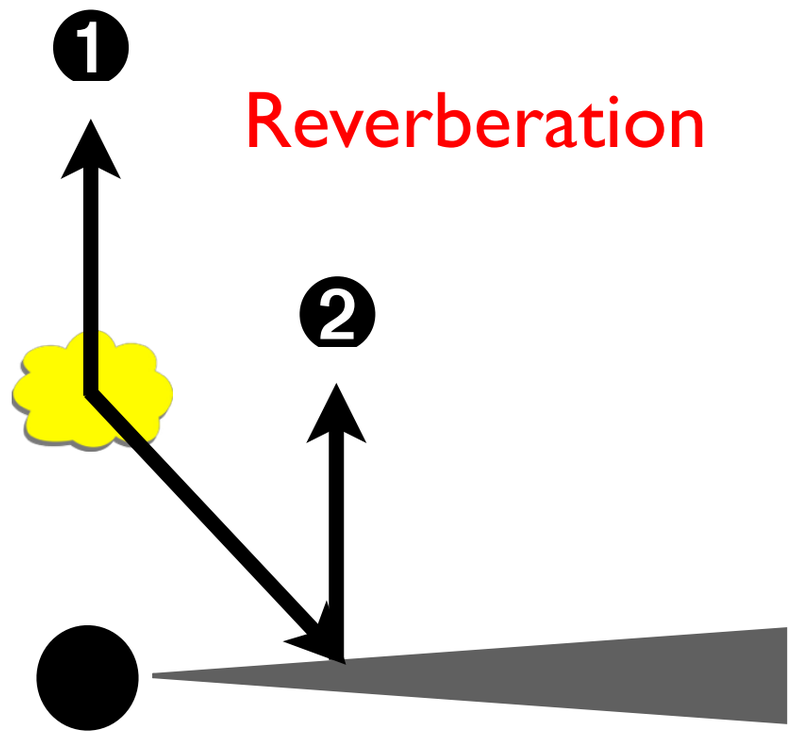


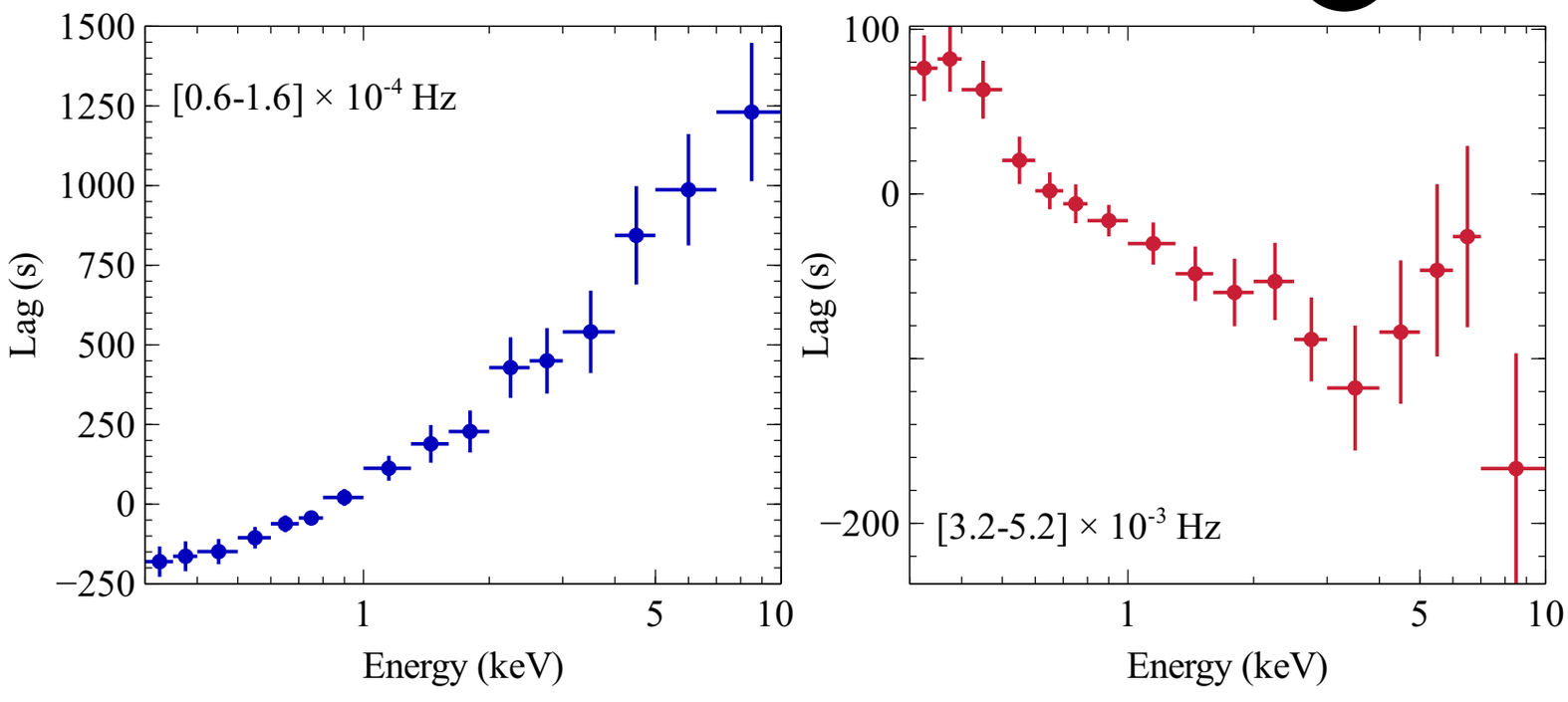


EK+13

Low-frequency lags

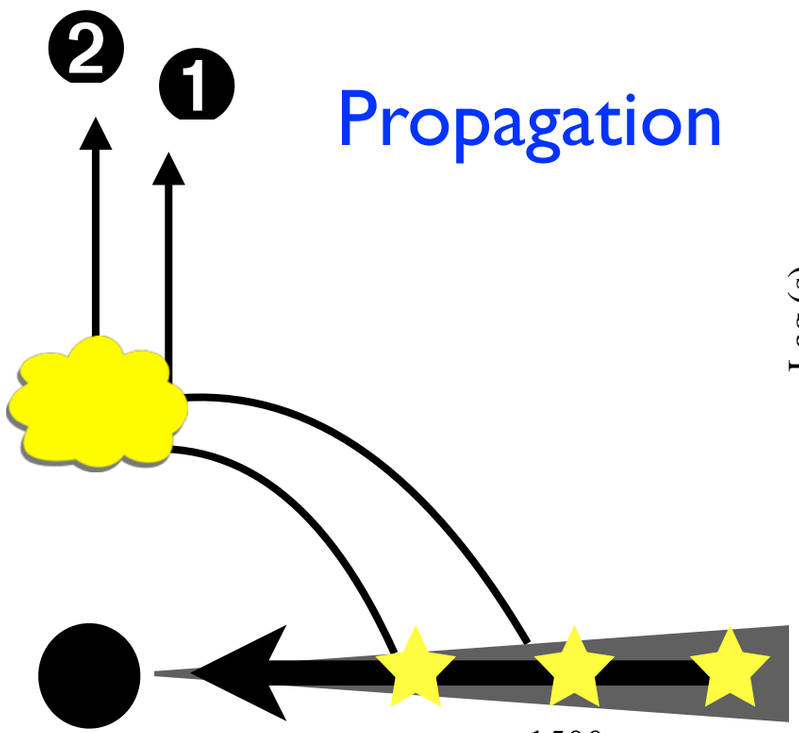




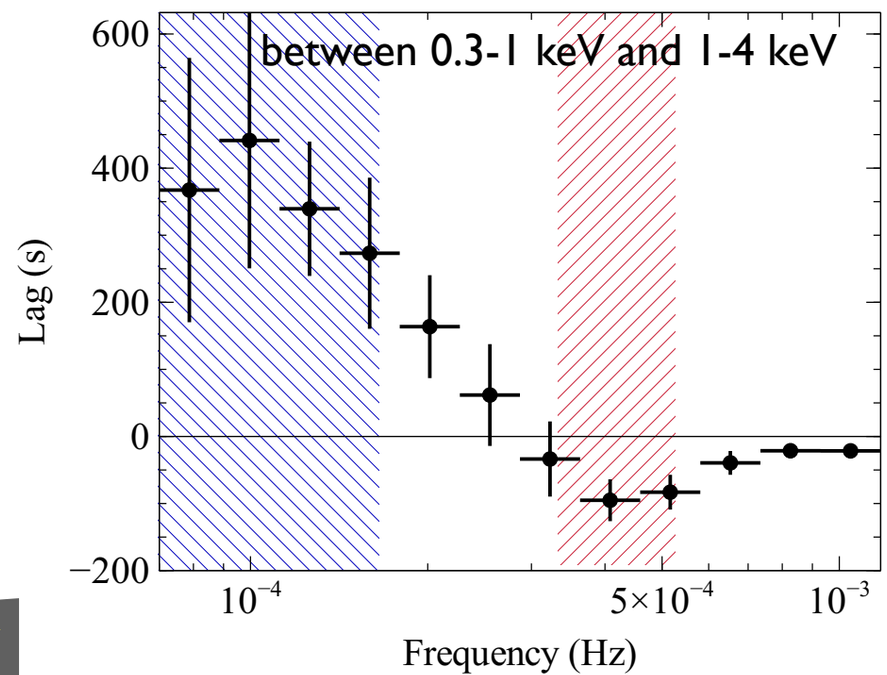


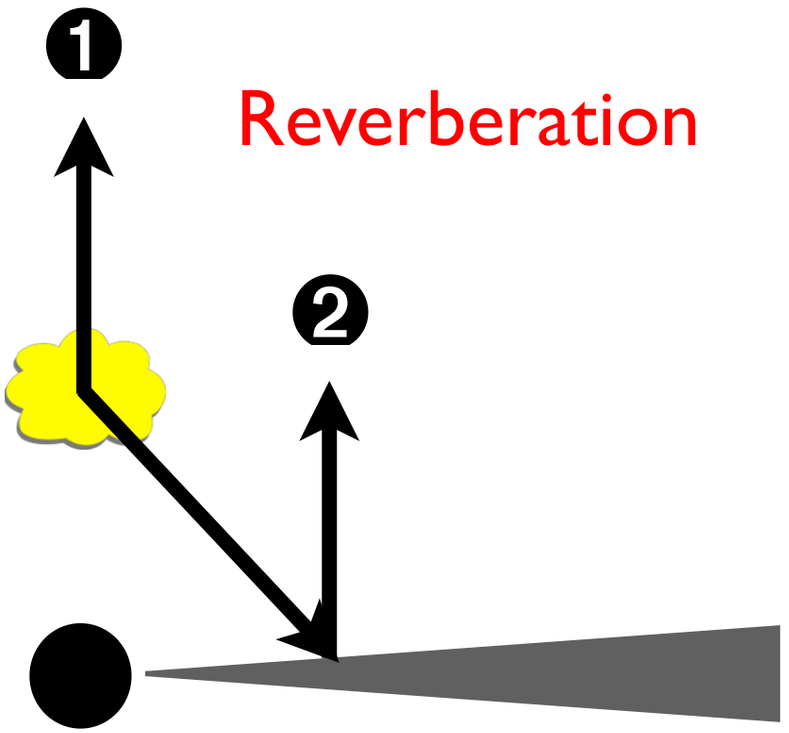
EK+13

Low-frequency lags

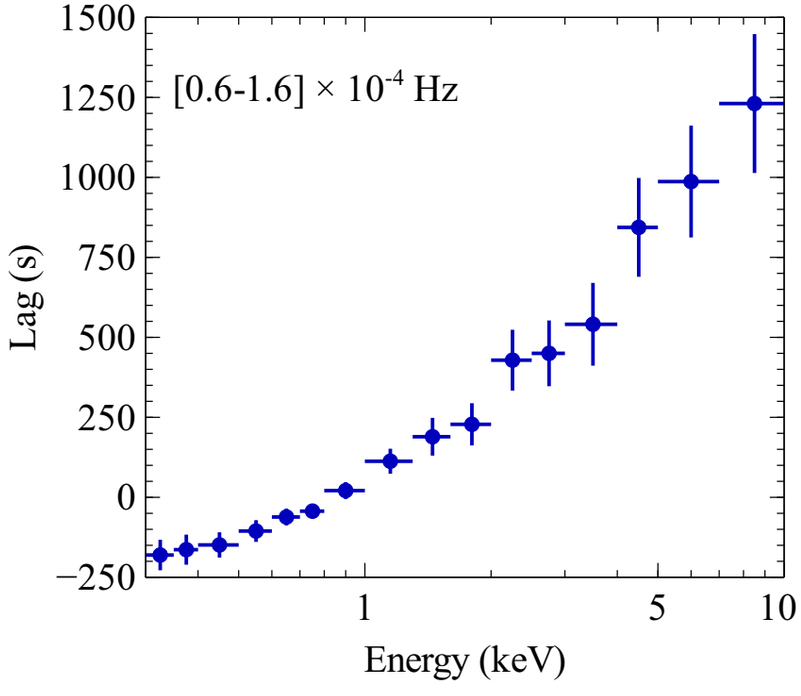


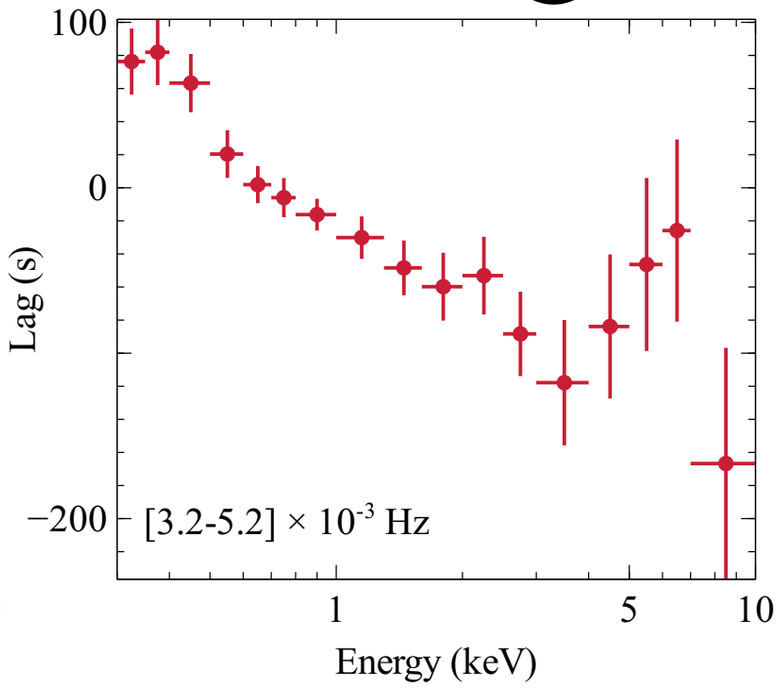
Propagation



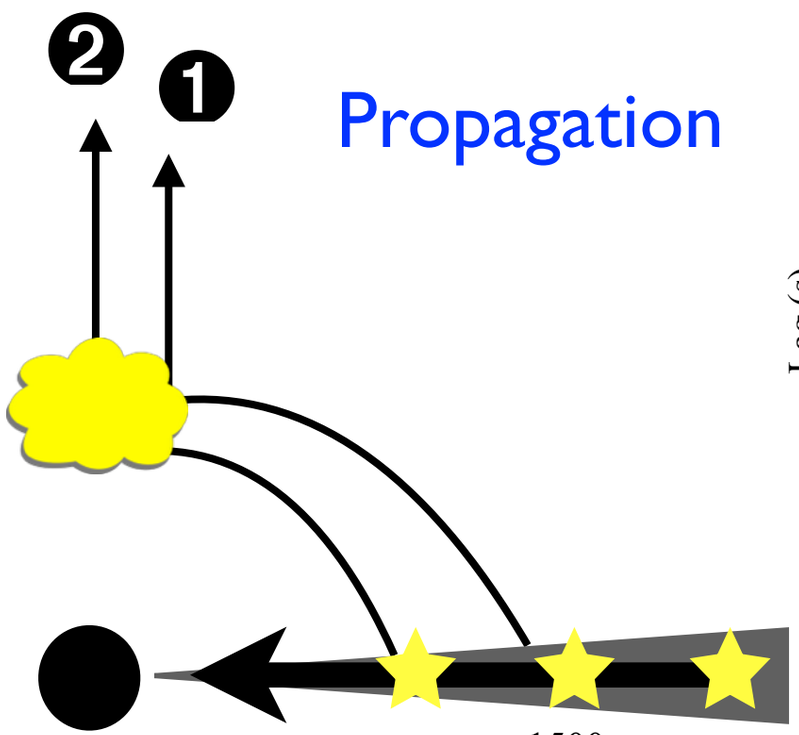


Reverberation

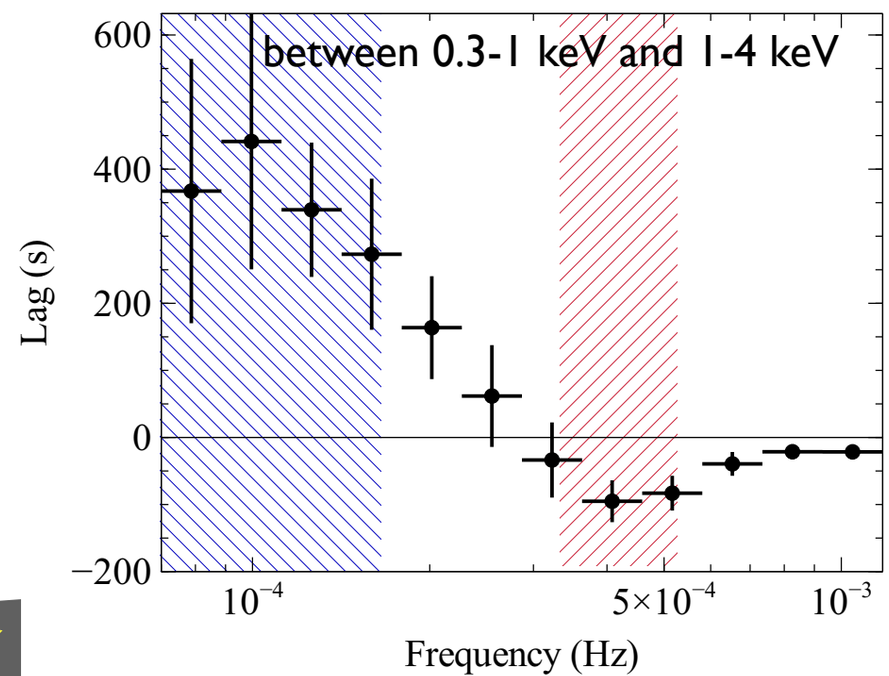


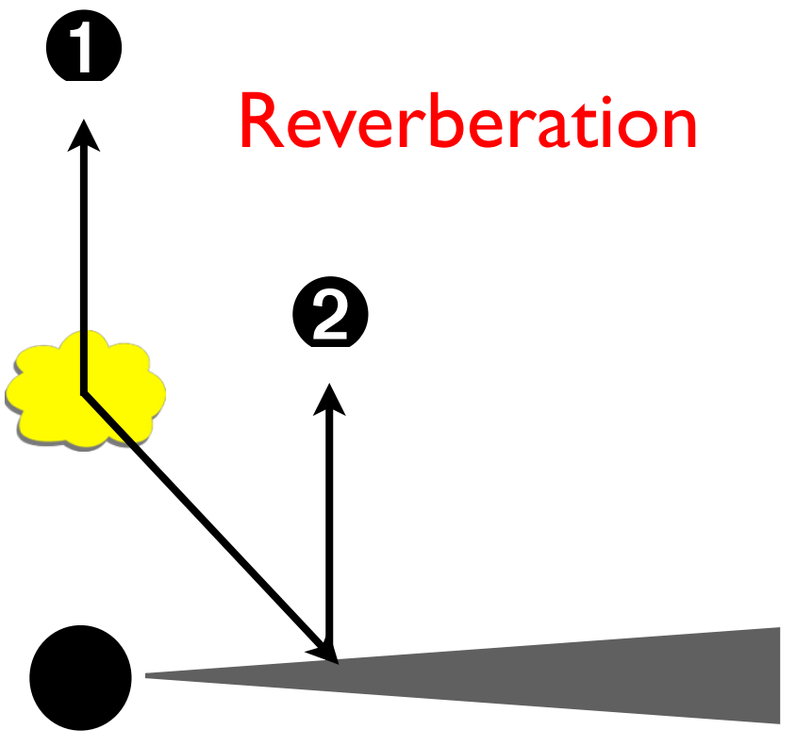


Low-frequency lags

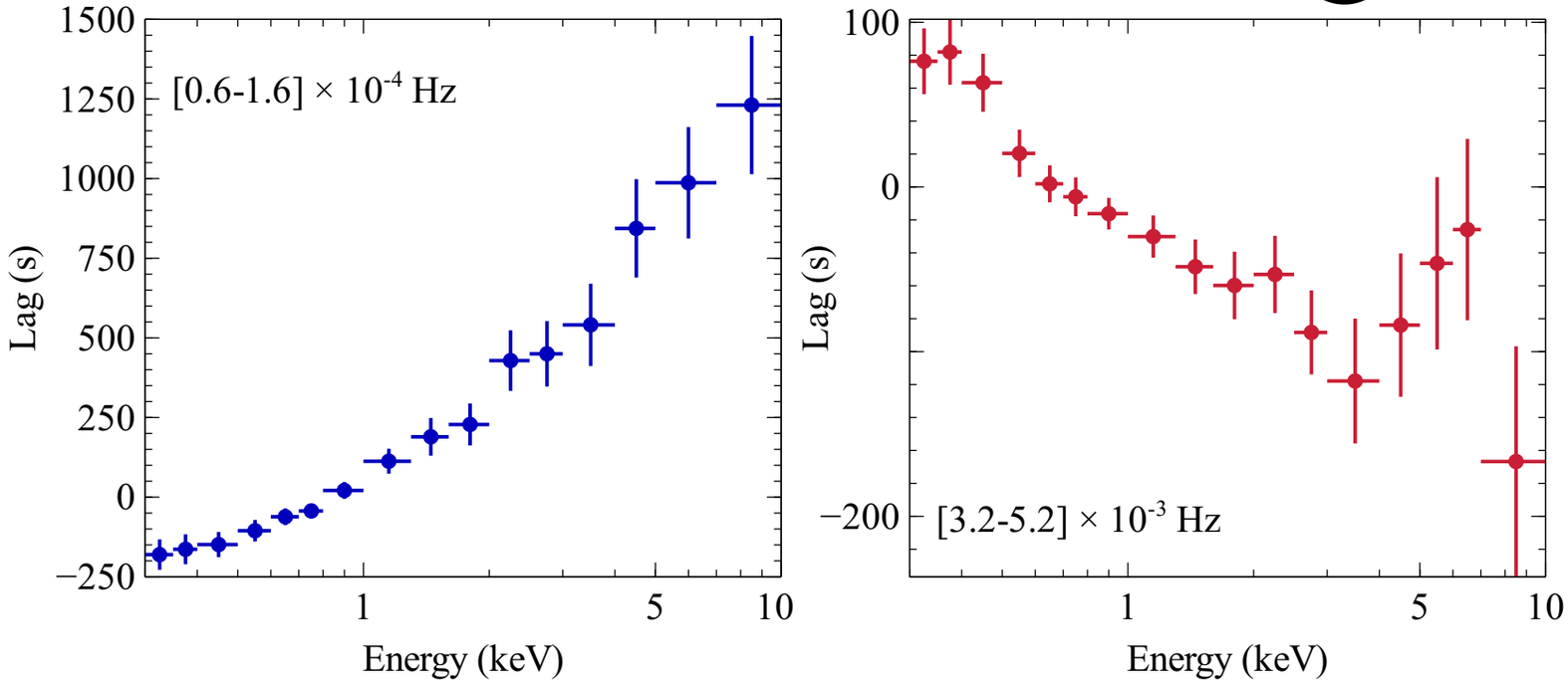


Propagation



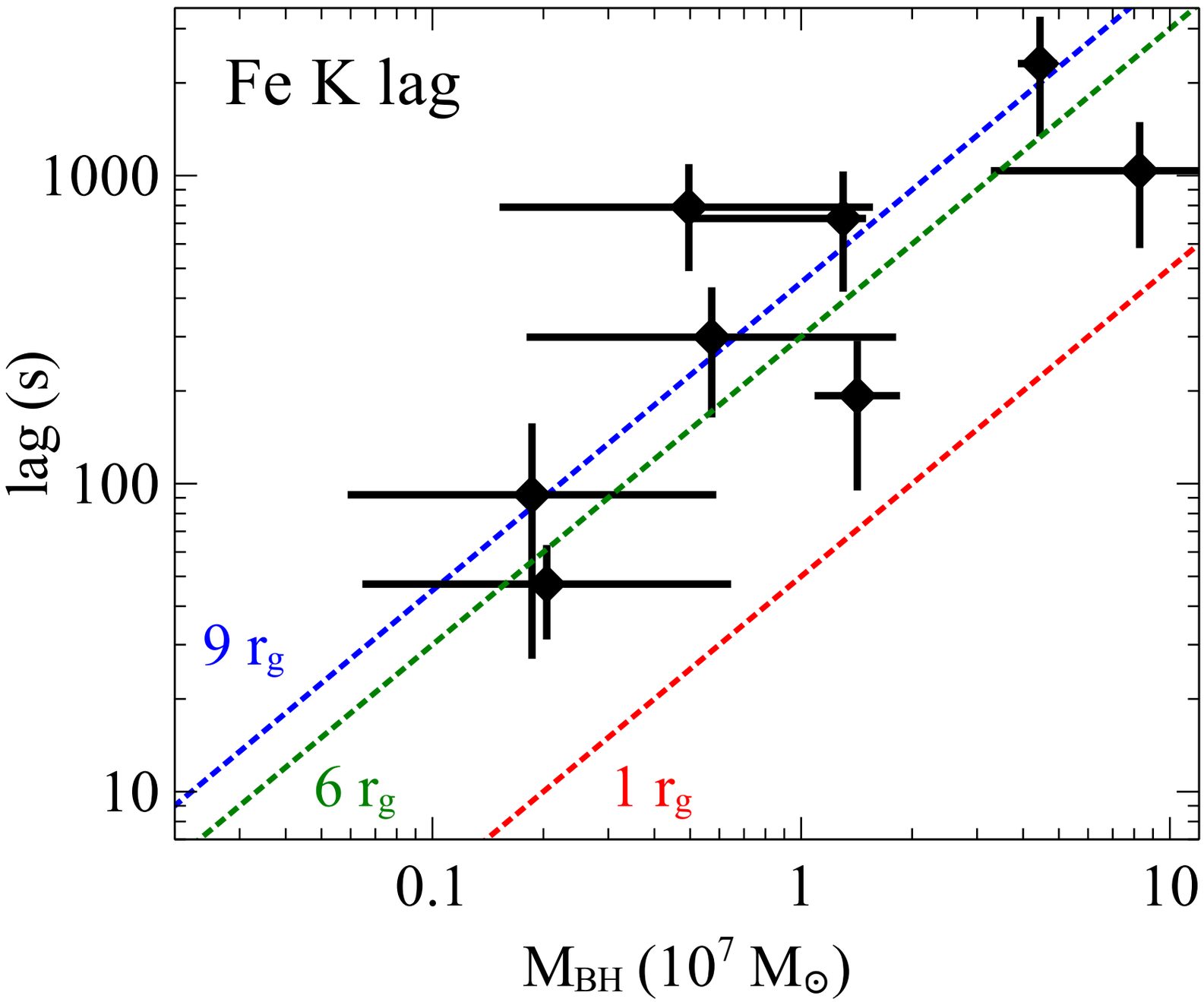


Reverberation



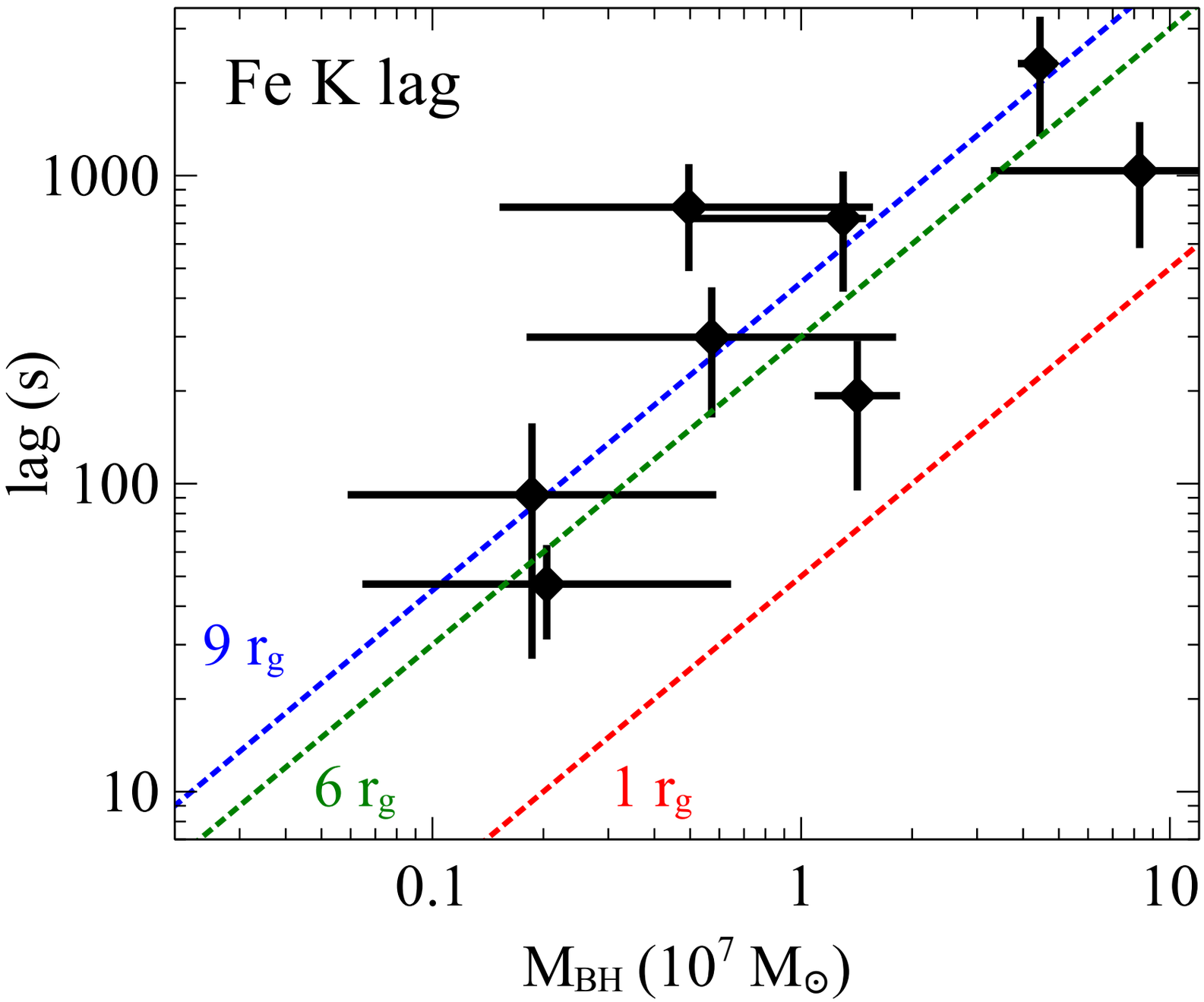
Lag-energy shows that reverberation is coming from a small, nearby reprocessor, not a large, distant one

Fe K lags scale with black hole mass



EK+13

Fe K lags scale with black hole mass



- BH spin
- Inclination
- Coronal geometry
- Shapiro delay
- Light bending

EK+13

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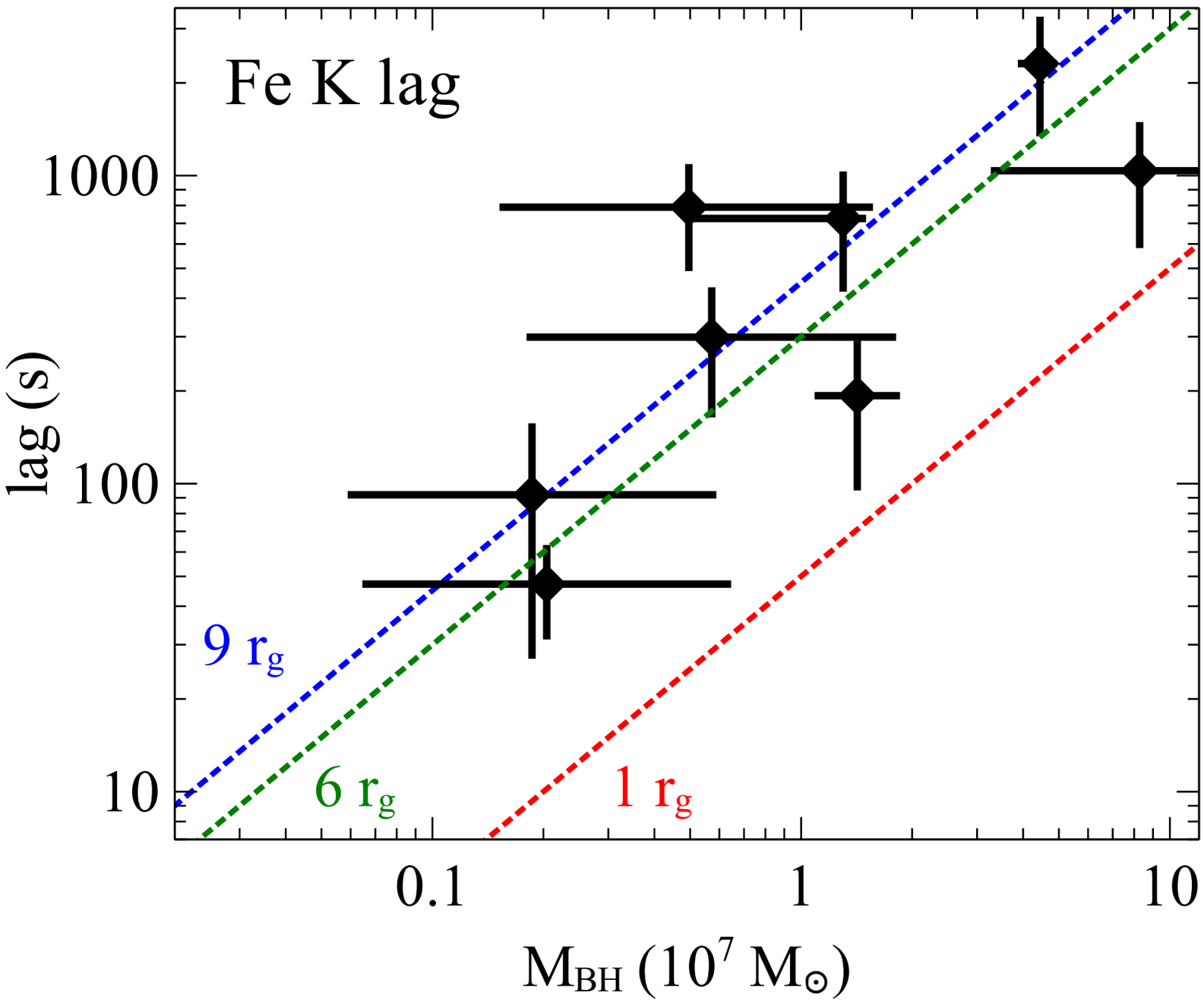

- BH spin ✔
- Inclination
- Coronal geometry ✔
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- Light bending ✔

EK+13

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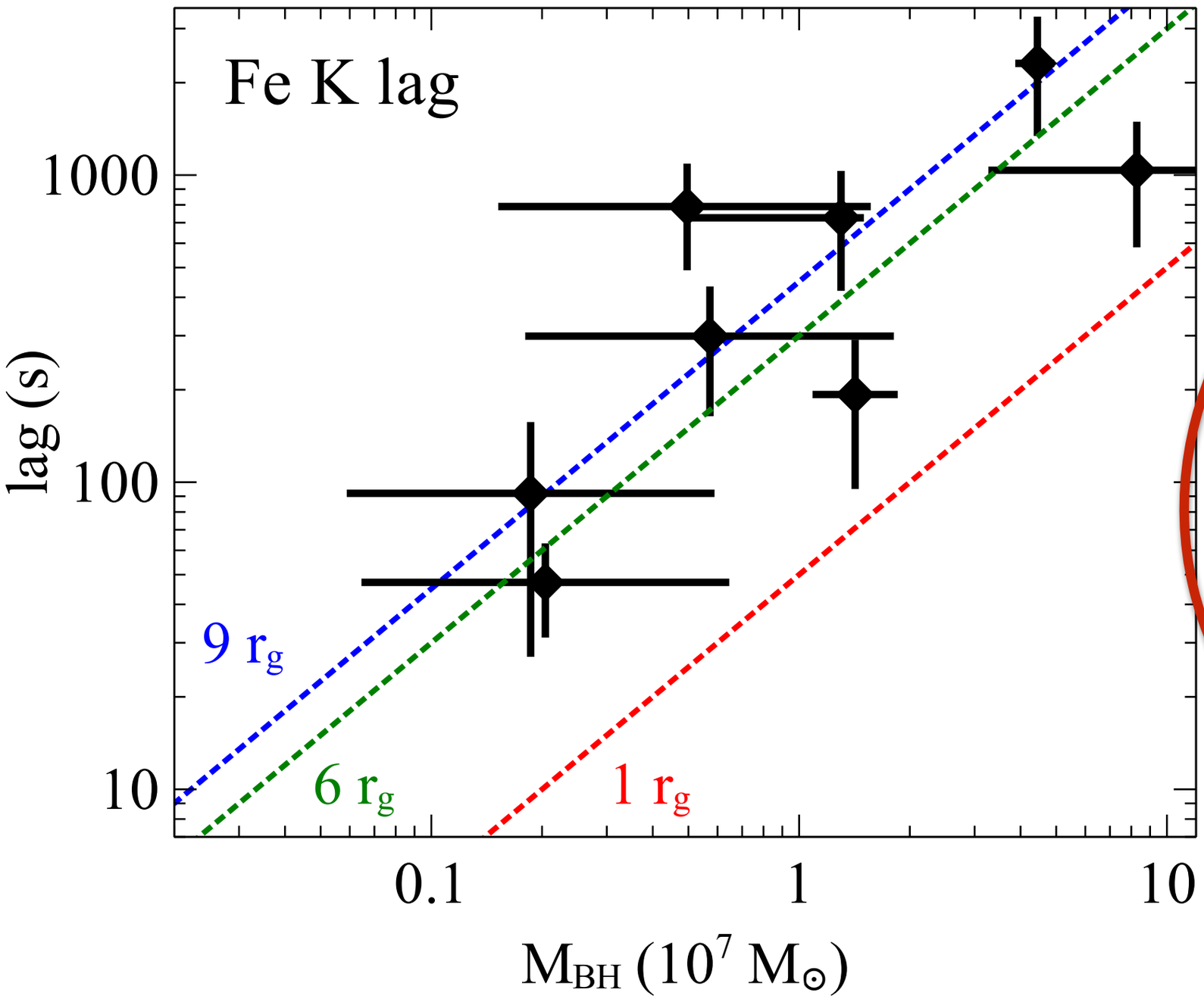
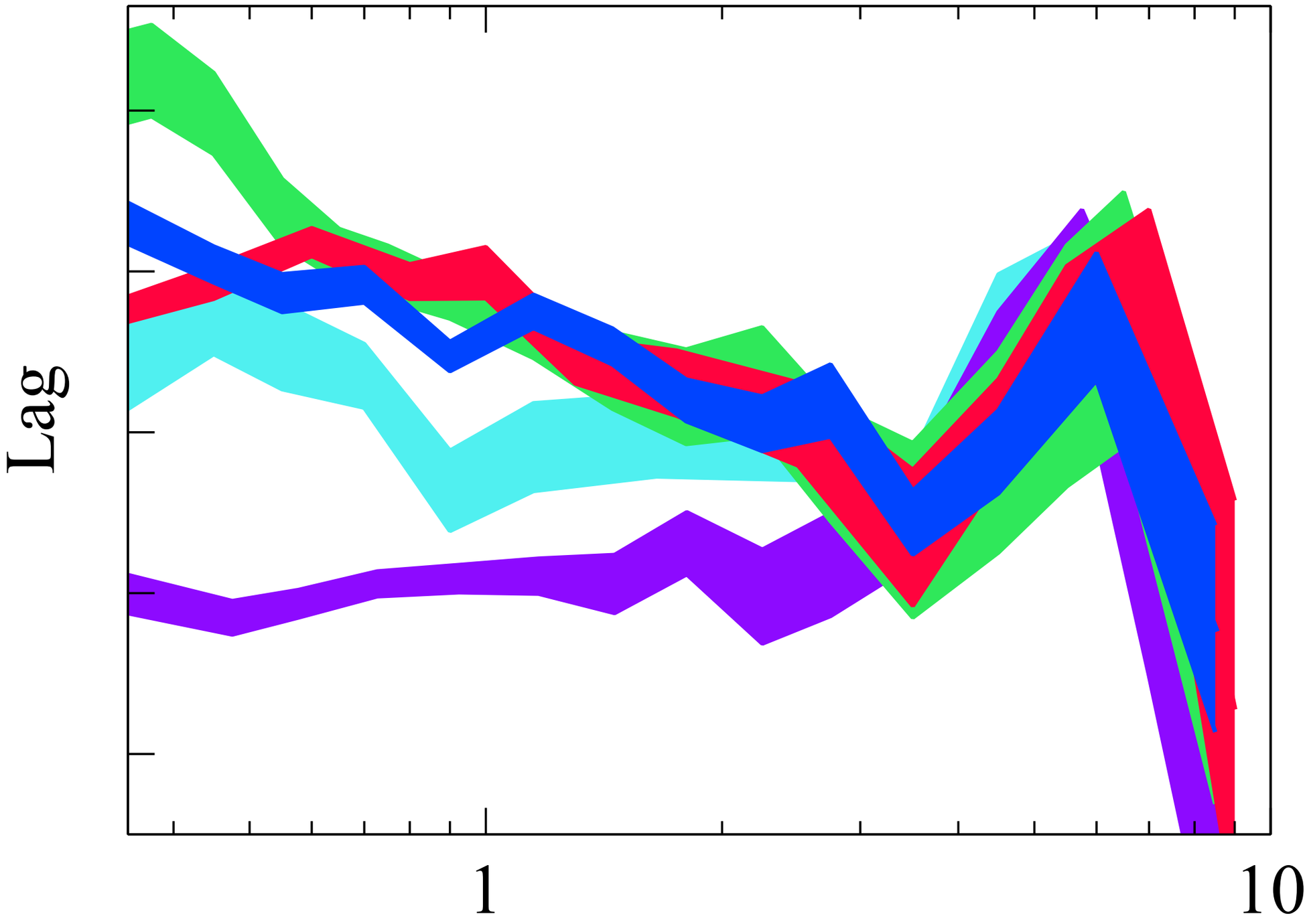


- BH spin ✔
- Inclination
- Coronal geometry ✔
- Shapiro delay
- Light bending ✔

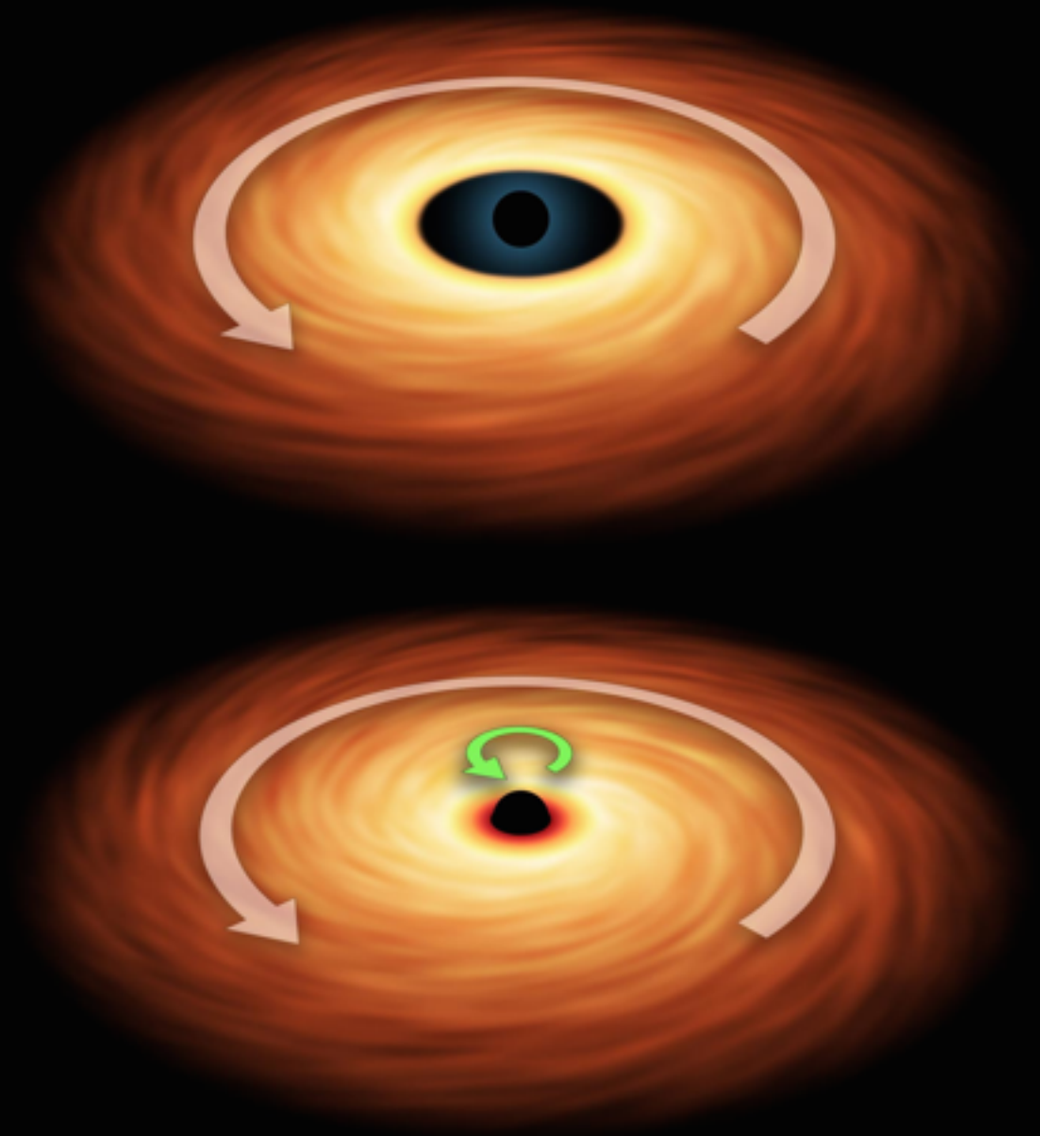
modelling

EK+13

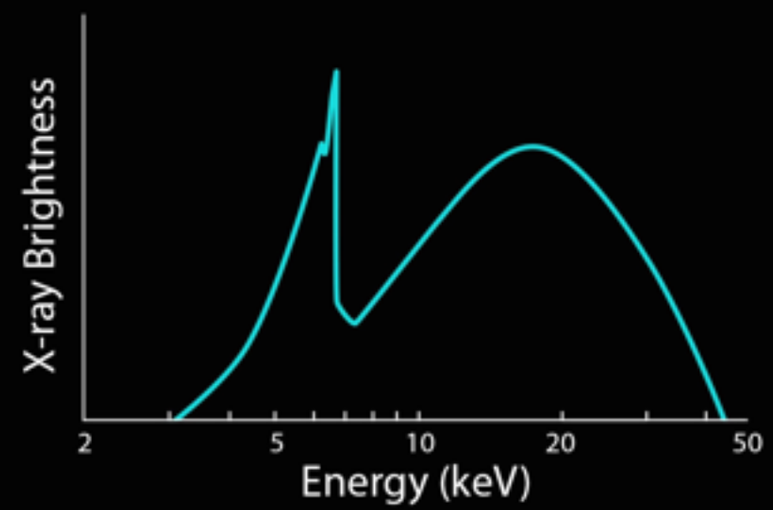
High frequency iron K lags



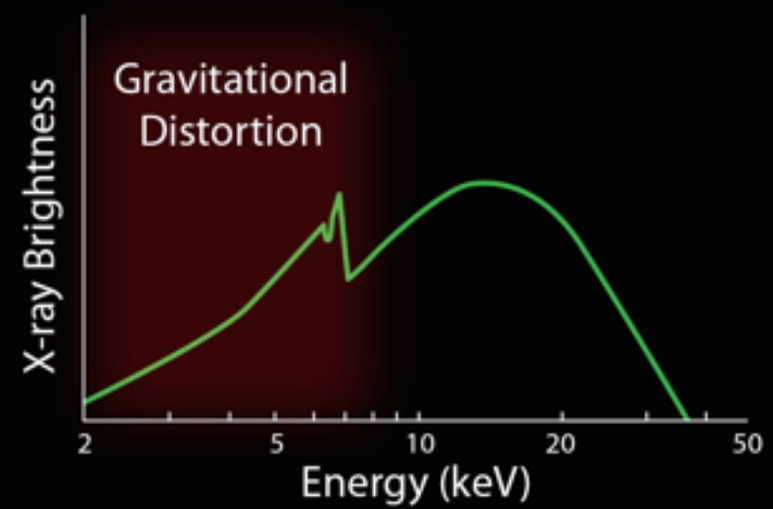
Black hole spin



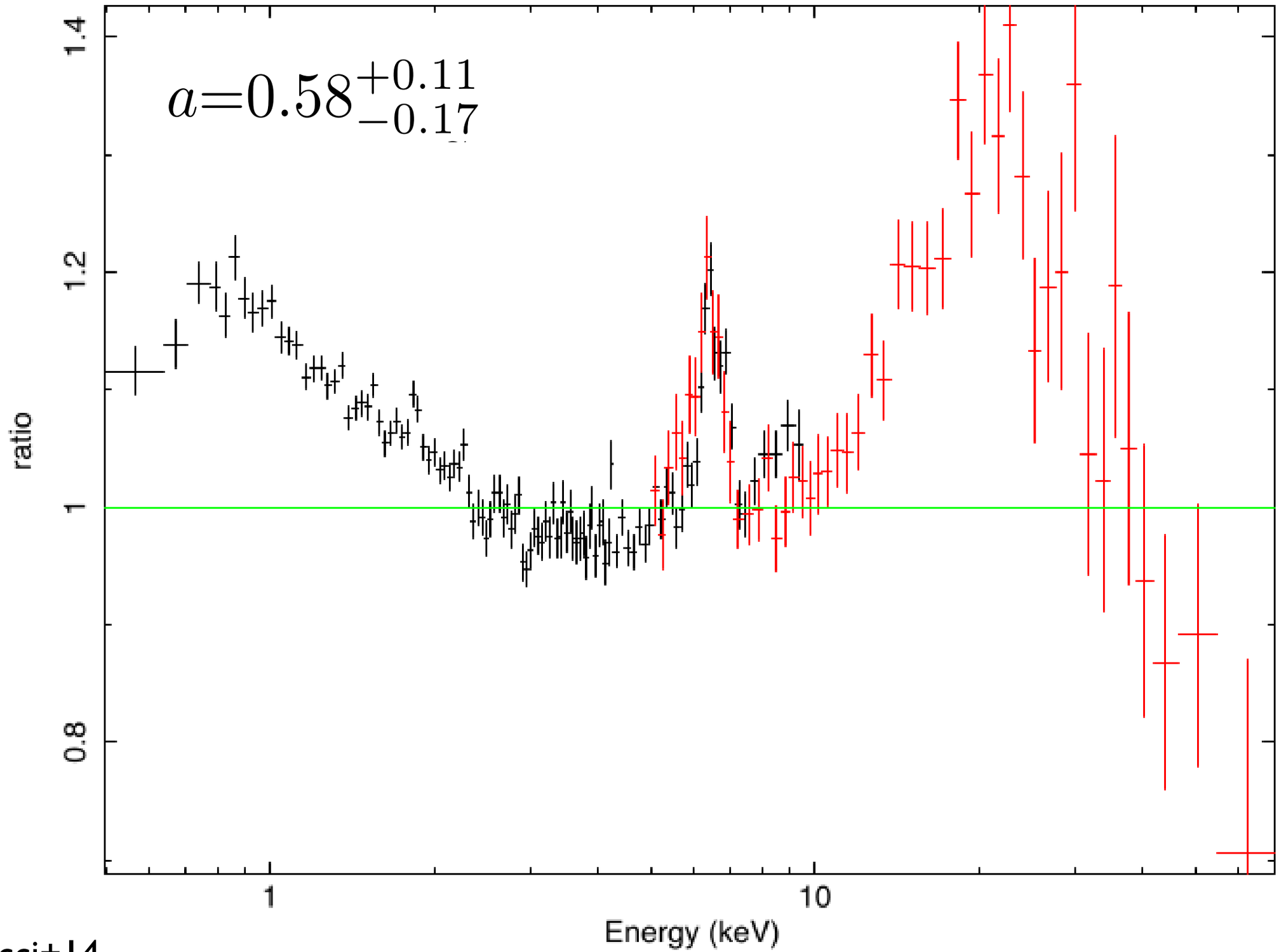
No Black Hole
Rotation



Prograde
Rotation



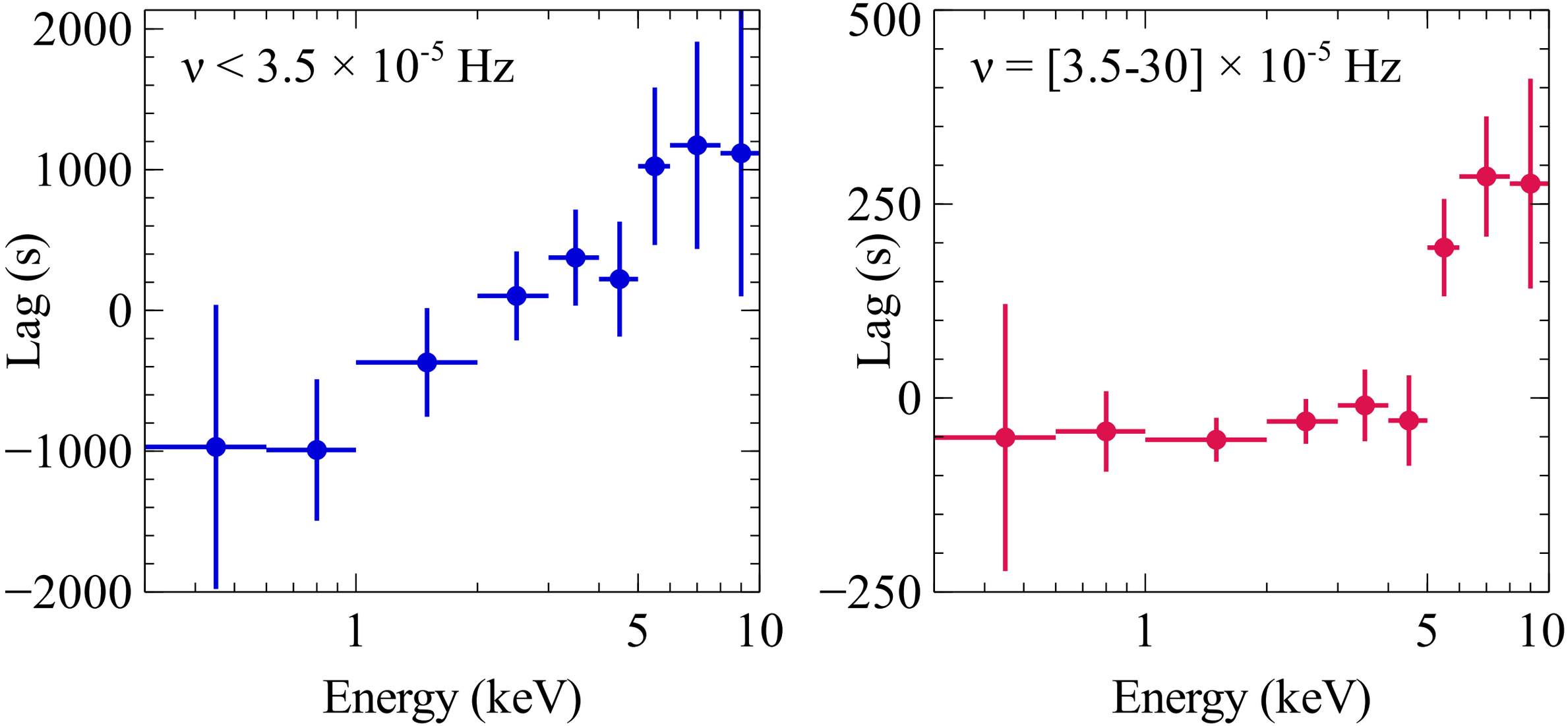
Swift J2127.4+5654



Marinucci+14

Swift J2127.4+5654

$$a=0.58^{+0.11}_{-0.17}$$



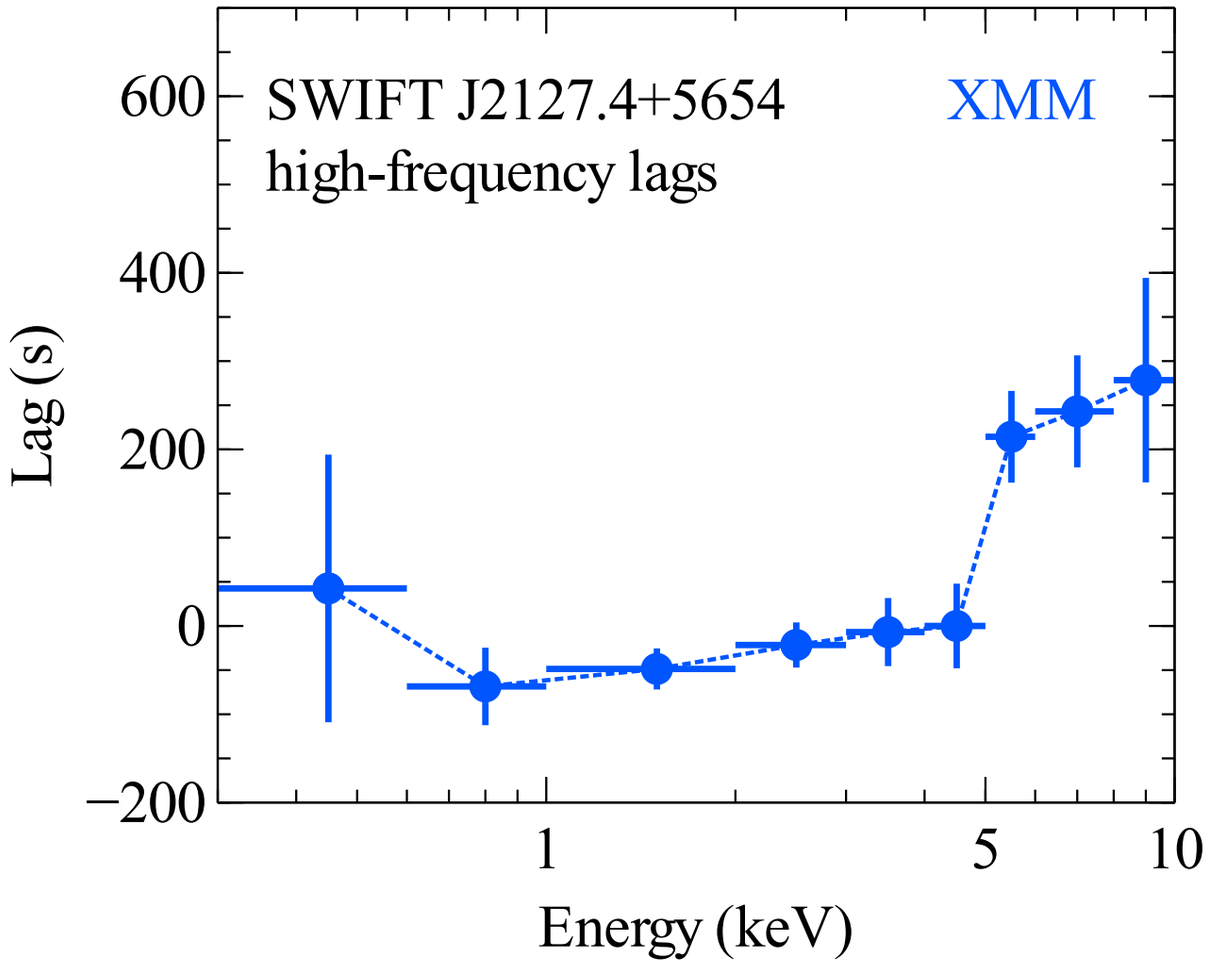
Marinucci+14

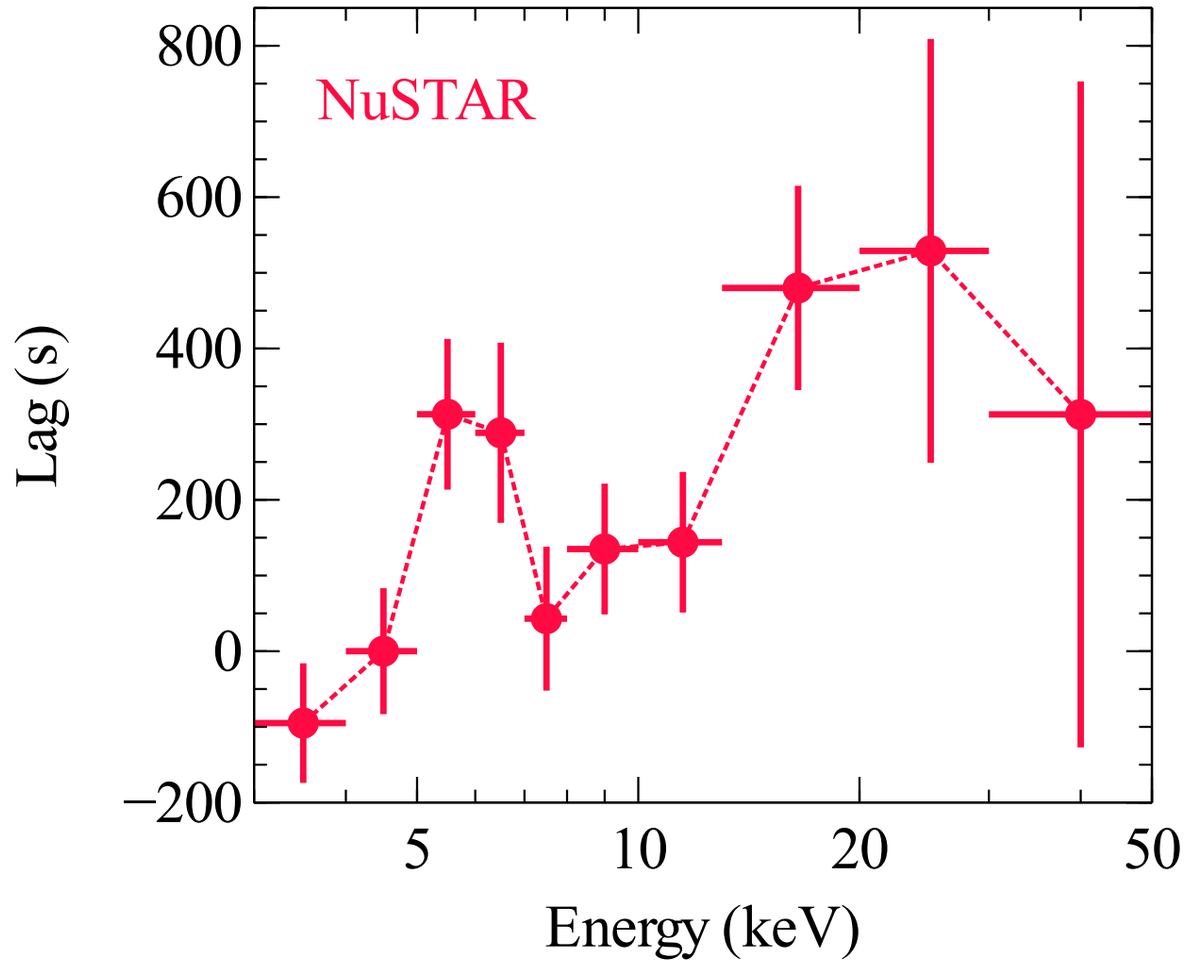
Swift J2127.4+5654

$$a=0.58^{+0.11}_{-0.17}$$

EK+14, submitted

NuSTAR Lags (using code from A. Zoghbi)



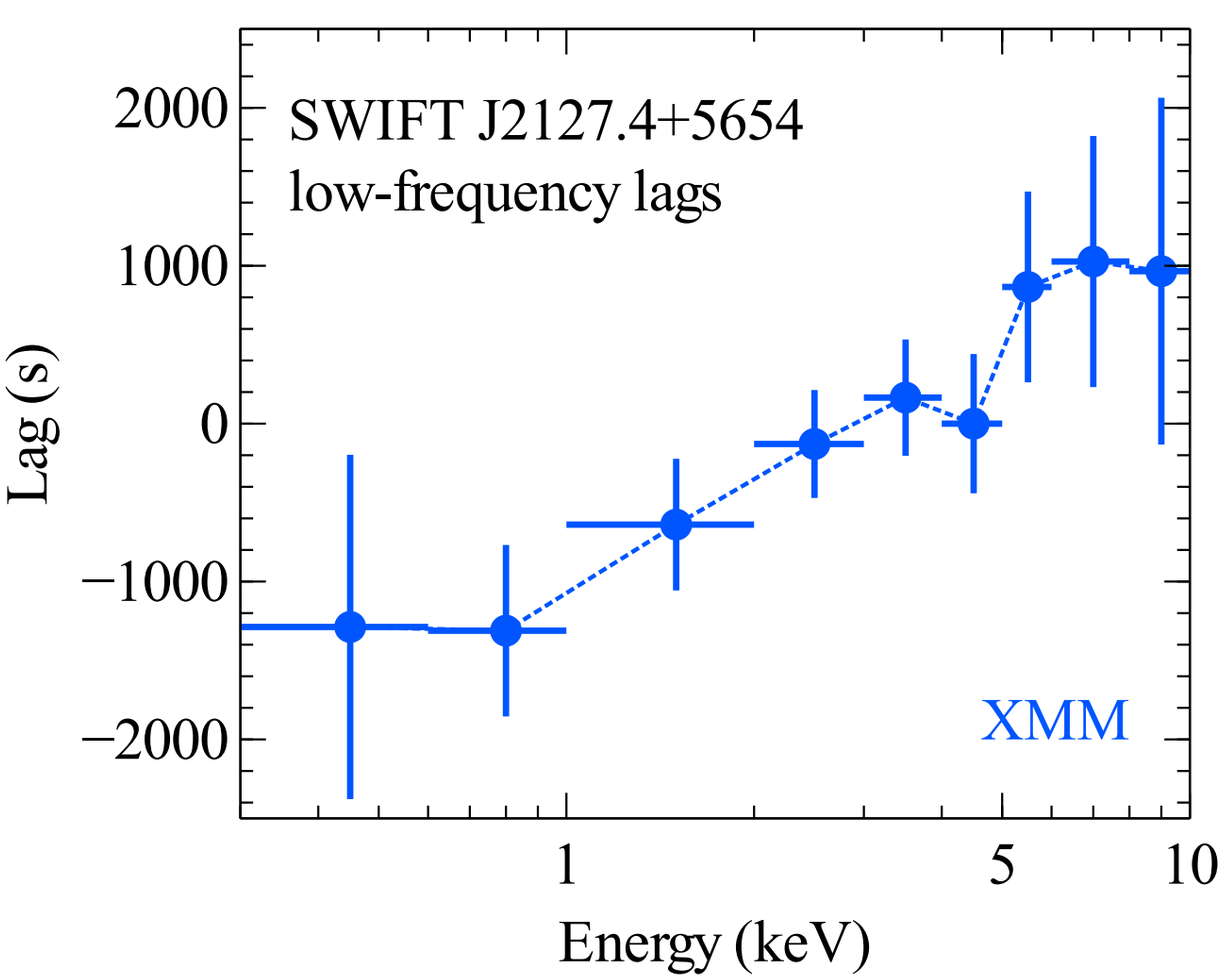


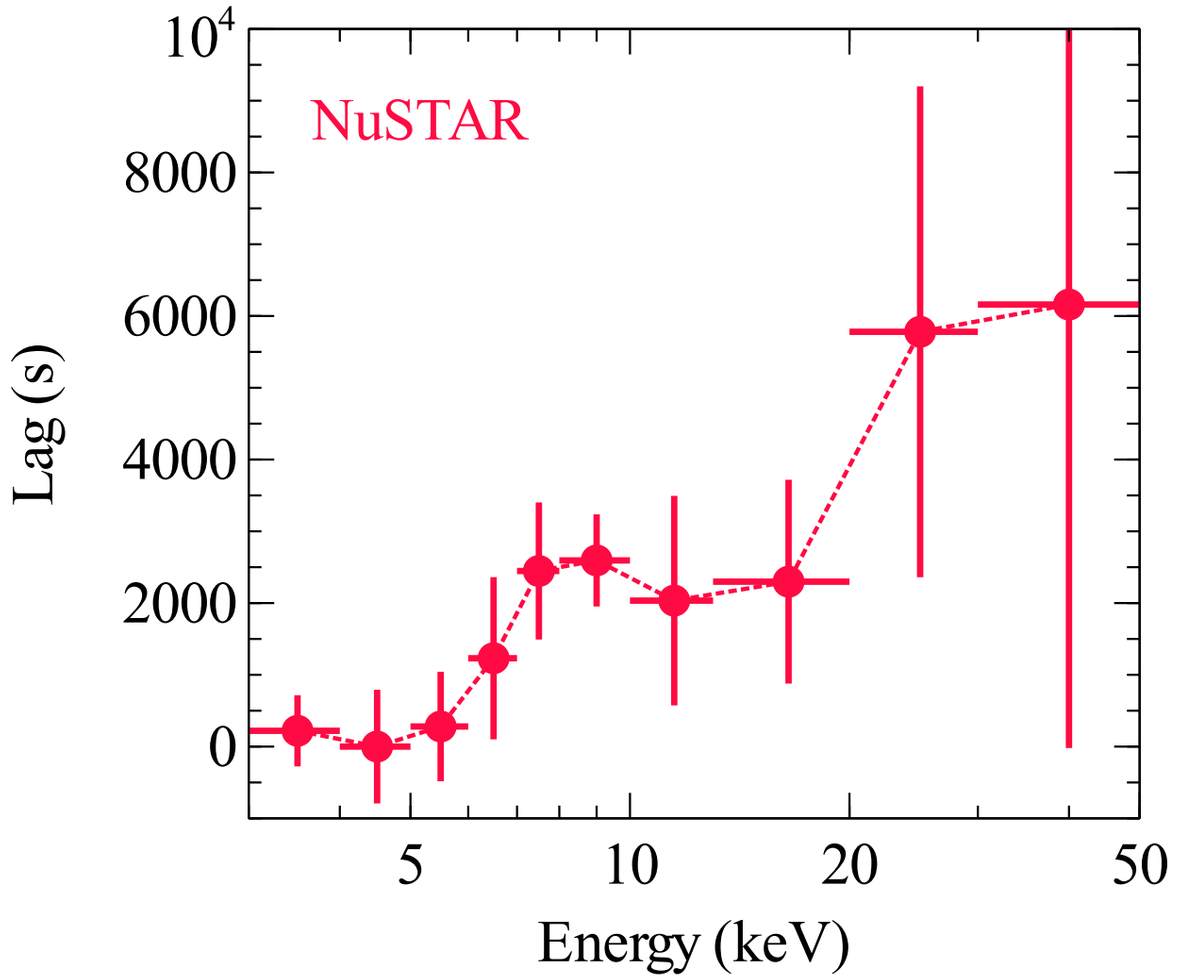
Clear detection of narrower Fe K and Compton hump lag

Swift J2127.4+5654

$$a=0.58^{+0.11}_{-0.17}$$

NuSTAR Lags (using code from A. Zoghbi)

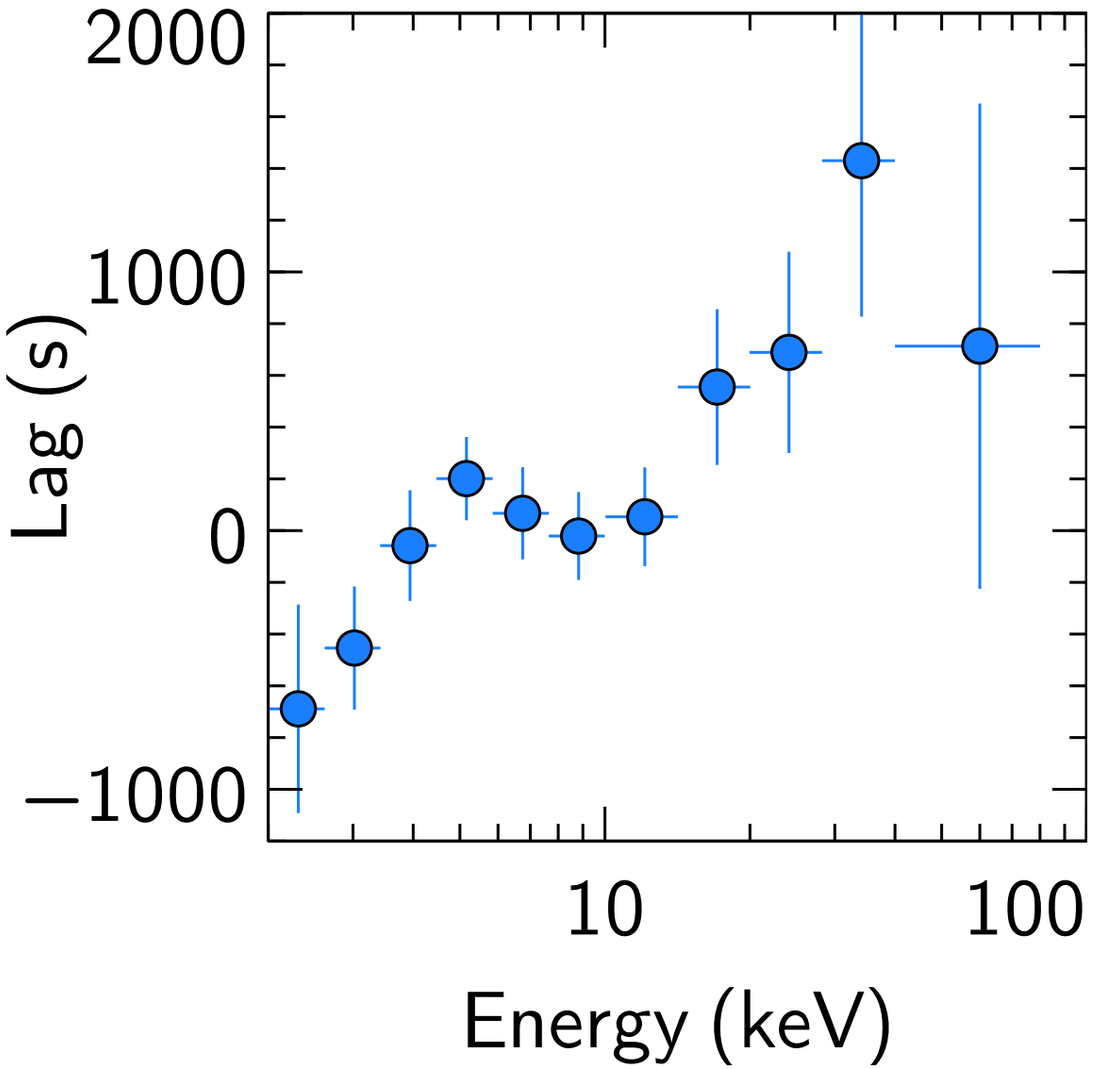




Propagation lag appears to increase above 10 keV

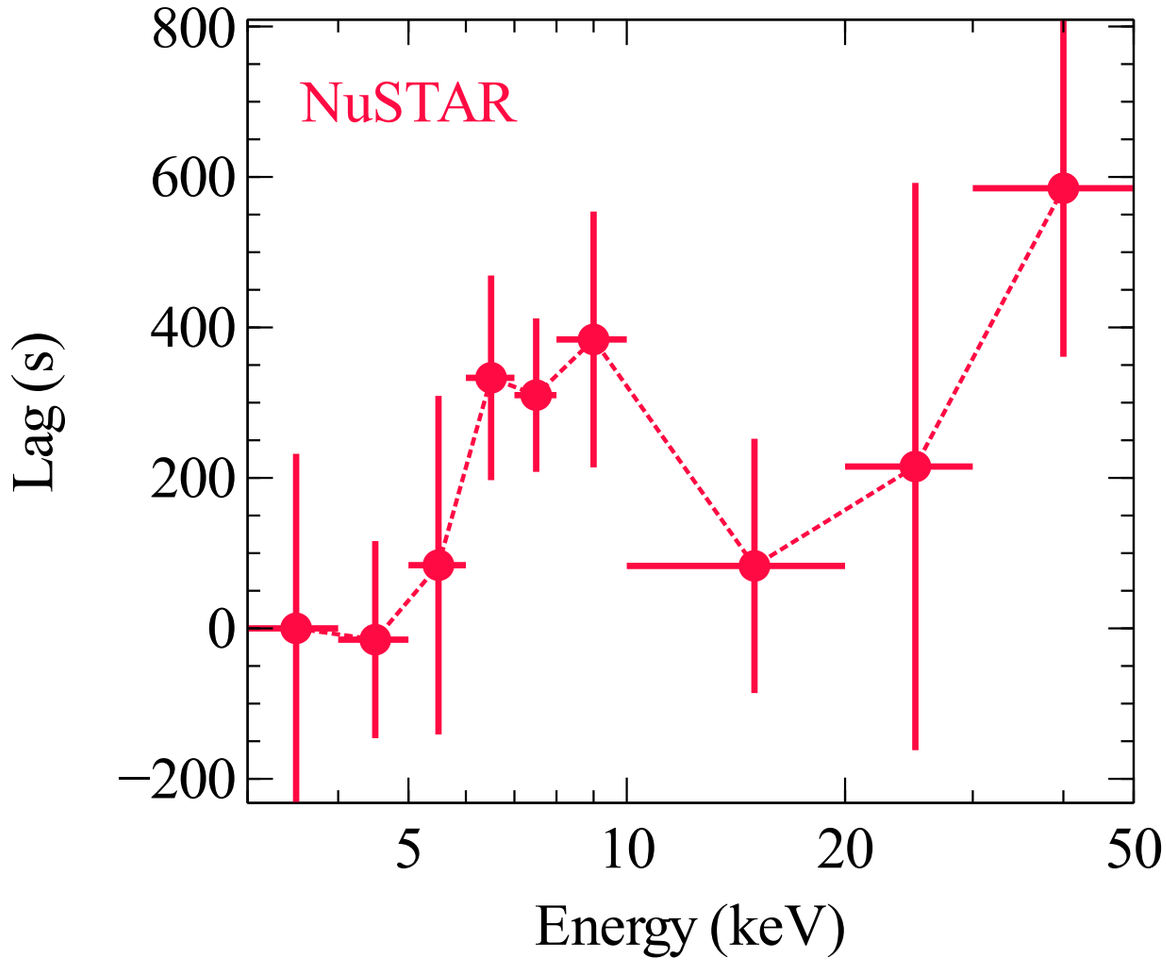
NuSTAR Lags

MCG-5-23-16



Zoghbi+14

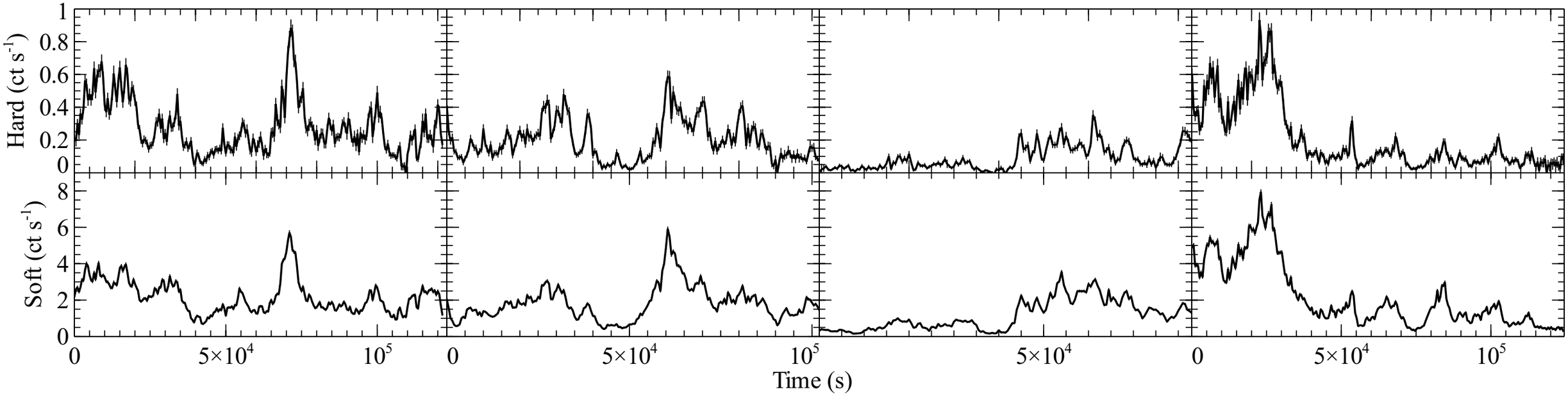
NGC 1365

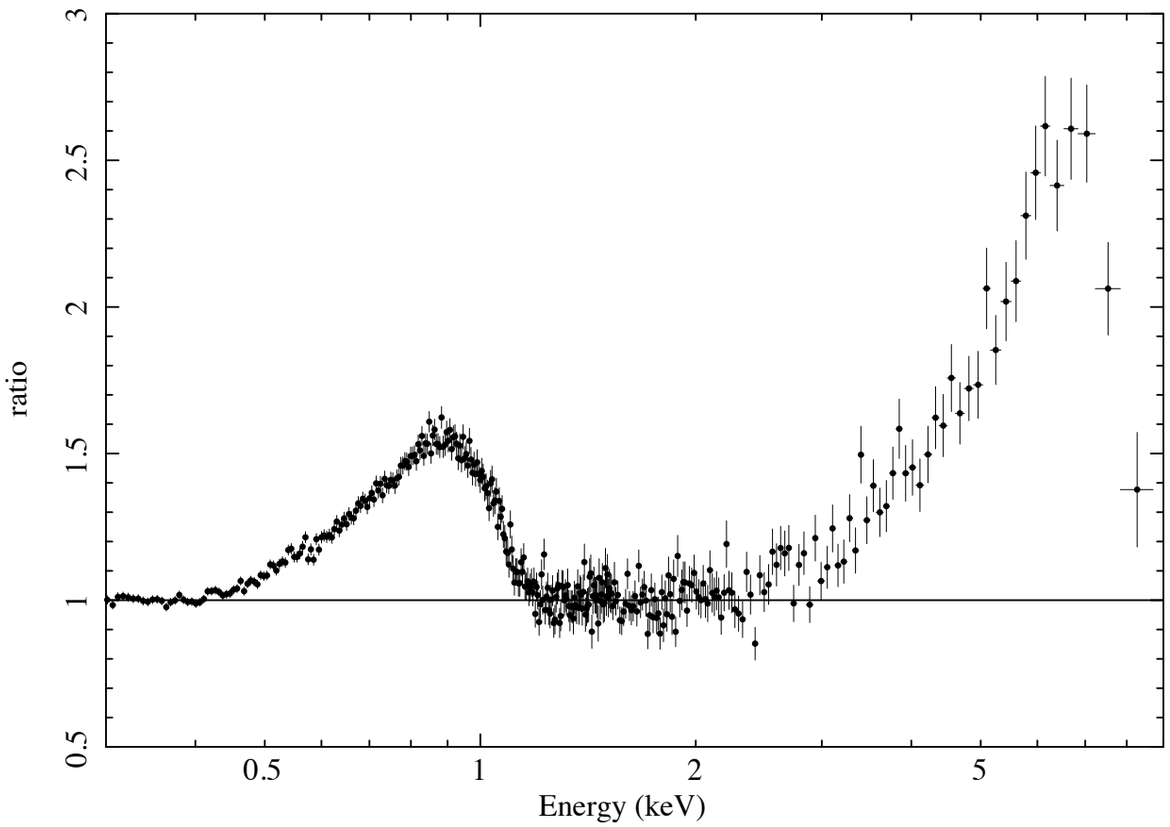


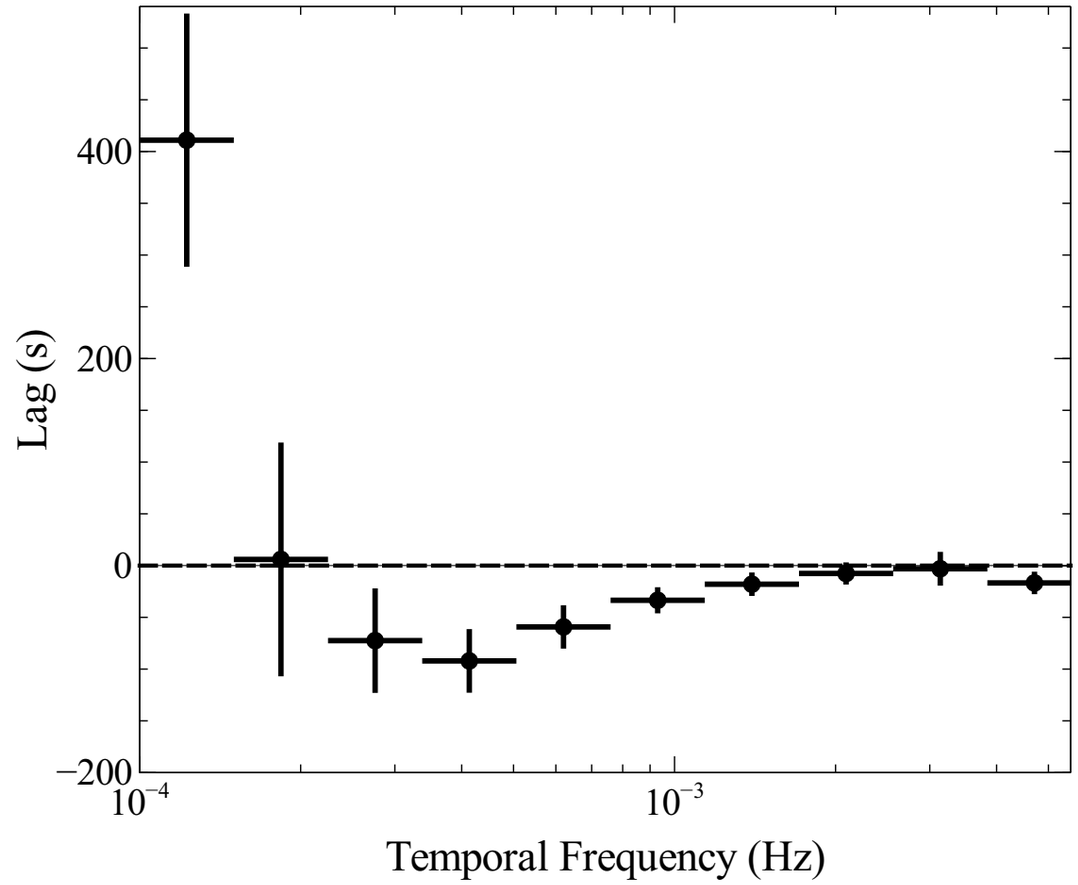
EK+14, submitted

Changing coronal geometry

IRAS 13224-3809 : 500 ks with XMM-Newton

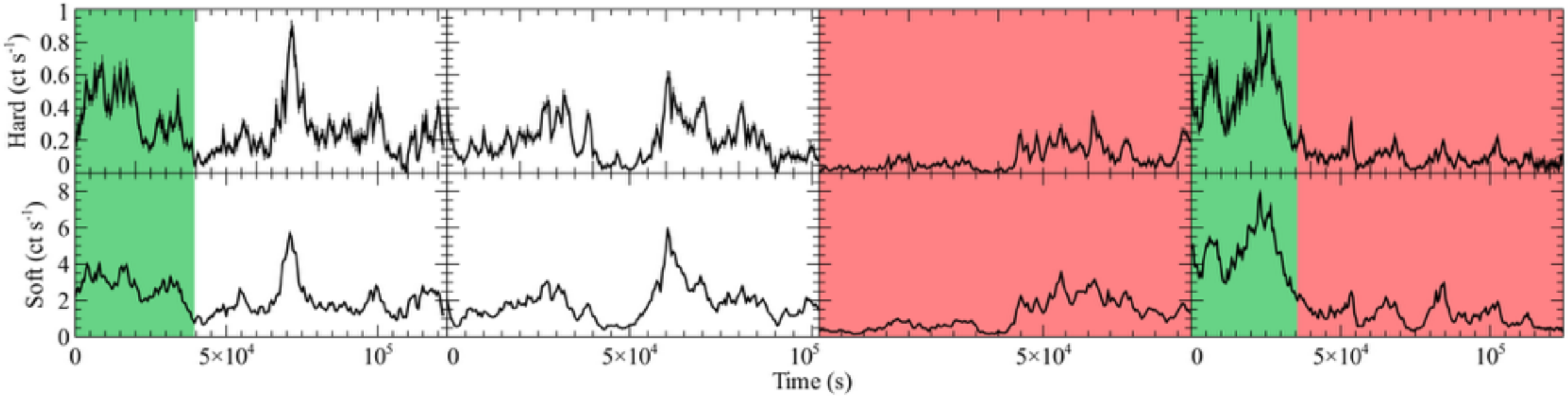






Fabian et al 2013

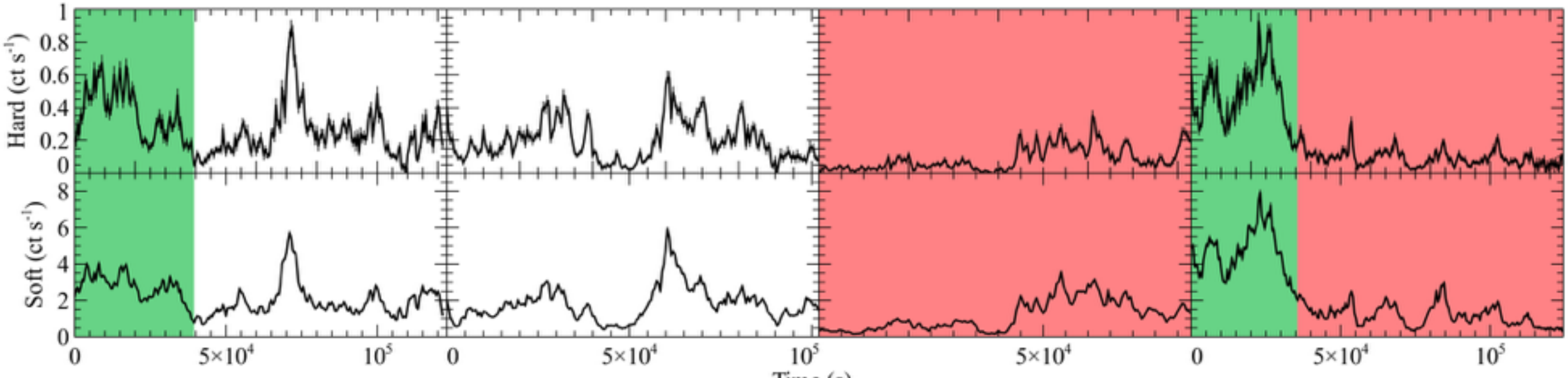
Flux-dependent lags

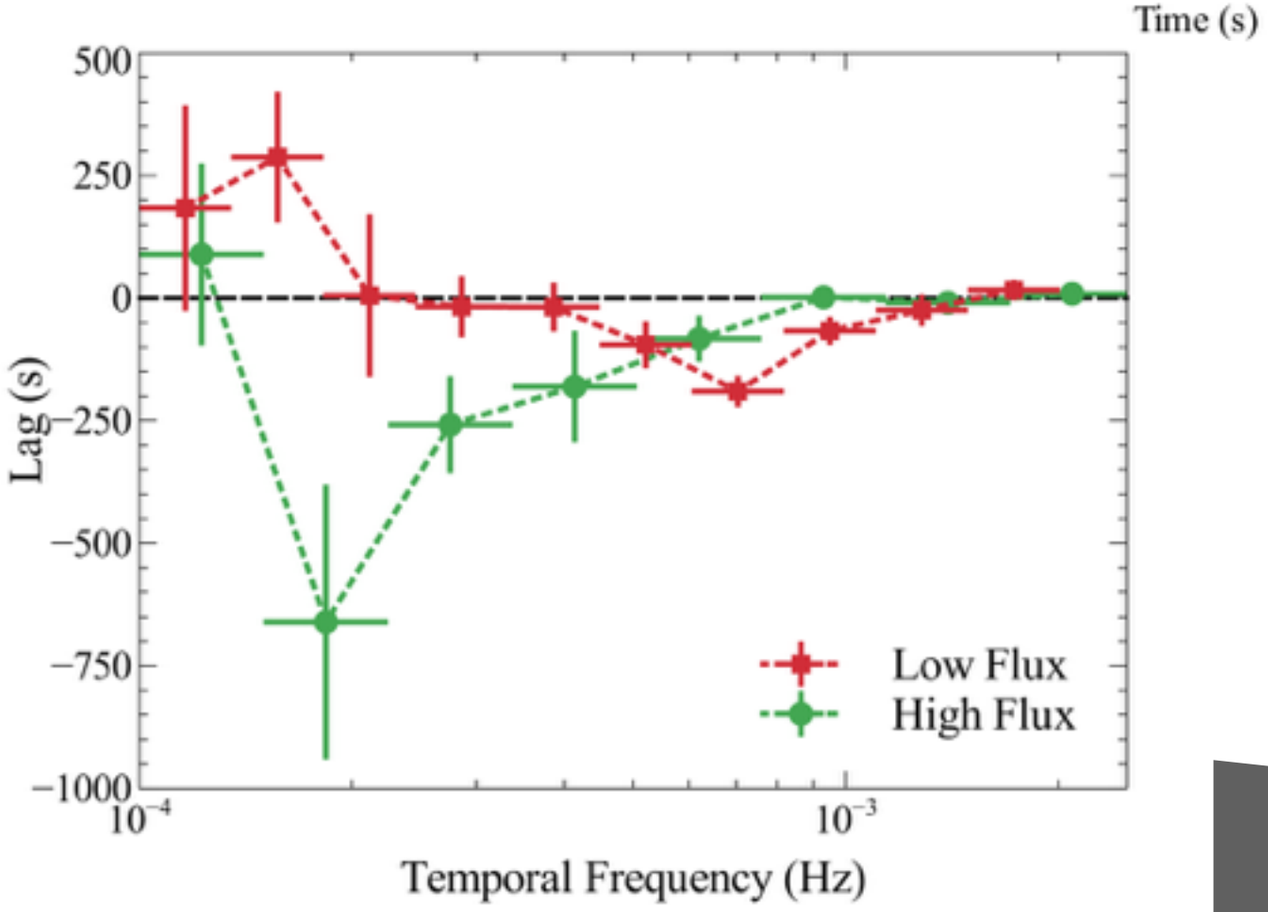


EK+13

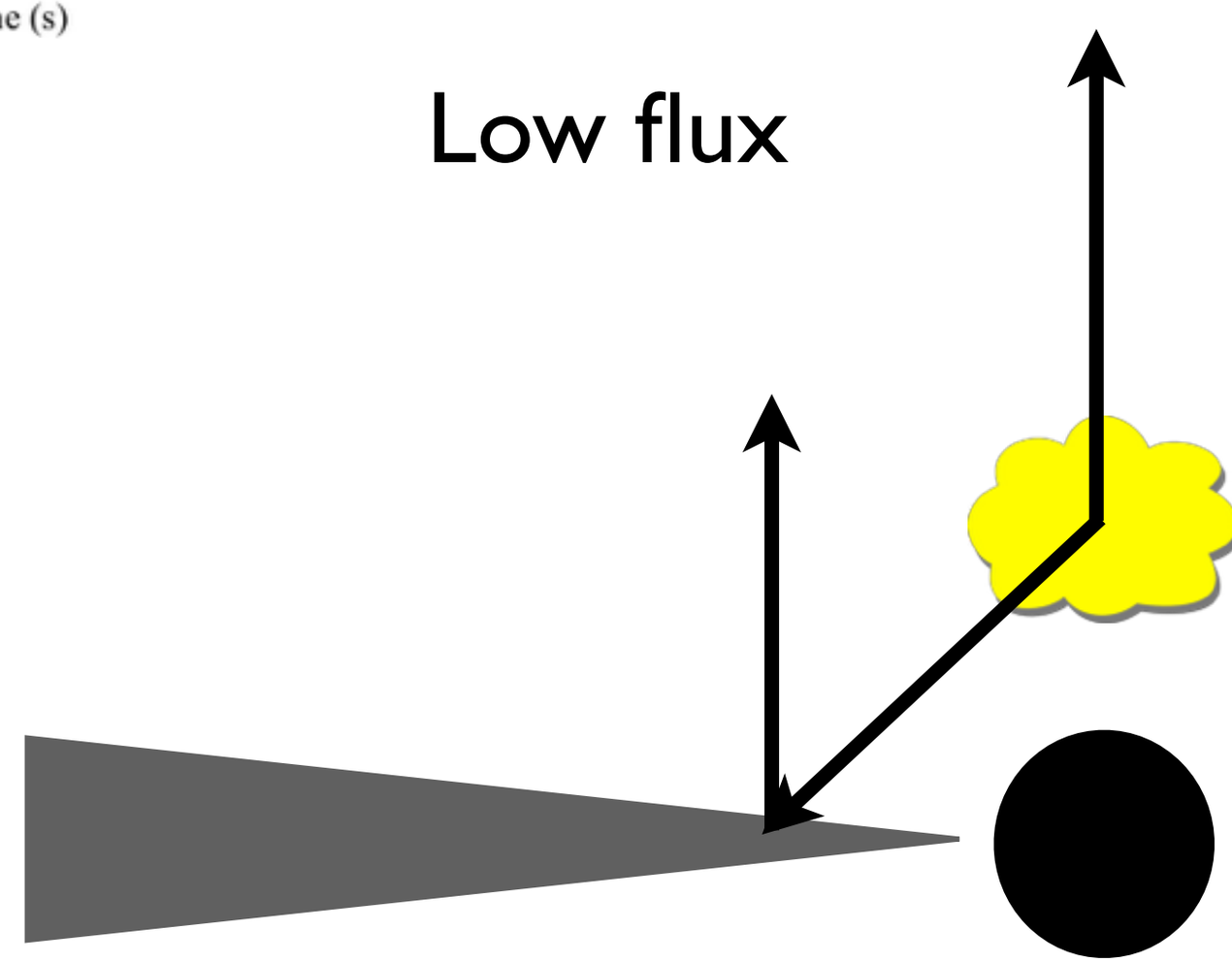
Flux-dependent lags

IRAS 13224-3809



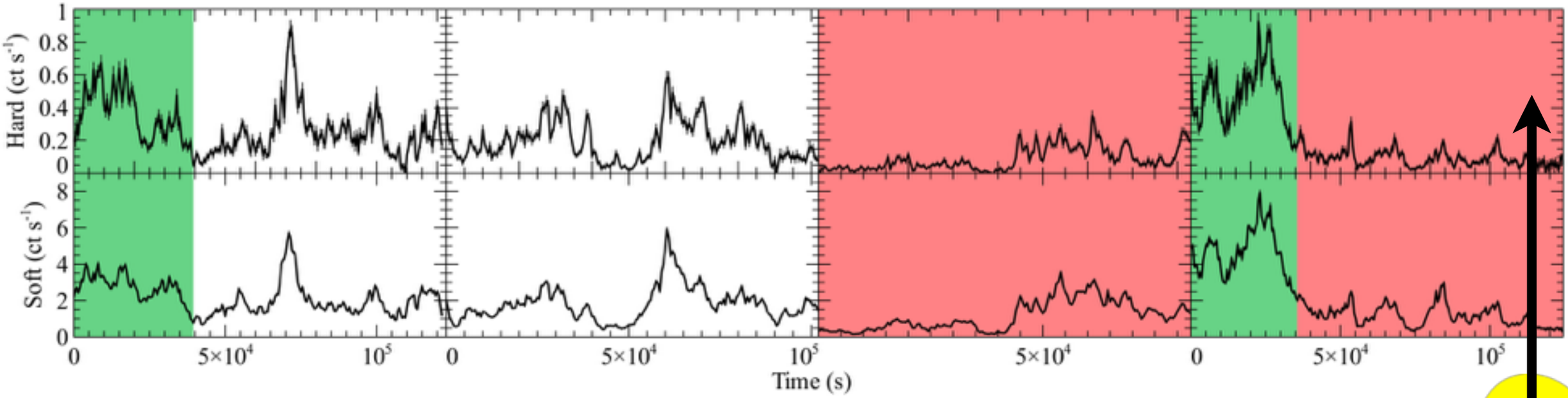


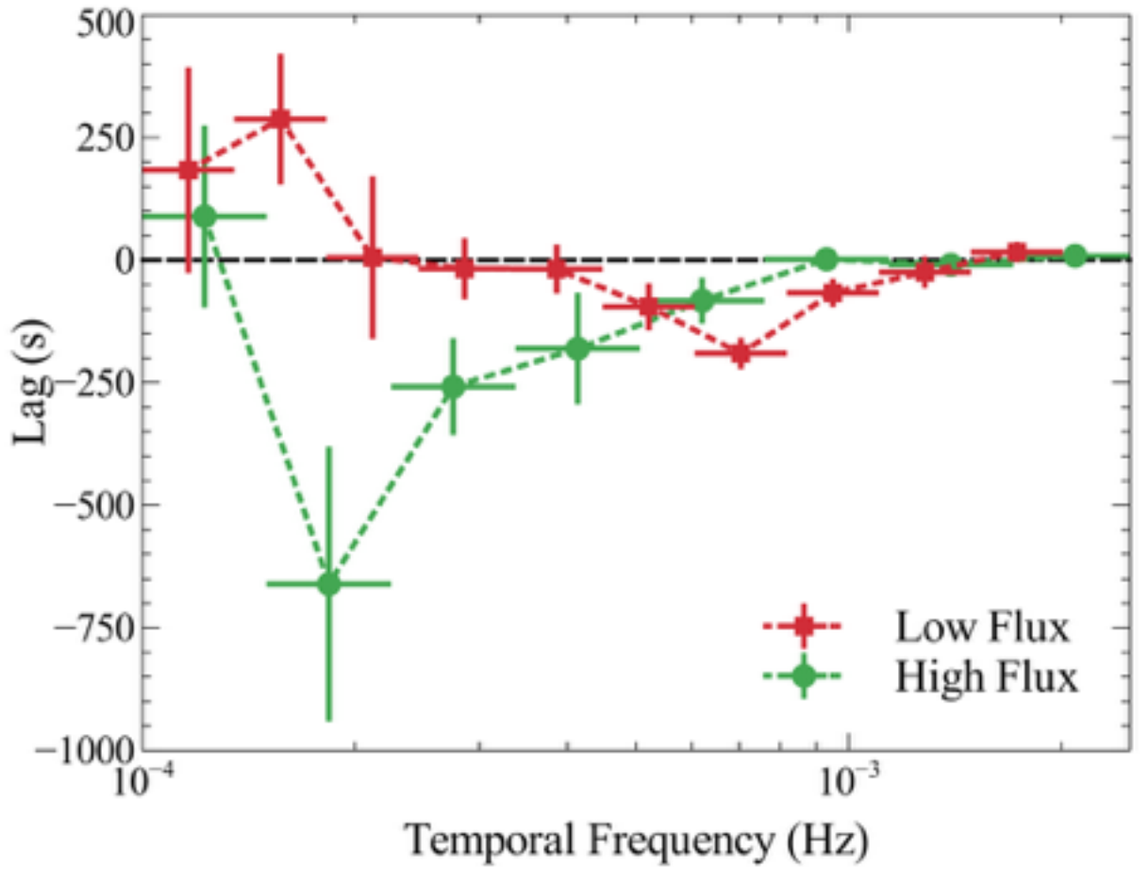
EK+13



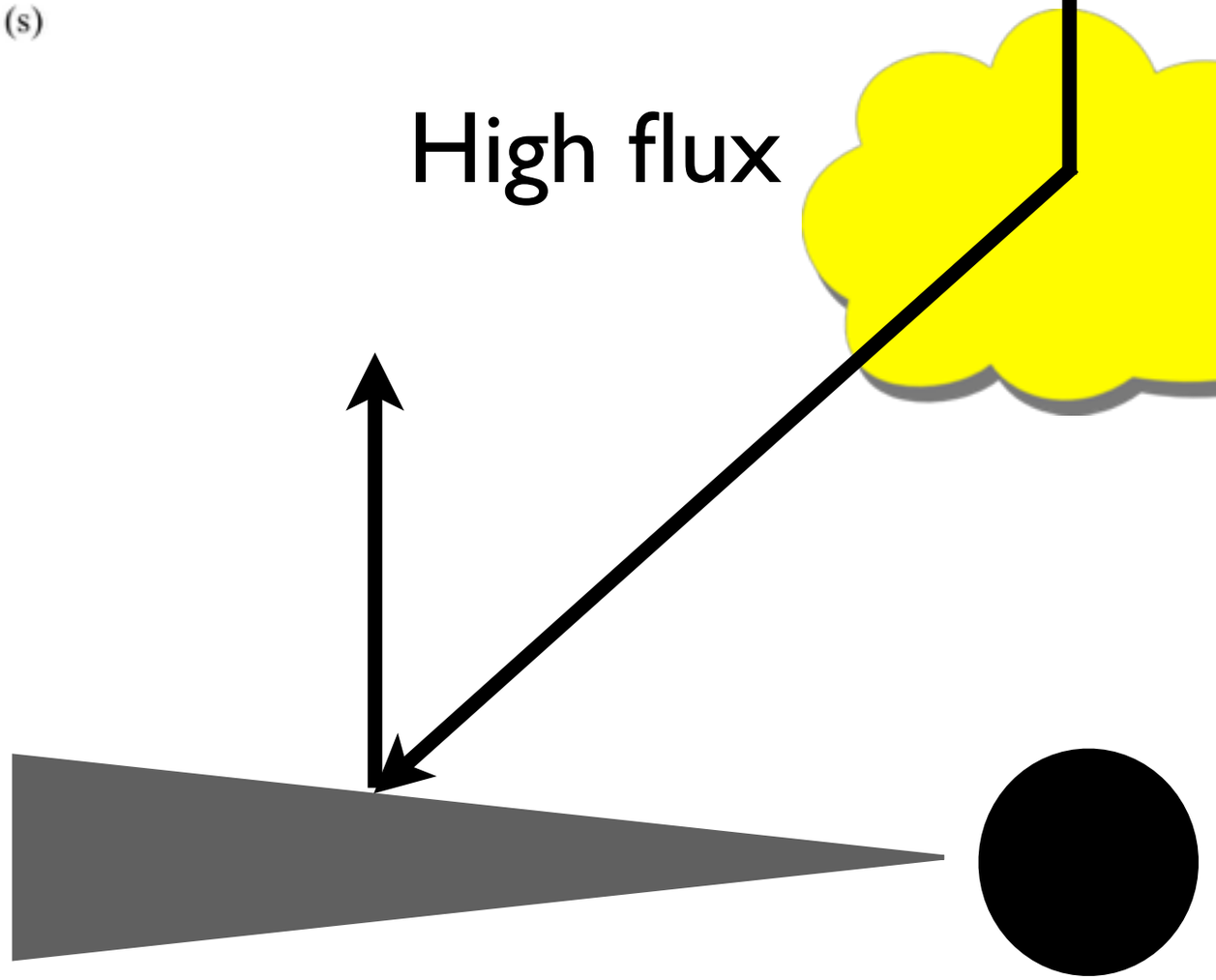
Flux-dependent lags

IRAS 13224-3809

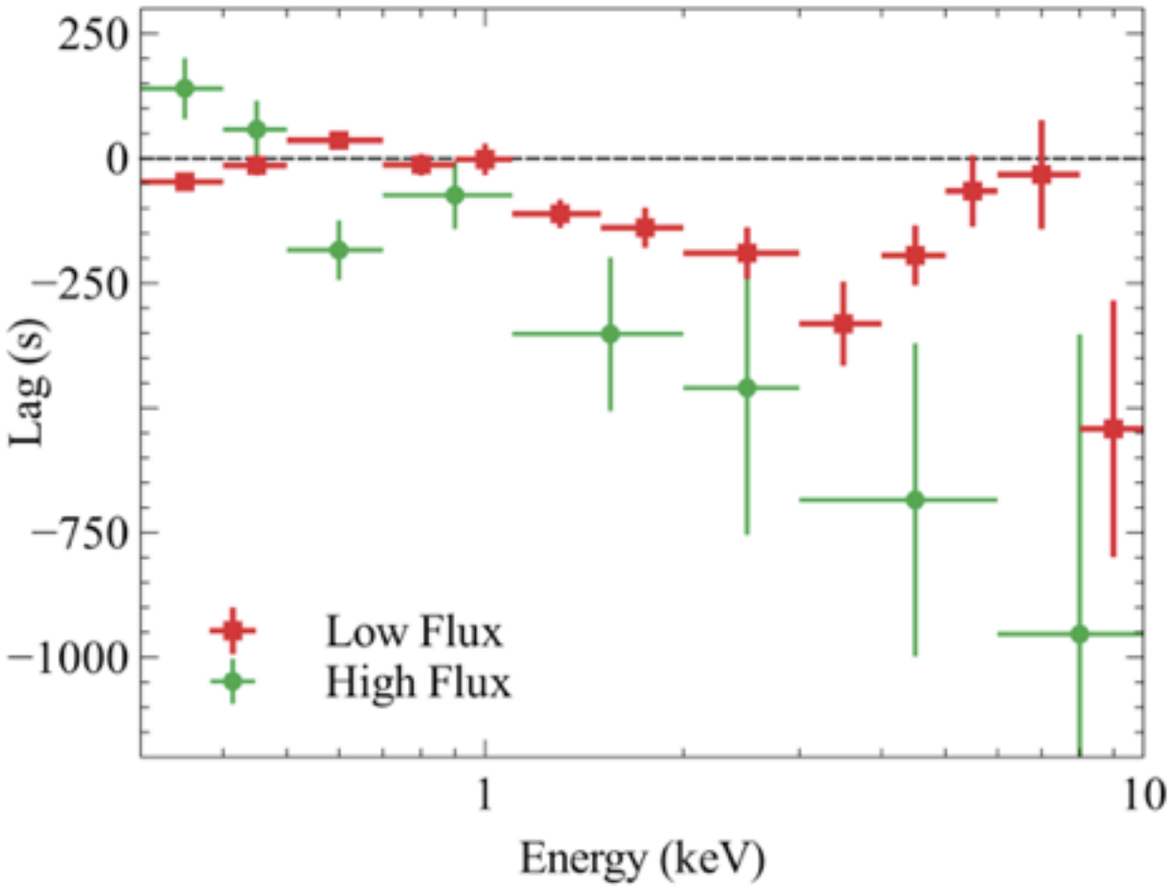


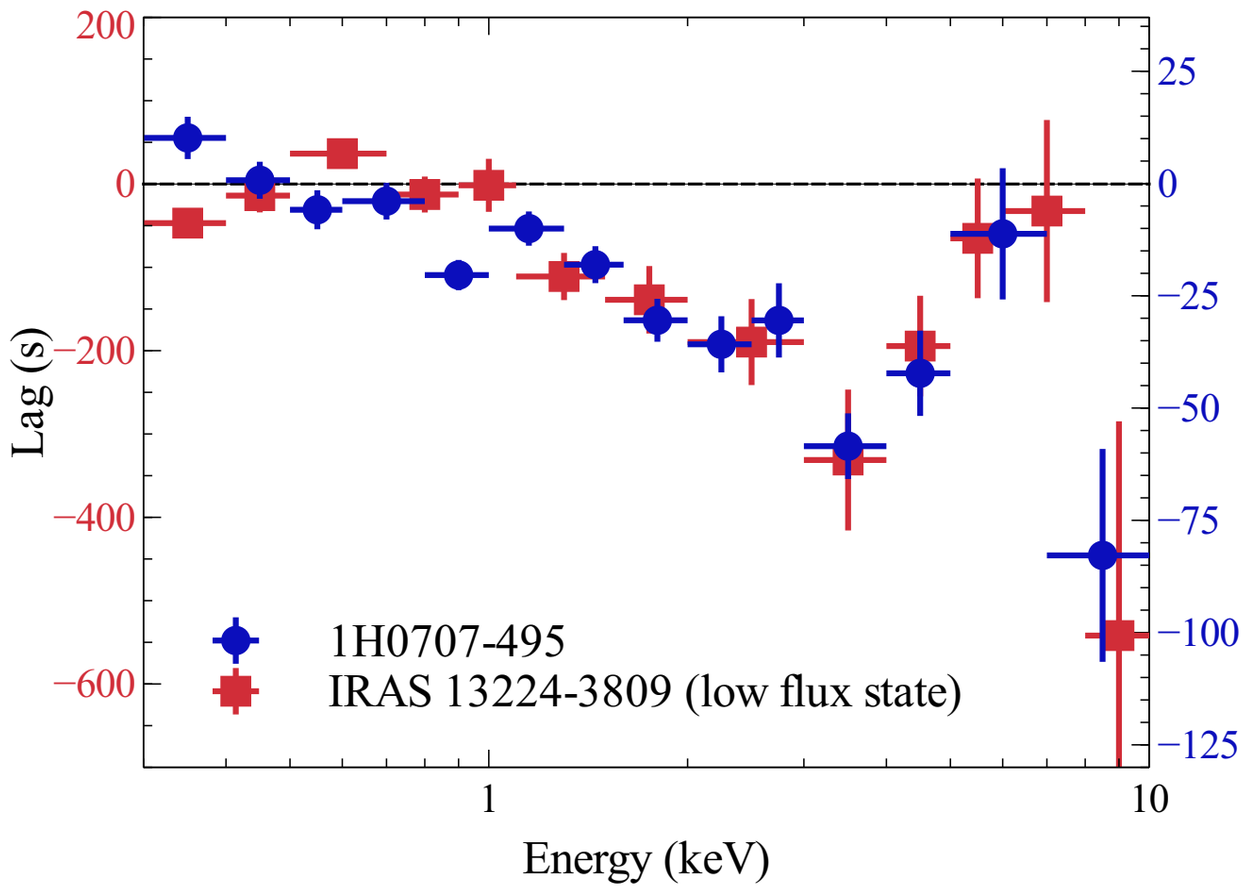


EK+13



Flux-dependent lags

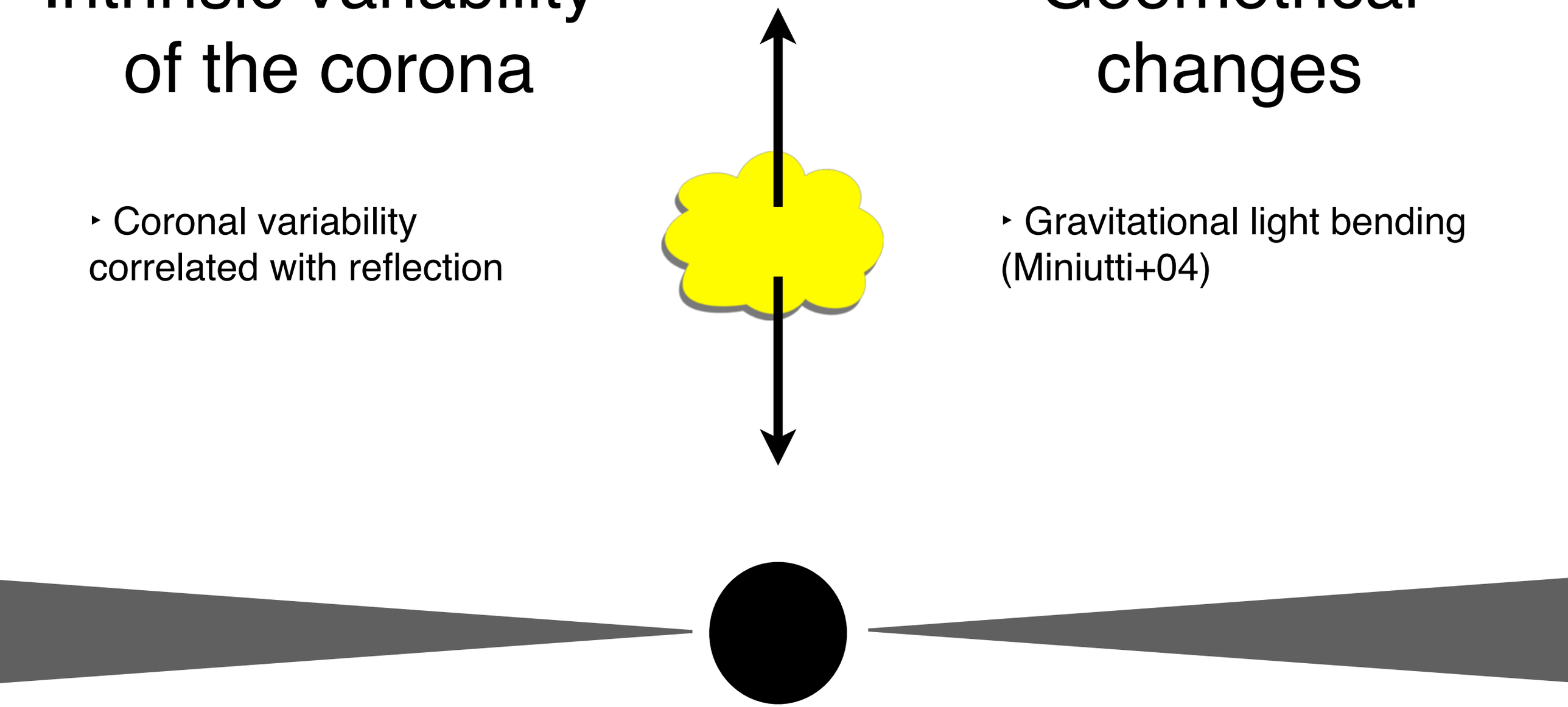




Understanding the X-ray variability

Intrinsic variability of the corona

- Coronal variability correlated with reflection

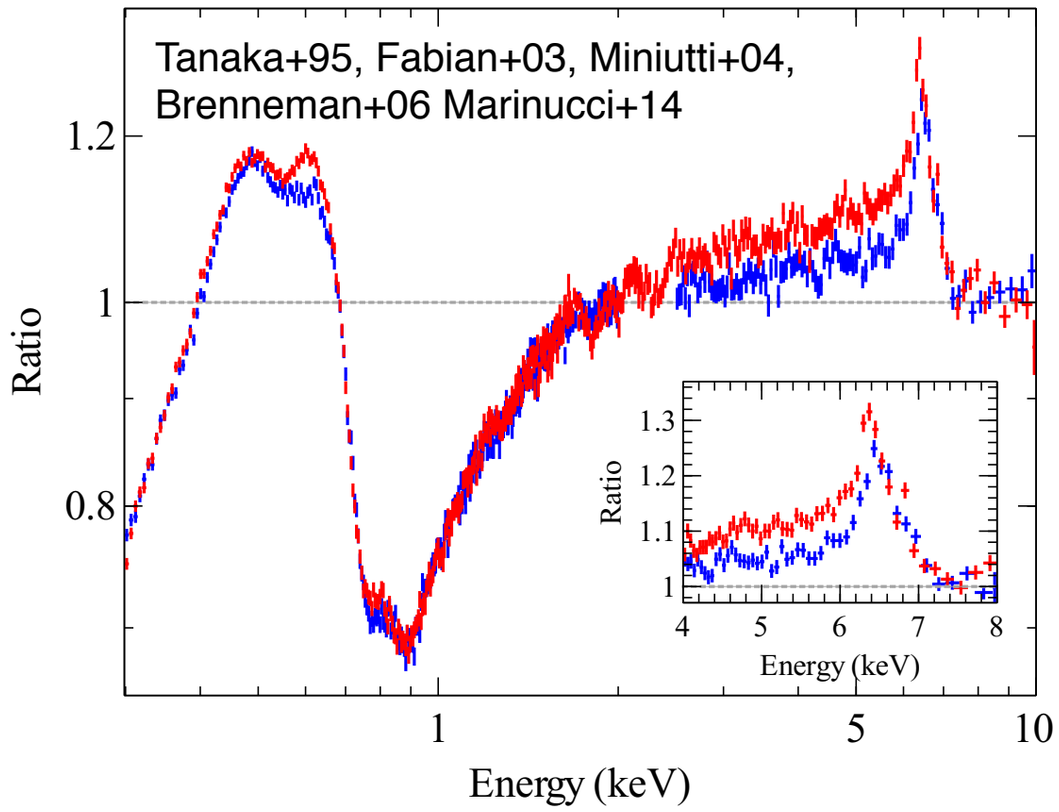


Geometrical changes

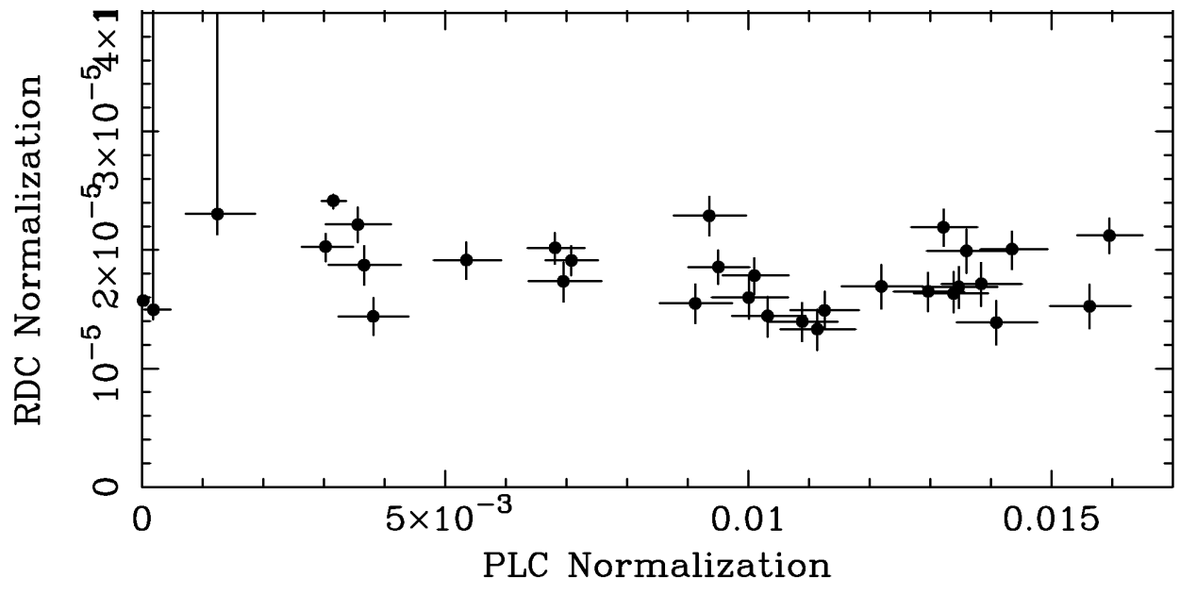
- Gravitational light bending (Miniutti+04)

Understanding the X-ray variability

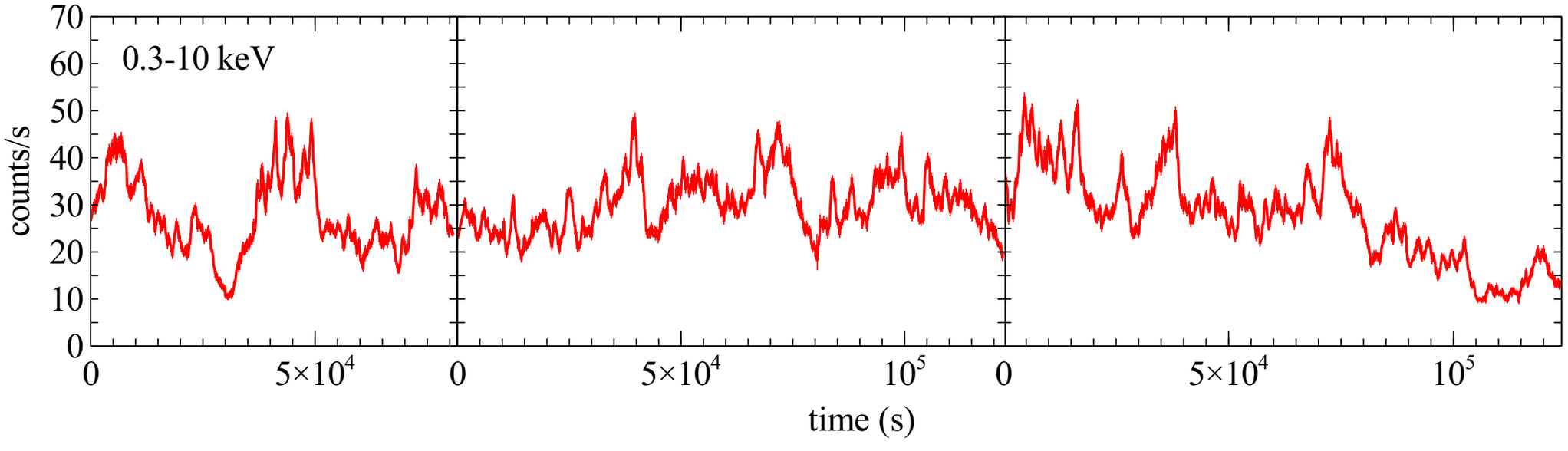
MCG-6-30-15



Evidence for light bending?



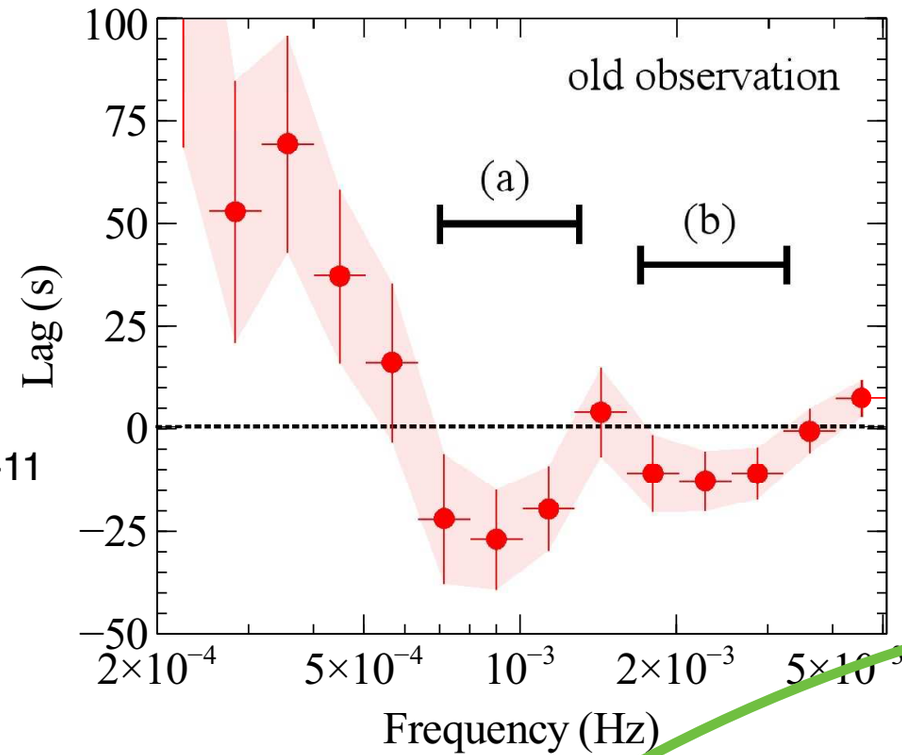
Fabian & Vaughan 03



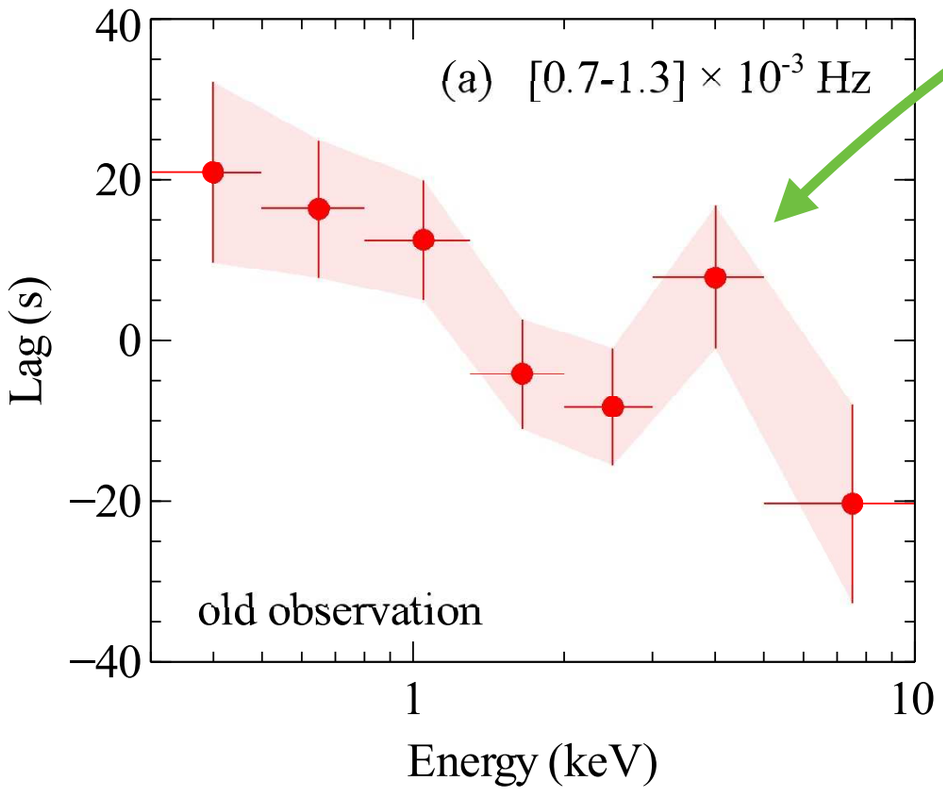
Understanding the X-ray variability

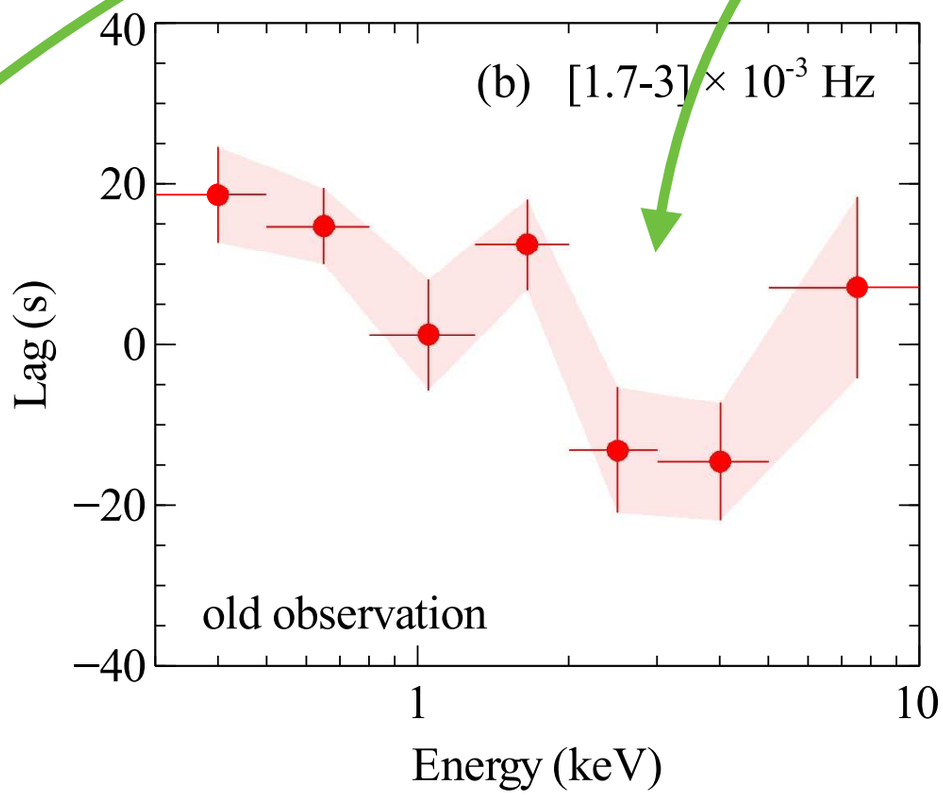
MCG-6-30-15

Emmanoloupolous+11



no clear Fe K lag

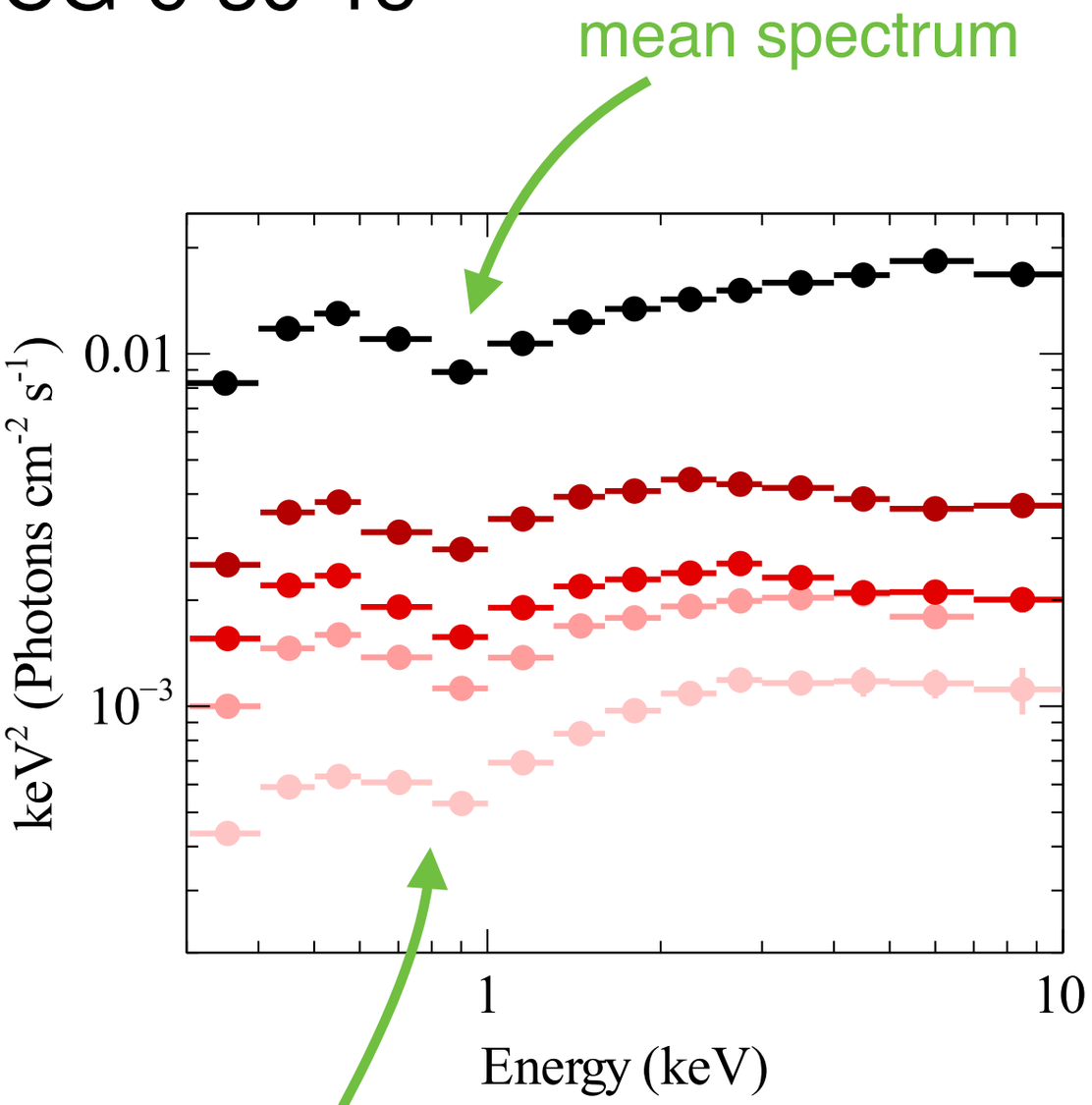


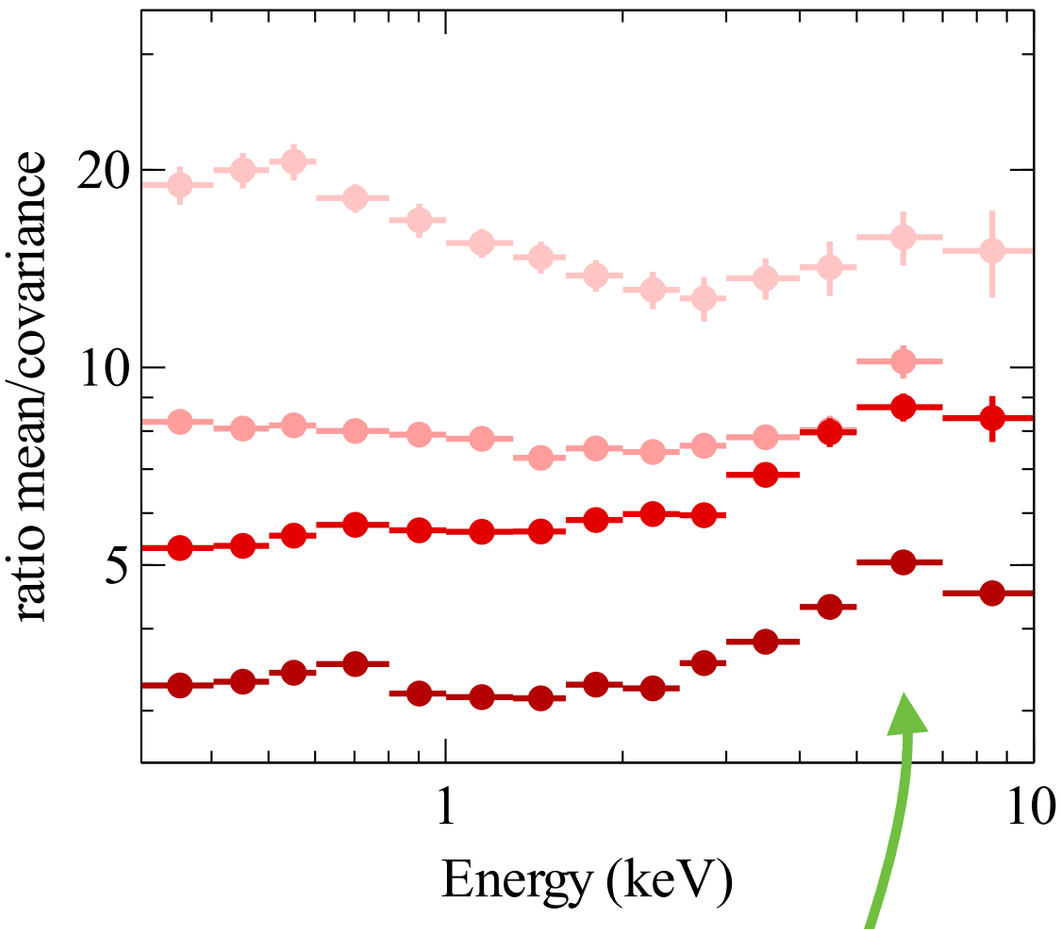


EK+14

Understanding the X-ray variability

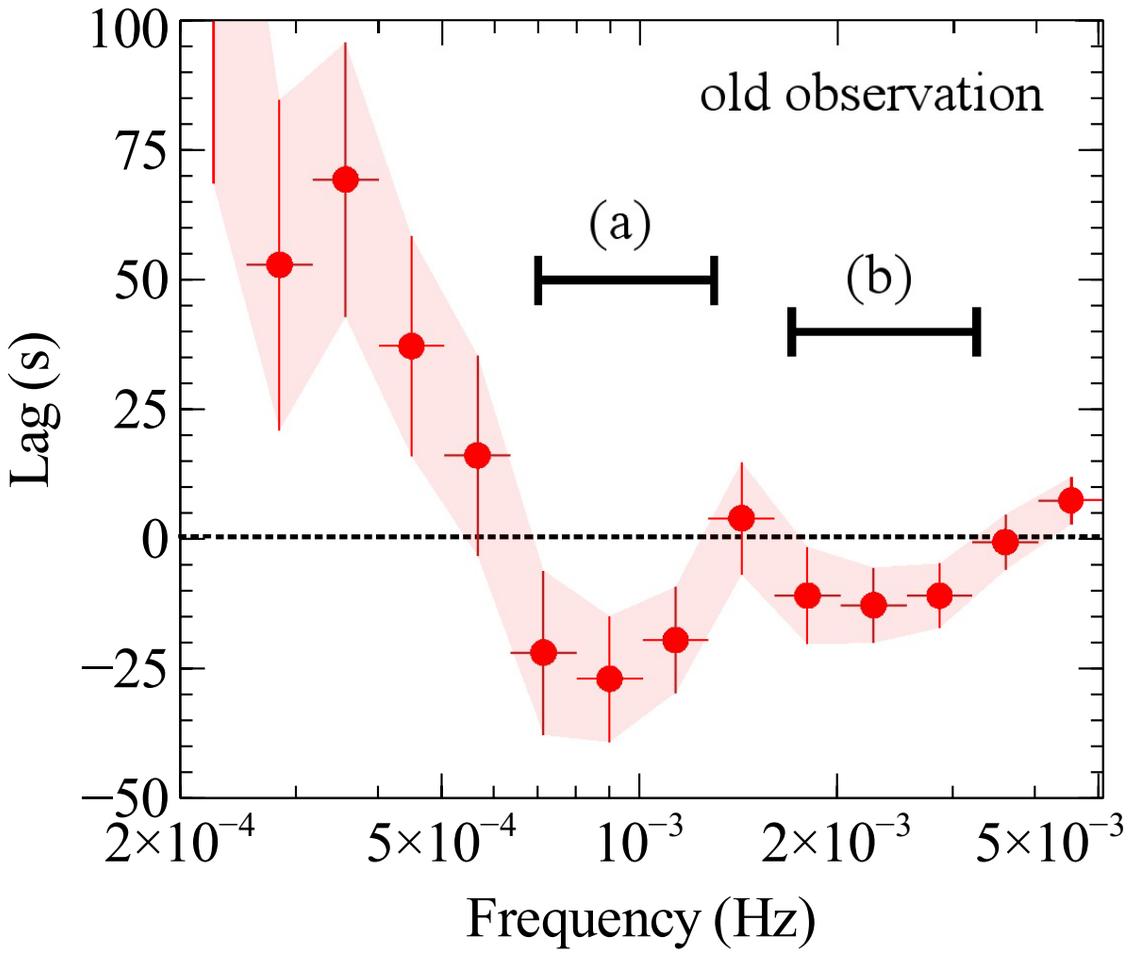
MCG-6-30-15

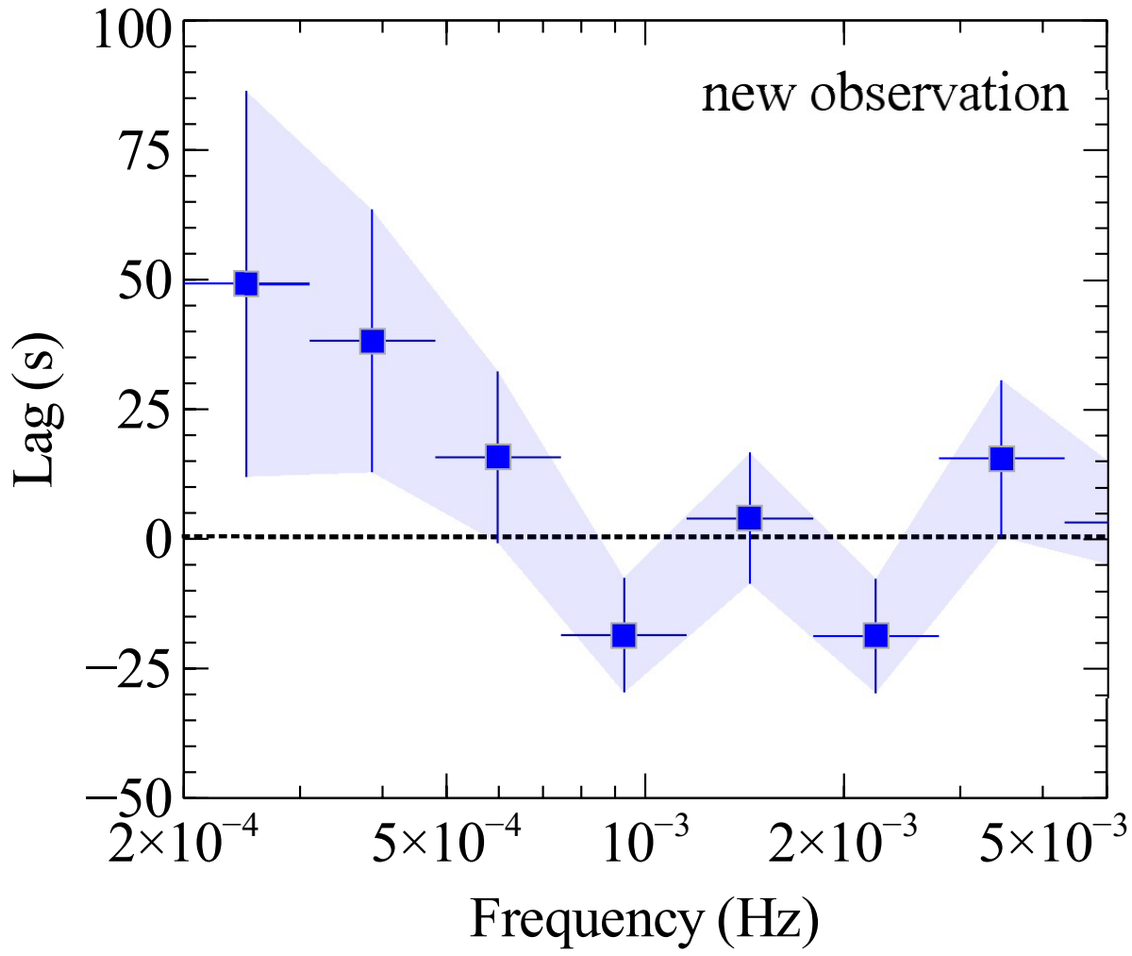




Question: What is causing these different variability mechanisms?
Why does MCG-6-30-15 appear to show more geometrical changes than most?

Understanding the X-ray variability





Conclusions

- Reverberation offers a model-independent, orthogonal approach to spectral analyses, giving insights into:
    - black hole spin
    - extent of the corona
    - variability mechanisms

- NuSTAR is probing a new energy band, revealing the reverberation lags associated with the Compton Hump

- Future work modeling the lags will help put constraints on the geometry and kinematics of the accretion flow

- See Uttley, Cackett, Fabian, Kara & Wilkins `14 for more…