X-ray reverberation mapping

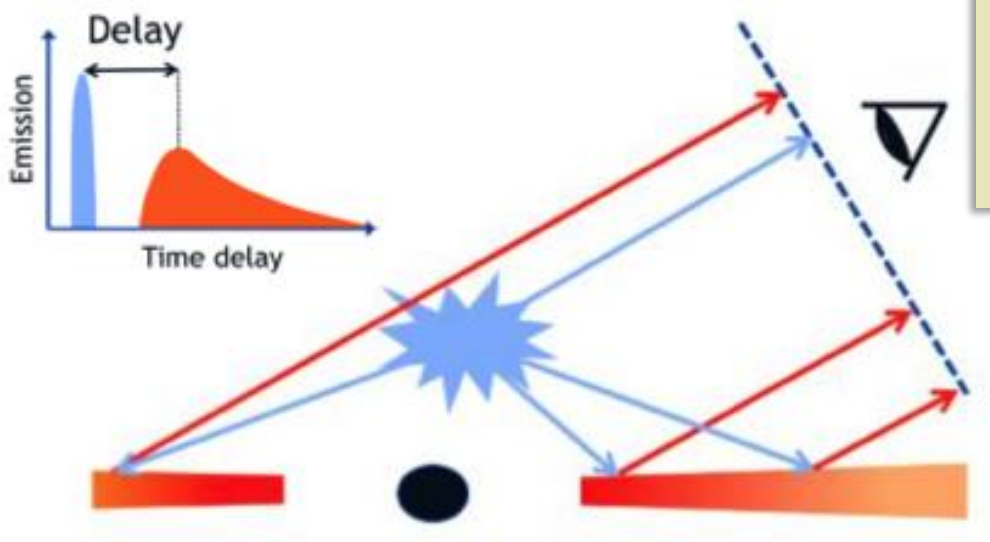
Phil Uttley (University of Amsterdam)

on behalf of the eXTP strong field gravity working group

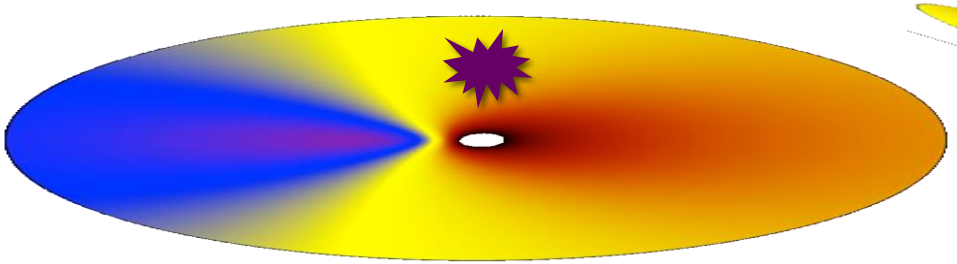
eXTP

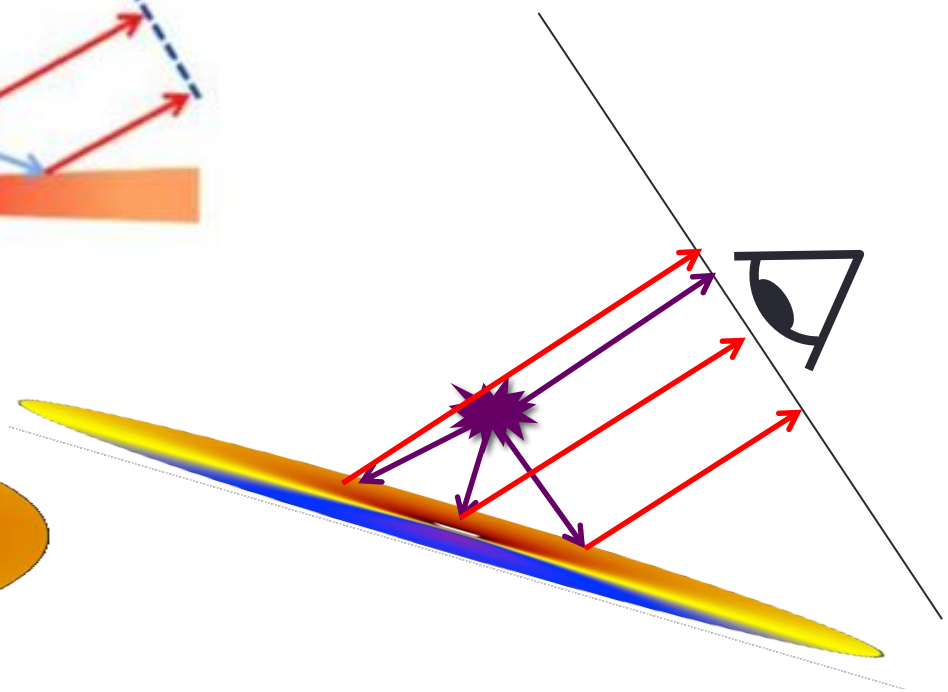
ANTON PANNEKOEK INSTITUTE

Reverberation mapping close to the event horizon



Radii+redshifts ➔
test dynamics of matter in strong field gravity

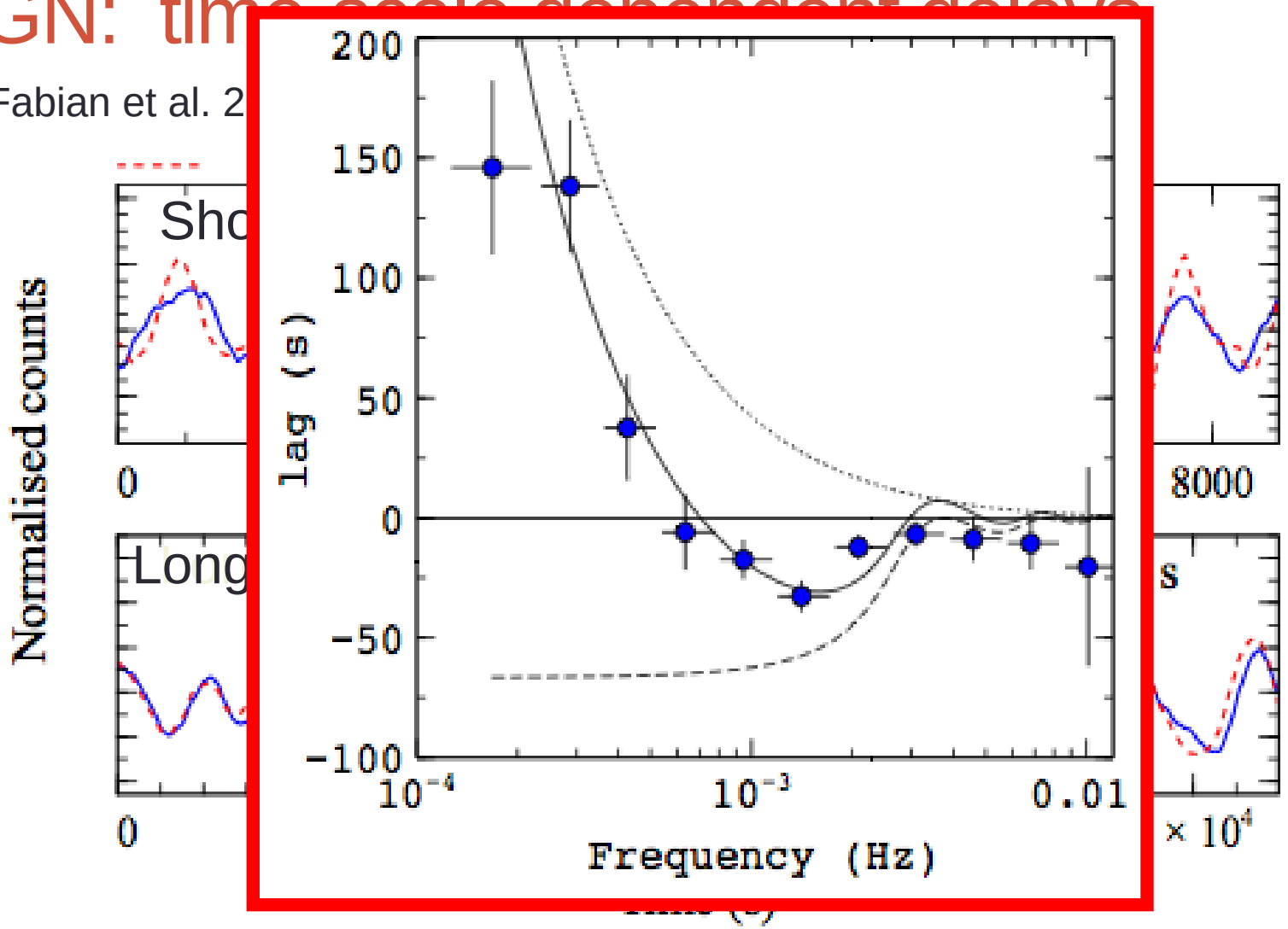




X-RAY REVERBERATION IN AGN

AGN: tim

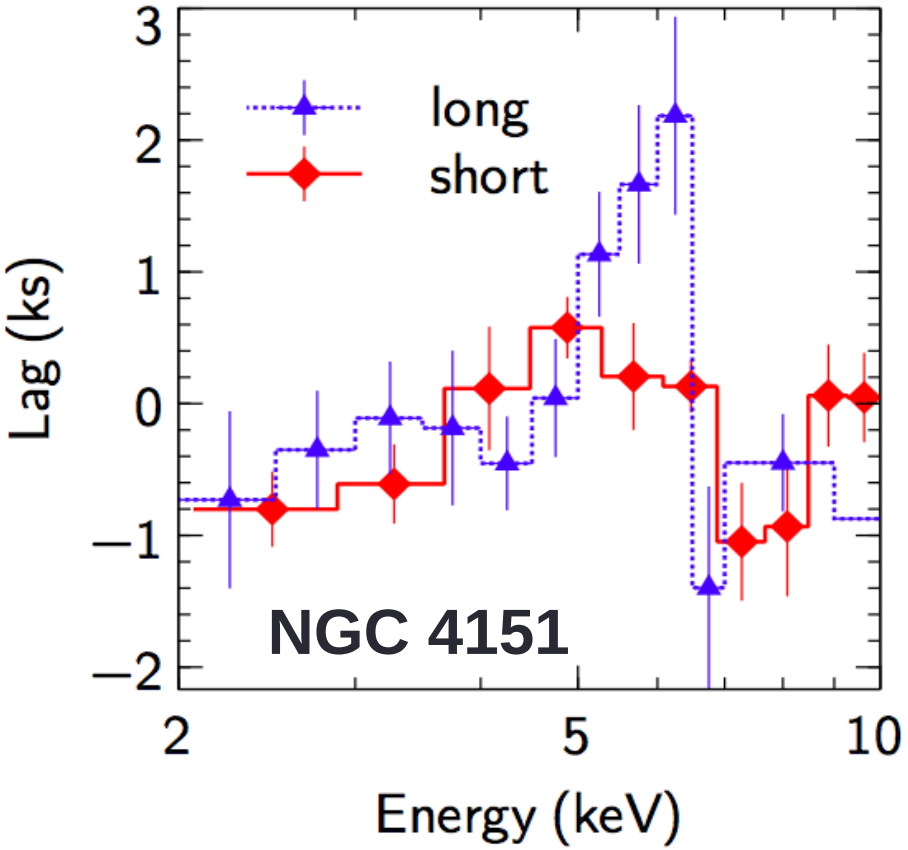
Fabian et al. 2



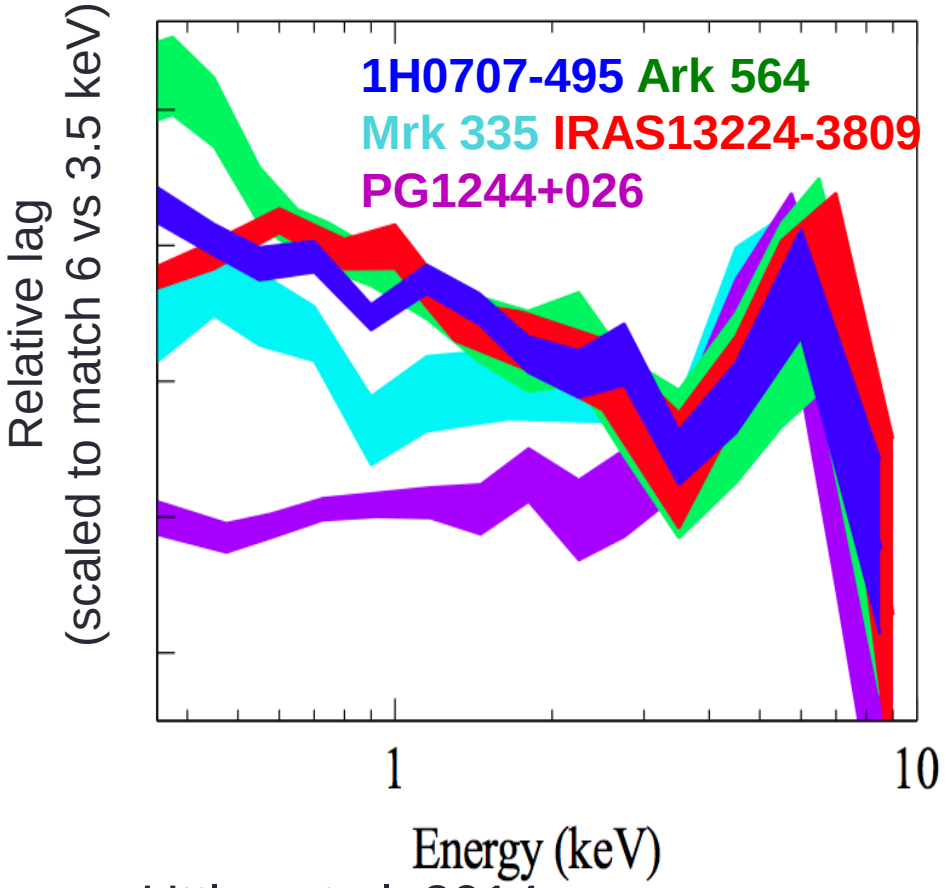
Low-frequencies: propagating accretion fluctuations?
High-frequencies: switch to X-ray reverberation?
-> we need to ensure good measurements of the lag at high frequencies

Fe K reverberation lags: measuring light-travel times to the inner disc

Lag vs energy spectrum: measure lag of small energy bins relative to a broad reference band. Note the different shapes in the soft band!



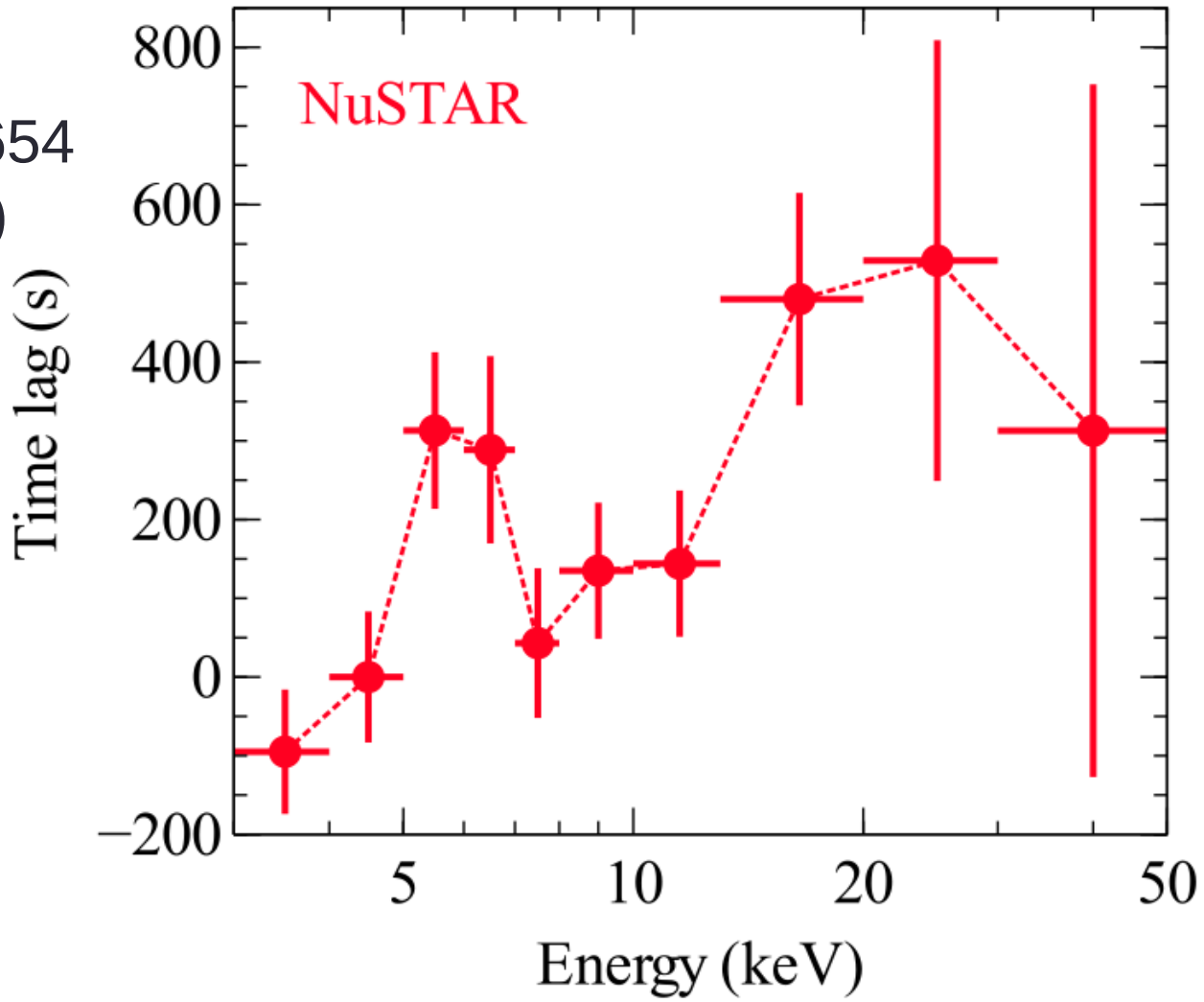
Zoghbi et al. 2012



Uttley et al. 2014
(adapted from Kara et al. 2013)

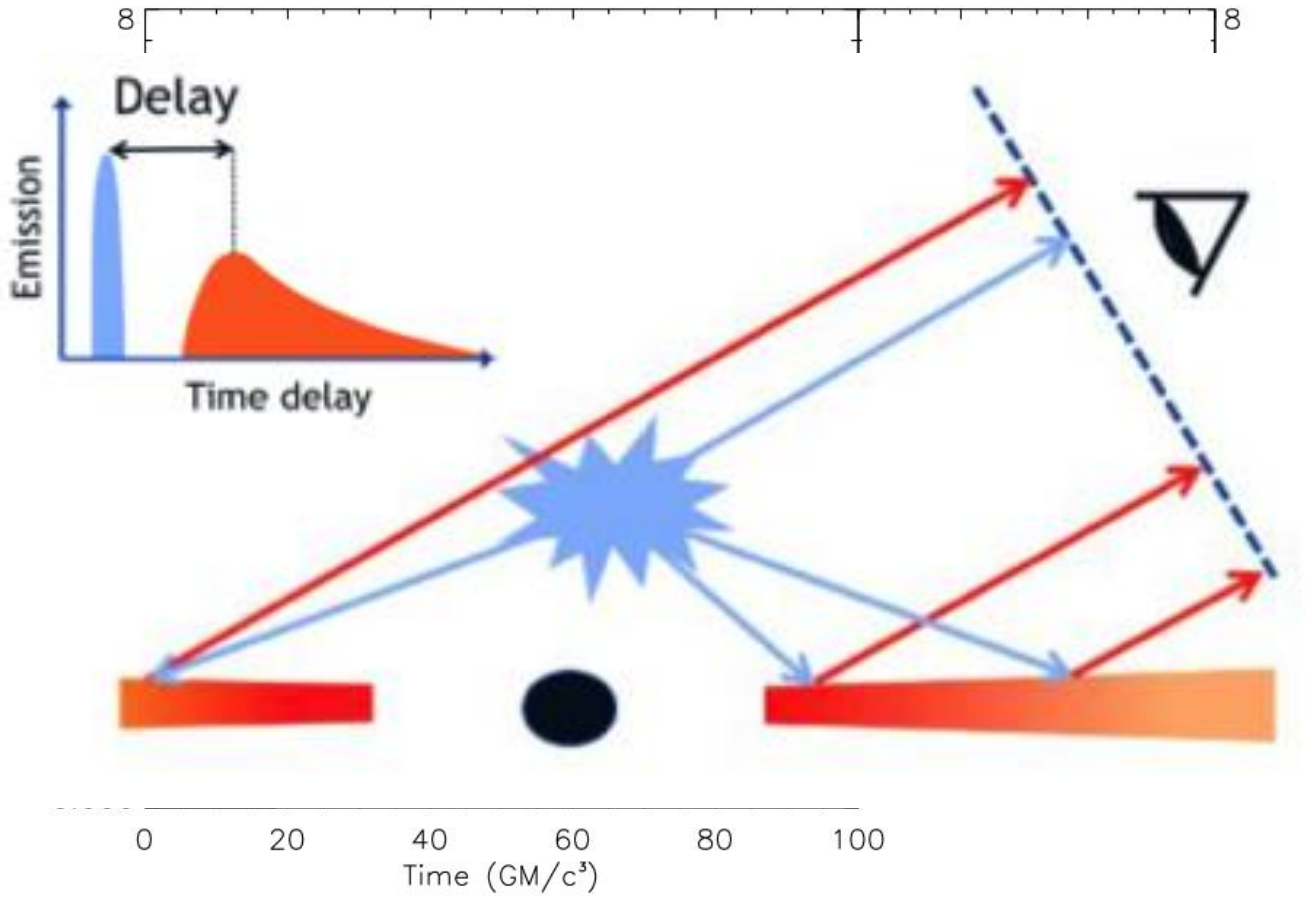
AGN X-ray reverberation with NuSTAR

Swift J2127.4+5654
(Kara et al. 2015)



GR-raytracing modelling of Fe K lags

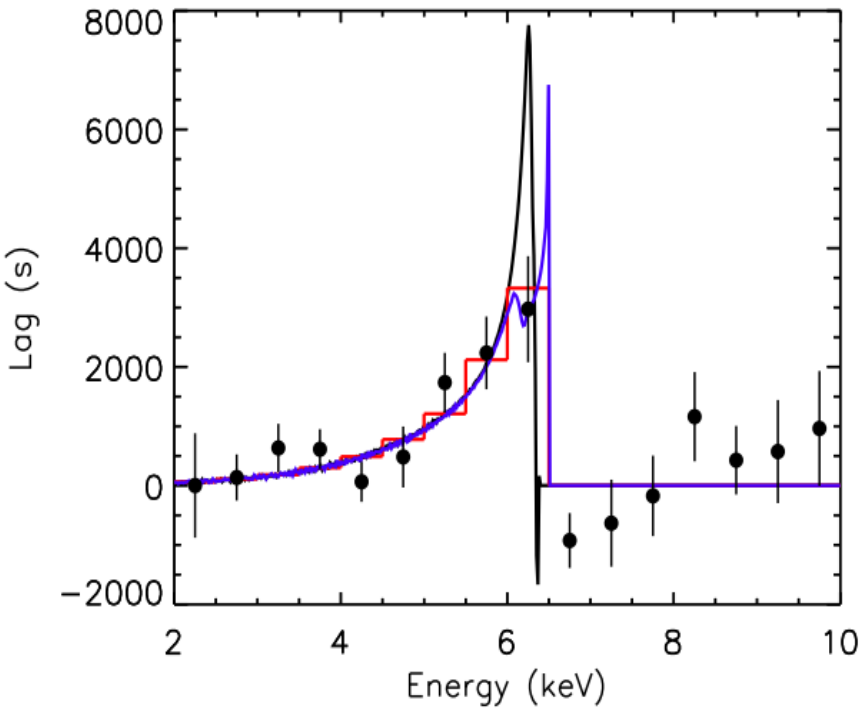
(Cackett et al., 2014)

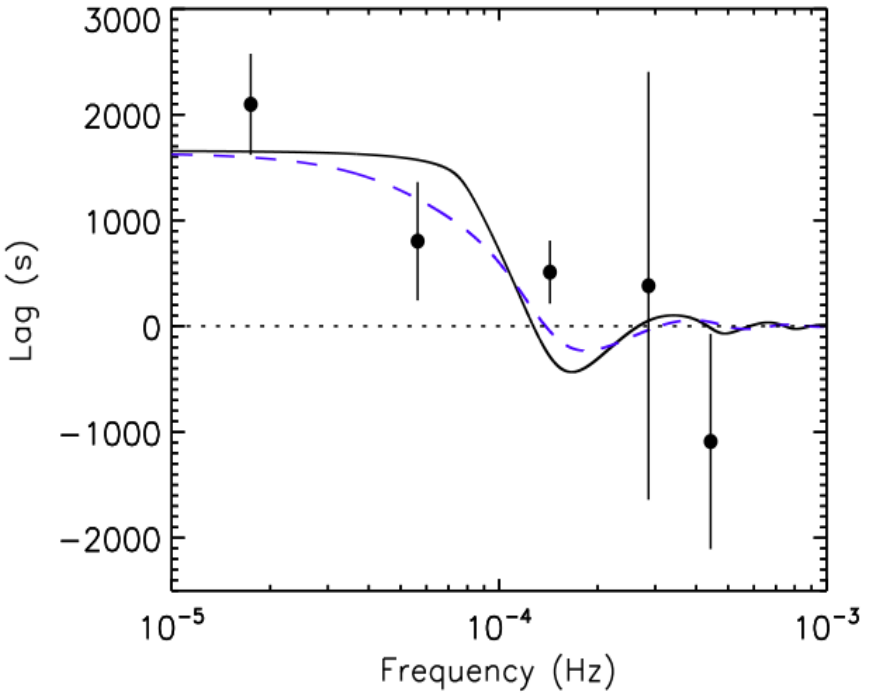


Impulse response relates intensity of line response at a given time-delay to energy

GR-raytracing modelling of Fe K lags

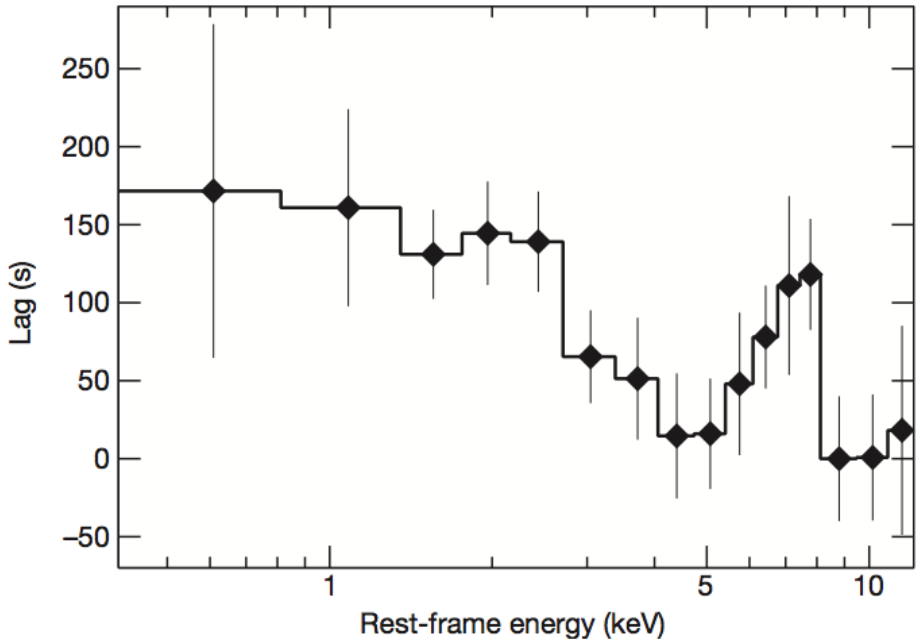
NGC 4151: Cackett et al., 2014





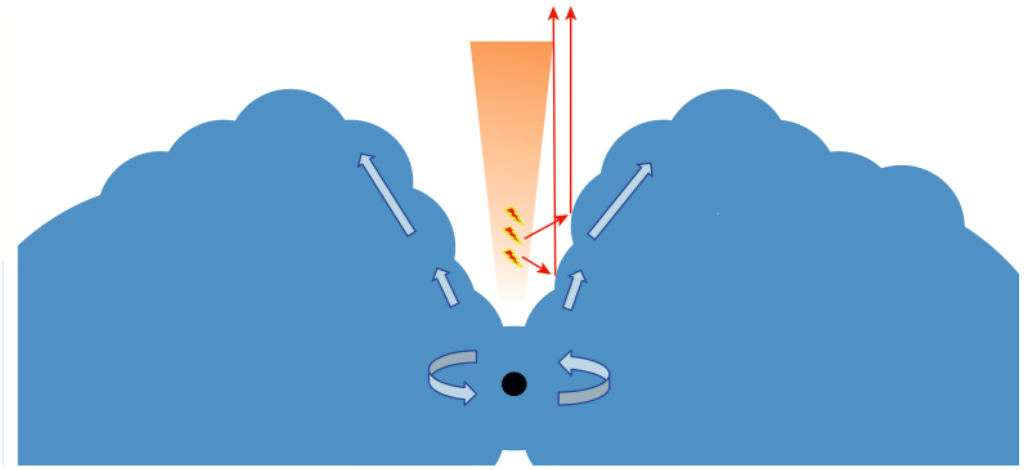
Good fit obtained for 7 R_g source height, reflection fraction ~1, assuming 4.6×10^7 M_{solar}. Spin unconstrained due to low S/N in red wing

Tidal disruption events: reverberation in Swift J1644+57



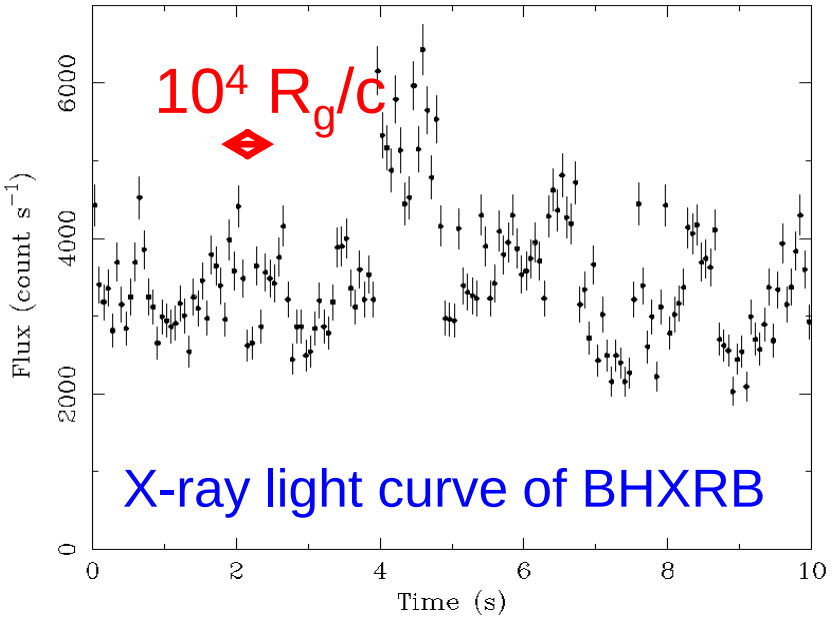
- **Kara et al. 2016**: first evidence for reverberation signature from a tidal disruption event.

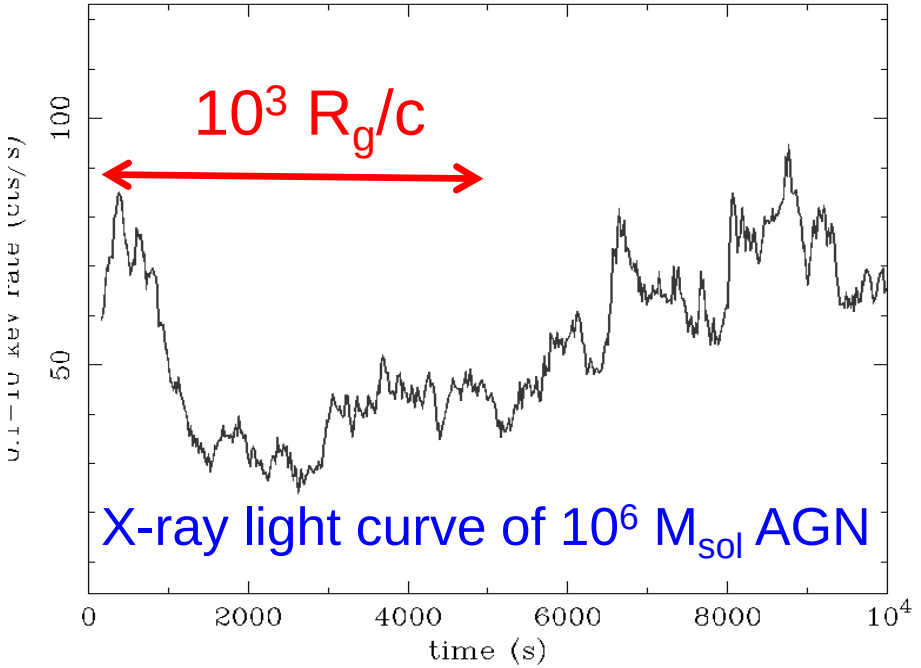
- Blueshifted iron line implies signal is reverberating from the wall of a super-Eddington, mildly relativistic outflow.



X-RAY REVERBERATION IN X-RAY BINARIES

Lag sensitivity: why XRBs are currently worse than AGN for reverberation lag measurements

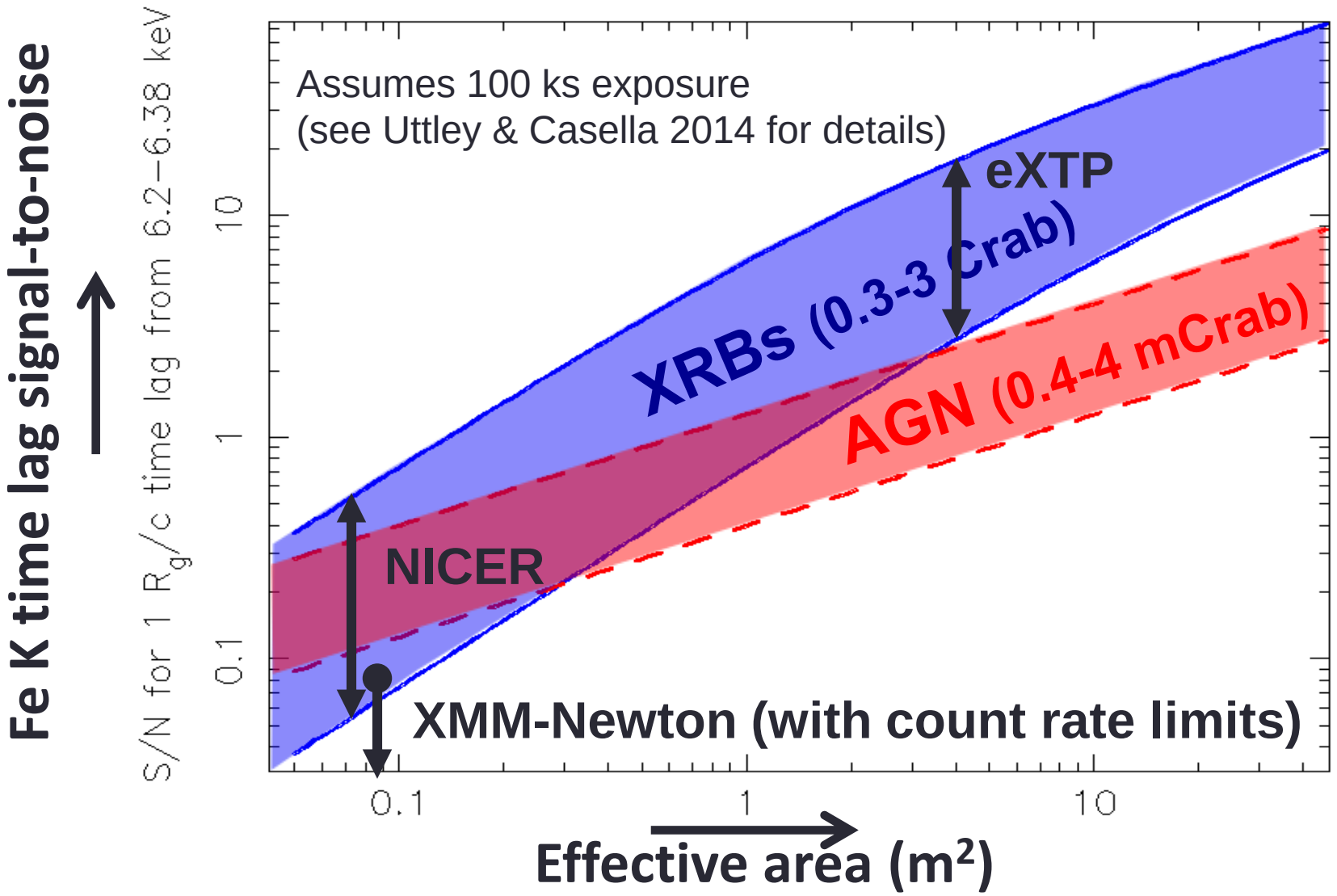




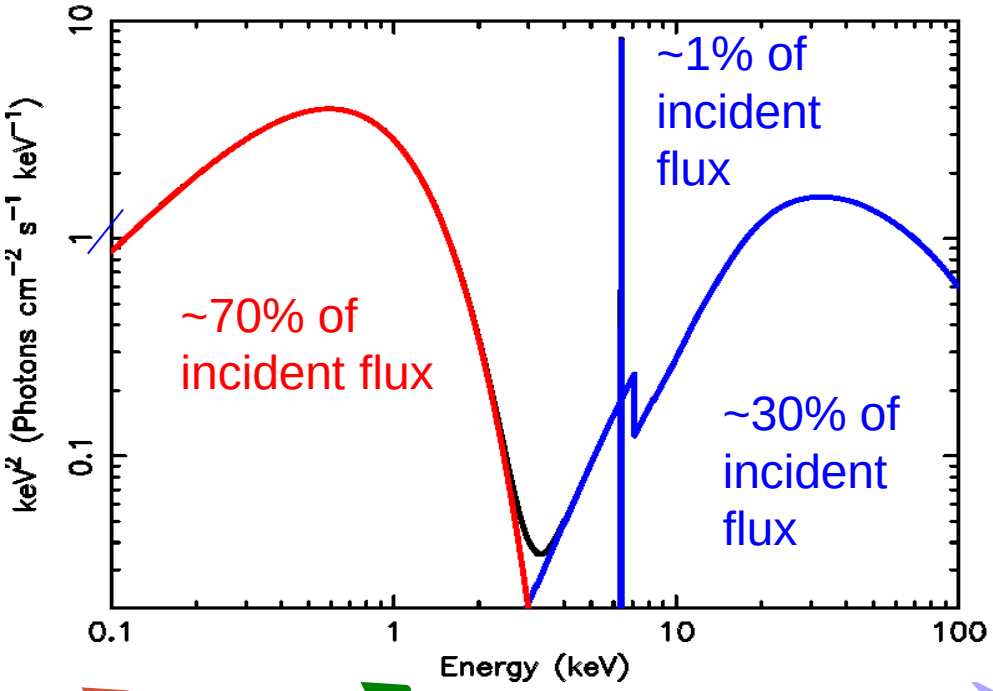
AGN: variations already well-sampled with many counts per variability time-scale ➔ limited improvements from increasing count rate (S/N scales with sqrt(rate))

XRBs: significant improvements from increasing count rate so individual rapid variability events are better sampled: S/N scales linearly with rate

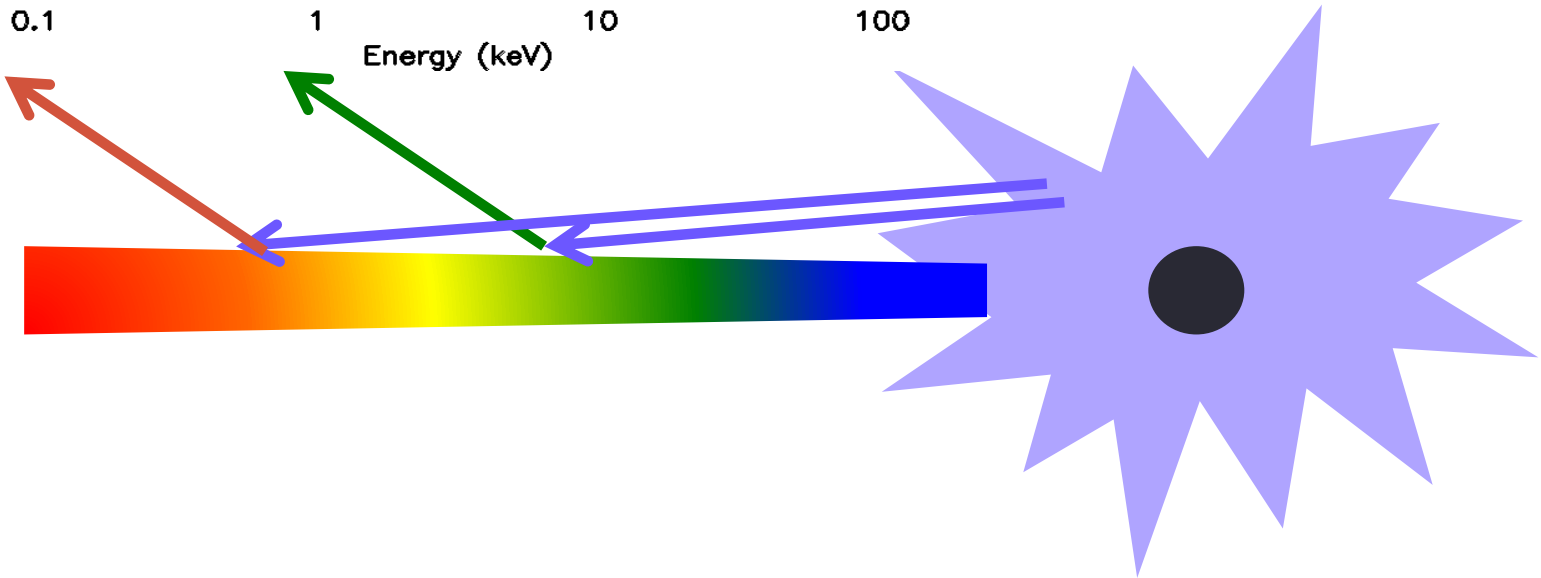
The need for large collecting areas



Disc reverberation components

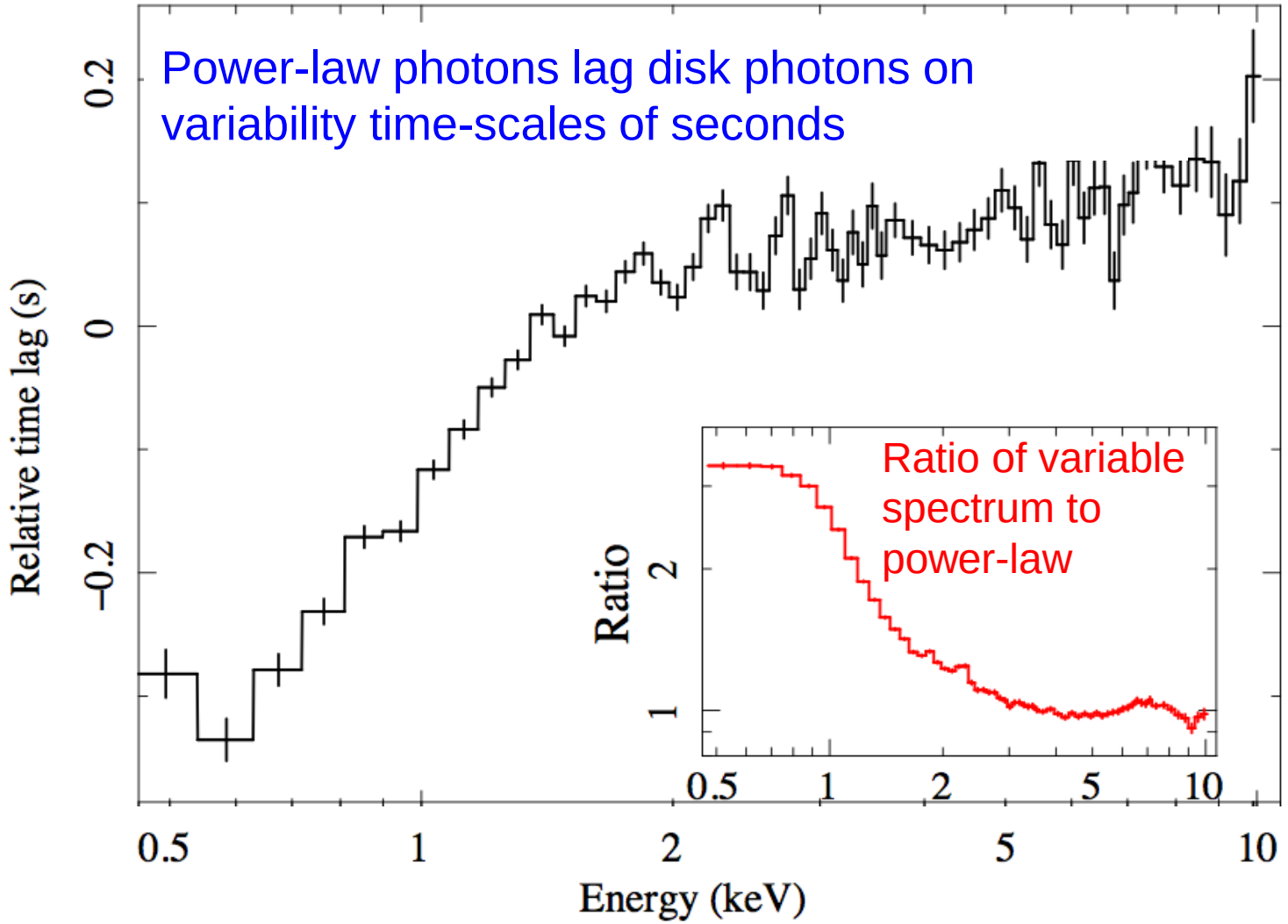


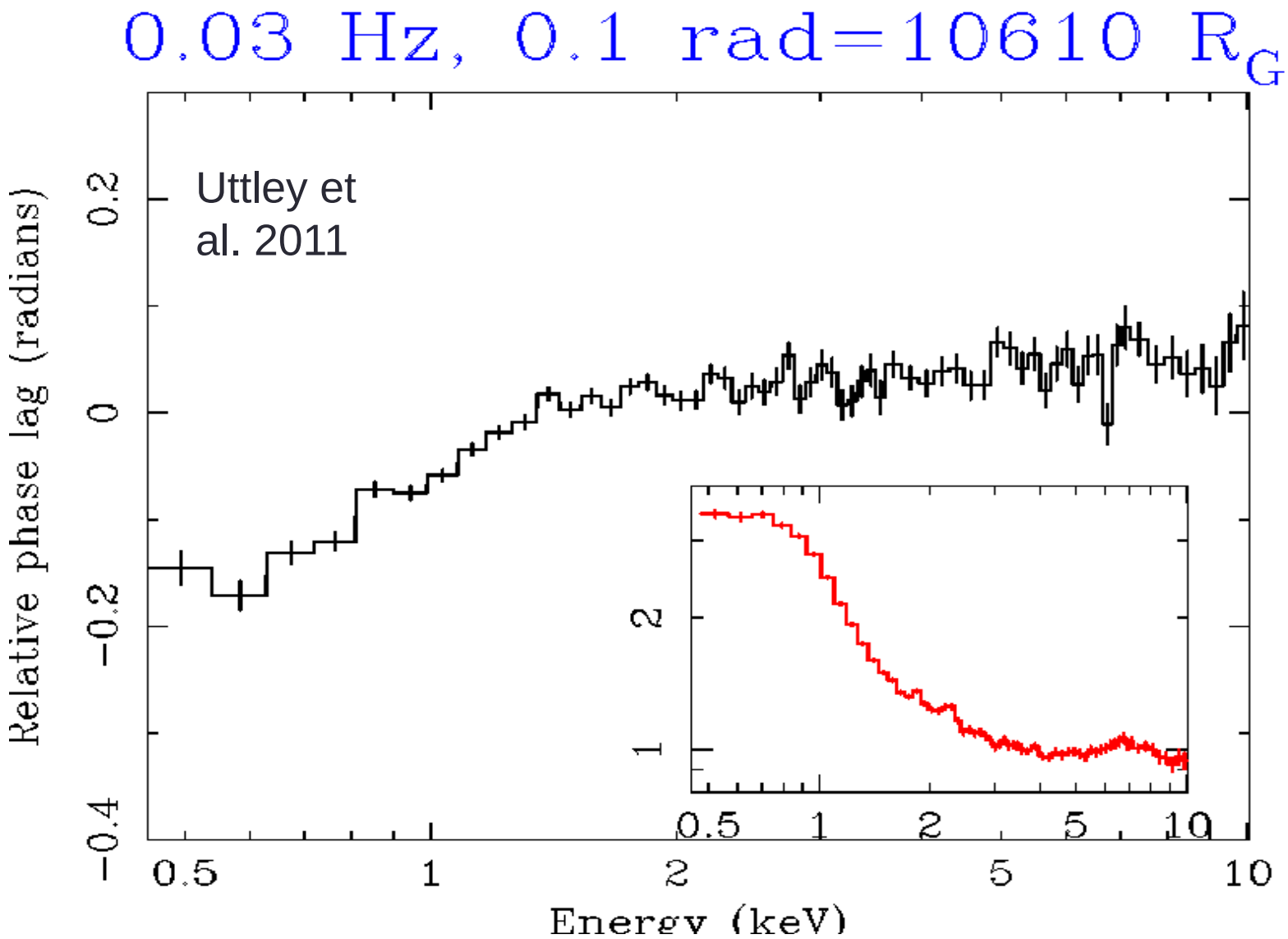
- In addition to the iron line and reflection continuum, the absorbed flux is reradiated by the disc as thermal blackbody radiation
- Uniquely, eXTP can study all three components simultaneously!



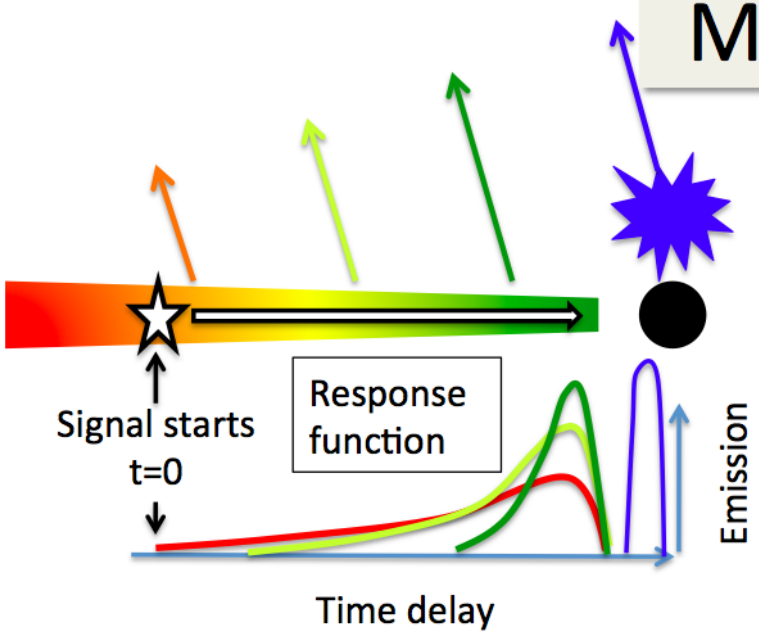
The disk drives broadband noise variability in the hard state

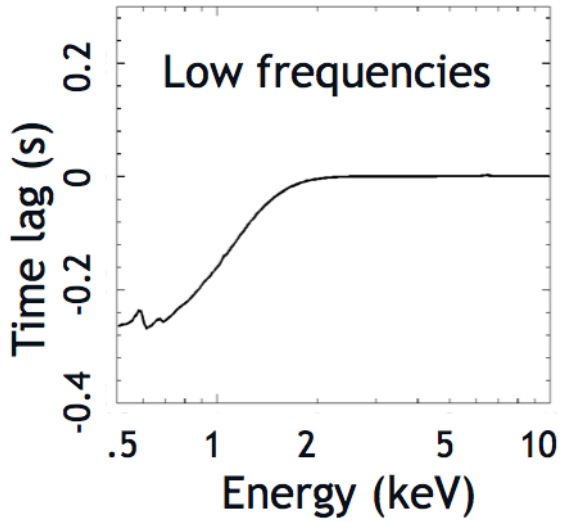
Uttley et al. 2011



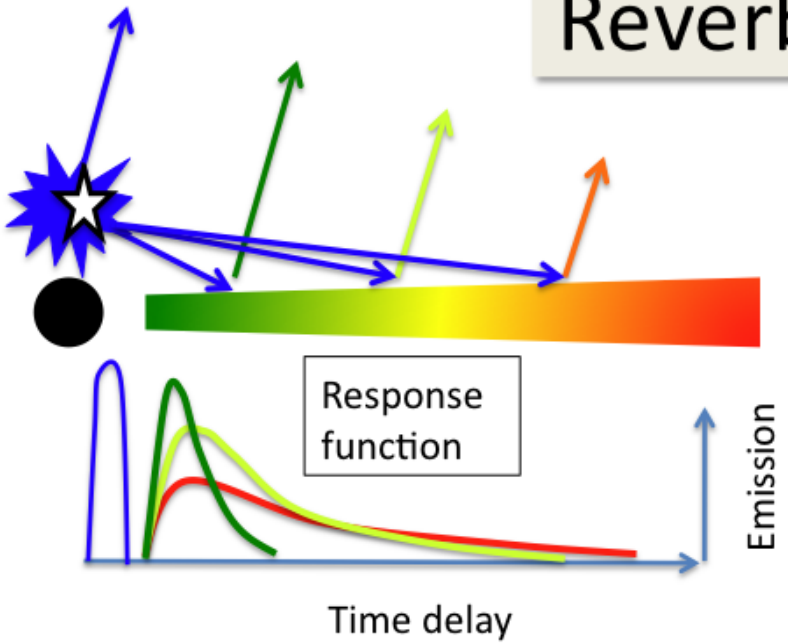

0.03 Hz, 0.1 rad=10610 R_G
Uttley et al. 2011
Relative phase lag (radians)
0.2
0
−0.2
−0.4
0.5
1
2
5
10
Energy (keV)
2
1
0.5
1
2
5
10

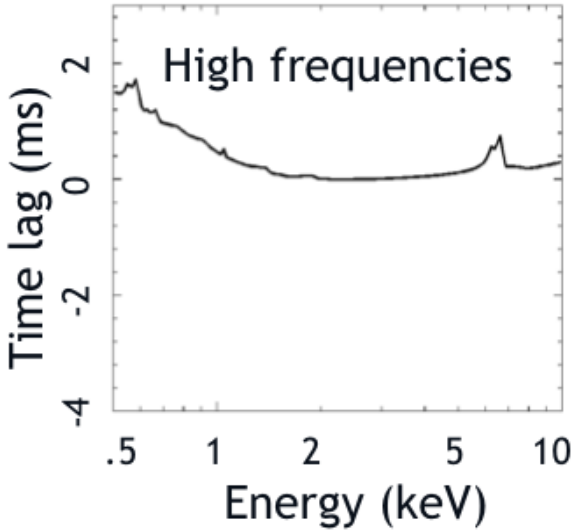
Mapping the inflow





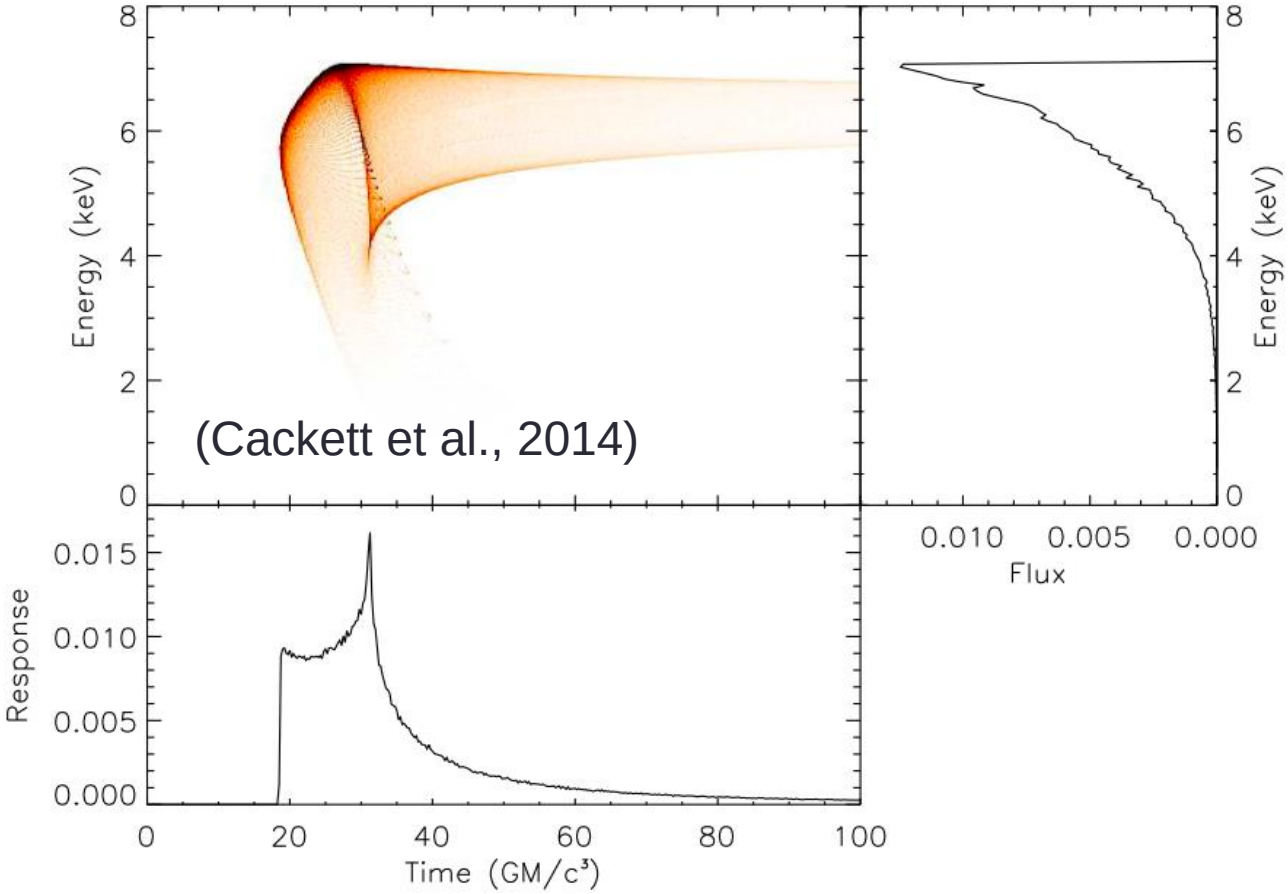
Reverberation mapping





X-RAY REVERBERATION WITH eXTP

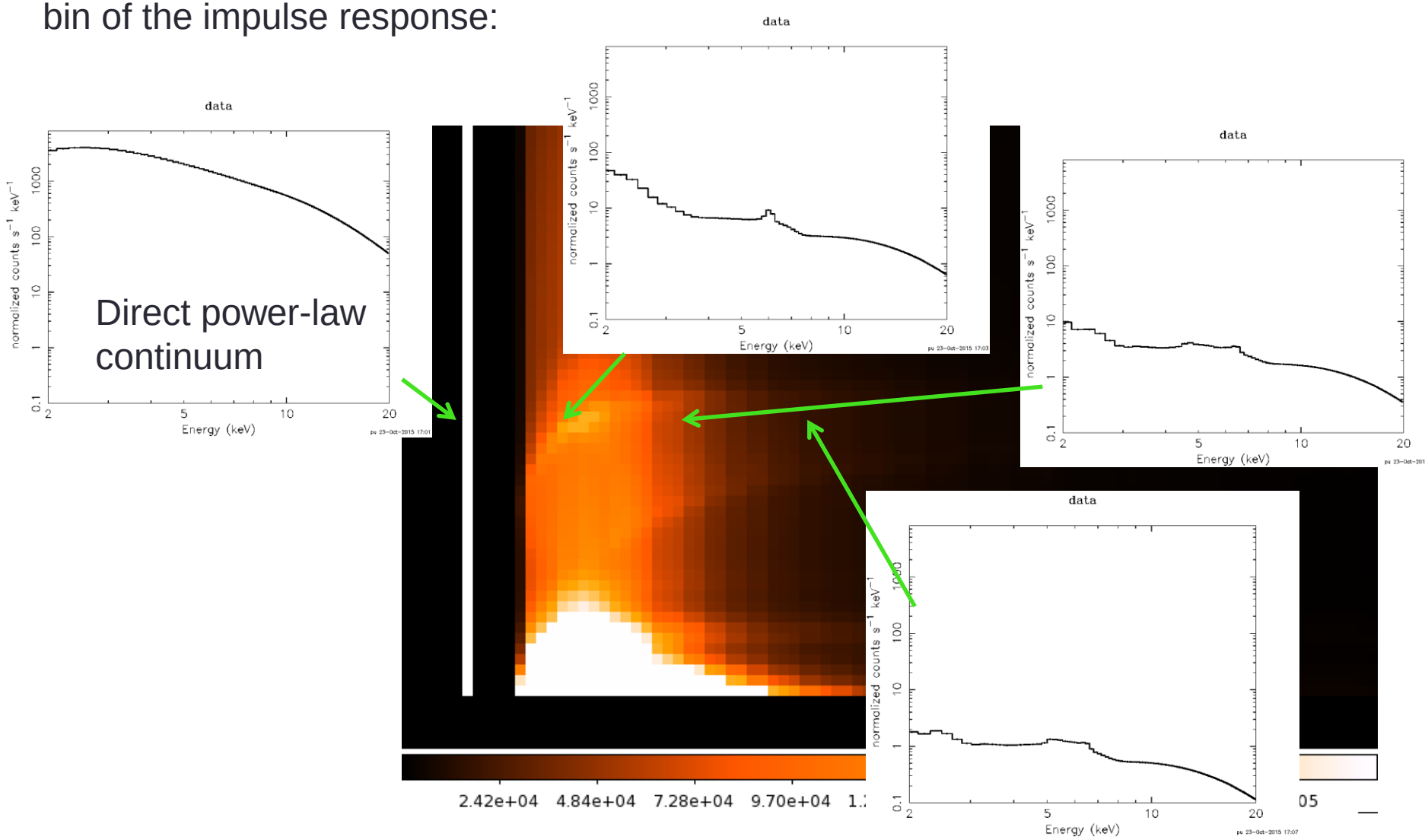
Modelling the lags



Impulse response relates intensity of line response at a given time-delay to energy

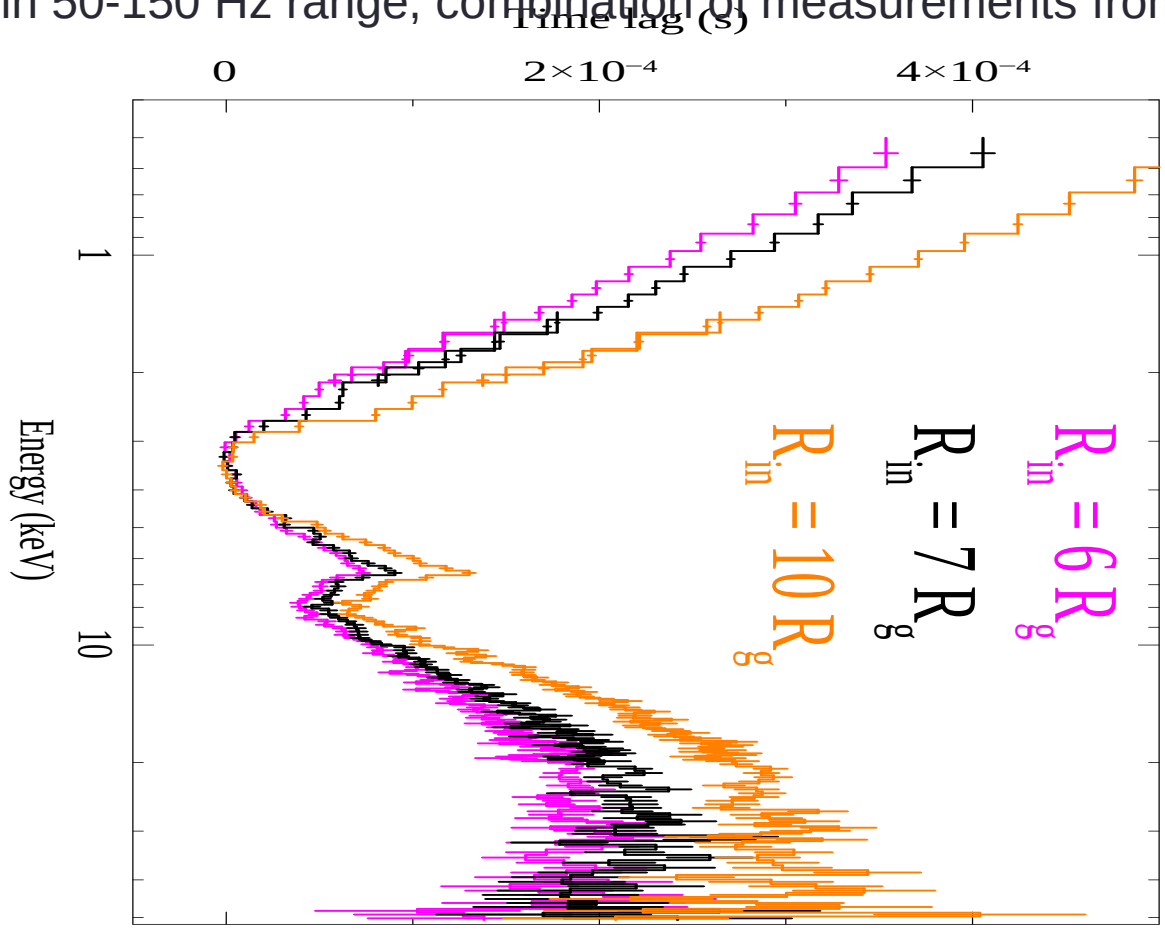
Building the impulse response

In practice we can make the impulse response for a given detector (e.g. LAD, 40 modules) by making a fake spectrum (xspec fakeit command) for each time delay bin of the impulse response:



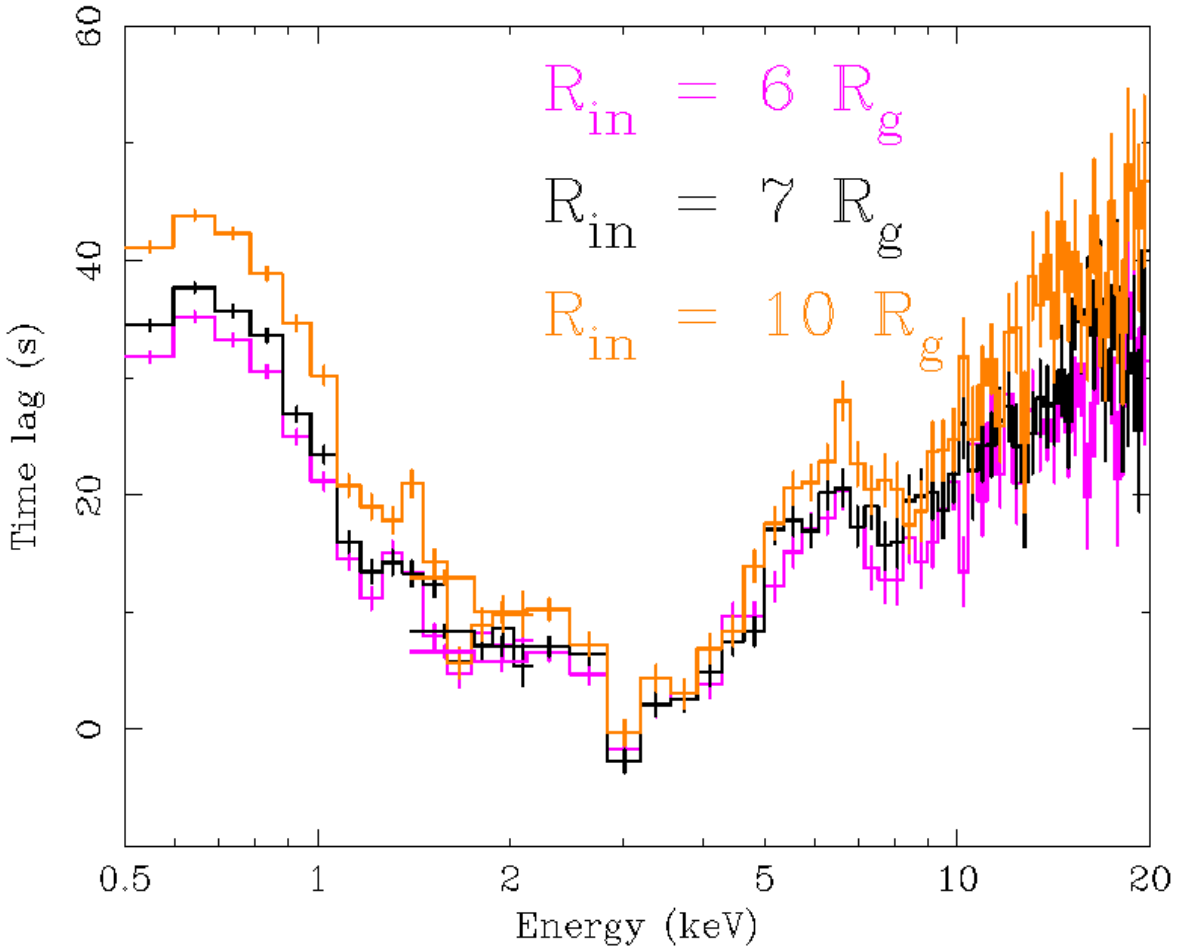
BH XRB: eXTP reverberation lag simulations

100 ks on bright hard (1 Crab) state/hard-intermediate state, lag vs energy measured in 50-150 Hz range, combination of measurements from SFA+LAD.



AGN: eXTP reverberation lag simulations

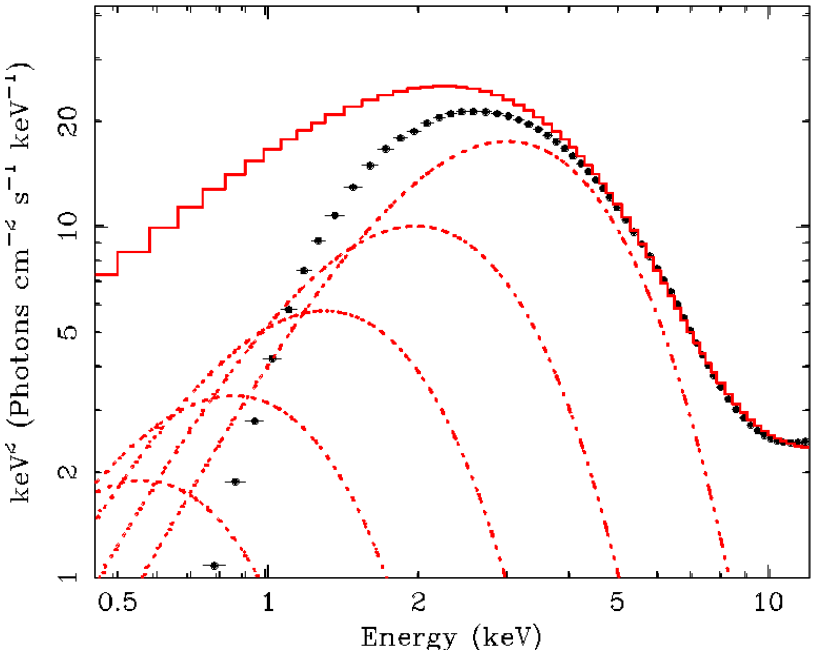
100 ks on bright (2 mCrab) AGN (4e6 Msolar), lag vs energy measured in 0.3-3 mHz range, combination of measurements from SFA+LAD.

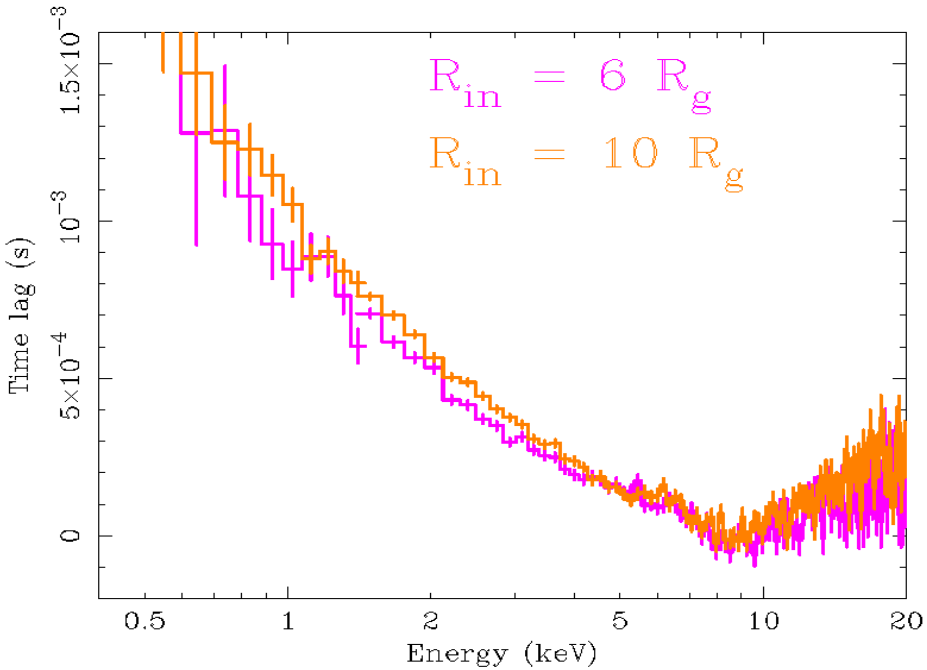


Self-consistency of lag and disk continuum measurements

Independent measurement of radius vs temperature (and test of accretion disk theory!).

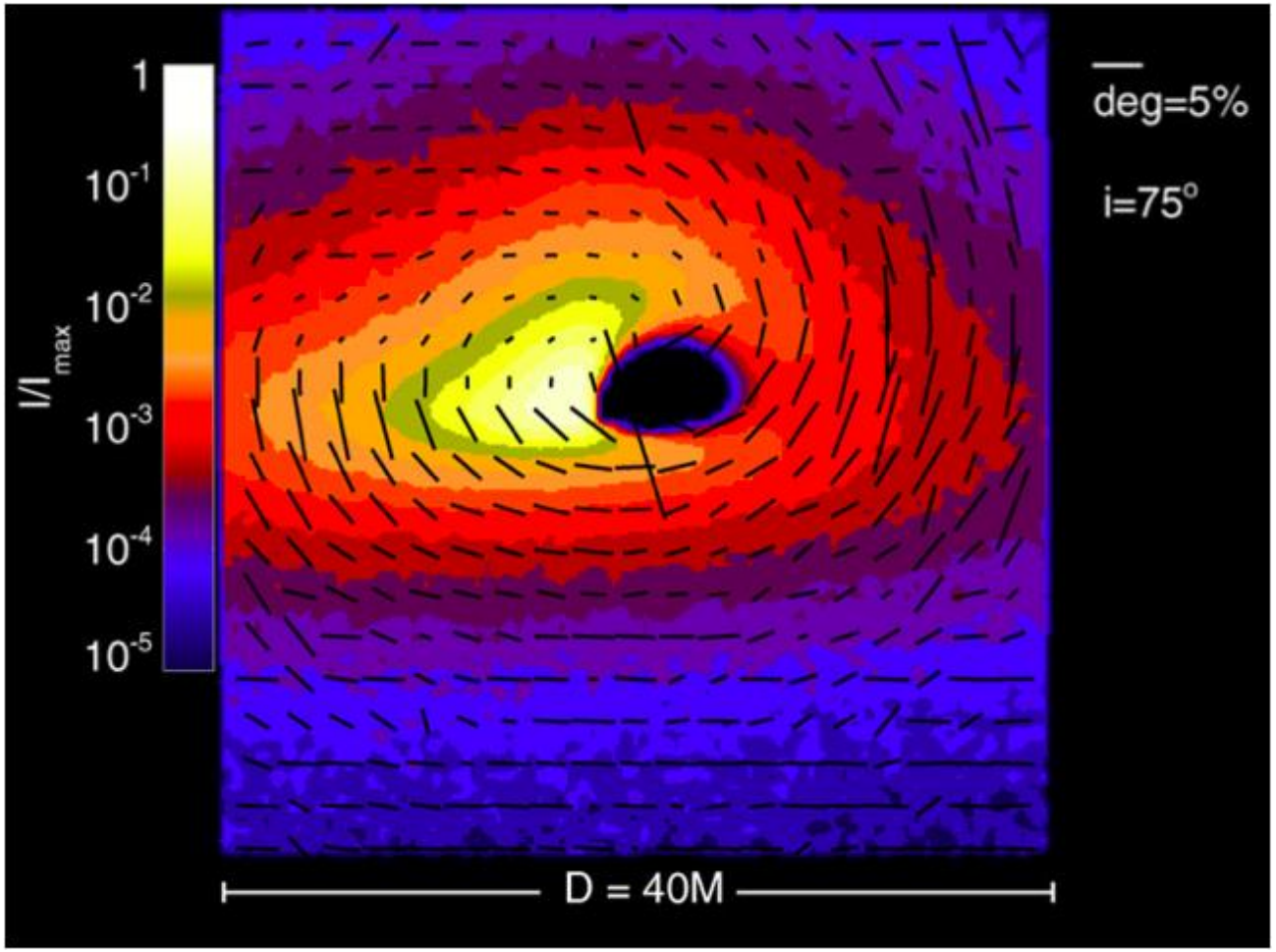
By giving a radius, lags also give an area: consistency check on continuum fitting method.





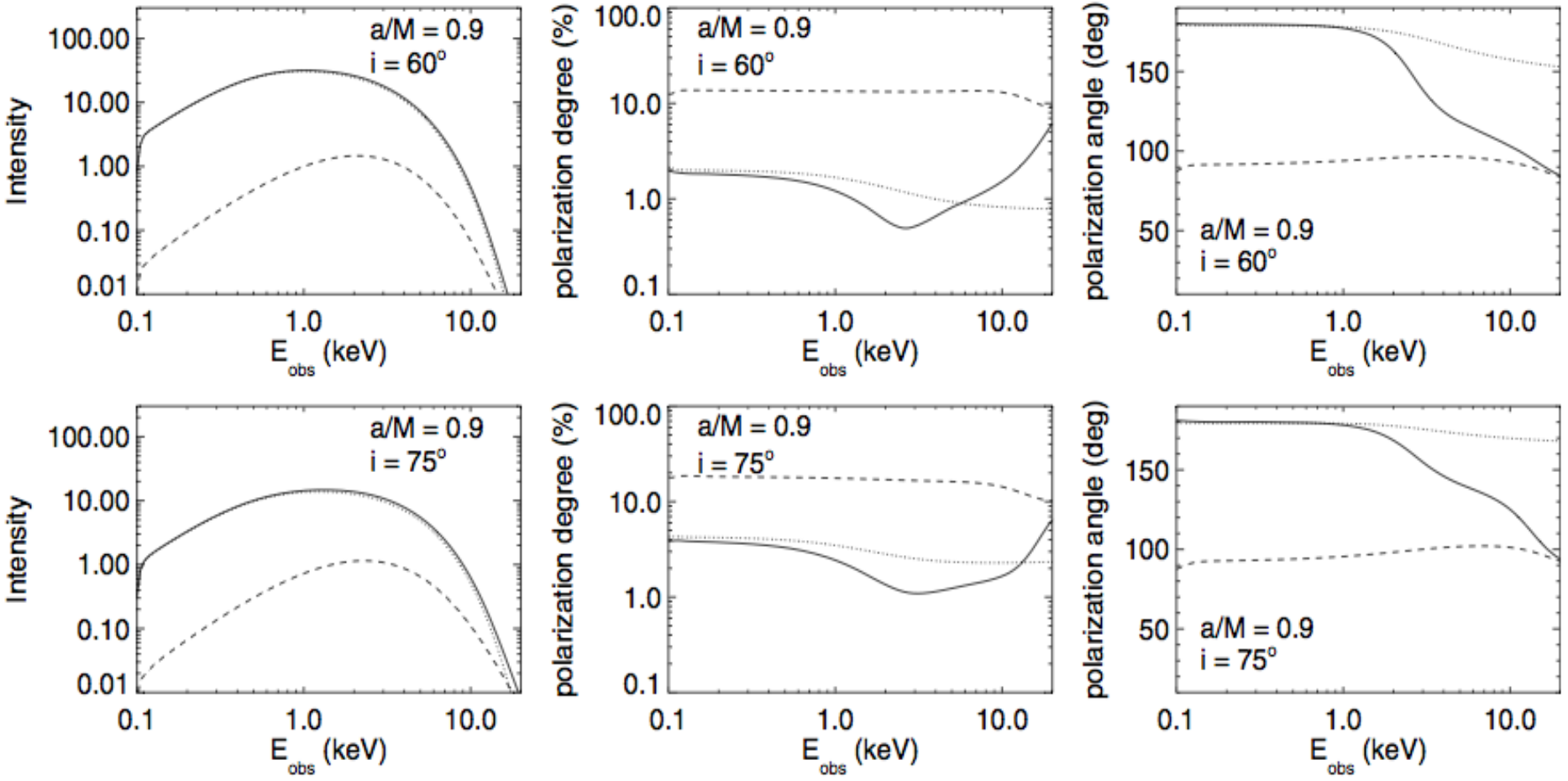
Reverberation mapping polarimetry

Returning radiation of disk photons bent back on to disk has significant impact on observed polarization signal: strongly dependent on black hole spin



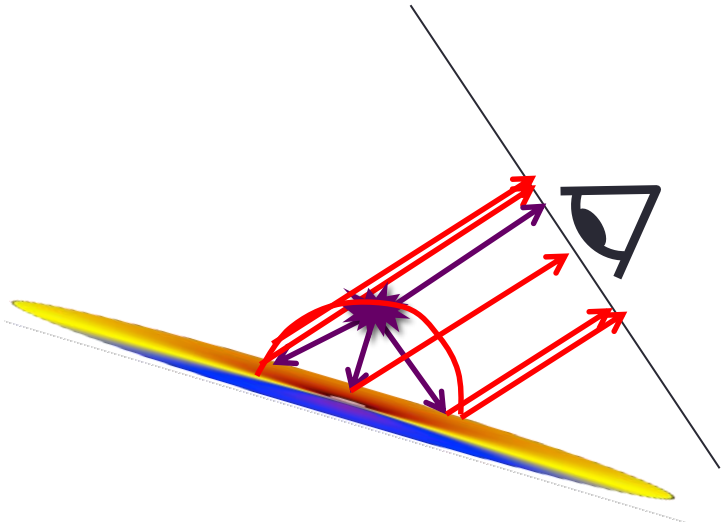
(Schnittman & Krolik 2009)

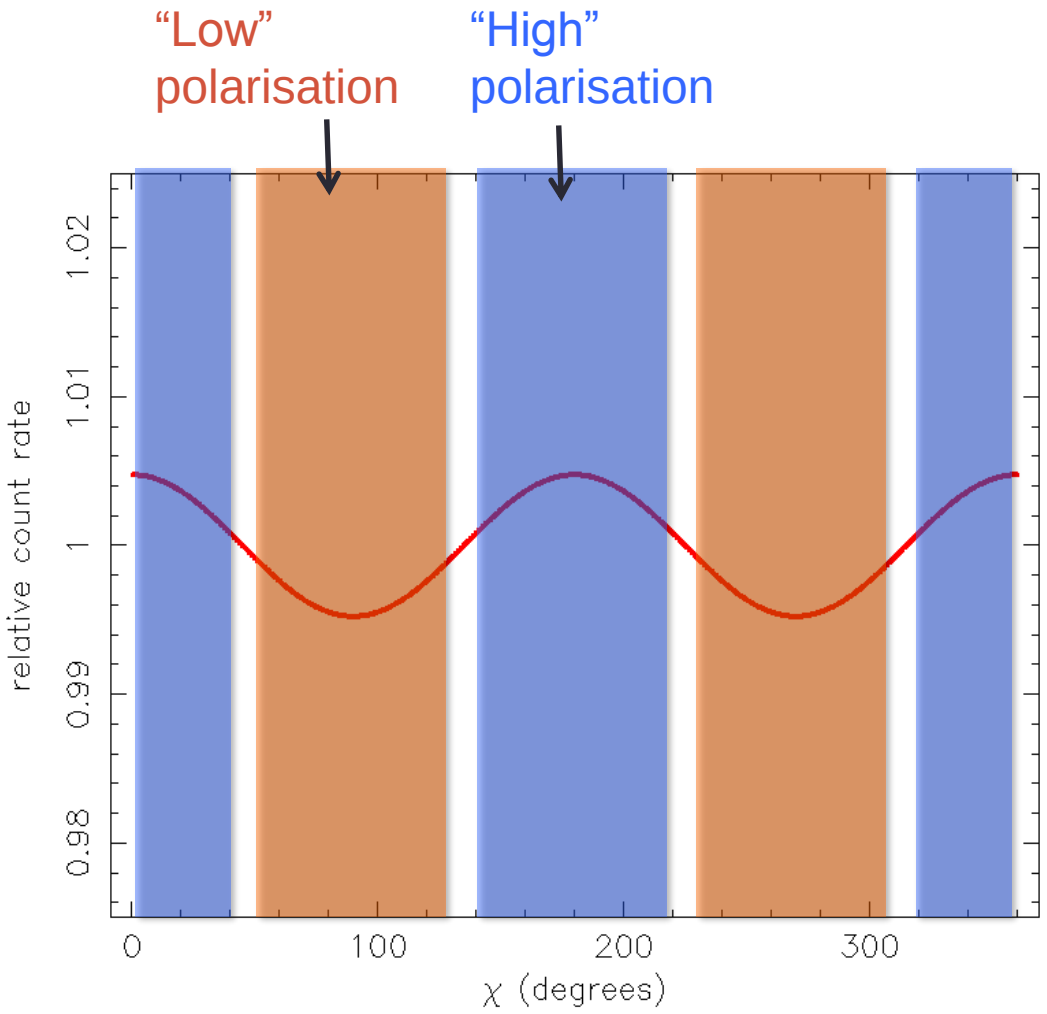
Reverberation mapping polarimetry



(Schnittman & Krolik 2009)

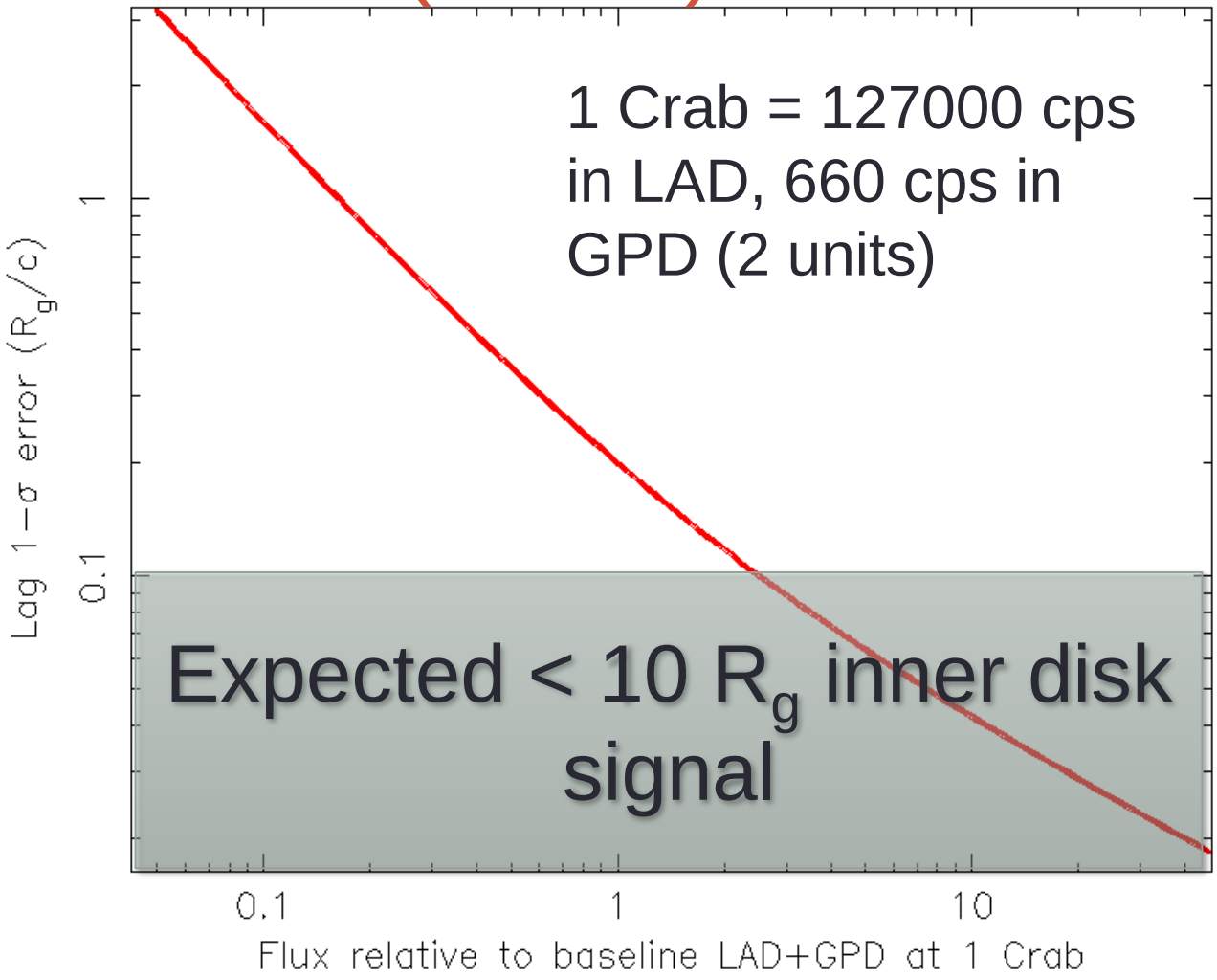
Reverberation signal





Light-travel times of order ~10 R_g/c but the changes in polarisation are tiny so observed delay between different 'bands' of detected angle is only ~0.1 R_g/c

eXTP sensitivity to polarisation lags from the inner disk (100 ks)



Summary and Outlook

- Inner disk reverberation signatures have been detected and are an active field of study in AGN (also TDEs!) and XRBs

- Sensitivity to reverberation signal increases linearly with count rate for XRBs: going to few m^2 area enables detailed study of the reverberation signal and hence accurate mapping of inner radius and strong gravity effects.

- Soft eXTP response from SFA also enables reverberation mapping of disk thermal emission to large radii

- eXTP opens up new field of timing-polarimetry, allowing new independent tests of the disk reverberation signal.