IASF
Istituto di Astrofisica Spaziale
e Fisica cosmica
Palermo

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Disk precession to explain the super-orbital modulation of LMC X-4:

results from the Swift monitoring campaign

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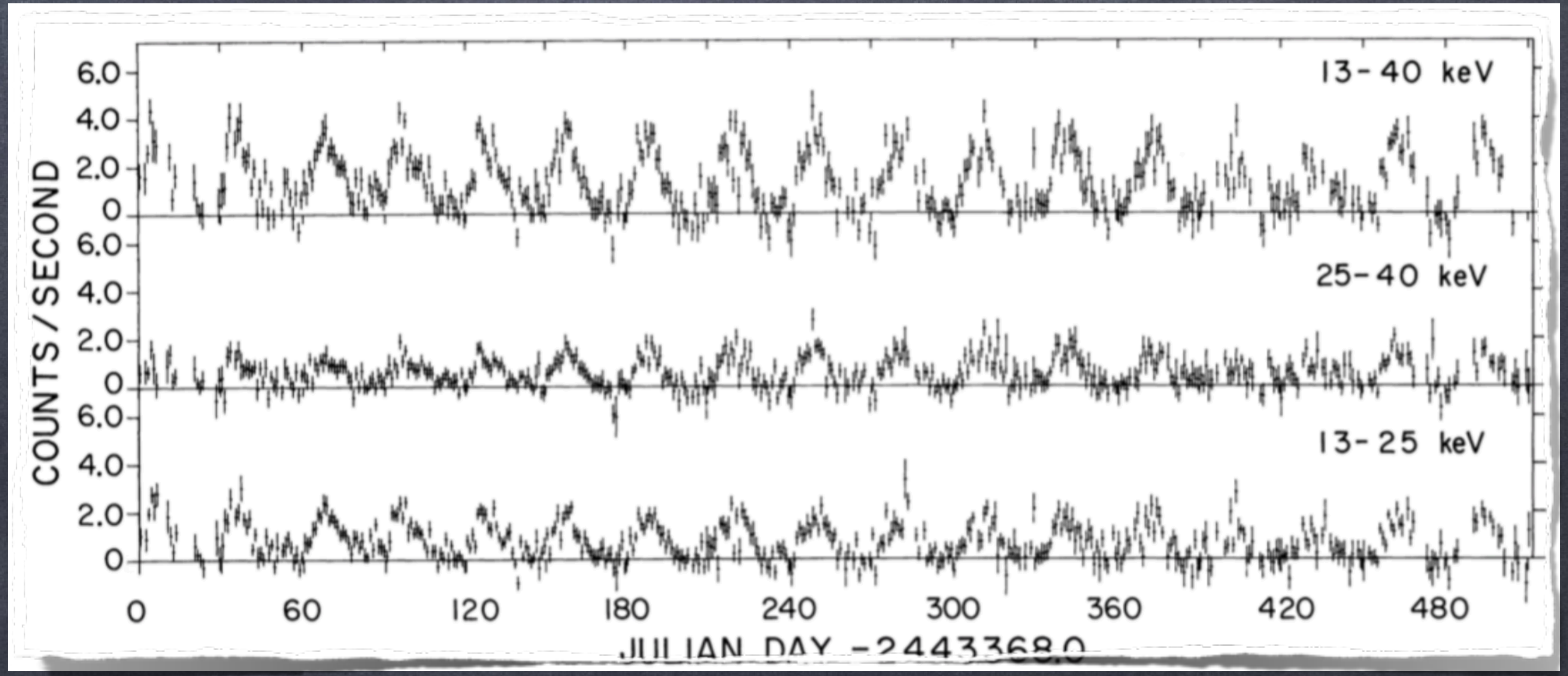
HMXB LMC X-4

- $M_{NS} = 1.57 \pm 0.11\ M_\odot$; $M_c = 18 \pm 1\ M_\odot$(Kelley et al. 1983), O type star
- $P_{orb} = 1.4d$; $P_{spin} = 13.5s$; $P_{sup} \simeq 30.4d$ (Molkov et al. 2015)
- $L_x \sim 2 \cdot 10^{38} ergs^{-1}$ (Levine et al. 1991)
  frequent X-ray flares few $10^{39} ergs^{-1}$ (e.g. Brumback et al. 2018)

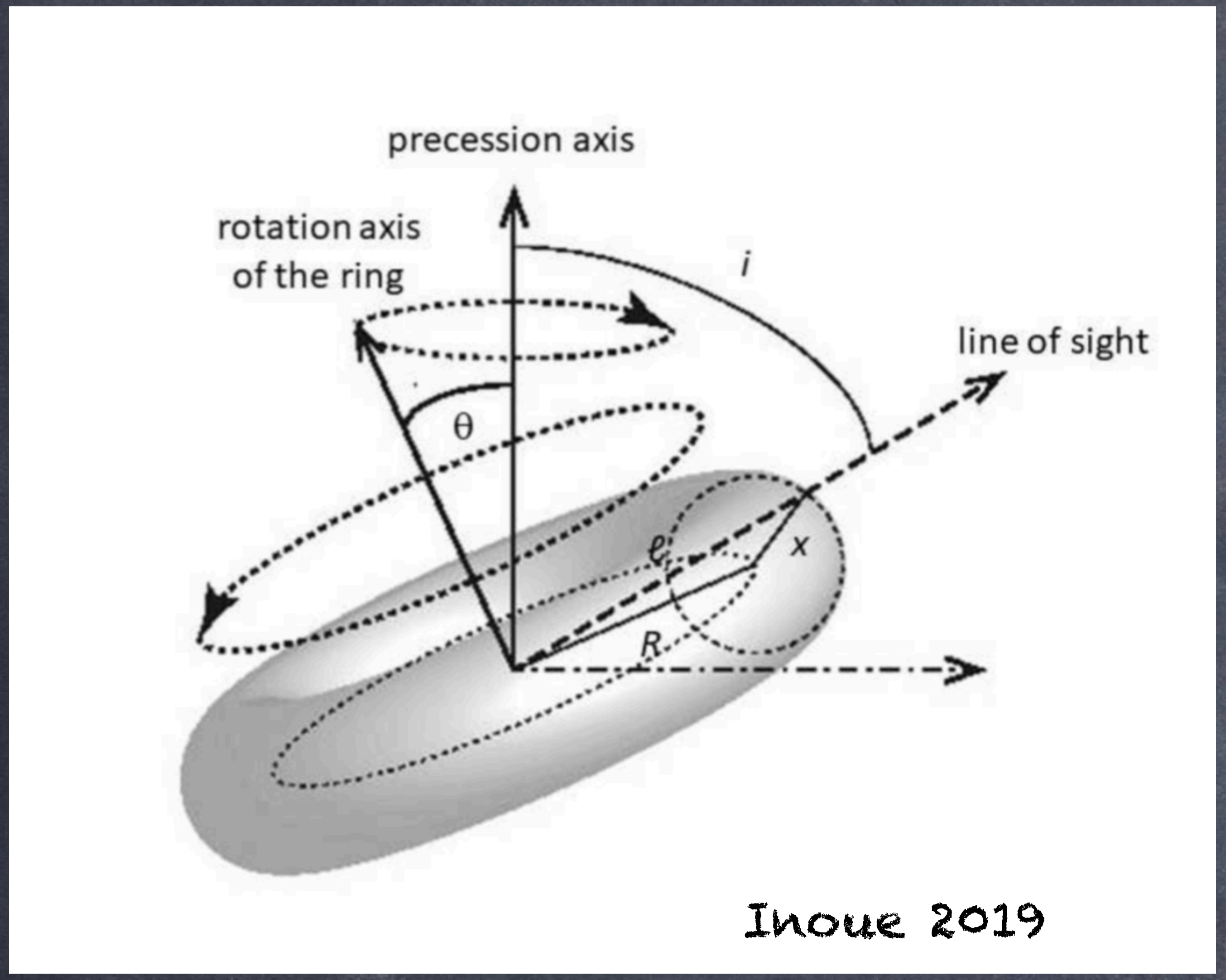
LMC X-4 is a benchmark to study S-O modulations:

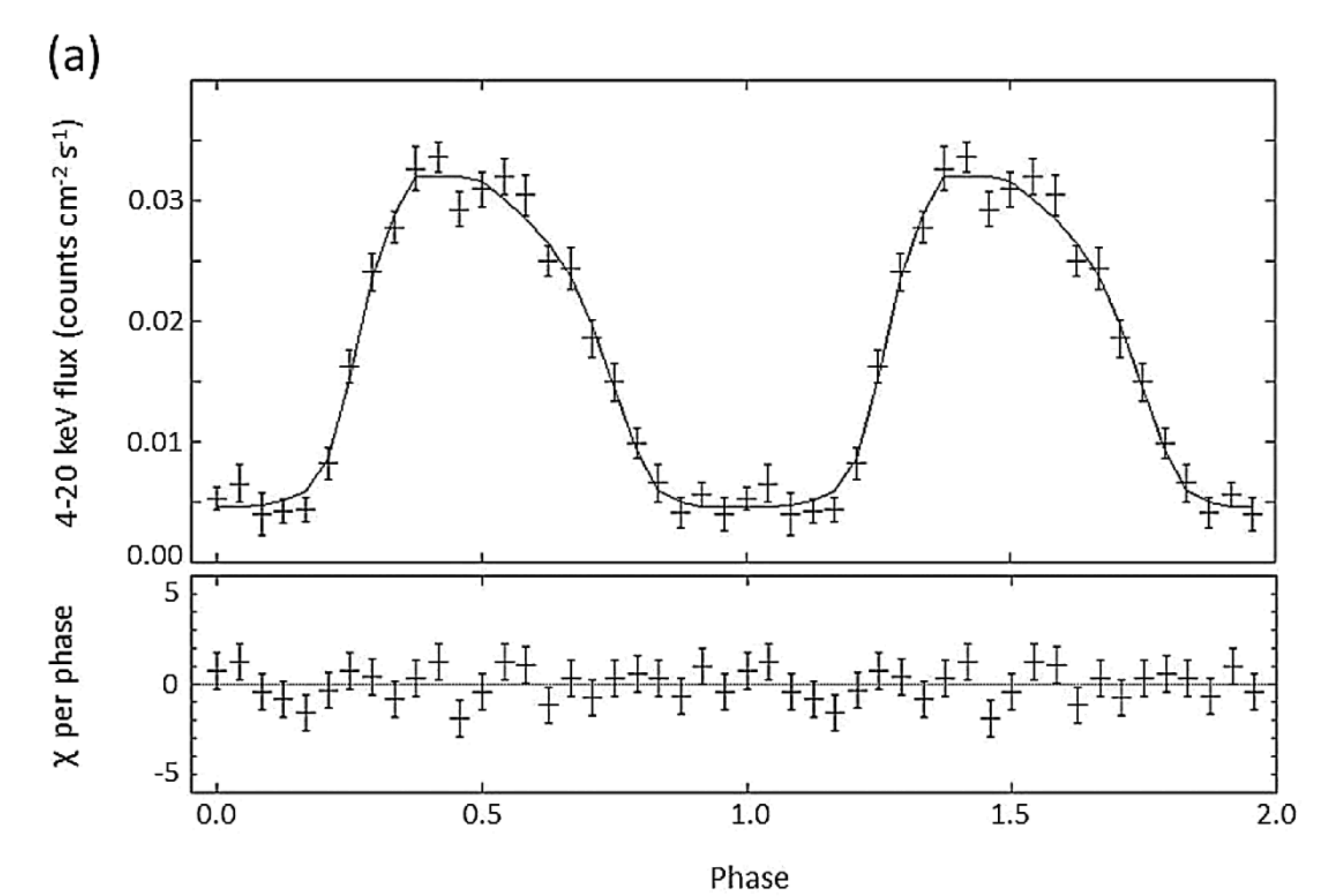


Modulation is:
- persistent over decades
- stable
- detected from hard X-rays to optical

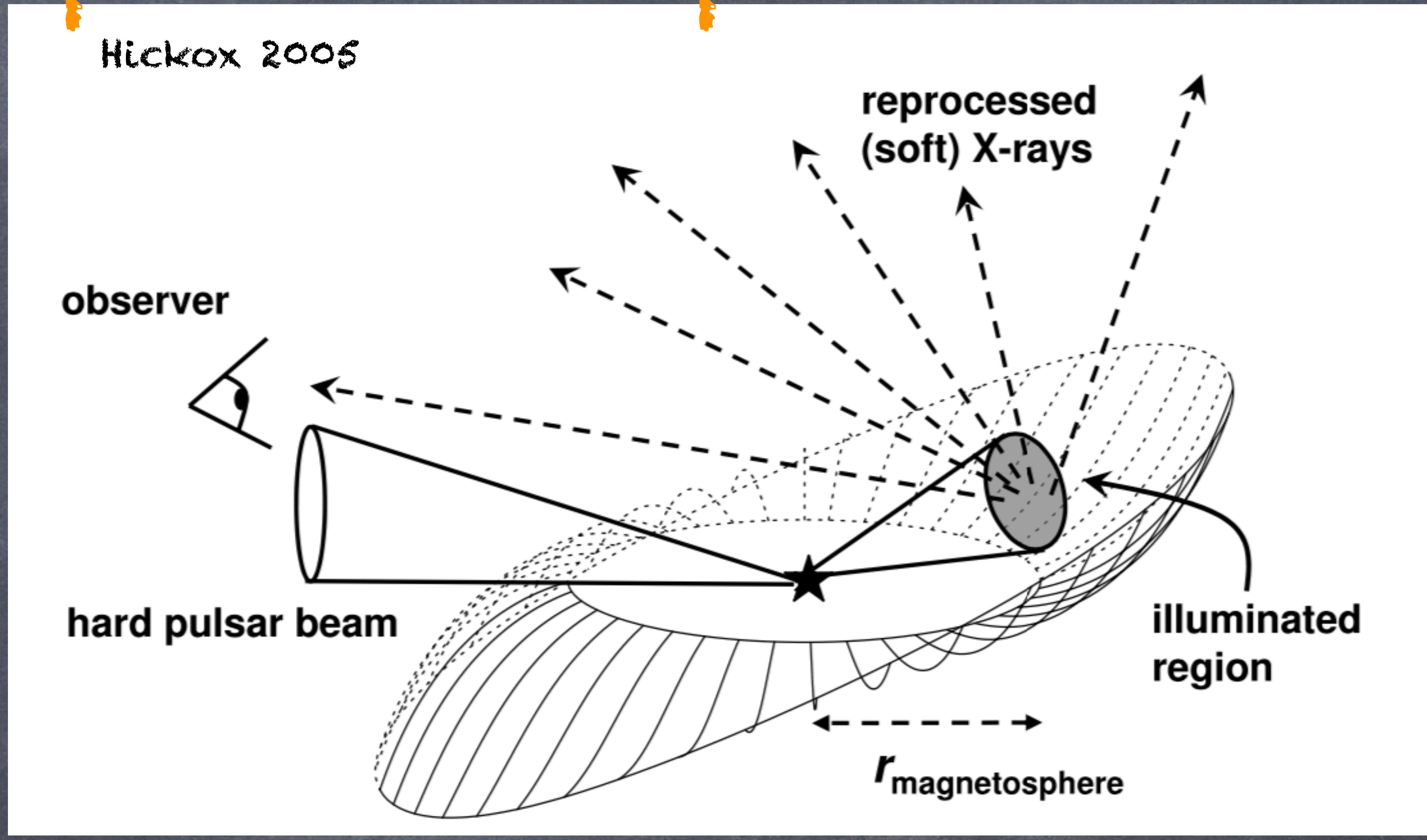
Origin of super-orbital modulation of LMC X-4?

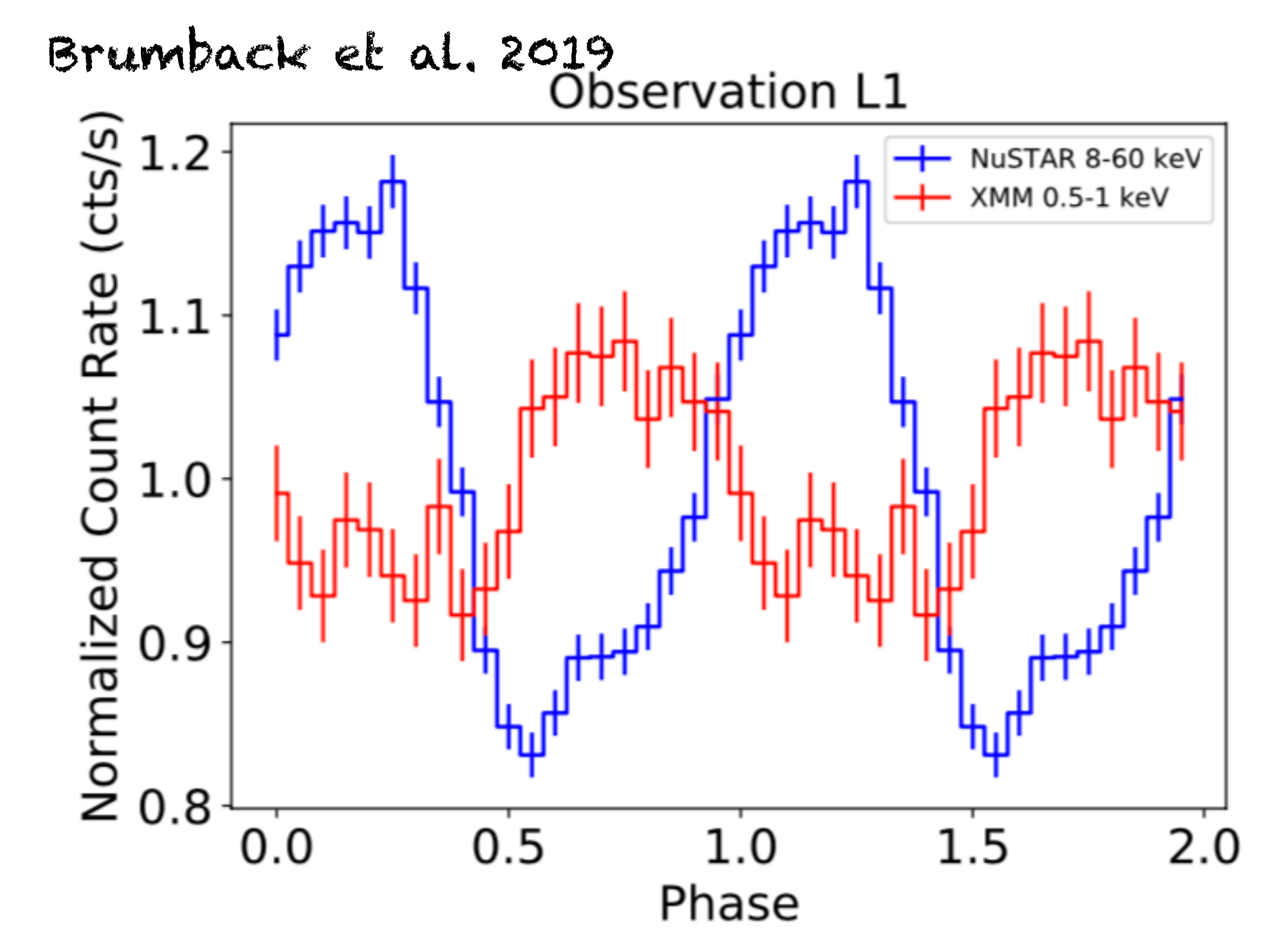
Disk precession



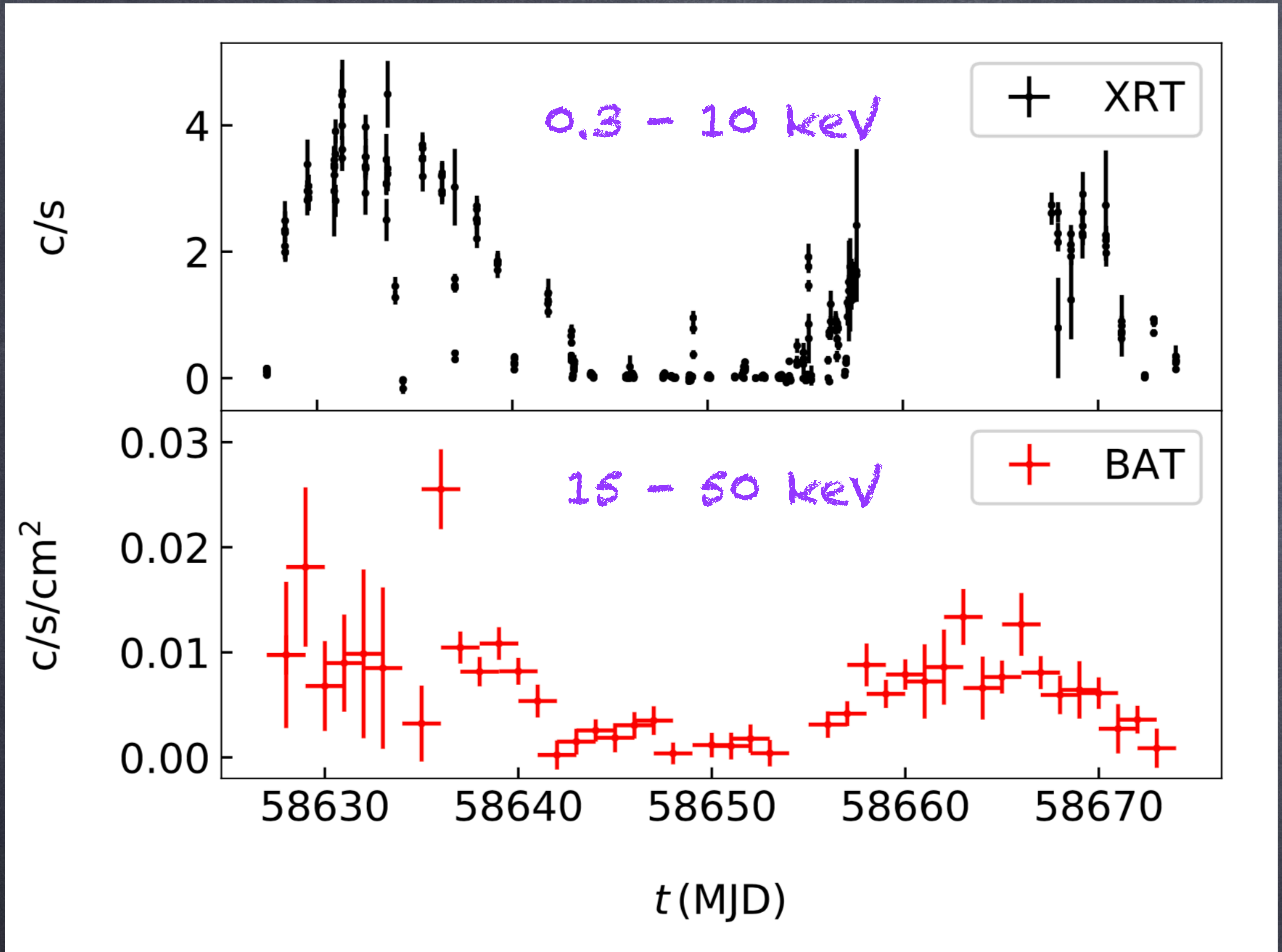


Warped Disk precession





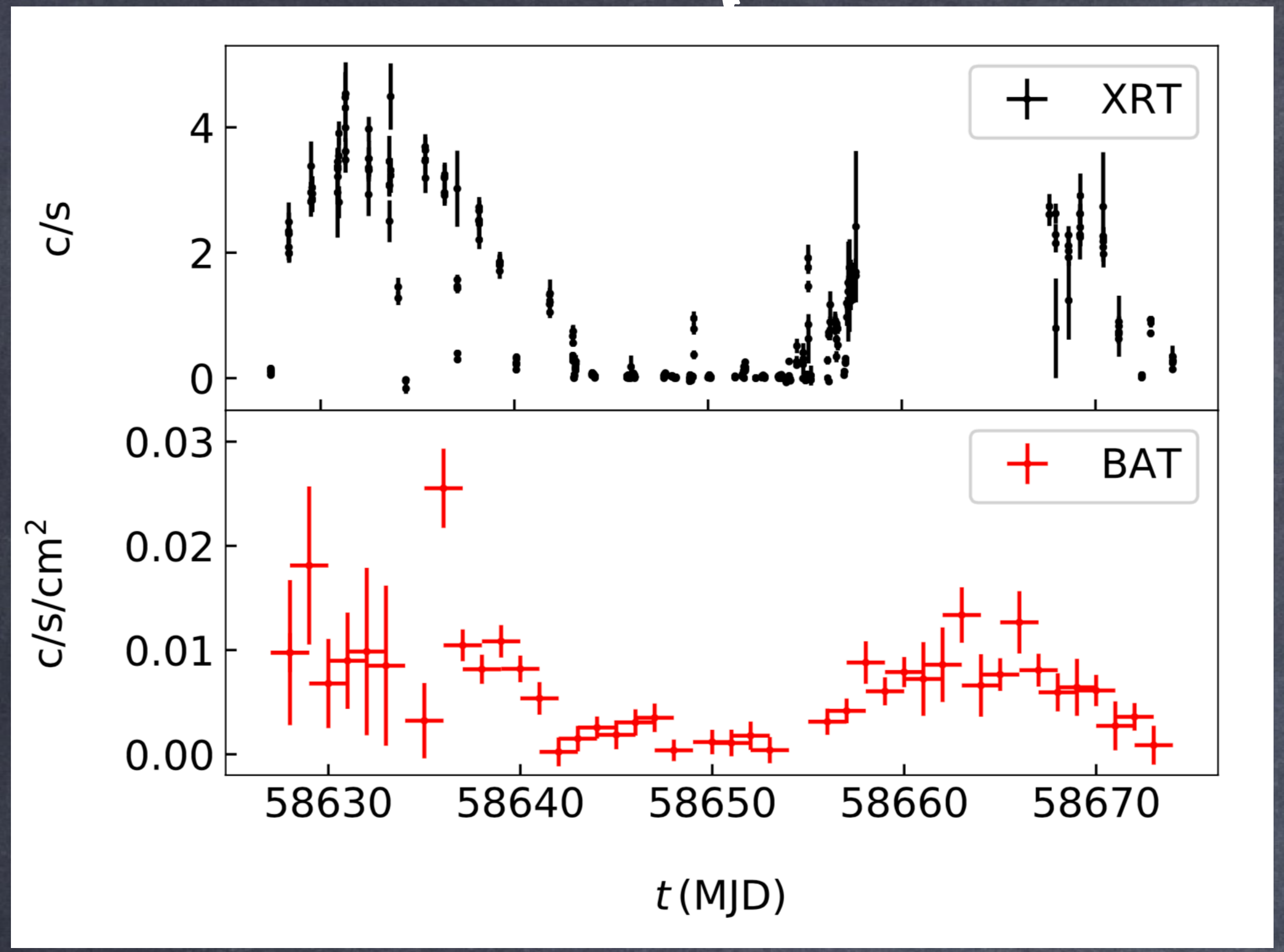
Monitoring : 2019-05-24 to 2019-07-09



XRT: affected by orbital motion

BAT: Low S/N

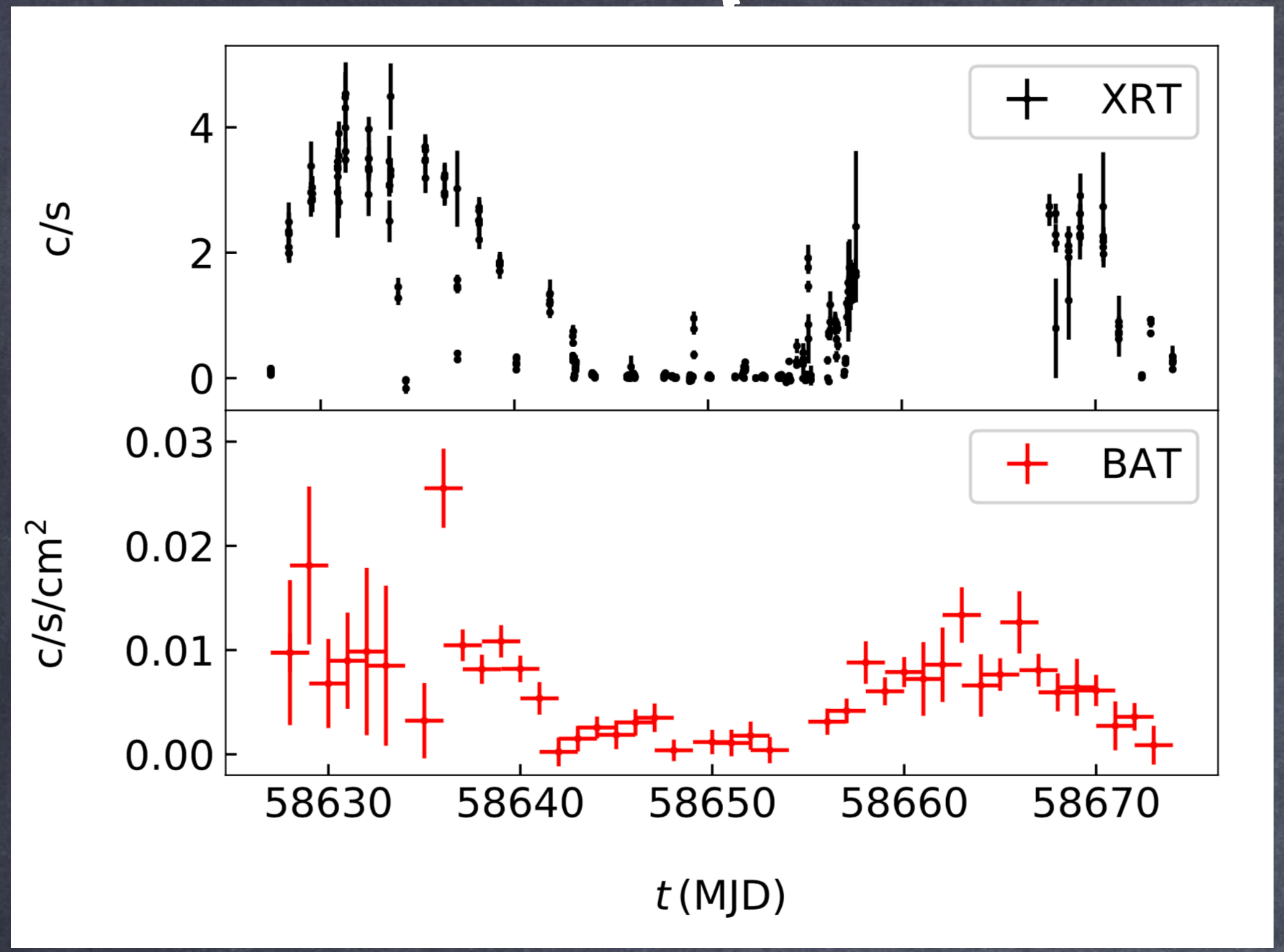
Super-Orbital Phase Resolved Spectroscopy



XRT: - rejected time intervals in the eclipse (or close to it)

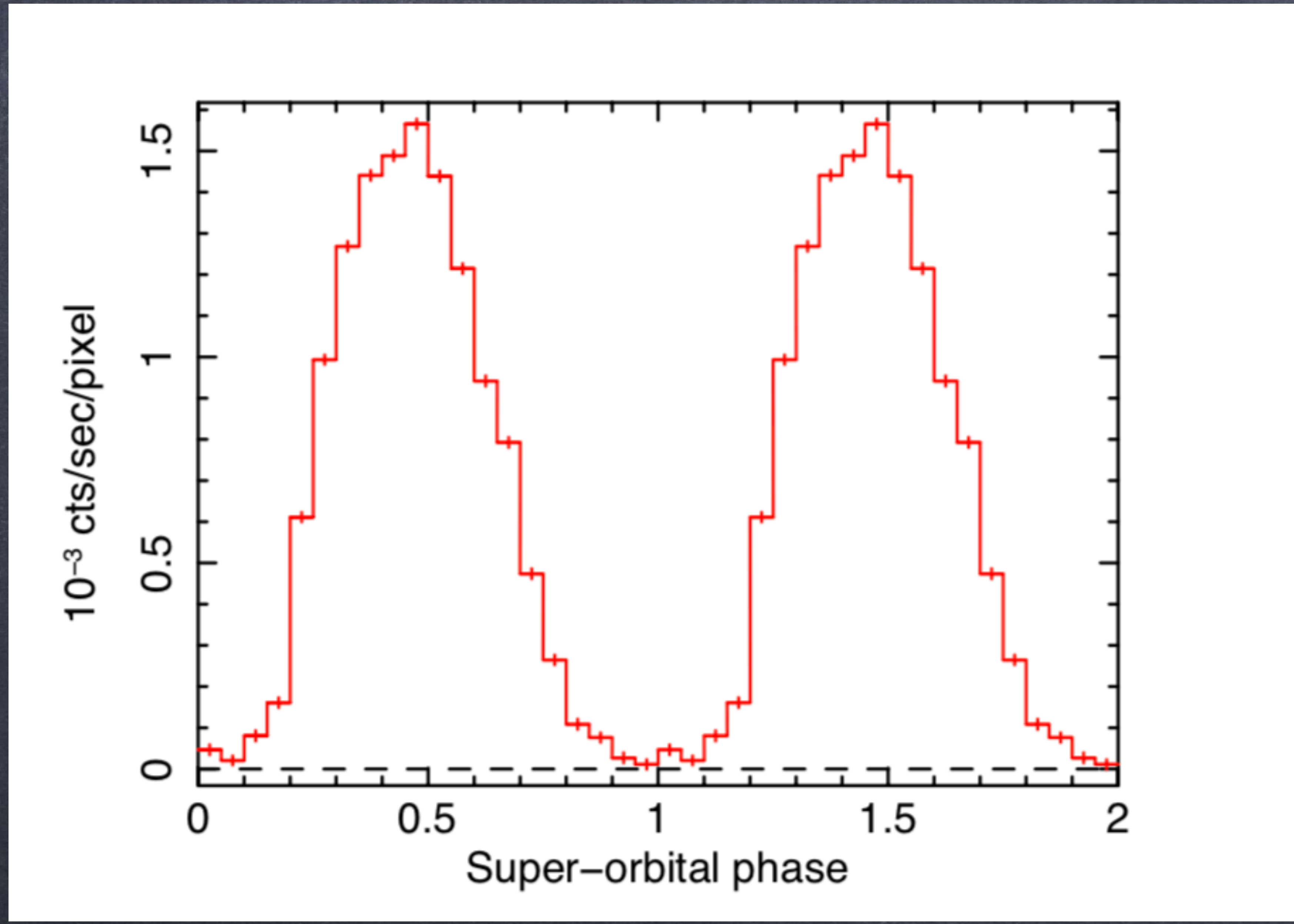
-sum OBS in the same ψ_{sup}

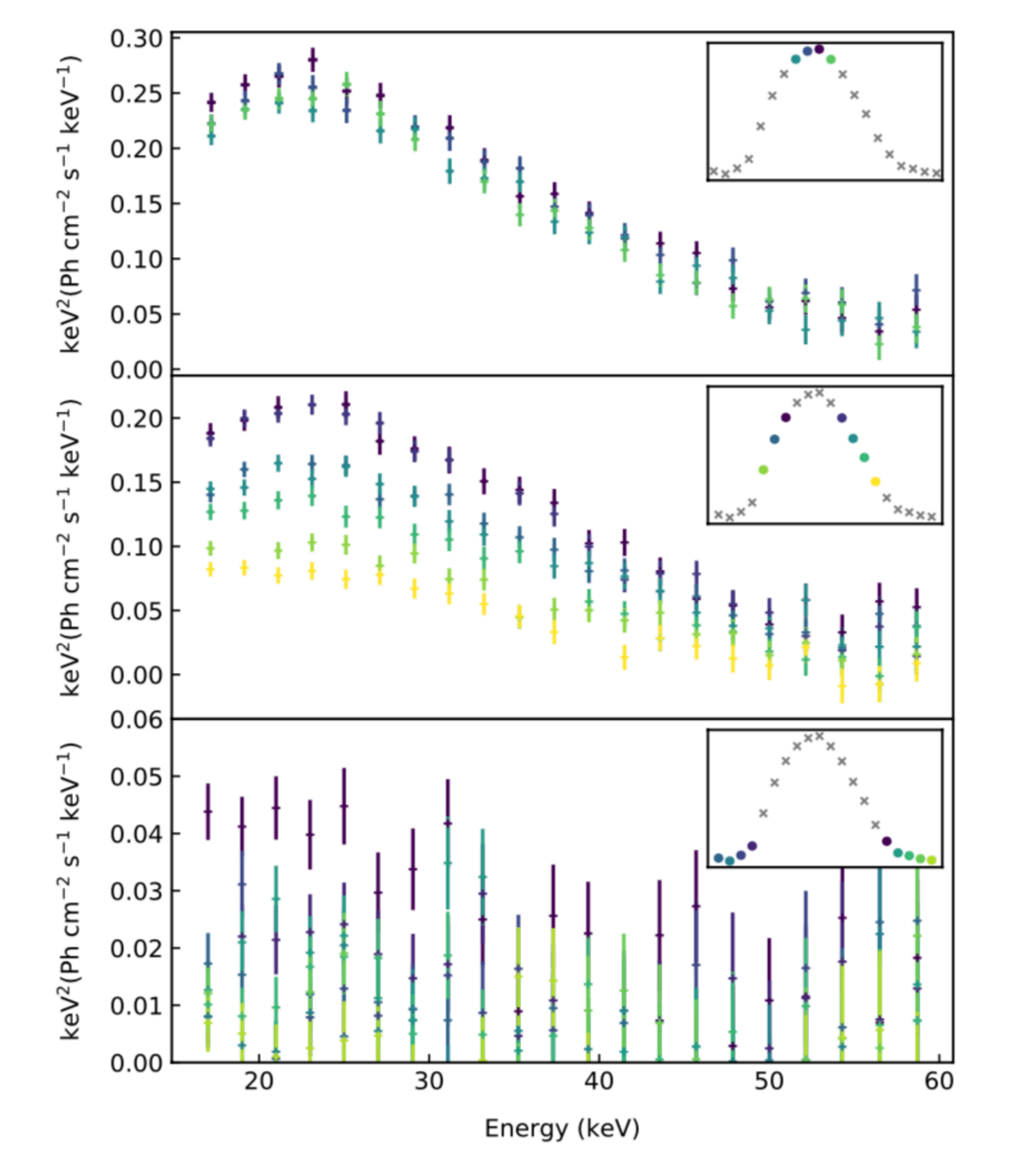
Super-Orbital Phase Resolved Spectroscopy



XRT: - rejected time intervals in the eclipse (or close to it)
-sum OBS in the same ψ_{sup}

BAT: Super-orbital phase resolved data over 4.75 years (BATIMAGER, Segreto et al. 2010)





It is a flux diminishing Of the same model (tested with nthcomp)

How does it change the broad-band spectrum with SO phase?

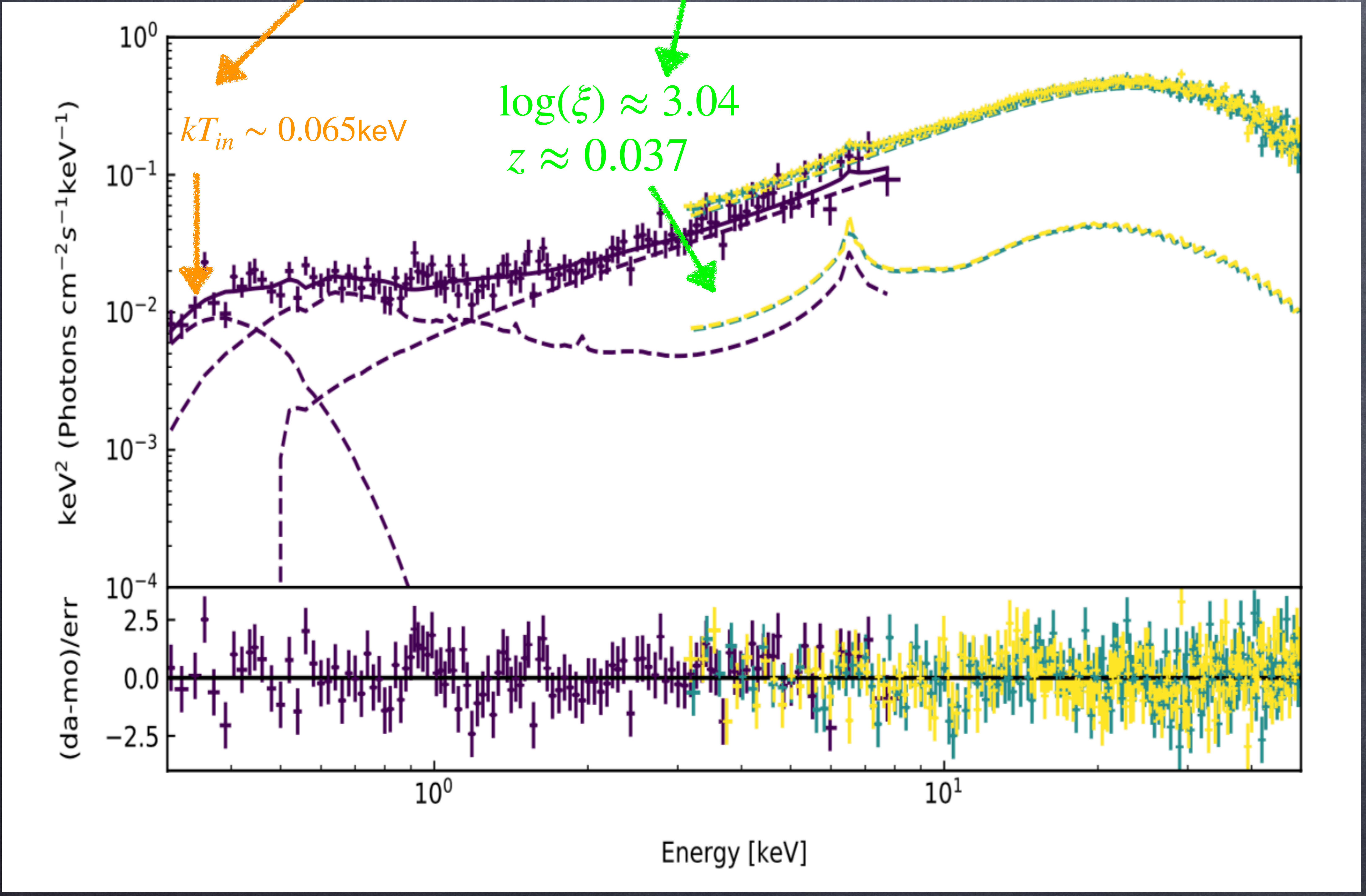
What can we say about the soft excess?

↓

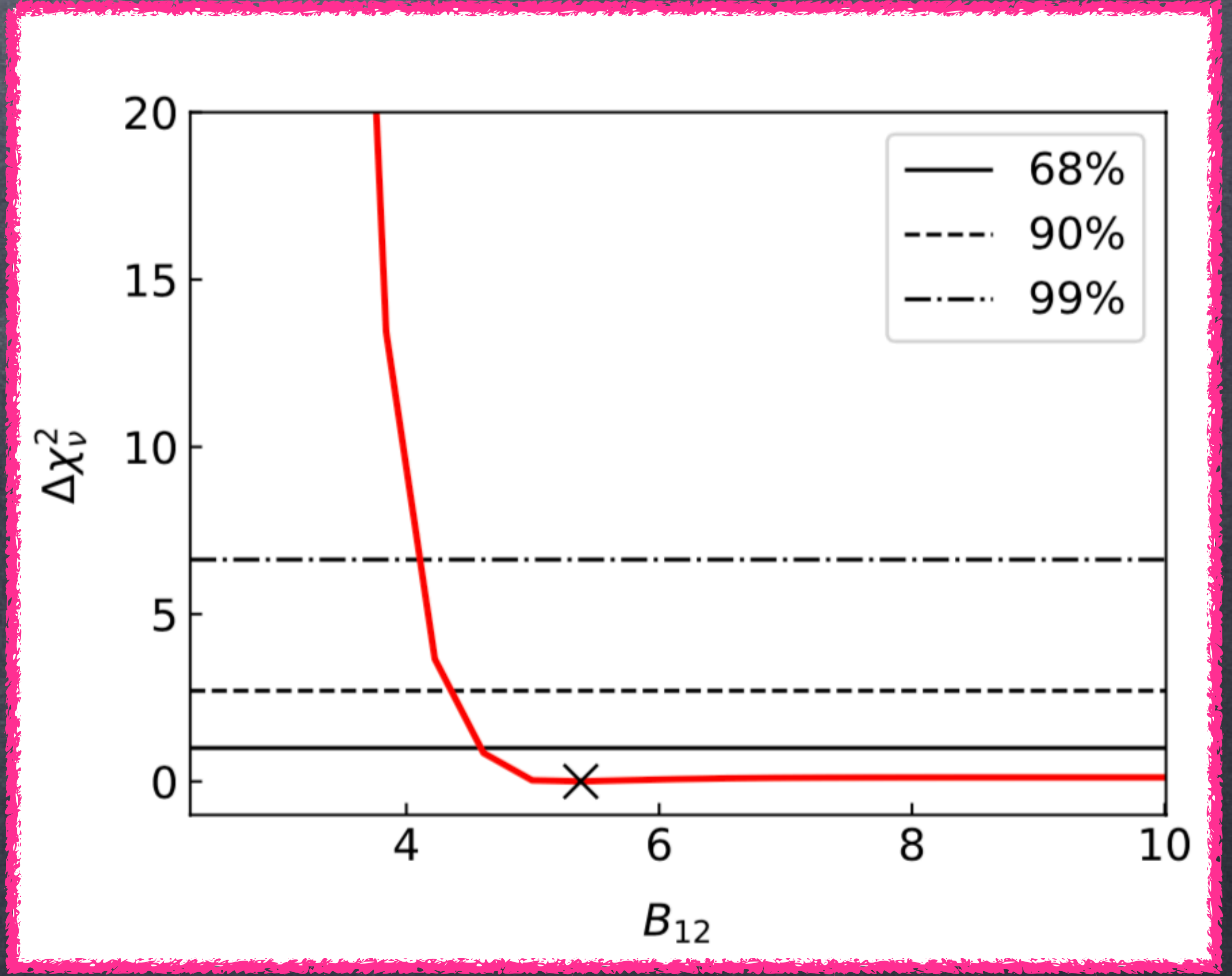
1. Determine the spectrum at high flux (XRT+NuSTAR)
2. Study the variation at different phases

1. Model of high flux epoch

TBabs * (diskbb + coplrefl + BWcycl)



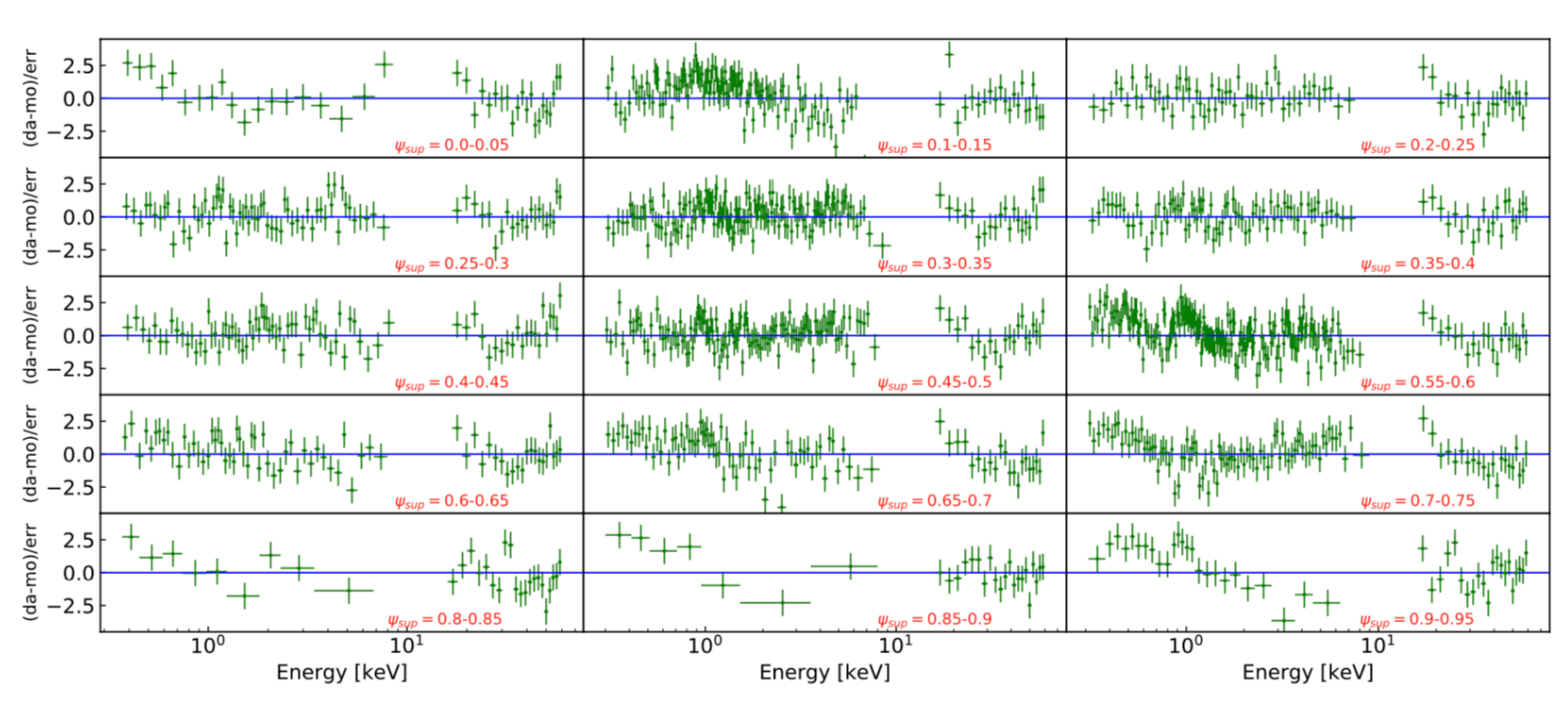
Physical Model		
TBABS	$N_{\rm H}$ $(10^{22}{\rm cm}^{-2})$	0.08 (fixed)
DISKBB	$kT_{\rm in}$ (keV)	$0.065^{+0.018}_{-0.014}$
	Norm	$(7^{+45}_{-6}) \times 10^5$
COPLREFL	$\log(\xi)$	3.04 ± 0.04
	Γ	0.775 (fixed)
	$E_{\rm cut}$ (keV)	18.20 (fixed)
	$E_{\rm fold}$ (keV)	14.99 (fixed)
	z	0.037 ± 0.007
	Norm	$(1.37 \pm 0.11) \times 10^{-31}$
BWCYCL	ξ	$2.9^{+0.8}_{-0.4}$
	δ	0.41 ± 0.11
	$kT_{\rm e}$ (keV)	6.20 ± 0.17
	r_0 (m)	855^{+120}_{-90}
		$1.53^{+0.09}_{-0.08}$
		$1.57^{+0.10}_{-0.09}$
		1.08 (446)



2. Super-Orbital phase-resolved Spectroscopy

Is the flux variation energy - independent? ⟶ K*(high flux model)

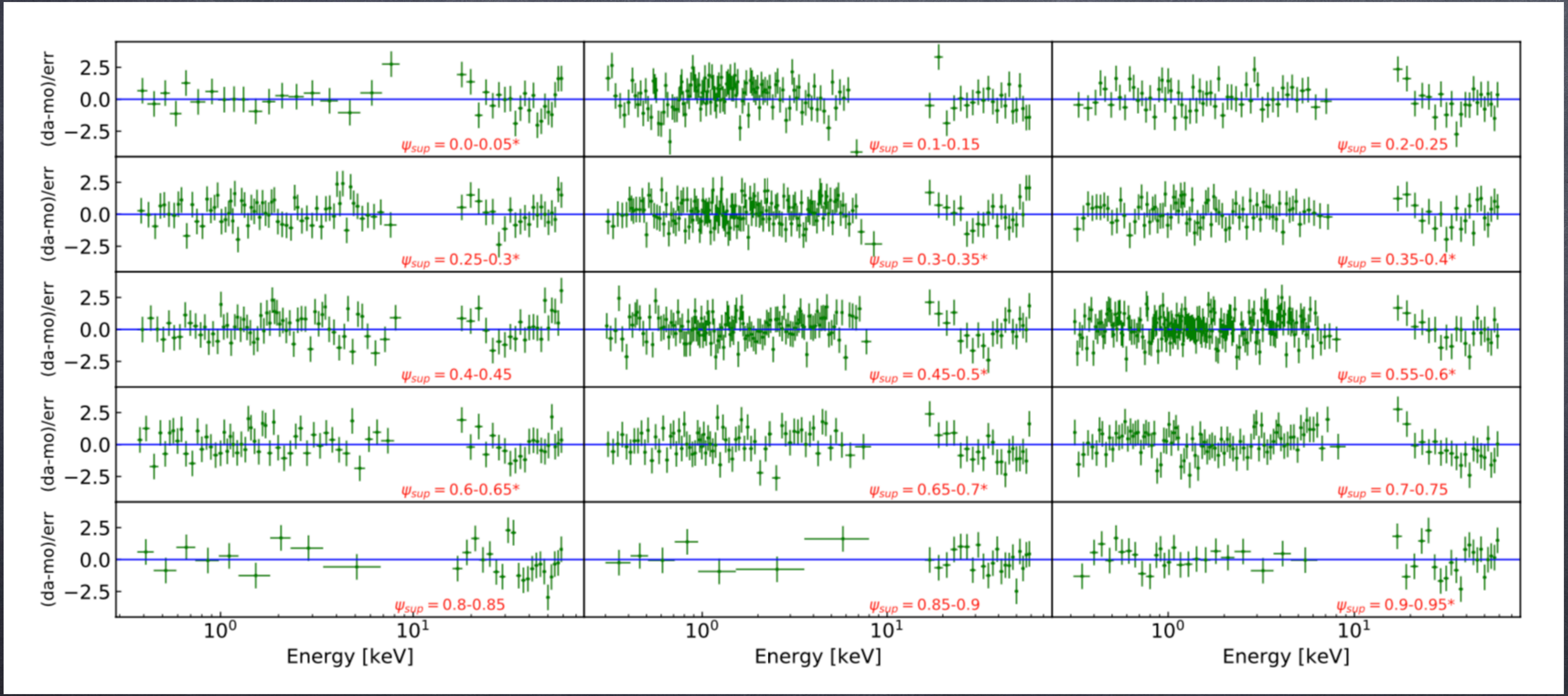
Only flux variation ?

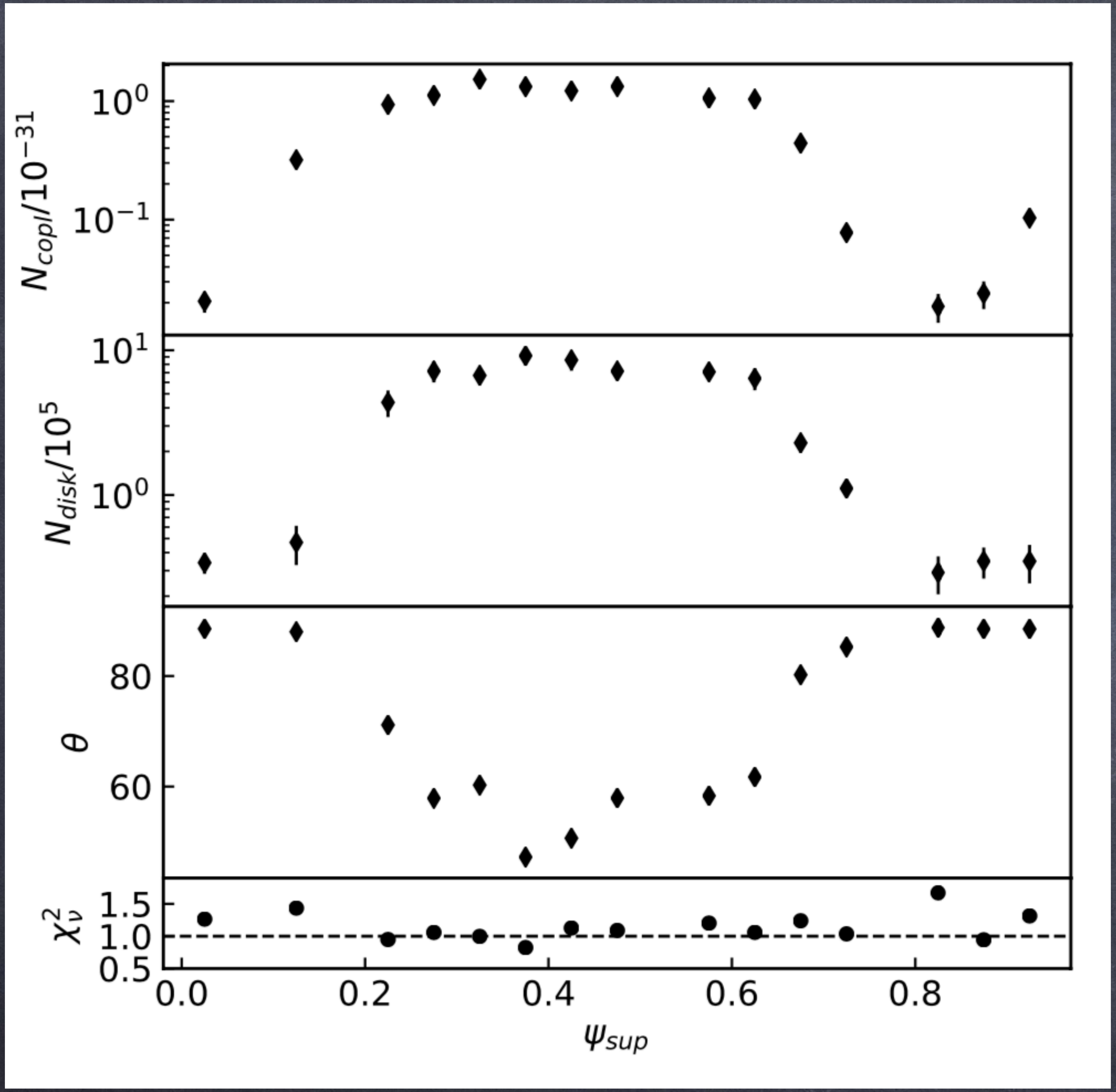


2. Super-Orbital phase-resolved Spectroscopy

Is the flux variation energy - dependent —>TBabs*(diskbb+coplrefl+BWcycl)

Free normalizations





Reflection

Disk

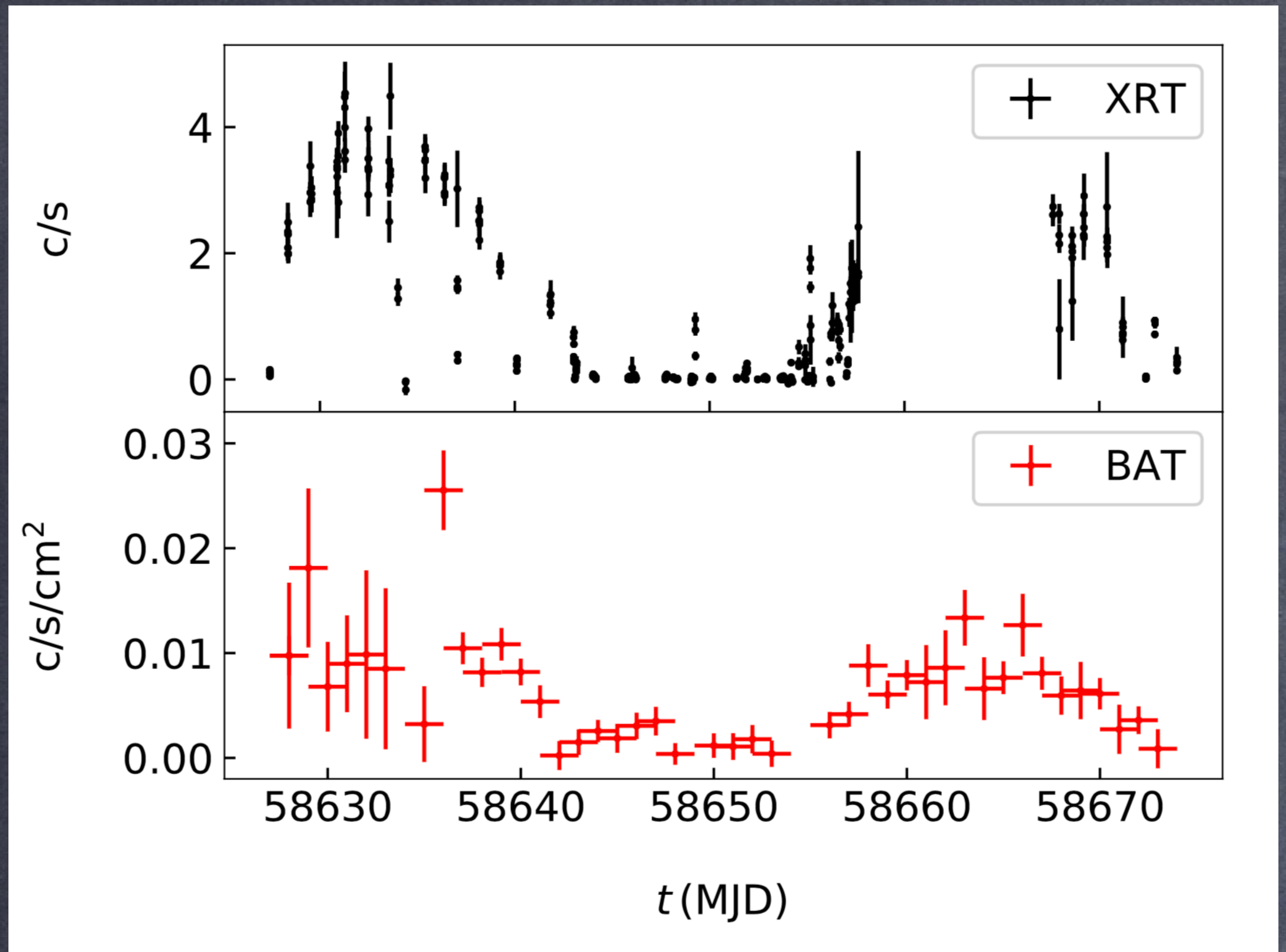
Disk inclination :) :) !!

Changes with Ψ_{sup}

Almost edge-on at minimum

(As Nielsen et al. 2009 found with high res. spectroscopy)

Conclusions

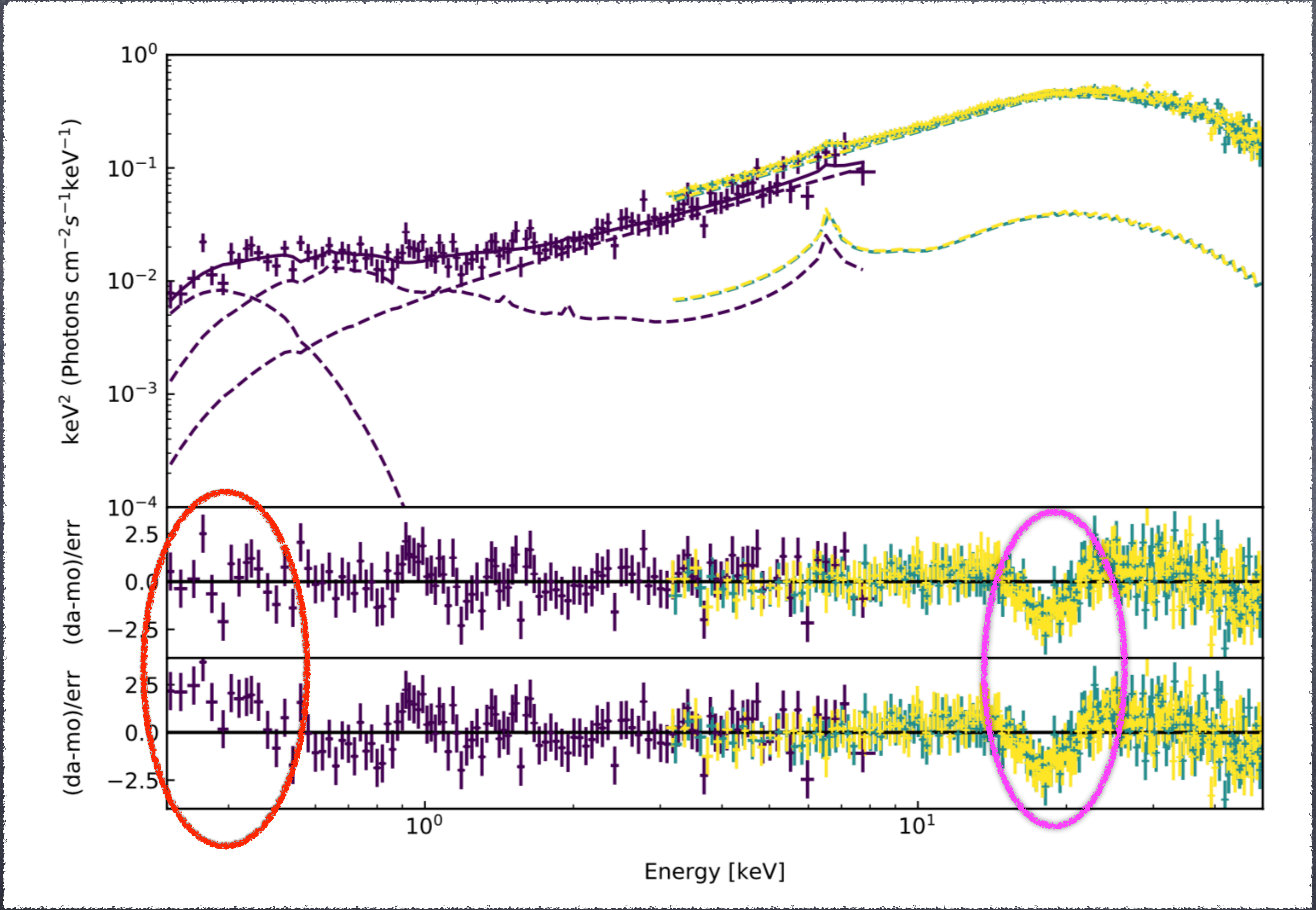


A. Light curve modulation:
1st order effect of disk precession

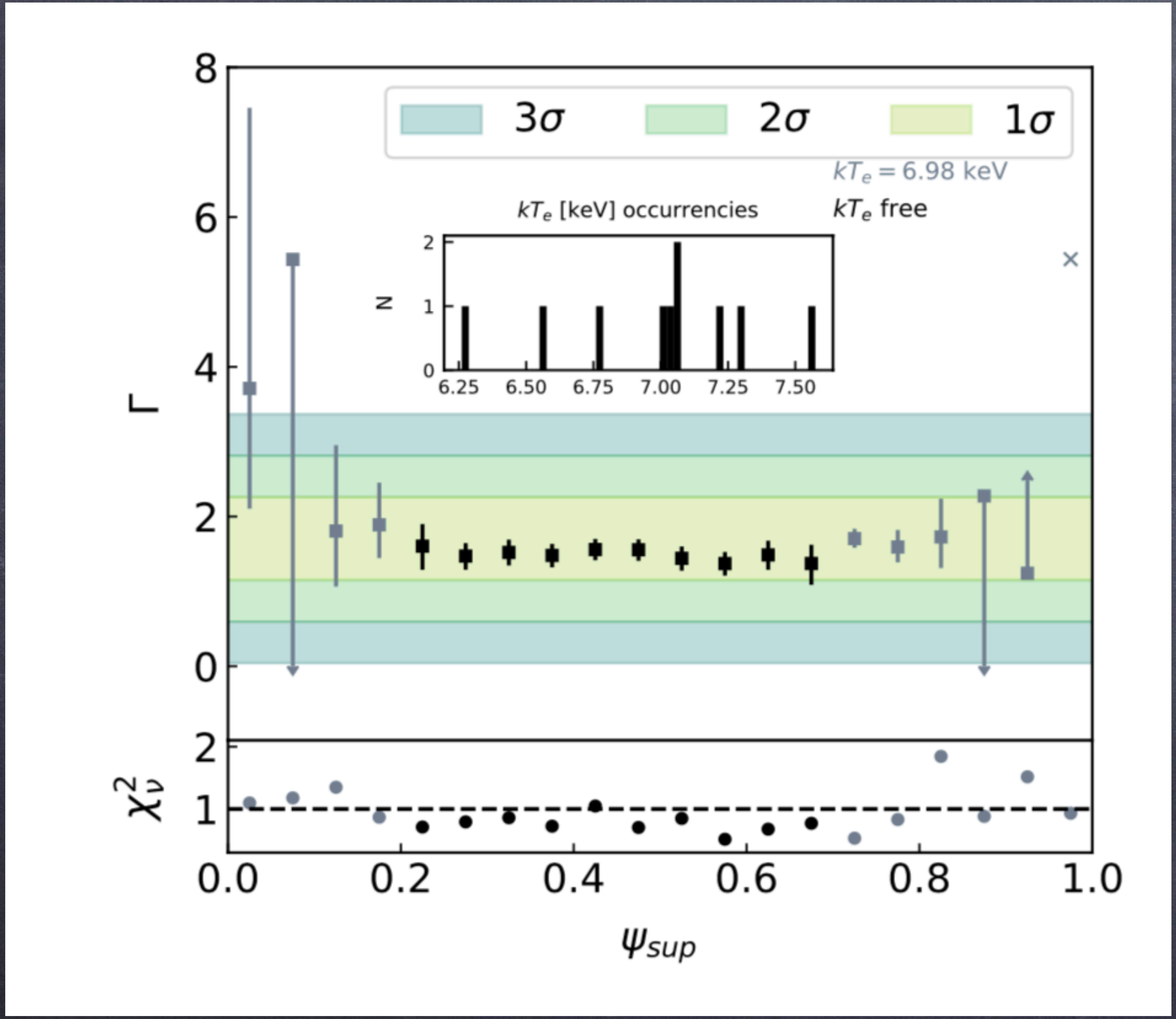
B. Mismatch between hard and soft emission:
2nd order effect: tilt of the disk

Additional slides

Semi-phenomenological model

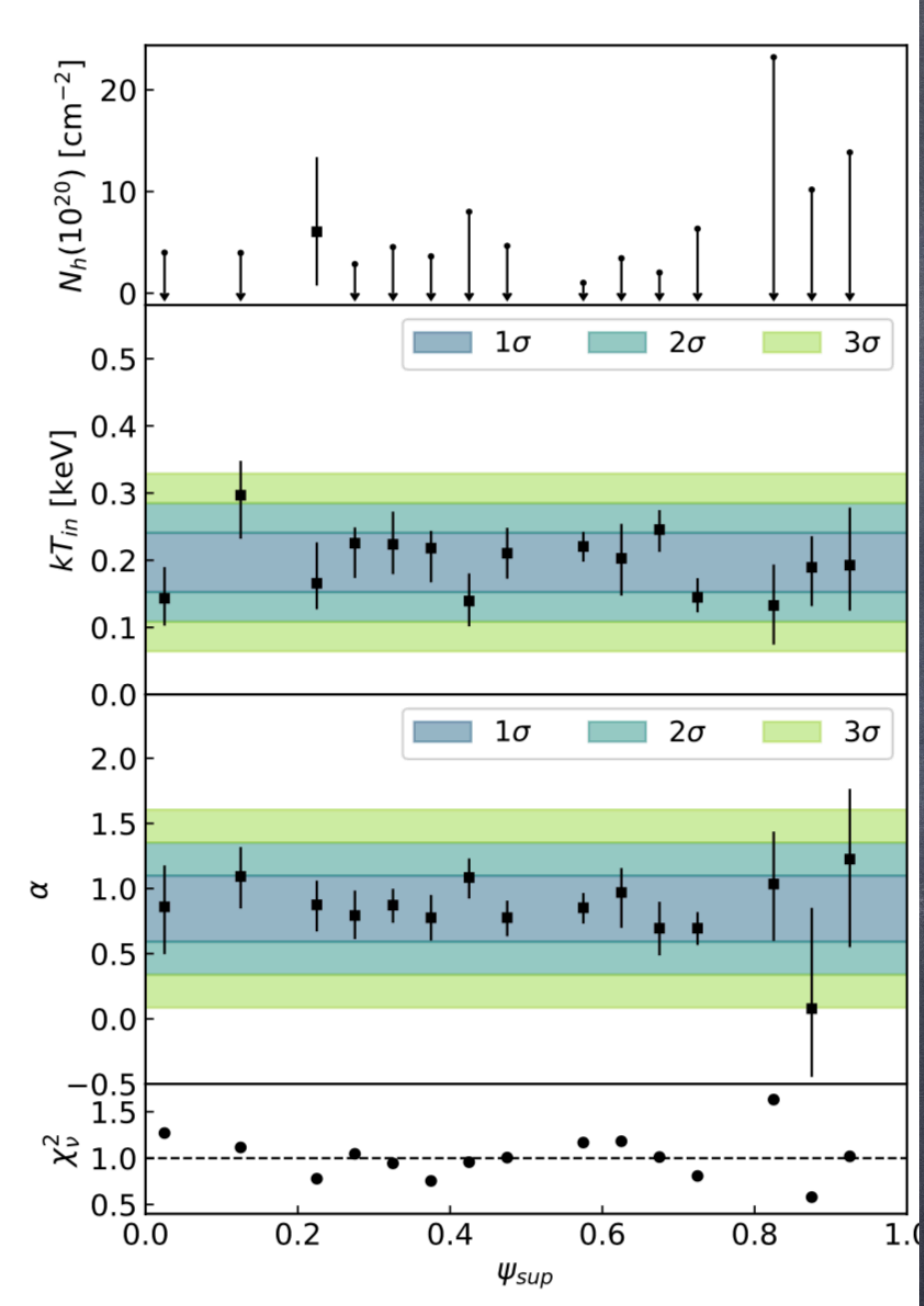


BAT nthcomp

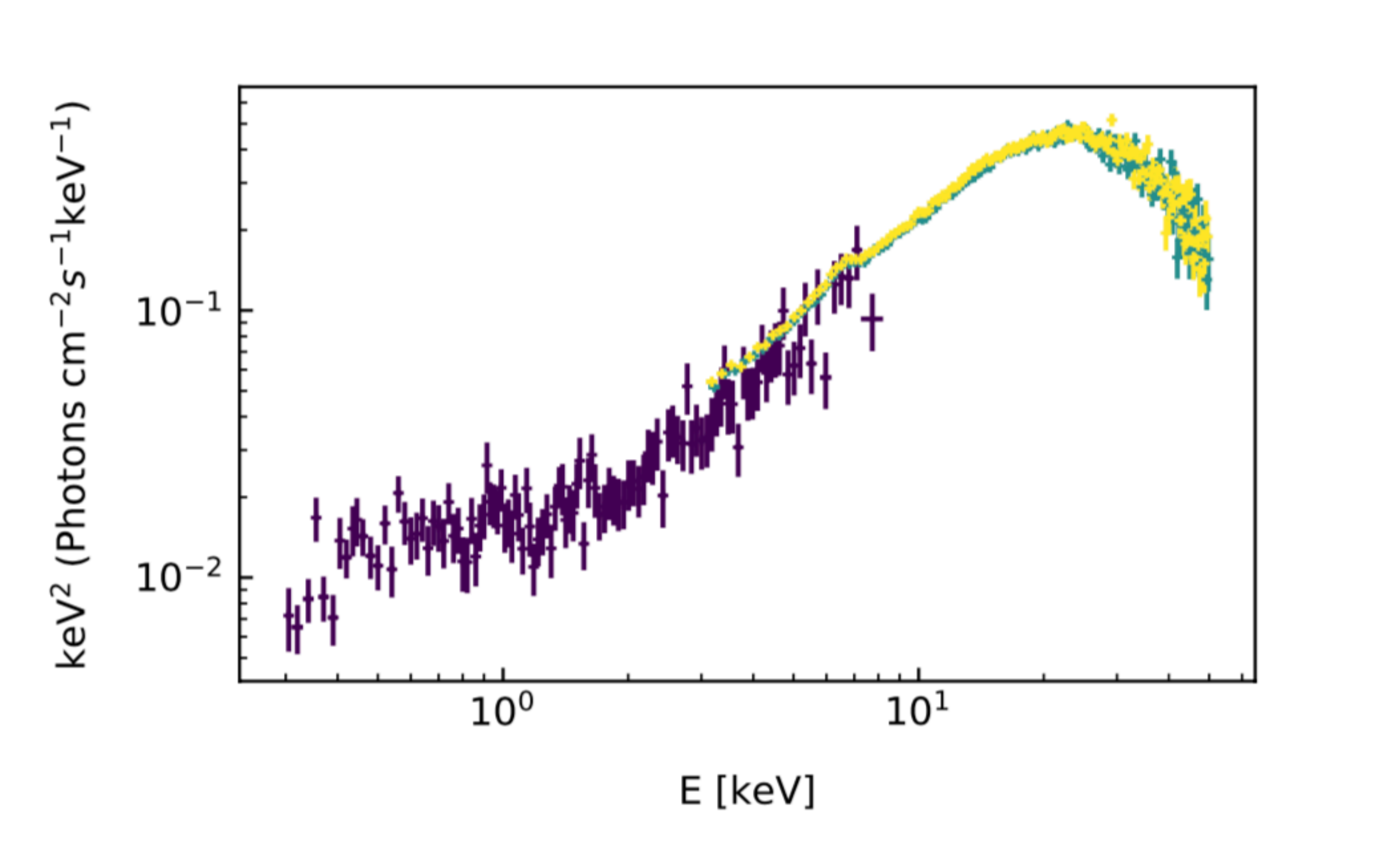


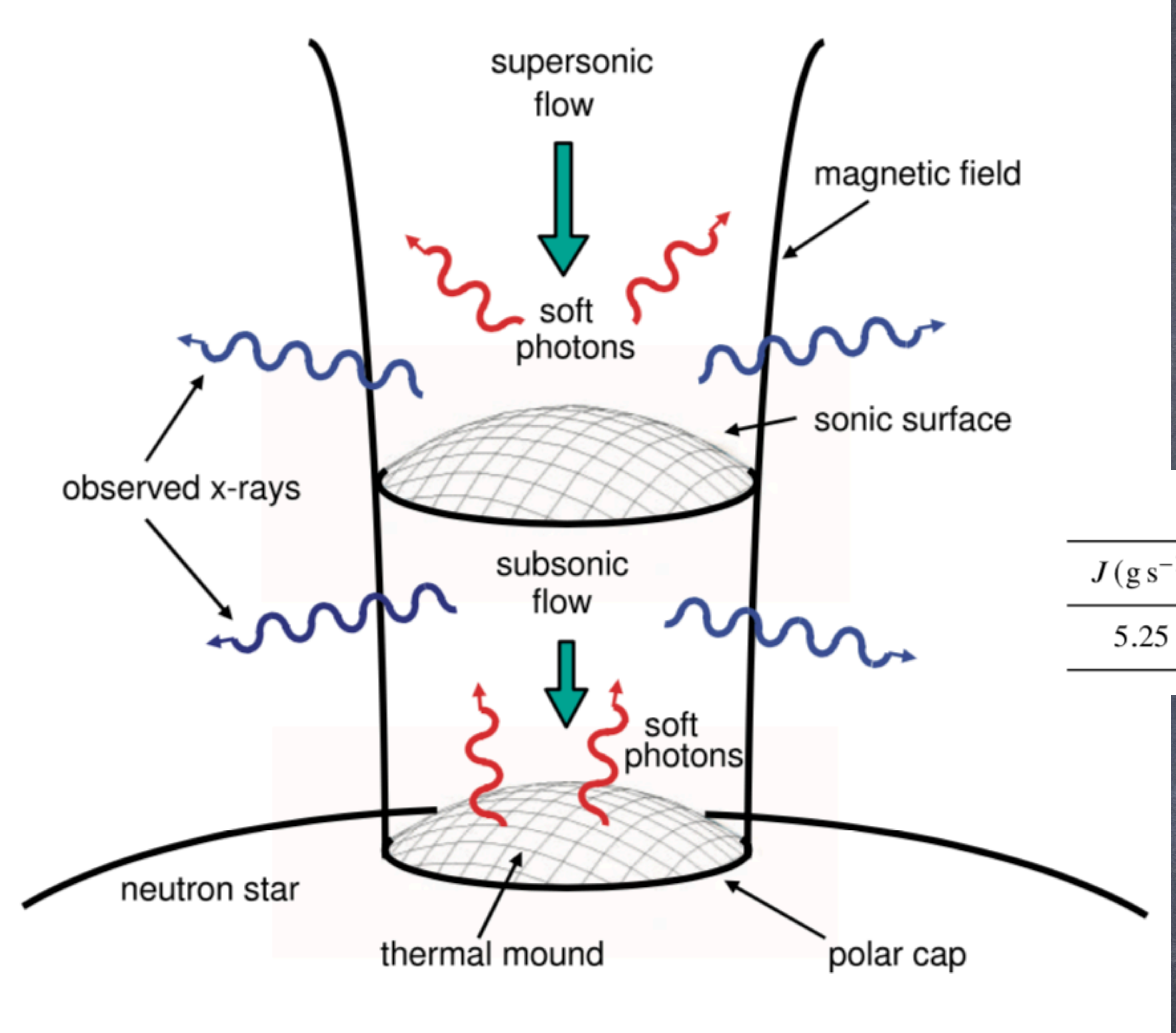
3σ
2σ
1σ
$kT_e = 6.98$ keV
kT_e free
kT_e [keV] occurrencies
N
Γ
χ^2_ν
ψ_{sup}

XRT TBabs*(diskbb+pow)



Joint fit feasible





$J\,(\mathrm{g\,s^{-1}\,cm^{-2}})$	T_{th} (K)	v_{th}/c	z_{th} (cm)	z_{trap} (cm)	z_{sp} (cm)	L_{crit} (erg/s)
5.25×10^{7}	2.04×10^{7}	0.02	1.09×10^{4}	2.10×10^{7}	3.57×10^{6}	5.52×10^{38}

[a] Last two digits of the *Swift*/XRT OBSID: 000335380XX

Ψ_{sup}	XRT ObsID[a]
0.00 – 0.05	34
0.10 – 0.15	38, 39
0.20 – 0.25	12
0.25 – 0.30	13
0.30 – 0.35	14, 15
0.35 – 0.40	16
0.40 – 0.45	17
0.45 – 0.50	**19, 20**
0.55 – 0.60	22, 23, 43, 44
0.60 – 0.65	45
0.65 – 0.70	25,47
0.70 – 0.75	26, 48
0.80 – 0.85	29
0.85 – 0.90	30
0.90 – 0.95	32