The Lense-Thirring precession model of the low-frequency X-ray QPO

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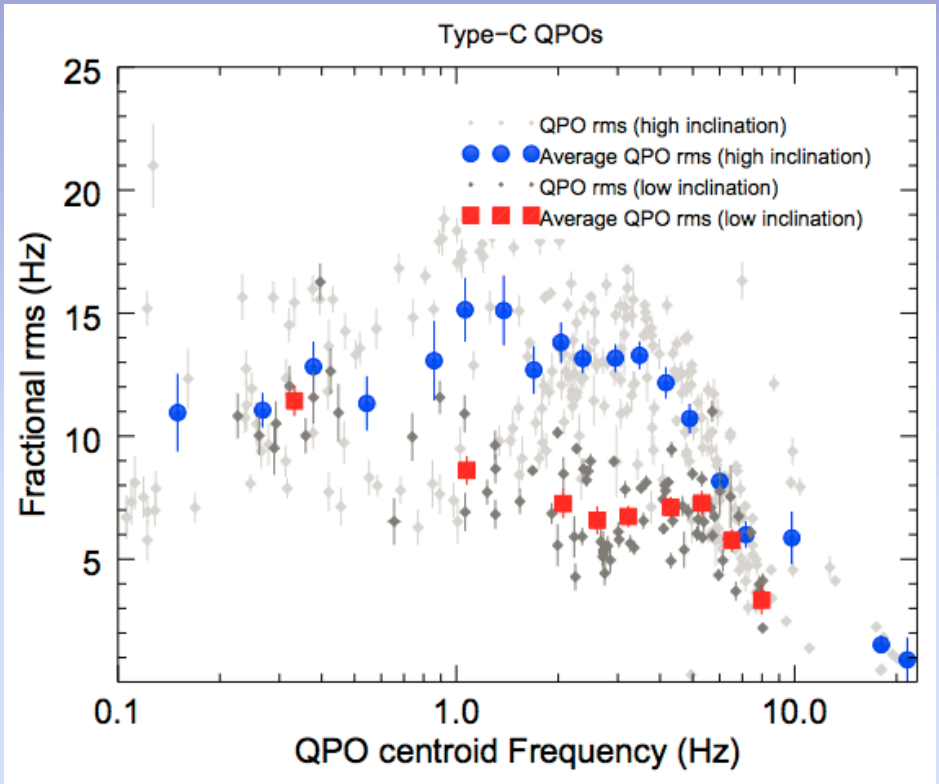
Important observational hint



Higher inclination sources have stronger QPO
(Motta et al., 2014; Heil, Uttley & Klein-Wolt 2014)

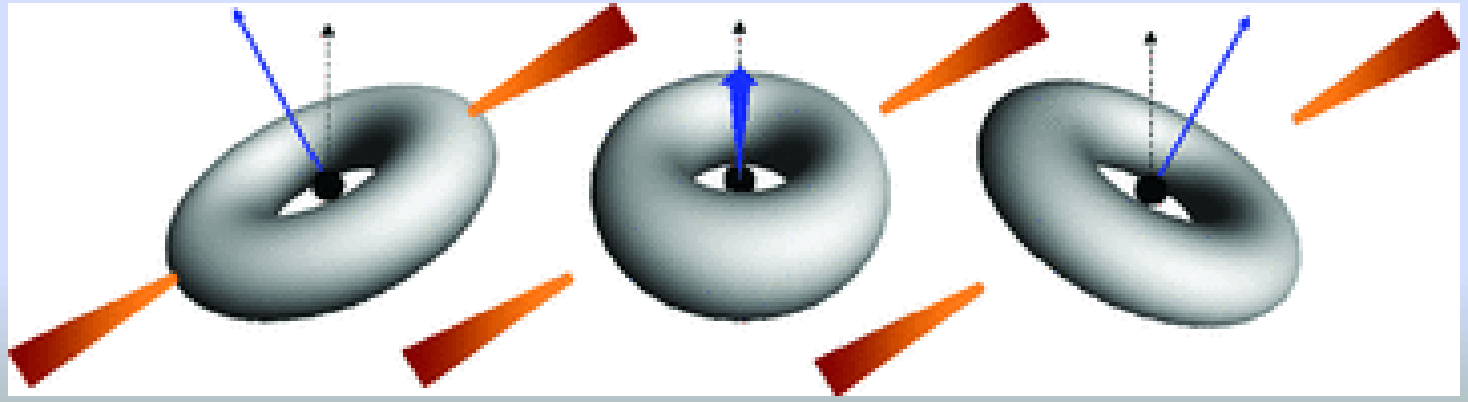
The Lense-Thirring precession model for low-*f* QPO

Formulated by Stella & Vietri (1998)

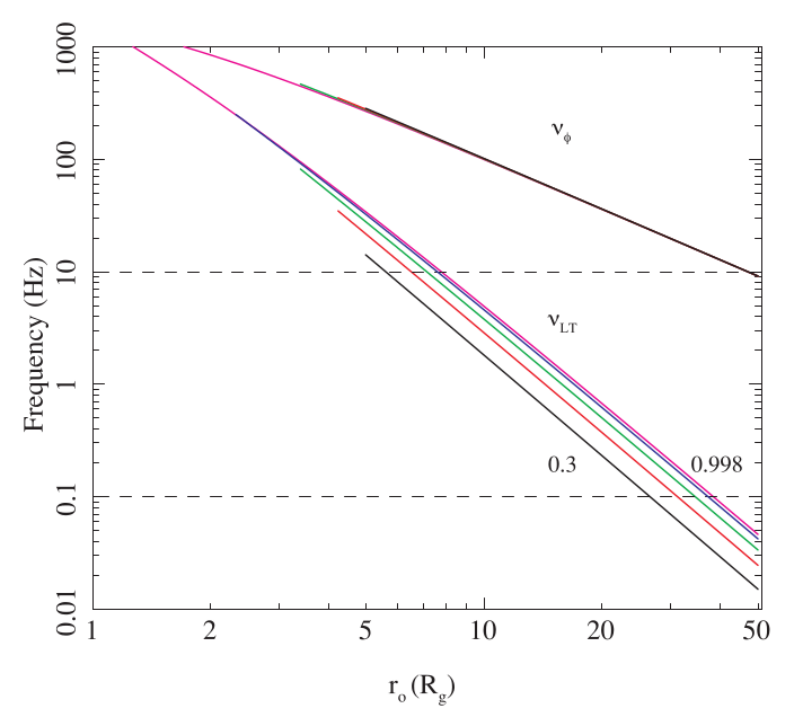
Recent hydrodynamical simulations suggest that the hot flow behaves (precesses) like a solid body.

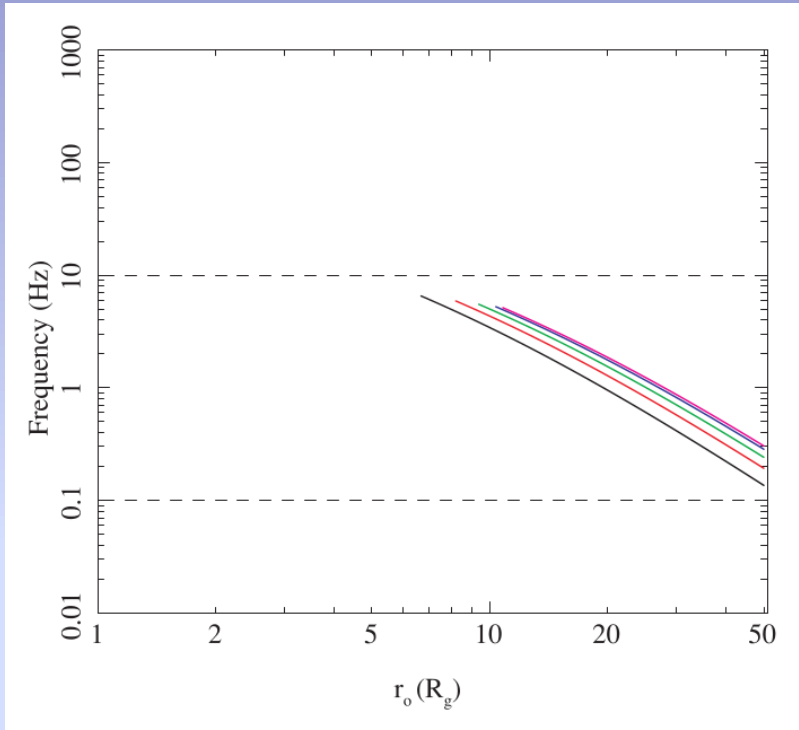
Inner radius of the flow is determined by properties of the bending waves. It is approximately independent of the spin of the black hole. As a result the maximum precession frequency does not depend on the spin)

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



Precession frequency

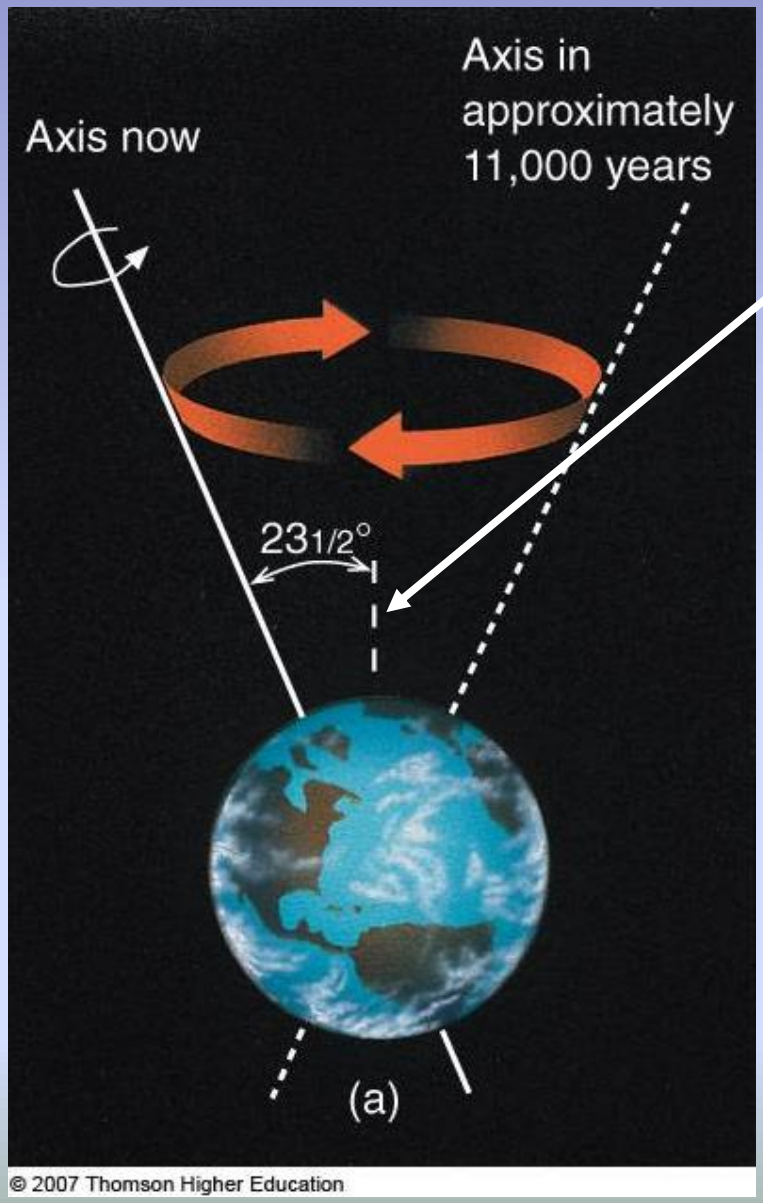




LT frequency vs radius of precessing particle

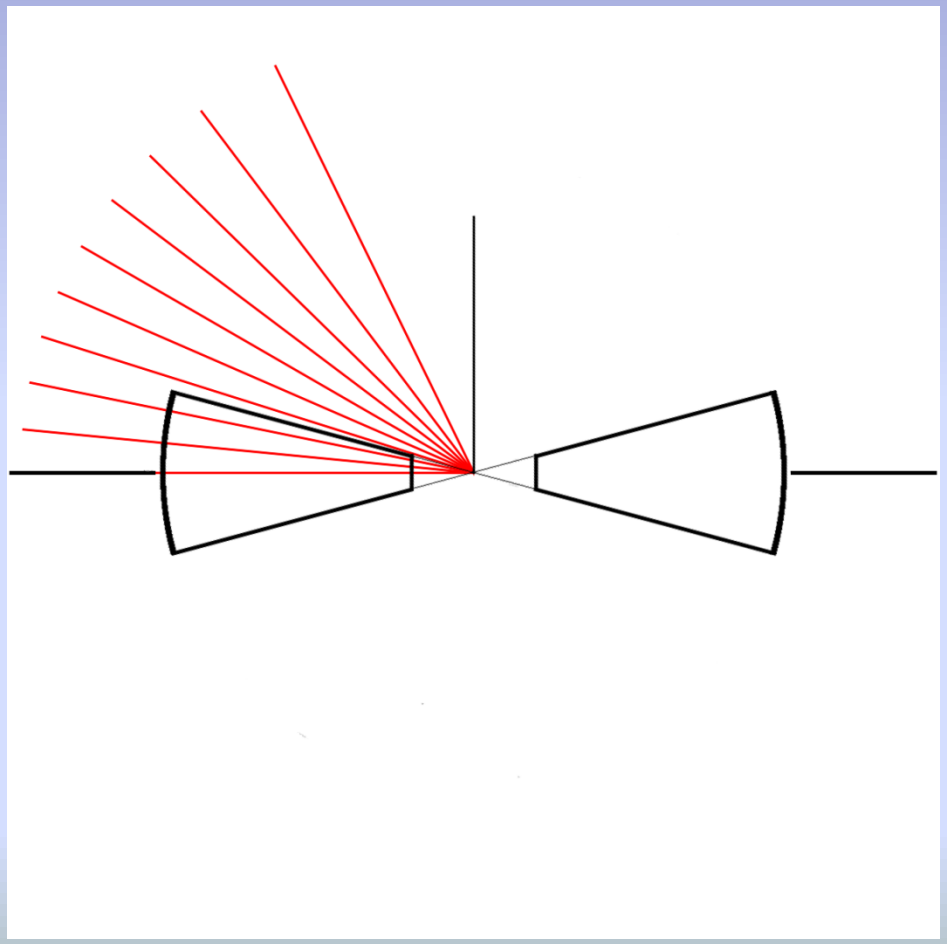
LT frequency vs outer radius of precessing solid body torus with inner radius set by bending waves

The LT precession is of relativistic origin (requires Kerr metric) but we want to get rid of the dependence on *a.*



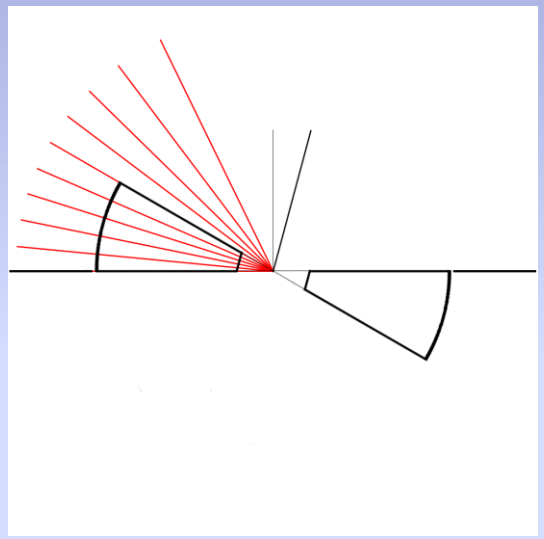
Precession axis

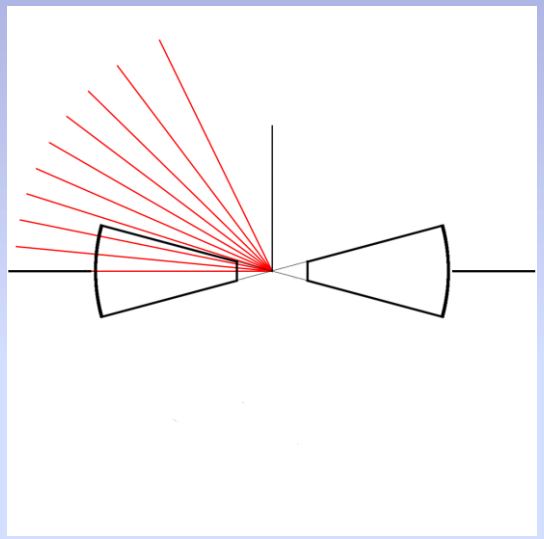
Geometry

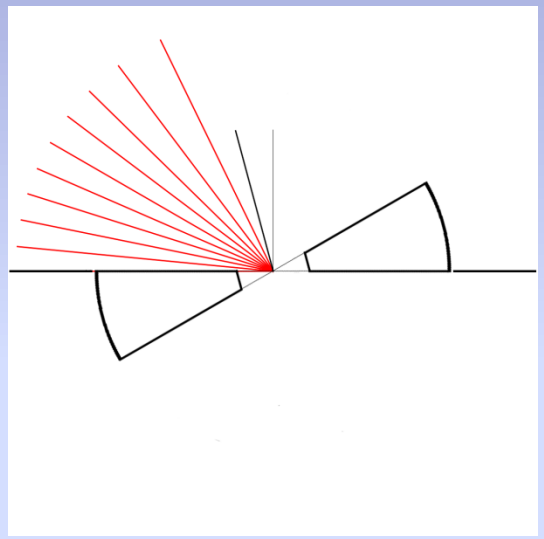


Two geometrical scenarios:
1.precession axis perp. to the outer disk
2.Precession axis inclined to the outer disk (based on Bardeen-Peterson effect)

Geometry 1

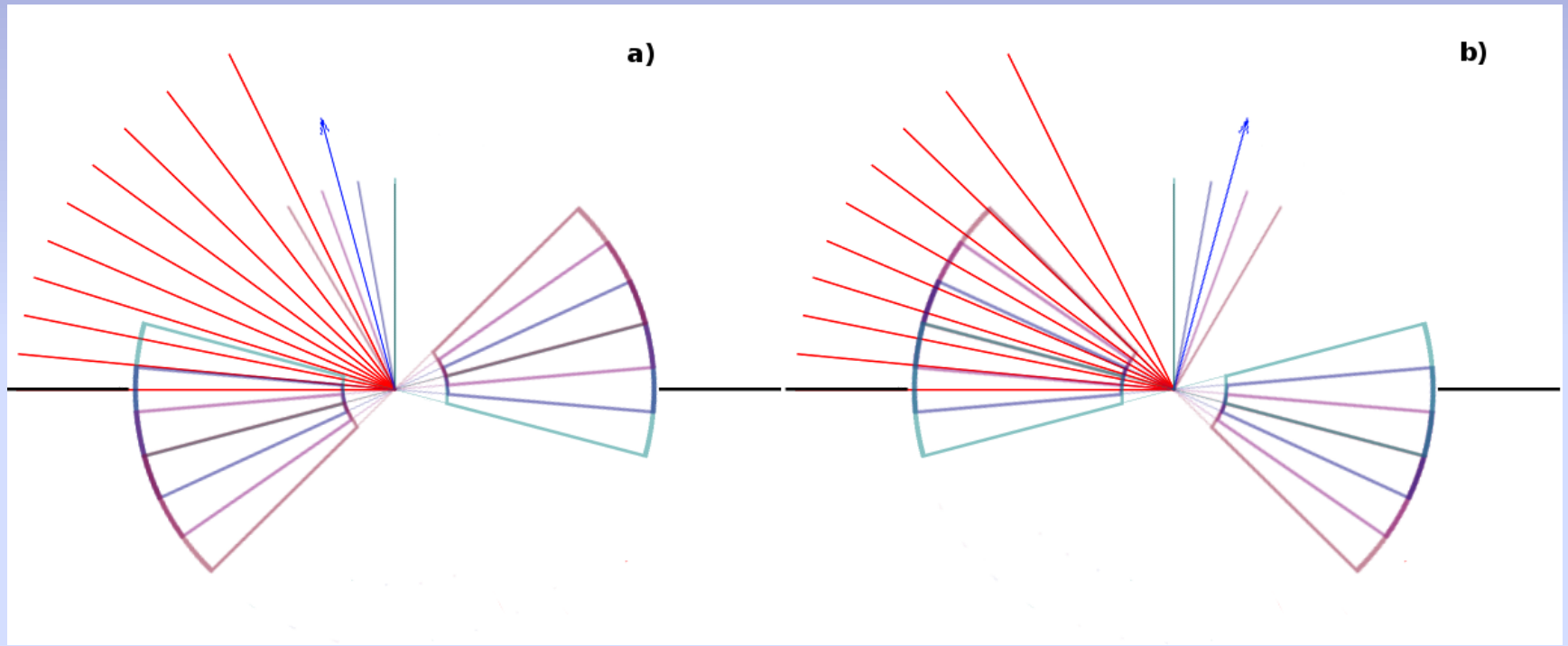






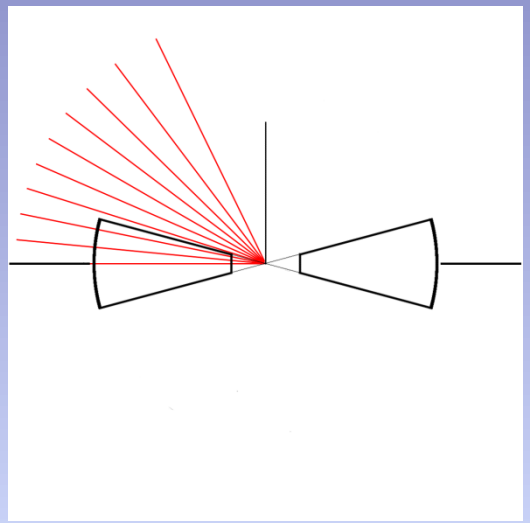
3D geometry does NOT change with the precession phase

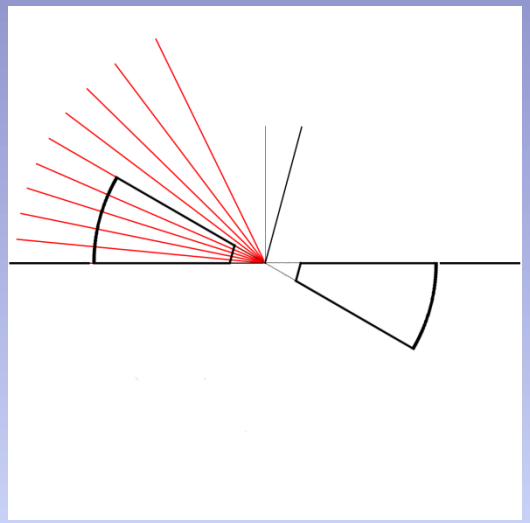
Geometry 2:

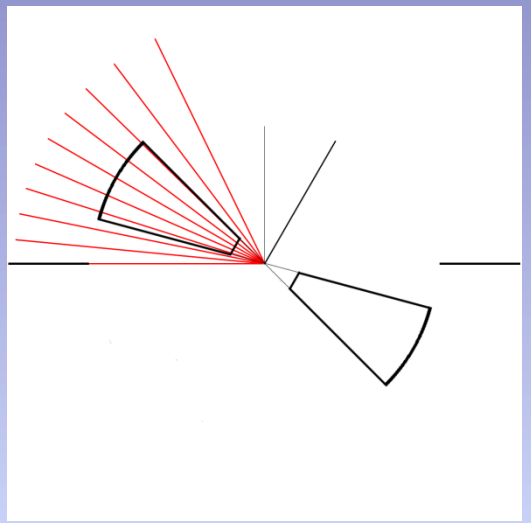


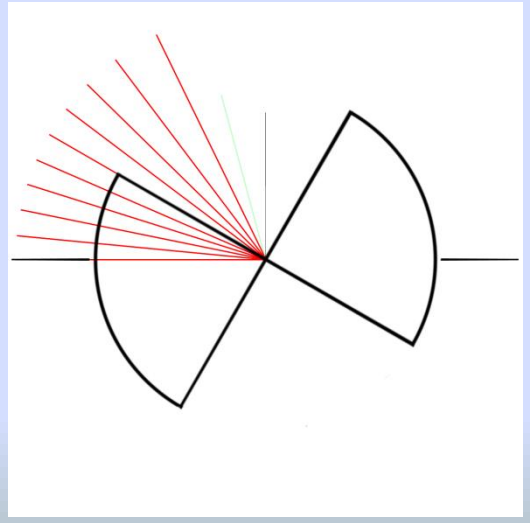
Position (azimuthal) angle of the precession axis is an additional parameter

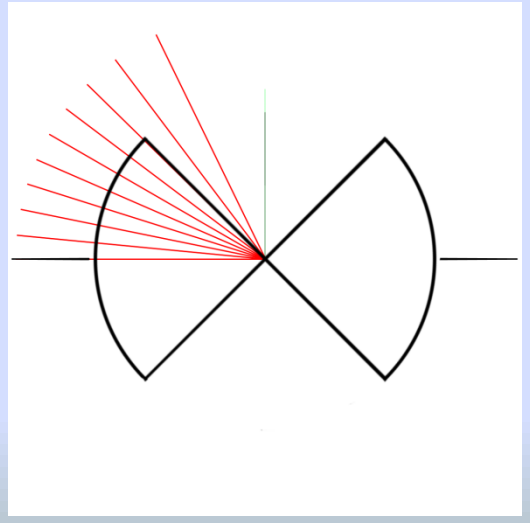
Geometry 2:

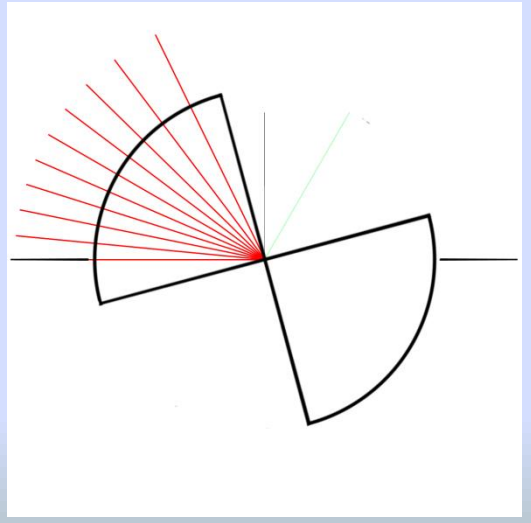




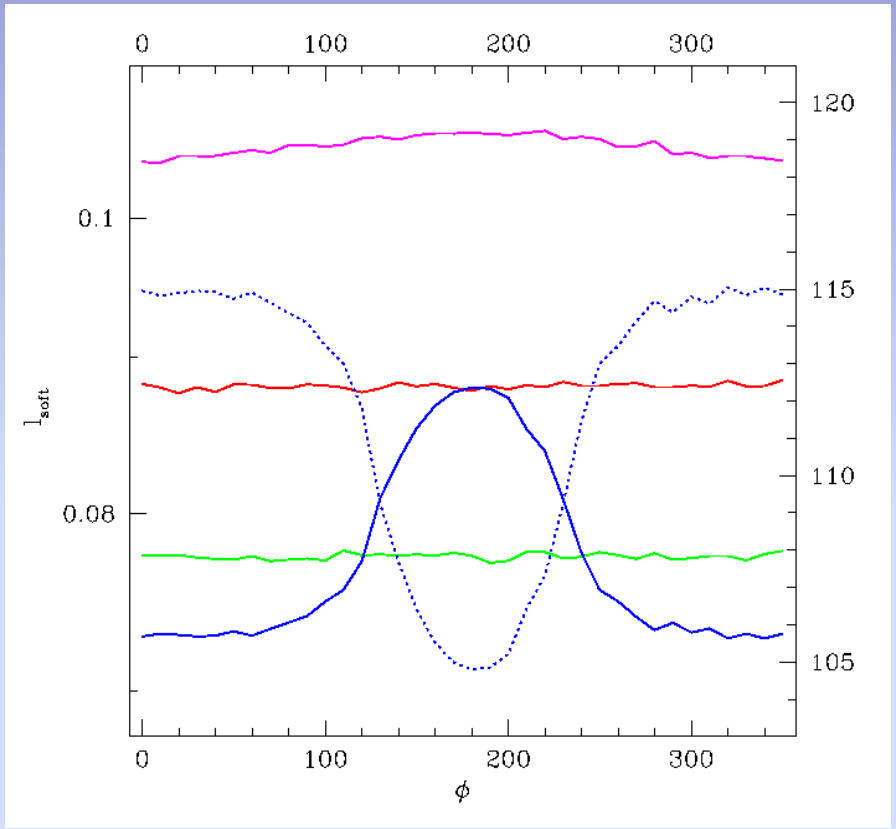








Soft photons



geometrically thick torus; to be compared with the blue curve

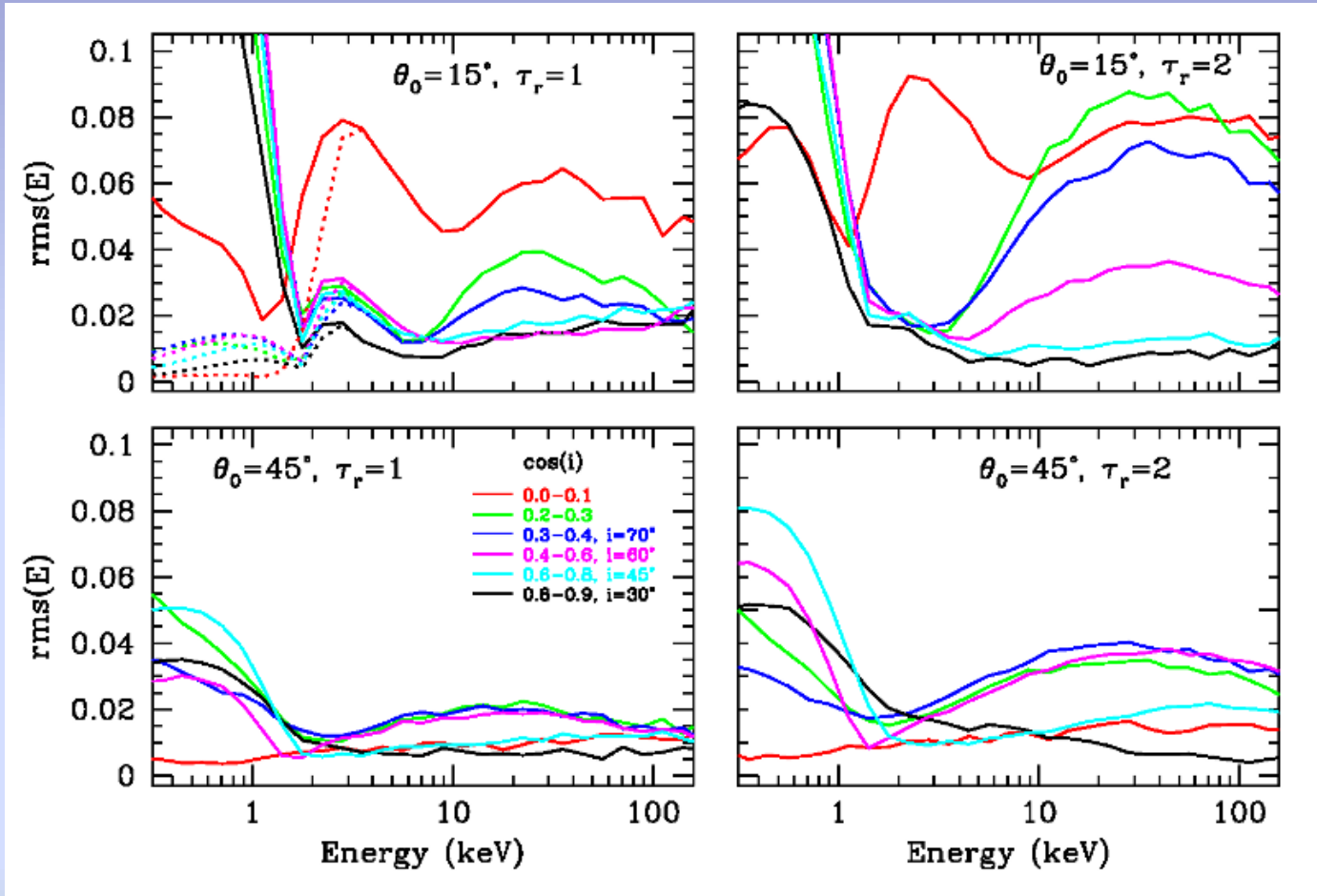
coplanar config.

prec. axis perp. to the outer disk

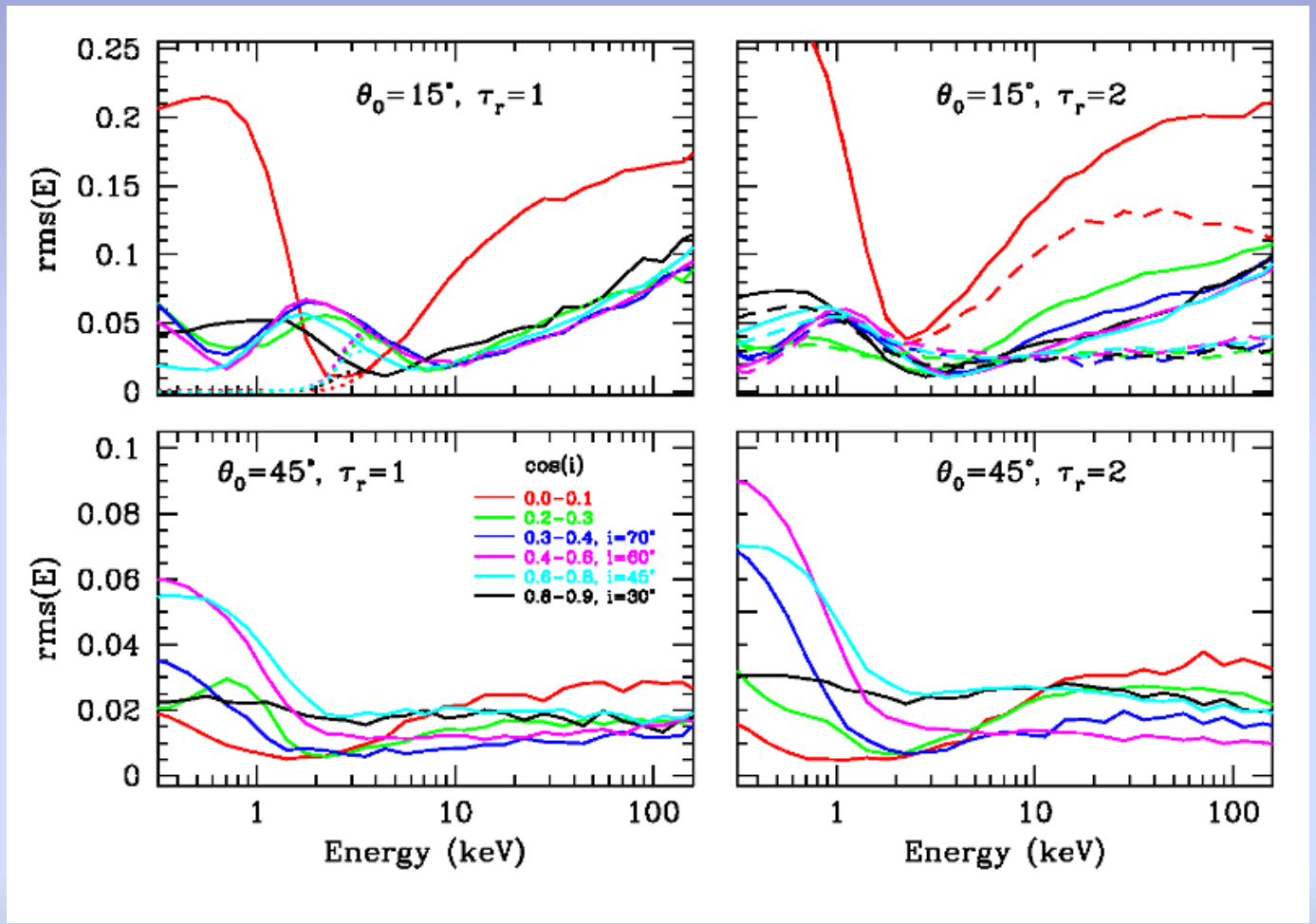
prec. axis inclined to the outer disk

Results

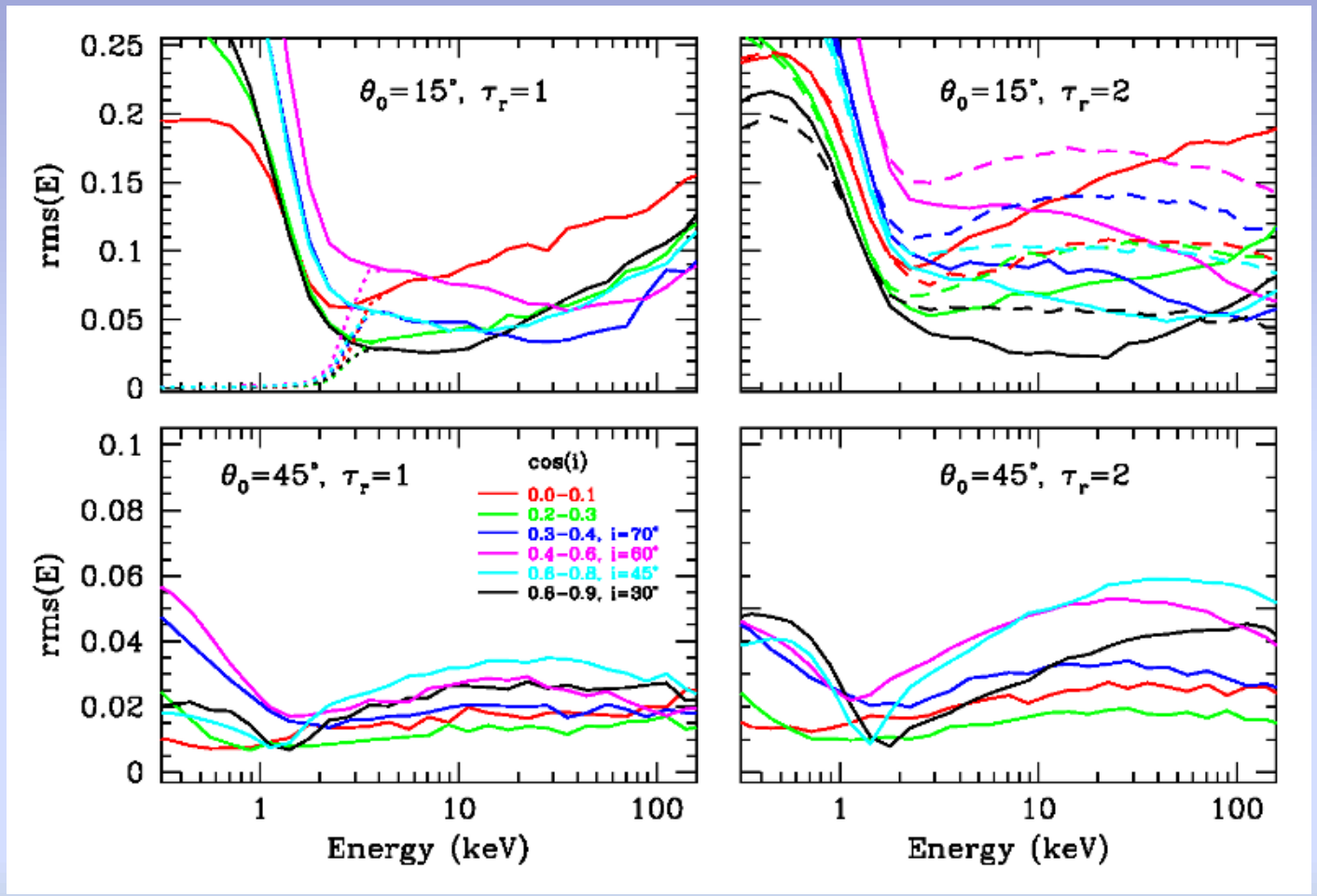
Precesion scenario **1** (precession axis *perpendicular* to the outer disk axis)



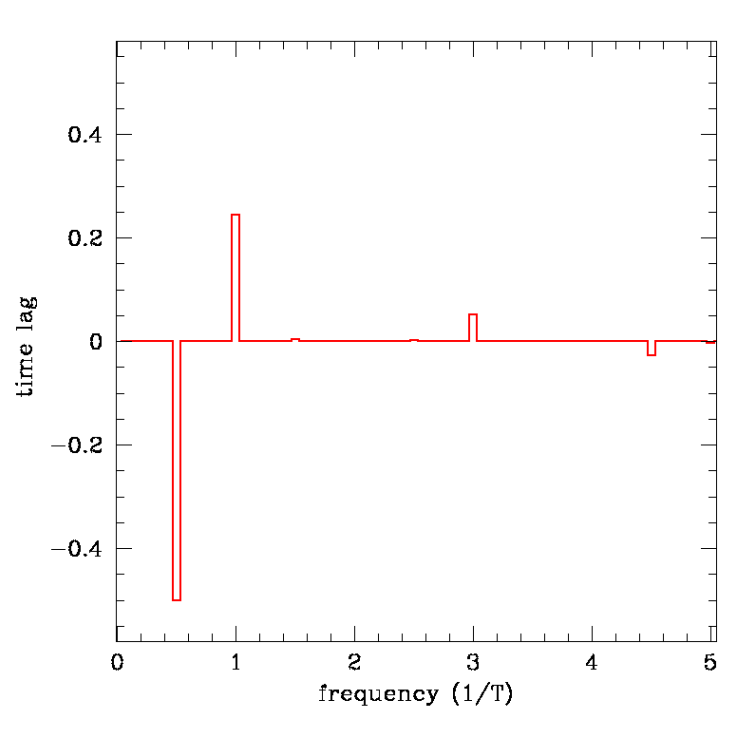
Precesion scenario **2** (precession axis *inclined* to the outer disk axis)
precession axis *towards* the observer



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



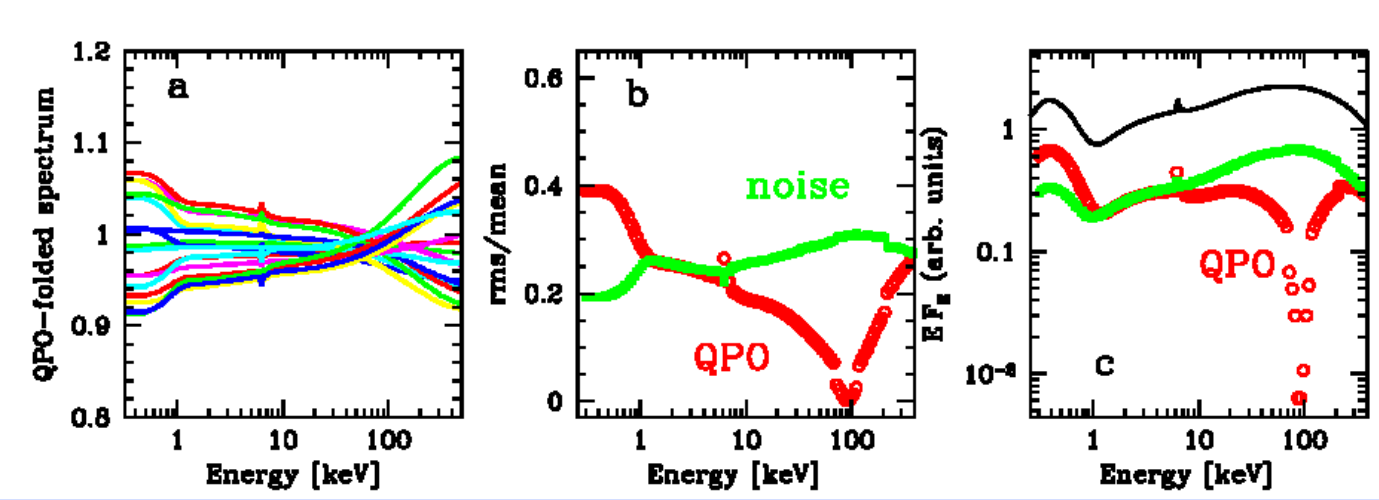
Timing properties of the QPO



Time lags between two energy bands (1 vs 10 keV)

Future

Add Fe line



When the QPO is created by the modulation of the geometry, the line changes and produces a signal in the QPO spectrum

Possible developements:

Model:

1. Illumination of the outer disk
2. Modification of the geometry: additional corona above the outer disk
3. Relativistic effects: not easy, since emission comes from a geometrically thick torus; even more difficult to introduce rel. effects inside the torus
4. Simulations of the timing properties of the QPO

Visualization:

Precessing torus

Data:

More data, systematic studies of QPO behaviour