Timing properties of the X-ray quasi-periodic oscillations in the Lense-Thirring precession model

Piotr Życki

Nicolaus Copernicus Astronomical Center, Warsaw, Poland

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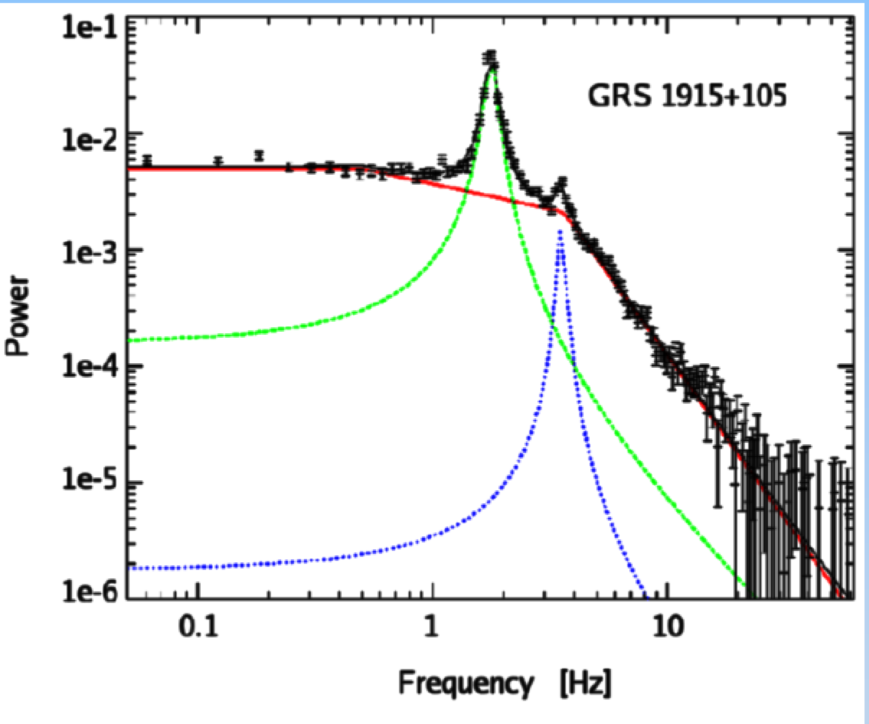
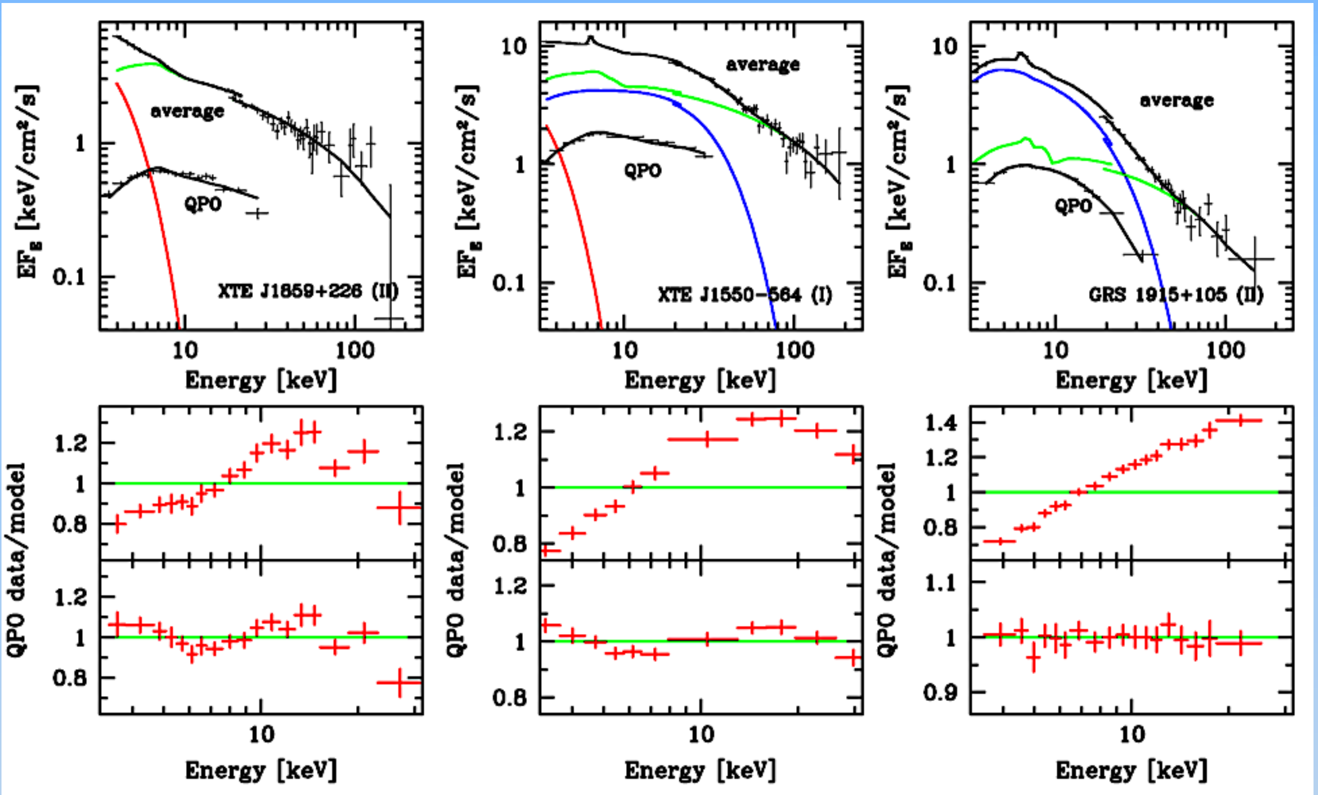
SEVENTH FRAMEWORK PROGRAMME
NATIONAL SCIENCE CENTRE

X-ray QPO

Low-*f* QPO



Observed energy spectra of QPO



Sobolewska & Życki 2006

Disk emission is ***not*** present in the QPO spectra.

When time averaged spectra are soft, the QPO spectra are *harder* than the time averaged spectra.

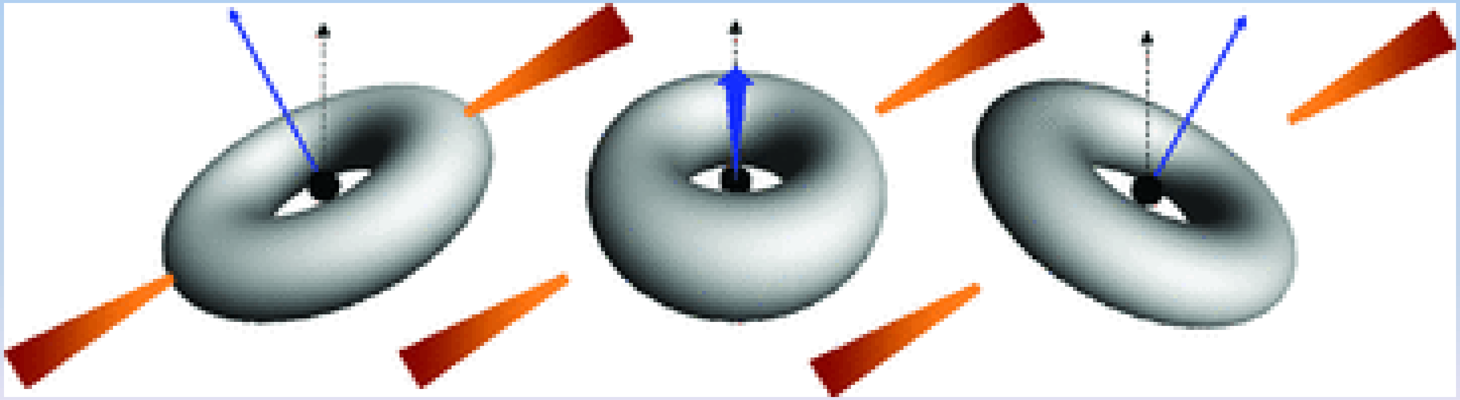
Lense-Thirring precession model for low-*f* QPO

Formulated by Stella & Vietri (1998)

Recent hydrodynamical simulations suggest that the hot flow behaves (precesses) like a solid body.

Inner radius of the flow is determined by properties of the bending waves. It is approximately independent of the spin of the black hole. As a result the maximum precession frequency does not depend on the spin.

(C. Done, A. Ingram, C. Fragile)



The model

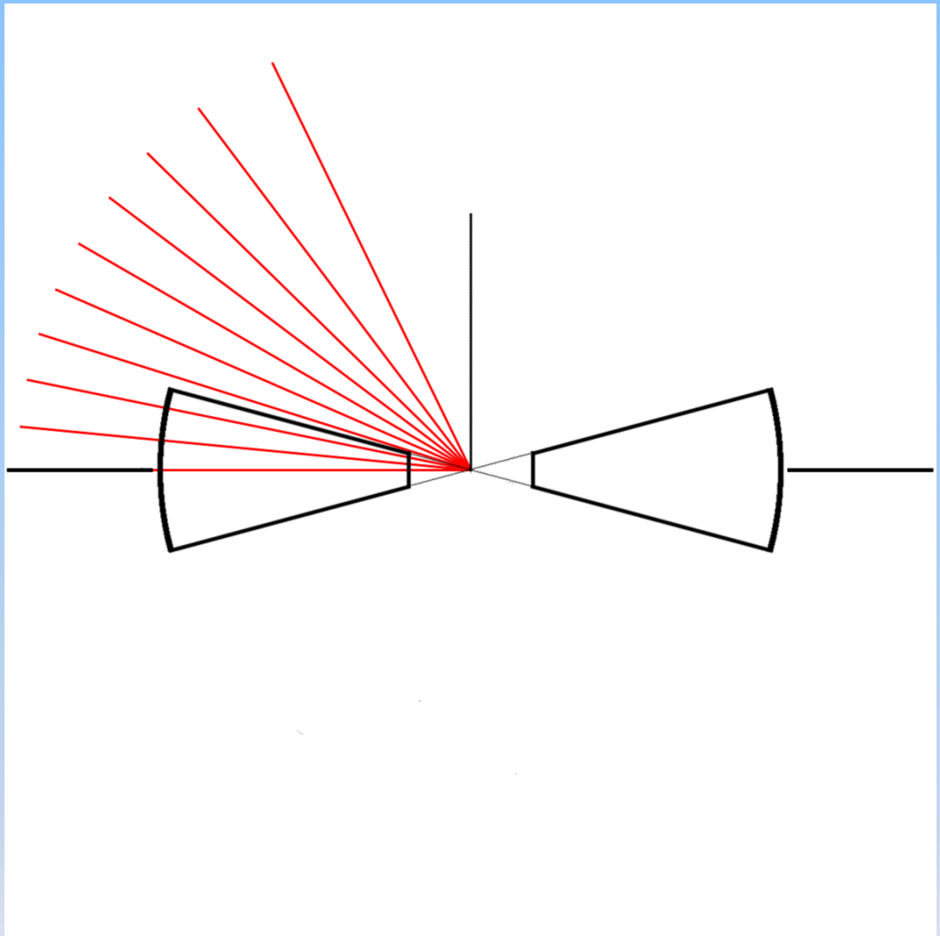
+

Connects the „standard” geometry of the transition between the hard-soft state with timing properties

-

- Can the torus really precess like a solid body?
- Unclear trigger of the QPO
- Does it require a misaligned spin and orbital angular momentum?
- Requires rotating black hole but does not give a possibility of determining *a*

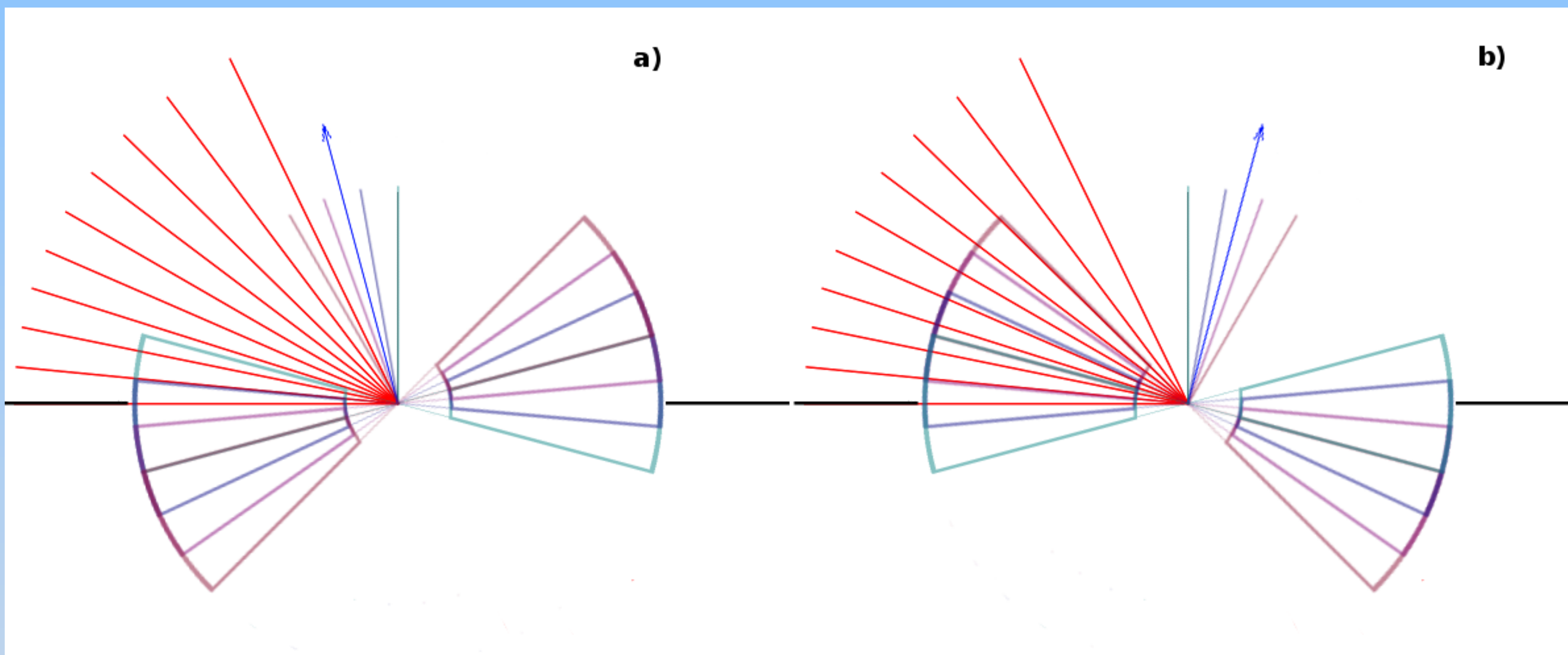
Geometry

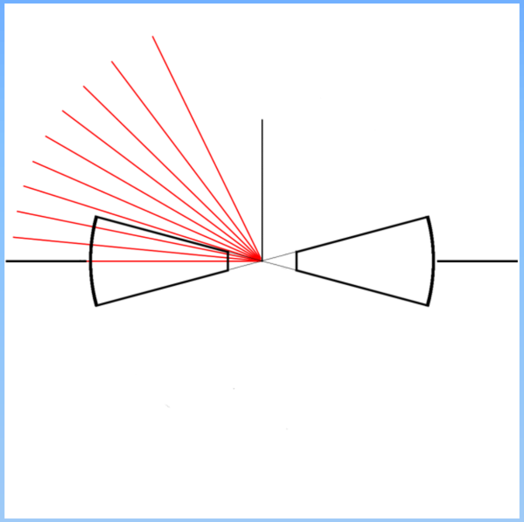
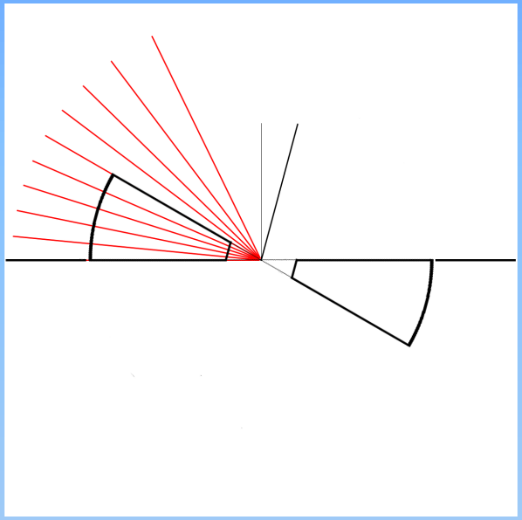
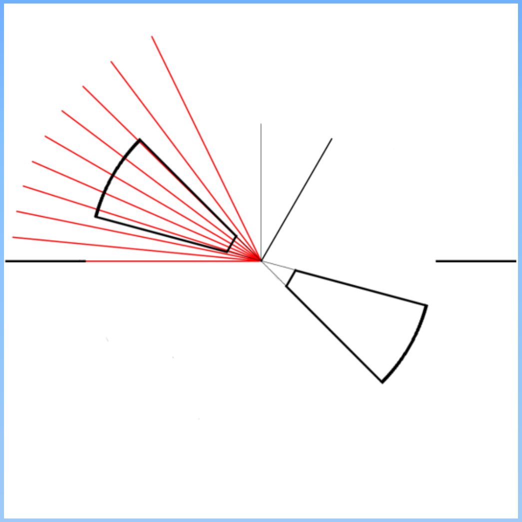
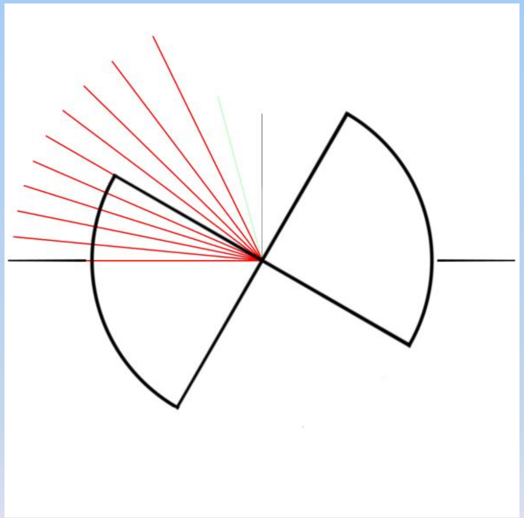
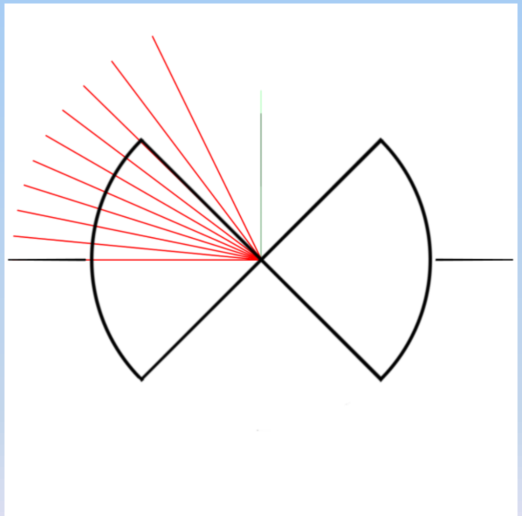
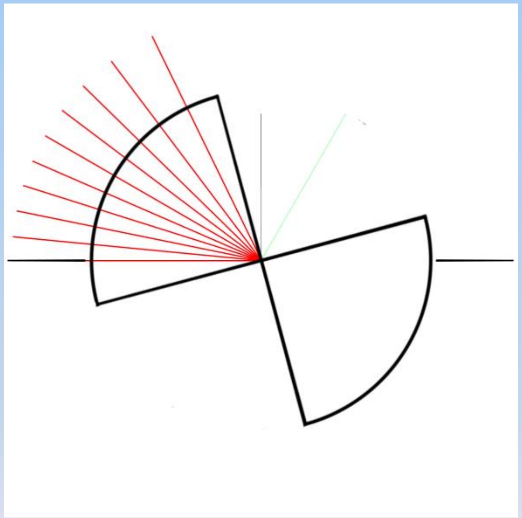


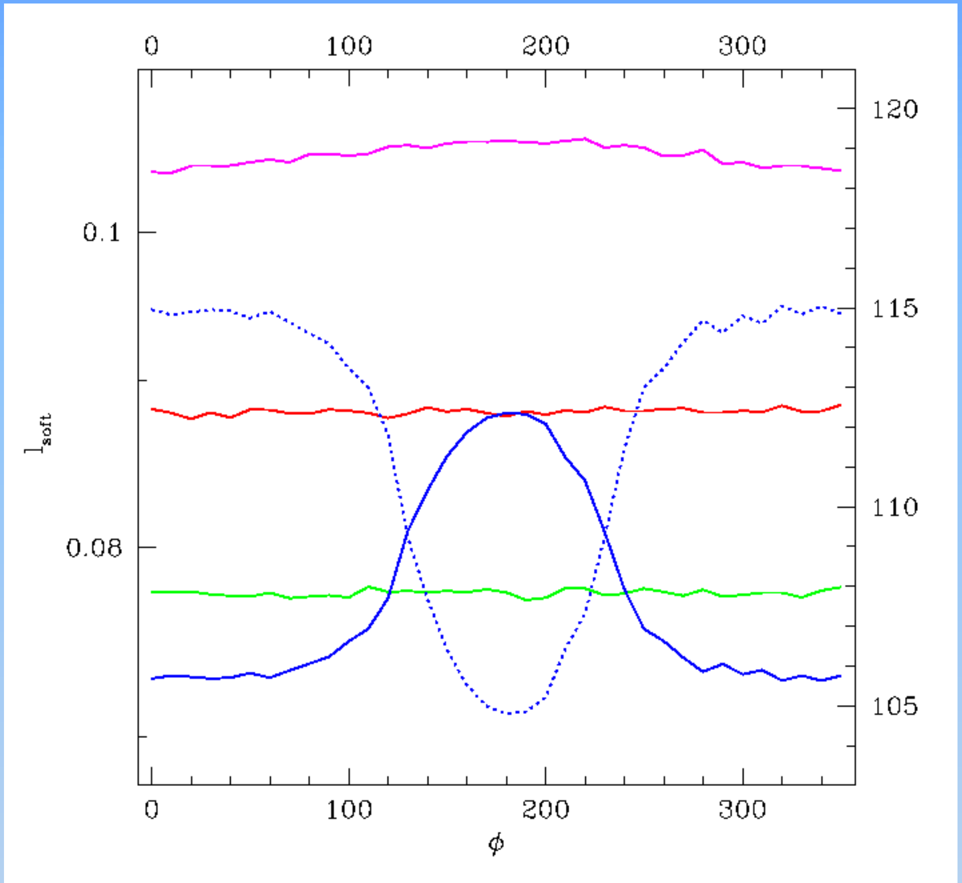
Two geometrical scenarios:

1. precession axis perp. to the outer disk
2. Precession axis inclined to the outer disk (based on Bardeen-Peterson effect)

Geometry





geometrically thick torus; to be compared with the blue curve

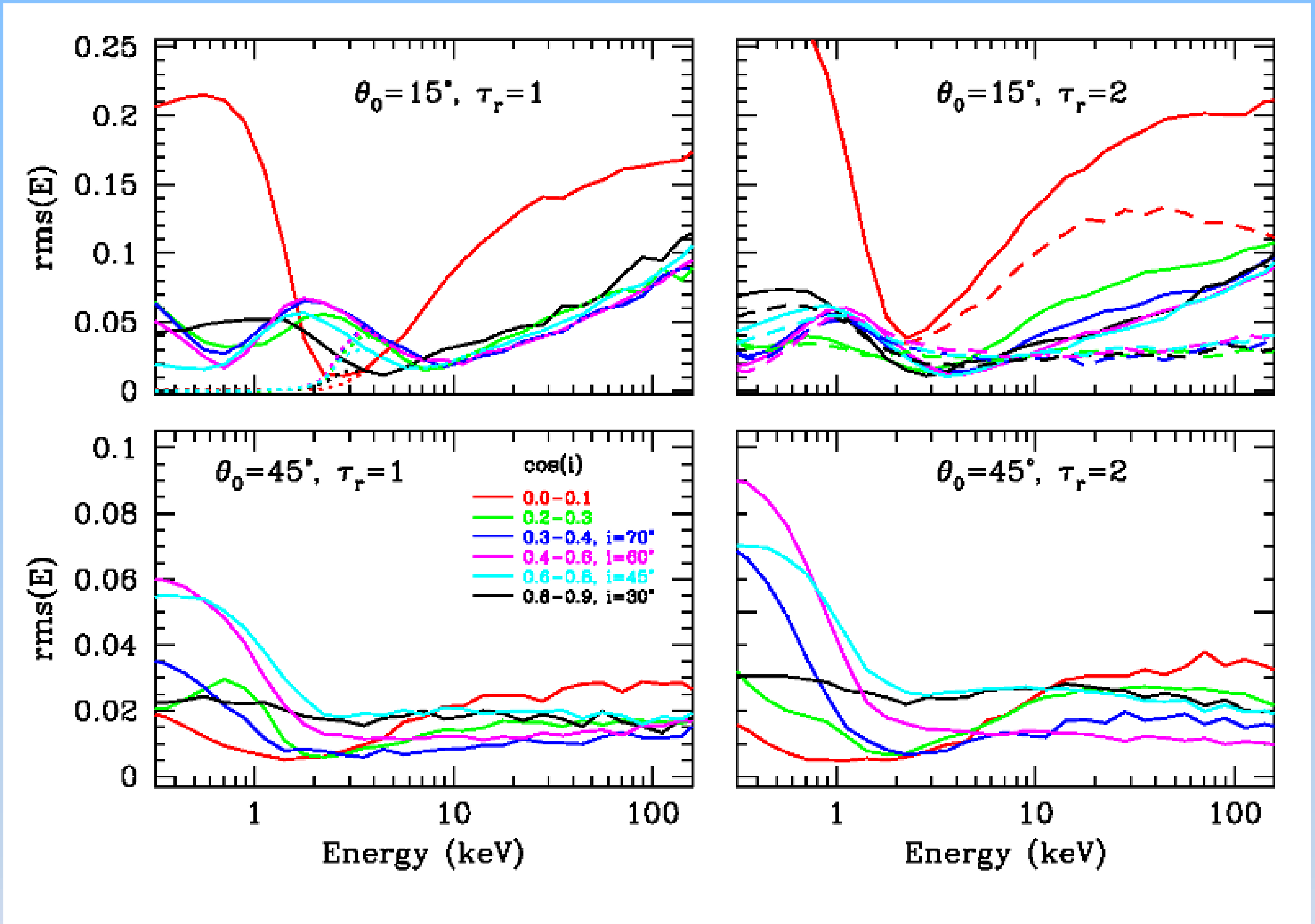
coplanar config.

prec. axis perp. to the outer disk

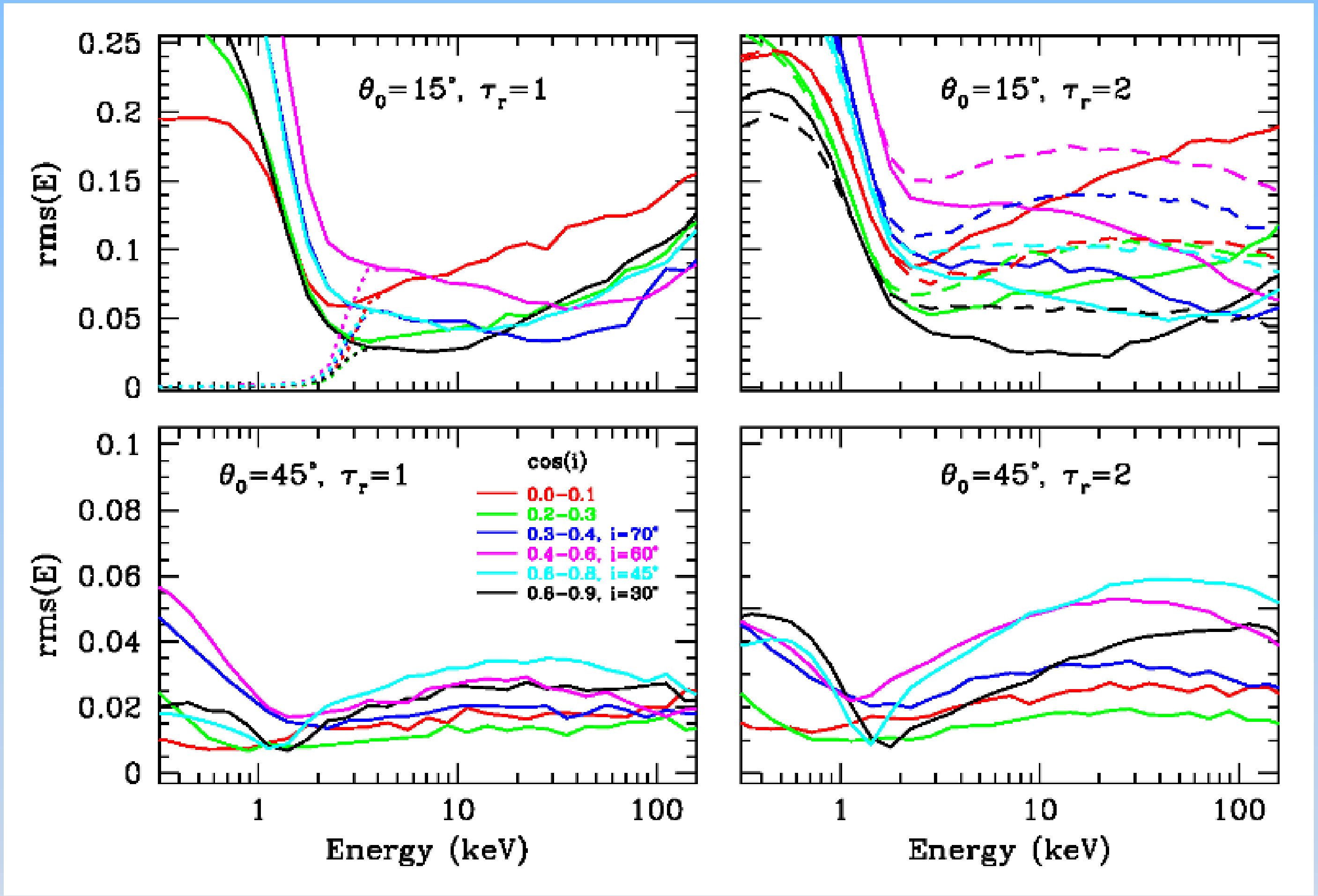
prec. axis inclined to the outer disk

Concept of compactness used here!

Precesion scenario **2** (precession axis *inclined* to the outer disk axis)
precession axis *towards* the observer

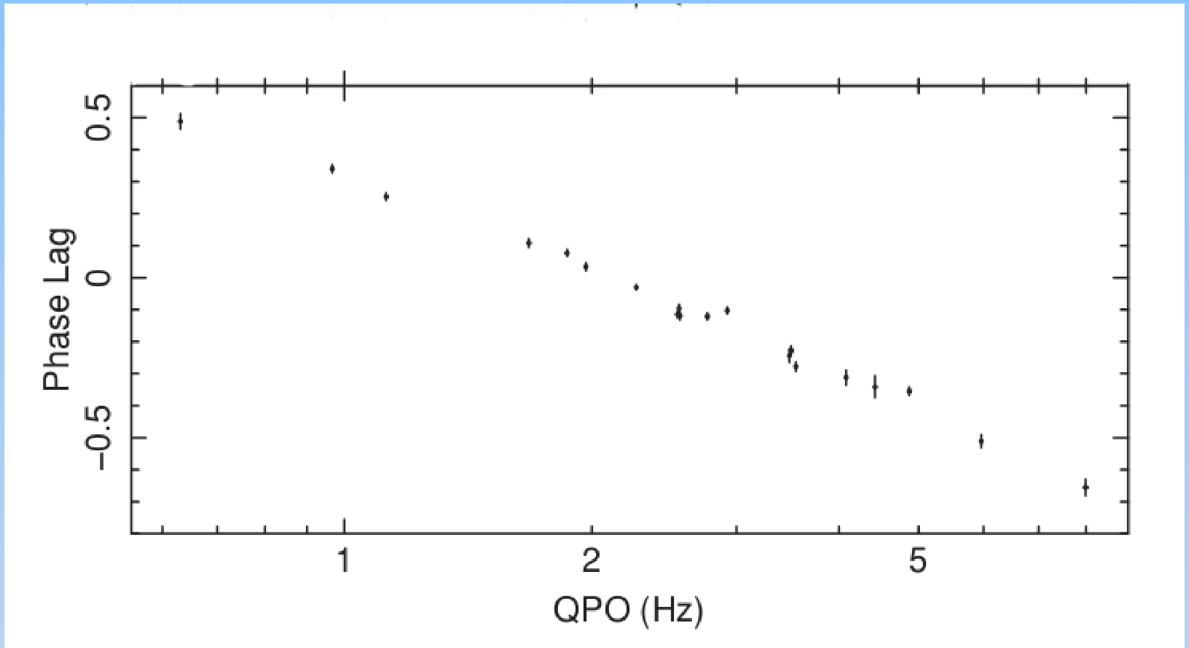


Precesion scenario **2** (precession axis *inclined* to the outer disk axis)
precession axis *away from* the observer



QPO phase lags - observations

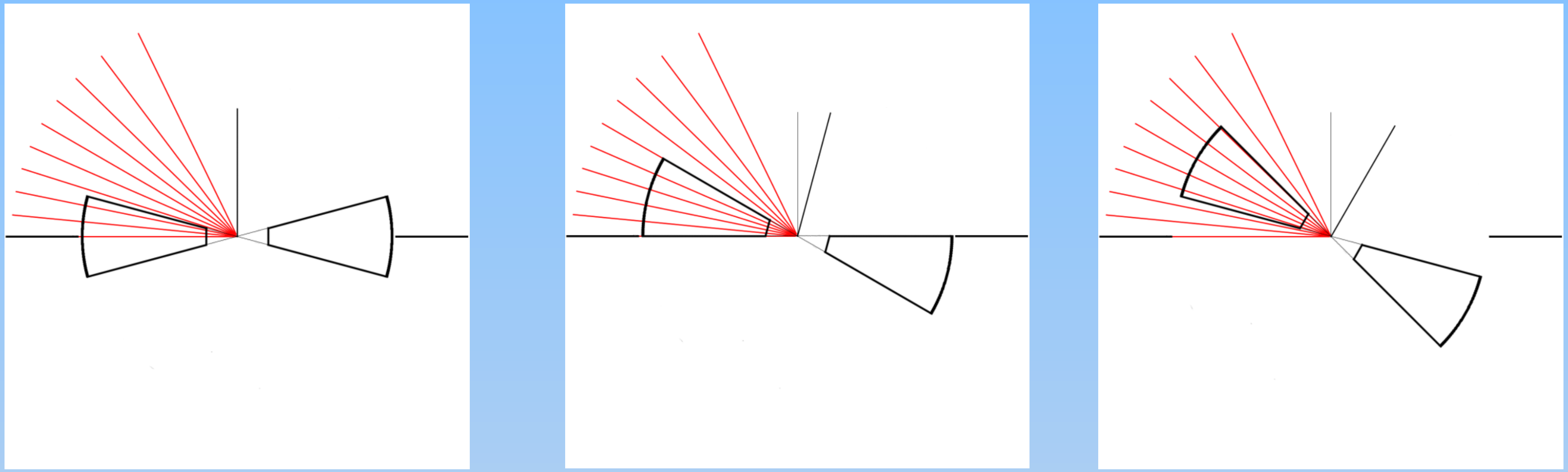
Phase difference between 2-5 keV and 13-18 keV QPO;



Qu et al., 2010

GRS 1915+105; RXTE observations

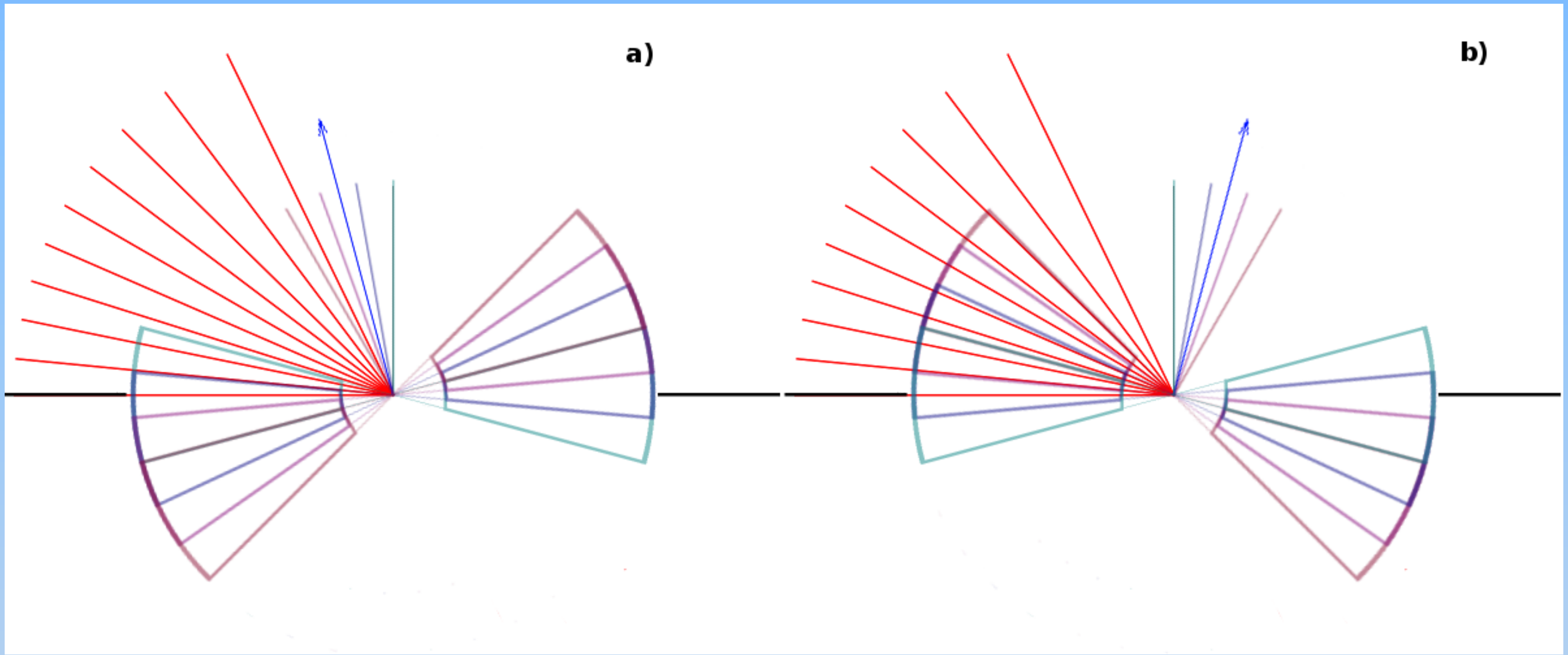
Simulations



Half opening angle of the torus – 15 deg
Angle between system axis and precession axis – 15 degs

Inclination angle: 60 degs

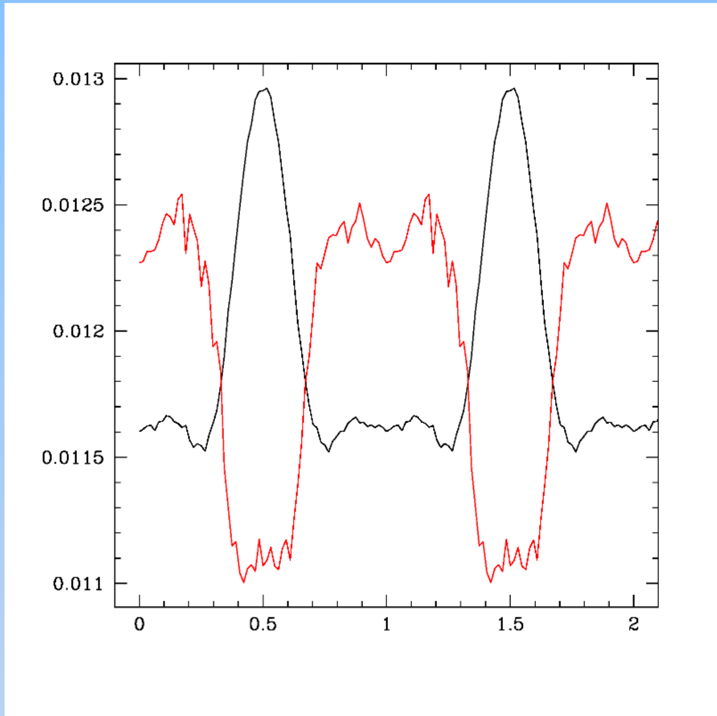
Simulations

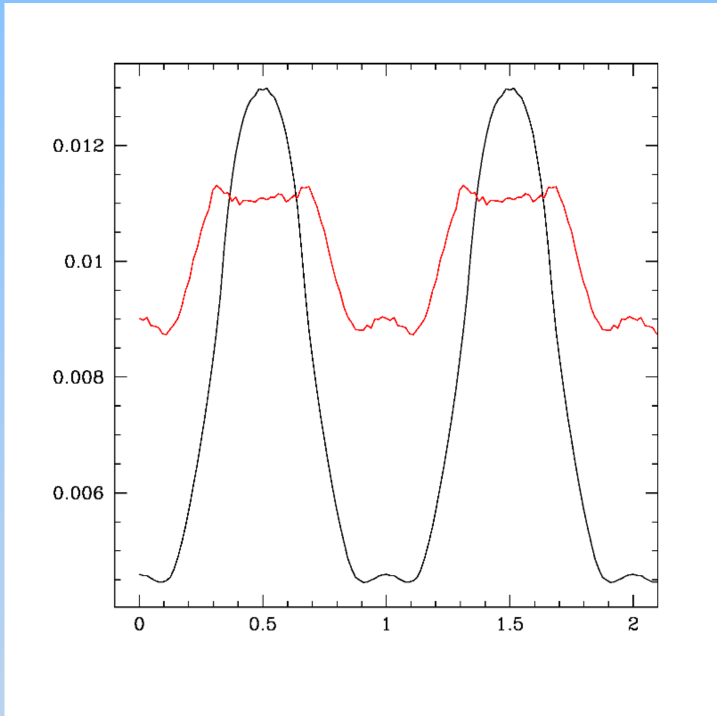


Precession axis towards the observer and away from the observer

Lightcurves

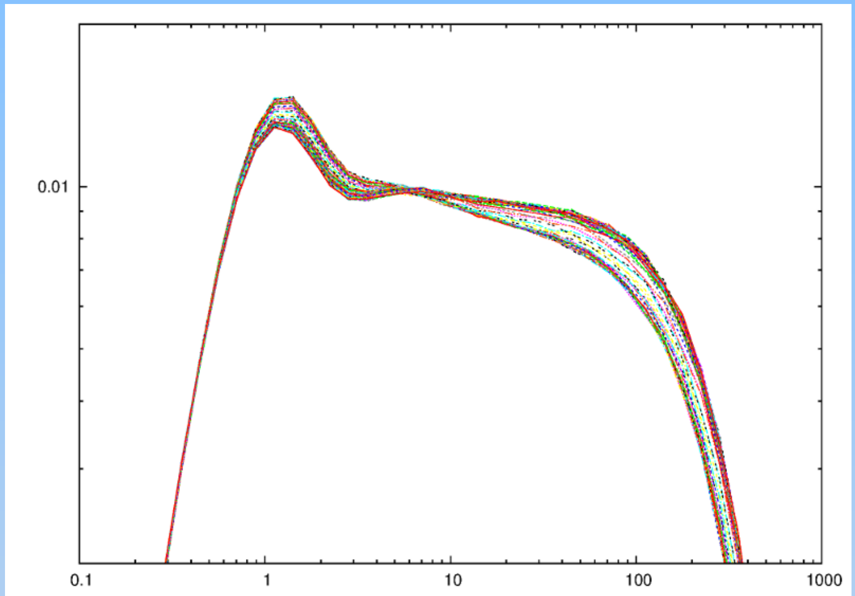
1 keV and 30 keV light curves

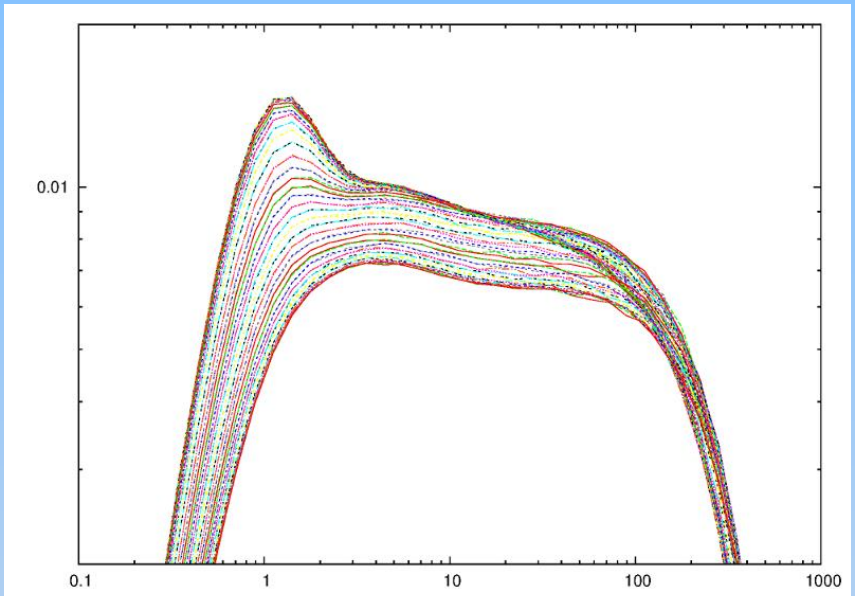




Precession axis **towards** the observer and **away from** the observer

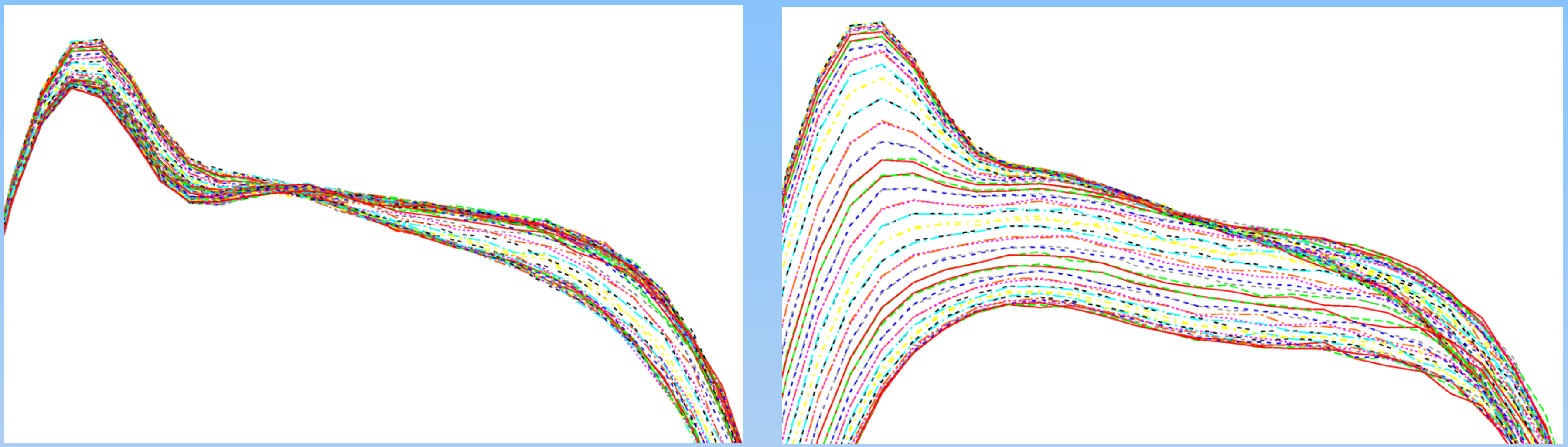
Spectral variability





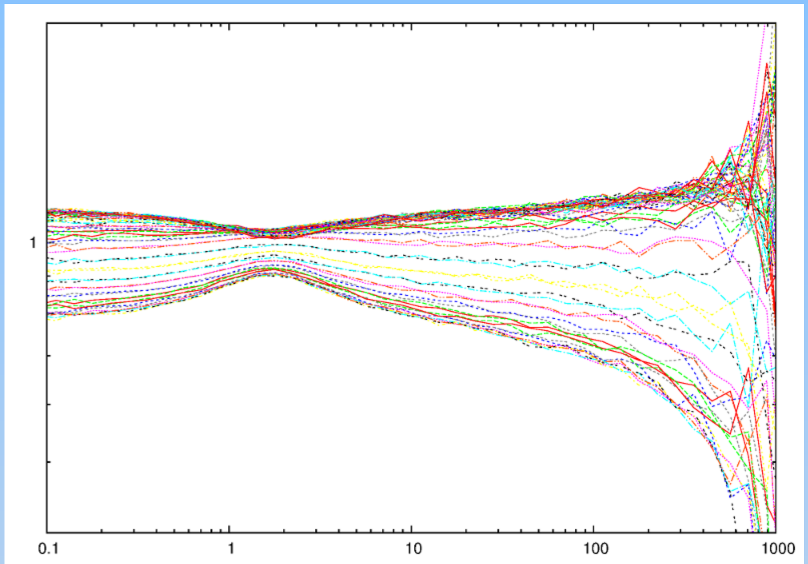
Precession axis **towards** the observer and **away from** the observer

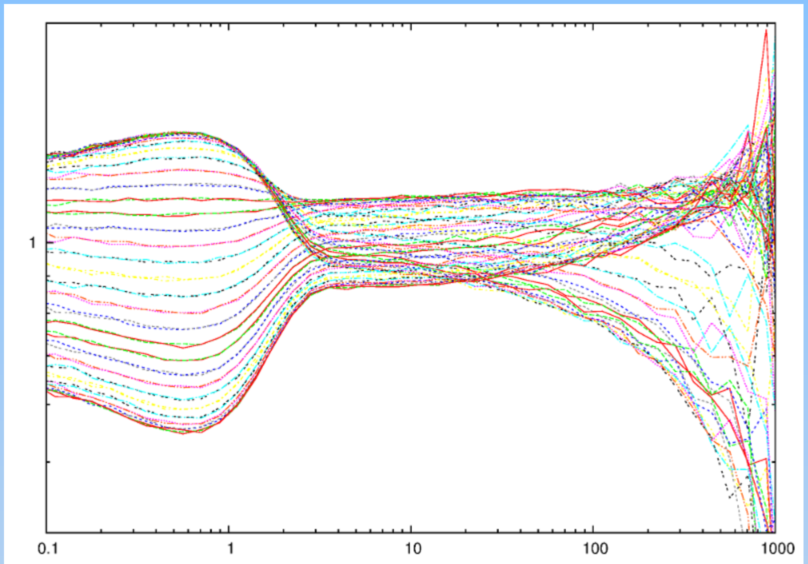
Spectral variability



Precession axis **towards** the observer and **away from** the observer

Spectral variability

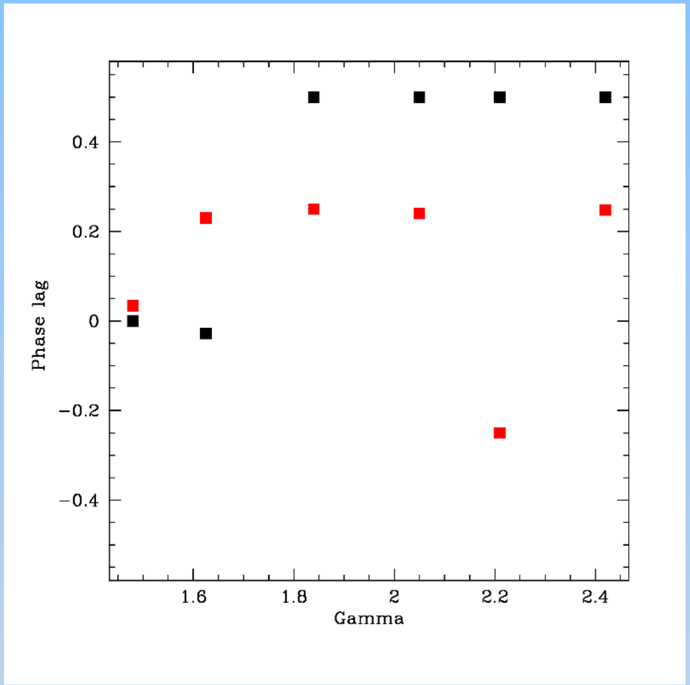


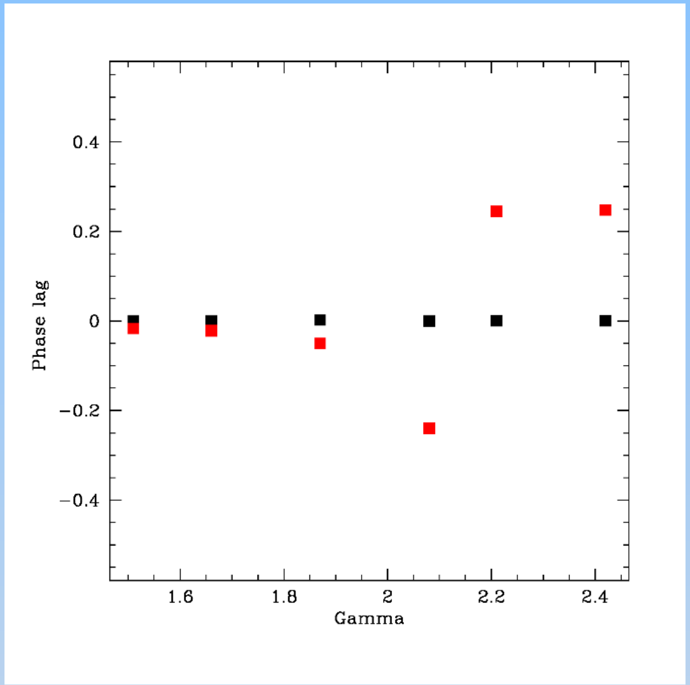


Precession axis **towards** the observer and **away from** the observer

Phase lags

3 keV vs 30 keV; signal at f_{QPO} and its first harmonic

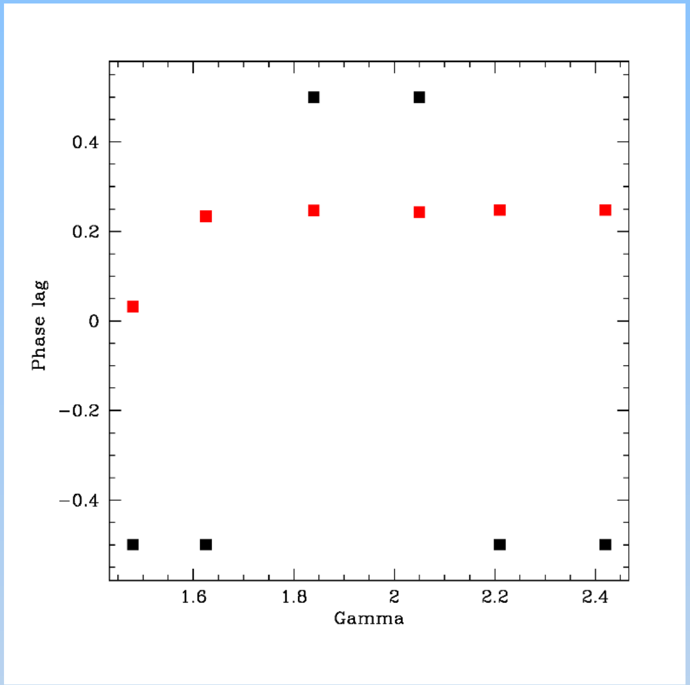


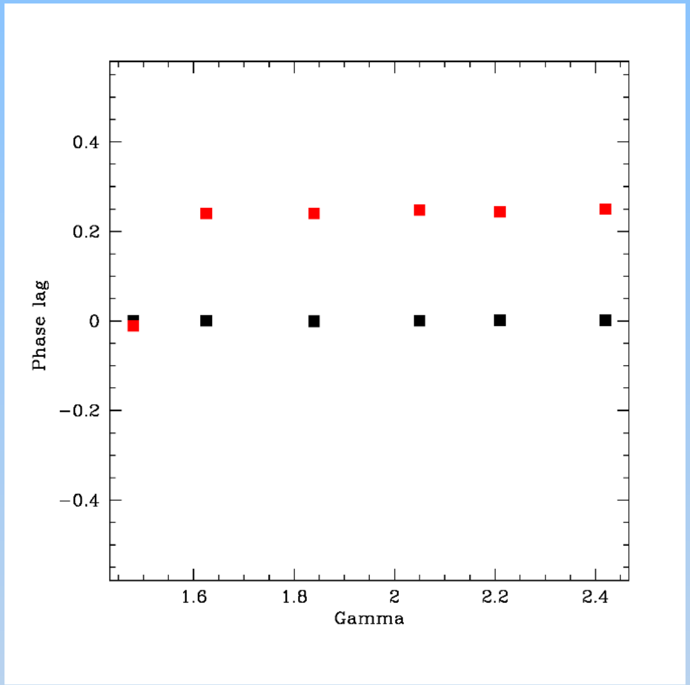


Precession axis **towards** the observer and **away from** the observer

Phase lags

1 keV vs 30 keV; signal at f_{QPO} and its first harmonic

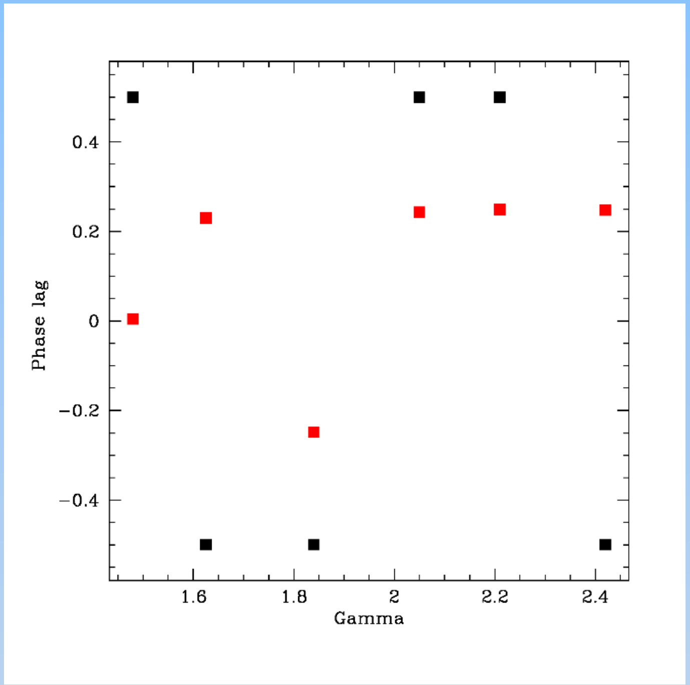


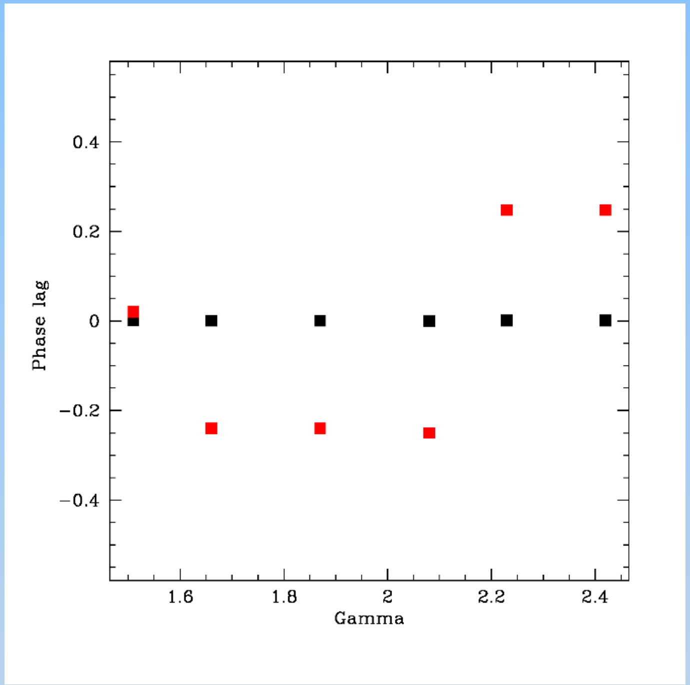


Precession axis **towards** the observer and **away from** the observer

Phase lags

1 keV vs 20 keV; signal at f_{QPO} and its first harmonic

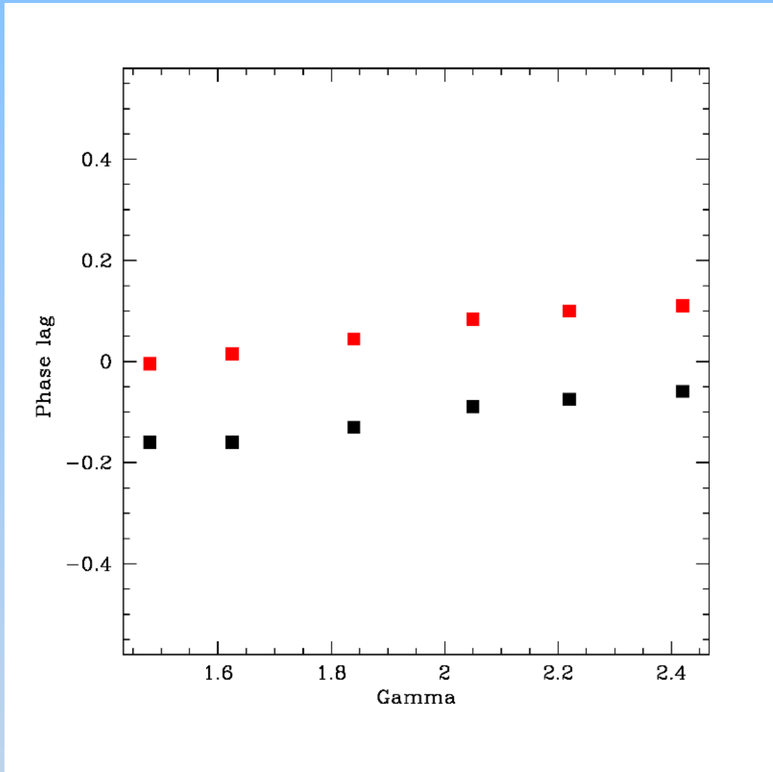




Precession axis **towards** the observer and **away from** the observer

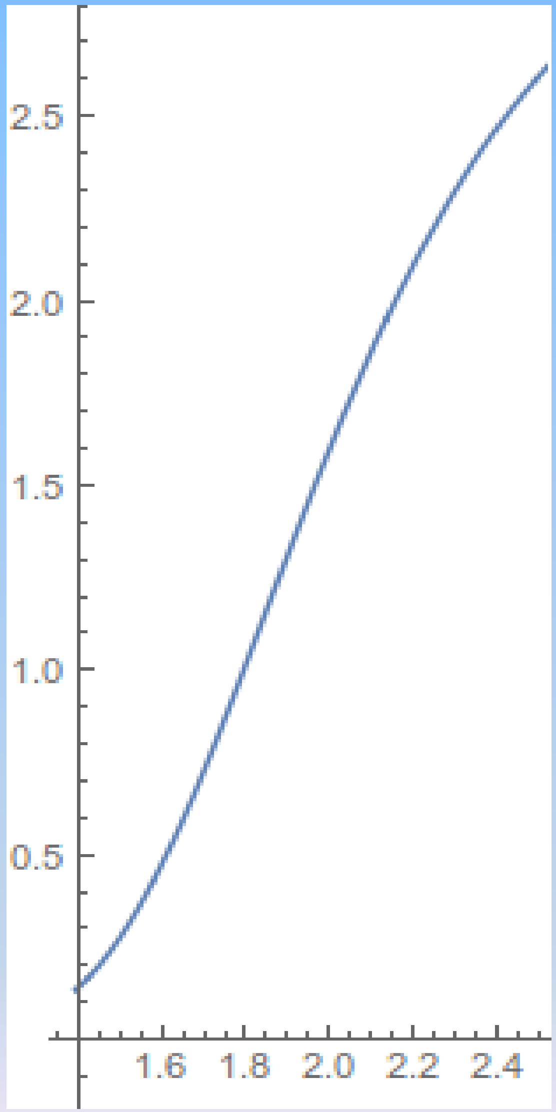
Phase lags

1 keV vs 20 keV; signal at f_{QPO} and its first harmonic

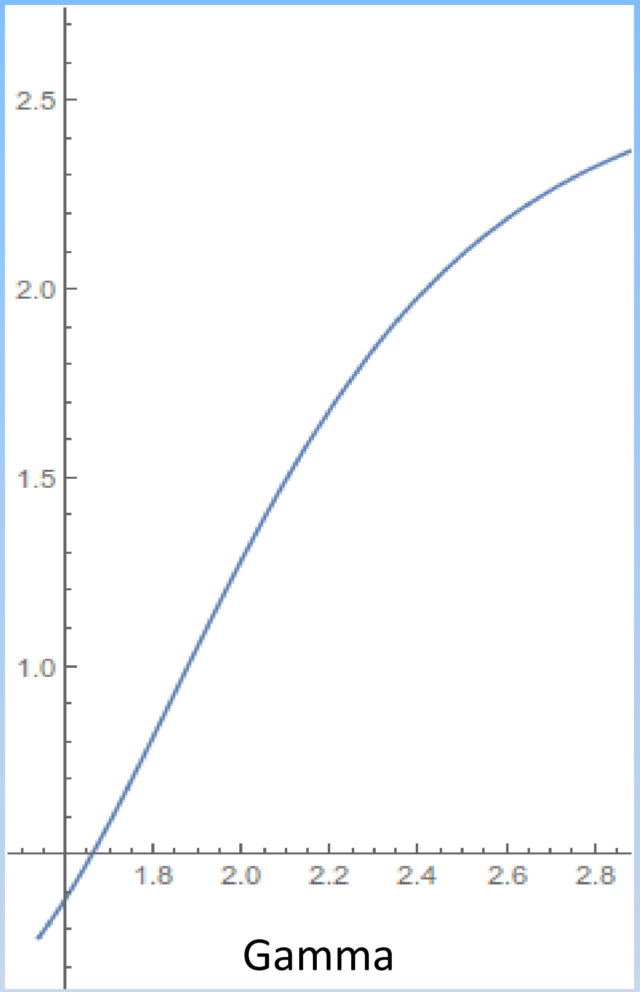


Precession axis **at 90 degs angle** wrt the observer

Spectral slope vs QPO frequency



Gamma



Gamma

In summary…

The Monte Carlo approach assumes a simple **uniform** (density, temperature) configuration.

It may be that the radial structure is crucial for explaining the details.