Black hole accretion rings revealed by future X-ray spectroscopy

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Motivation

We can imagine the accretion disc as a superposition of radiating accretion rings.

The existence of an emissivity profile of a narrow ring in a spectrum may represent a realistic profile (magnetic flares as sites of local illumination).

The Large Observatory For X-ray Timming (LOFT) should have the necessary capability to measure the rings in spectra.

Then we can establish the parameters of the system with a black hole (spin, location of rings, inclination of observer) from the knowledge of extremal energy shifts of rings in spectra.

Motivation

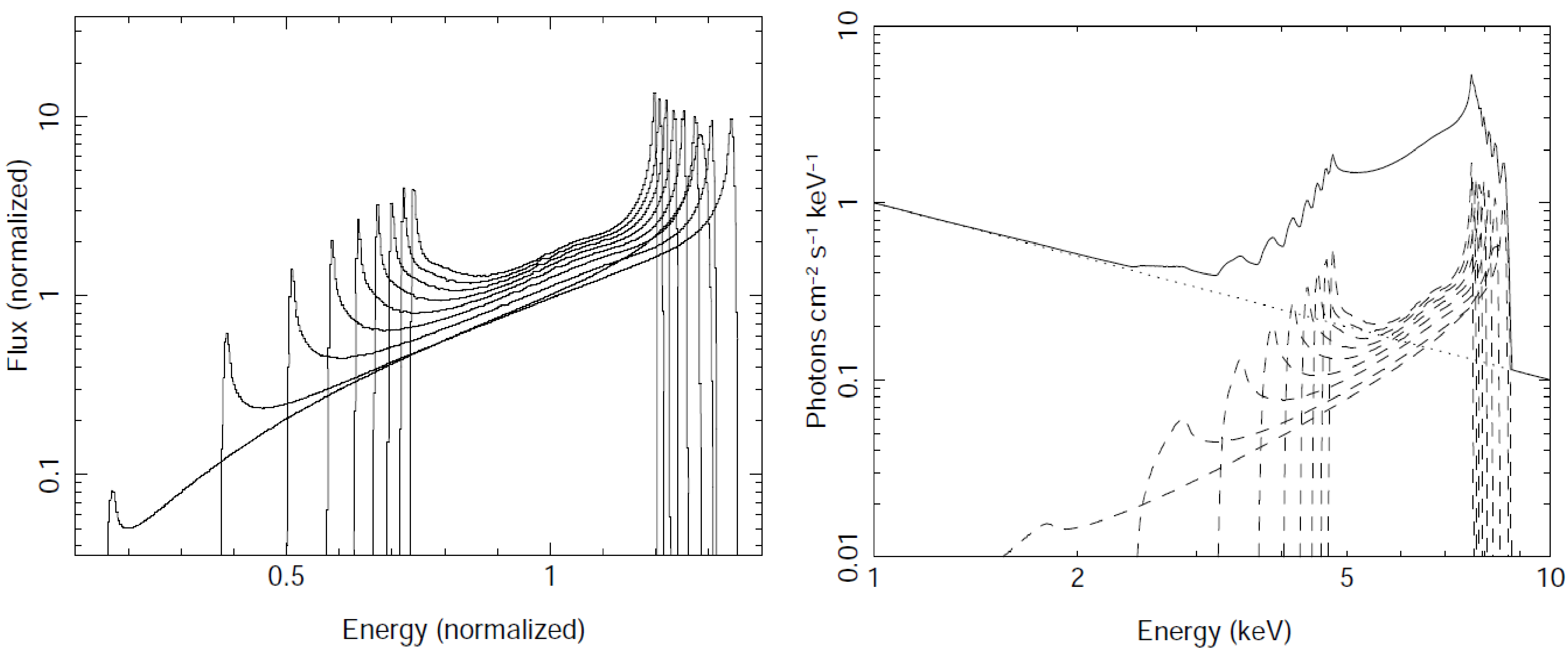

Fig. 1: Double-horn spectral lines for observer's inclination 75 deg, black hole spin a = 0.998.
Left: theoretical profiles of narrow rings orbiting in equatorial plane of a Kerr black hole.
Right: theoretical profile from a set of extended (Δr = 1) rings with power-law continuum.
(Karas & Sochora, 2010)

The LOFT mission*

The Large Observatory For X-ray Timing is a medium-class mission selected for the assessment phase of the ESA M3 Cosmic Vision call.

The goal of the mission are observations of compact objects to provide direct acces to strong-field gravity, black hole masses and spins, and the equation of state ultradense matter.

LOFT achieves an effective area of ~12 m^2 in the 2-30 keV range (broadened 6-7 keV Fe-K lines), energy resolution about 150 eV.

A good possibility to measure the double-horn profiles in spectra.

*http://gri.rm.iasf.cnr.it/

The energy shifts

$$g = \frac{E_{obs}}{E_{em}} = \frac{1}{u^t} \frac{1}{1 - \lambda \Omega}$$

Ω is Keplerian angular velocity
***u**^t* **is time component of four velocity**
λ is one of the constants of motion (*L_z/E*)
q^2 **is the second constants of motion (*Q/E* ^{2})**

$$\pm \int \frac{dr}{\sqrt{R(r, \lambda, q^2)}} = \pm \int \frac{d\theta}{\sqrt{\Theta(\theta, \lambda, q^2)}}$$

Carter equation describes the motion in radial and latitudinal direction.

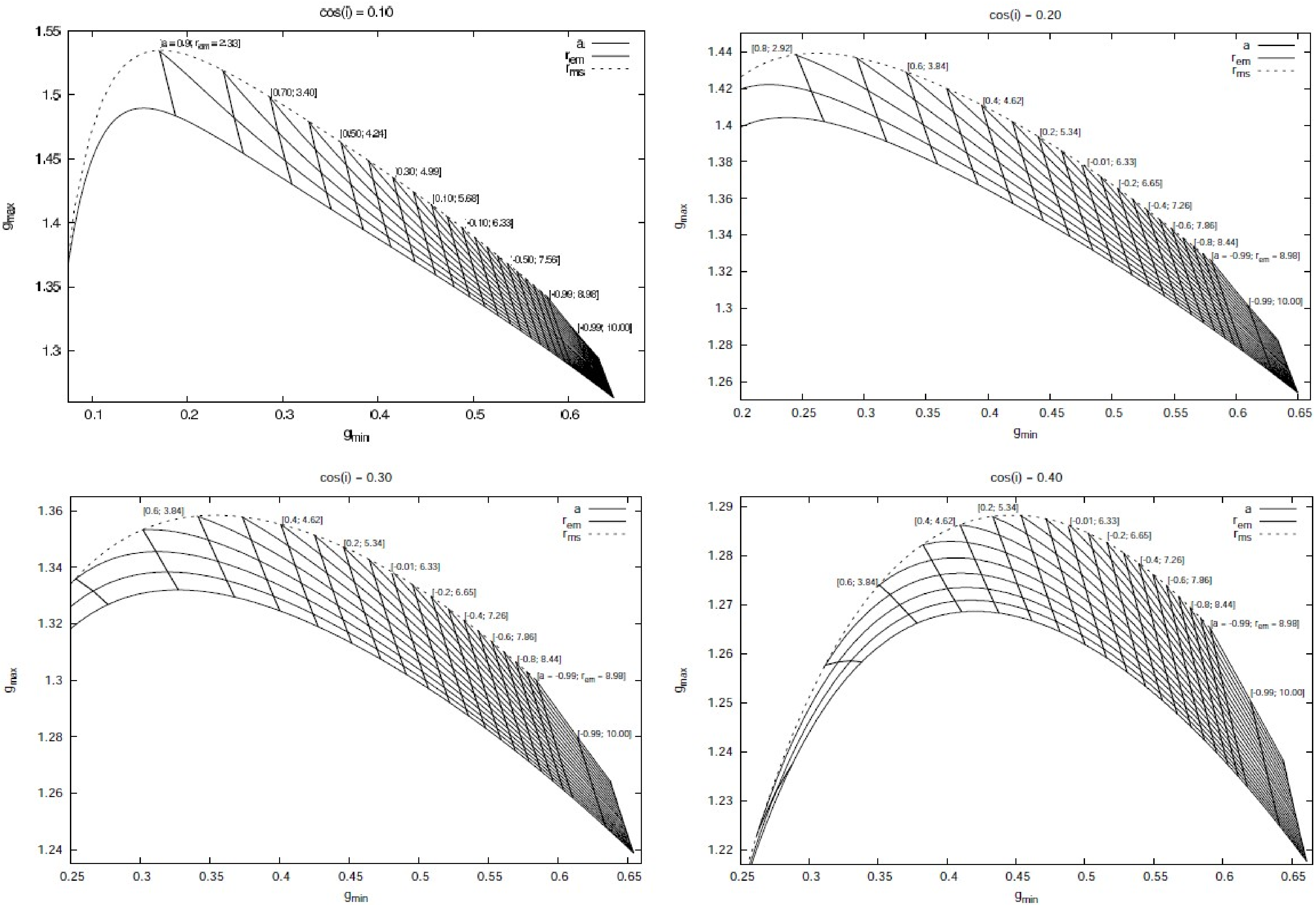

Fig. 2: Extremal energy shifts (g_{min} and g_{max}) for different inclinations cos*i* (84 deg, 78 deg, 72 deg and 66 deg), -1< *a* < 1.

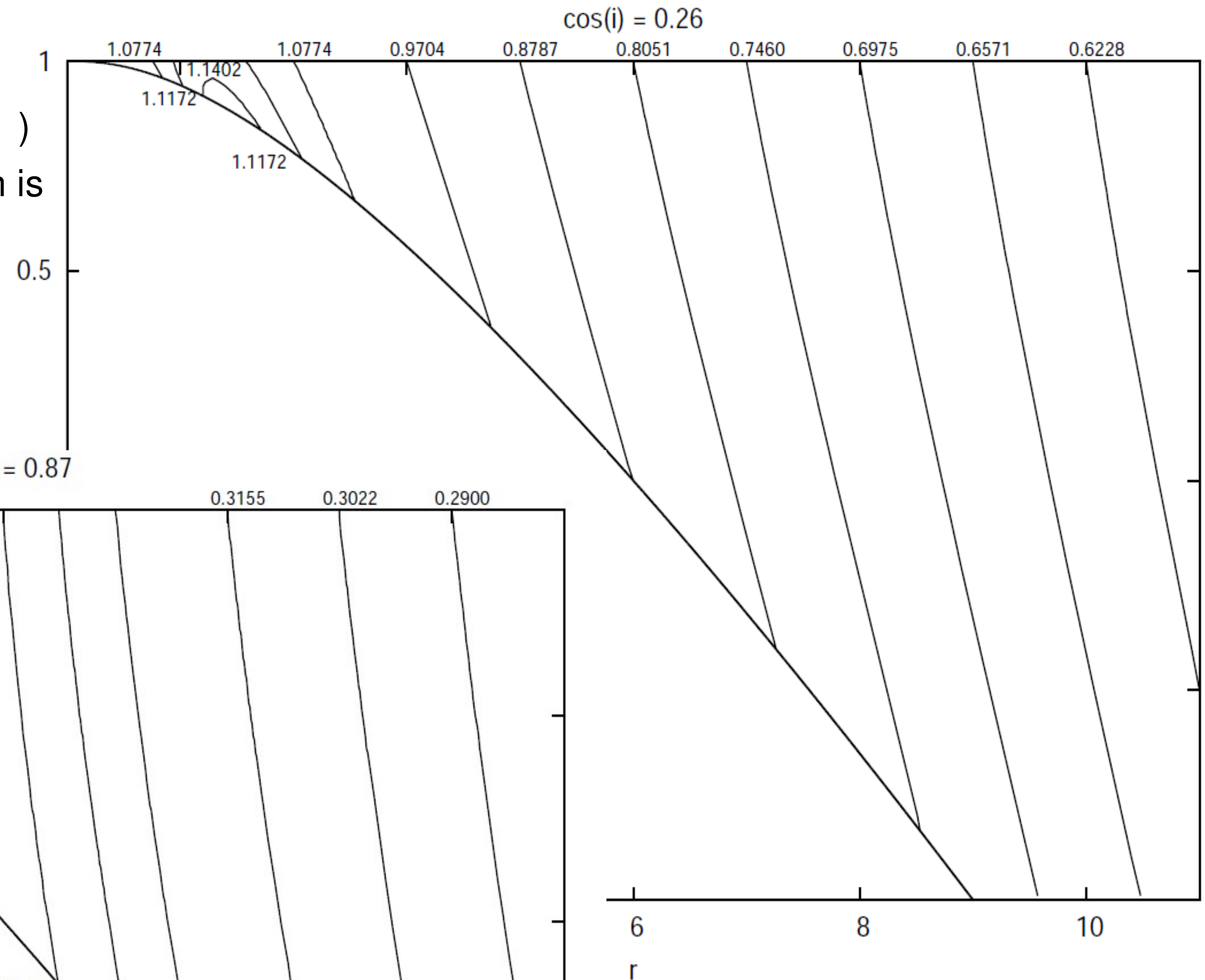

Fig. 3: The spectral width (g_{max} - g_{min}) of narrow rings. Observer's inclination is ~75 deg (cos$i$ = 0.26).

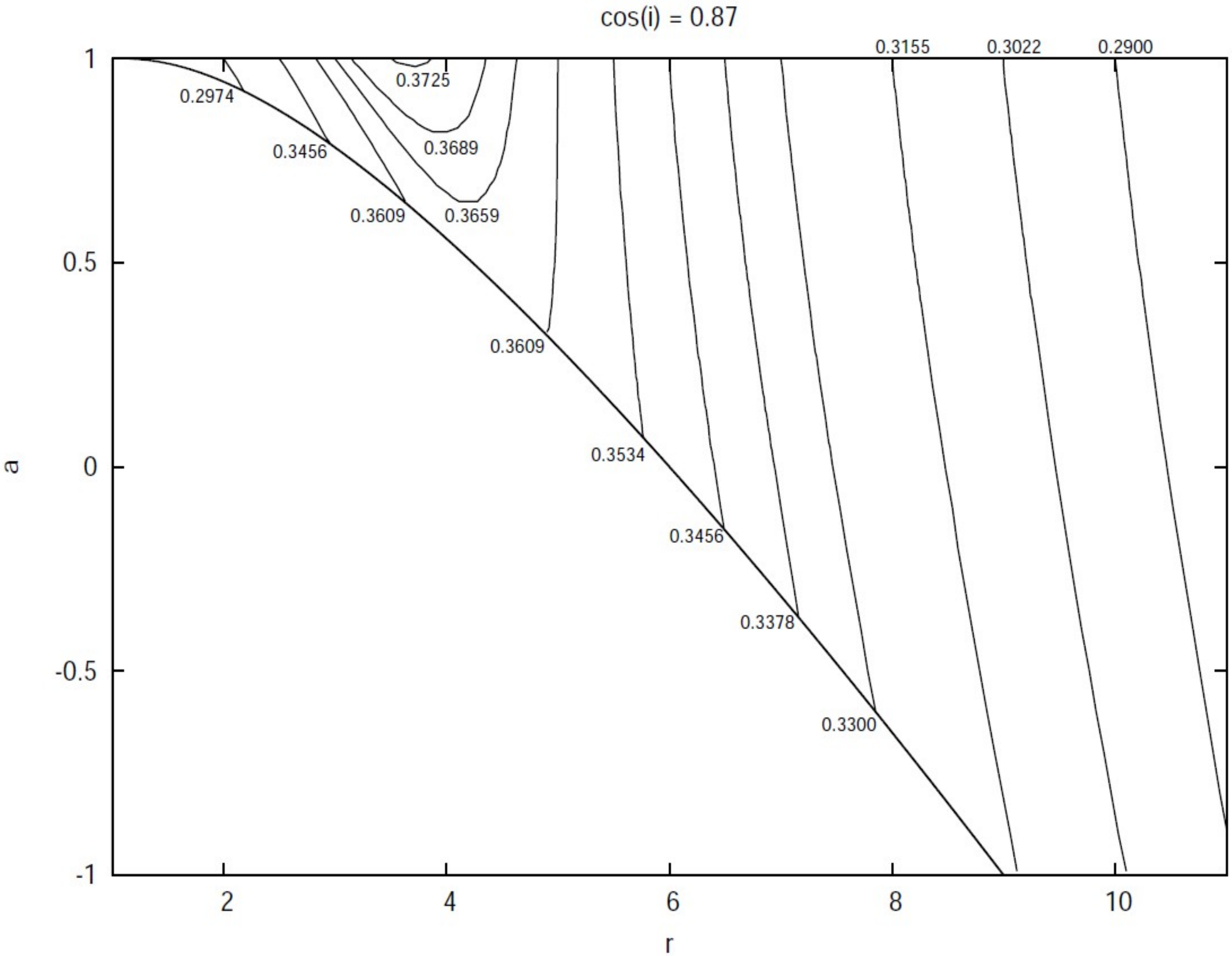

Fig. 4: The spectral width (g_{max} - g_{min}) of narrow rings. Observer's inclination is ~30 deg (cos$i$ = 0.87).

The test model

Rapidly spinning black hole in prograde rotation, $a = 0.93$.

Modarate inclination typical for a Seyfert 1 nucleus, $i = 30$ deg.

A photon-absorbed power-law continuum ($\Gamma = 1.9$, $n_H = 4 \times 10^{21}$ cm^{-2}) and four lines component blurred by ralativistic effects.

One component originates over the entire disc surface ($r_{rms} < r < 400\, r_g$, photon index $\alpha = 3$).

The last components are three rings ($r_{in} = 3, 4, 6\, r_g$), the width $\Delta r = 0.5\, r_g$.

The rest energy $E = 6.4$ keV.

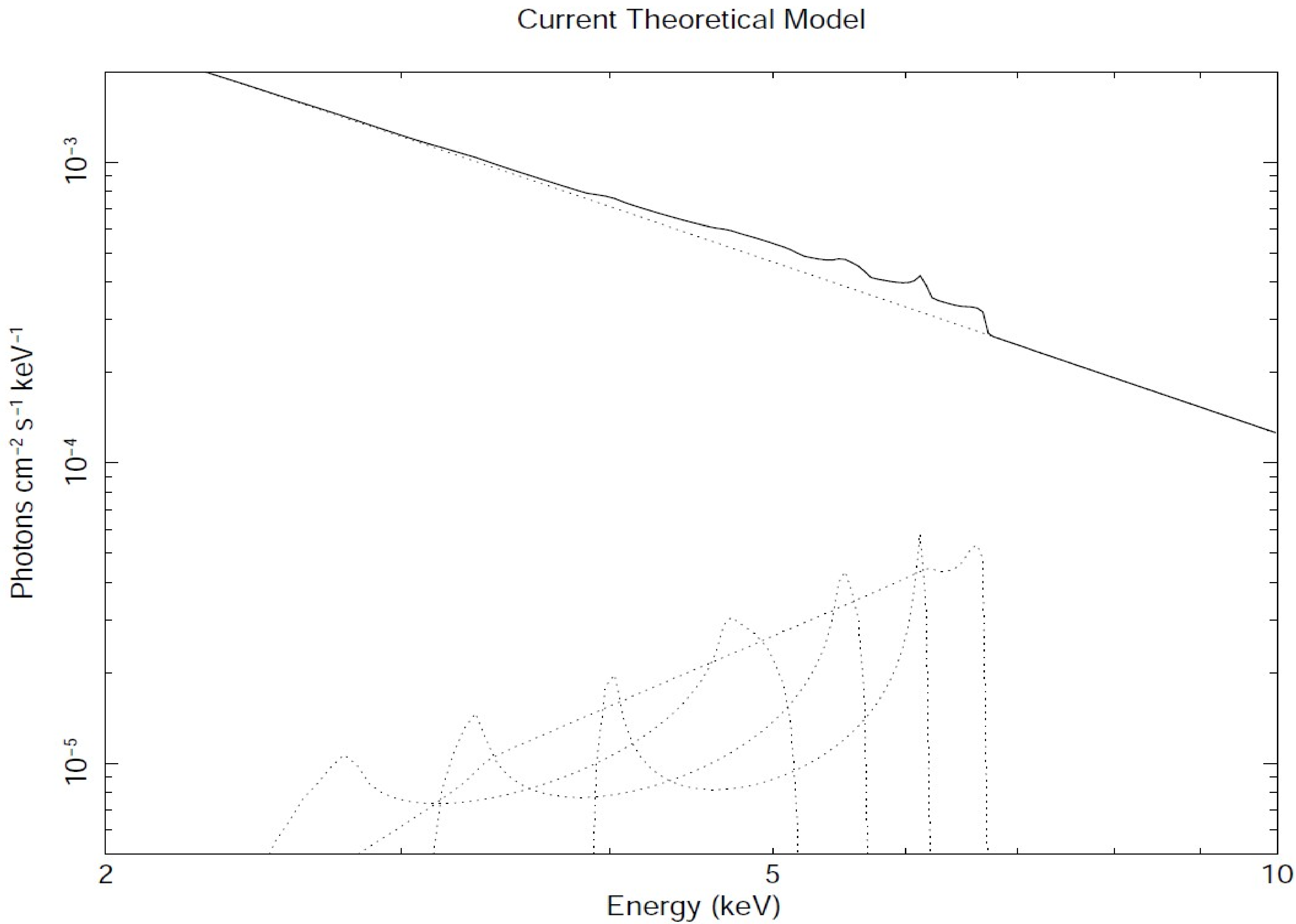

Fig. 5: The profile of the test model.

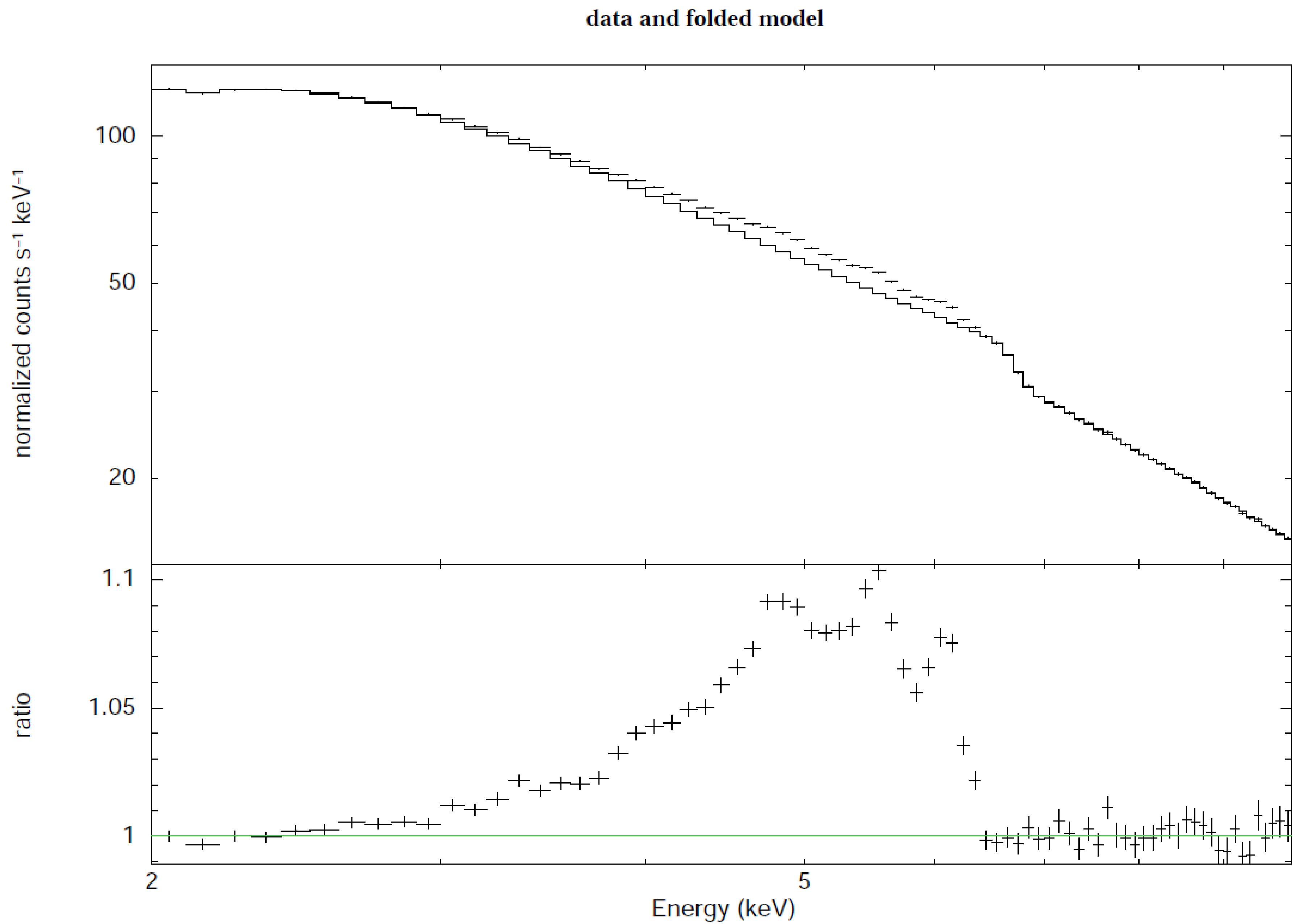

Fig. 6: Simulated data and the ratio to the test model for $N = 3$, exposure time 100 ksec.

Results

Ring	$g_{\min}$	$g_{\max}$	r_{in}		r_{out}	
			$a = 0.76$	$a = 1.00$	$a = 0.76$	$a = 1.00$
1	0.363	0.808	3.11	2.82	3.68	3.38
2	0.478	0.906	4.11	3.90	4.87	4.63
3	0.588	0.981	5.76	5.58	7.12	6.93

The analysis of the spectrum gives us

- **the range of black hole spins**
- **the number of rings**
- **the position of rings**
- **the width of rings**
- **LOFT is in the present the best mission to observe rings**