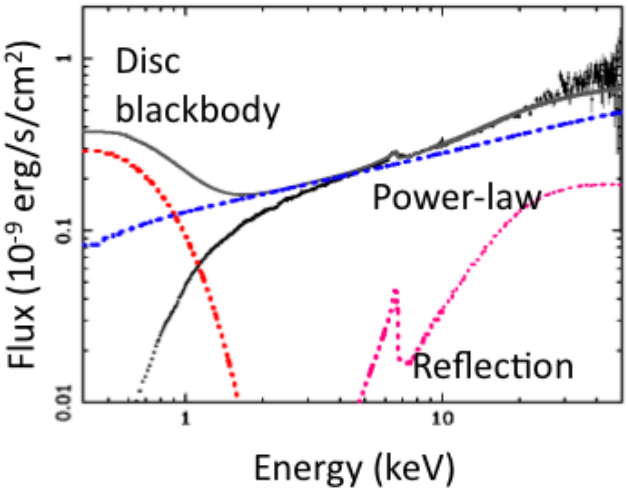
Mapping the extreme: X-ray reverberation in X-ray binaries and AGN

Phil Uttley

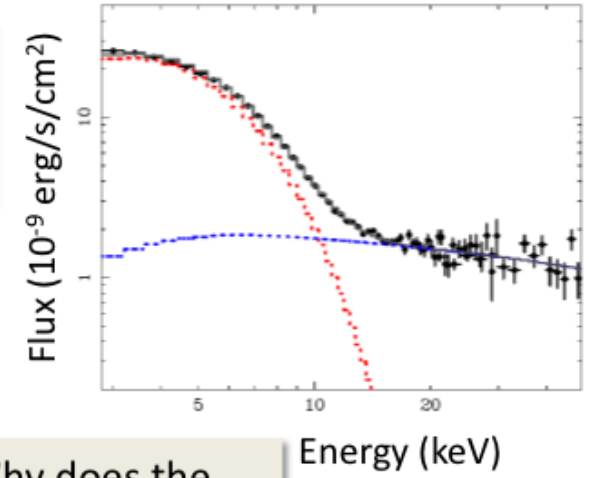
University of Amsterdam

The innermost ~100 R_g

Hard State



Soft State



What produces the jet?

?

Why does the jet switch off?

sub-nanoarcsecond scales!

What produces the variability?

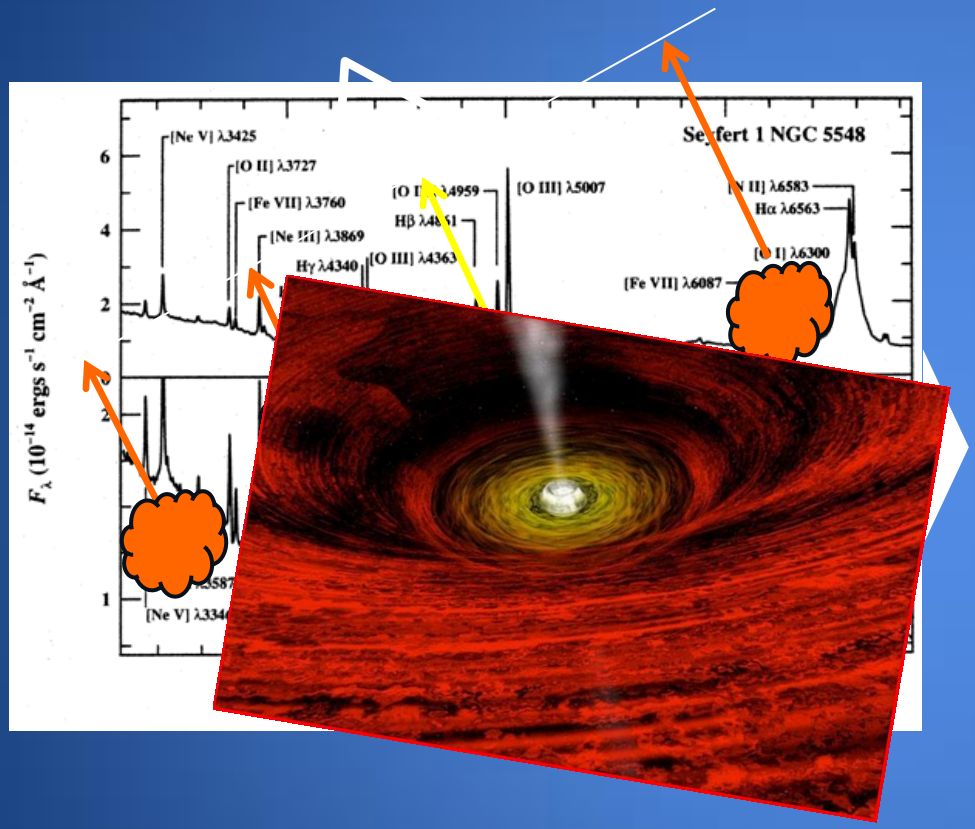
Where does the **power-law** come from? Corona above the disc? Inner hot flow? Jet?

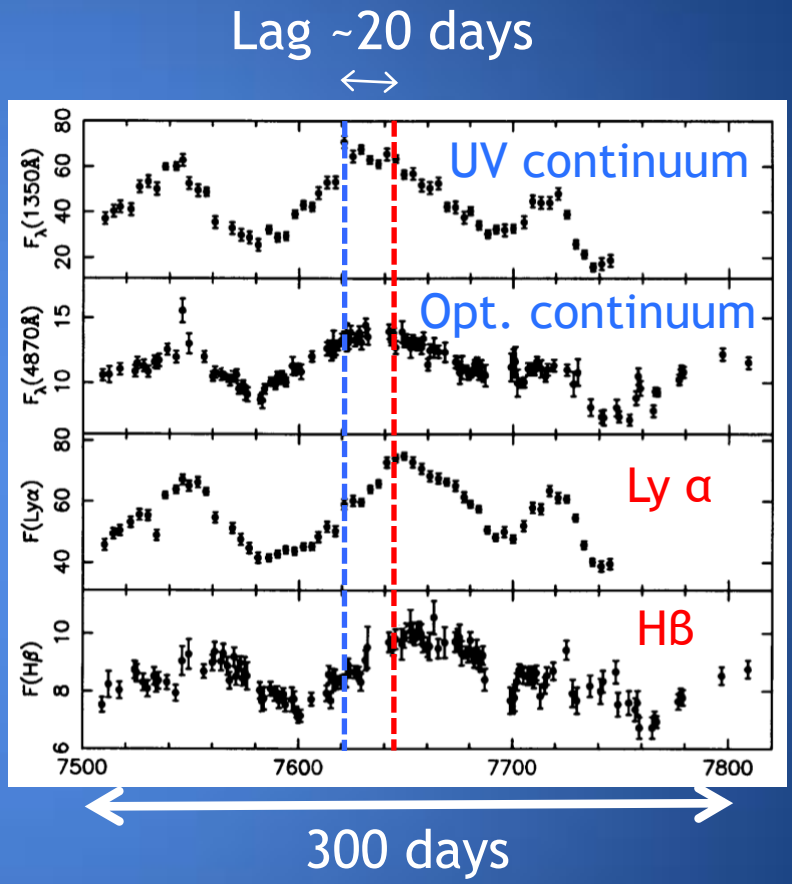
Does the **disc** extend all the way down to the ISCO?

Key themes

1. “Physical” models for spectral components (e.g. diskbb, reflection) assume spatial/dynamical information: link to timing
2. Even if we don’t understand precise origin of variability (e.g. is it ‘just weather’?), we can use it to map emitting regions through their response to it (c.f. helioseismology)
3. High throughput and at least moderate spectral resolution is crucial (not limited by telemetry)

Reverberation mapping

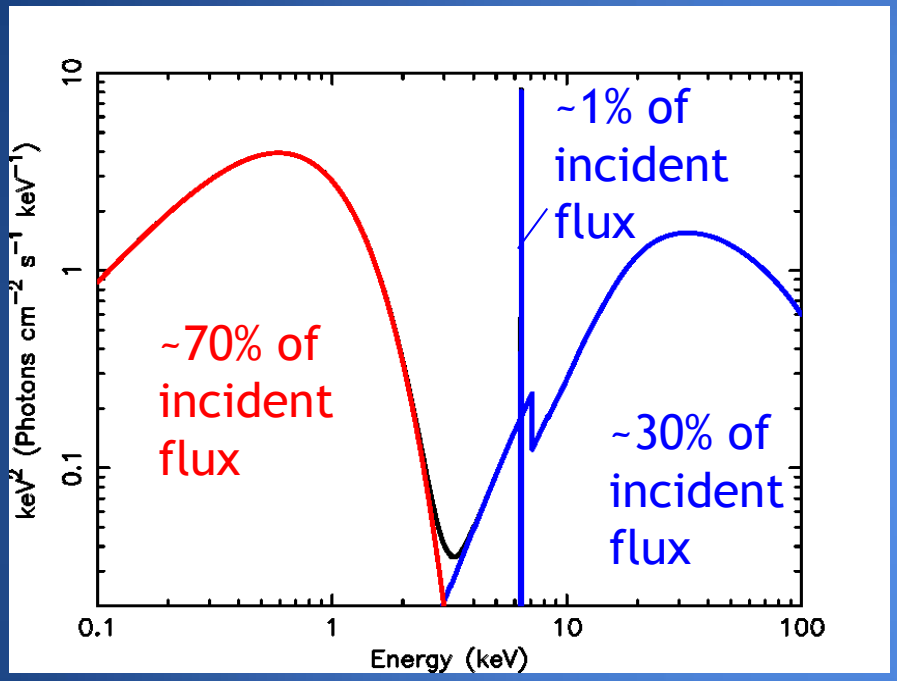




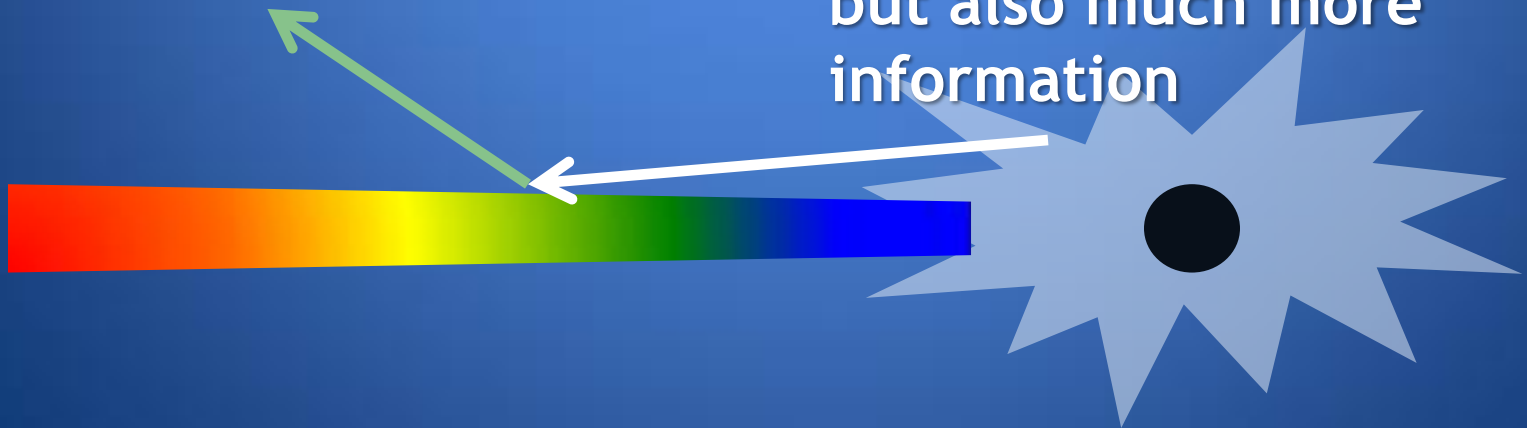
Optical time lags in AGN can be used to map scales of light-days

X-rays can map <light-mins in AGN, and <light-ms in XRBs!

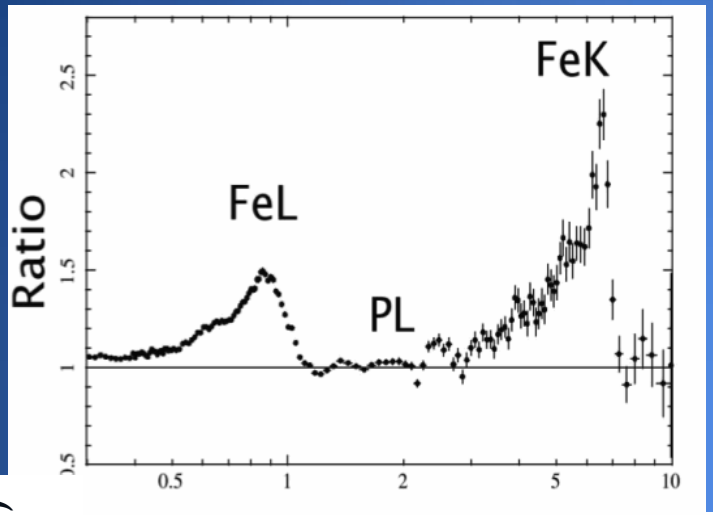
Inner disc X-ray reverberation

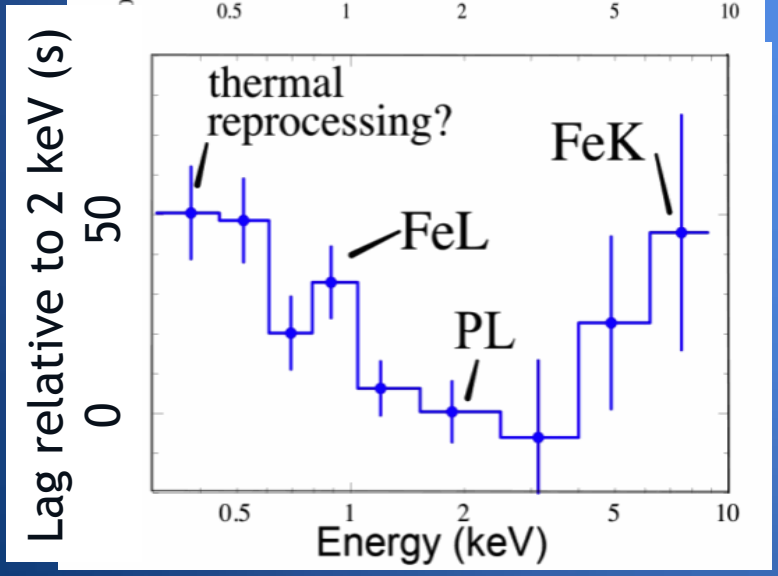


- ✧X-rays from the continuum source (corona, NS boundary layer) are reprocessed/reflected by the disc
- ✧Very small scales: 10 s to 1 ks lags in AGN, <ms in XRBs - but more variability in X-rays
- ✧ Complex emitting regions - but also much more information



Disc reverberation evidence: The AGN 1H 0707-495





(Fabian et al. 2009, Zoghbi et al. 2010, 2011)

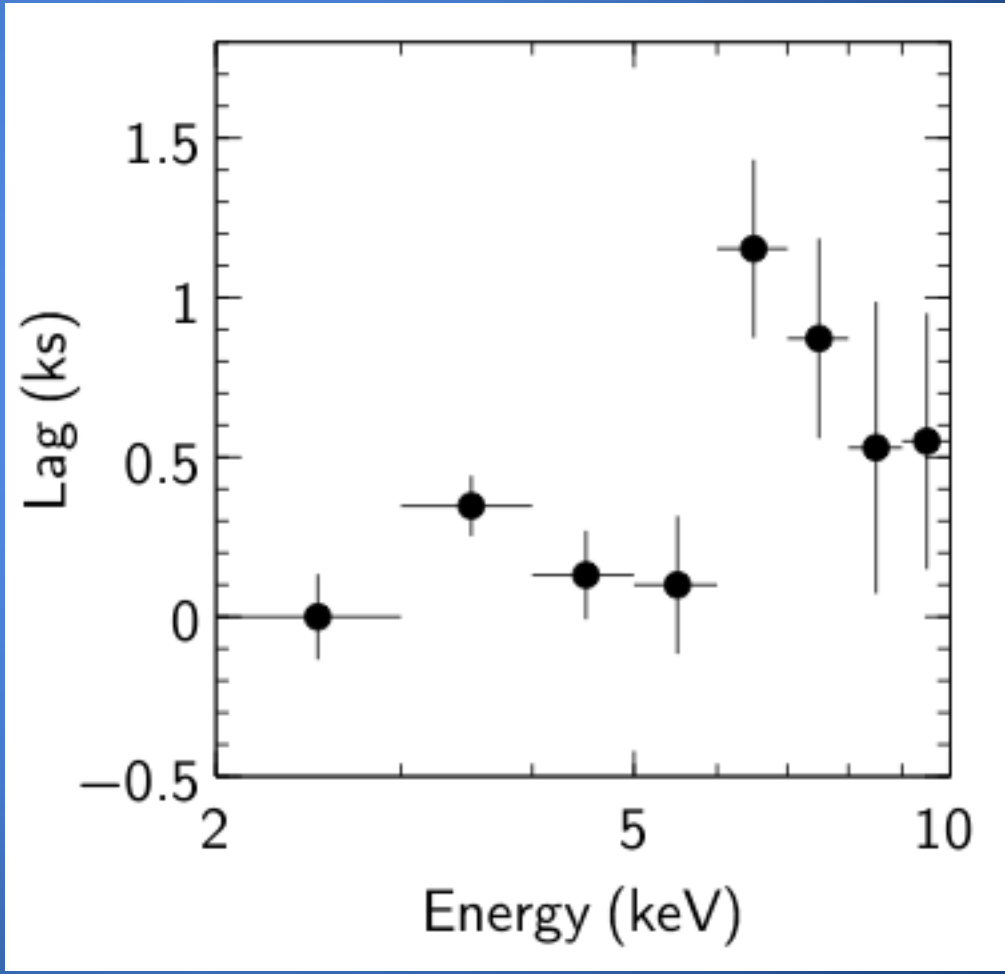
The observed lags imply R_{in} ~ few R_G

Similar small soft X-ray lags now seen in many other AGN

(E.g. Emmanoulopoulos et al. 2011, de Marco et al. 2011, 2013, Zoghbi et al. 2011, Kara et al. 2013)

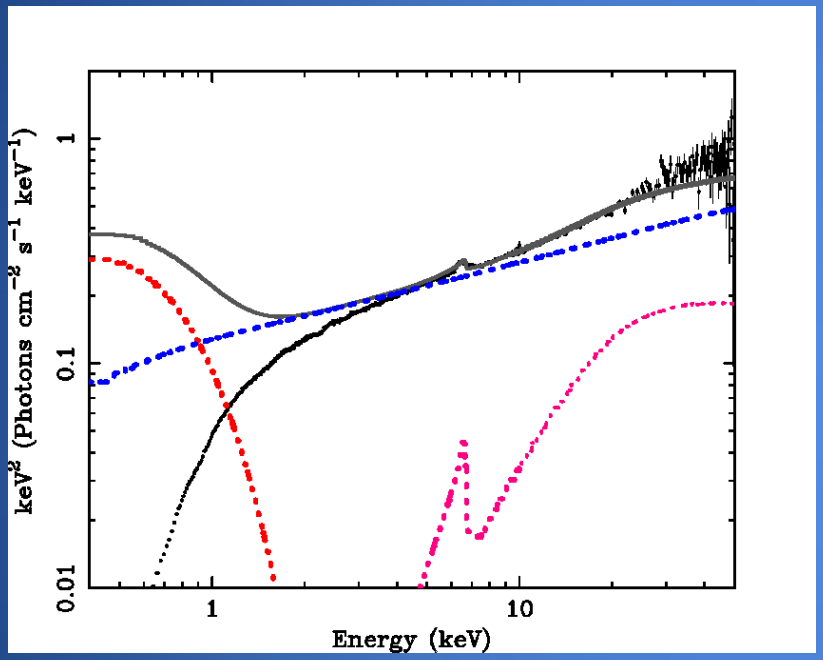
Fe K reverberation

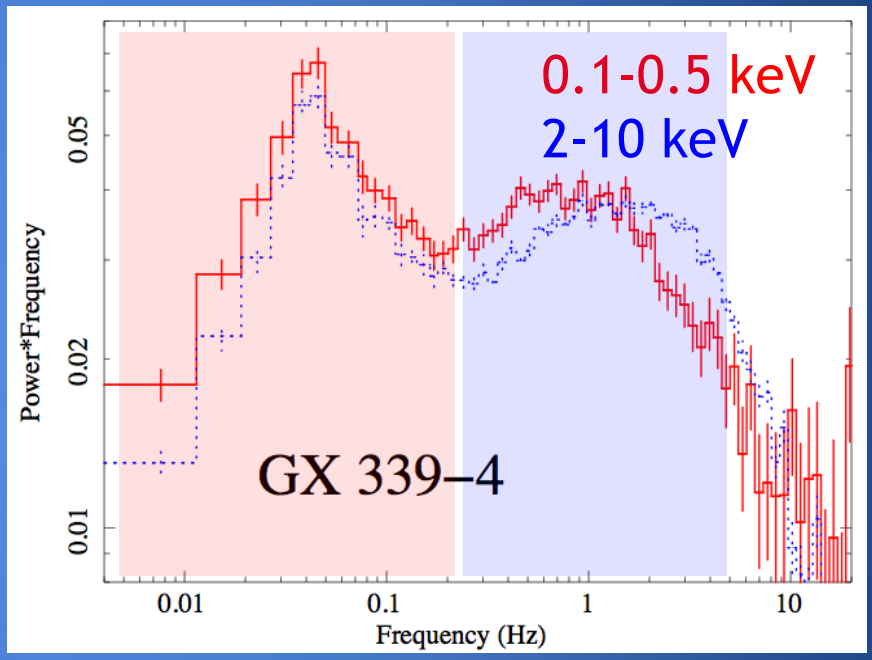
Seyfert galaxy NGC 7314 (Zoghbi et al. 2013)



XMM-Newton observations of a black hole ‘hard state’

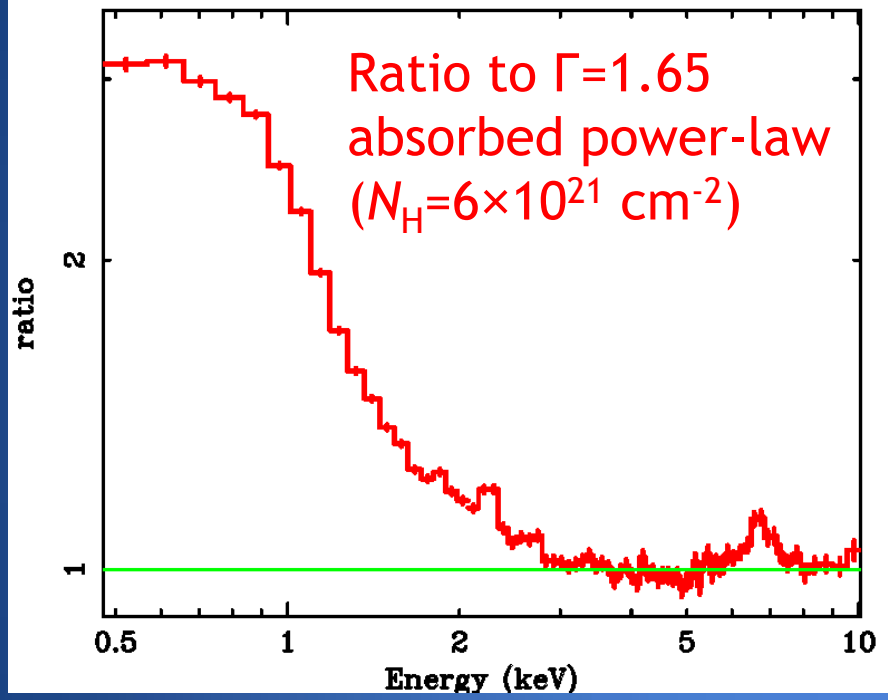
(Wilkinson & Uttley 2009)

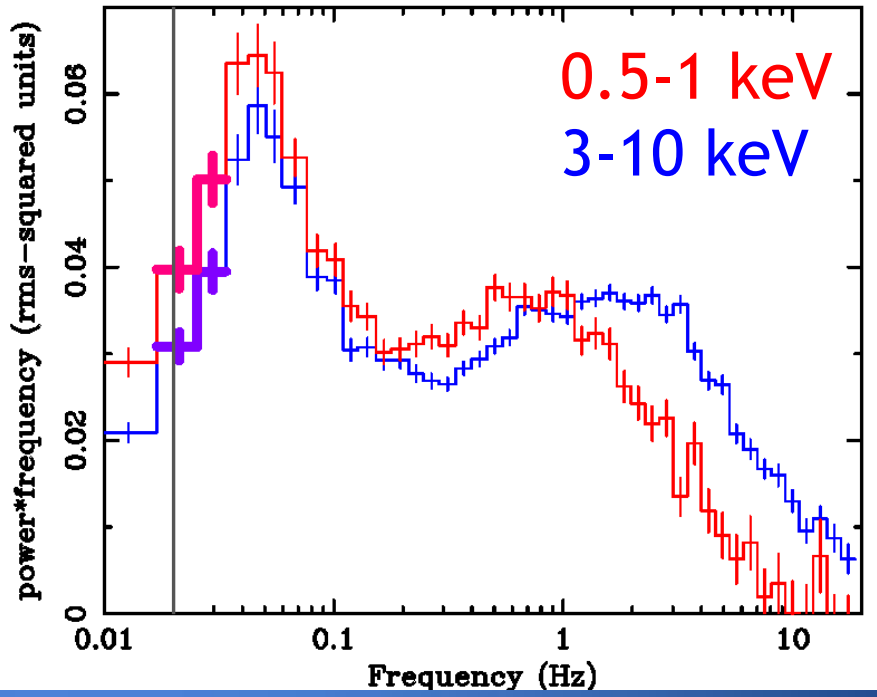




- Use EPIC-pn from 2004 long-look at GX 339-4
- Typical hard state spectrum and PSD

‘Fourier-resolved’ spectra

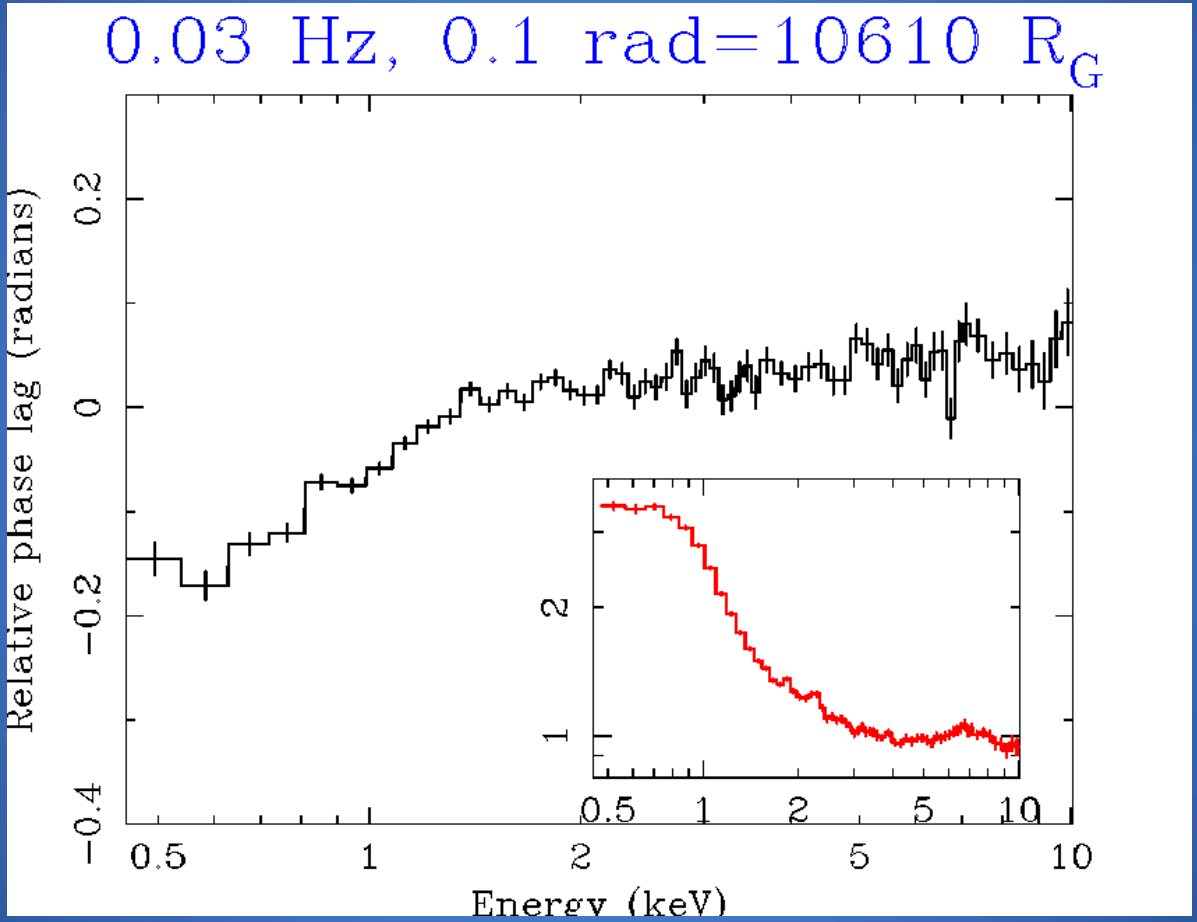




The amplitude of variable disc emission is strongly frequency-dependent

GX 339-4 hard state: the causal connection between disc and power-law

Uttley et al. 2011

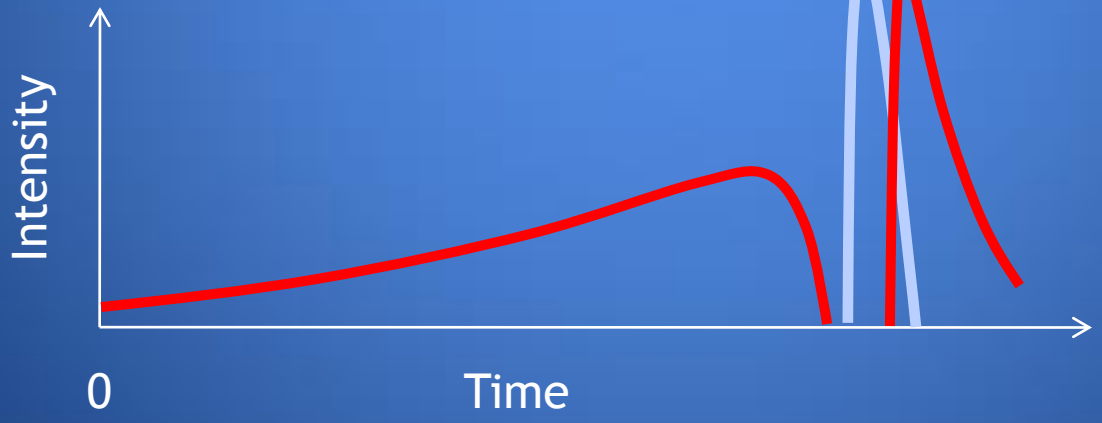


The disc drives the variability!

Modelling disc driven variability + reverberation

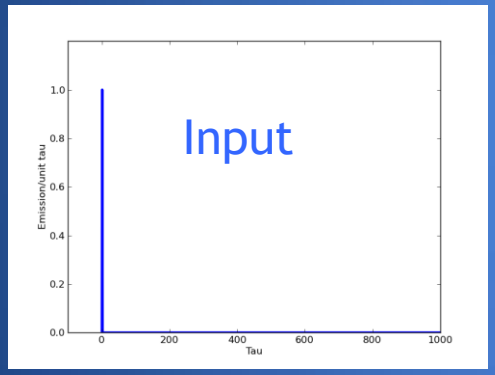
mdot fluctuation –
observed time-scales
imply origin within 20 R_G

Impulse Response Function:

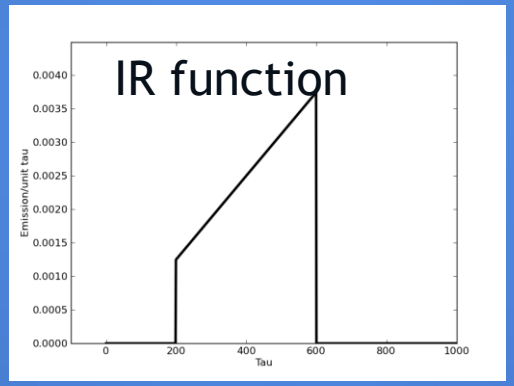


The ‘impulse response function’

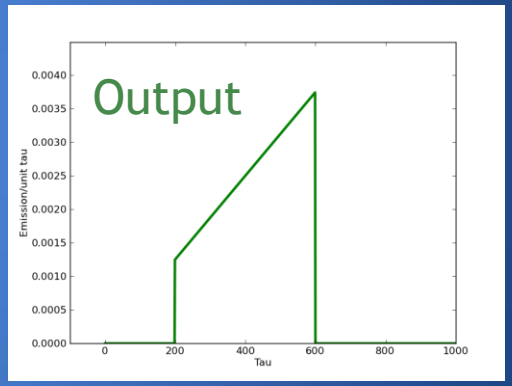
The variable input signal is ***convolved*** with an ‘impulse response function’ (the response of the emitting region to a delta-function input signal)



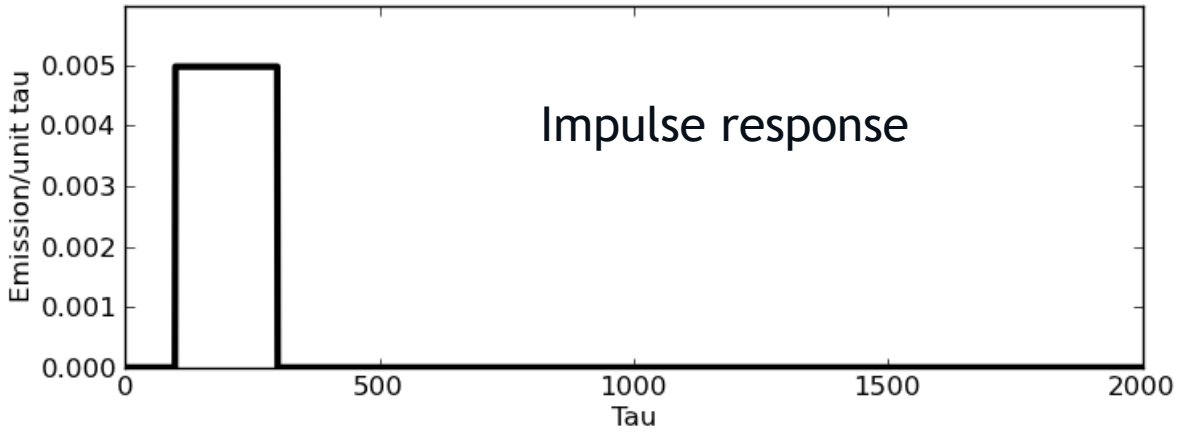
*

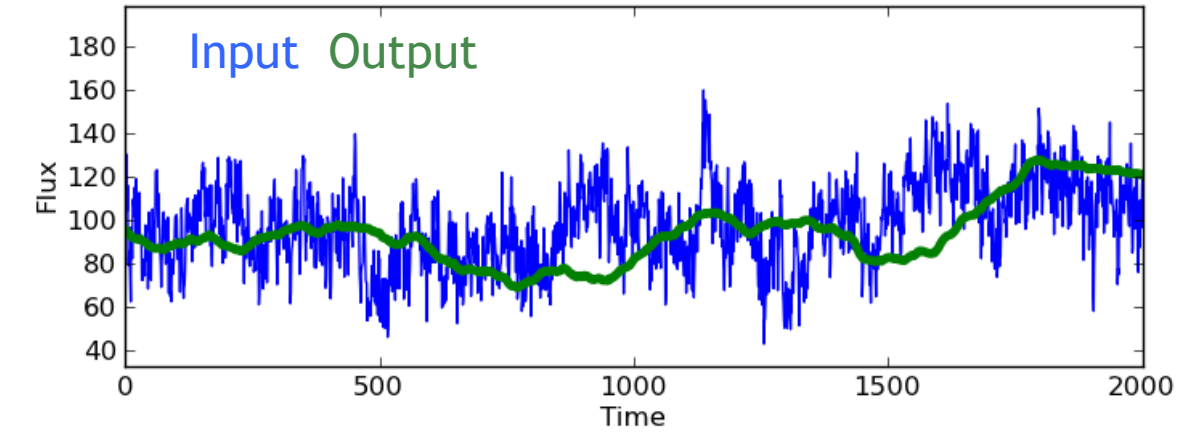


=

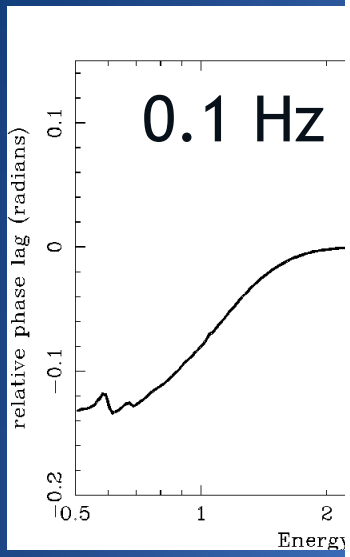


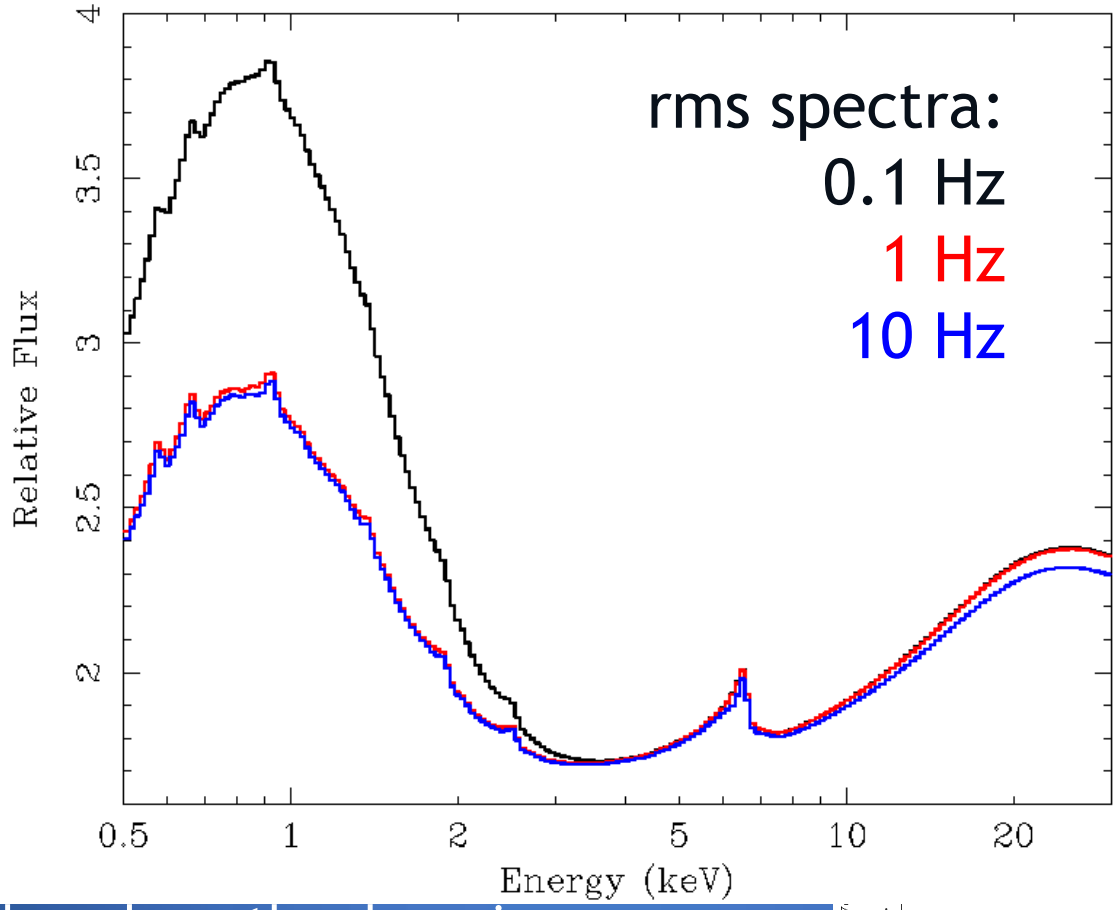
Impulse response function example: A tophat function

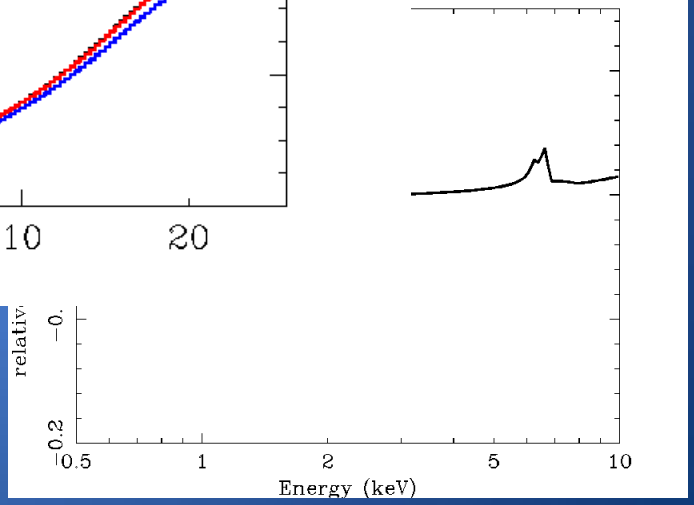




A viscous propagation model

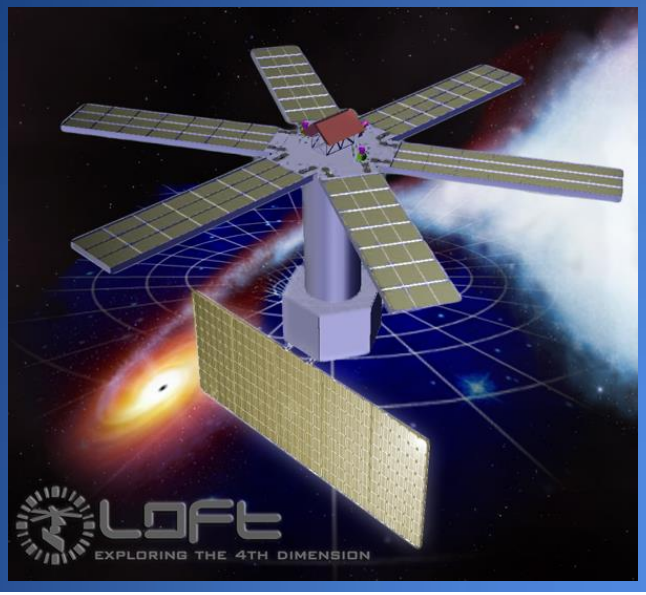


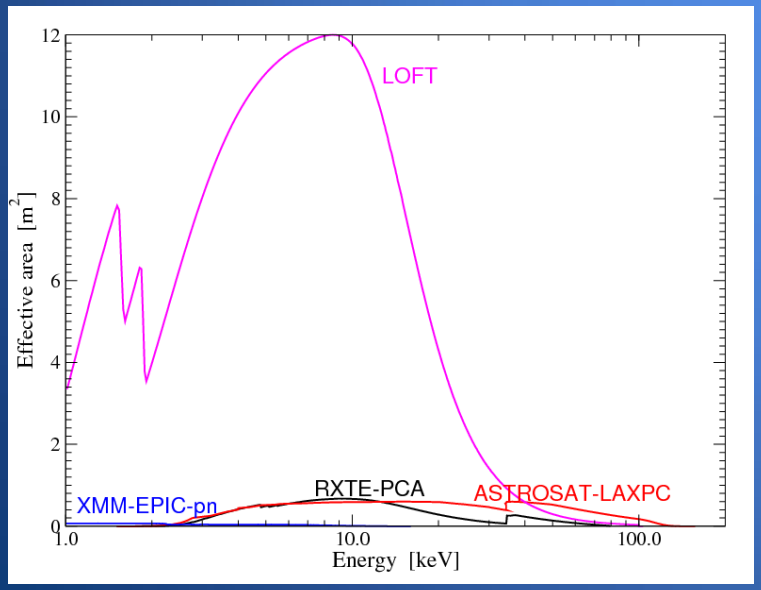


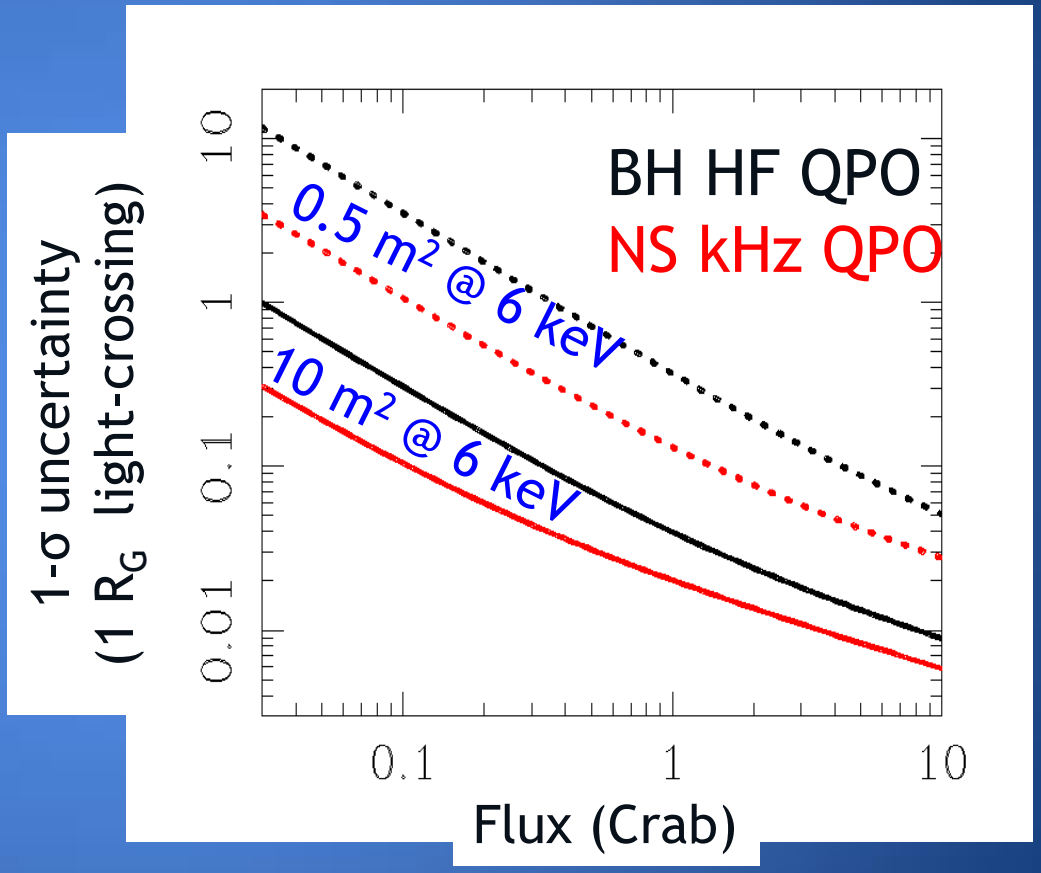


Reverber
time-scales where the slow viscous time-scale variations of the disc are washed out

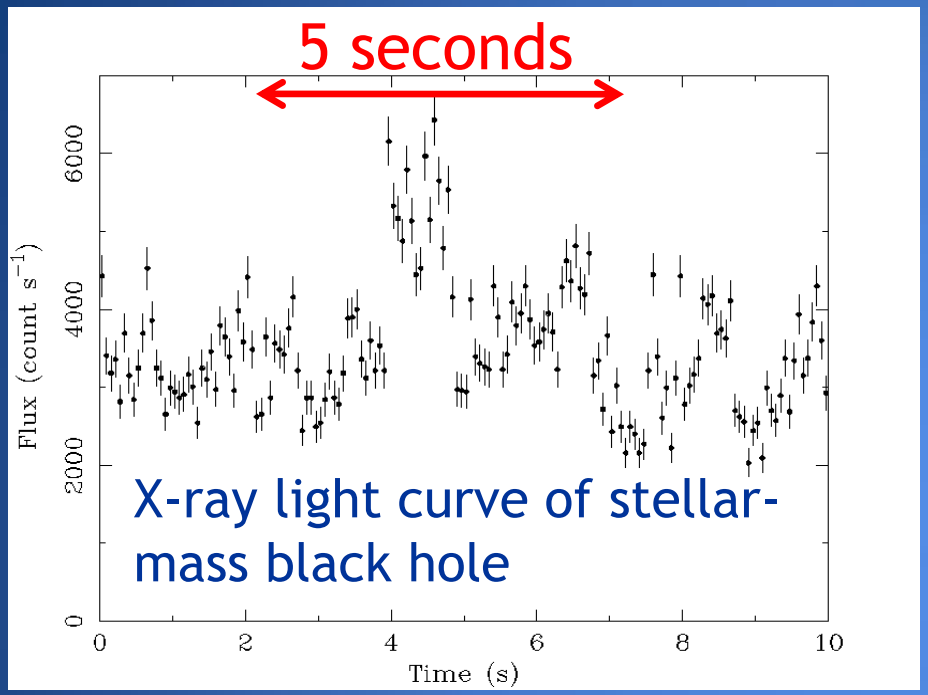
The view from the LOFT

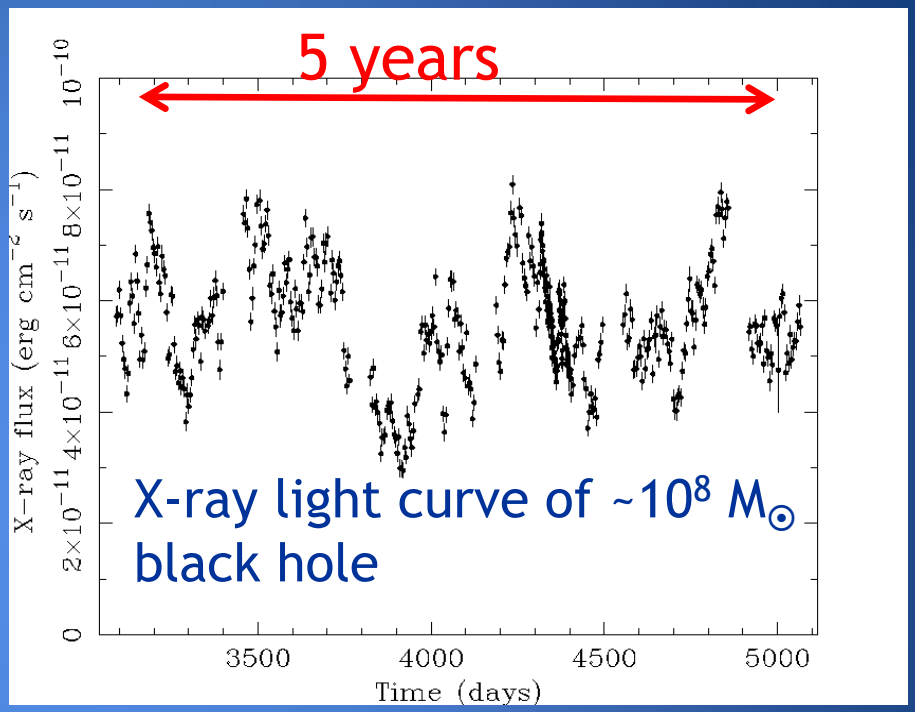






X-ray variability: XRB-AGN comparison

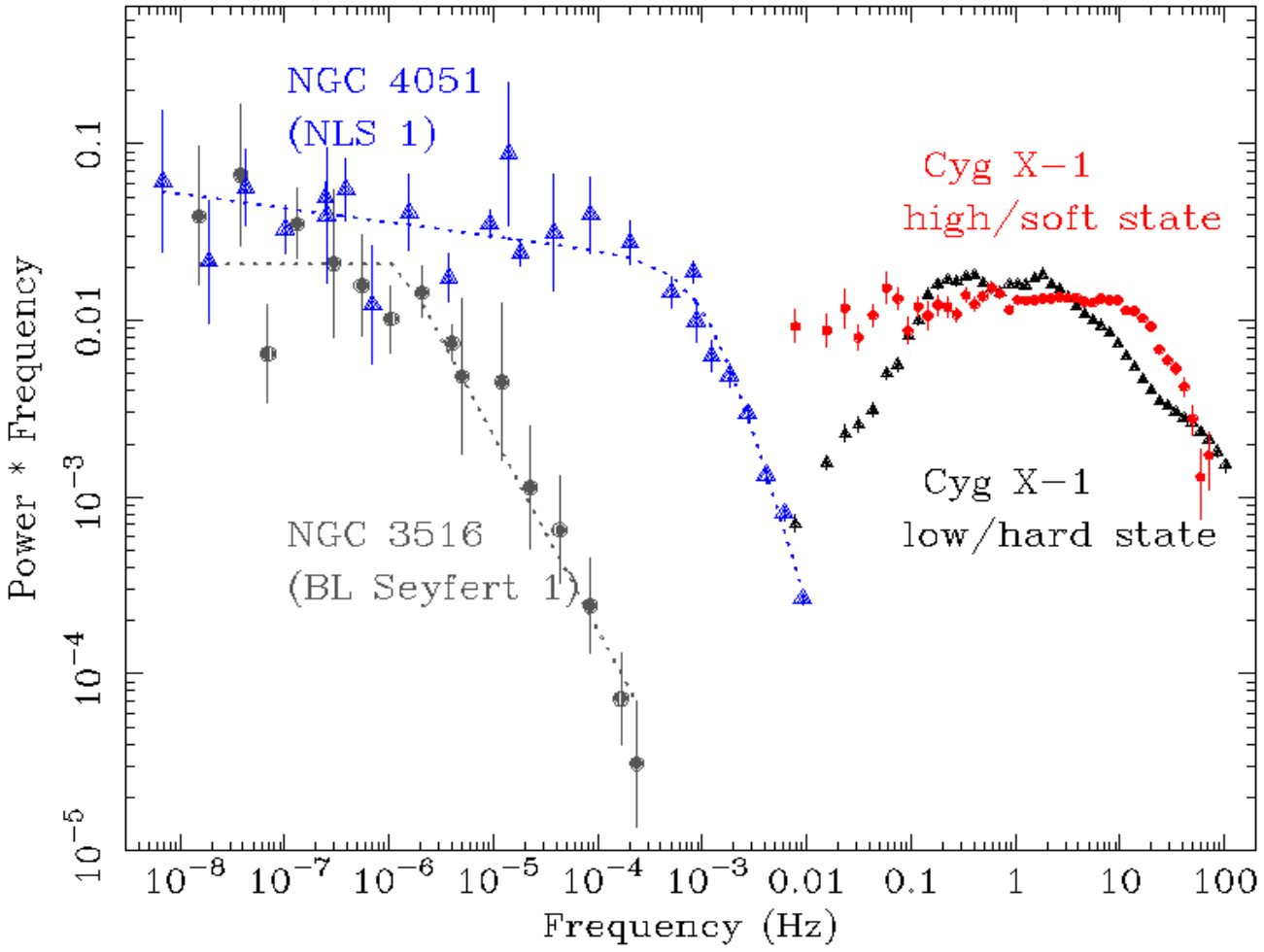




Time-scales scale linearly with BH mass (e.g. Uttley et al. 2002, McHardy et al. 2006, Körding et al. 2007)

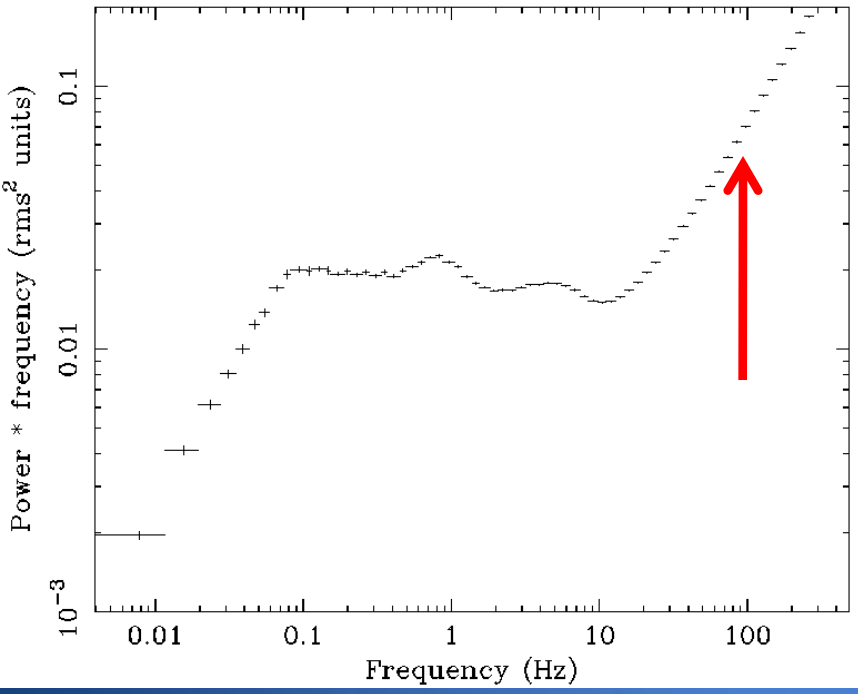
Scaling variability by mass

Uttley et al. 2002

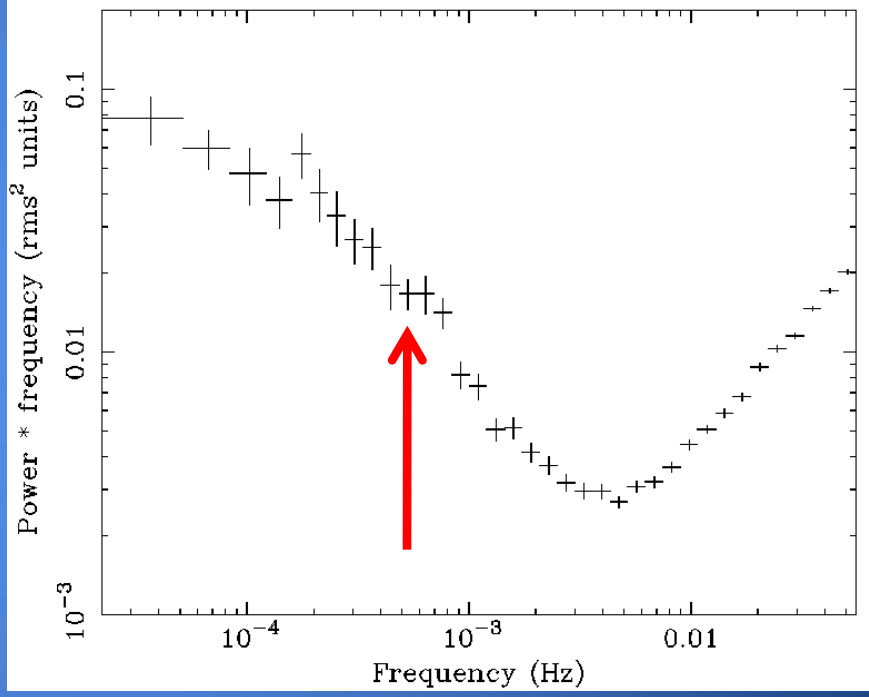


Signal-to-noise: 2 regimes

BHXRB: Cyg X-1



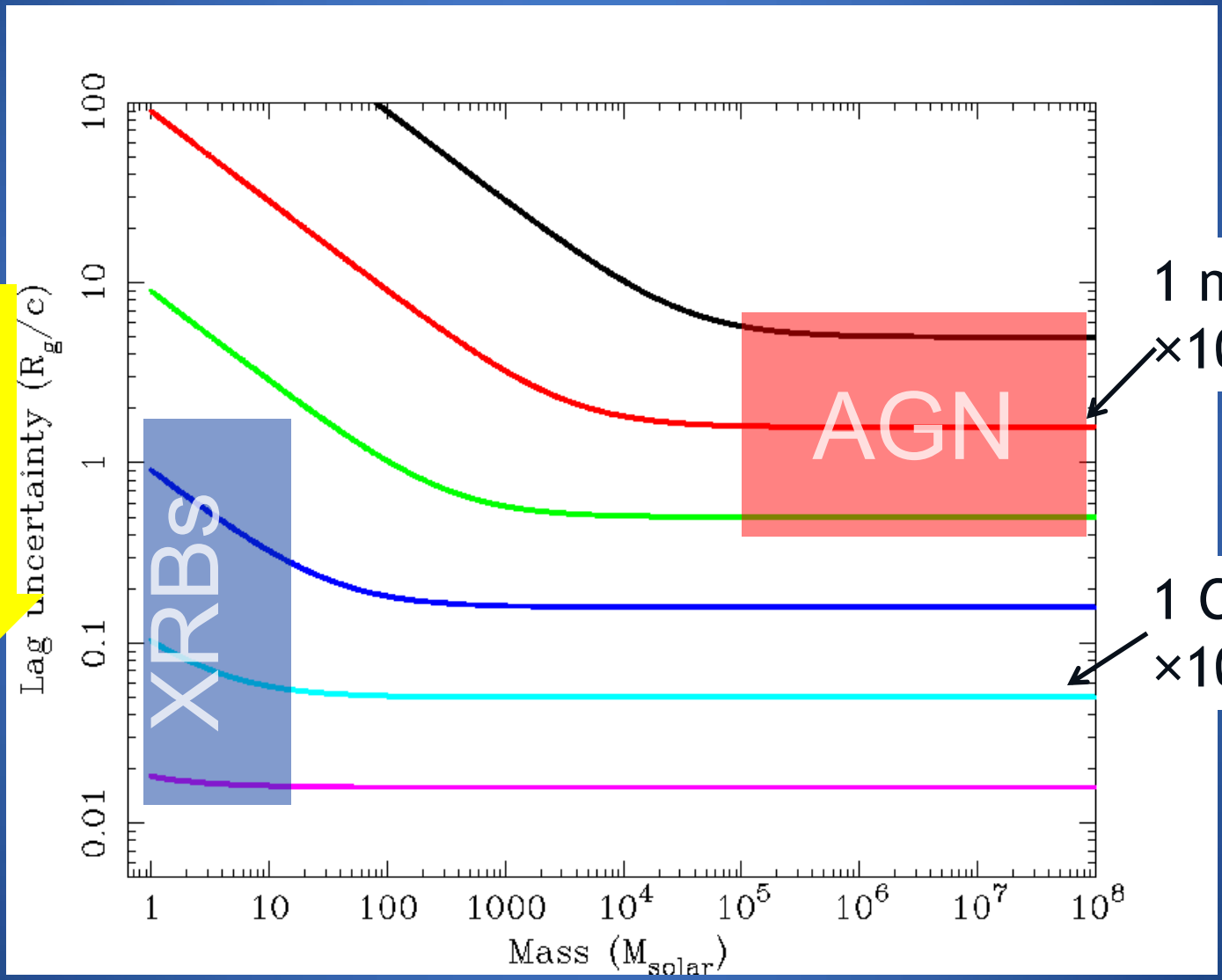
AGN: NGC 4051



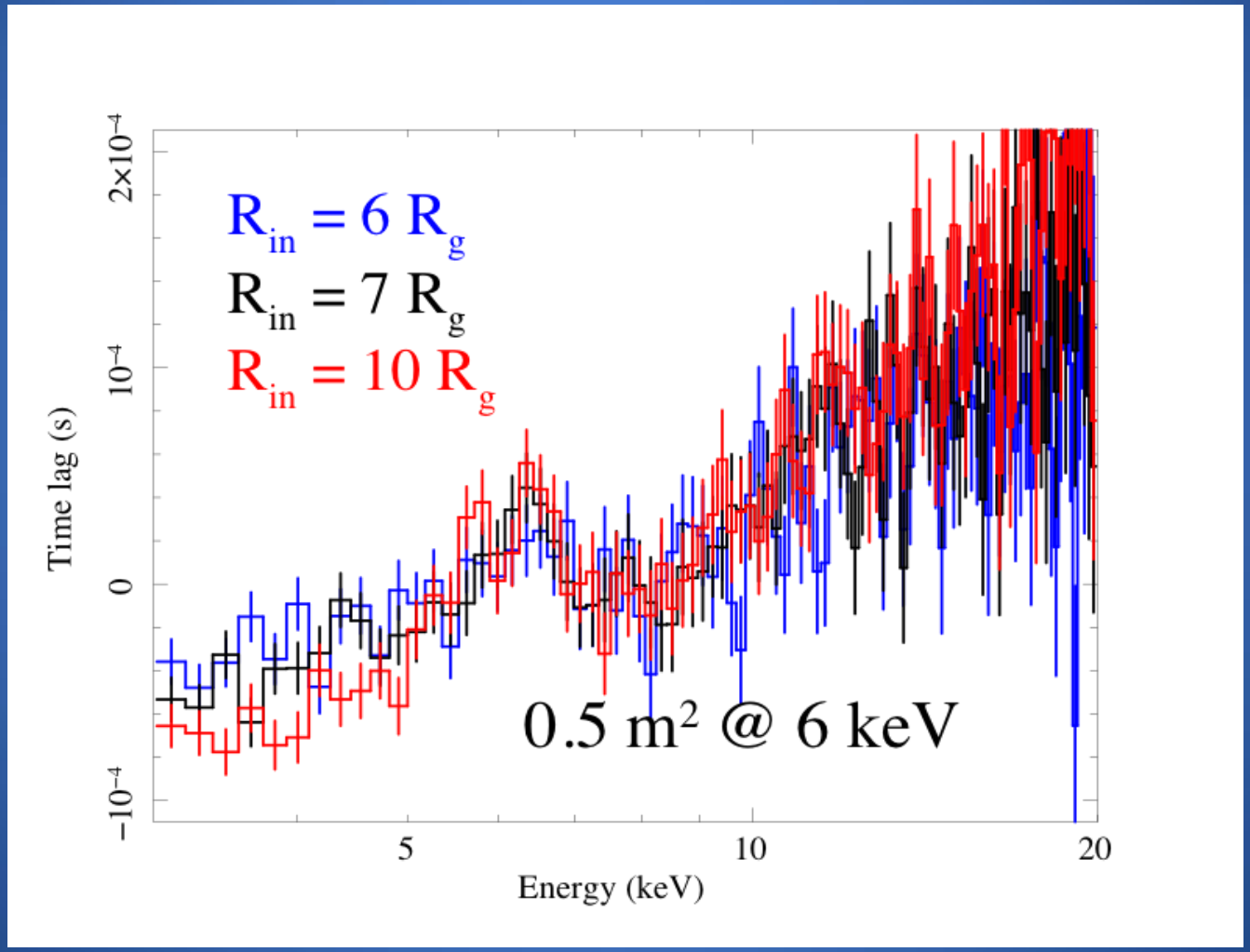
Same ‘mass-scaled’ frequency: in AGN intrinsic noise variability signal dominates errors, in BHXRBs Poisson noise level dominates

Lag sensitivity 6.22-6.4 keV @ 1000/M Hz: 'typical' broadband noise PSD, 100 ks exposure

Increasing Flux or Area



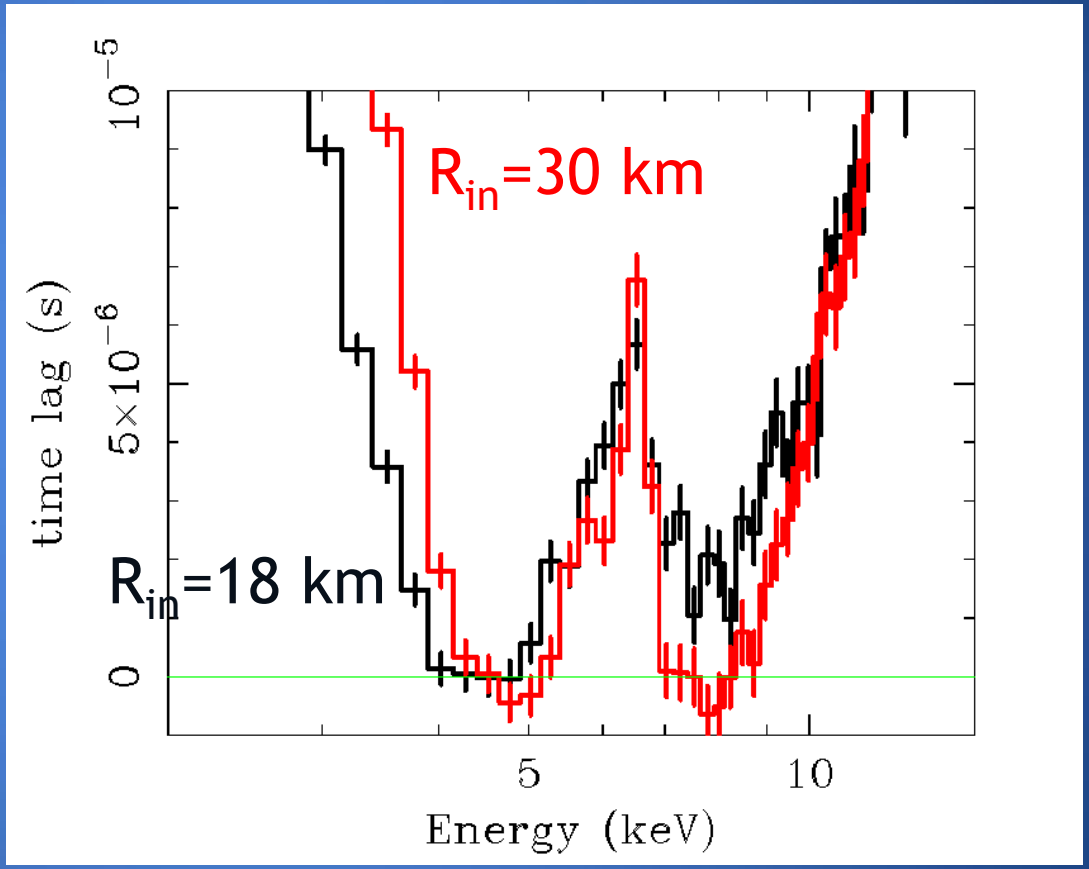
BHXRB reverberation lags example: 100 ksec, 1 Crab, 60-200 Hz



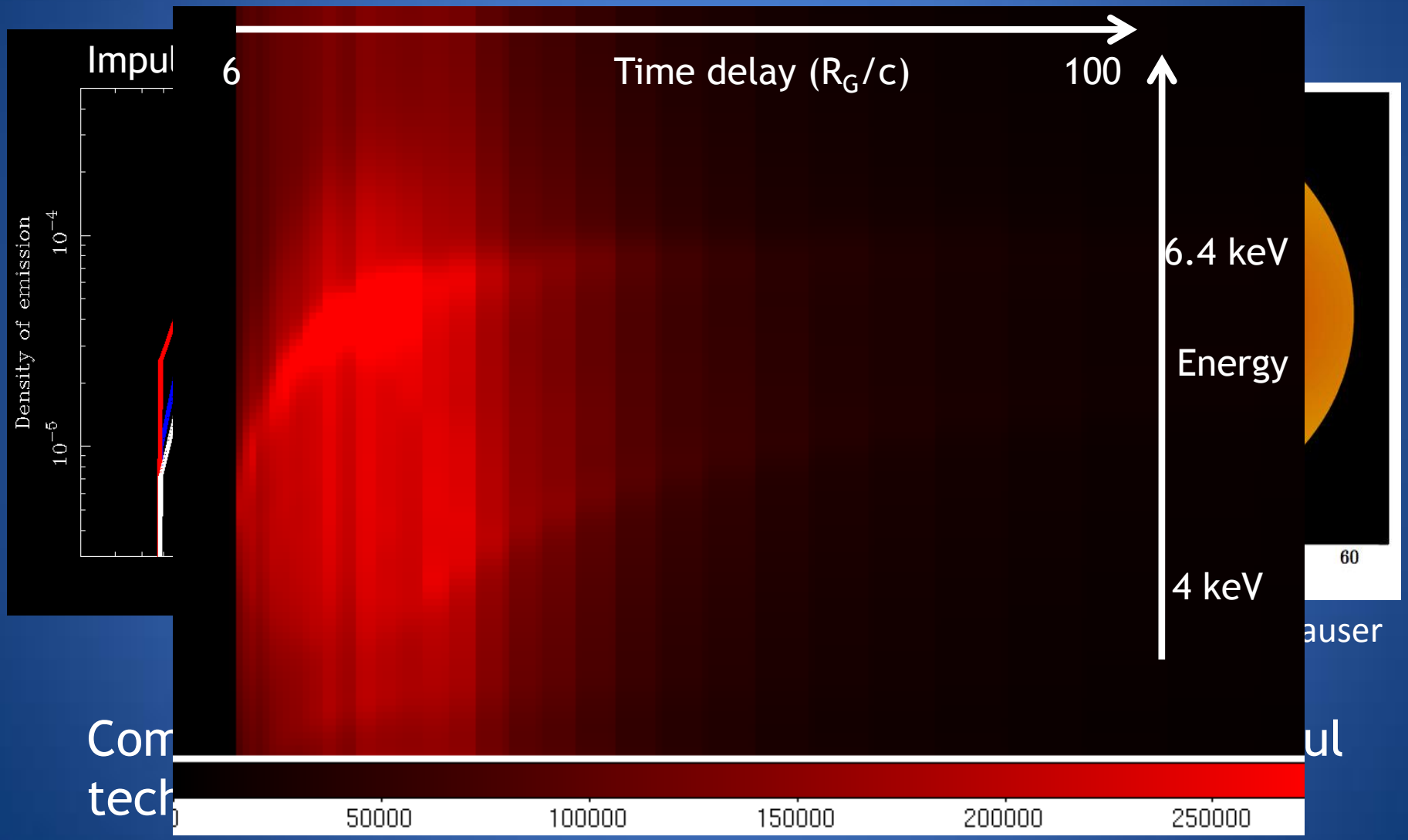
LOFT example:
10 ksec, 0.4 Crab, NS 900 Hz QPO (10% rms)

Precision to see detailed reverberation features not reachable with RXTE data

In principle with LOFT we can measure lag vs. line width as in AGN optical reverberation mapping, to get an **independent estimate of NS mass**



Fe K line: relativistic reverberation mapping



auser

Com
tech
ul