Variability signals from rotating bright arcs near black holes

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ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
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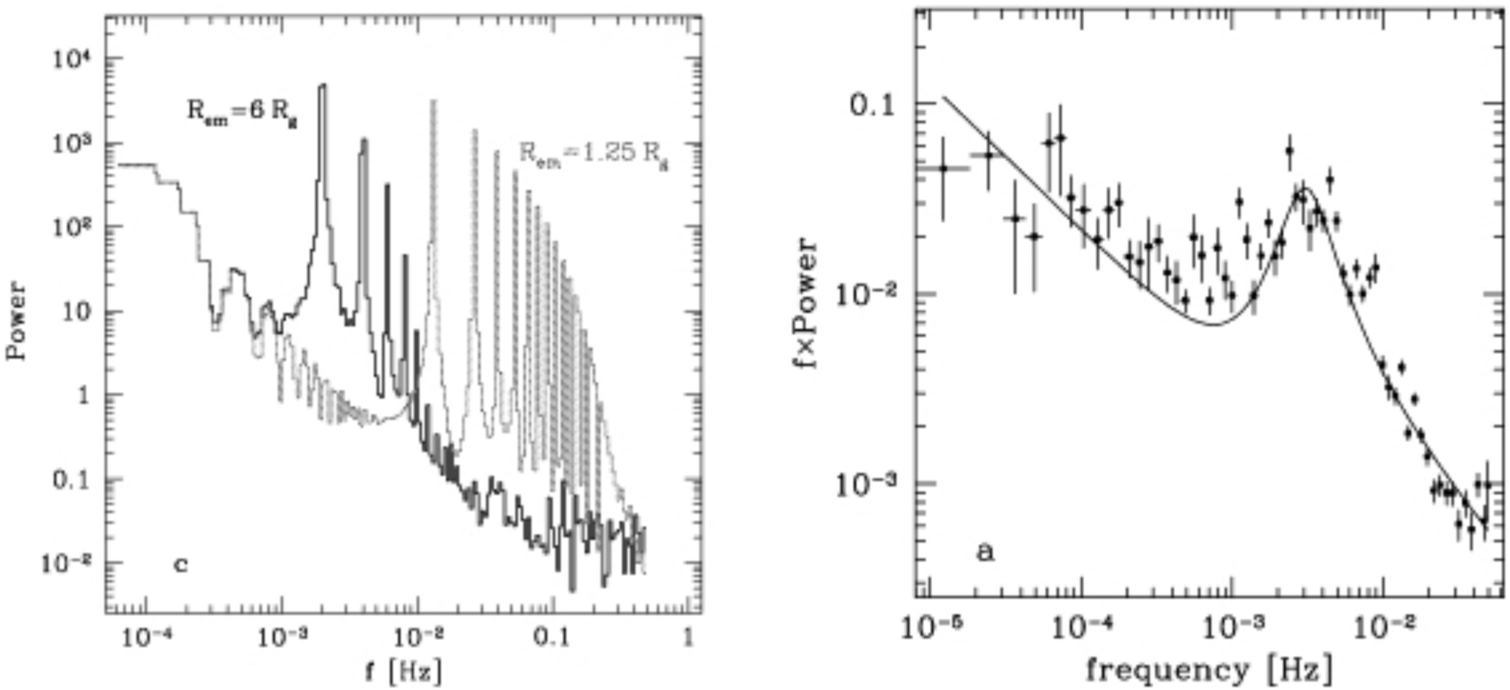
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

Introduction

Relativistic effects in the case of a rotating X-ray emitting “spot/flare” have been studied many times in the past.

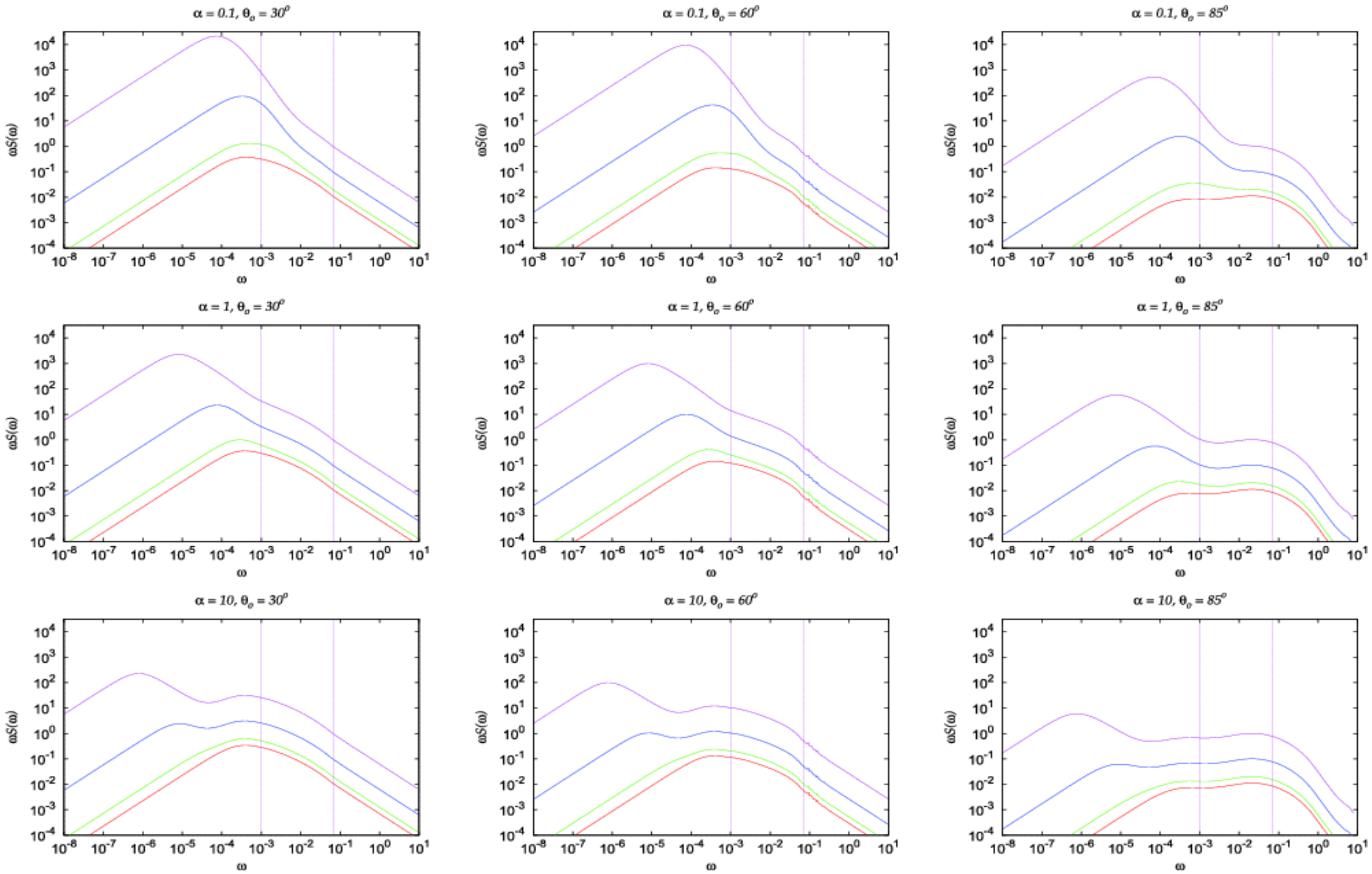
a) Życki & Niedźwiecki, 2005

X-rays are produced in compact regions co-rotating with a Keplerian accretion disc, concentrated toward the inner disc edge, around the black hole. Variability is due to flaring of these regions, and the X-ray emission is modulated in time by Doppler effects.



b) Pechácek, Karas, & Czerny 2008

Signal generated by an ensemble of "hot-spots" randomly created on the accretion disc surface. Spot generation is governed by Poisson or by Hawkes processes – the last one corresponding to an avalanche mechanism. General relativity effects were included.



It is not clear yet whether the X-ray source(s) is(are) rotating or not.

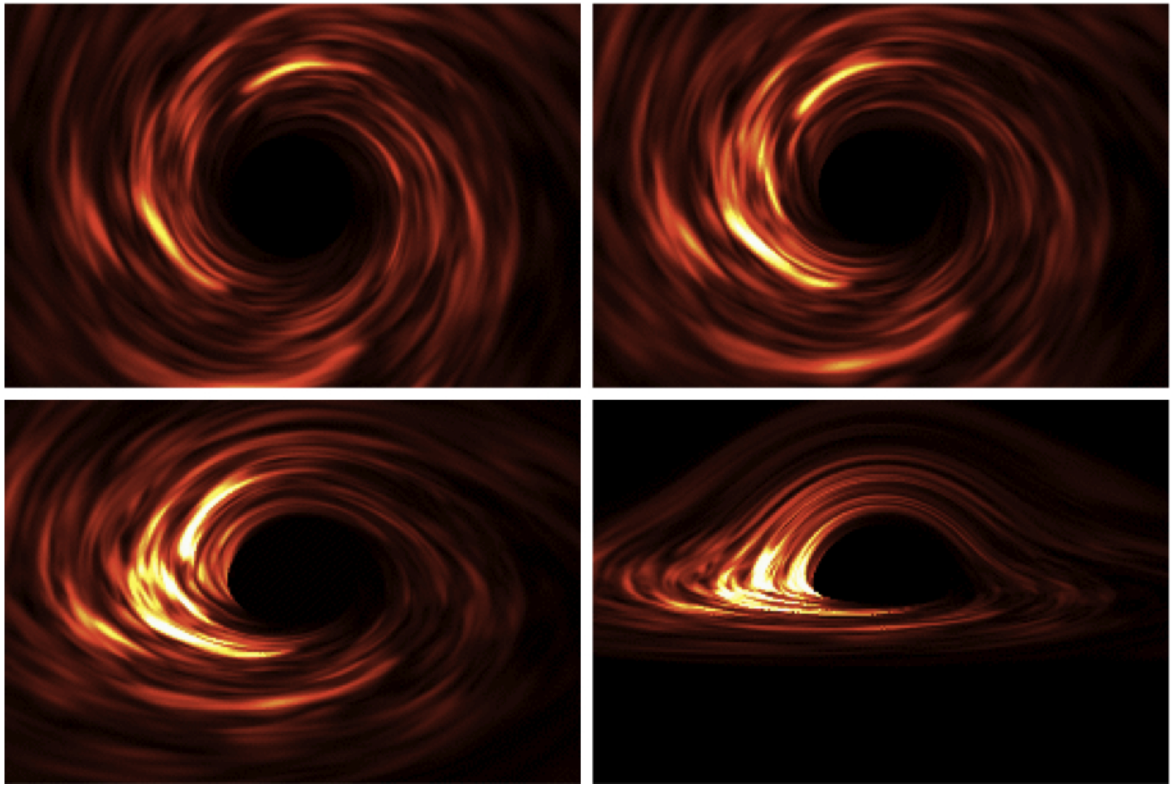
Nevertheless, we believe that an accretion disc is in place, and it must rotate.

Accretion discs may be inhomogeneous.

a) Armitage & Reynolds 2003:

Used MHD simulations to investigate the temporal variability of magnetized accretion discs around Schwarzschild black holes. Used the vertically averaged magnetic stress in the simulated disc as a proxy for the rest-frame dissipation, and emission.

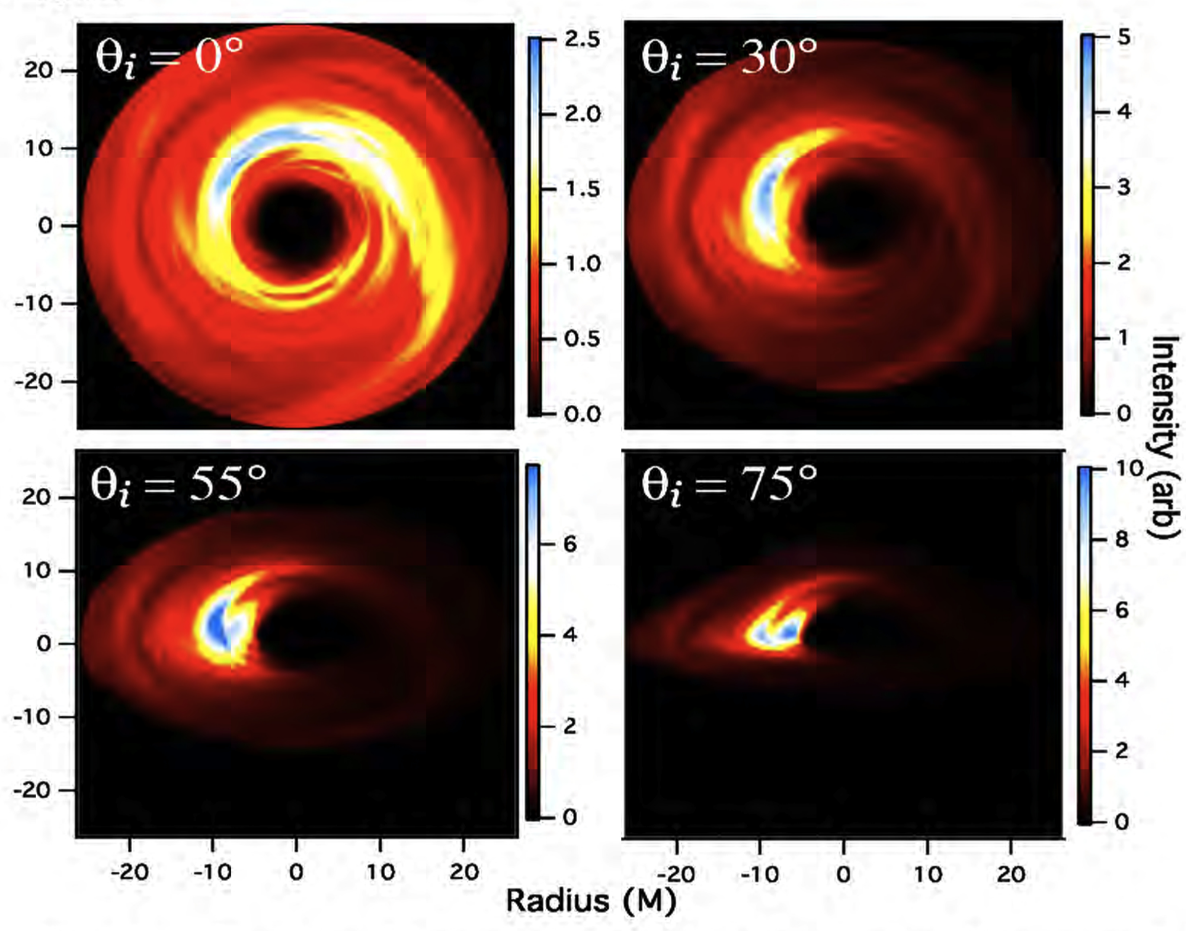
- Large fluctuations are observed, with the peak stress exceeding the local mean by a factor as large as ~4.
- Transient features, with a temporal coherence time of a few orbital period.



b) Welons, et al, 2014:

Studied the variability properties of GR-MHD simulations of thin accretion discs around rotating and non-rotating BHs.

Found temperature fluctuations, which lead to the formation of rotating hot parts in the inner disc.



So...

If the accretion disc is inhomogeneous, and bright arcs rotate in its innermost region,

and,

If X-ray irradiation of the inner disc takes place,

and,

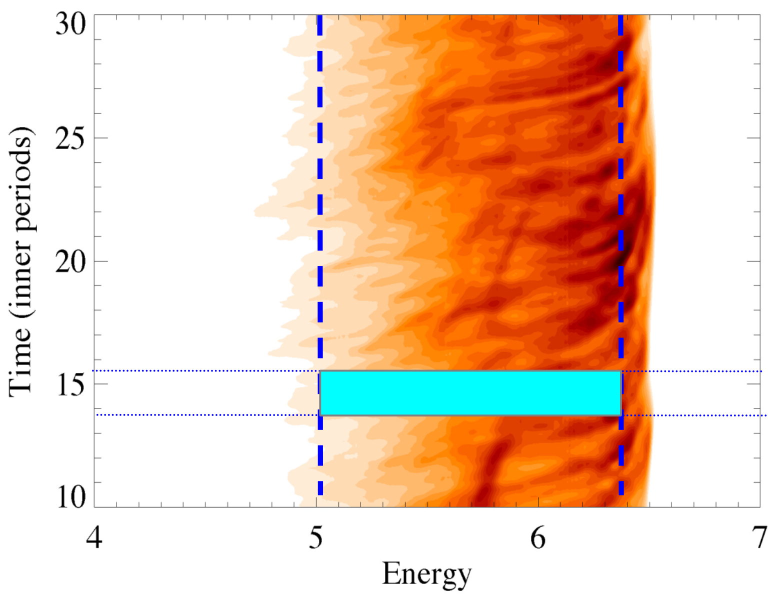
If the X-ray reflection spectrum coming from the surface of the disc is proportional to the local continuum intensity,

then

we may expect the X-ray reflection spectrum (i.e. the iron line, and the soft excess) to be periodically modulated.

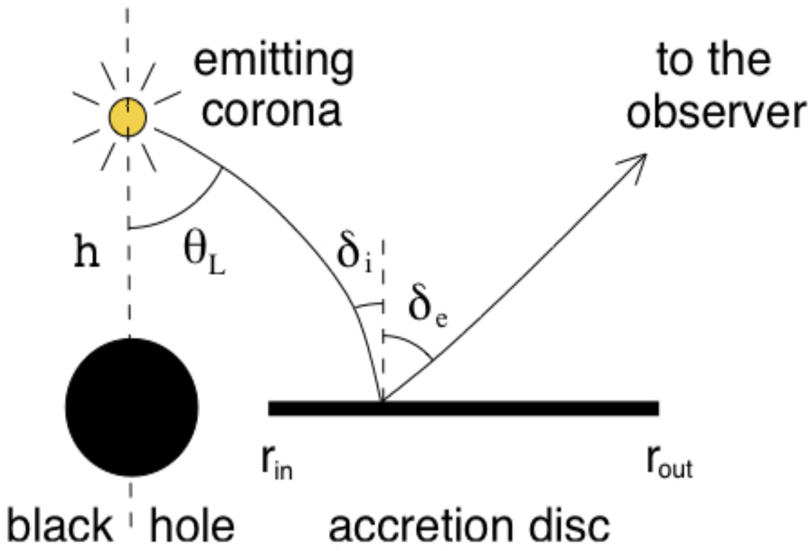
The science goal:

Assume "idealized" bright arcs in the inner accretion disc, and study the variability of the X-ray reflection component in AGN as observed by a distant observer in the 5-6.3, 6.6-7, and 5-7 keV bands



The set up.

a) We assume the "lamp-post" geometry, three inclinations: 20^o, 40^o, and 60^o, for $M_{BH}=10^6$ and 10^7 solar masses.



In this geometry the disc irradiation decreases rapidly with the radius of the disc, and only the innermost part of the disc contributes significantly to to the reflection component in the spectrum.

Thus, although arc-like overdensed regions may exist on the disc surface even at large distances from the center, we need only to consider the ones in the innermost region.

b) The disc is neutral (its rest frame spectrum is like "pexmon" in XSPEC, assuming solar abundances).

c) Bright arcs appear randomly. They appear (and disappear) instantaneously (with an average rate of one arc/50 sec).

They are characterized by:

i) their average life time, $<t_l>$,
ii) average size, $<\phi_a>$, and
iii) "contrast, f_c, with respect to the local mean emission.

We have considered the cases of arcs at $3R_S$, and:

$f_c = 5$

$<t_l>$	0.3(+/- 0.06) T_{orb}	1.2(+/- 6) T_{orb}	9.6(+/- 1.9) T_{orb}
$<\phi_a>$	3.6°(+/- 0.7)	32.4°(+/- 6)	291.6°(+/- 60)

The simulations

We created 50 sec binned light curves for each case, in the energy bands: 2-4, 5-6.3, 6.6-7, 5-7 (and 10-20) keV.

The observed count rate is equal to:

$$CR_{obs}(t) = CR_{cont}(t+delay)+f_b\times[CR_{ring}(t)+f_c\times CR_{arc}(t)]$$

$CR_{cont}(t)$ is the X-ray continuum count rate that the observer measures and the one that drives the reflection component variations as well (the X-ray source is assumed to be variable, with a PSD that has a "bending-PL" shape, with a break that depends on BH mass (as in Gonzalez-Martin & Vaughan, 2012), and an rms amplitude of ~ 30% and 20%, over a time scale of 80 ksec, for the 10^6 and 10^7 BH mass, respectively.

f_b is determined by the percentage, b, of the reflection over the total signal in each band, i.e.

$$b = f_b \times [CR_{\mathrm{refl}}(t)] / [CR_{\mathrm{cont}}(t) + f_b \times CR_{\mathrm{refl}}(t)]$$

In the the lamp-post geometry, for $h=3R_S$, inclination of 40 degrees and a Schwarzschild BH:

b(2-4 keV) =	0.01			
b(5-6.3 keV) =	0.08			
b(5-7 keV) =	0.09	0.18	0.27	0.36
b(6.6-7 keV) =	0.13			
b(10-20 keV) =	0.2			

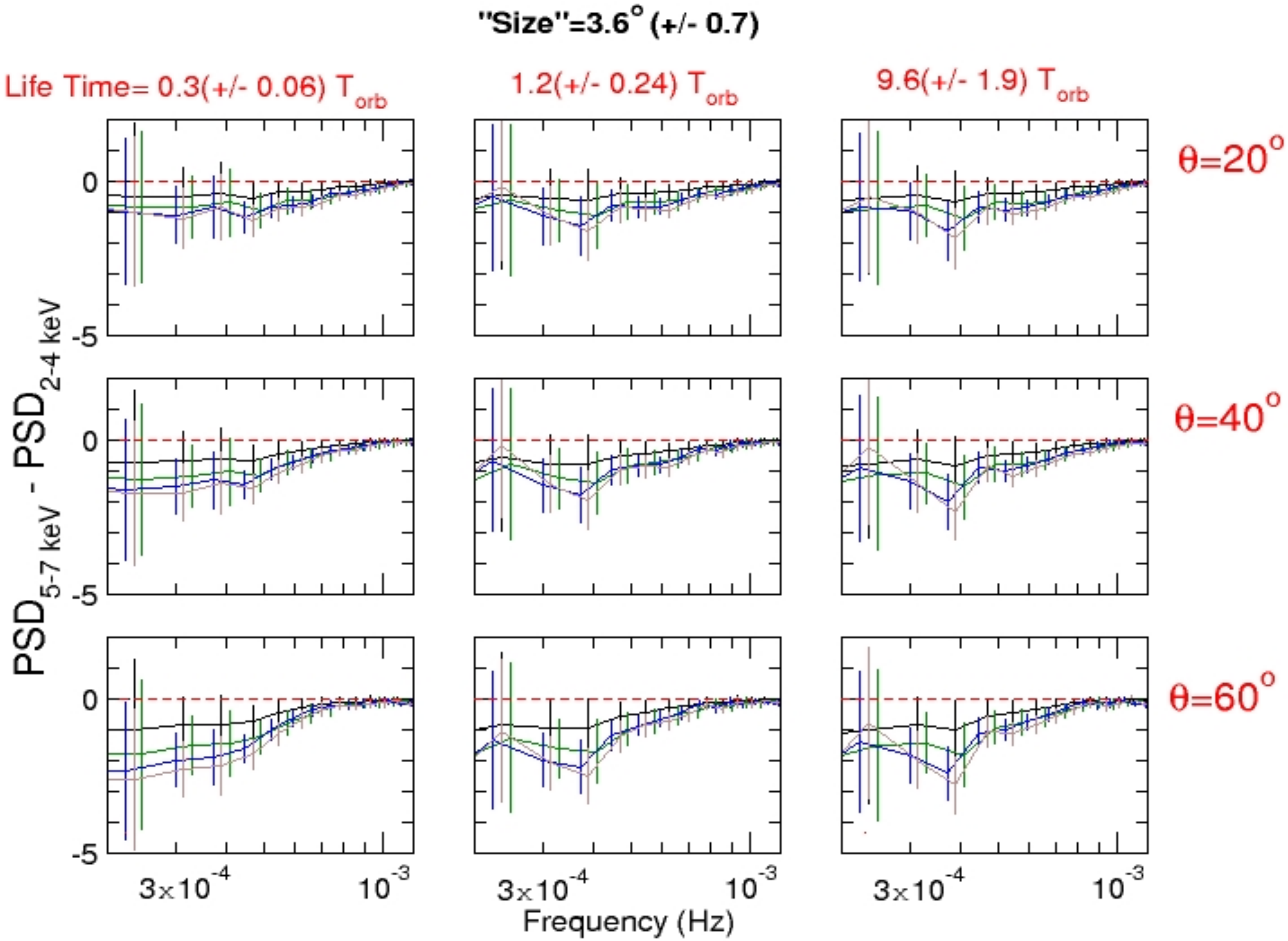
Our aim is to investigate whether the "signals" due to the rotating arcs can be detected using the existing data in the XMM-Newton (and Suzaku, and ASCA...) archives.

- We considered 50, 12.8 ksec long light curves (256 points), and we averaged their PSDs in each energy band (such light curves do exist in the archives for a handful of objects).

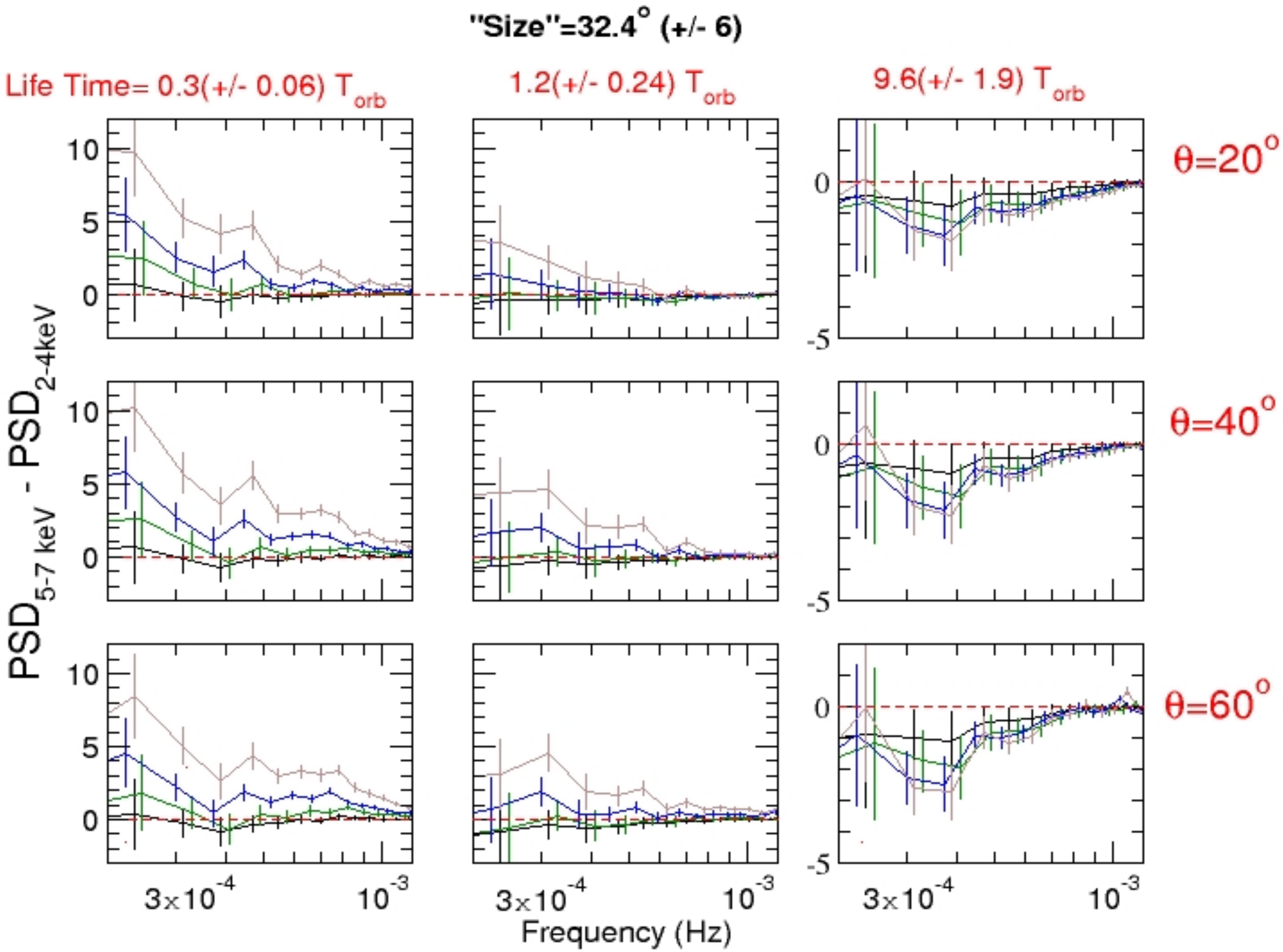
- We estimated the average PSD in each band, and

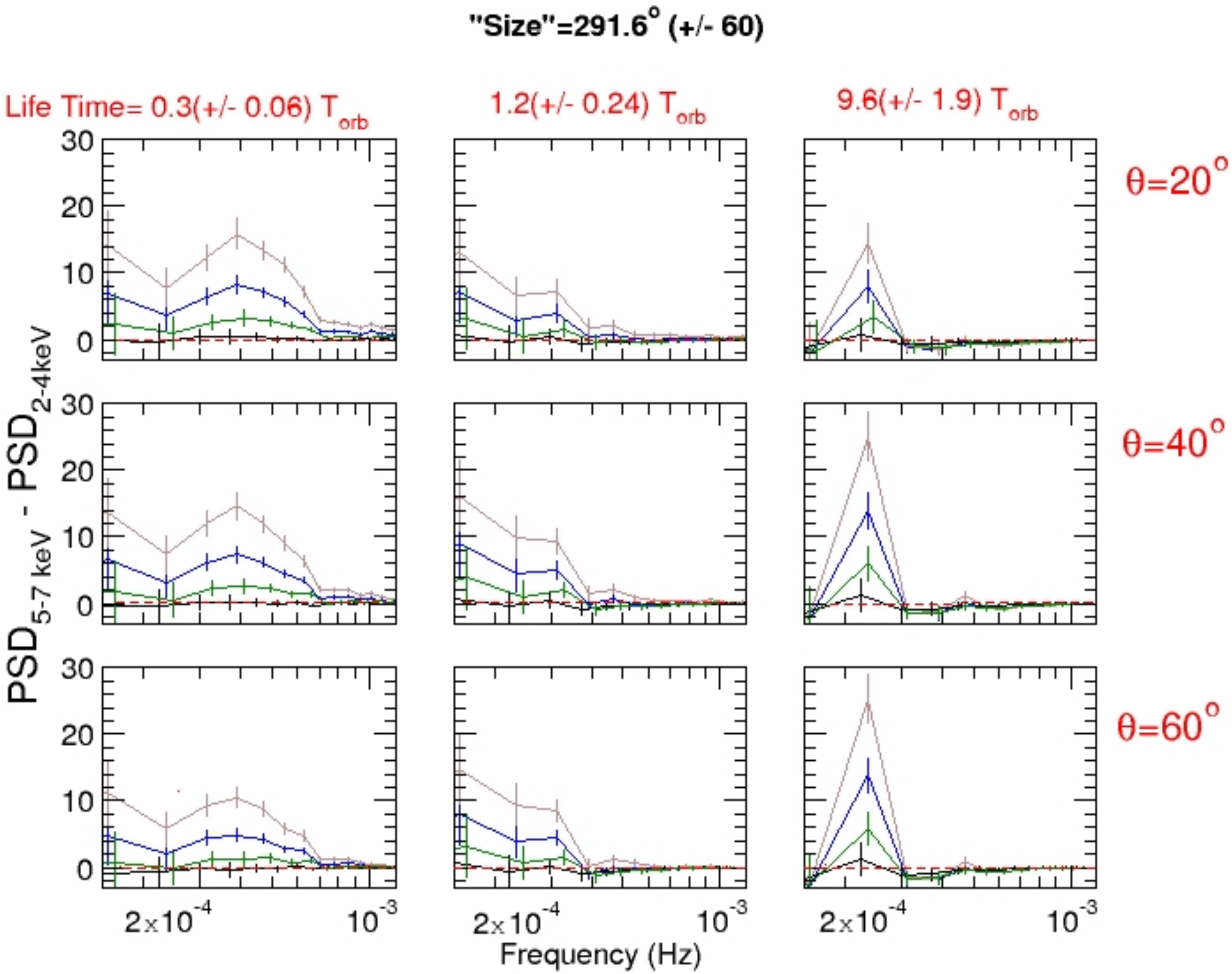
- We subtracted the PSDs in the "line" bands from the PSD in the 2-4 keV band.

The results (5-7 keV) band:



"Size"=3.6° (+/- 0.7)
Life Time= 0.3(+/- 0.06) T_orb
1.2(+/- 0.24) T_orb
9.6(+/- 1.9) T_orb
θ=20°
θ=40°
θ=60°
PSD_5-7 keV - PSD_2-4 keV
0
-5
3×10^-4
10^-3
Frequency (Hz)


"Size"=32.4° (+/- 6)
Life Time= 0.3(+/- 0.06) T_orb
1.2(+/- 0.24) T_orb
9.6(+/- 1.9) T_orb
θ=20°
θ=40°
θ=60°
PSD_5-7 keV - PSD_2-4keV
3×10^-4
10^-3
Frequency (Hz)


"Size"=291.6° (+/- 60)
Life Time= 0.3(+/- 0.06) T_orb
1.2(+/- 0.24) T_orb
9.6(+/- 1.9) T_orb
θ=20°
θ=40°
θ=60°
PSD_5-7 keV - PSD_2-4keV
Frequency (Hz)
2x10^-4
10^-3
0
10
20
30

We measured the significance of the features in the $2\times10^{-4}-10^{-3}$ Hz band, using the χ^2 test.

Conclusions:

Using data already in the archive, we can detect the arcs if they are "large" and last for up to ~ 10 orbital periods (for all *b*'s and all inclinations).

In all other cases (of arc's size and duration), we can detect the arcs if b>0.25, but we cannot detect them if b<0.10.

The results are promising.

✓Analyze existing light curves in the archive.

✓Consider Kerr Black Holes (and investigate the rate of the "bright arcs" appearance)

✓Consider Poisson Noise.