TIME LAGS FROM REFLECTION IN BLACK HOLE BINARIES

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Time lags?

Time lags are observed delays in the arrival times of two signals coming from the same source, e.g. in two different bands (soft and hard)

Firstly introduced by Miyamoto et al (1989), who showed that hard band photons are usually observed after soft photons

Allow mapping of emission mechanisms onto the accreting system, and give constraints on the geometry/physics

$S(t), H(t)$ → FT → $S(\nu), H(\nu)$ → $C(\nu)=S(\nu)^* H(\nu)$ → Phase lag: $\Phi(\nu)=\arg[C(\nu)]$ → Time lag: $\tau(\nu)=\phi(\nu)/(2\pi\nu)$
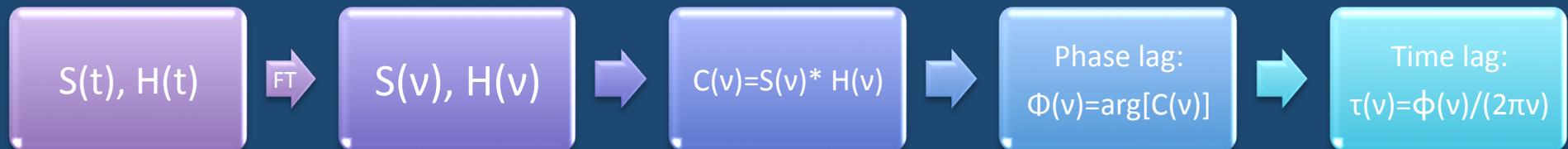
What can cause lags?

1. **Propagation of accretion instabilities** (Arévalo & Uttley, 2006; Kotov et al, 2001...)
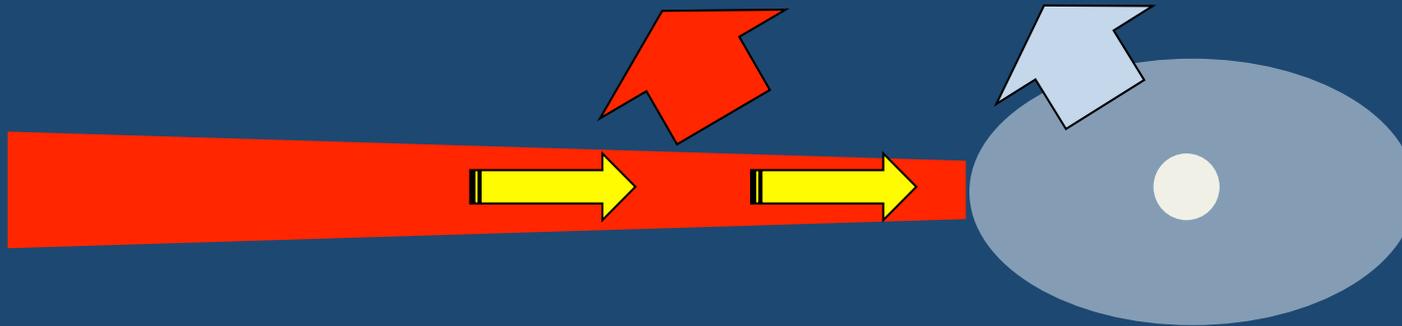
2. **Large scale reflection** (Kotov et al, 2001; Poutanen, 2002...)
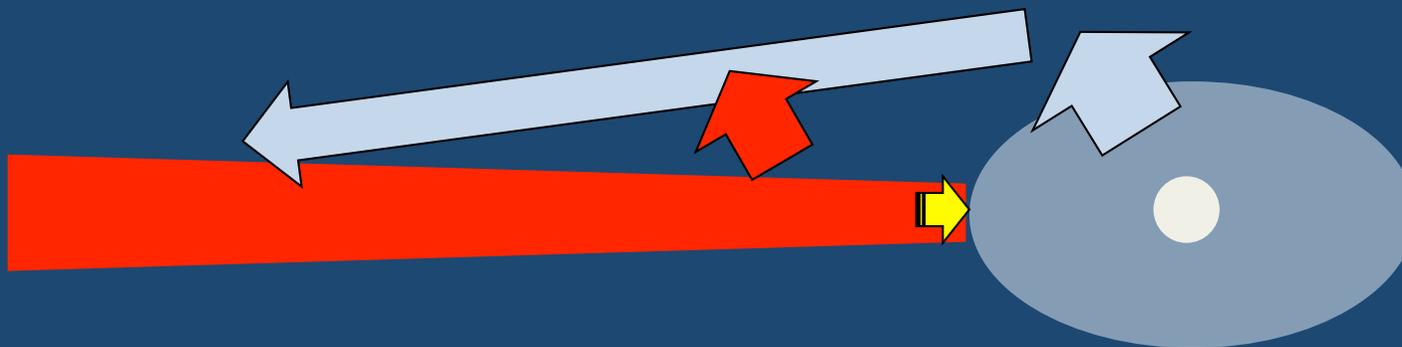
Disc fluctuations drive variability
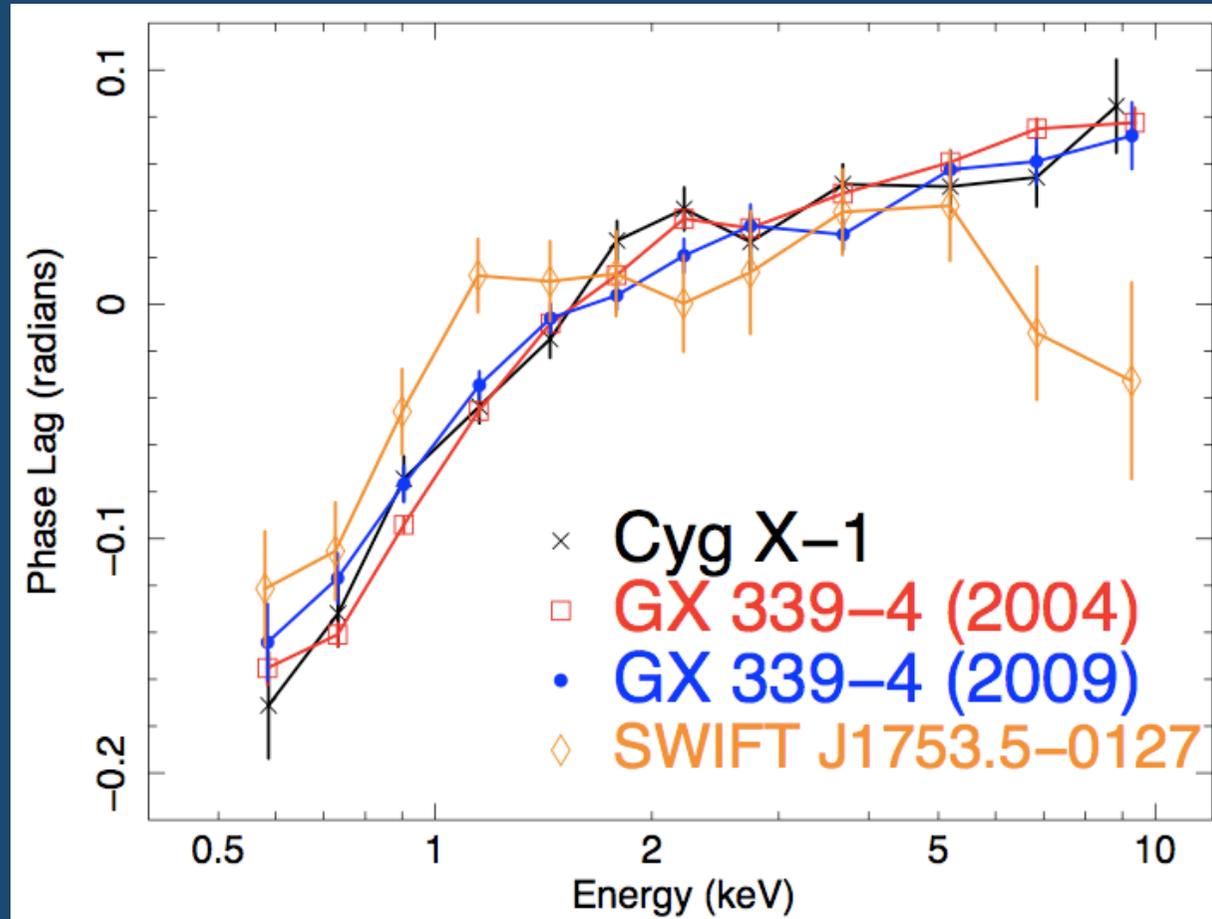
But what's the role of reverberation?

Disc reverberation
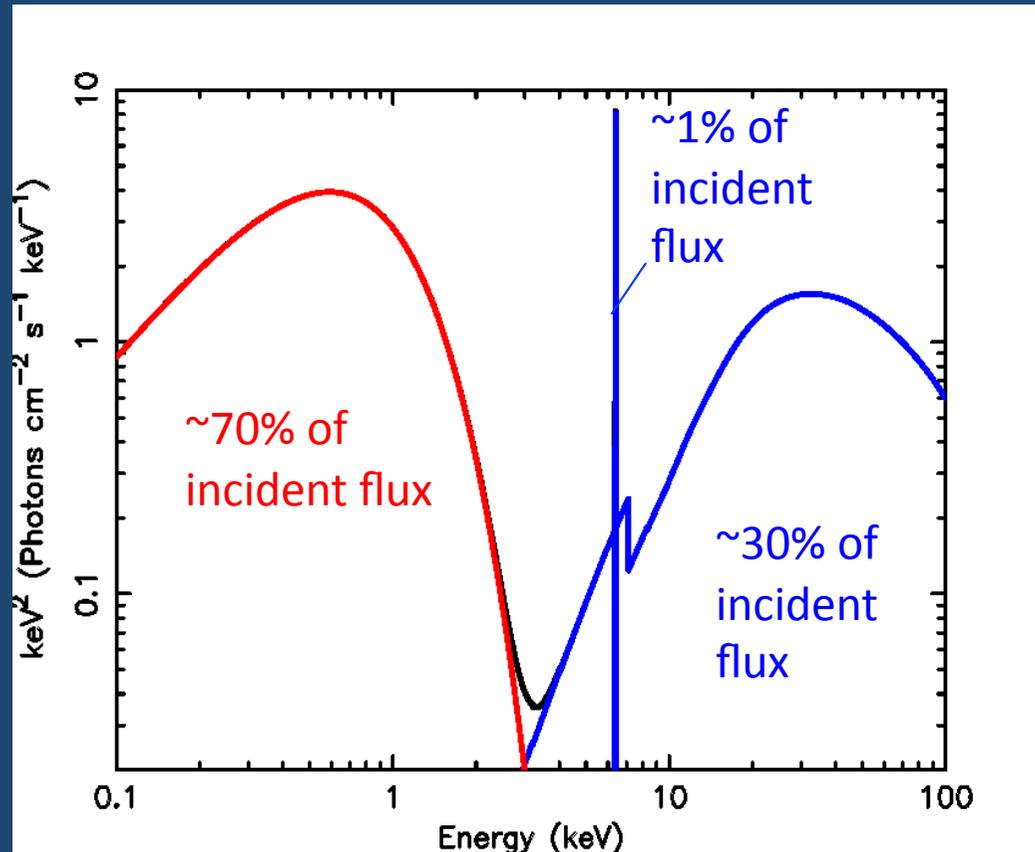
About 70% of the incident flux contributes to heating the disc, thus emitting at the local temperature

~ 30% is reflected

But approximately 1% of the incident flux contributes to the Fe Kα line
➔ Constraints on the solid angle subtended by the disc: how much direct emission can the disc see?

Disc reflection

- 'Quite hard' X-ray photons (E > 14 keV) hit the disc
- → Compton (down)scattering until they leave the medium or are photoabsorbed. Neutral iron contributes a fluorescence line at 6.4 keV
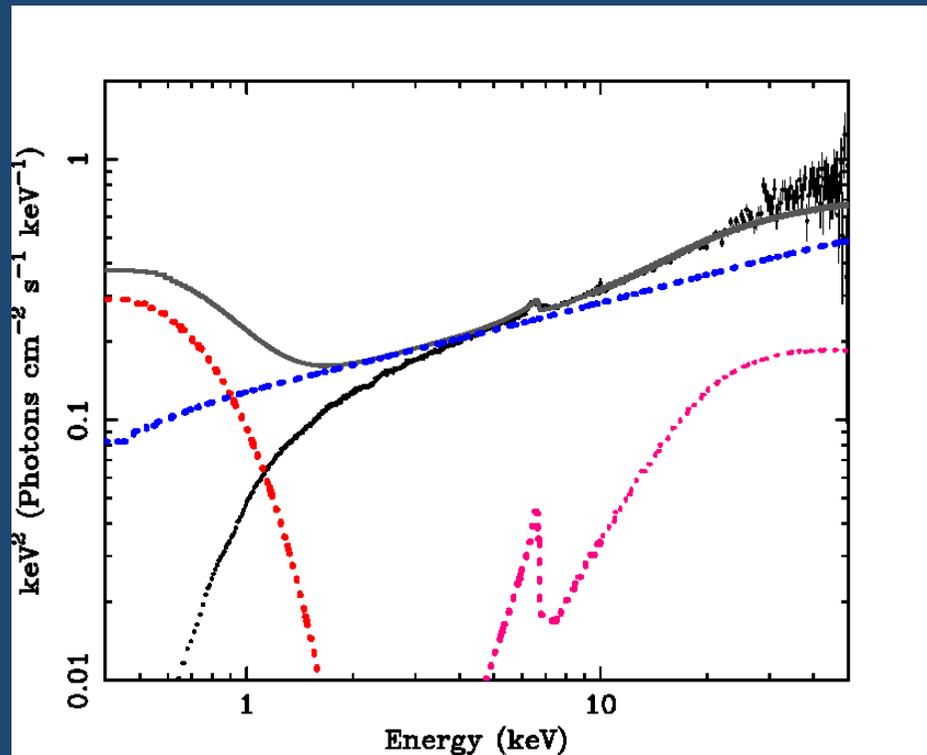
The contribution of the line to the total spectrum does depends on radius

blurring off

Blurring on

6.4 keV
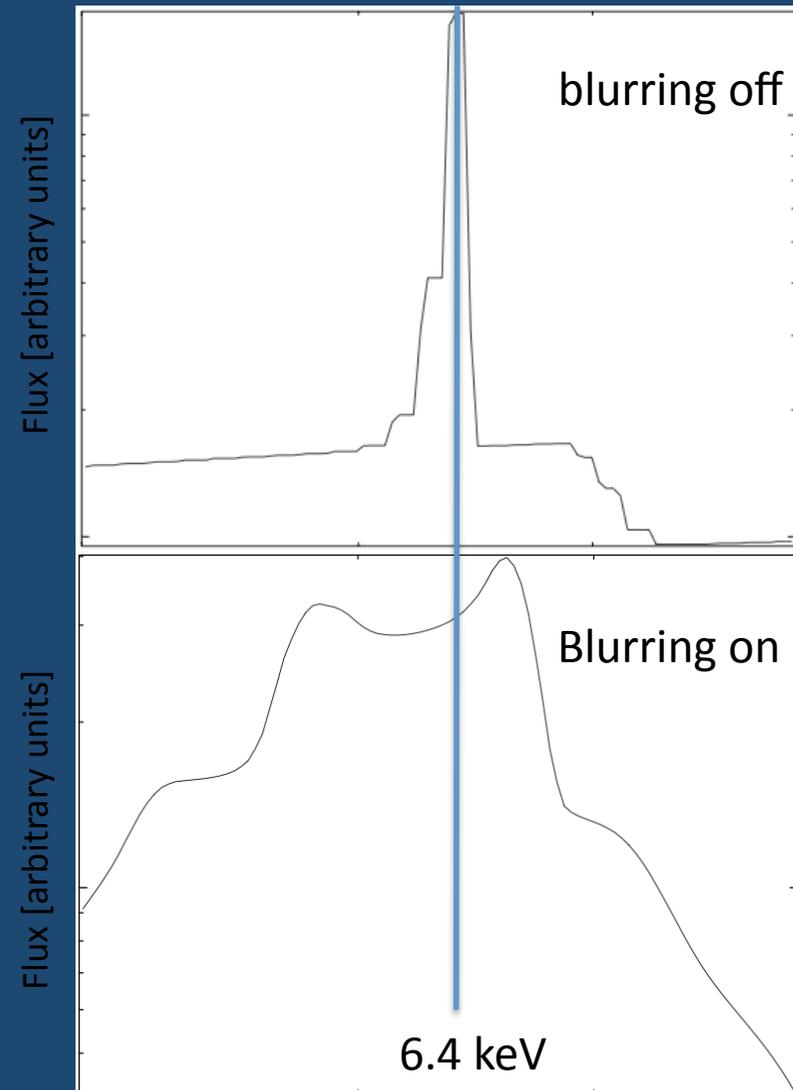
Lags from reflection: evidence (i)

GX 339-4 (2004): Fitting the iron line with a relativistic profile leaves an unresolved excess $F_{excess} \sim 5.6 \times 10^{-13}$ erg s^{-1} cm^{-2}
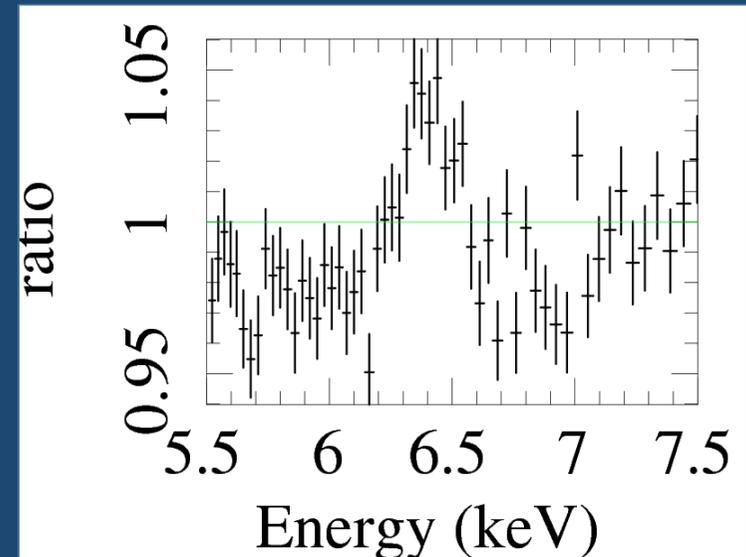
This is in agreement with the optical flux reprocessed by the outer disc found by
Coriat, Corbel et al (2009)

➔ Large scale reflection is present

Lags from reflection: evidence (ii)

$M = 10 M_\odot$
$h = 10 R_g$
$R_{in} = 50 R_g$
$\frac{\Omega}{2\pi} = 0.54$

Observed Lag

Lag due to the reflection

Time lag τ, sec

Energy E, keV

0.6 Hz

2.5 Hz

10 Hz
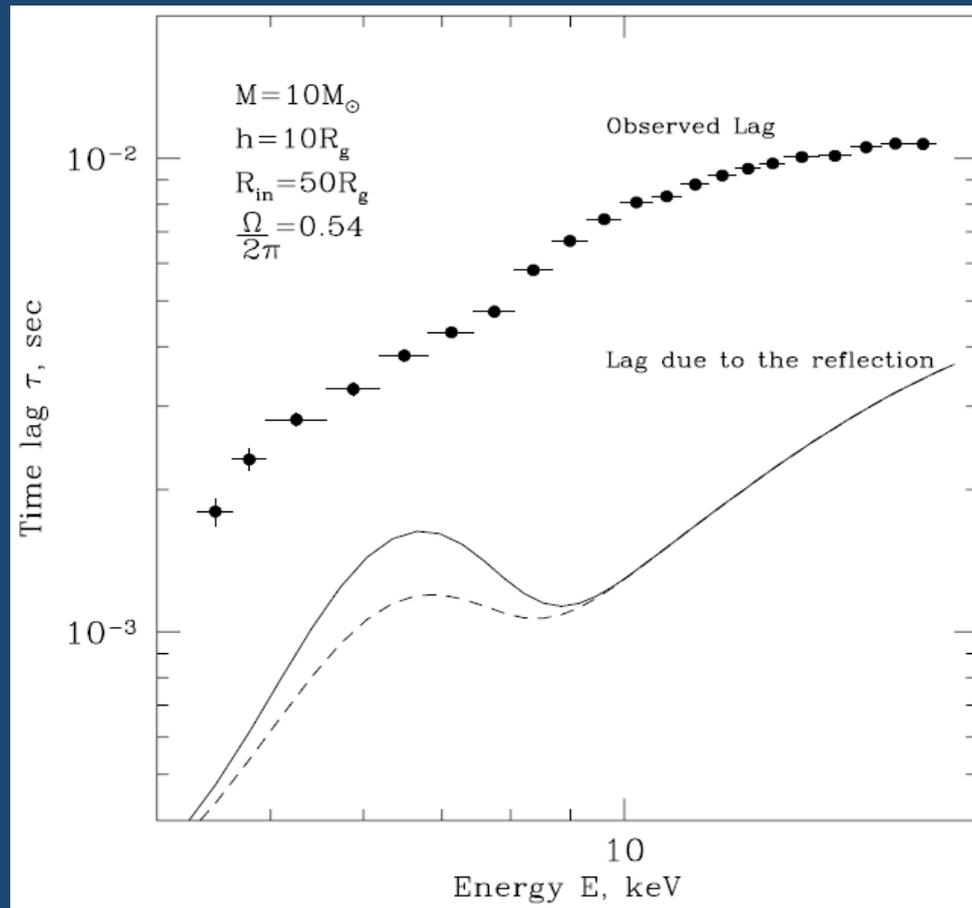
Kotov et al (2001) show a wiggle in the energy dependence of time lags at 6.4 keV, in agreement with a reflection origin.
Different line shapes could cause this?
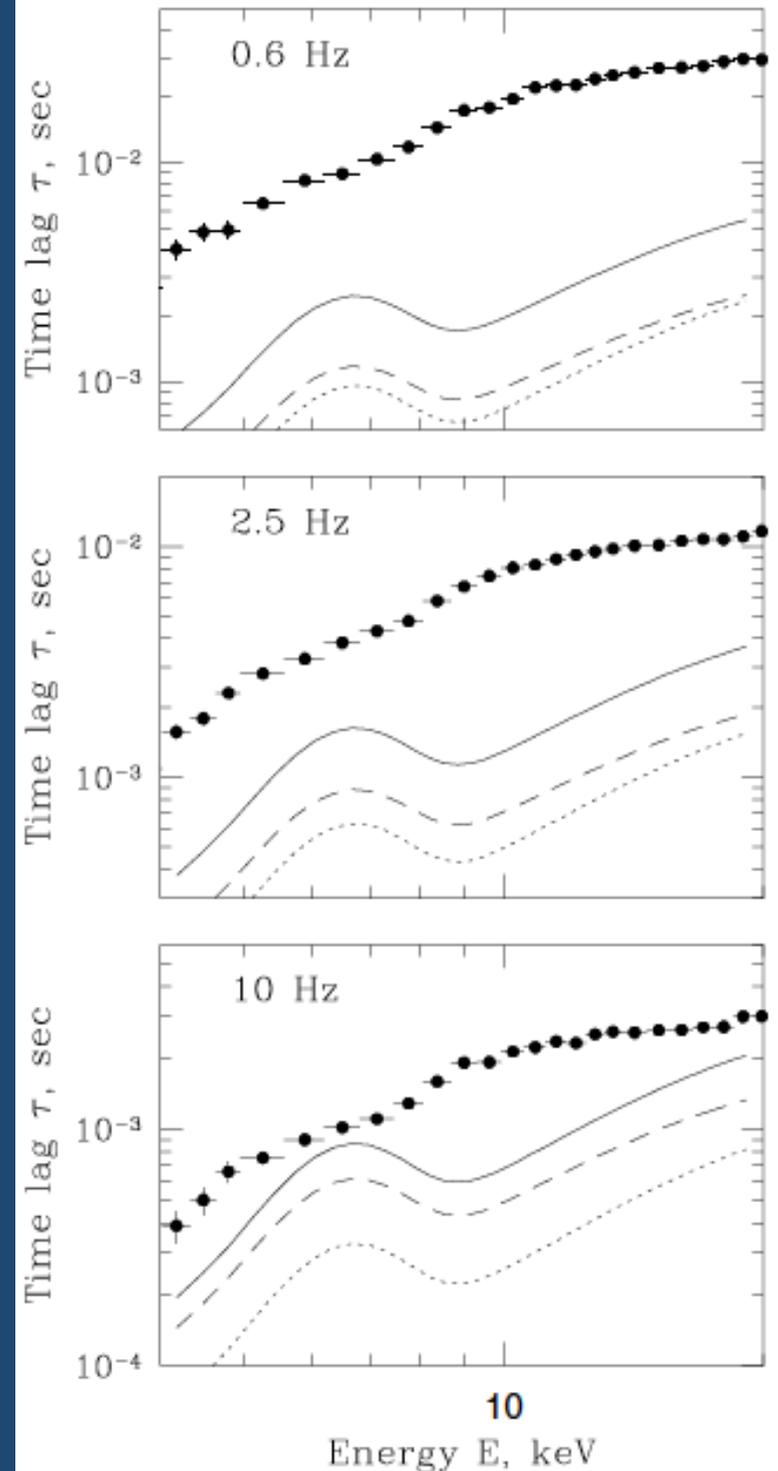
Distance reflection is present, but how can it be constrained from lags spectra?

Fitting lags is the way forward!

- Mean spectrum (aka spectrum)
- Iron line flux and shape
- Solid angle subtended by the disc
- Optical flux
- Lag vs spectra

} should be consistent!

• Existing packages allow fitting of non-spectral data, need some cheating (especially Xspec)

A model for disc reflection from flared discs

A central source at a height h from the disc plane emits photons, which are in part intercepted by the flared disc (ie $r \sim r^{\alpha}$) and reflected
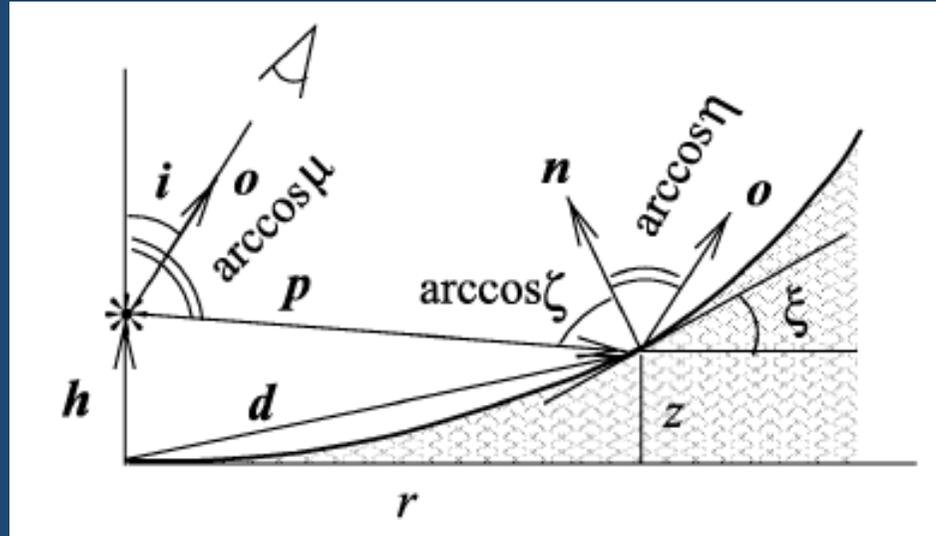
Poutanen (2002)

Depends on:

Inner disc radius	**Flaring index α ($r \sim z^{\alpha}$)**
Outer disc radius	**Central source height above the disc**
Black hole mass	**System inclination**
H_{max}/R_{out} scale height ratio	**Spectral shape/albedos**

From the geometry to the response (i)

$H/R = 0.2$

$R_{in} = 10\ R_s$

$R_{out} = 10000\ R_s$

$H_{src} = 10\ R_s$

$z(r) = H_{max}(r/R_{max})^{1.5}$

$a_s = 0,\ a_H = 1$
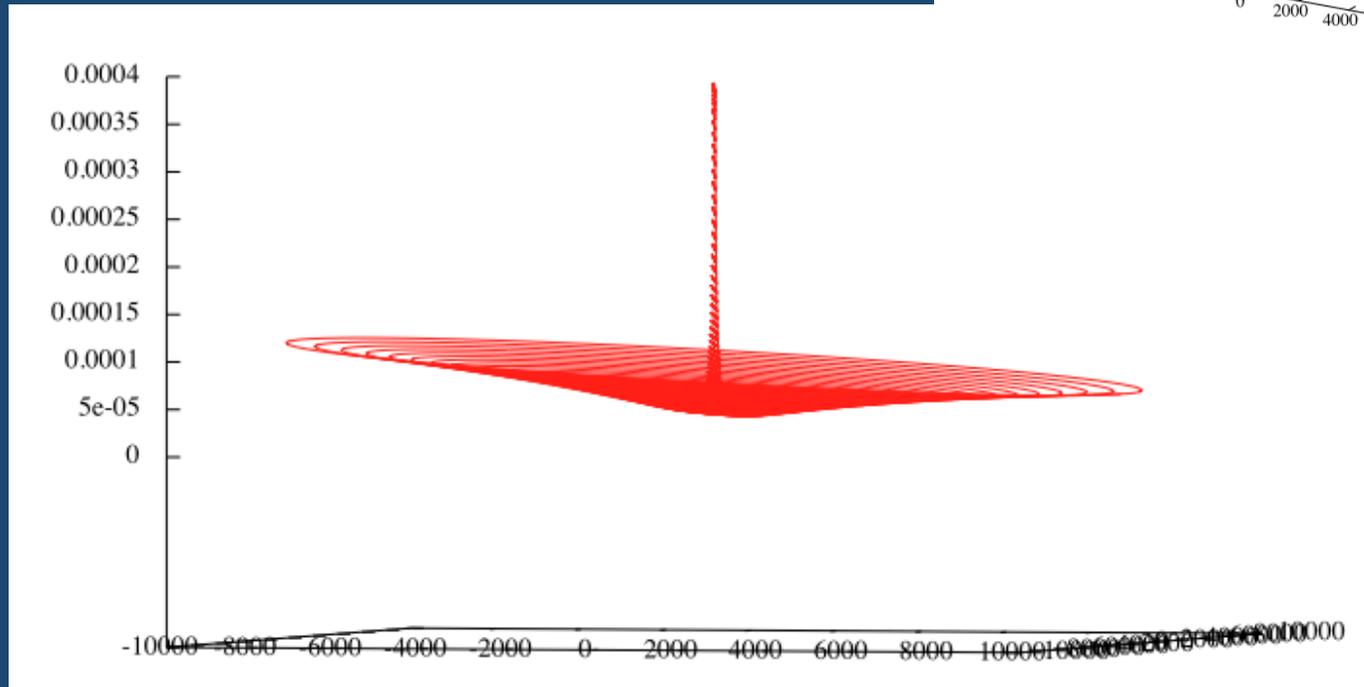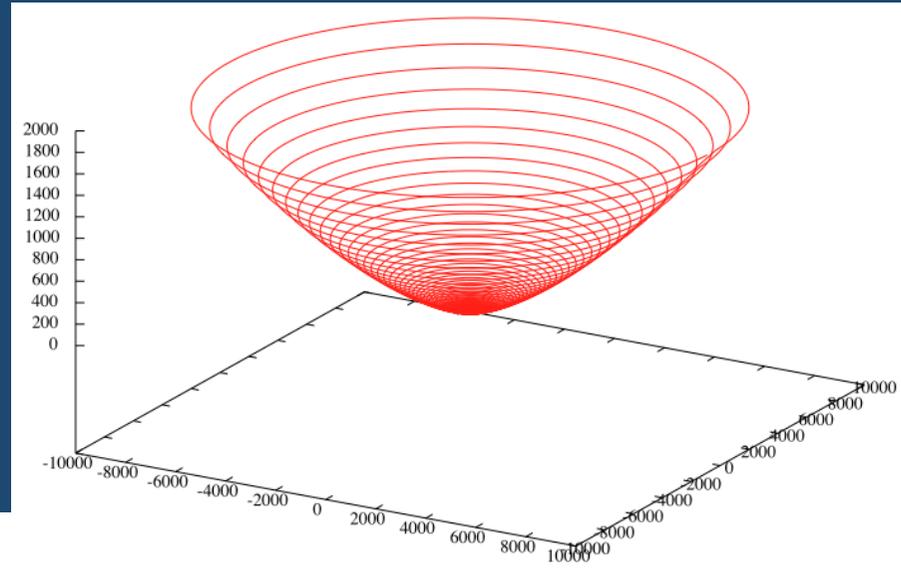
From the geometry to the response (ii)

$$L_S(\nu) = L_D(\nu)[1+a_S T(\nu)]$$

$$L_H(\nu) = L_D(\nu)[1+a_H T(\nu)]$$

$$C(\nu)=|L_D(\nu)|^2 [1+a_S T^*(\nu)+a_H T(\nu)+a_S a_H |T(\nu)|^2]$$

Simple two albedo values case

Response function

T(t)
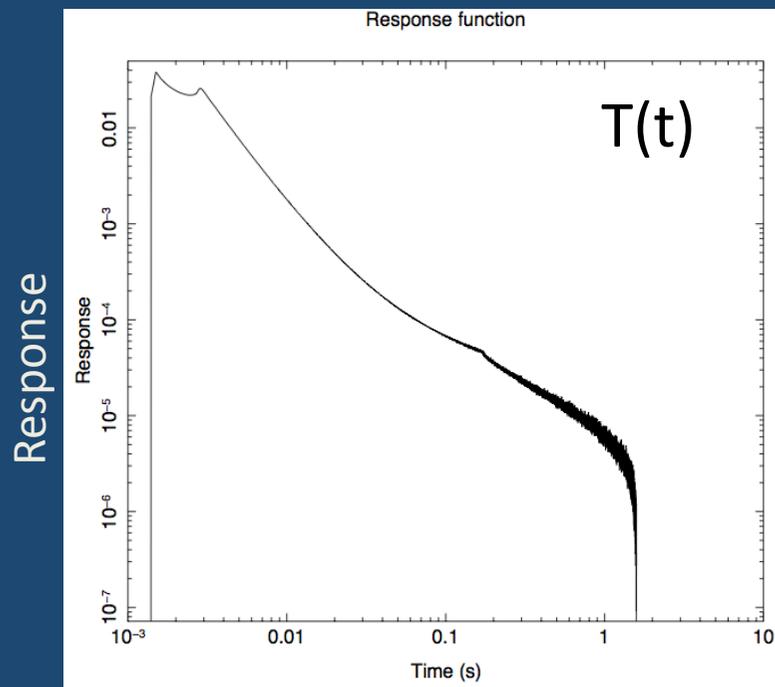
Response

Frequency (Hz)

Disc response
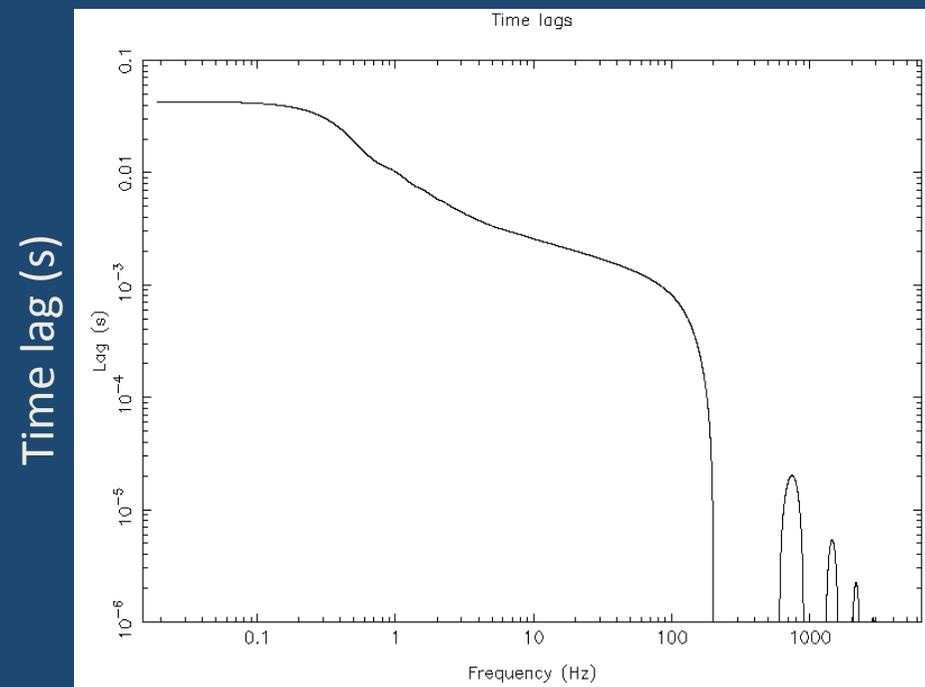
Time lags

Time lag (s)

Frequency (Hz)

Time lags

GX 339-4 in 2009 and 2010 (XMM+RXTE)

3-10 keV vs 0.5-2.0 keV
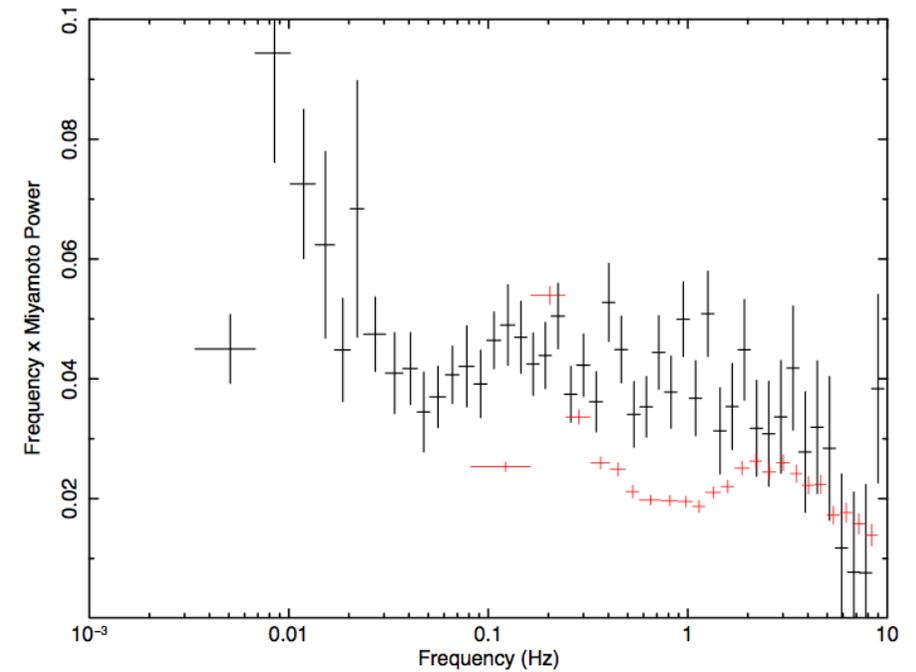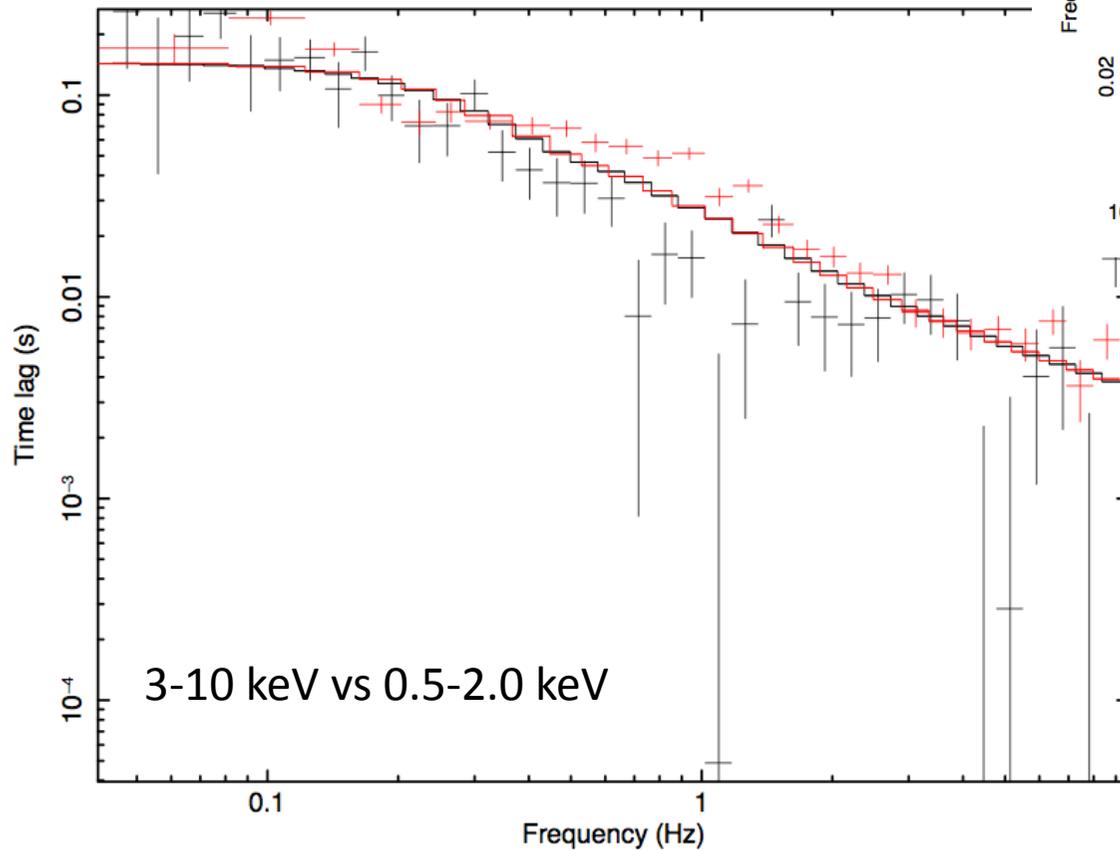
Why so little change?

Ongoing work

- Adding energy information to disc (eg Ballantyne 2004) plus relativistic smearing

- Adding code for covariance calculation