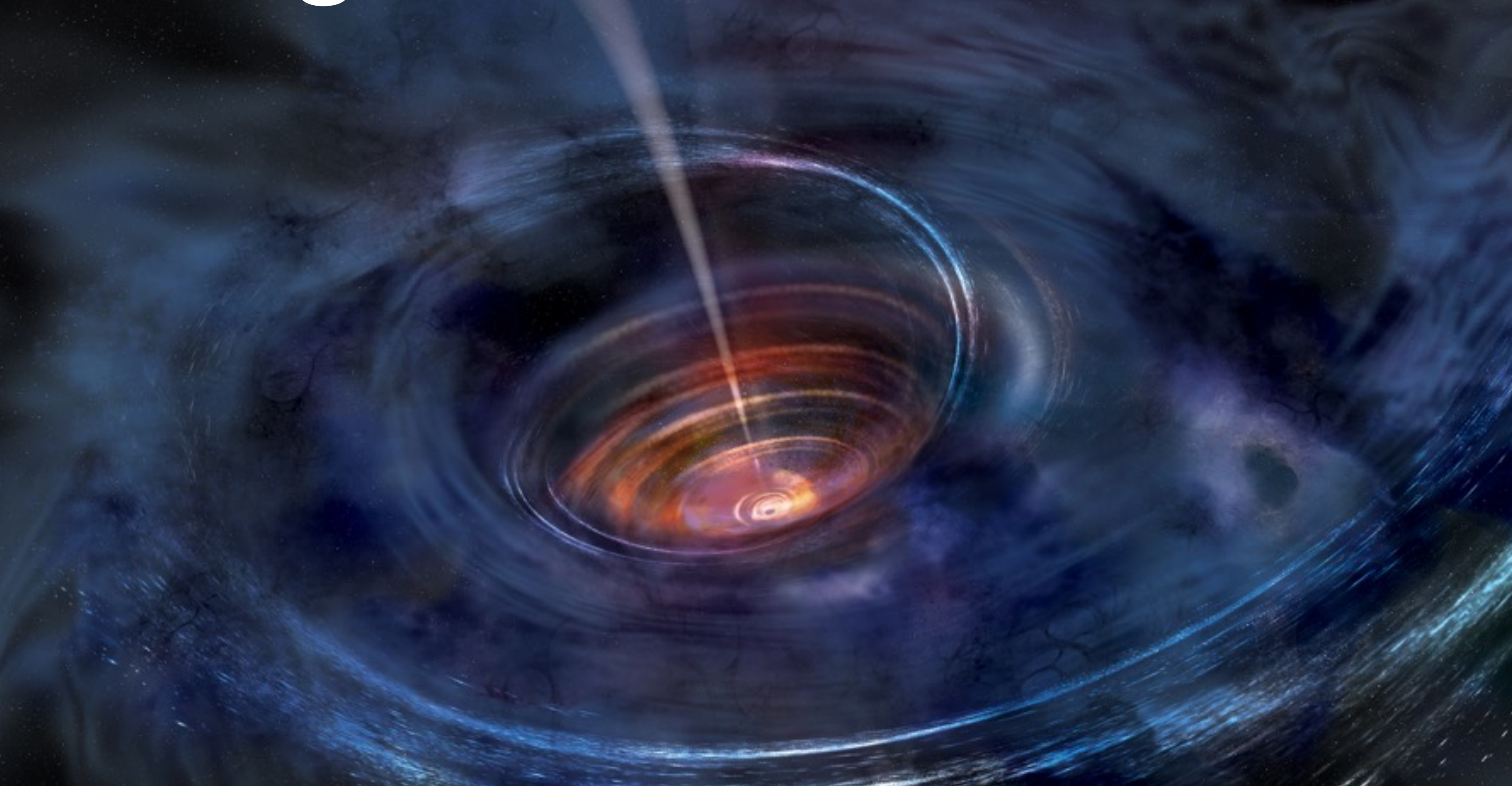
X-ray Astronomy
Bologna, Italy
11 September 2019

Massachusetts Institute of Technology

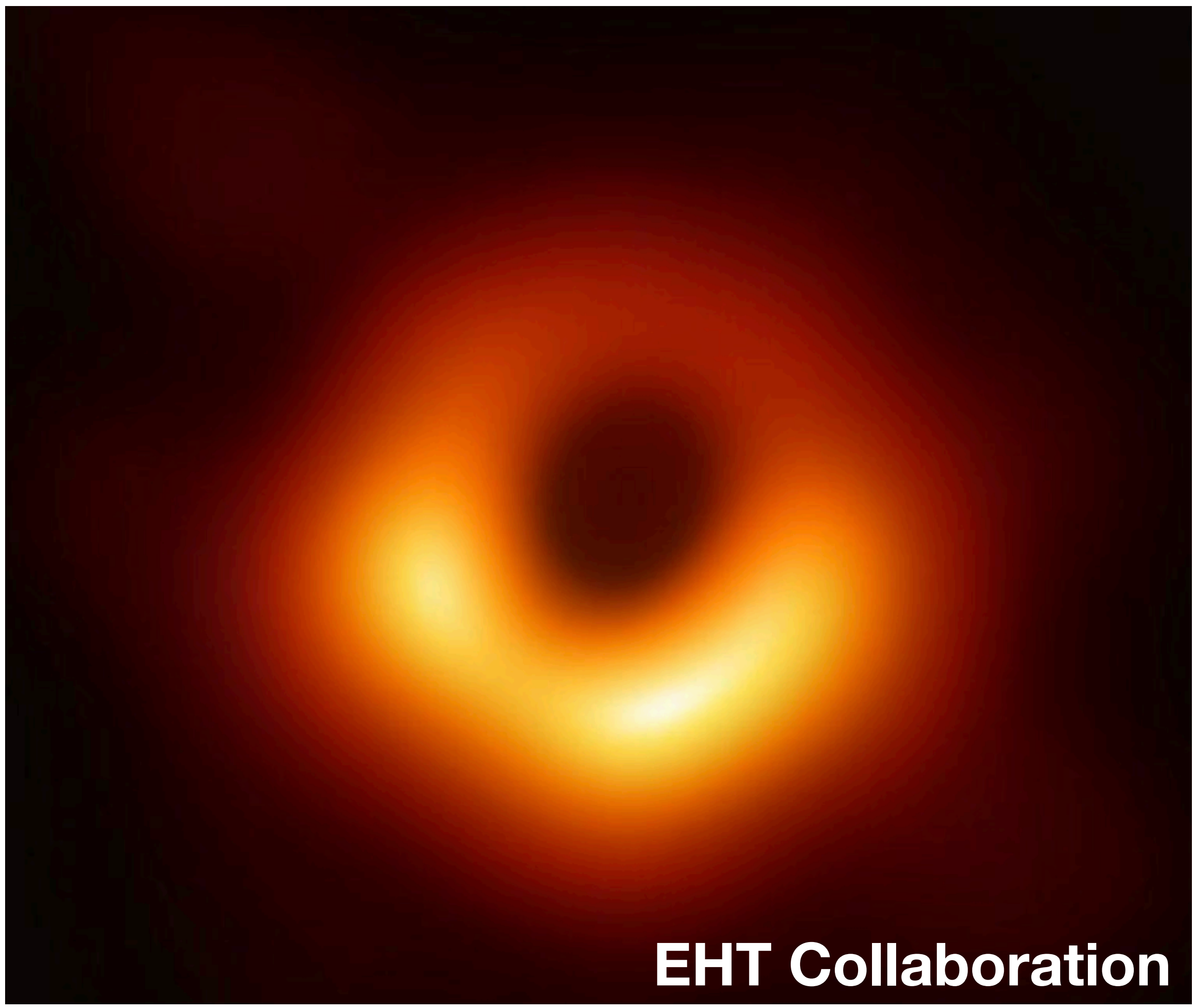
X-ray reverberation in accreting black holes

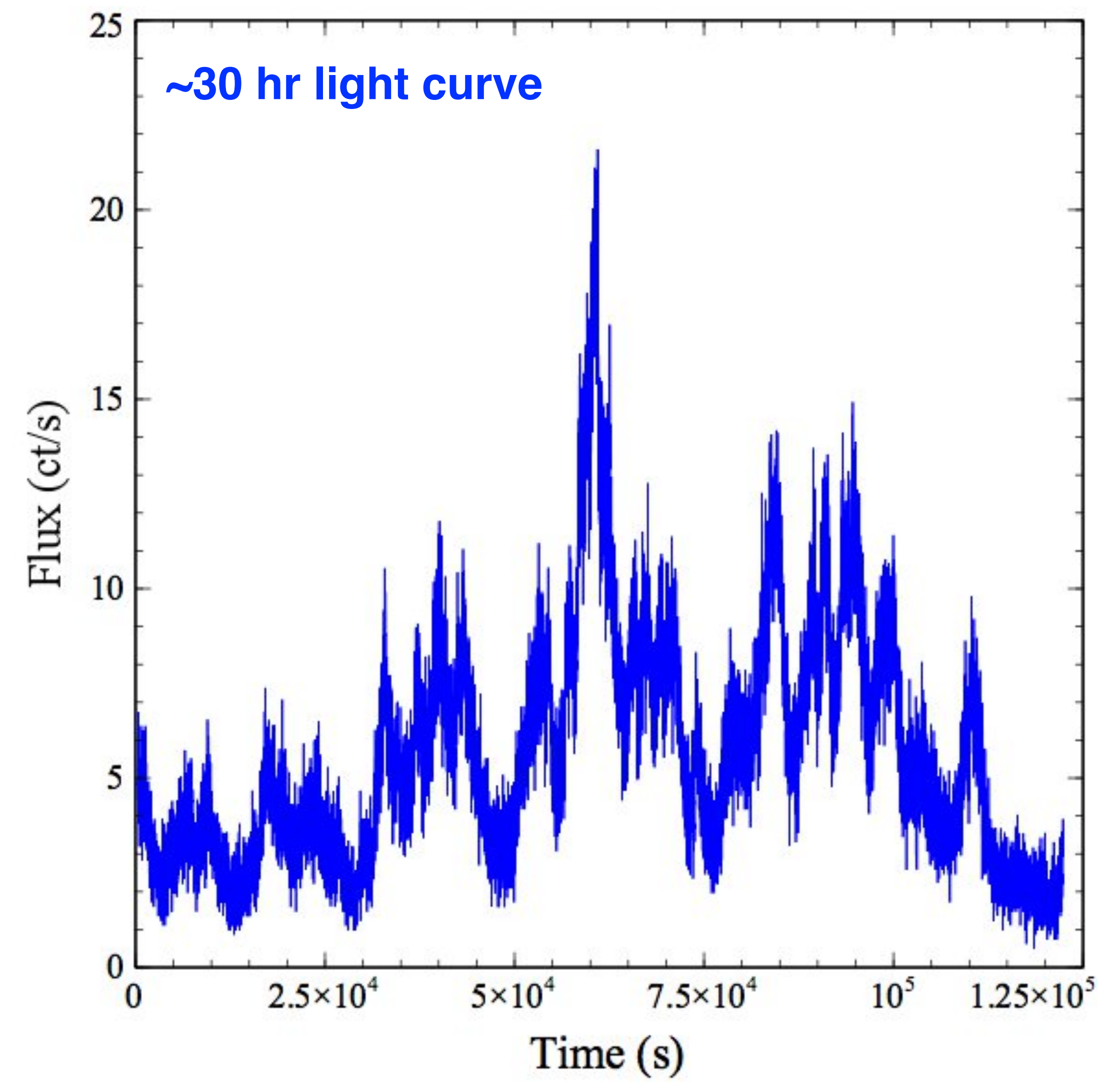


Erin Kara
ekara@mit.edu

X-ray Reverberation Mapping

X-ray reverberation → **mapping the inner accretion flow**

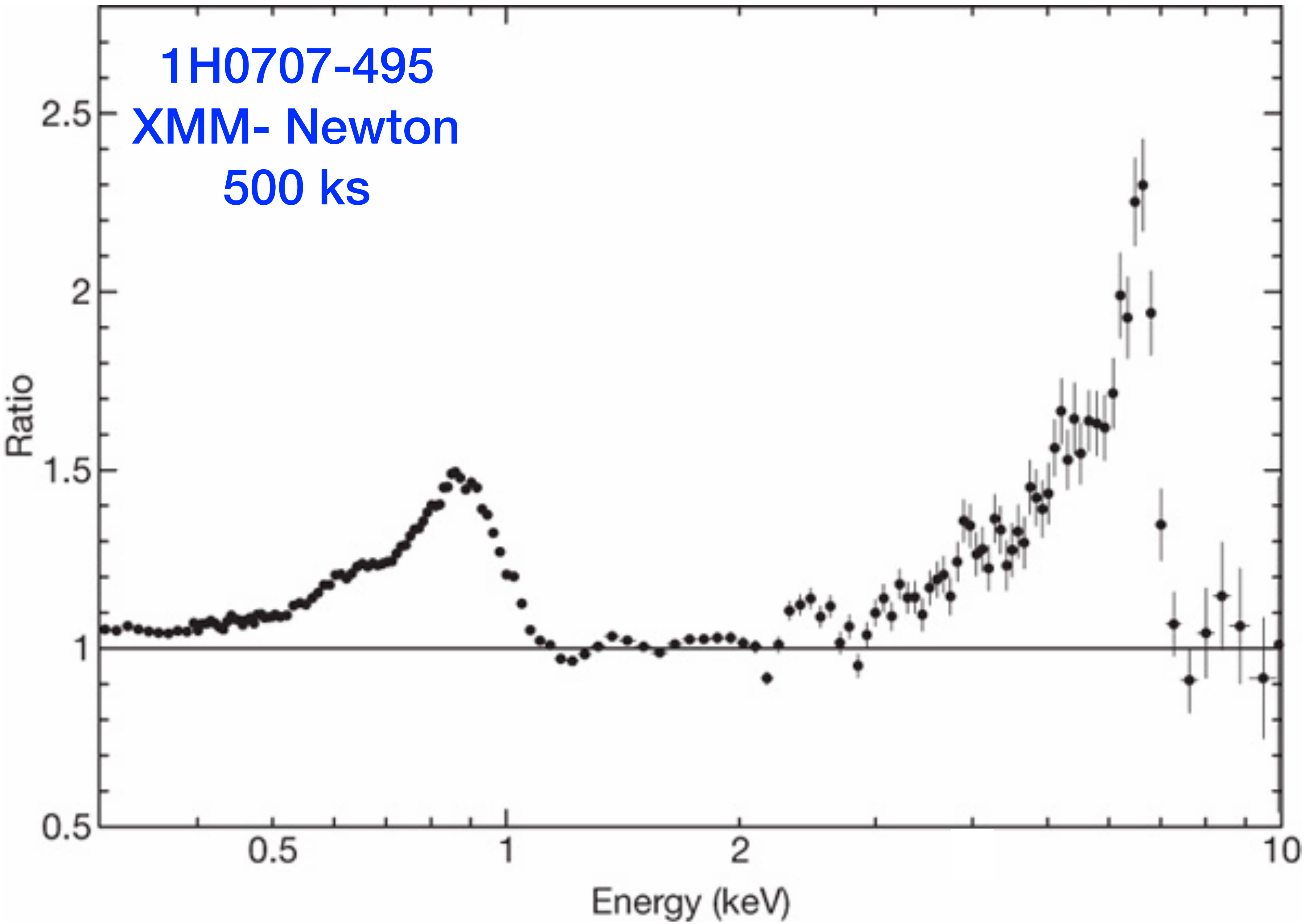




Δt ~ tens of seconds for 1e6 Msun

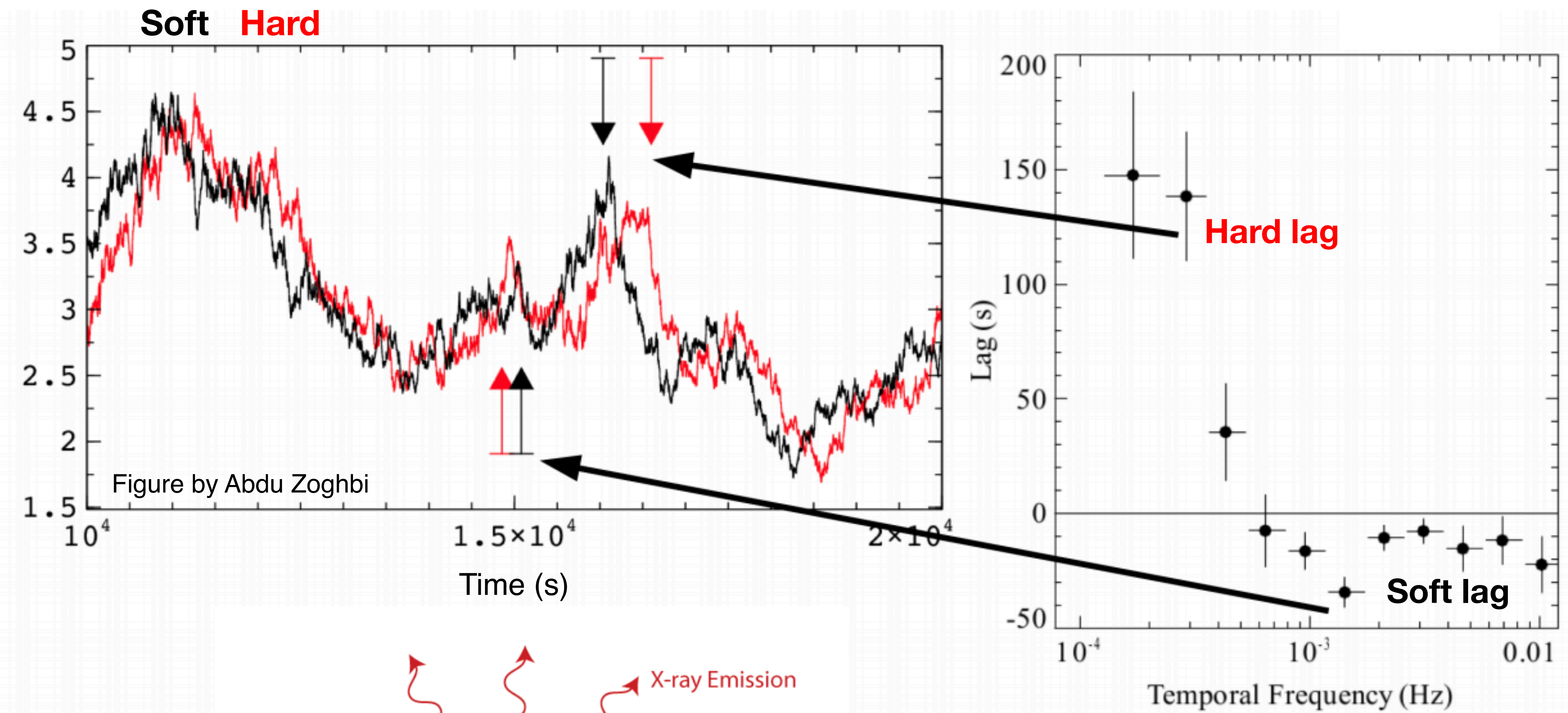
Δt ~ < milliseconds for 10 Msun

Discovery of X-ray Reverberation



Fabian et al. 2009
Uttley et al., 2014 for review

Discovery of X-ray Reverberation



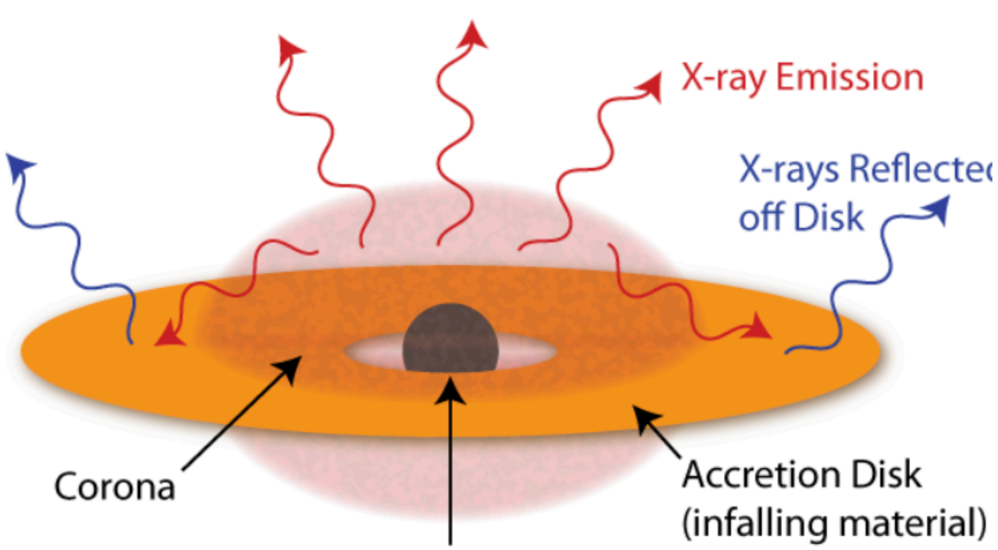
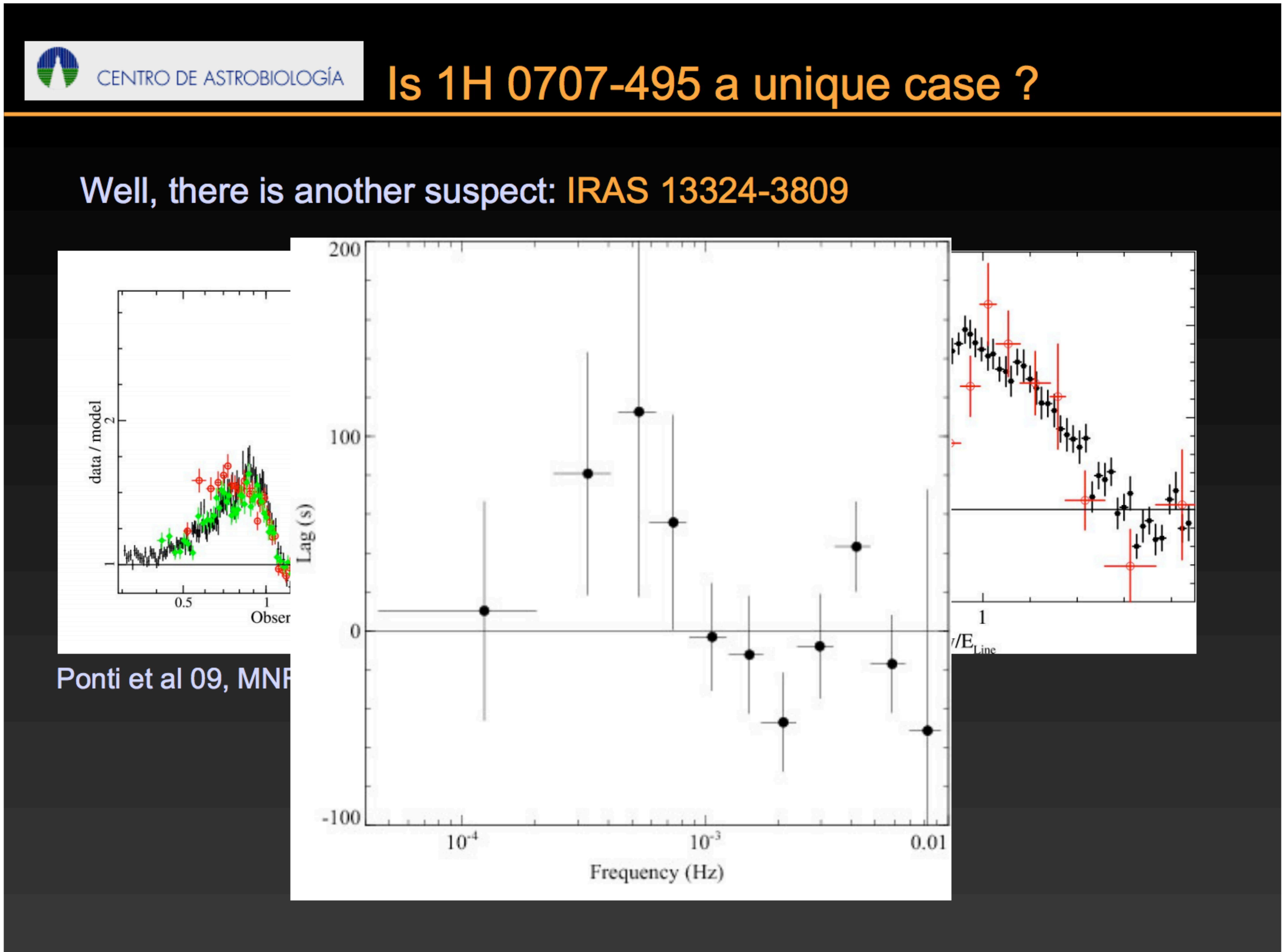


Image credit: Dan Wilkins

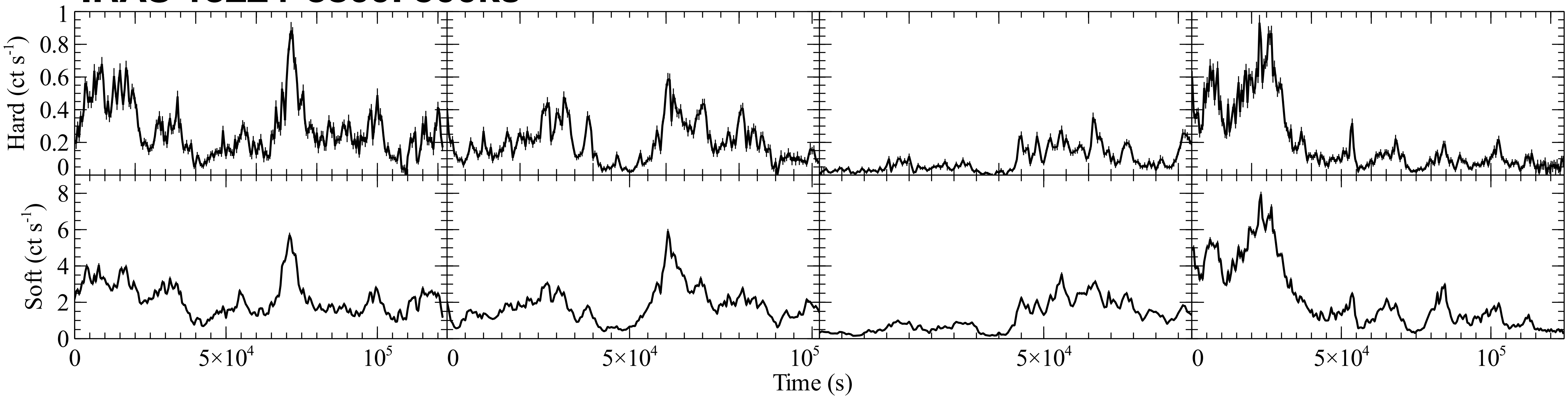
Fabian et al. 2009
Uttley et al., 2014 for review

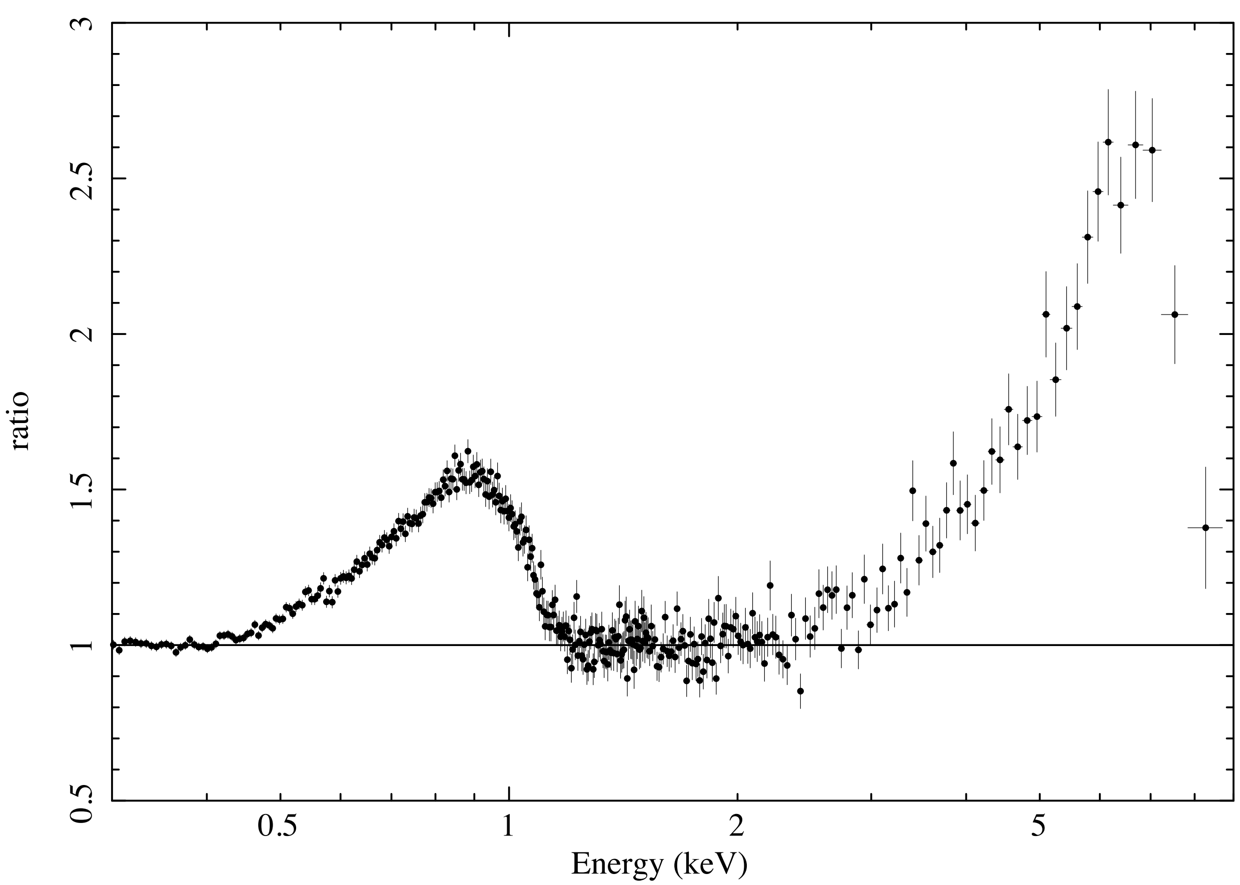
Slide from Giovanni Miniutti's review on Type 1 AGN :

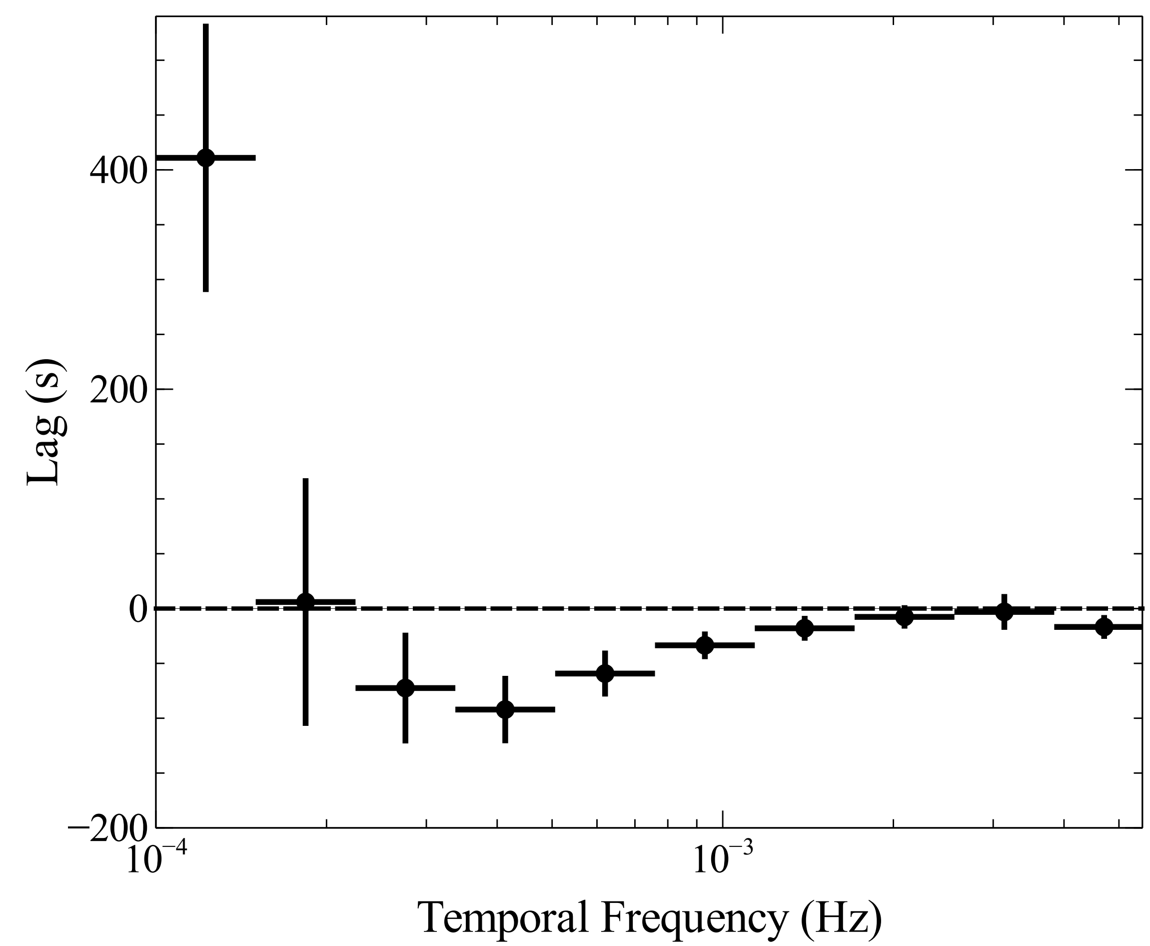


Probing the dynamics of the corona

IRAS 13224-3809: 500ks



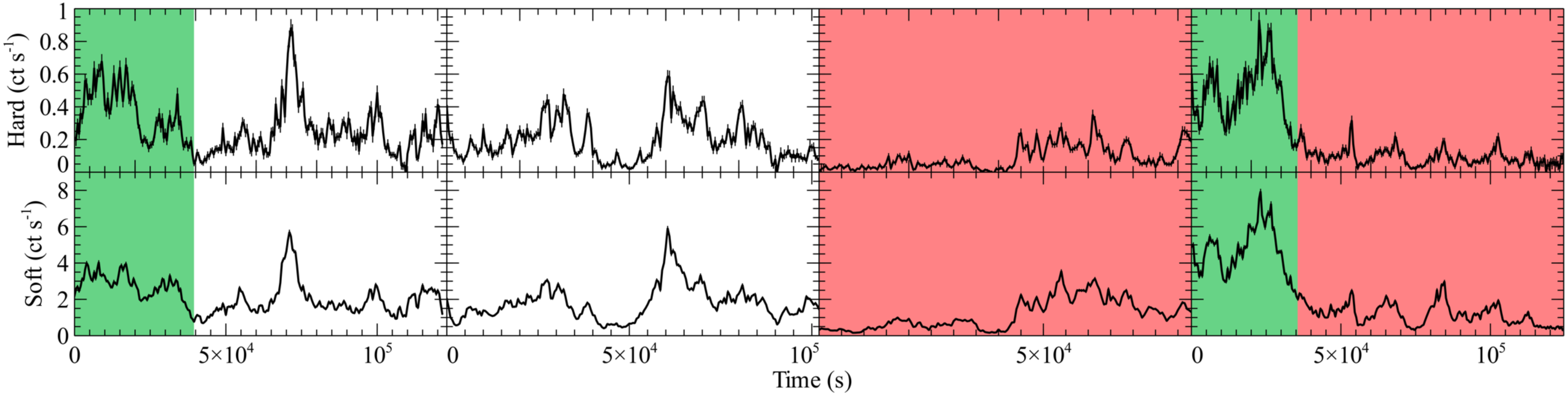


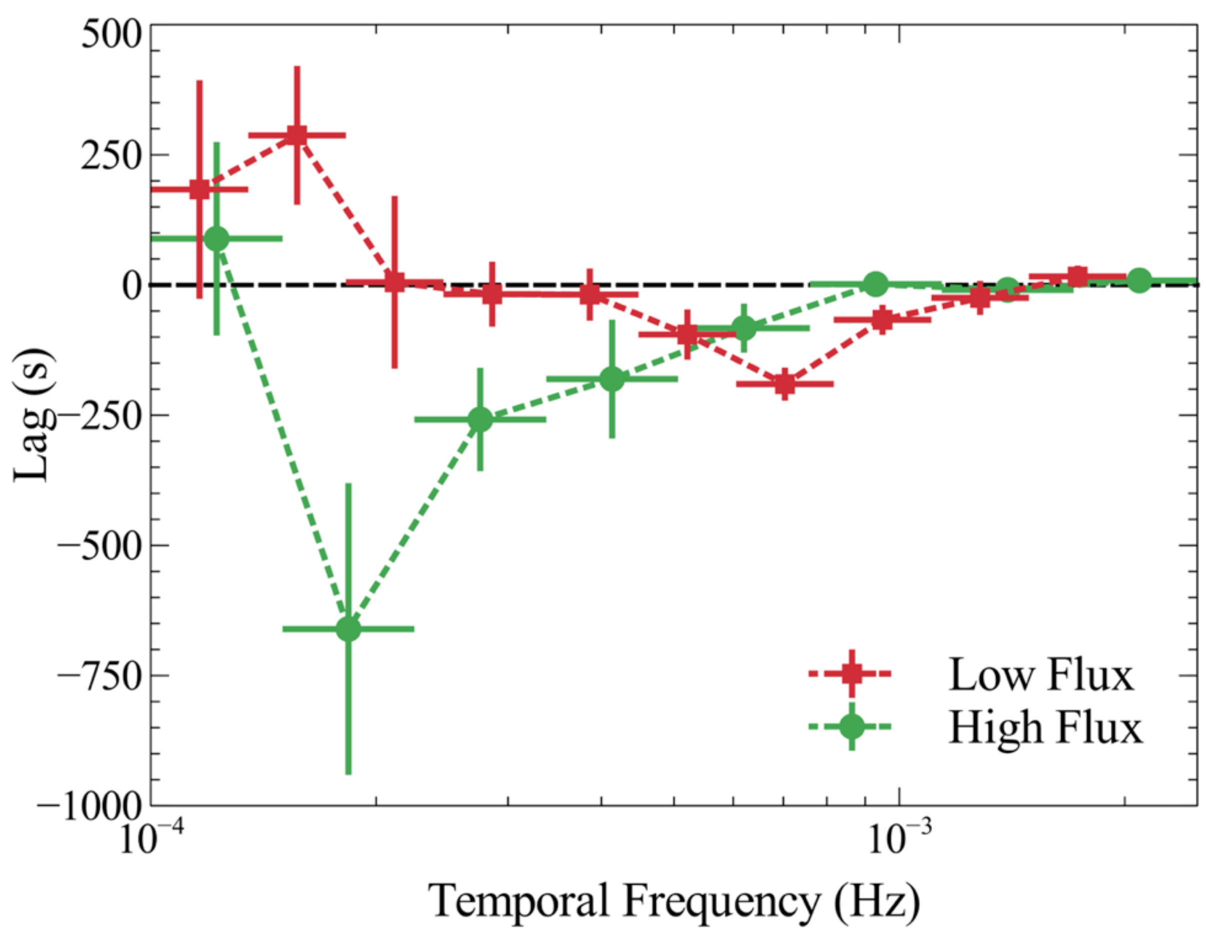


Fabian, EK, et al., 2012

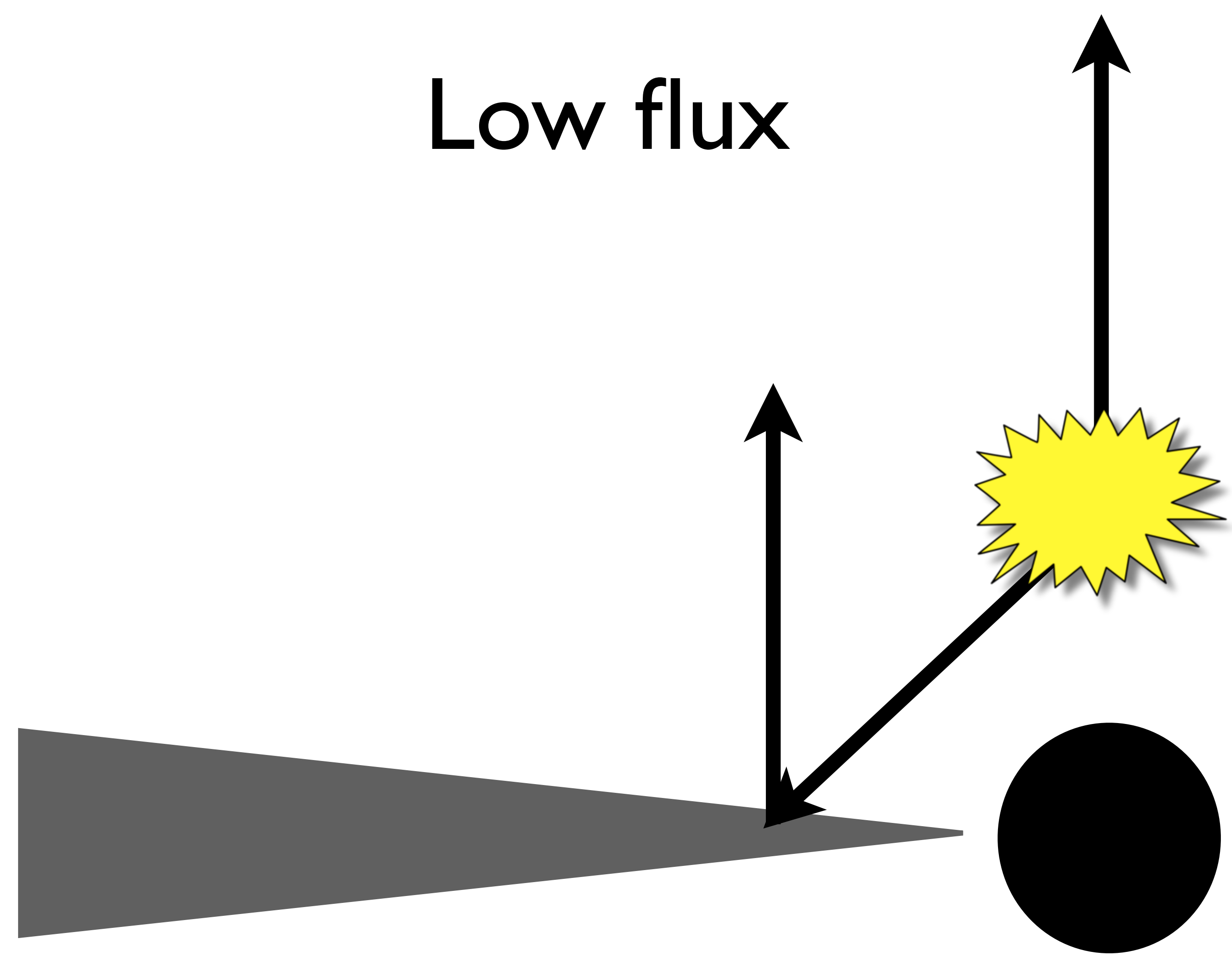
Probing the dynamics of the corona

IRAS 13224-3809





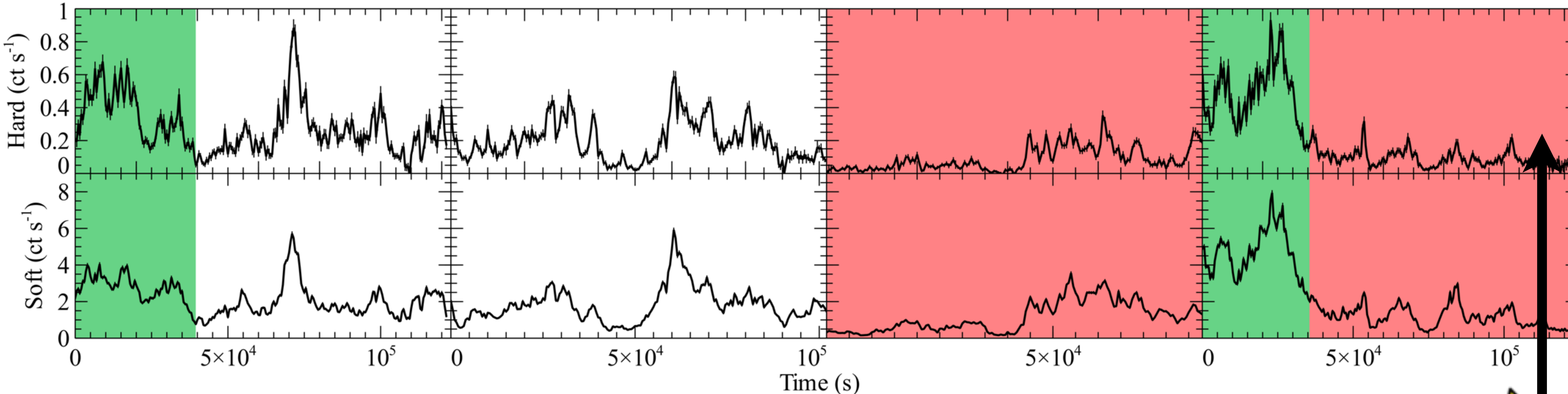
Low flux

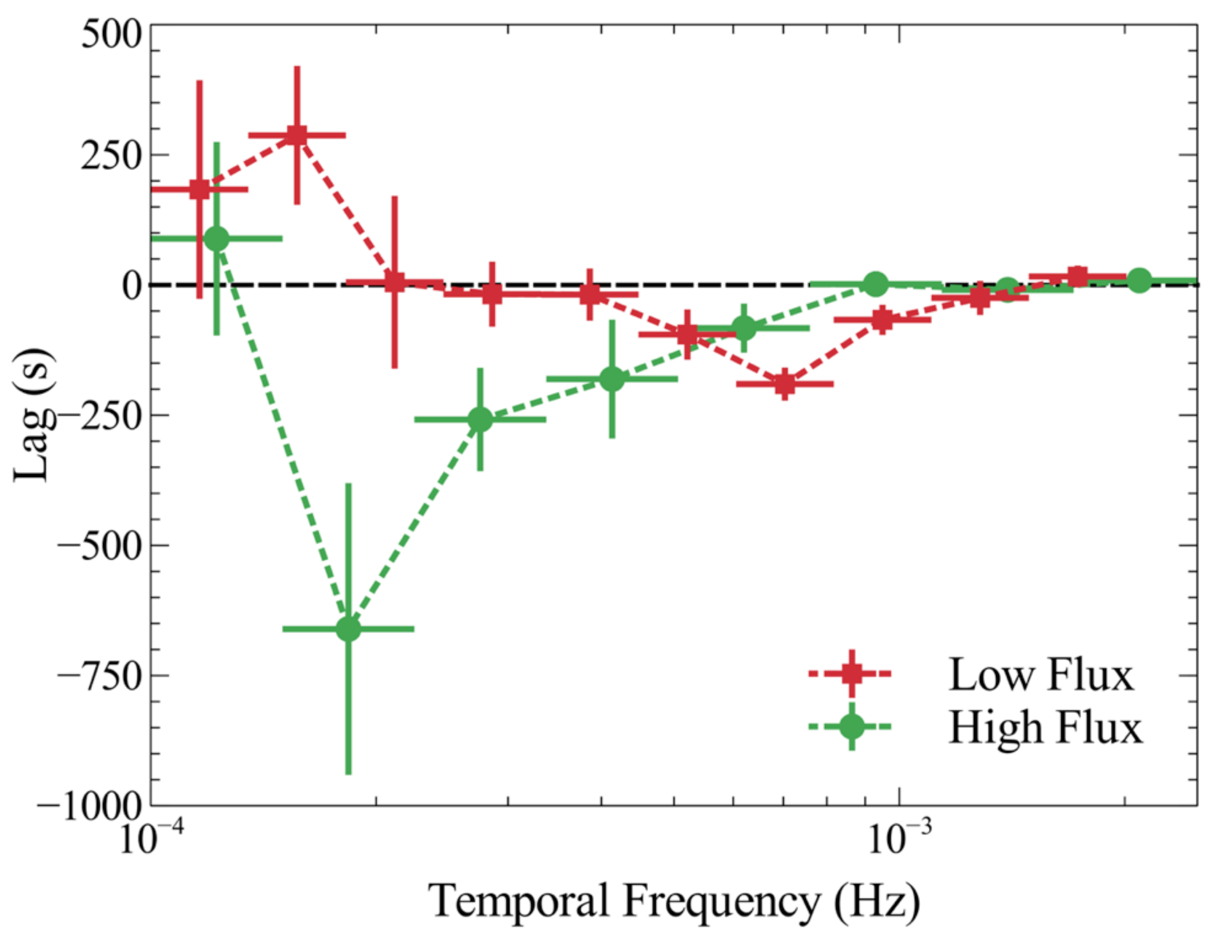


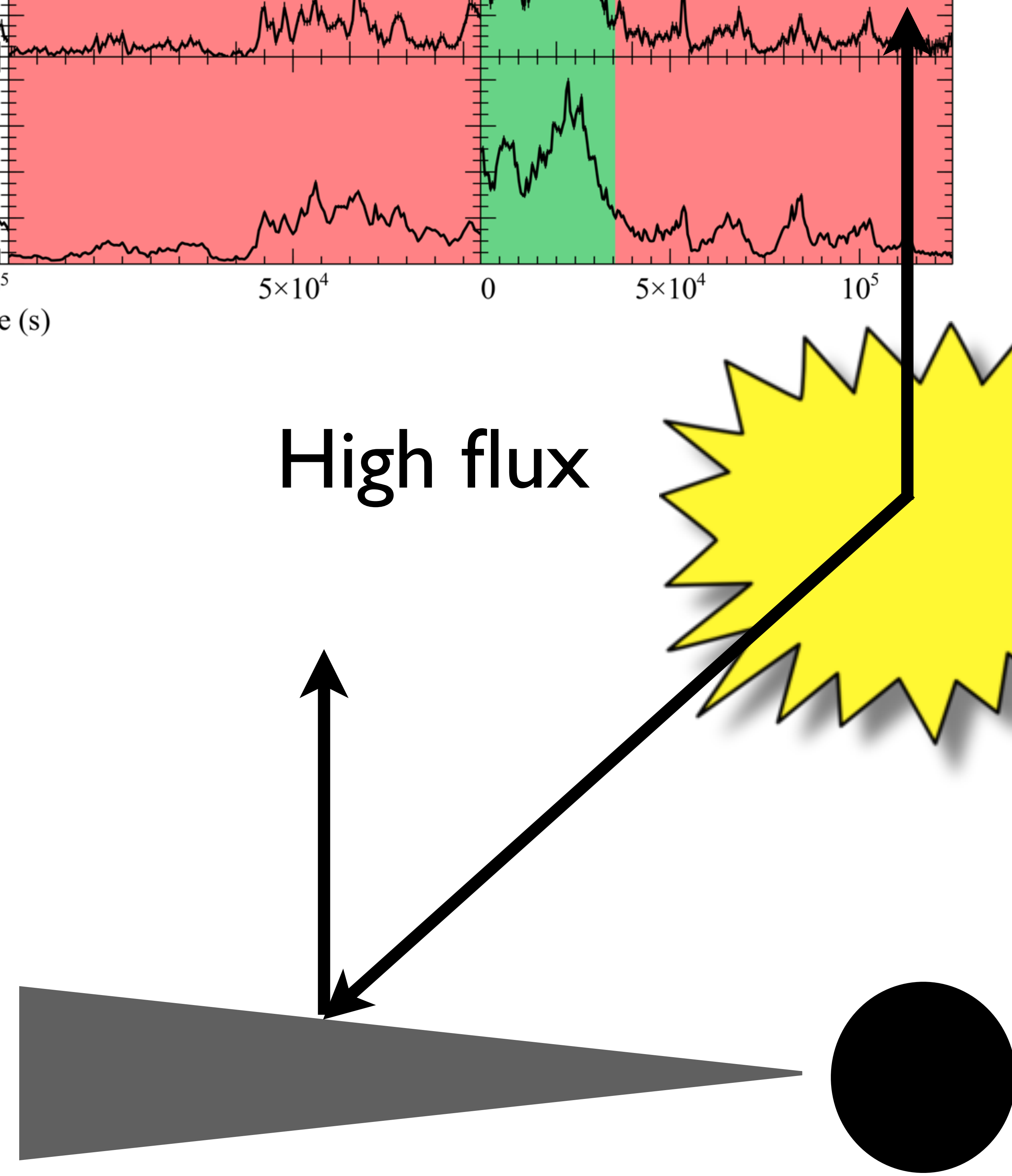
Kara et al., 2013

Probing the dynamics of the corona

IRAS 13224-3809



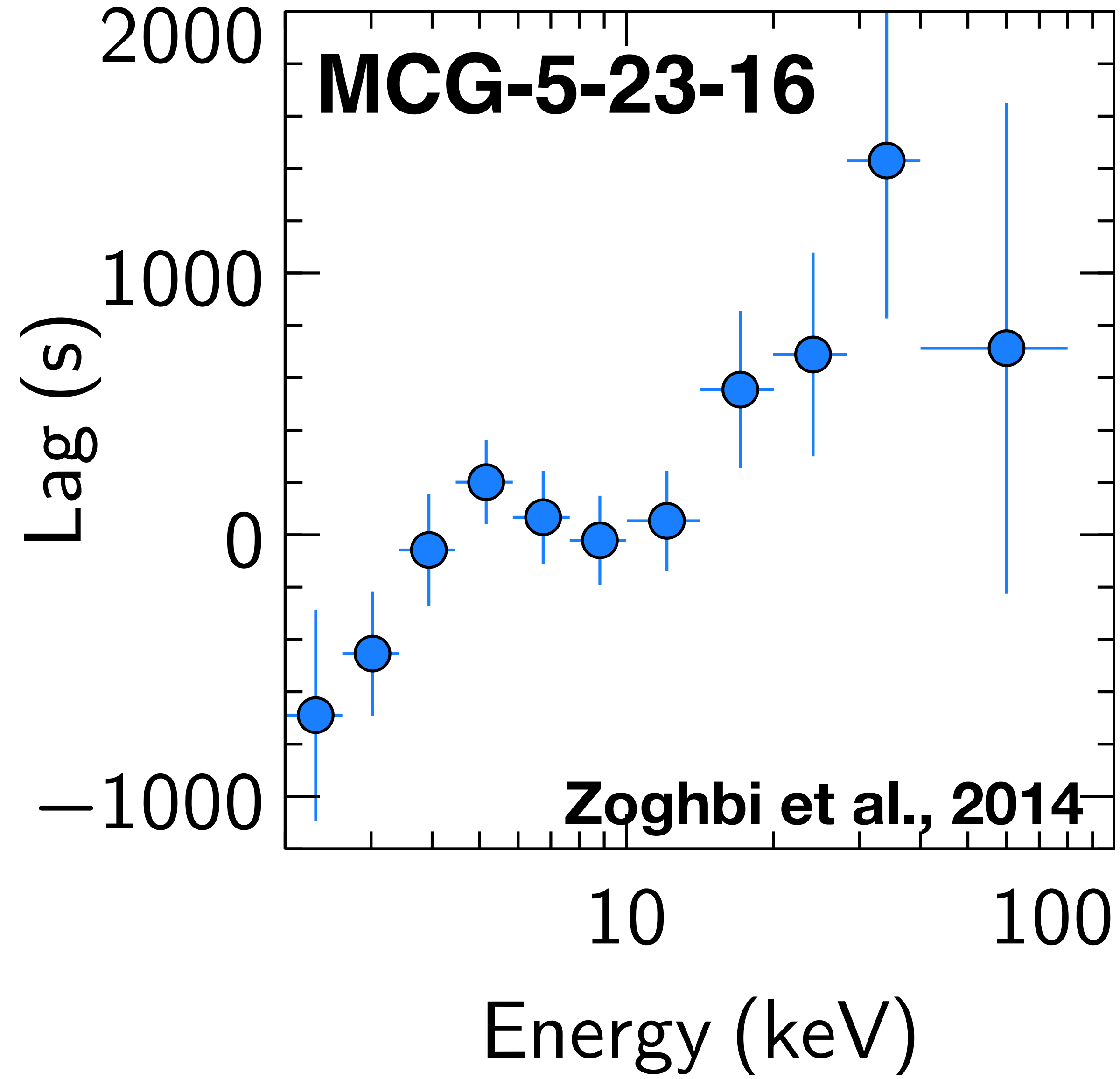


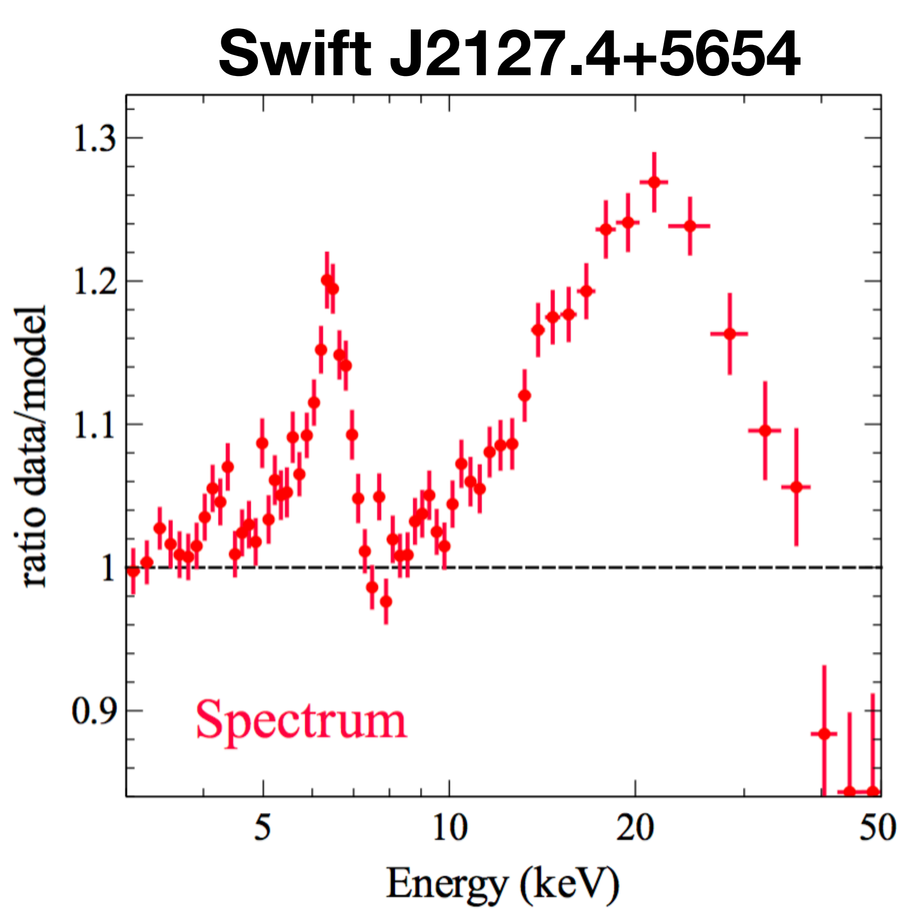


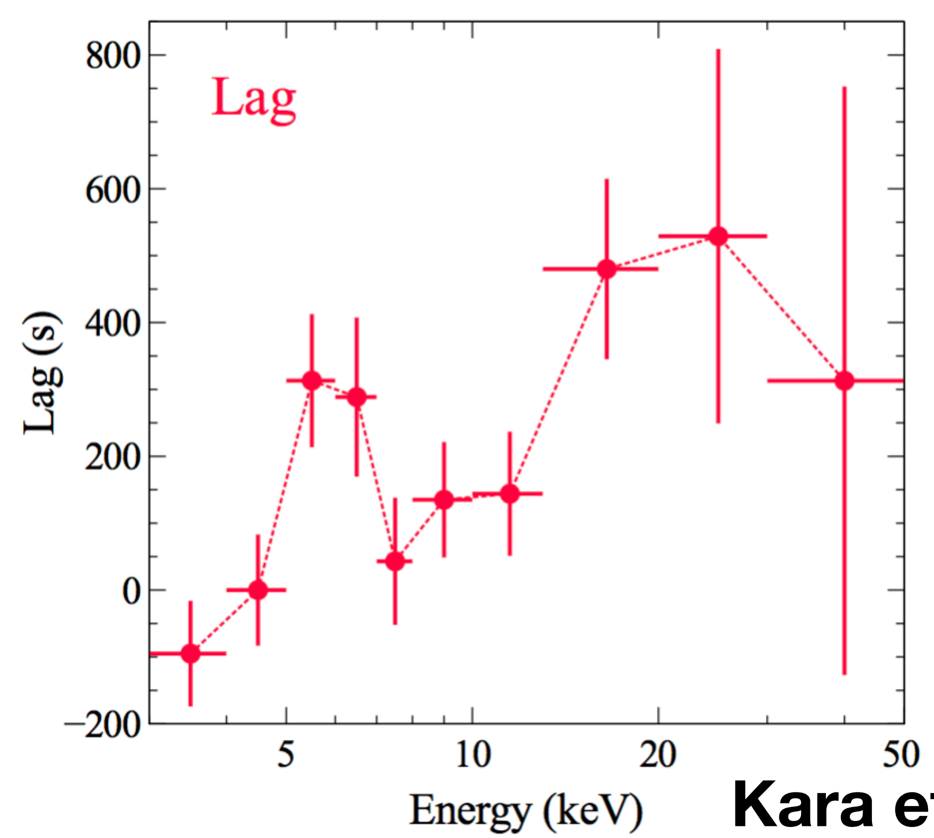
EK+13b

2012: NuSTAR launches

Zoghbi et al., 2013 - Lags can be measured through time domain techniques, allowing for reverberation measurements even from data with gaps

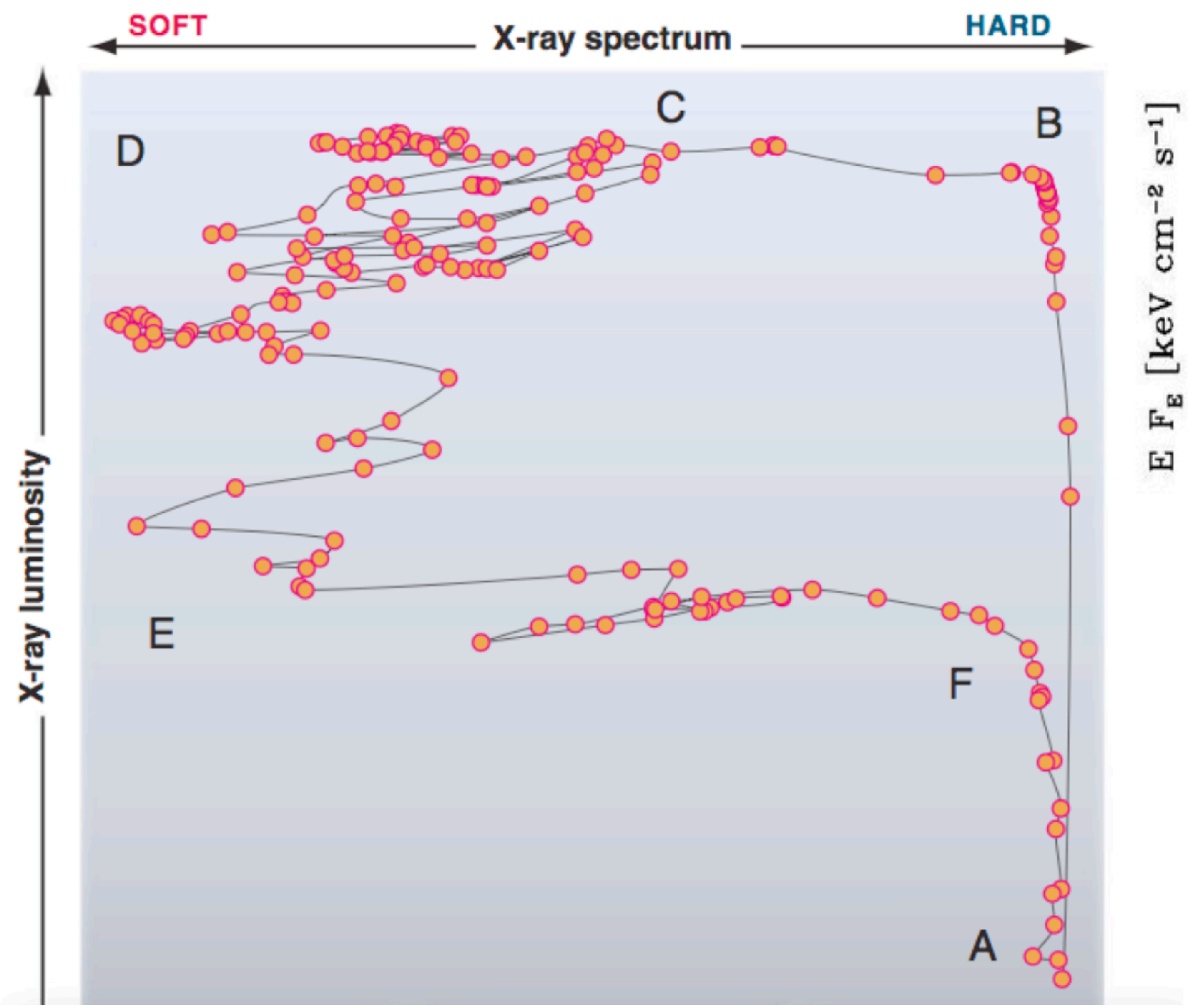




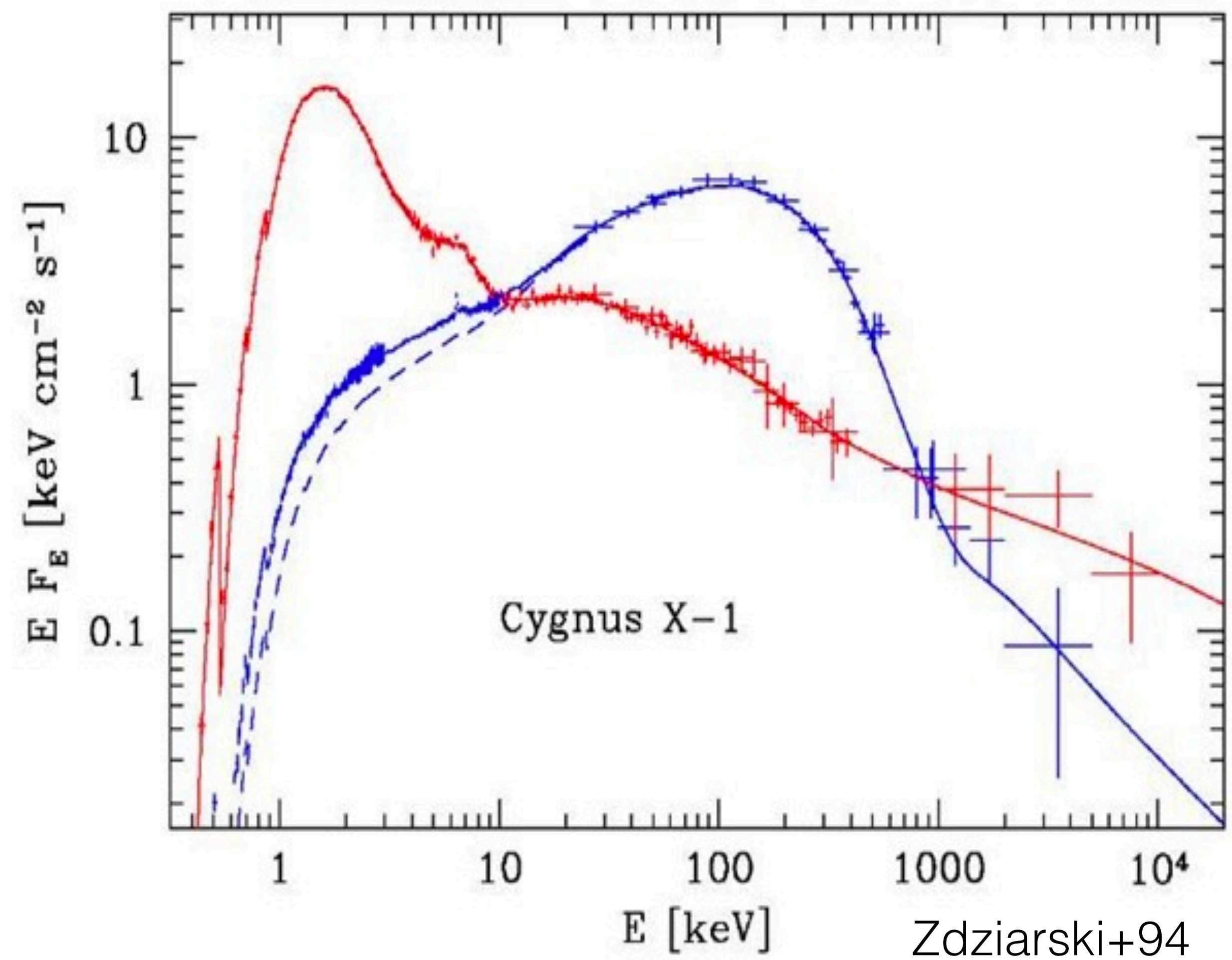


Kara et al., 2015

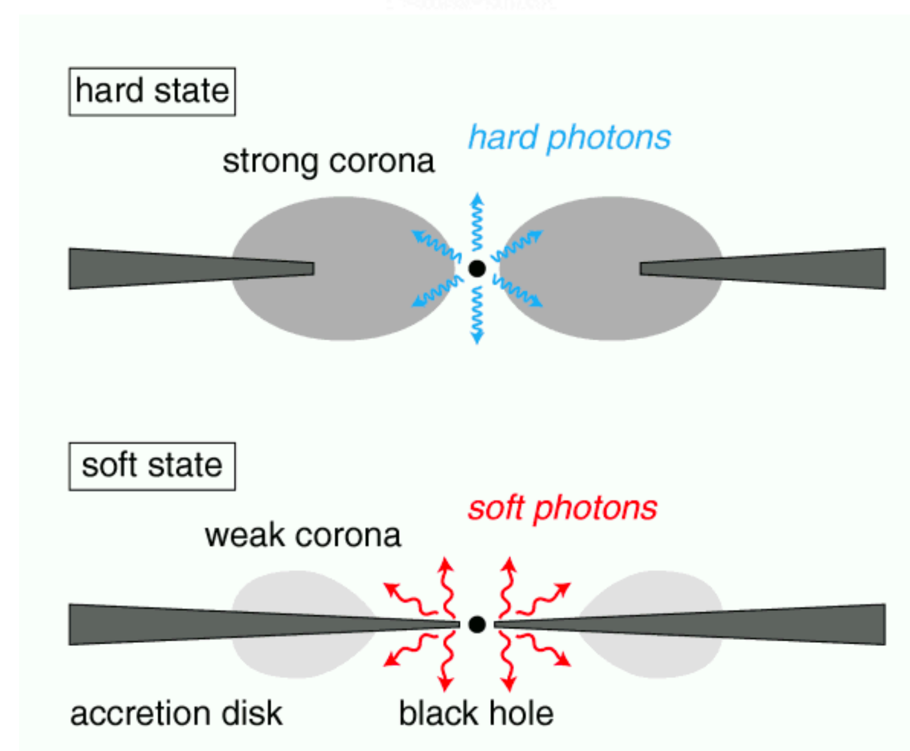
Black hole transients: analogous to AGN?



e.g. Fender+04

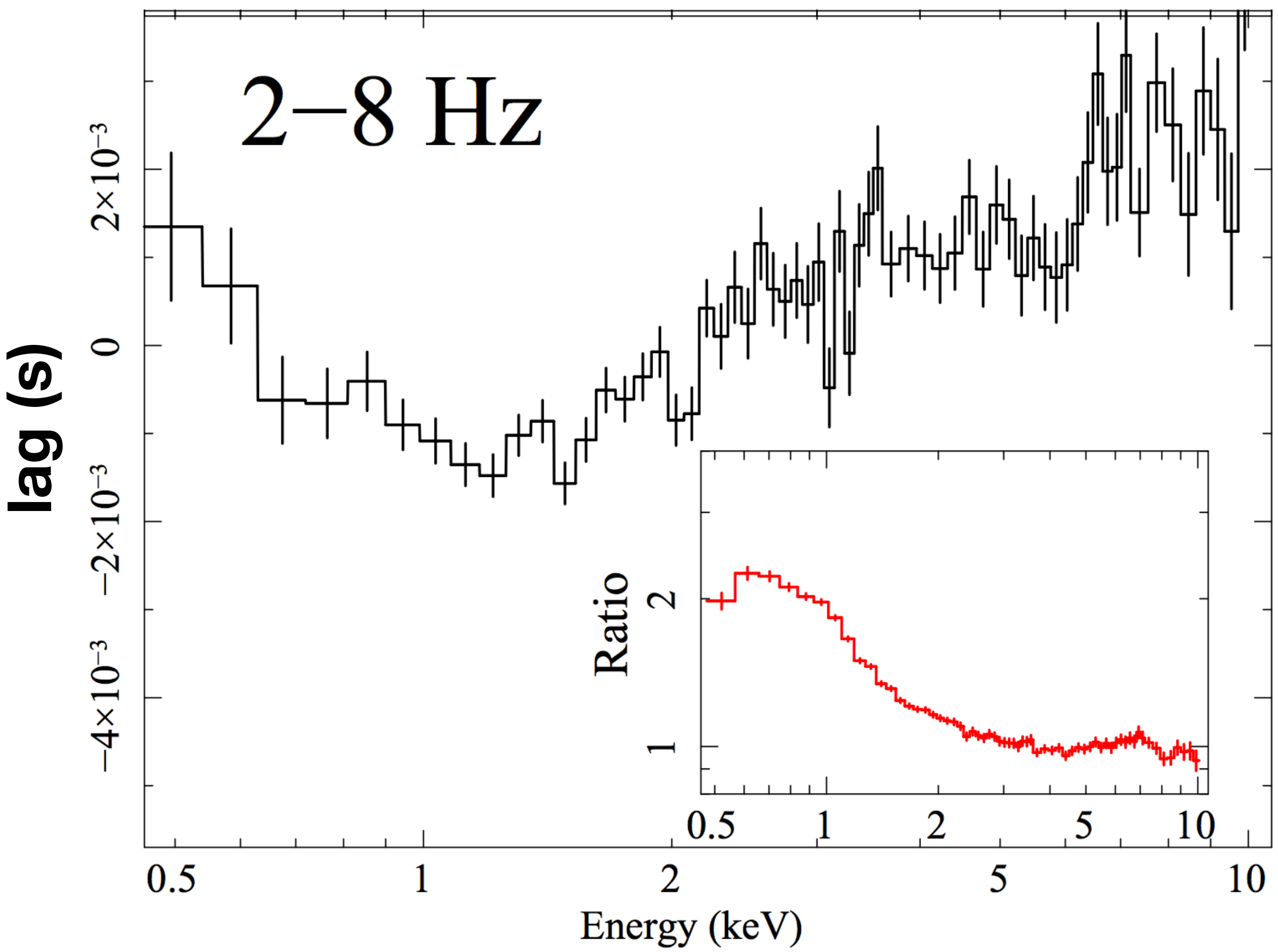


Zdziarski+94

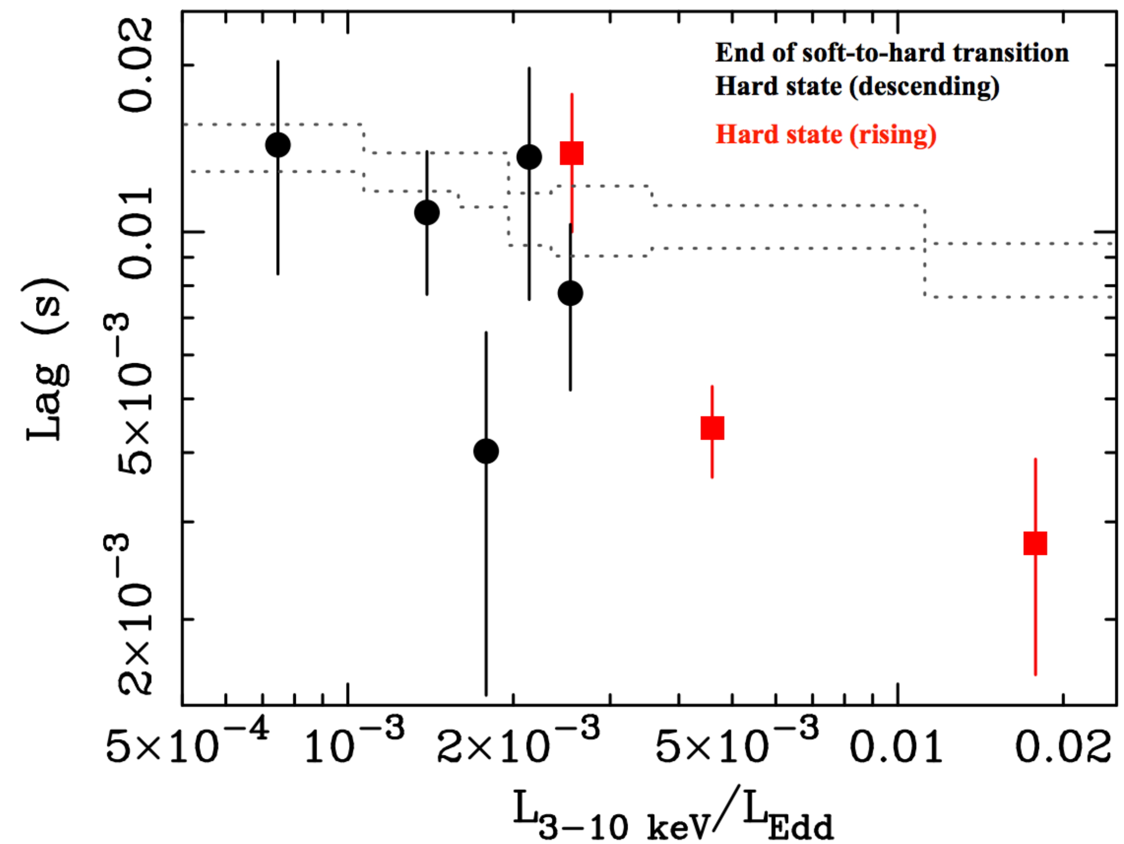


Equivalent duty cycle in AGN is millions++ of years

Studying the inner accretion flow in BHBs with XMM-Newton



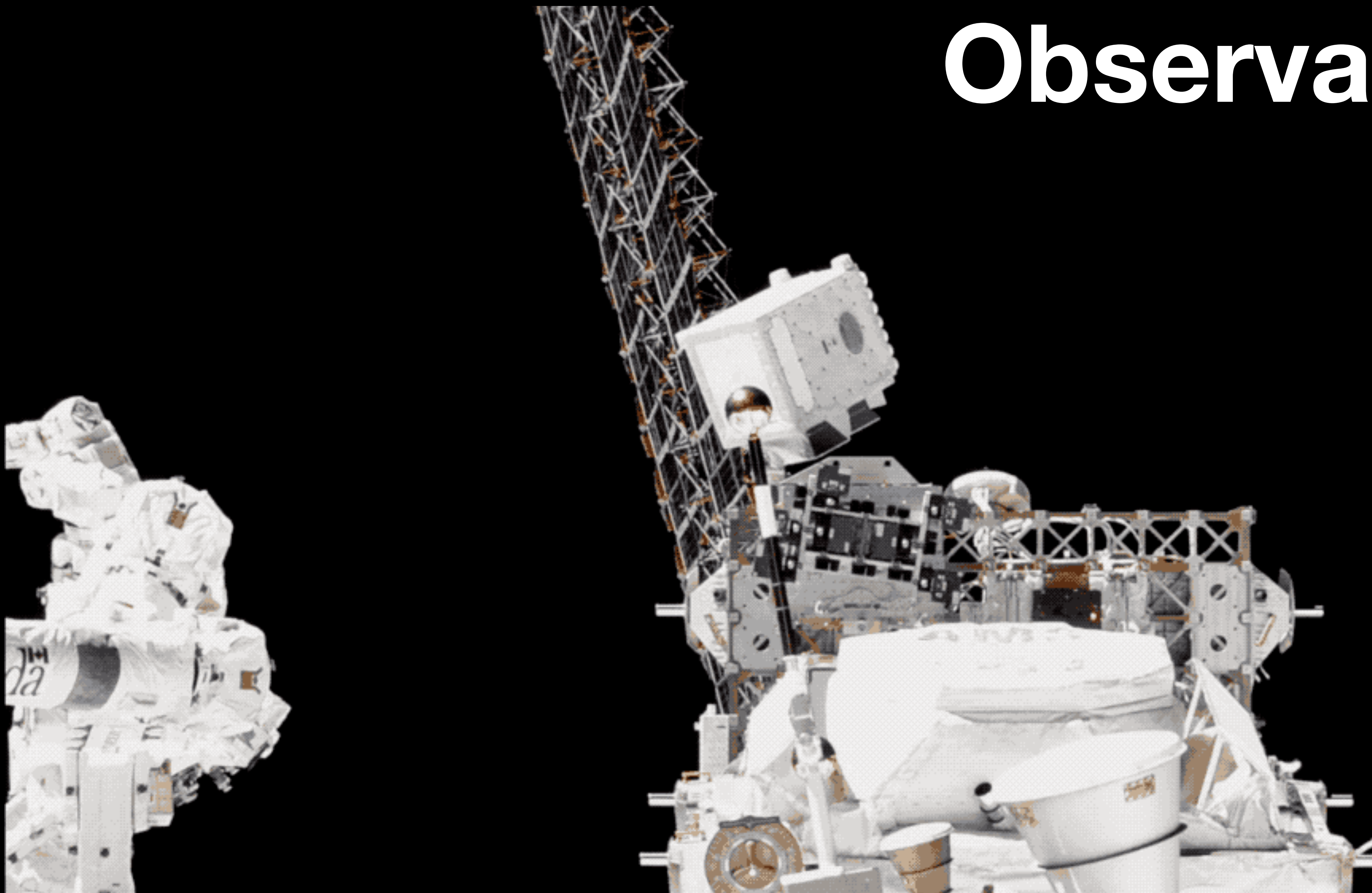
Uttley et al., 2011



De Marco & Ponti 2017

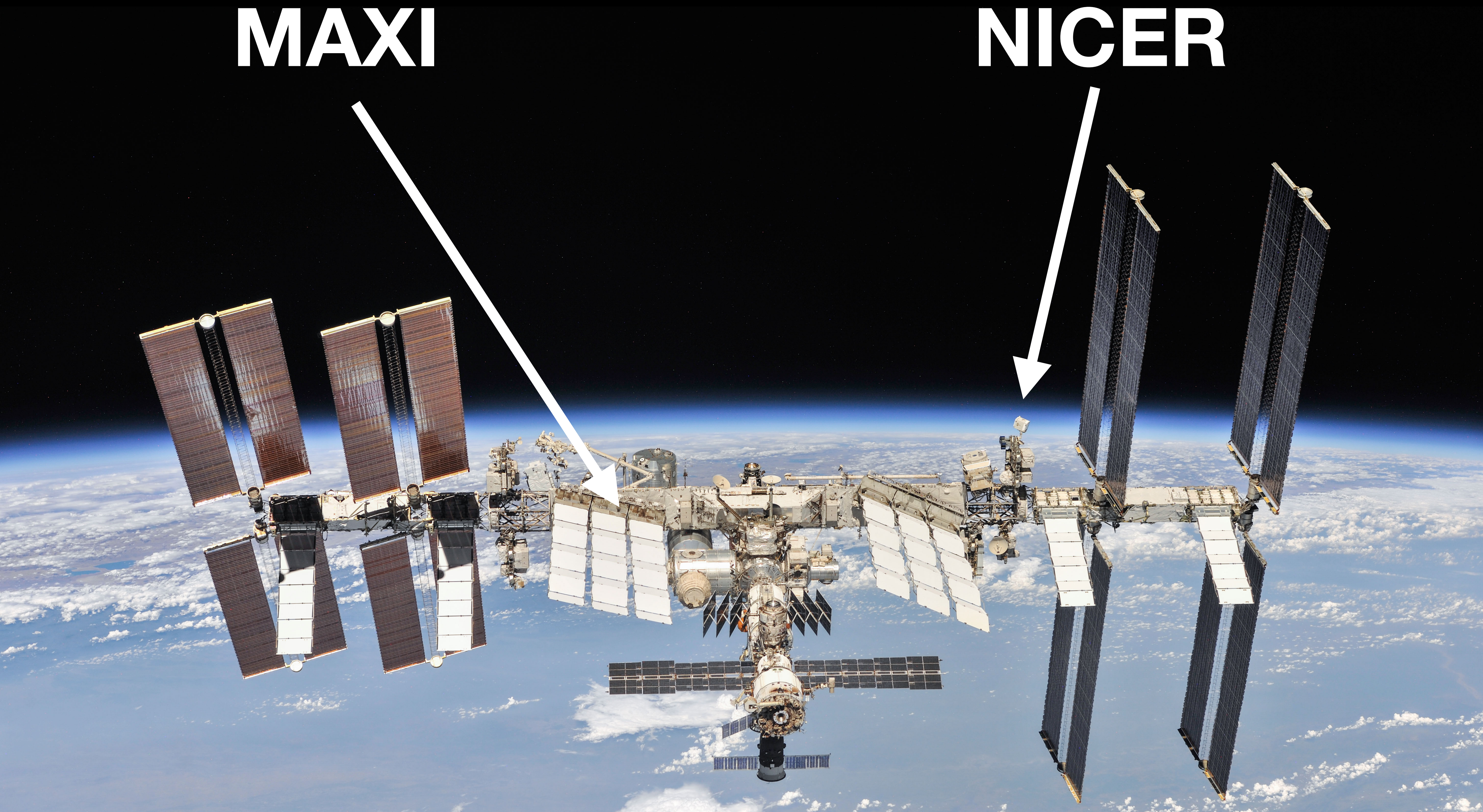
Reverberation lags due to thermal reprocessing

The NICER Observatory

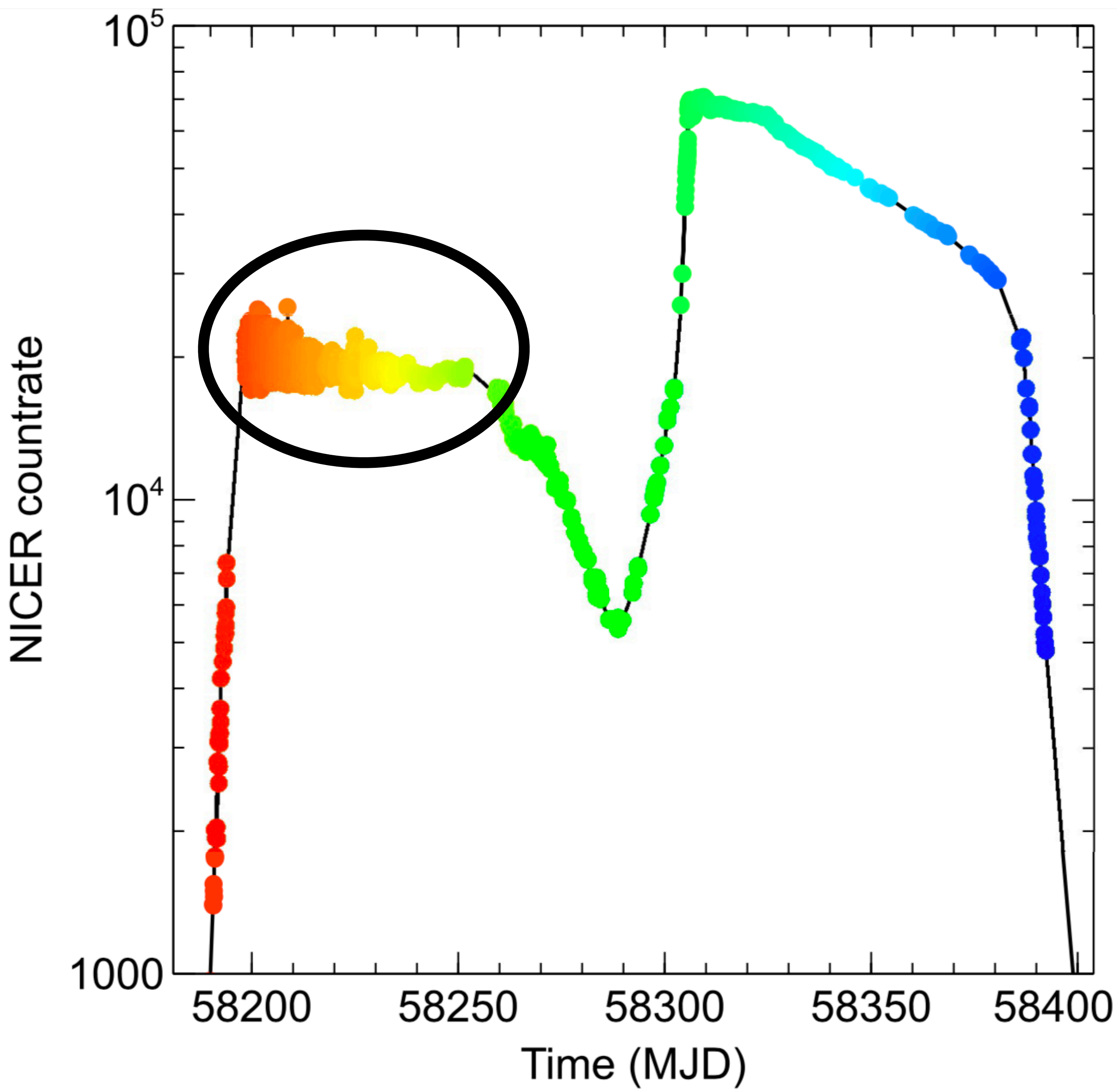


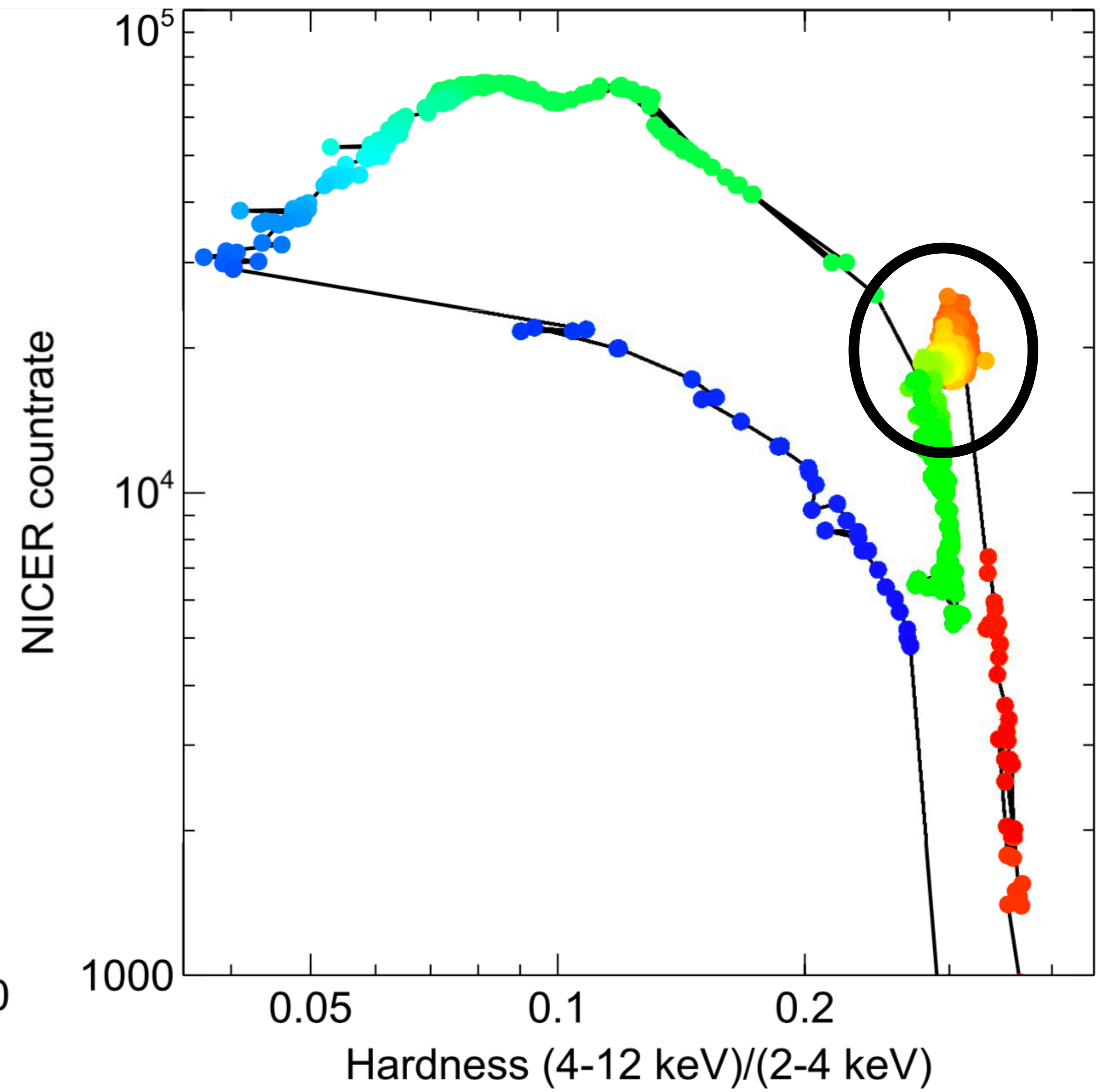
Highest ever soft band effective area (2x XMM or 20x Swift XRT)
Highest time resolution: >100 ns time resolution (25x RXTE)
~100 eV resolution at 6 keV

March 2018: MAXI J1820+070 emerges

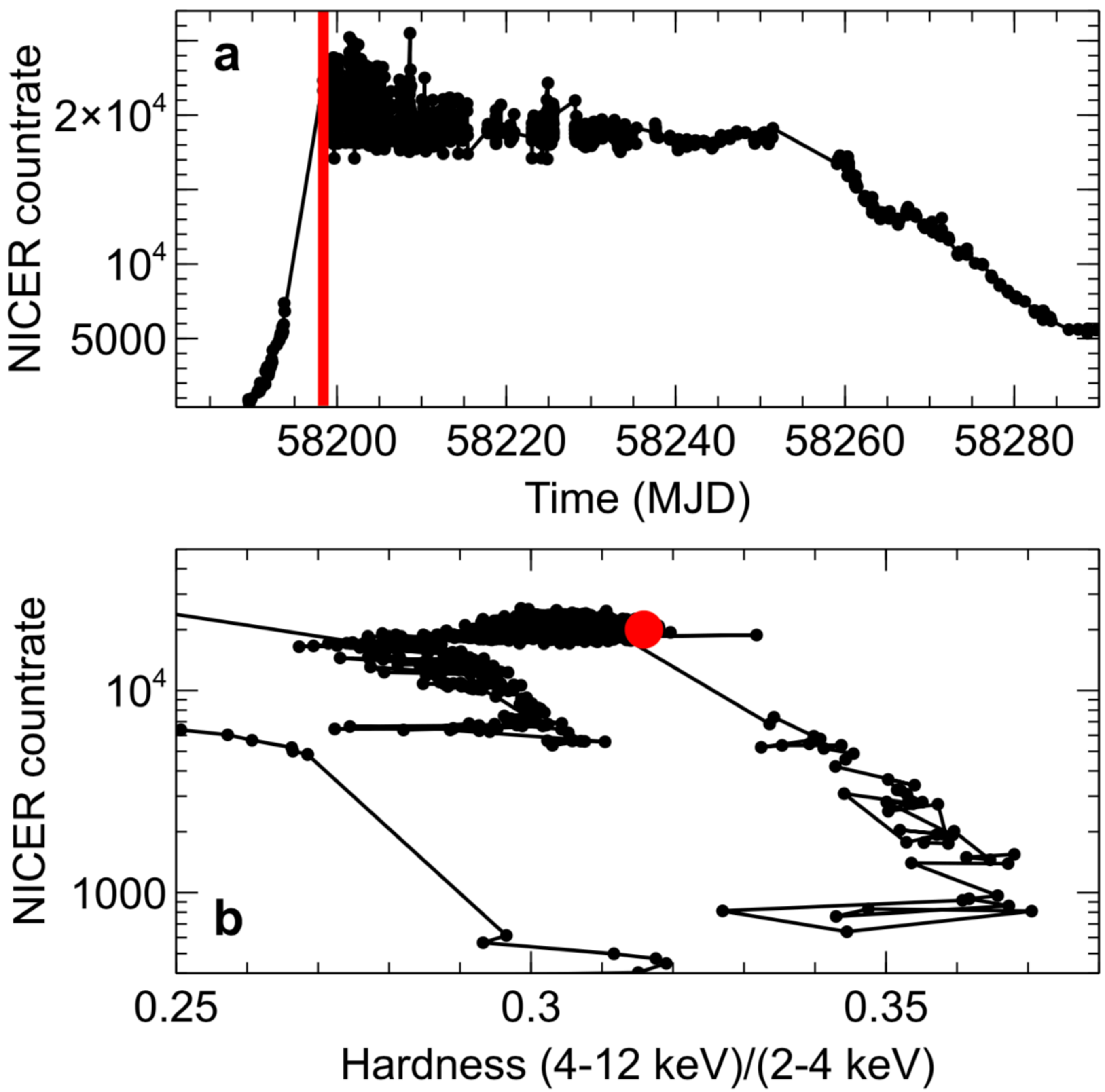


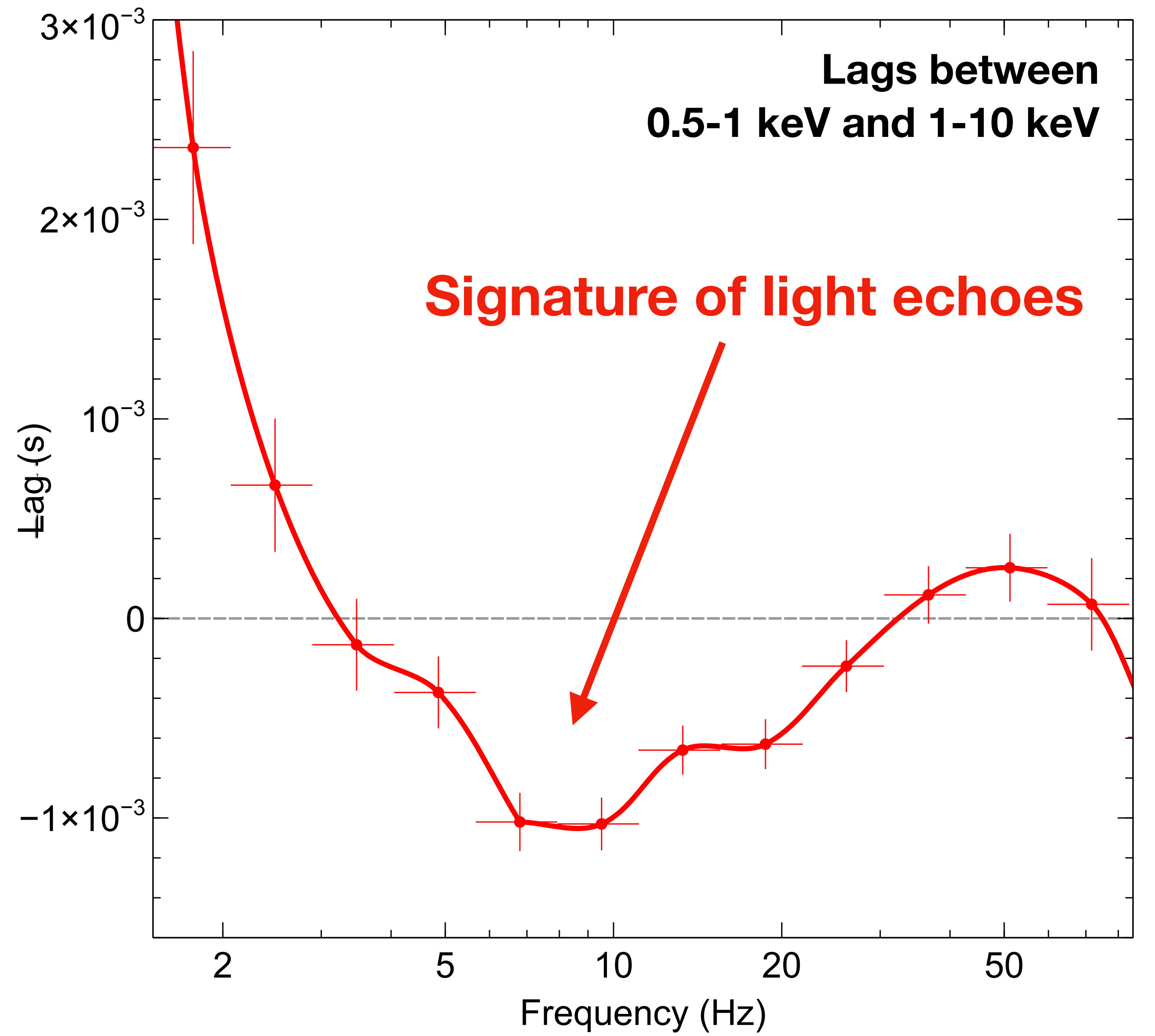
NICER observations of MAXIJ1820+070





NICER measures short reverberation lags

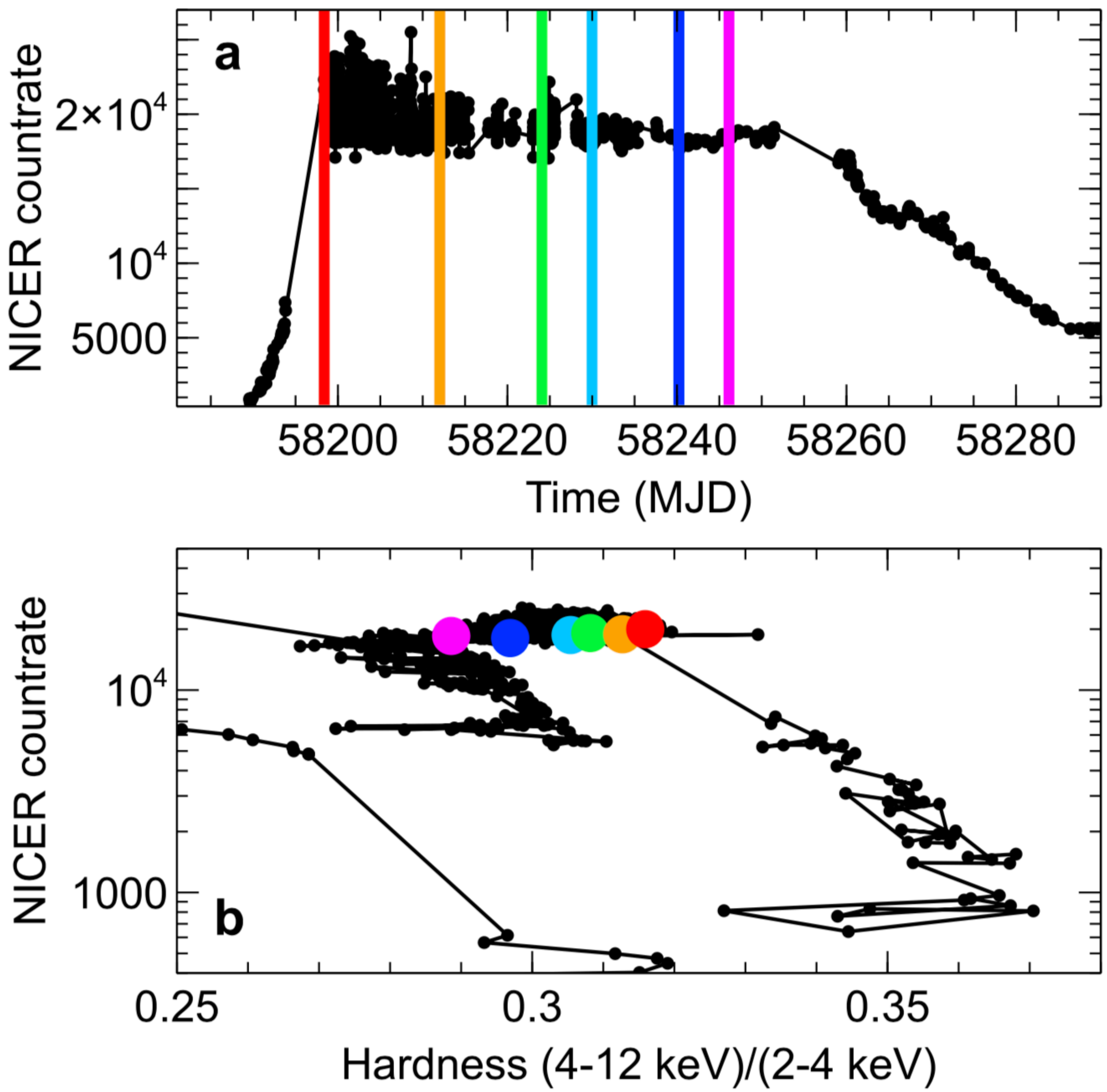


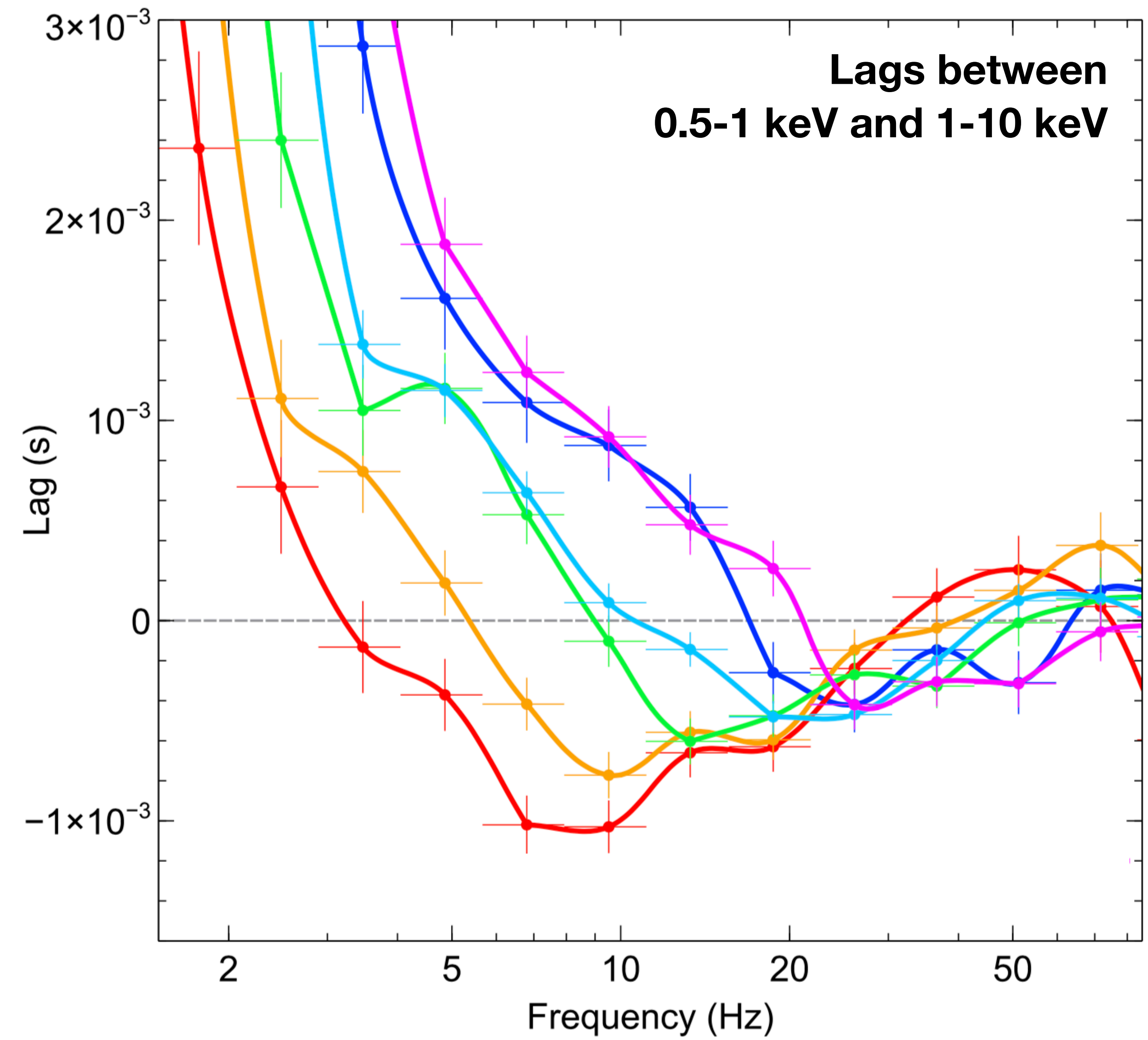


(Temporal Frequency — how rapidly light curve varies)

Reverberation in XRBs: Uttley et al., 2011, De Marco et al., 2017

NICER measures short reverberation lags

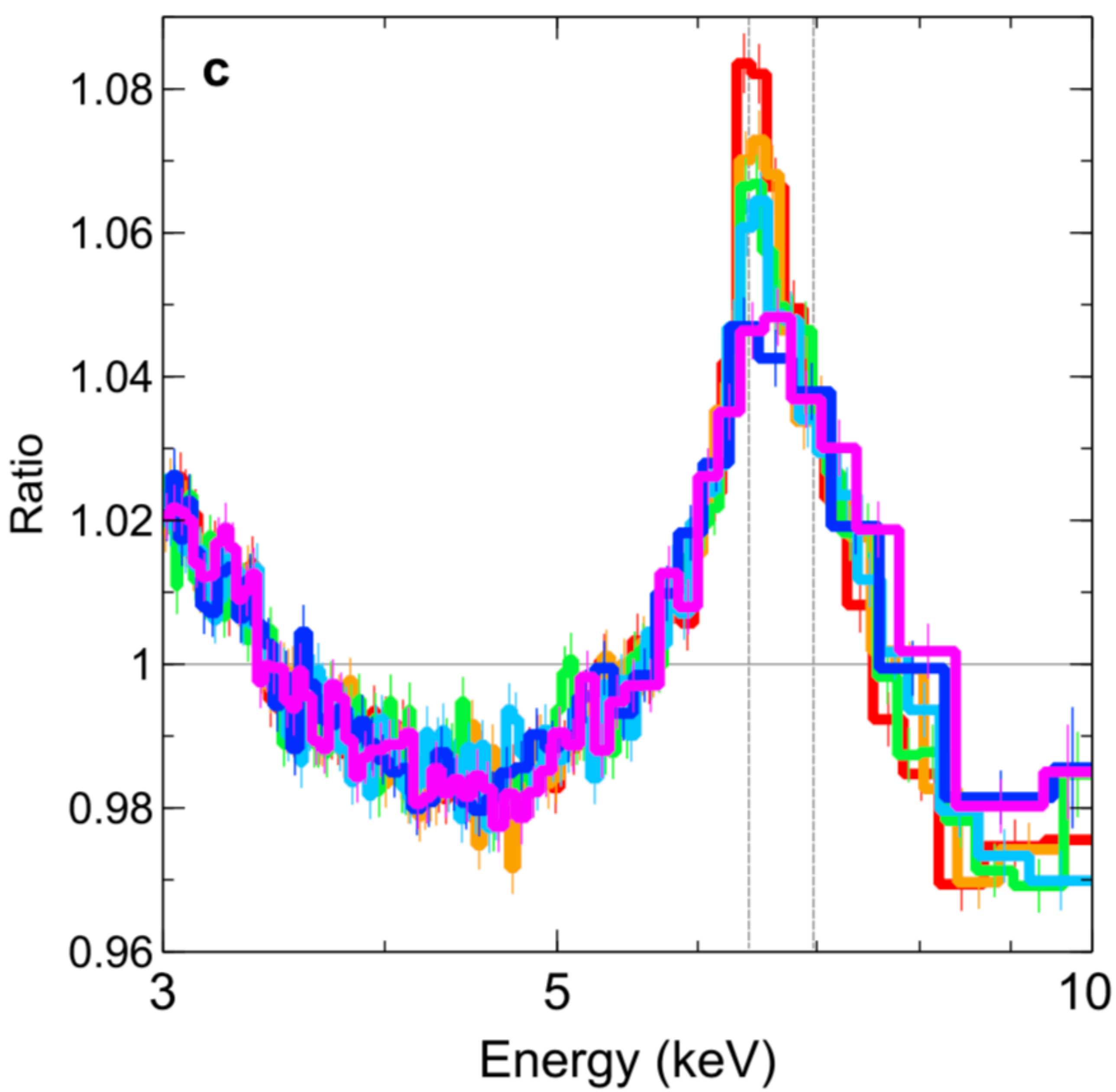




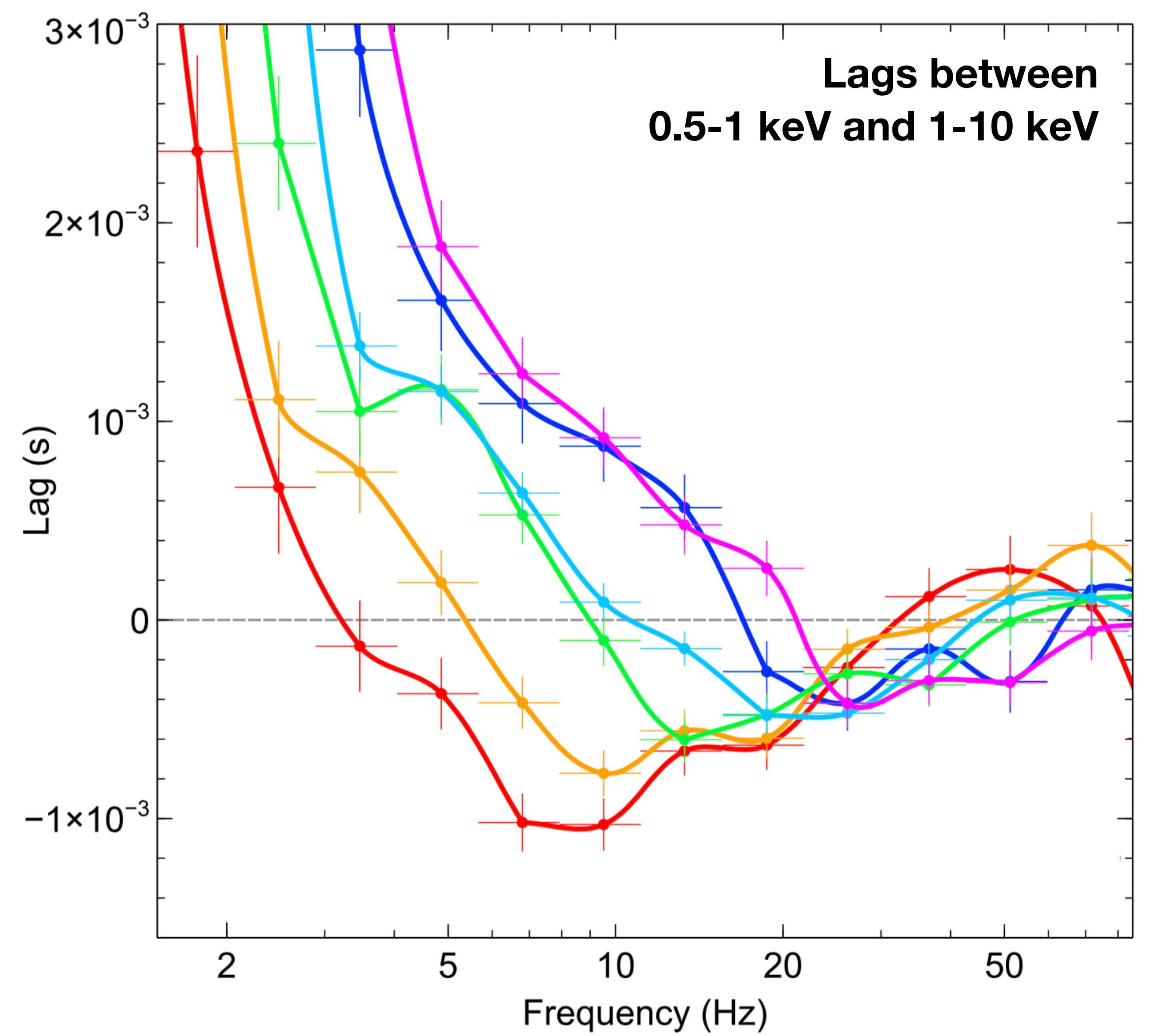
Lags evolve to higher frequencies

Reverberation in XRBs: Uttley et al., 2011, De Marco et al., 2017

relativistic reflection and reverberation



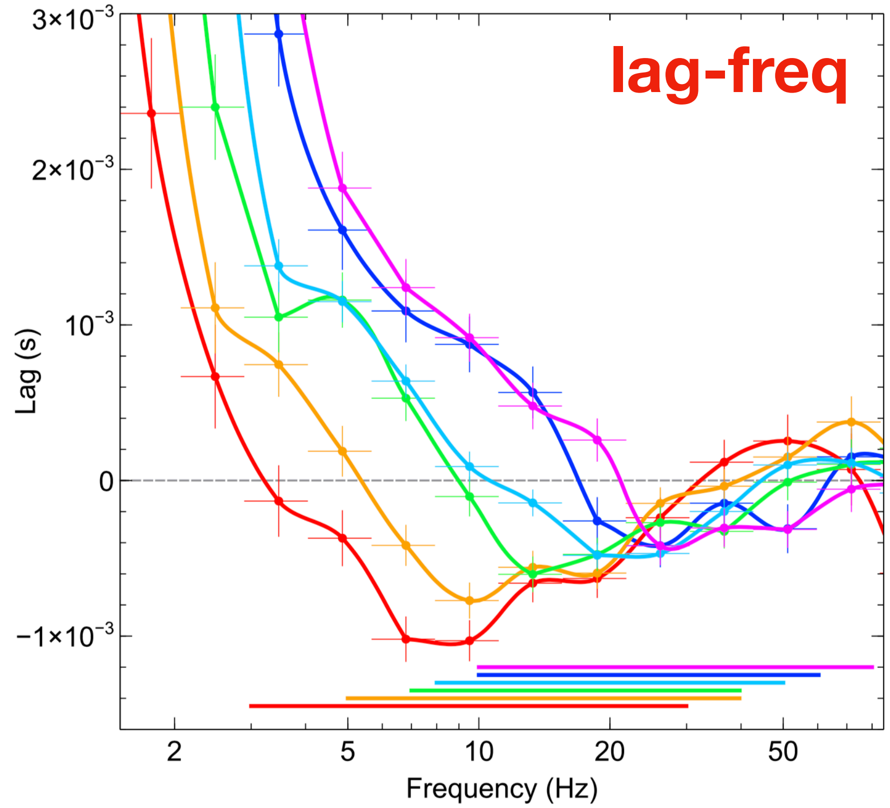
Broad line is constant over time

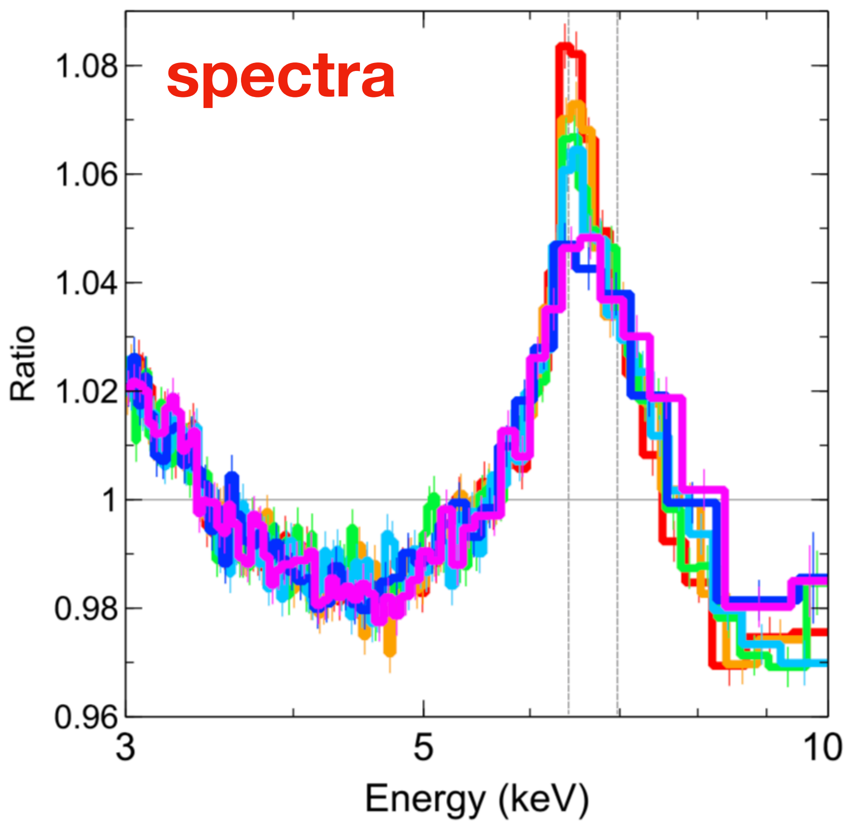


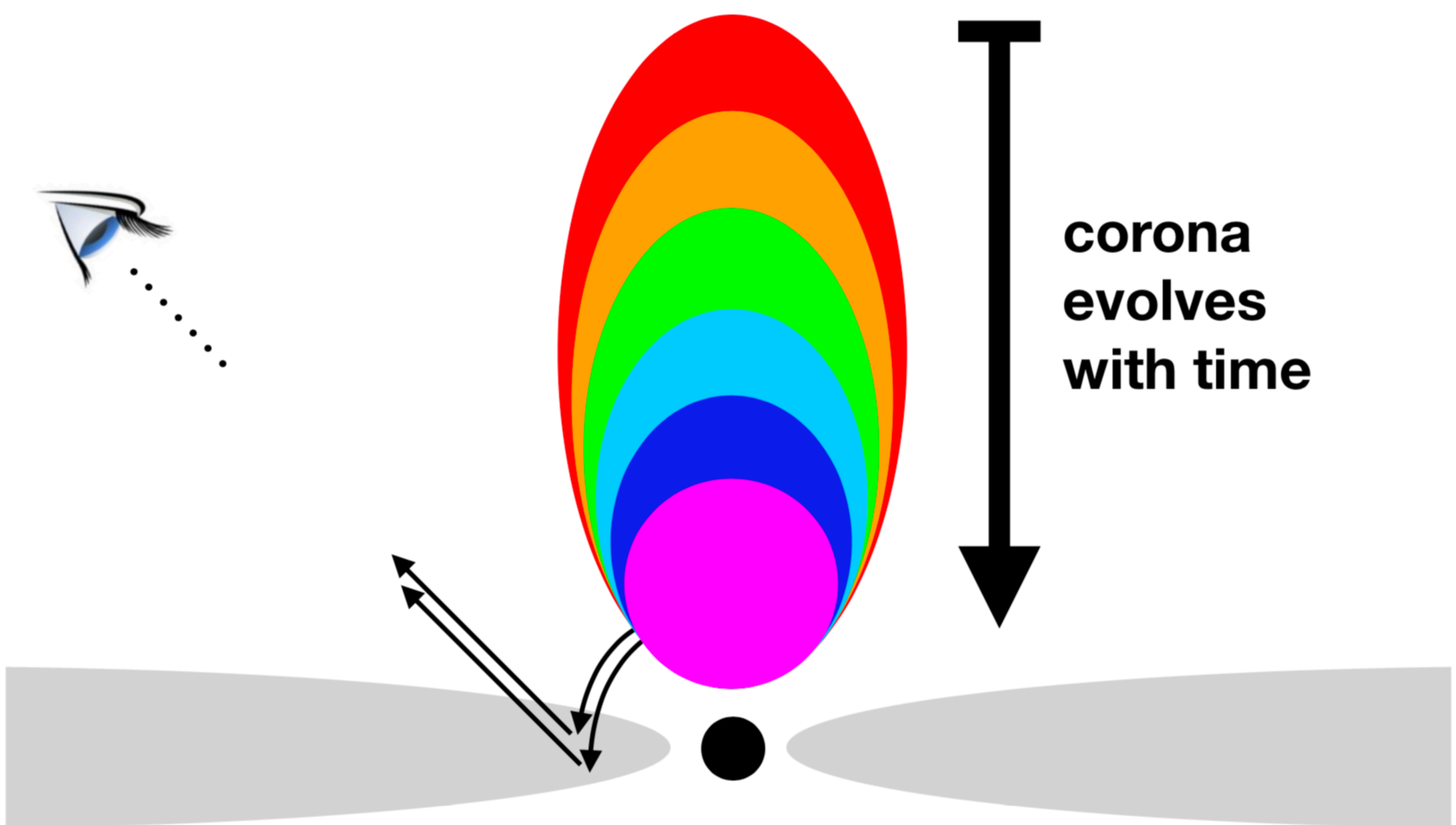
Lags evolve to higher frequencies

Kara et al., *Nature*, 2019

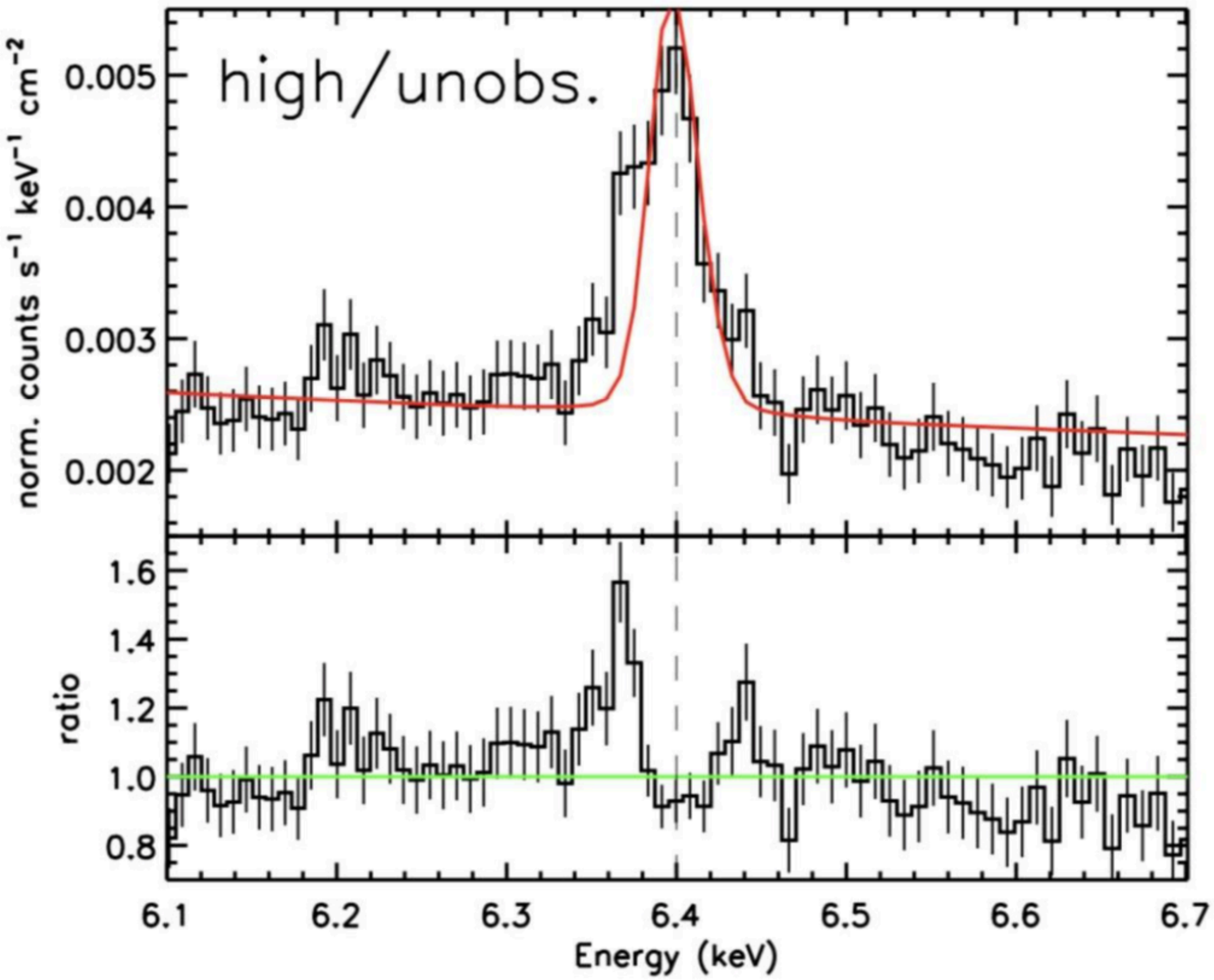
Consistent picture between spectra and timing analyses!





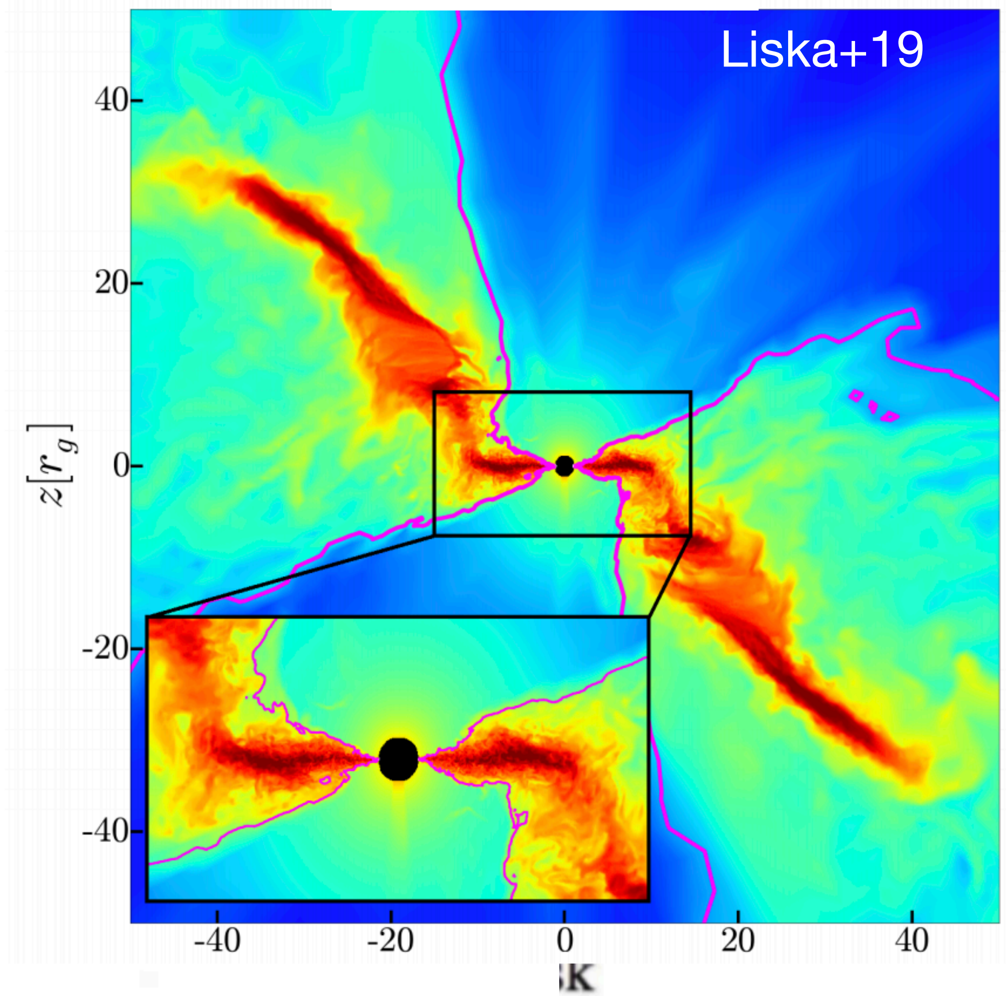


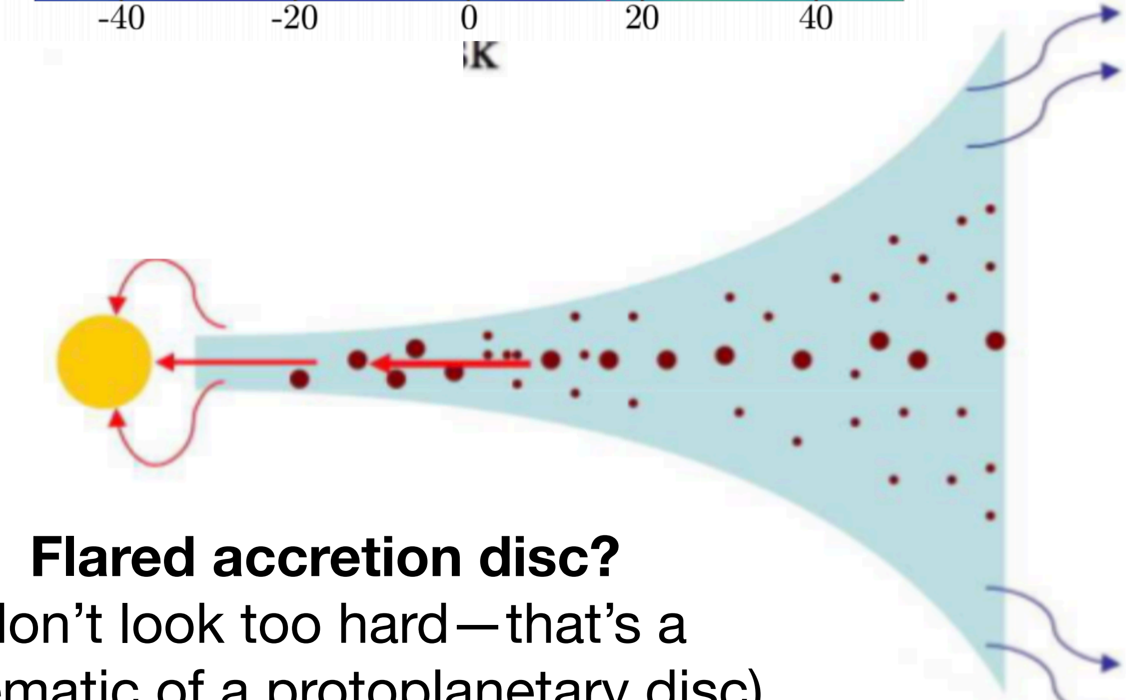
Using the narrow core of the line to measure kinematics at large scales
Compare to inner disc



Miller et al., 2018
HETG observations of NGC 4151
6.4 keV Fe I is not gaussian

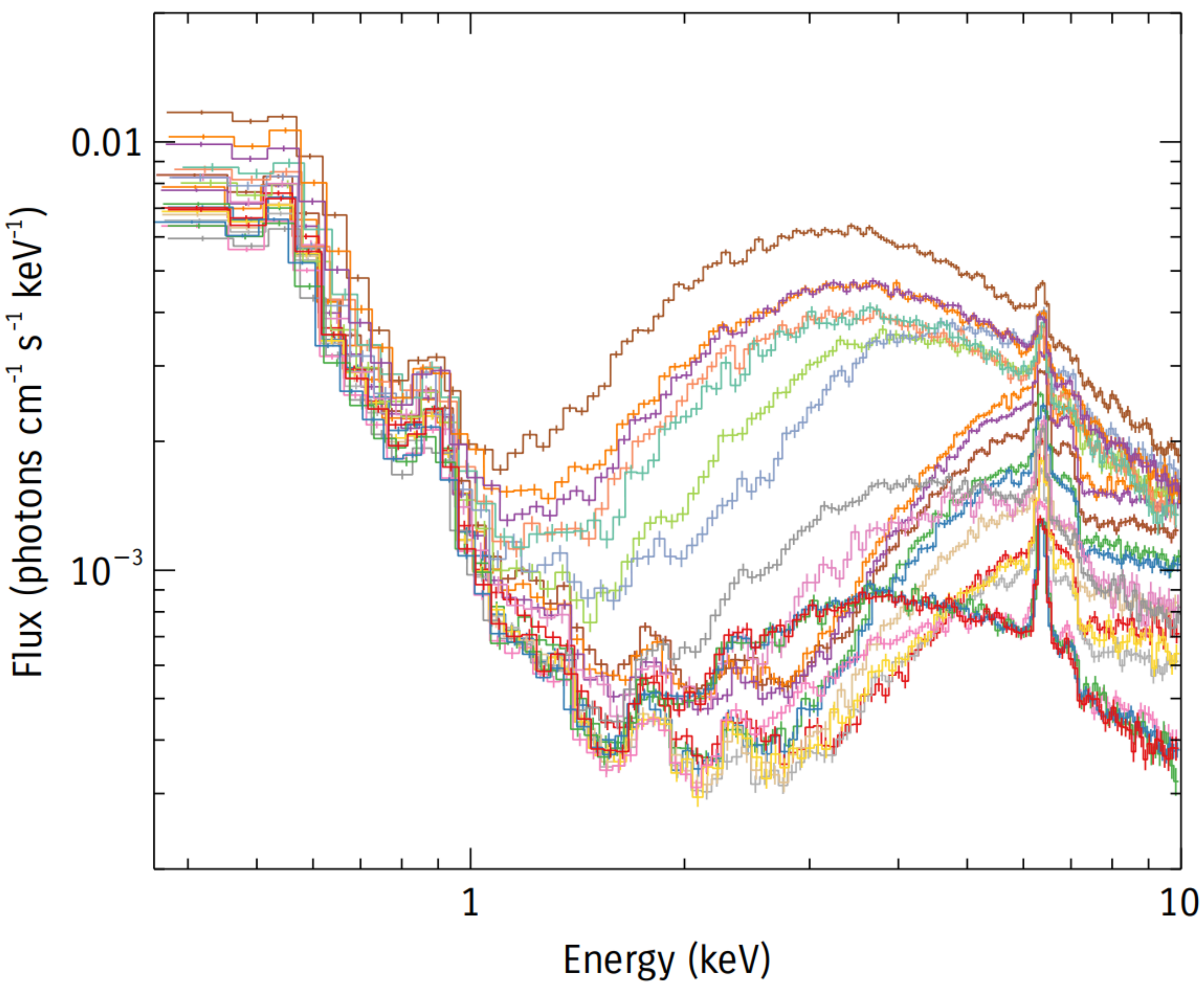
Tilted discs?



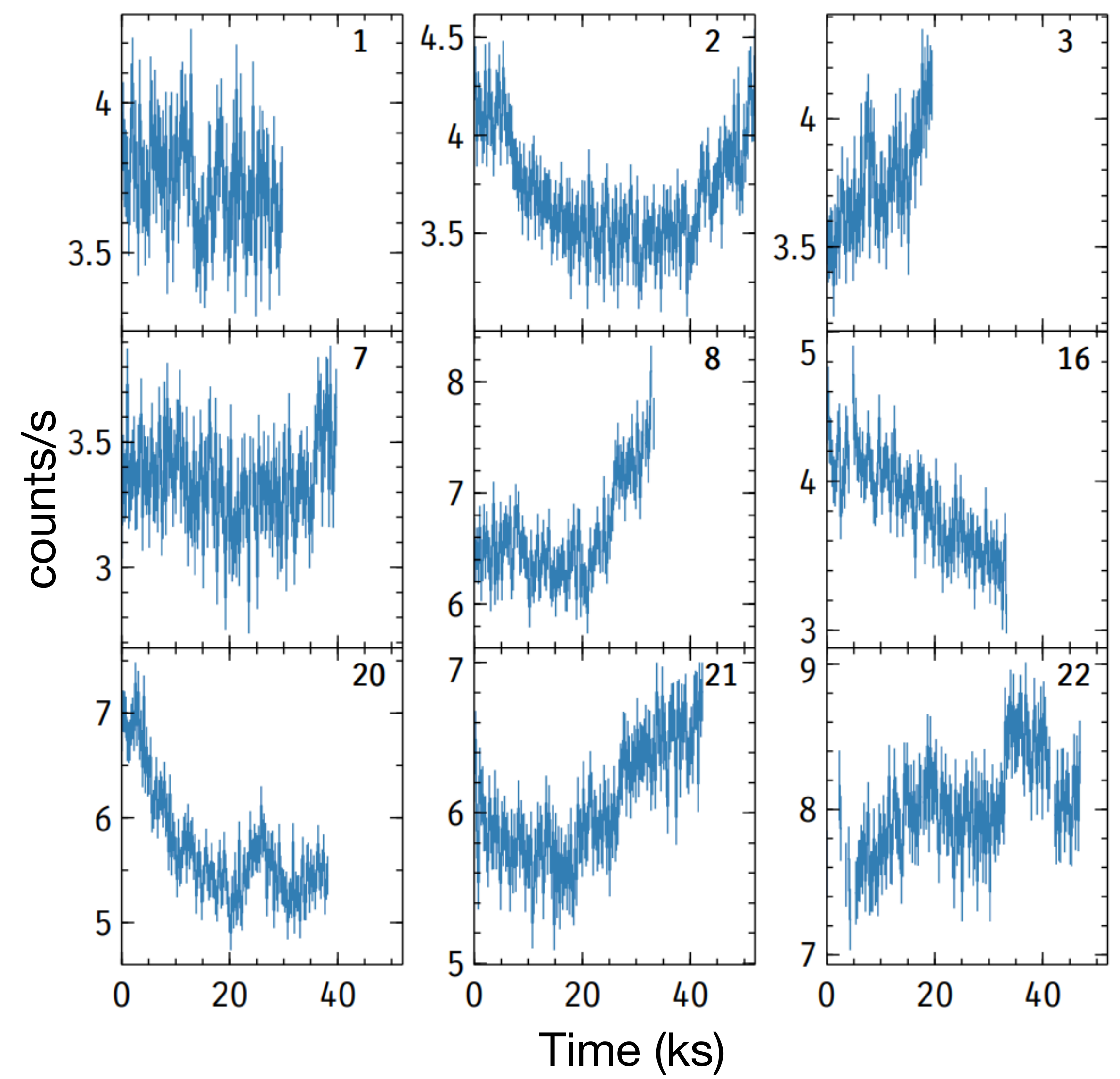


Flared accretion disc?
(don't look too hard—that's a schematic of a protoplanetary disc)

But is there relativistic reflection in NGC 4151?



Spectra is complex, doesn’t require broad line



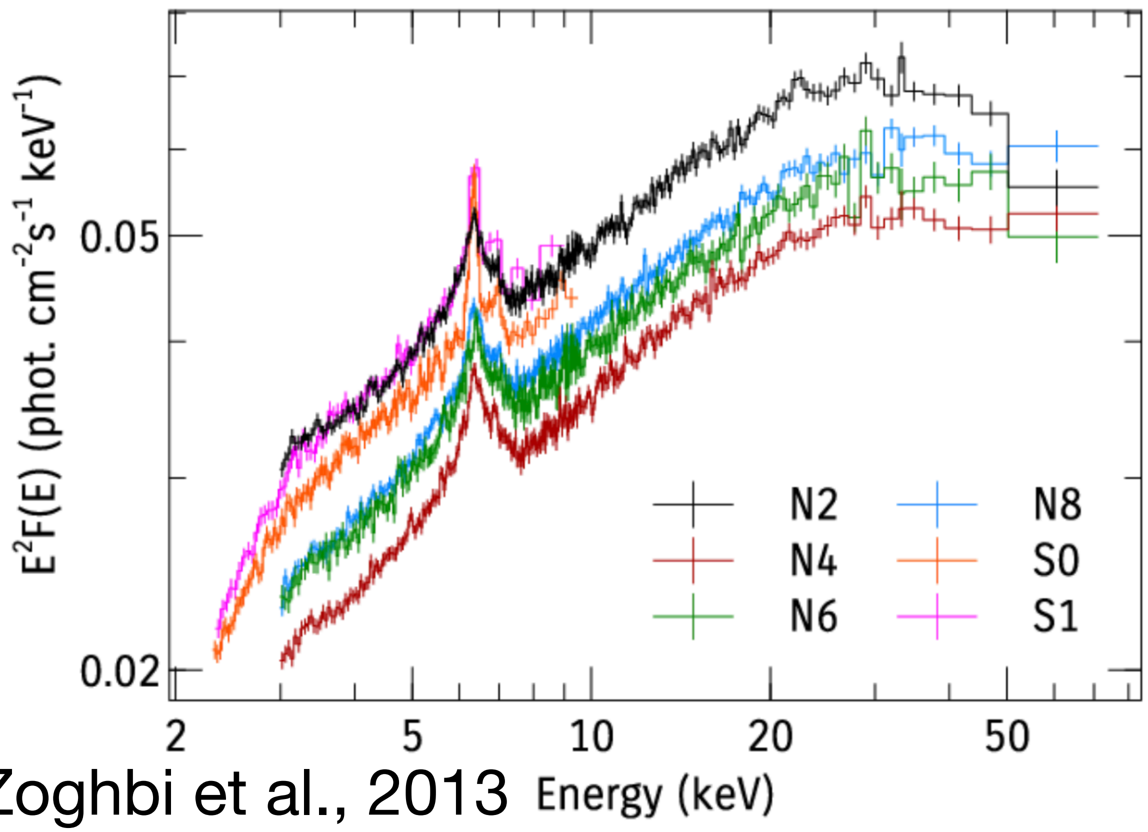
No signatures of reverberation

High mass black hole, short observations → Are we probing long enough timescales?

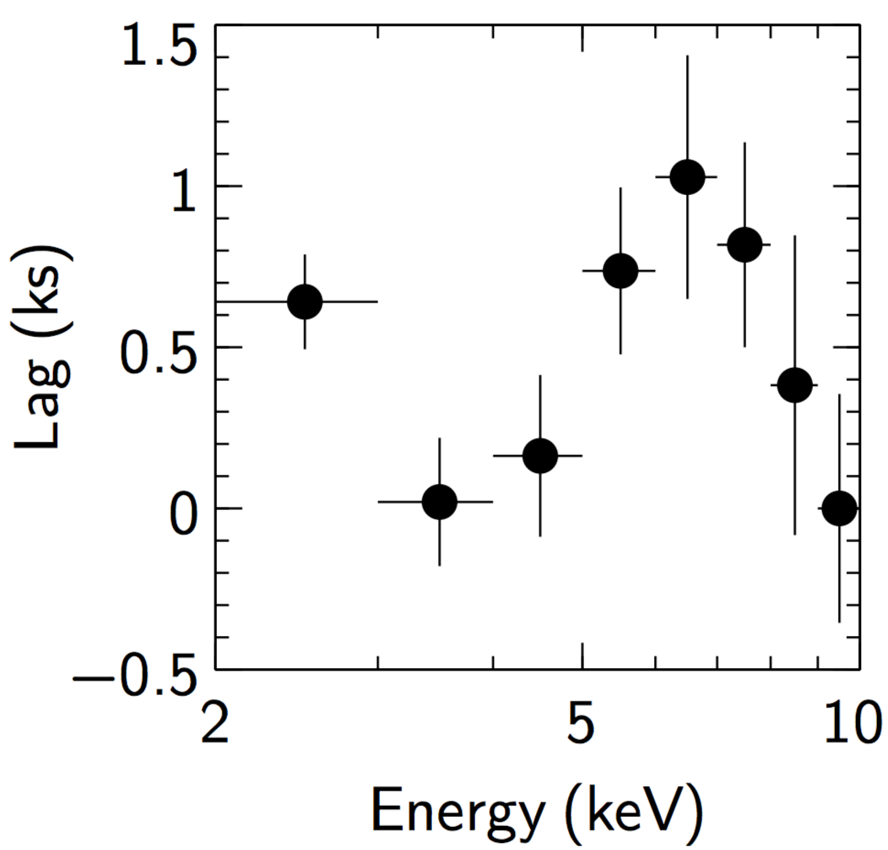
Zoghbi, Miller & Cackett 2019

Using the narrow core of the line to measure kinematics at large scales

MCG-5-23-16



Zoghbi et al., 2013



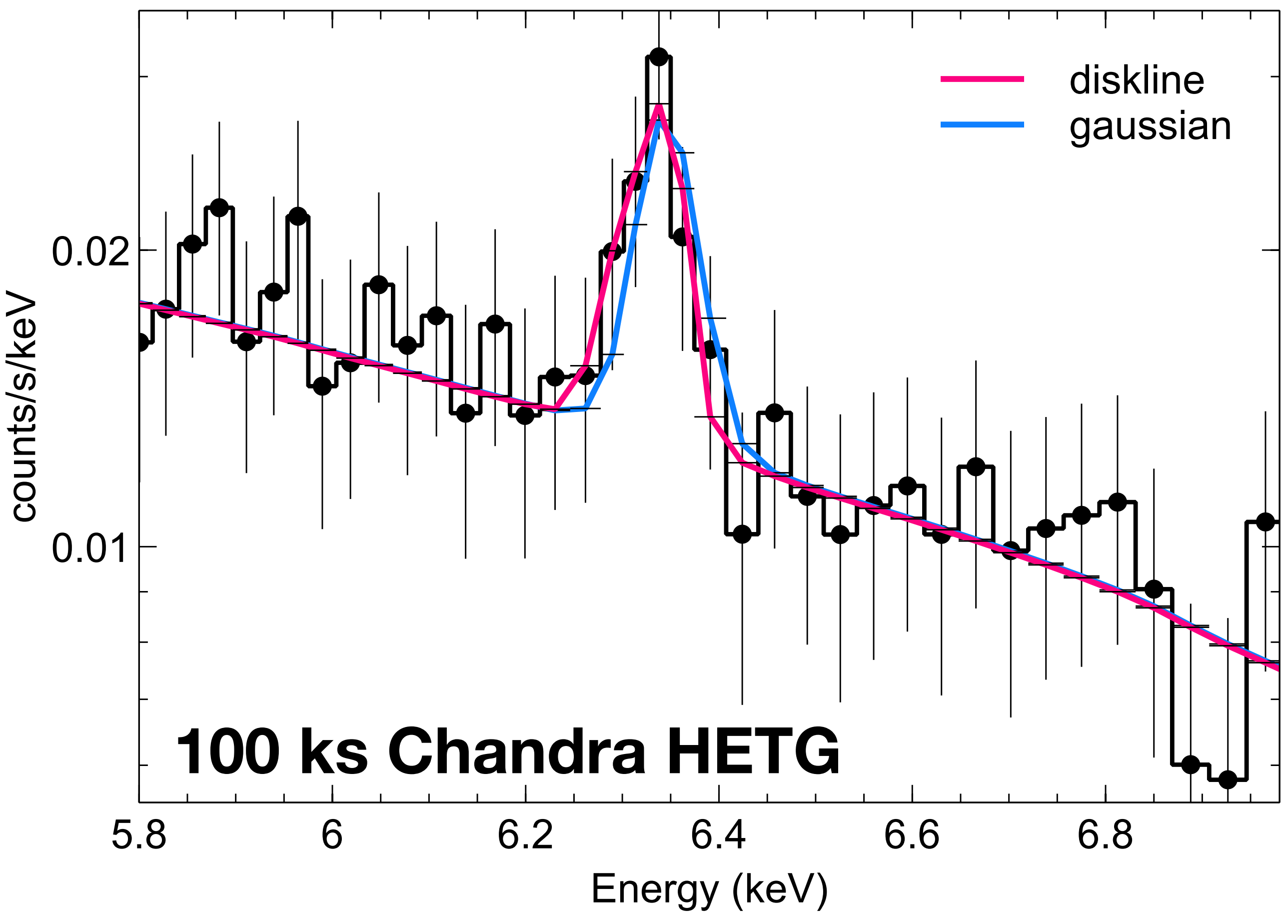
XRISM X-Ray Imaging and Spectroscopy Mission

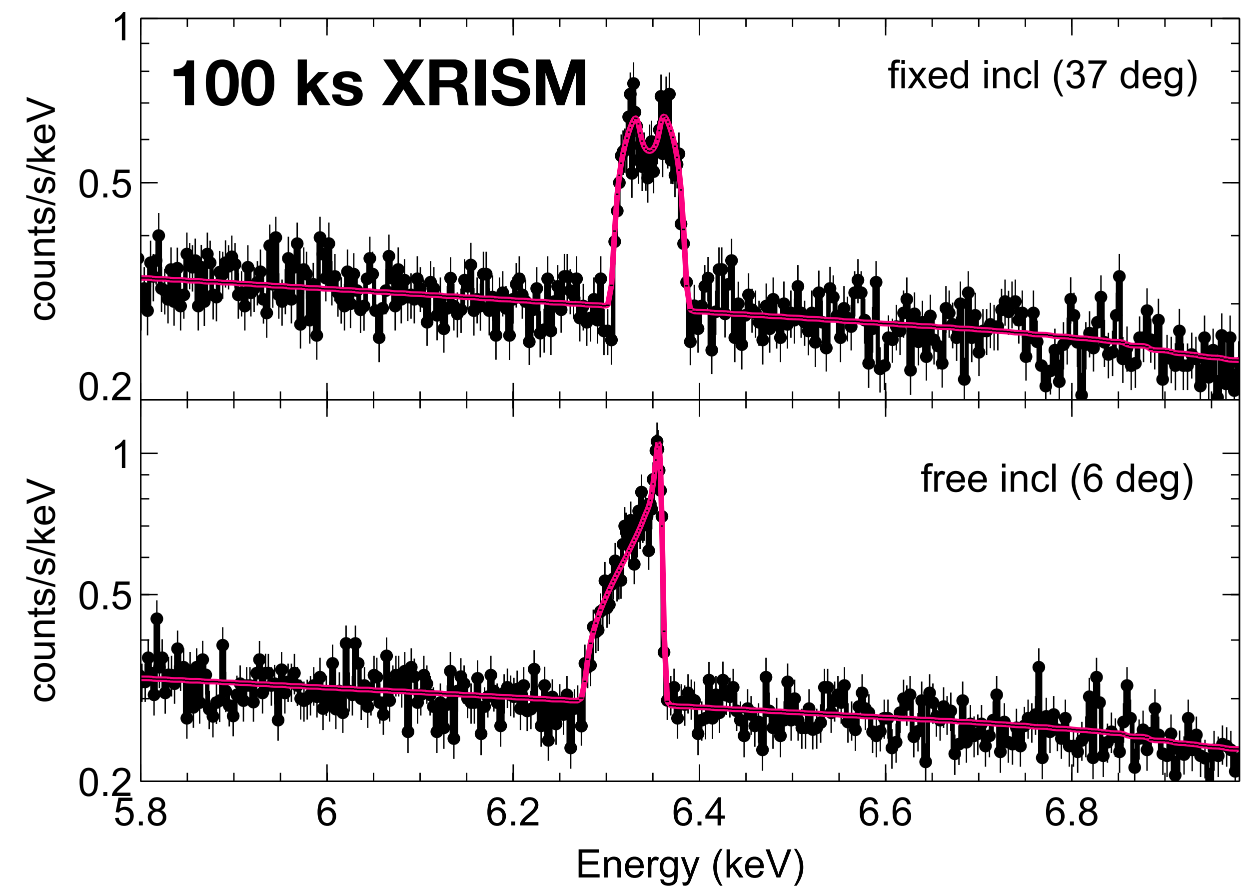
X-RAY OBSERVATORY LYNX

STROBE-X

Where will we be at the next X-ray Astronomy Conference in Bologna?

MCG-5-23-16

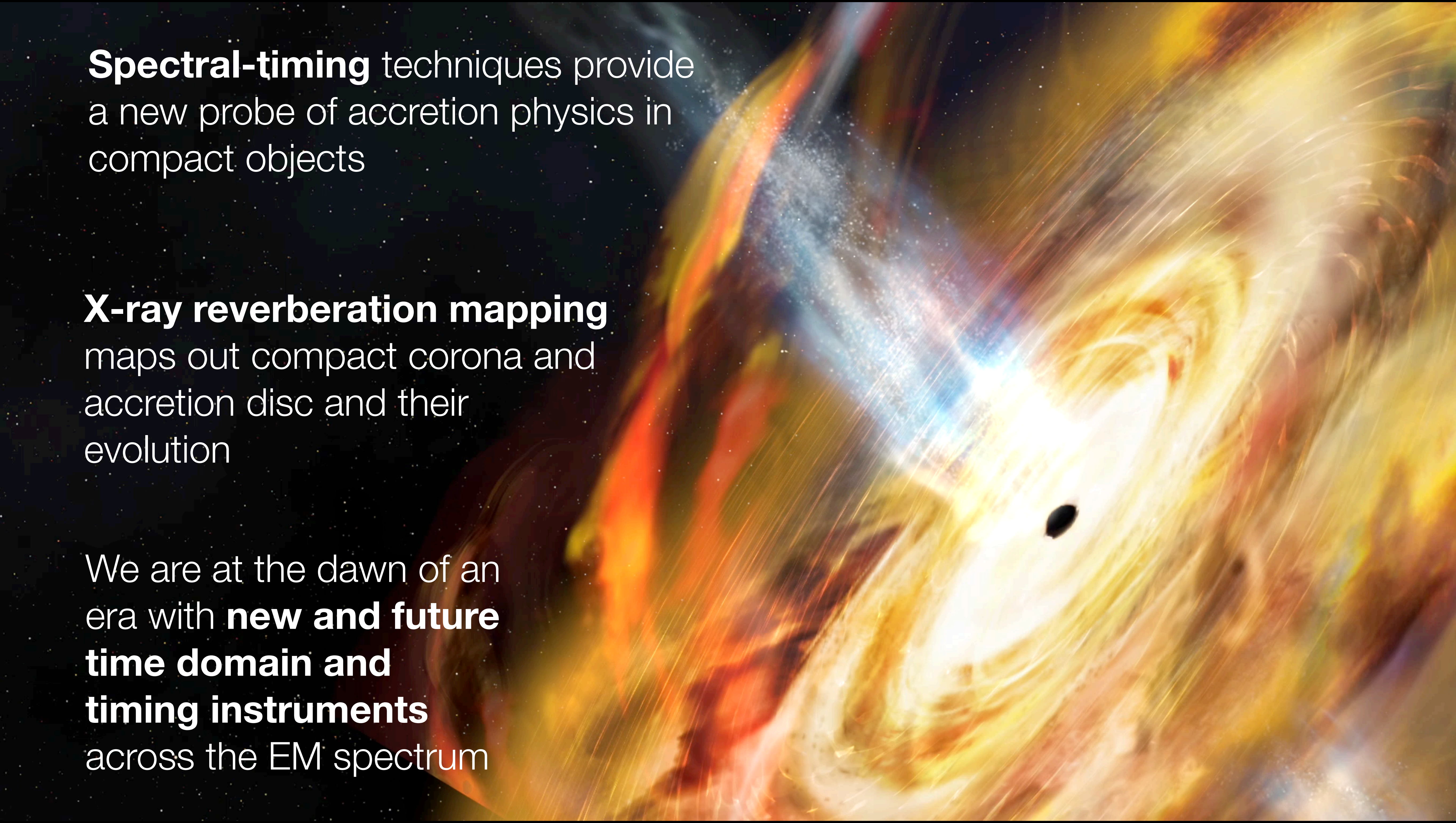




XRISM X-Ray Imaging and Spectroscopy Mission

To launch early 2022!

Conclusions



Spectral-timing techniques provide a new probe of accretion physics in compact objects

X-ray reverberation mapping maps out compact corona and accretion disc and their evolution

We are at the dawn of an era with **new and future time domain and timing instruments** across the EM spectrum

NASA/GSFC Press Office. Image Credit: Aurore Simonnet