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The reflection spectrum of the low-mass X-ray binary 4U 1636–53

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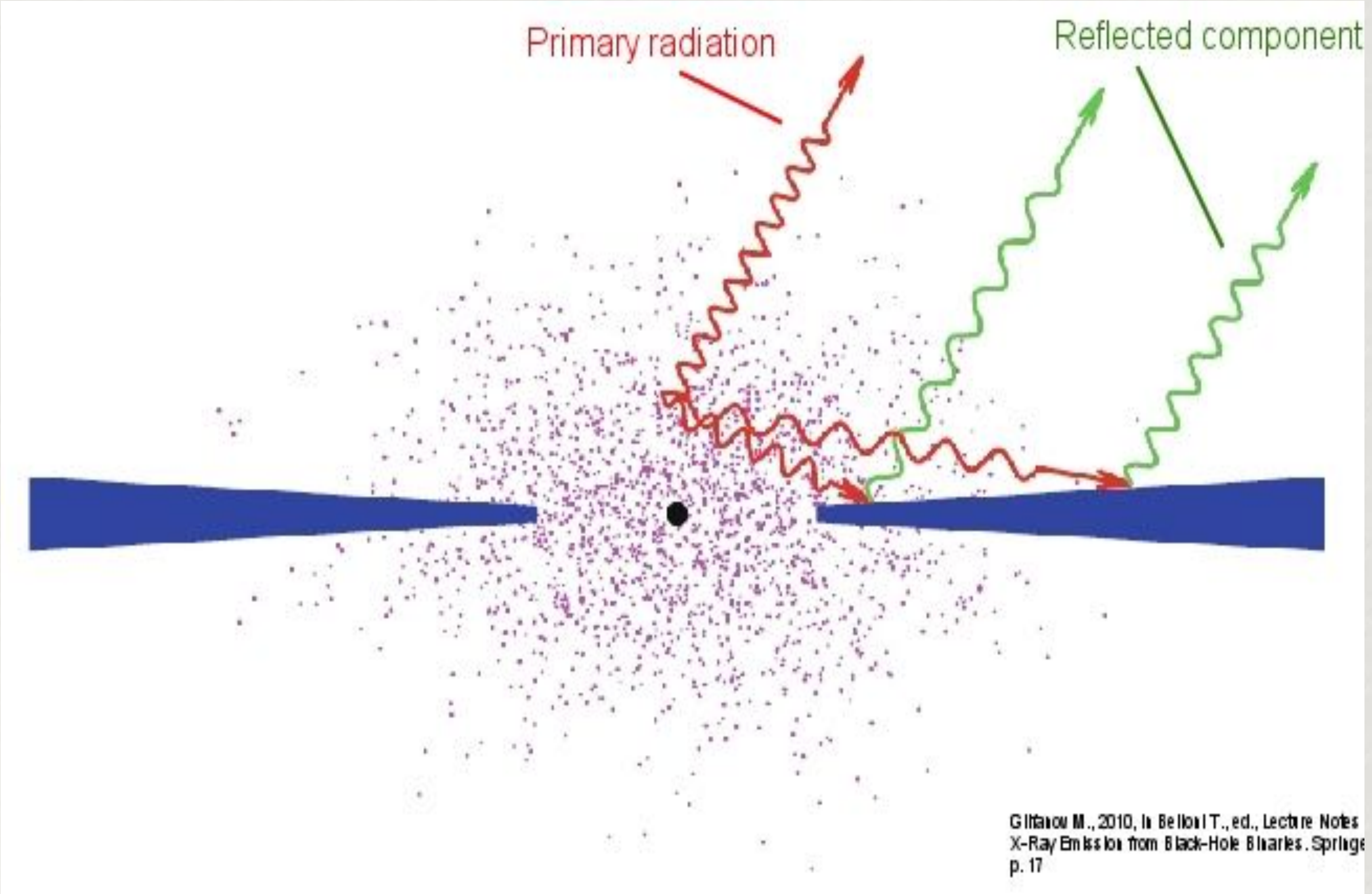
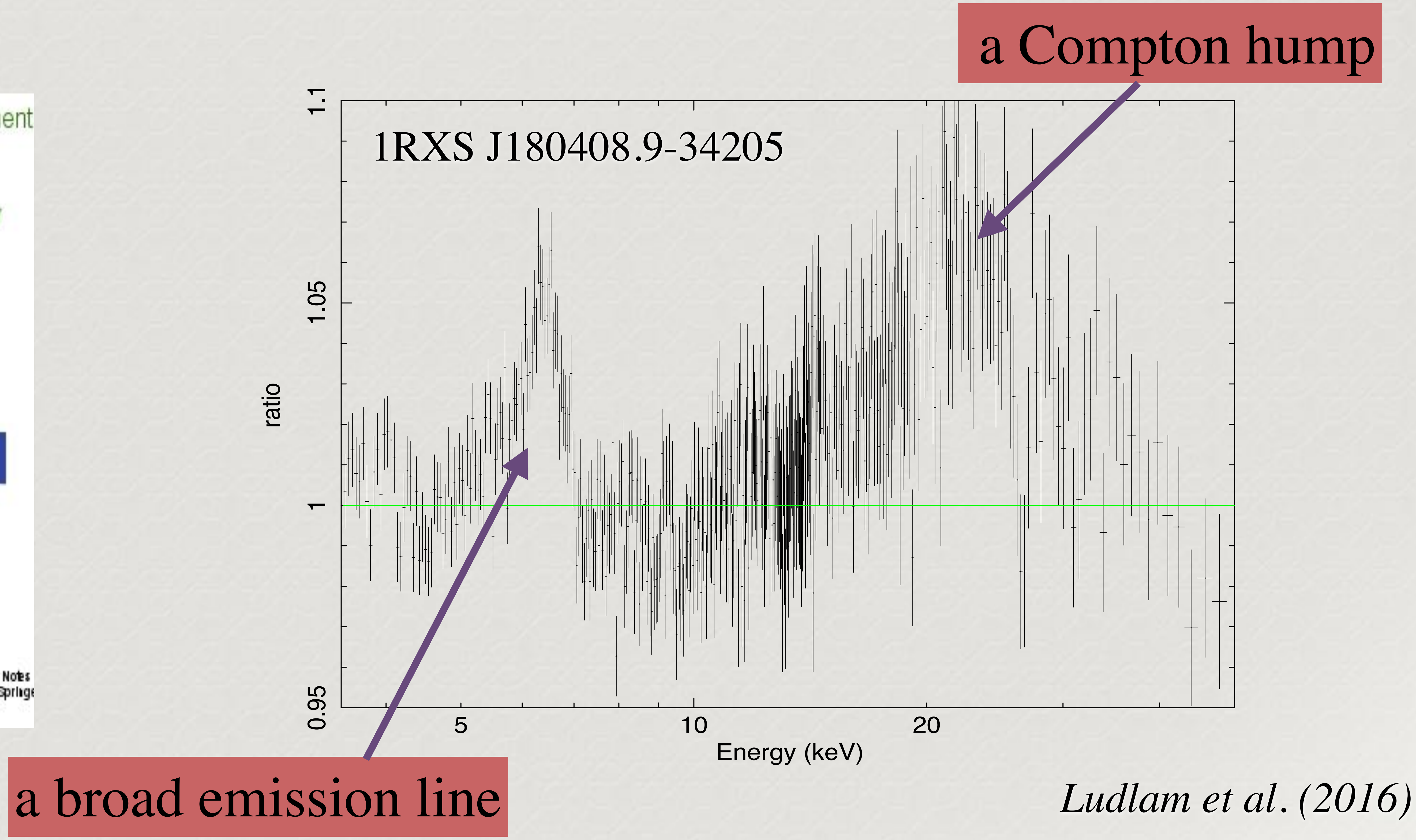
Introduction





Ludlam et al. (2016)

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Introduction

- Pandel, Kaaret & Corbel (2008): no correct for pileup; at least two Fe-K lines from iron in different ionization states; > 64°, most cases peg at 90°
- Cackett et al. (2010) : no correct for pileup; the boundary layer illuminating a geometrically thin disc; all cases peg at 90°
- Ng et al. (2010) : considering pileup and background effects; symmetric line profiles; upper limit at 70°
- Sanna et al. (2013) : considering pileup and background effects; both the NS surface/boundary layer and the corona illuminating the disc; ~ 48-89°, most cases peg at 90°

High inclination? Pileup effects? Primary source? Line profiles?

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Table 1. *NuSTAR* Observations of 4U 1636-53 used in this paper

Obervation	Identification Number	Observation Times (UTC) (day.month.year hr:min)	Exposure (ks)
Obs. 1	30102014002	25.08.2015 02:51 - 25.08.2015 18:36	27.4[A] (27.3*)/27.7[B] (27.5*)
Obs. 2	30102014004	05.09.2015 17:41 - 06.09.2015 11:01	30.3[A] (30.2*)/30.4[B] (30.3*)
Obs. 3	30102014006	18.09.2015 07:06 - 18.09.2015 23:26	28.9[A] (28.8*)/29.0[B] (28.9*)

[A]Total exposure time of FPMA of *NuSTAR*;
[B]Total exposure time of FPMB of *NuSTAR*;
*Final exposure time excluding X-ray bursts.

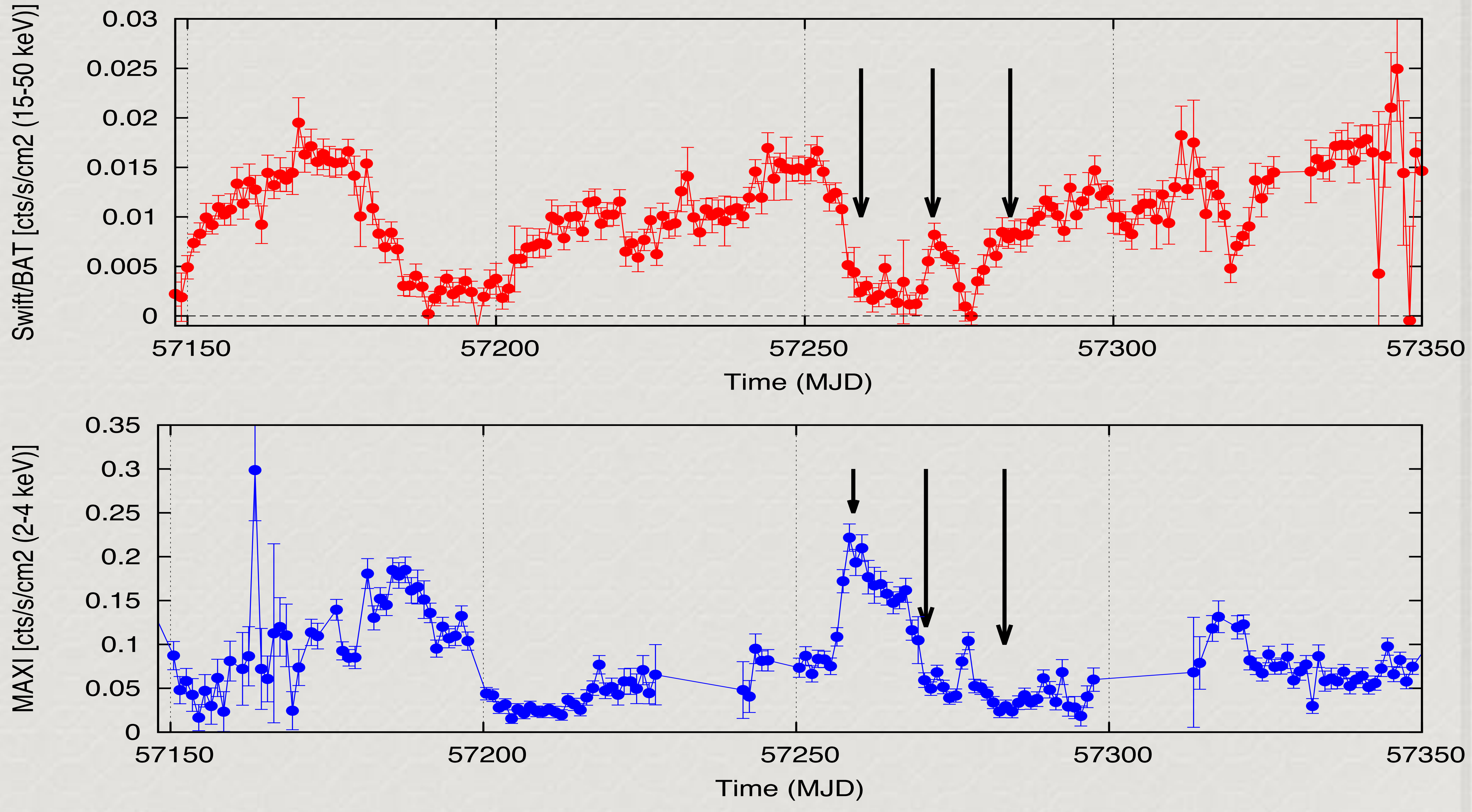

Figure 1. Hard and soft long-term light curves of 4U 1636−53. Top and bottom panels show, respectively, the *Swift*/BAT (15−50 keV) and the MAXI (2−4 keV) light curve of this source.

Simultaneously observing the broad emission line and the Compton hump without pileup effects!

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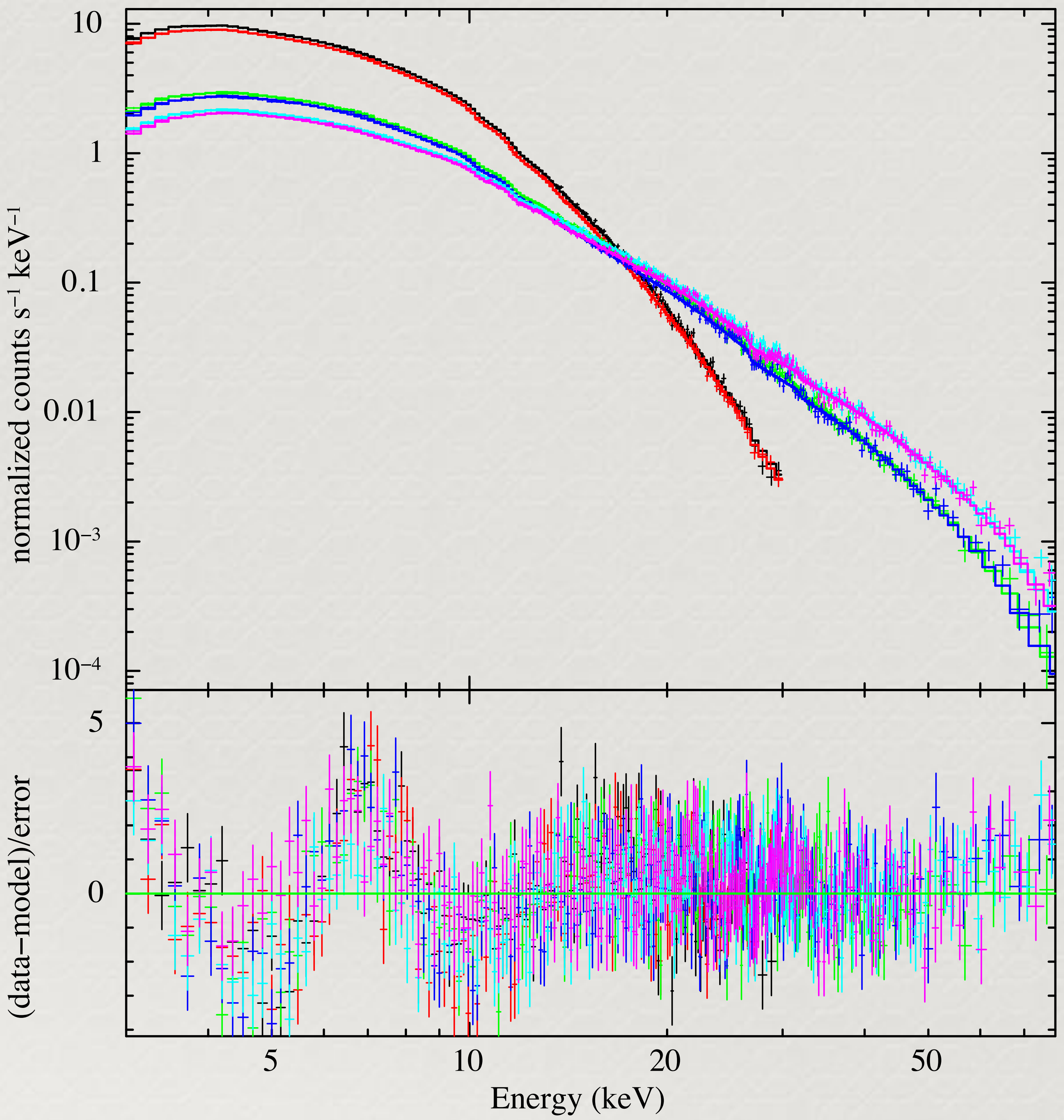

Figure 2. *NuSTAR* spectra and models for the fit with *const*phabs*(bbody+nthcomp)* for 4U 1636–53. The bottom panel shows the residuals in terms of sigmas. The spectra have been rebinned for plotting purposes.

- large positive residuals at around 5-10 keV
- no clear Compton hump at high energies (above 10 keV)

Note: In Obs.1, we only fit the spectra at the energy range of 3-30 keV.

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Models we used to fit the line in this work:

- a simple symmetric model, **GAUSSIAN**;
- relativistically broadened emission line model, **KYRLINE**;
- two models including relativistically smeared and ionized reflection off the accretion disc with different coronal heights, **RELXILL** and **RELXILLLP**.

Hereafter, rel is short for RELXILL and relp is short for RELXILLLP!!!

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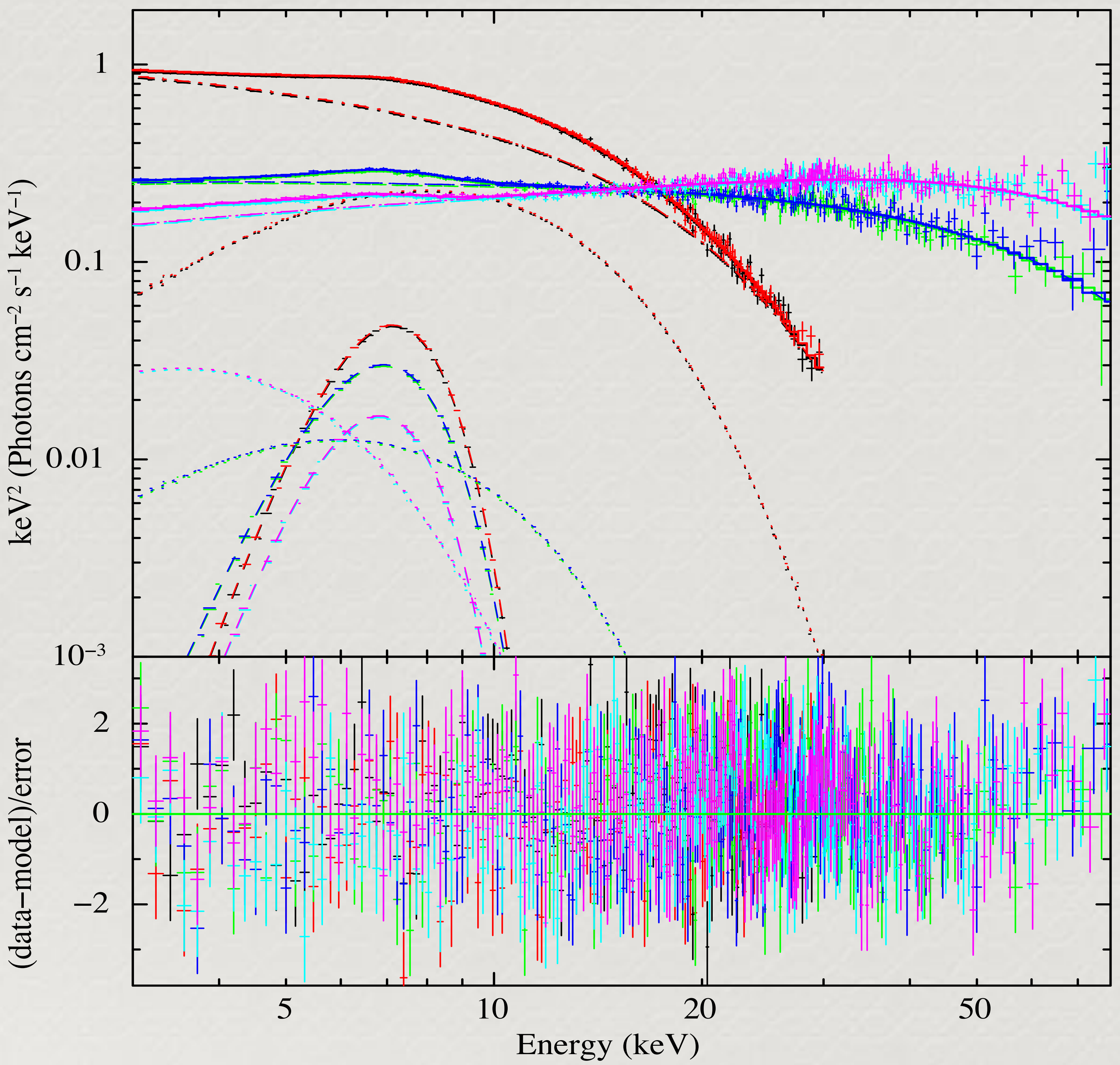

Figure 3. *NuSTAR* unfolded spectra and models fitted with the model *const*phabs*(bbody+gaussian+nthcomp)* for 4U 1636–53.

Results of M1:

- kT_{bb} goes down from Obs. 1 to Obs. 3;
- Γ_{nth} decreases while kT_e increases from Obs. 1 to Obs. 3, indicating the soft, transitional and hard state;
- E_{gau} decreases from Obs. 1 (~6.7 keV) to Obs. 2 and 3, suggesting the disc becomes less ionized.

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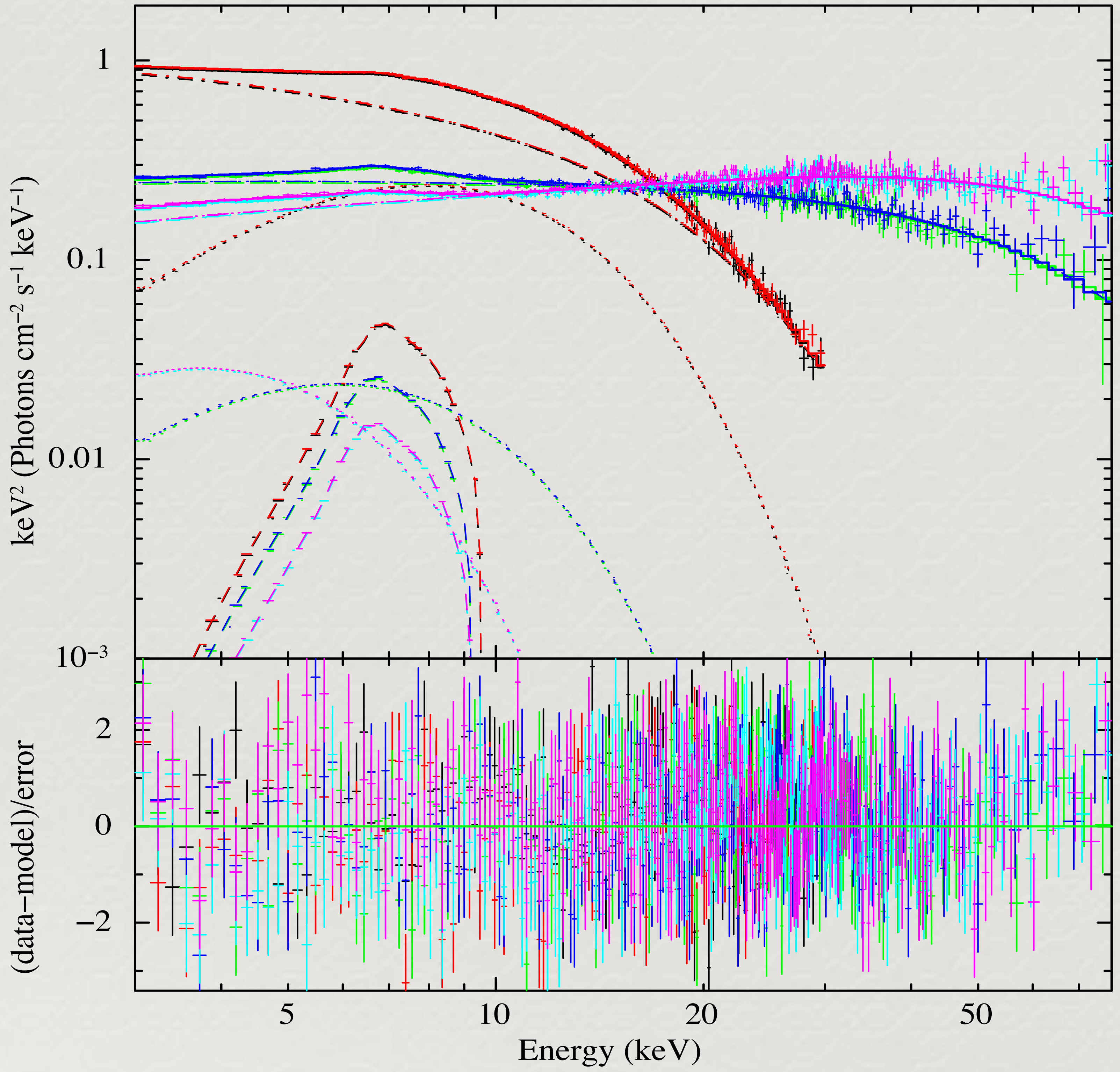

Figure 4. *NuSTAR* unfolded spectra and models fitted with the model *const*phabs*(bbody+kyrline+nthcomp)* for 4U 1636–53.

Results of M2:

- the parameters more or less followed the same trend with them in M1;
- inclination ~88°, excluding the possible effect of calibration uncertainties of *XMM-Newton*.

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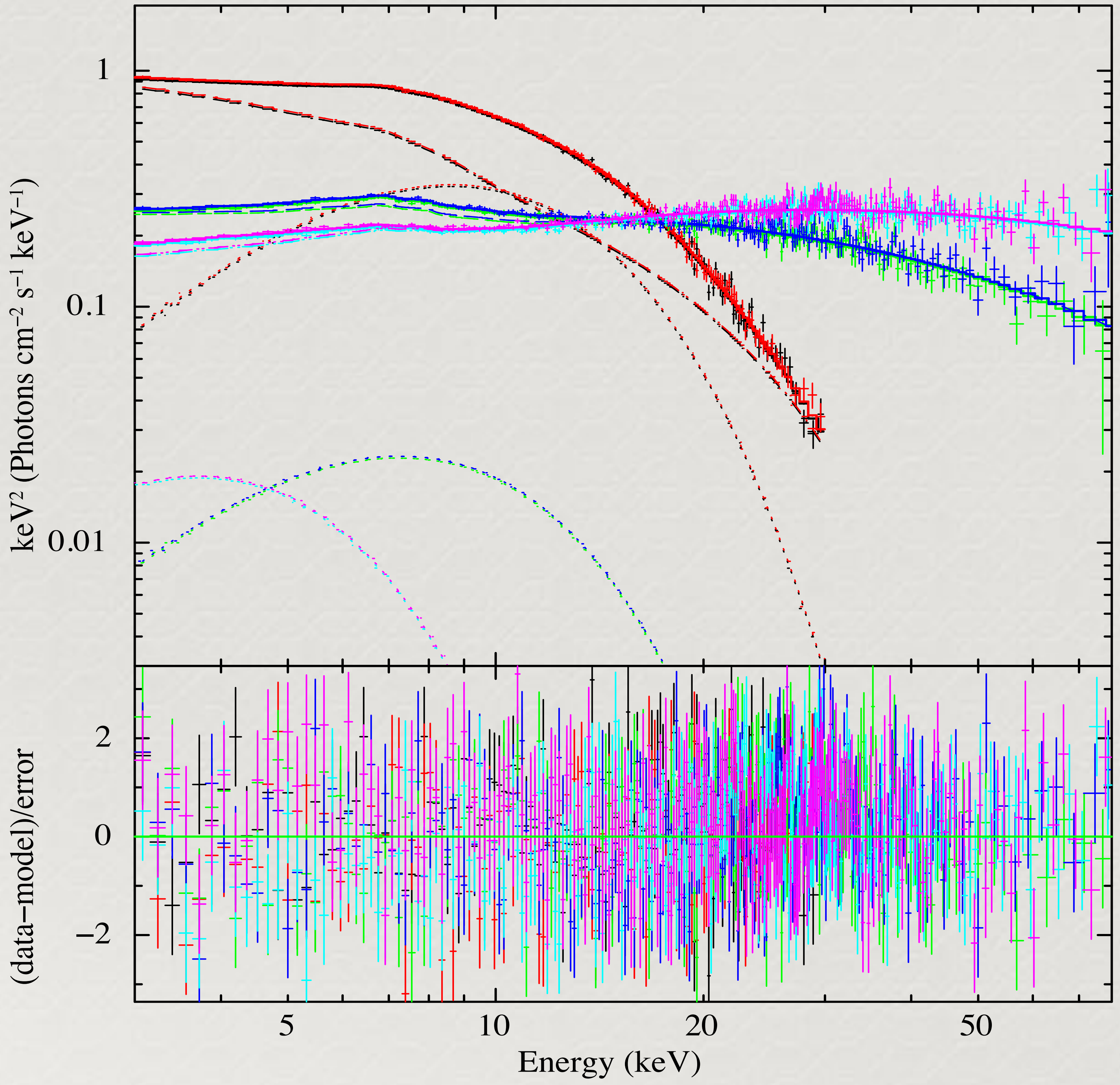

Figure 6. *NuSTAR* unfolded spectra and models fitted with the model *const*phabs*(bbody+relxill)* for 4U 1636−53.

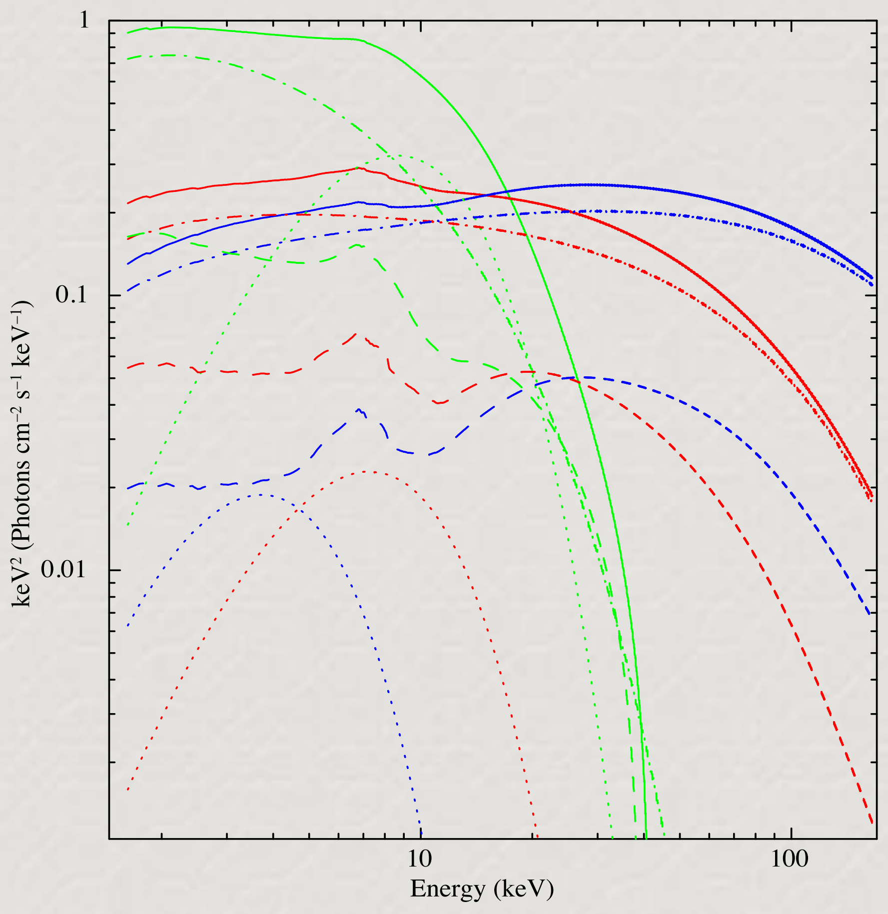

Figure 7. The unfolded best-fitting model *const*phabs*(bbody+relxill)* to three spectra of 4U 1636−53.

Results of M3:

- most of the parameters follow the same trend as those in other models; inclination ~88°;
- R_{in} increases from ~6 R_g in Obs. 1 to ~17 R_g in Obs. 3;
- the ionization parameter **ξ** decreases with time;

supporting the standard accretion disc model.

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	Component	M4		
		Grp. 1	Grp. 2	Grp. 3
	const		$1.00^f/1.02\pm0.01$	
BB	kT_{bb} (keV)	2.13±0.01	1.82±0.02	0.93±0.02
	k_{bb} (10^{-3})	9.2±0.02	0.6±0.01	0.5±0.01
	F_{bb} (10^{-11})	71.3±0.07 64.6±0.07	4.4±0.05 4.4±0.05	2.0±0.03 2.5±0.03
RELXILLLP	i_{relp} (°)		55.7±0.2	
	h/R_g	2.3±0.2	2.5±0.1	$2.8^{+0.1}_{-0.3}$
	R_{in}/R_g	5.7±0.07	10.3±0.04	11.4±0.08
	Γ_{relp}	2.19±0.01	1.93±0.01	1.76±0.01
	E_{cut} (keV)	7.9±0.05	61.5±0.6	135.9±0.7
	τ	4.9±0.04	1.5±0.02	0.9±0.01
	$log(\xi)$	4.4±0.03	3.4±0.03	3.1±0.06
	k_{relp} (10^{-3})	$289.9^{+332}_{-0.3}$	46.7±0.05	21.3±0.03
	F_{relp} (10^{-9})	1.4±0.01 1.4±0.01	1.1±0.01 1.1±0.01	1.2±0.01 1.2±0.01
	Total flux F_{ttl} (10^{-9})	2.12±0.01 2.11±0.01	1.13±0.01 1.12±0.01	1.17±0.01 1.19±0.01
	χ^2_ν (dof)		1.04(4636)	

Table 3. Best-fitting parameters of the *NuSTAR* spectra of 4U 1636−53 with reflection model RELXILLLP.

Results of M4:

- most of the parameters follow the same trend as those in other models;
- the height of corona, h, increases from 2.3 R_g in Obs. 1 to 2.8 R_g in Obs. 1;
- inclination ~56°.

No geometry assuming and no relativistic boosting effects considering in the *RELXILL* model.

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Conclusion

- Four models fit the data well with different line profiles, even the simple symmetric model **Gaussian**;
- The inclination is ~88° in **KYRLINE** and **RELXILL**, but is ~56° in **RELXILLLP**;
- The variation of the direct and reflection continuum evolves with the source state.

Submitted!

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