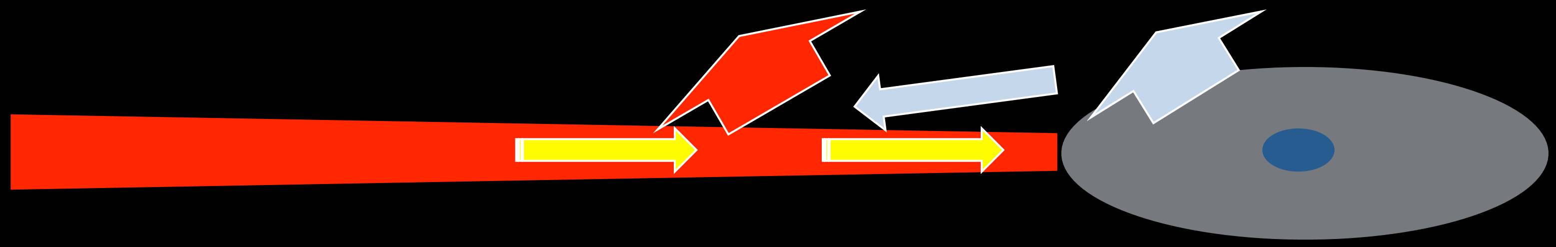
Time lags and reflection in black hole X-ray binaries

Pablo Cassatella
University of Southampton

Phil Uttley, Jörn Wilms, Juri Poutanen

Variability in the hard state



Disc may be truncated

Soft, disc blackbody emission variable on τ > 1s

→drives hard, coronal variability

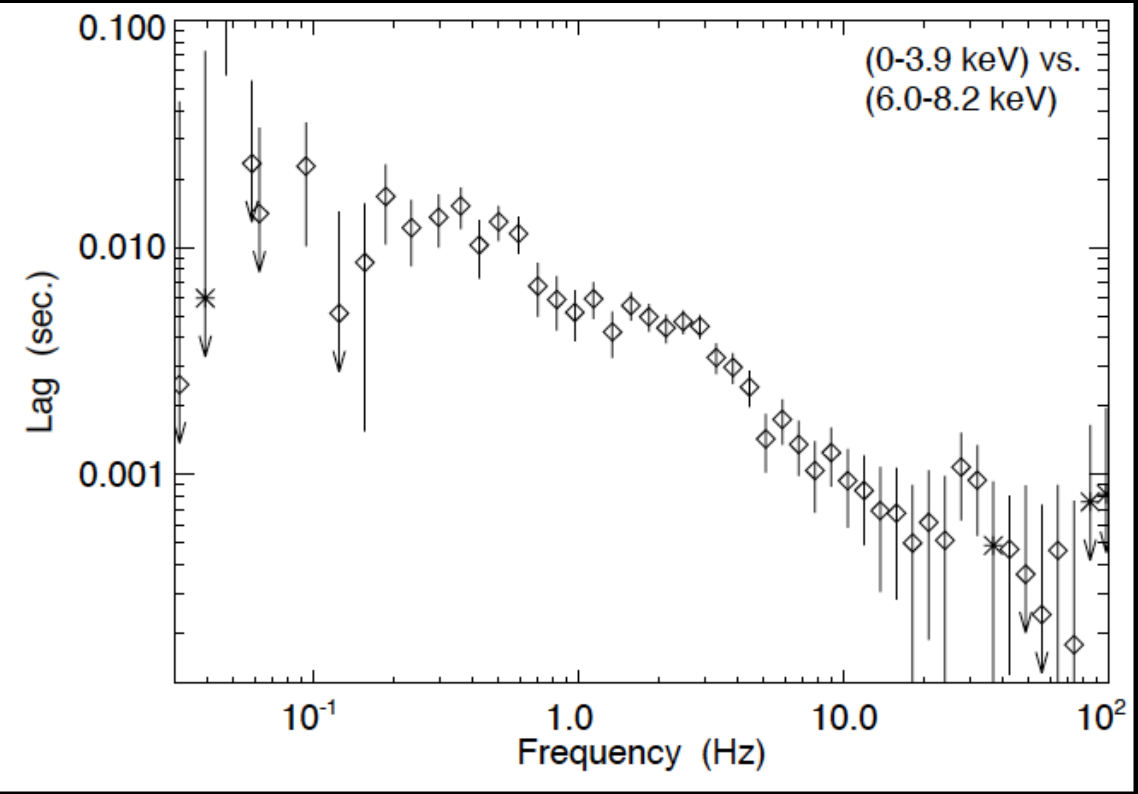
→ heating of the disc and reflection spectrum

(see Uttley's talk)

Time lags

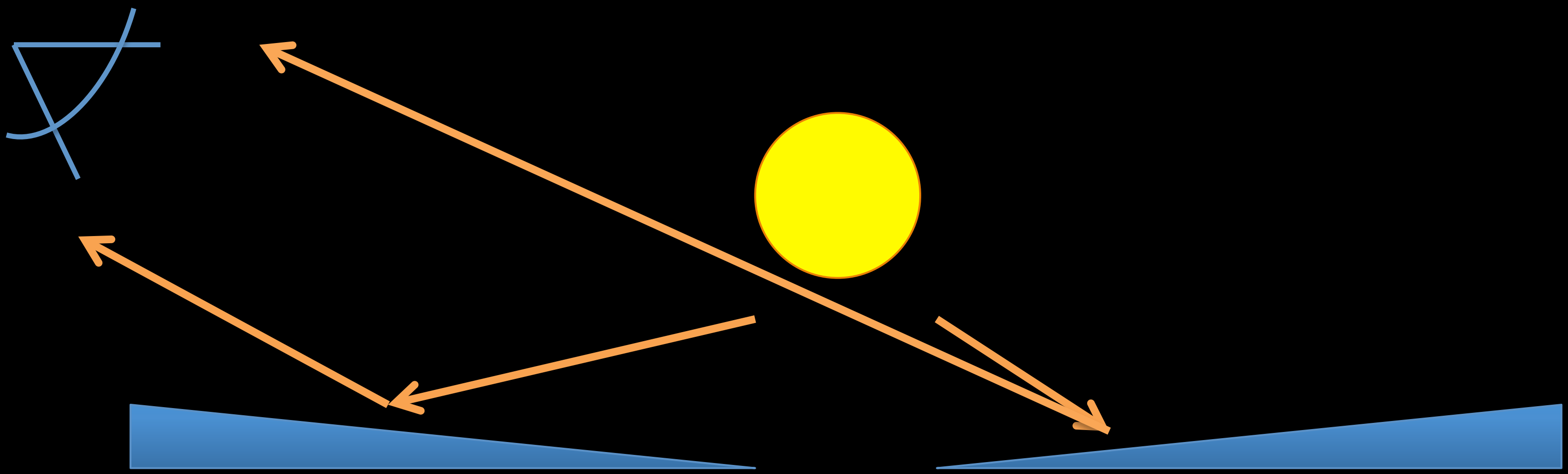
S(t), H(t) → FT → S(ν), H(ν) → C(ν)=S(ν)* H(ν) → Phase lag: Φ(ν)=arg[C(ν)] → Time lag: τ(ν)=ϕ(ν)/(2πν)

$$\tau \propto \nu^{-0.7}$$



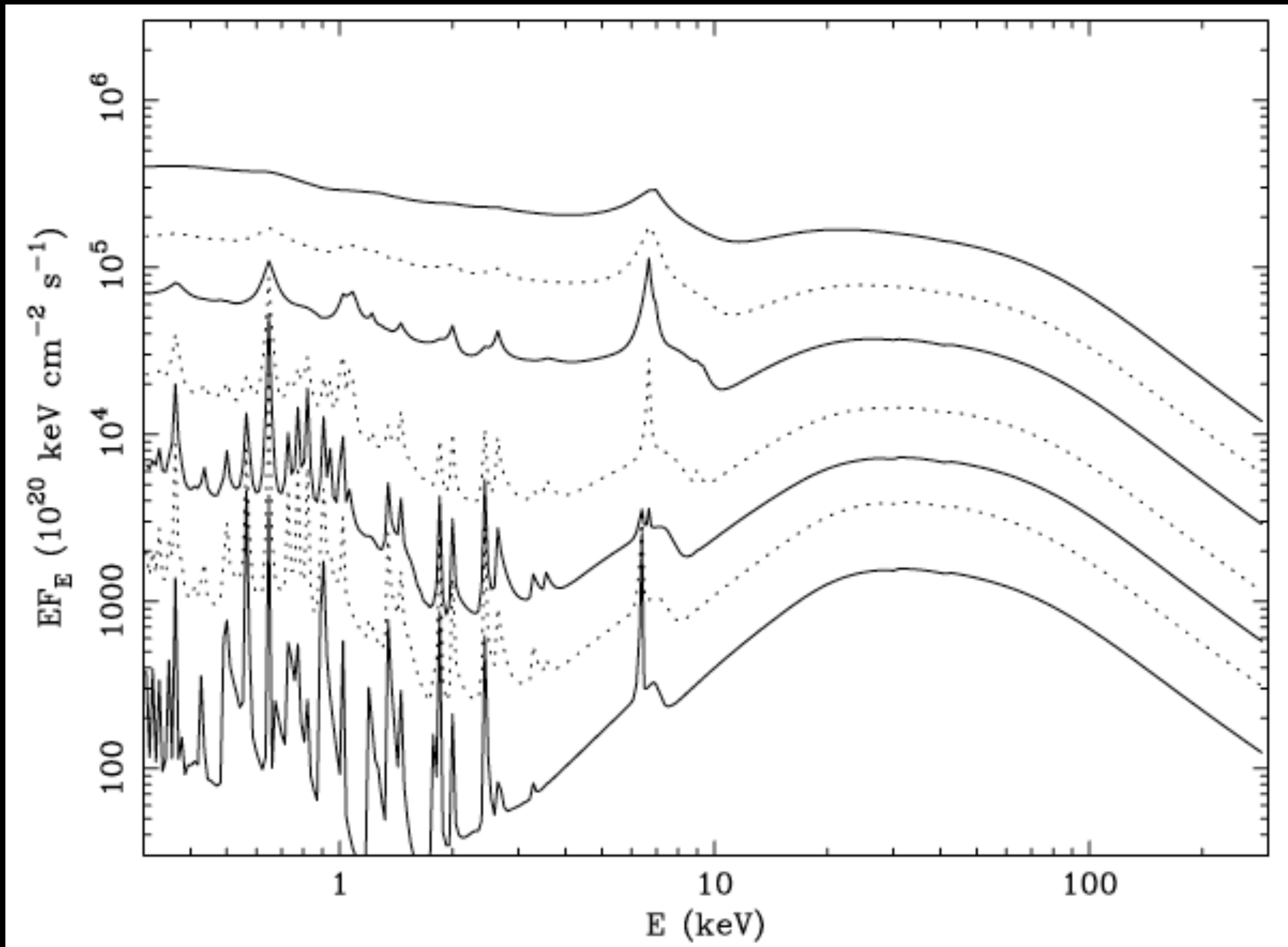
Cygnus X-1 (Nowak et al 1999)

Reflection in accretion discs



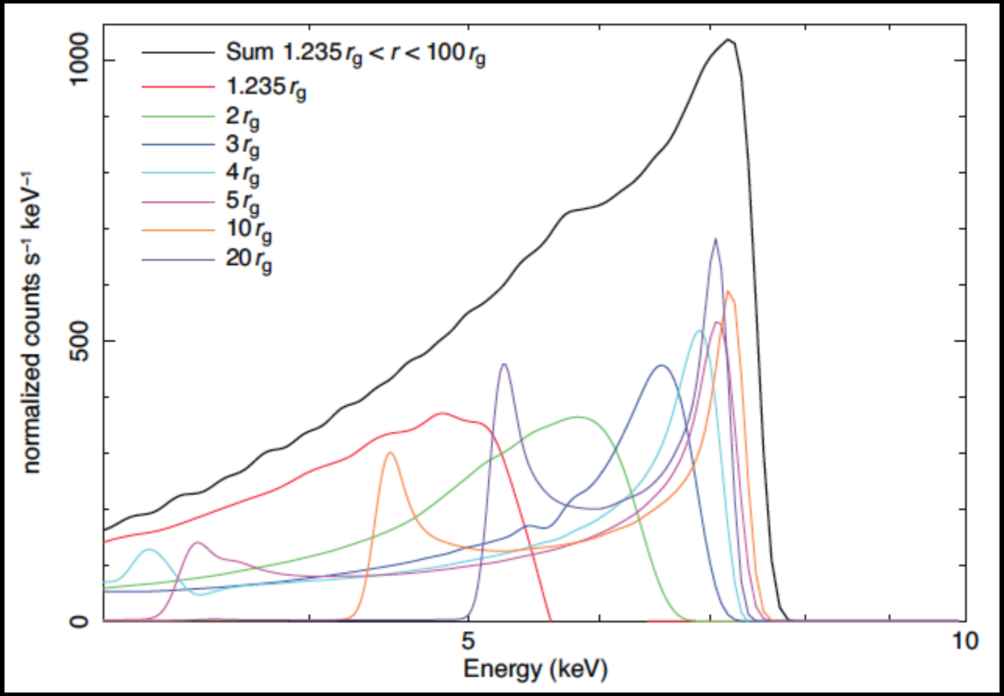
- Reflected flux is ~30% of flux of hard, coronal component that intercepts the disc
- Intrinsic reflection spectrum depends on incident Γ and ionisation parameter ξ

Reflection shape



Ross & Fabian (2007)

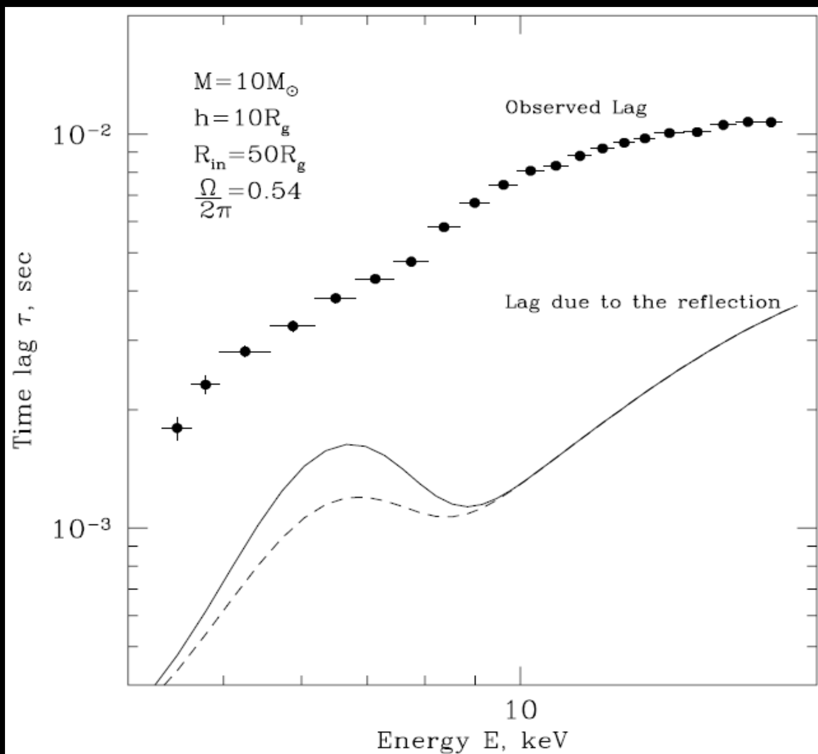
The iron line



Wilkins & Fabian (2011)

Disc geometry and BH spin can in principle be constrained, however even EPIC-pn resolution doesn’t seem enough (+ instrumental effects)

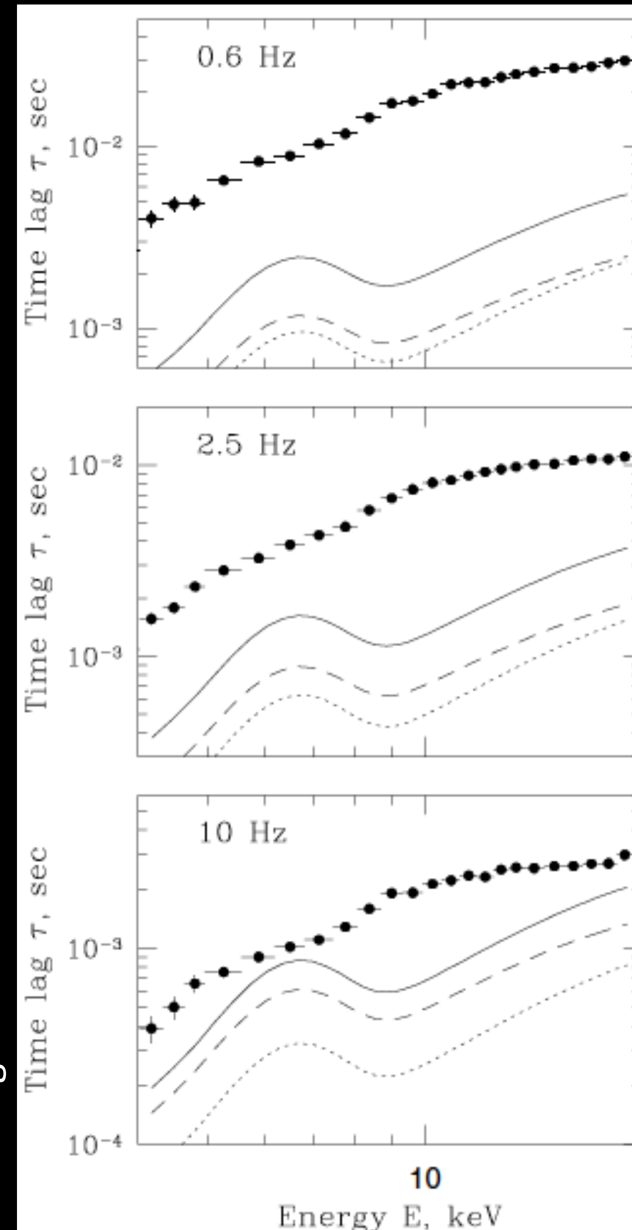
Cygnus X-1



Time lag (s) →

Energy (keV) →

Kotov et al. (2001)



Time lag →

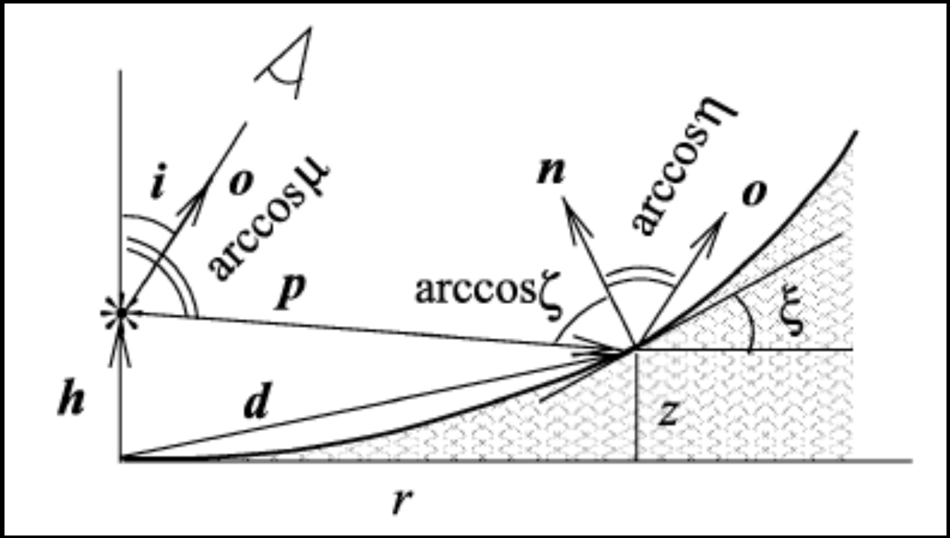
Energy (keV) →

Wiggle around 6.4 keV?

Spectral response?

An XSPEC/ISIS reflection model

Central source at a height h from the disc plane emitting photons, which are in part intercepted by the flared disc
(ie $z(r) \sim r^{\alpha}$) and in part reflected

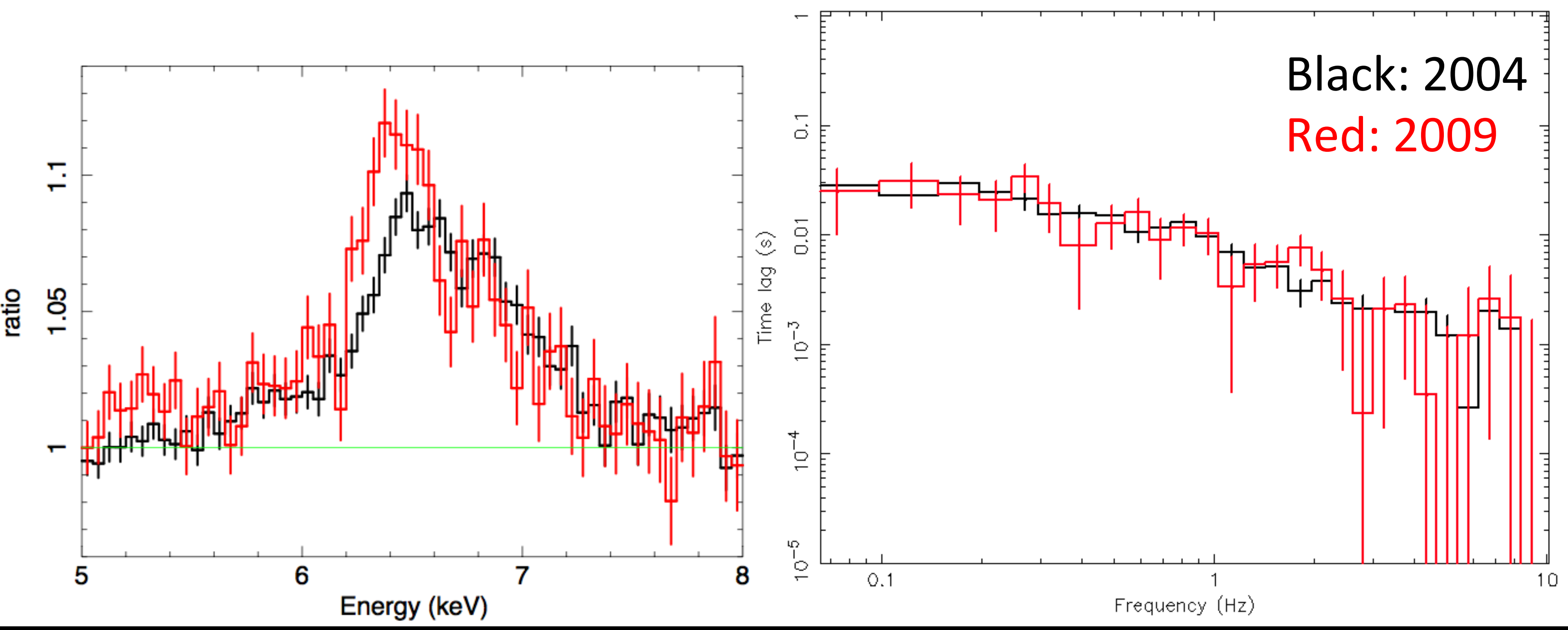


Poutanen (2002)

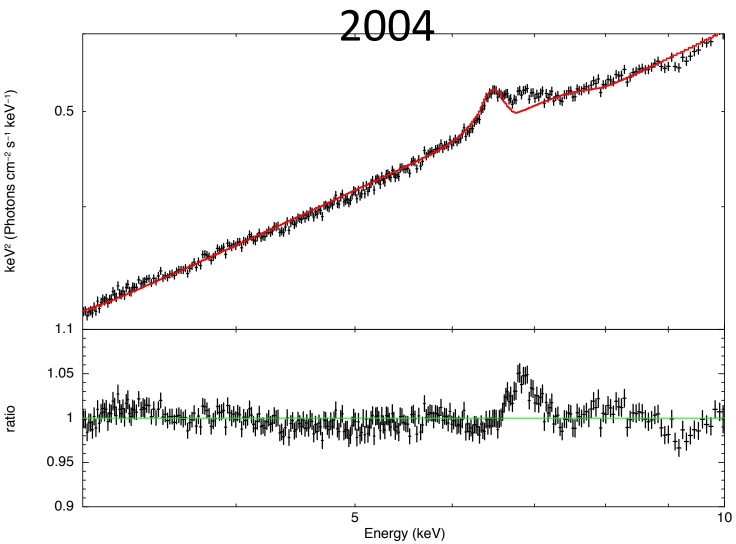
Spectrum and lags can be fitted simultaneously

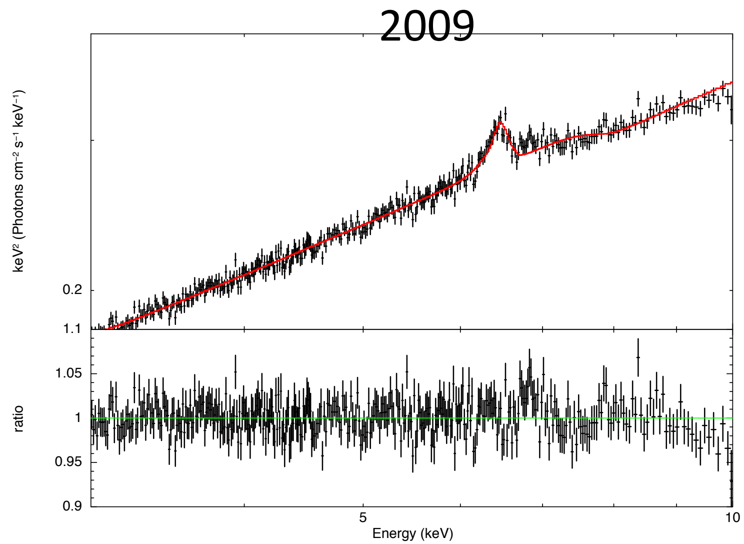
GX 339-4 in 2004 and 2009

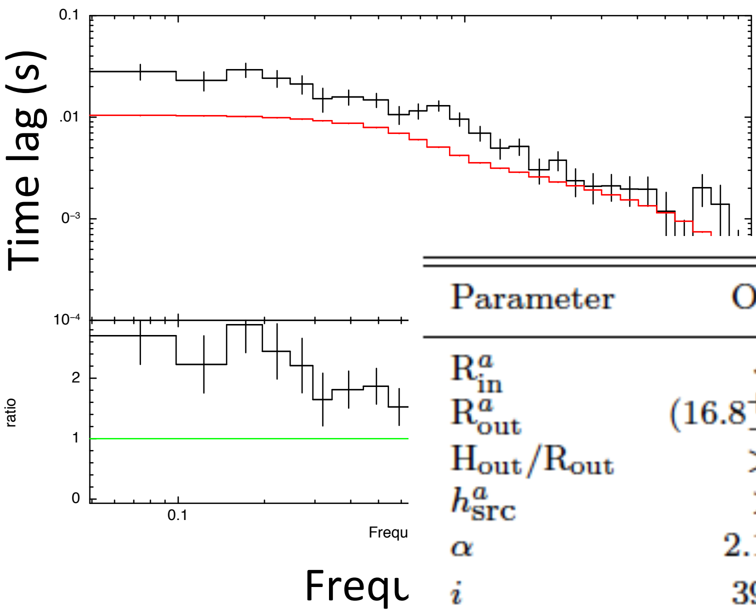
$$\tau \propto \nu^{-0.7}$$

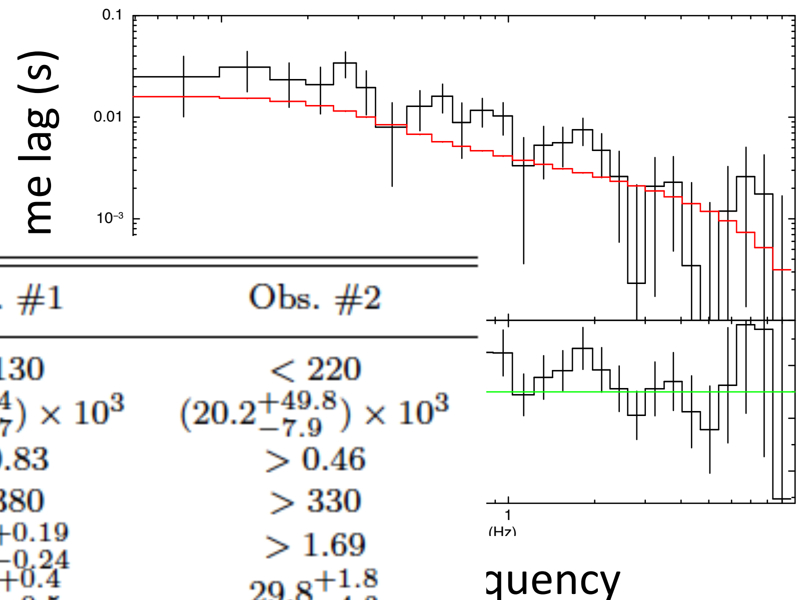


Soft: 2 – 3.5 keV Hard: 4 – 10 keV





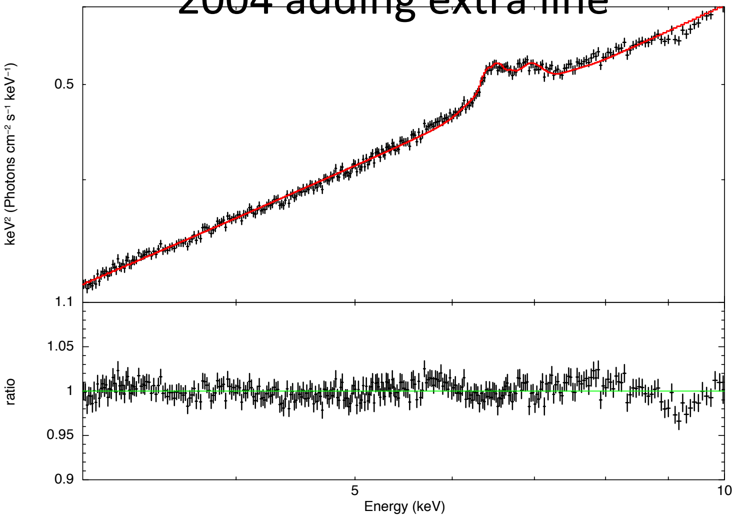




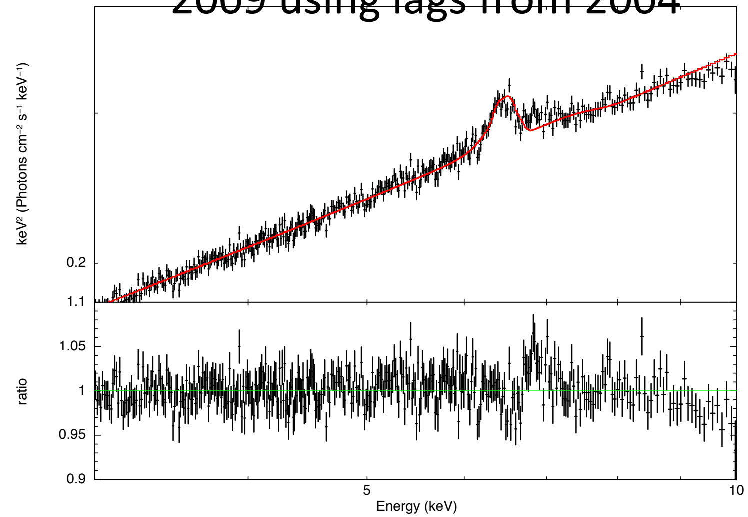
Parameter	Obs. #1	Obs. #2
R_{in}^{a}	< 130	< 220
R_{out}^{a}	$(16.8^{+2.4}_{-2.7}) \times 10^3$	$(20.2^{+49.8}_{-7.9}) \times 10^3$
H_{out}/R_{out}	> 0.83	> 0.46
h_{src}^{a}	> 380	> 330
α	$2.18^{+0.19}_{-0.24}$	> 1.69
i	$39.7^{+0.4}_{-0.5}$	$29.8^{+1.8}_{-4.3}$
Γ	1.48 ± 0.00	$1.47^{+0.00}_{-0.01}$
$\log \xi$	$2.05^{+0.03}_{-0.02}$	$2.03^{+0.02}_{-0.01}$
χ^2/ν	1557.1 / 1417	1334.3 / 1416

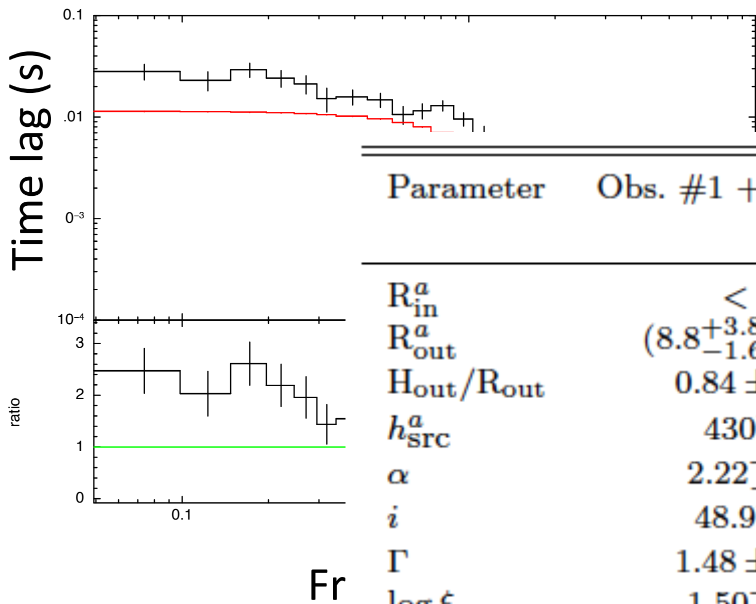
E in keV, distance in GM/c^2

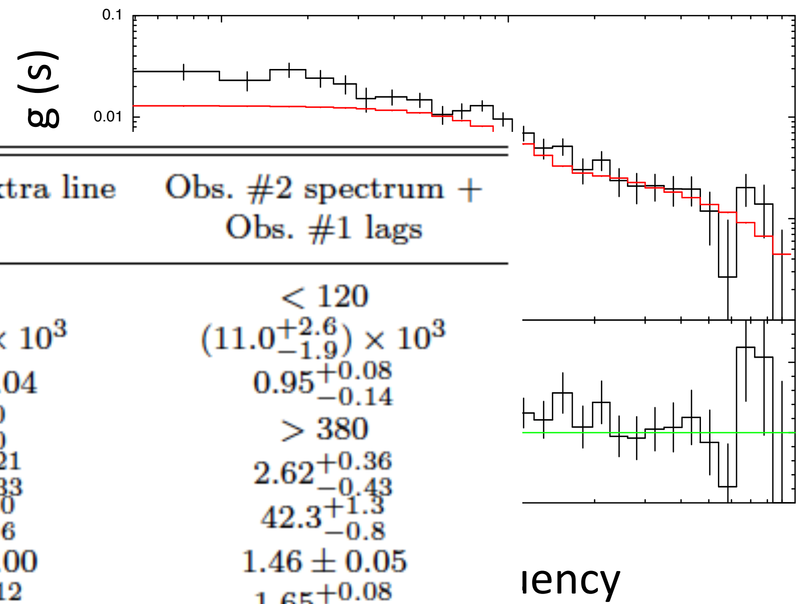
2004 adding extra line



2009 using lags from 2004

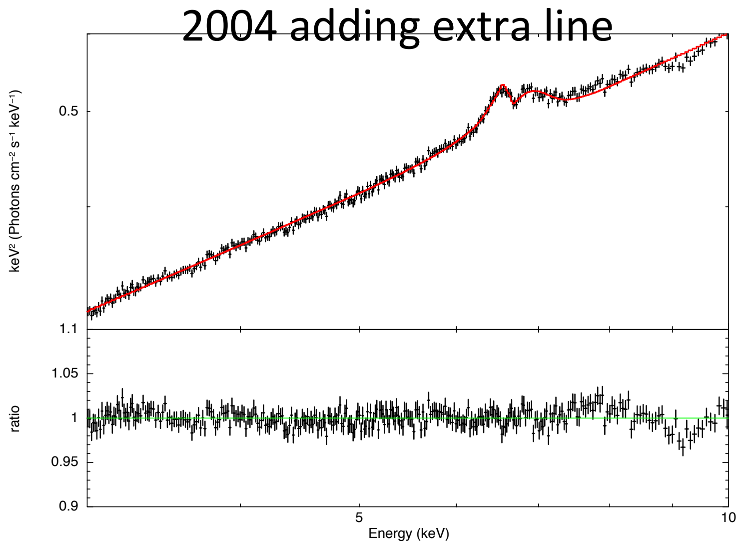


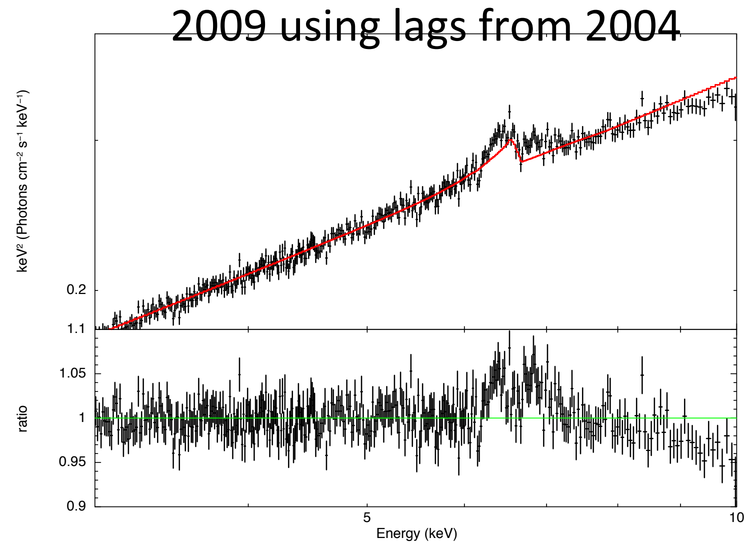


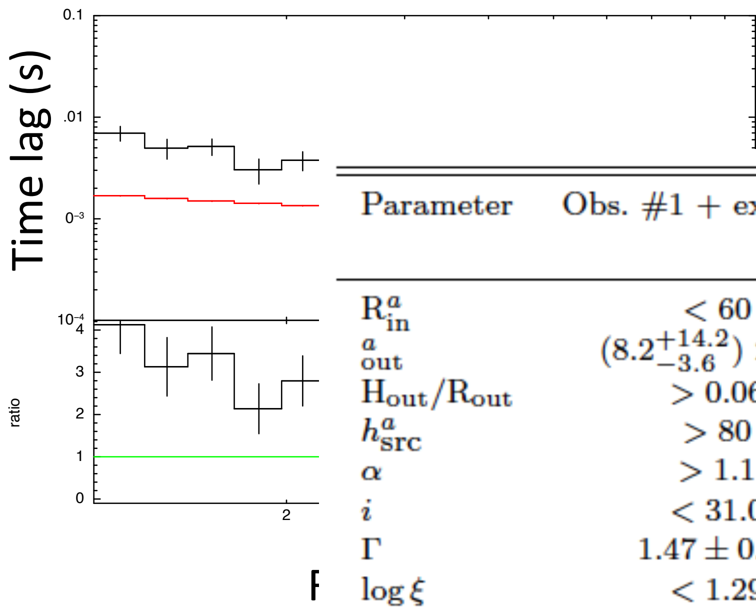


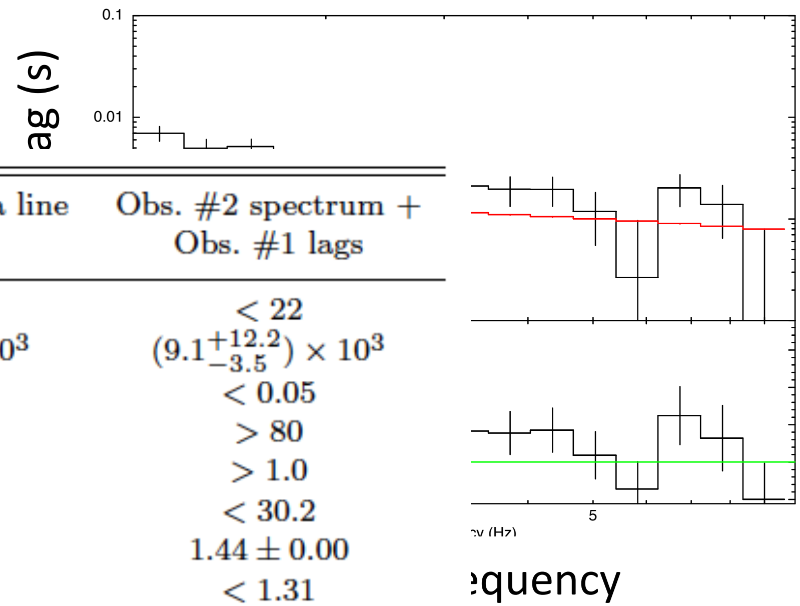
Parameter	Obs. #1 + extra line	Obs. #2 spectrum + Obs. #1 lags
R^a_{in}	< 90	< 120
R^a_{out}	$(8.8^{+3.8}_{-1.6}) \times 10^3$	$(11.0^{+2.6}_{-1.9}) \times 10^3$
H_{out}/R_{out}	0.84 ± 0.04	$0.95^{+0.08}_{-0.14}$
h^a_{src}	430^{+90}_{-80}	> 380
α	$2.22^{+0.21}_{-0.33}$	$2.62^{+0.36}_{-0.43}$
i	$48.9^{+1.0}_{-0.6}$	$42.3^{+1.3}_{-0.8}$
Γ	1.48 ± 0.00	1.46 ± 0.05
$\log \xi$	$1.50^{+0.12}_{-0.24}$	$1.65^{+0.08}_{-0.17}$
E_c	6.92 ± 0.02	–
σ_c	$0.17^{+0.03}_{-0.02}$	–
χ^2/ν	1239.4 / 1414	1410.81 / 1417

E in keV, distance in GM/c^2









Parameter	Obs. #1 + extra line	Obs. #2 spectrum + Obs. #1 lags
R^{a}_{in}	< 60	< 22
$^{a}_{out}$	$(8.2^{+14.2}_{-3.6}) \times 10^{3}$	$(9.1^{+12.2}_{-3.5}) \times 10^{3}$
H_{out}/R_{out}	> 0.06	< 0.05
h^{a}_{src}	> 80	> 80
α	> 1.1	> 1.0
i	< 31.0	< 30.2
Γ	1.47 ± 0.00	1.44 ± 0.00
$\log \xi$	< 1.29	< 1.31
E_{C}	6.85 ± 0.08	–
σ_{C}	0.25 ± 0.05	–
χ^2/ν	1181.8 / 1402	1526.8 / 1405

E in keV, distance in GM/c^2

Conclusions

- Timing information is the perfect complement to spectra, need more models
- Radially-dependent ionisation should be used
- Disc reflection is unlikely to explain time lags below 1 Hz, propagation models are still a valid cause
- Lags at > 1 Hz could be explained by reflection, but we need more constrains from eg optical (work in progress)