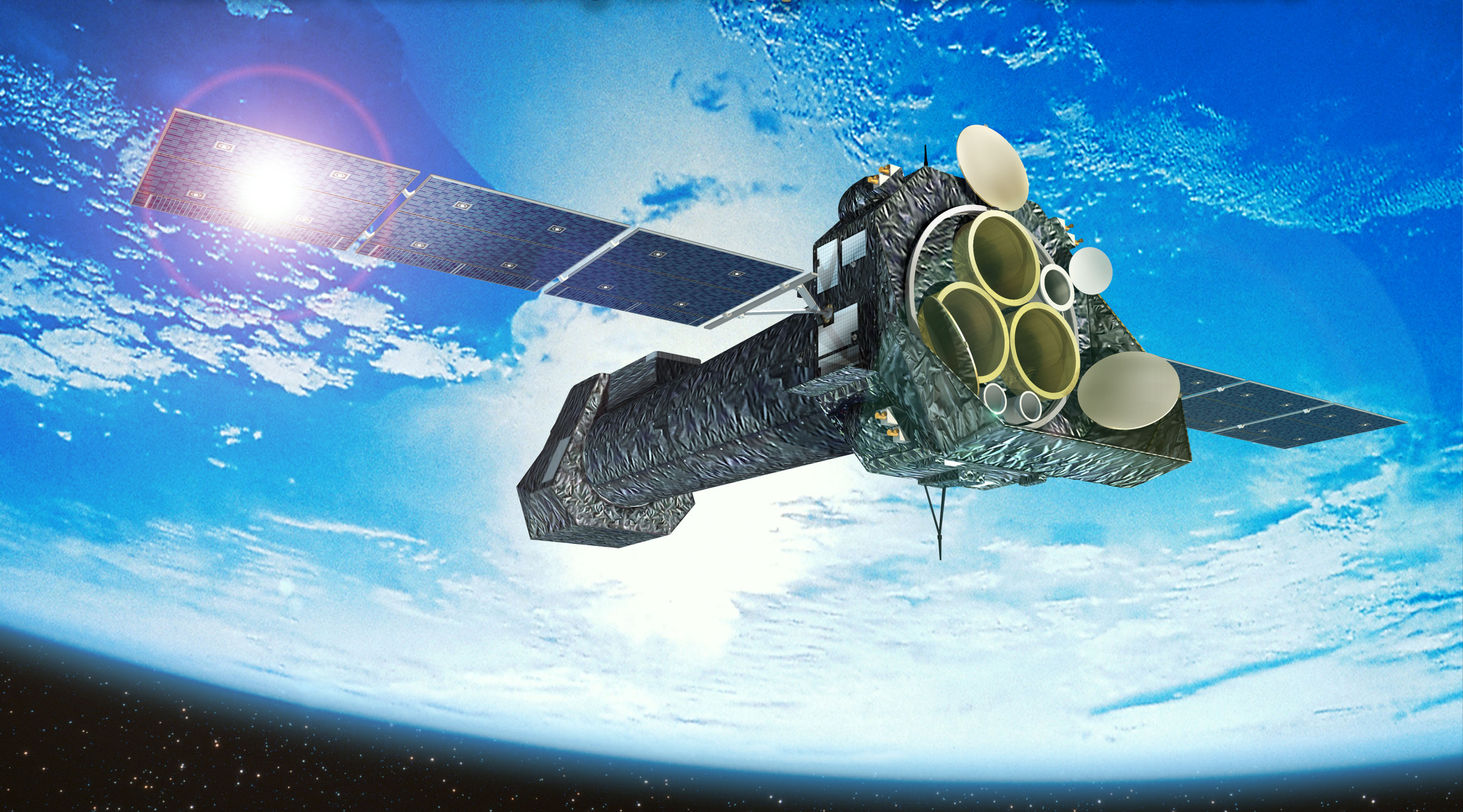
An empirical method for improving the XMM-Newton/EPIC-pn RMF and ARFs



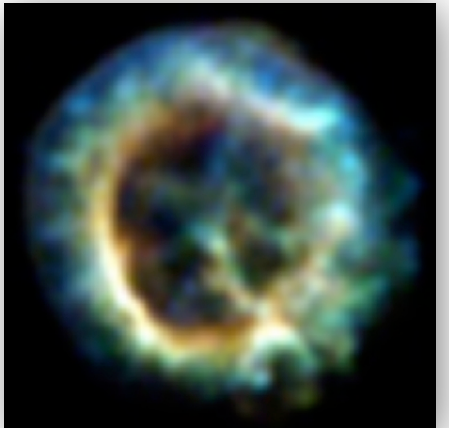
Konrad Dennerl - Max Planck Institute for Extraterrestrial Physics – Garching - Germany

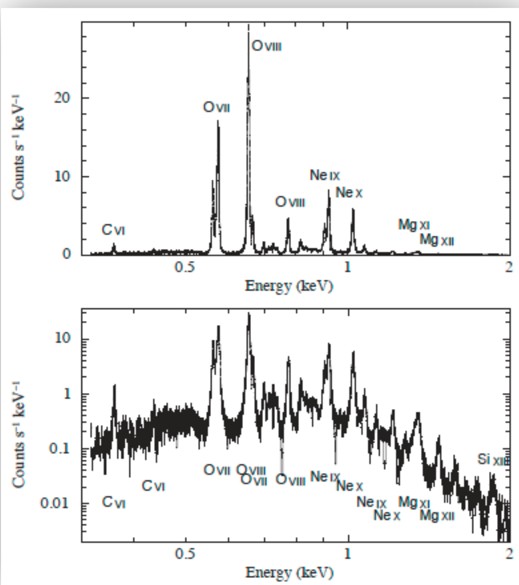
± 20%

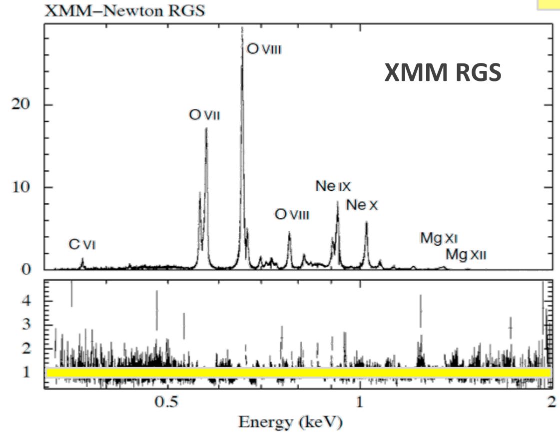
Plucinsky et al. 2017 (A&A 597)

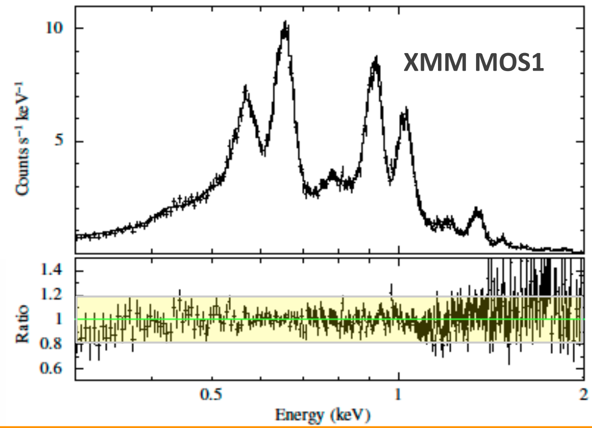
SNR 1E 0102.2-7219 as an X-ray calibration standard in the 0.5–1.0 keV bandpass and its application to the CCD instruments aboard *Chandra*, *Suzaku*, *Swift* and *XMM-Newton*

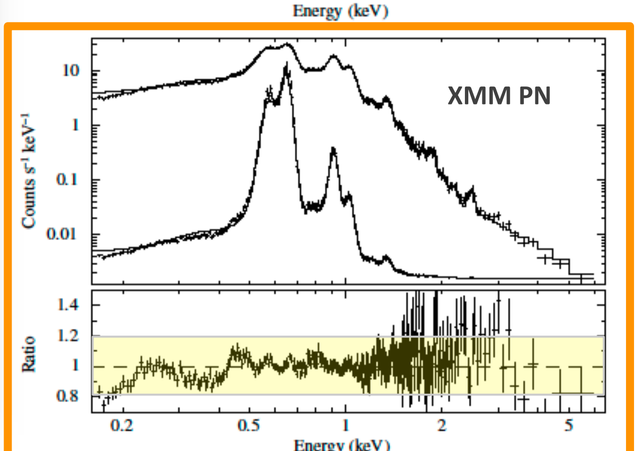
Paul P. Plucinsky[1], Andrew P. Beardmore[2], Adam Foster[1], Frank Haberl[3], Eric D. Miller[4], Andrew M. T. Pollock[5], and Steve Sembay[2]

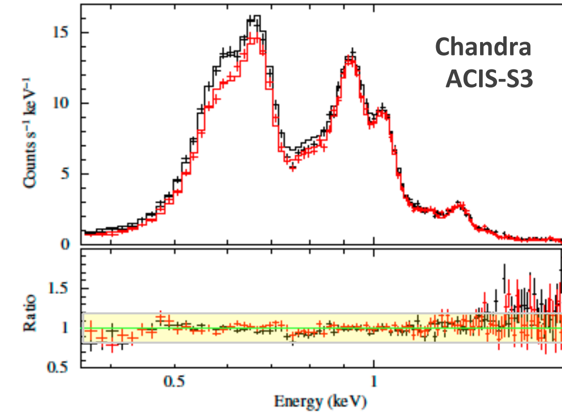


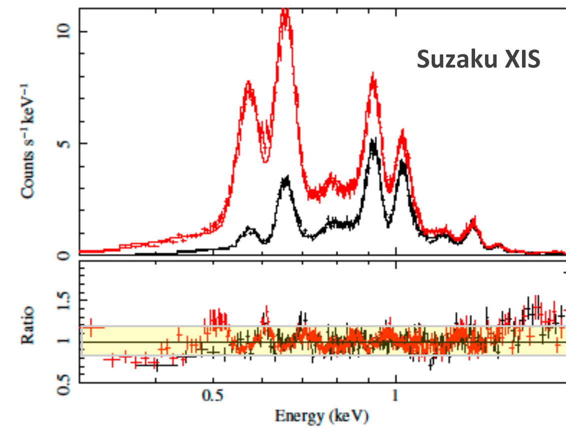


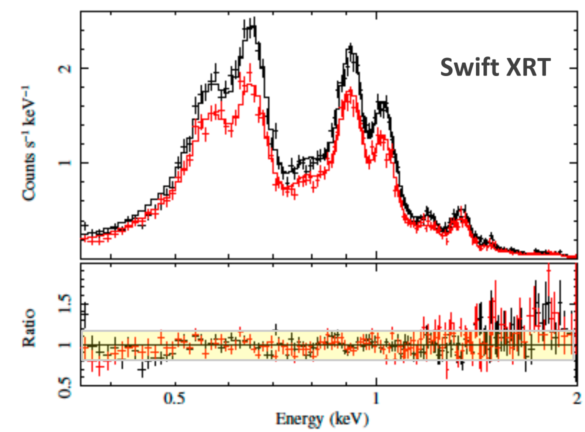








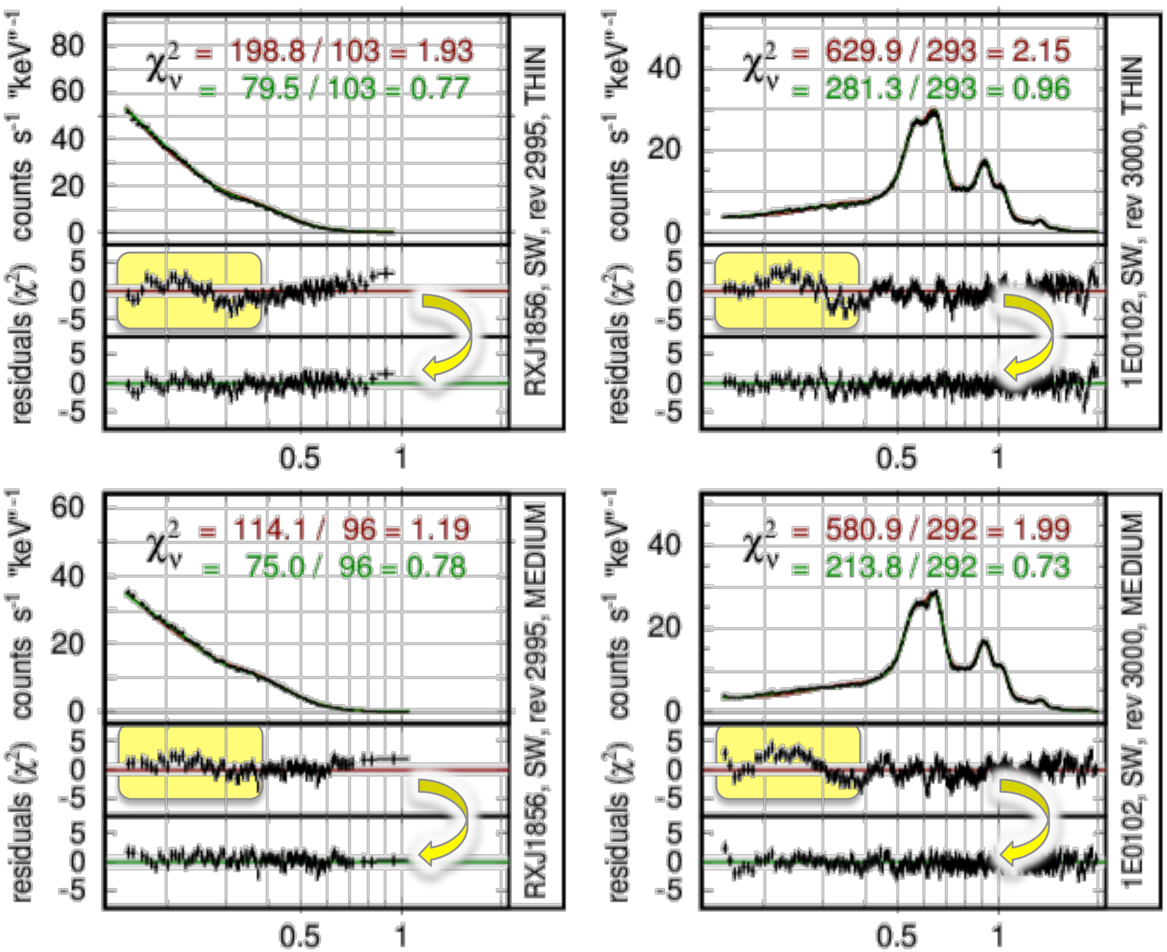




Warning: ARF adjustments alone may be dangerous !

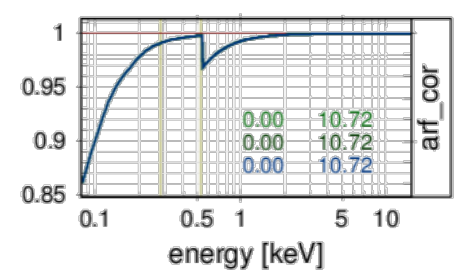
Example: XMM/EPIC-pn, simultaneous fit to RXJ 1856 and 1E0102 in three filters each, using the same model spectrum for each source, with no normalization between the filters

RXJ 1856 1E 0102



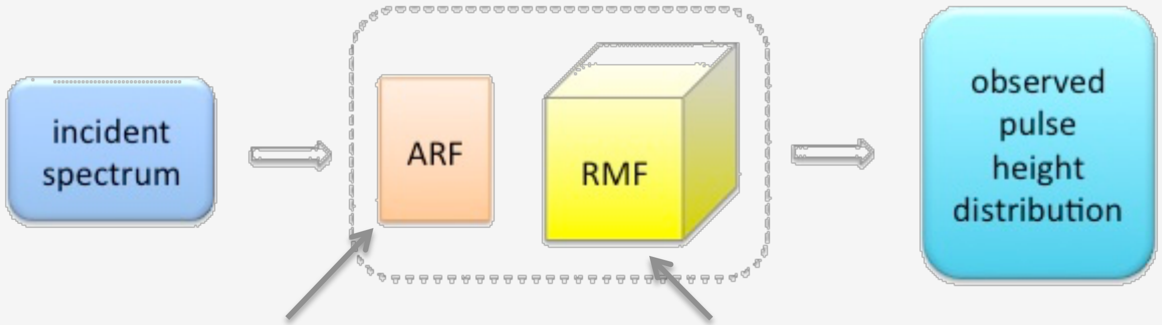
The apparent excess in residuals below 0.4 keV could be „repaired“ by **increasing the ARF** at low energies ..

Work on the RMF refinement, however, suggests to **increase the redistribution** and to **decrease the ARF** at low energies !



General properties of the ARF and RMF

ARF: „Ancillary Response File“, RMF: „Redistribution Matrix File“



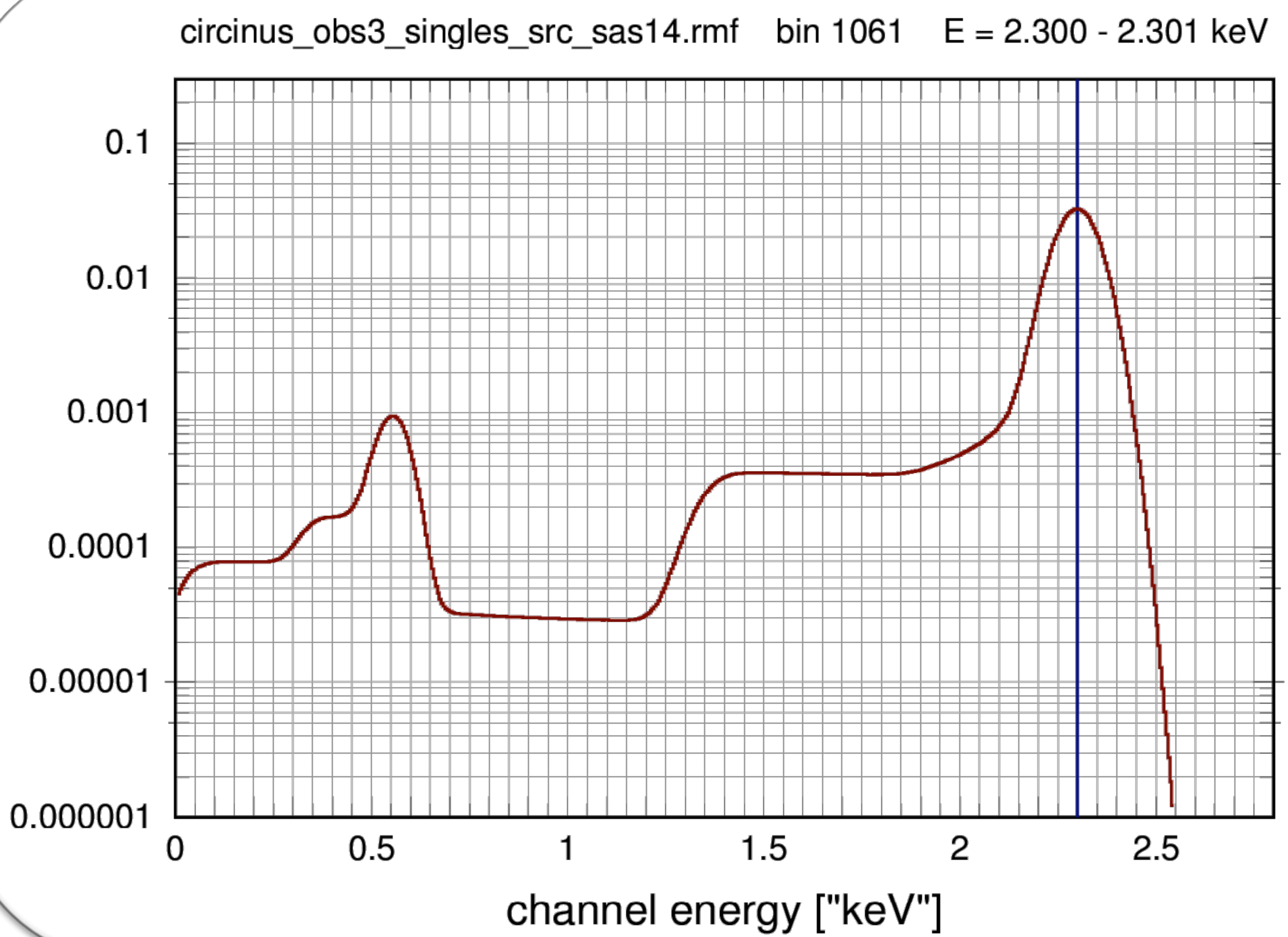
EPIC pn: 2067 vector elements; 2067 x 4096 = 8 446 432 matrix elements

RMF @ EPIC pn: 4096 adu bins from 0.0 to 20.5 ‚keV‘ („EBOUNDS“)
2067 eV bins from 50 eV to 16 keV

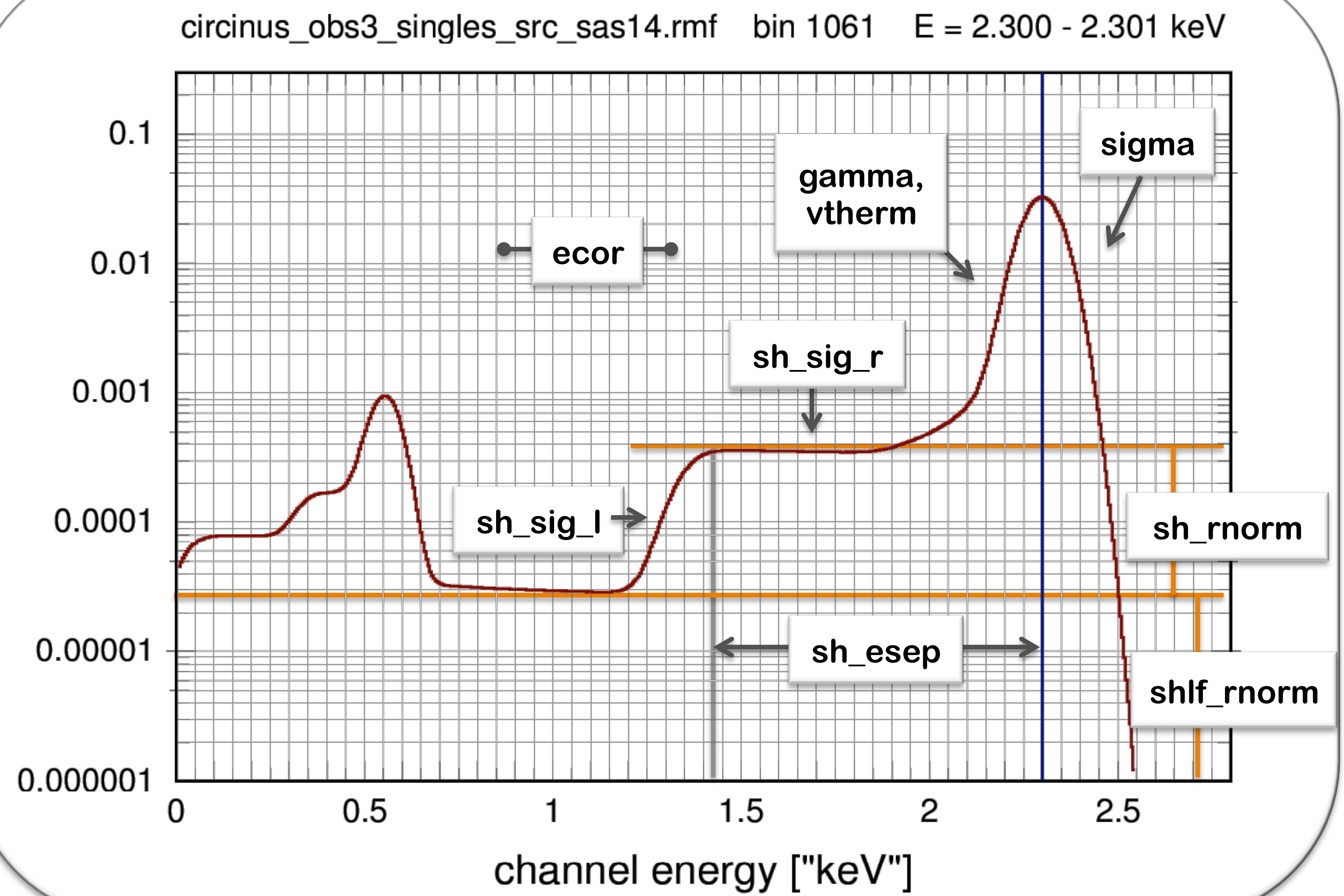
EPIC pn RMF: 8.5 million matrix elements → **HUGE** parameter space!
EPIC pn ARFs: 3 x 2067 elements → comparatively trivial

→ find appropriate RMF parameterization and try to optimize it..

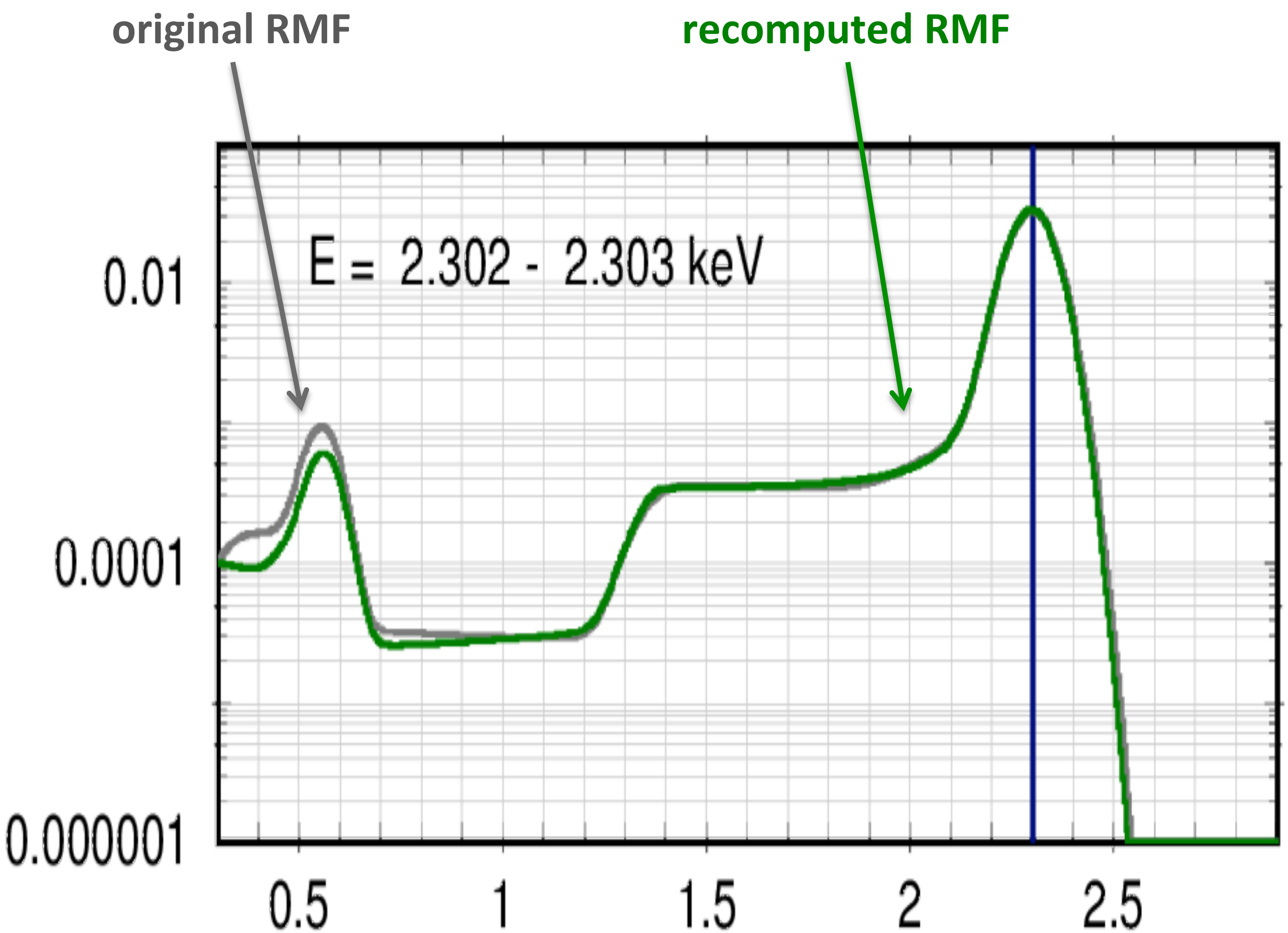
Model Parameters for the EPIC pn RMF



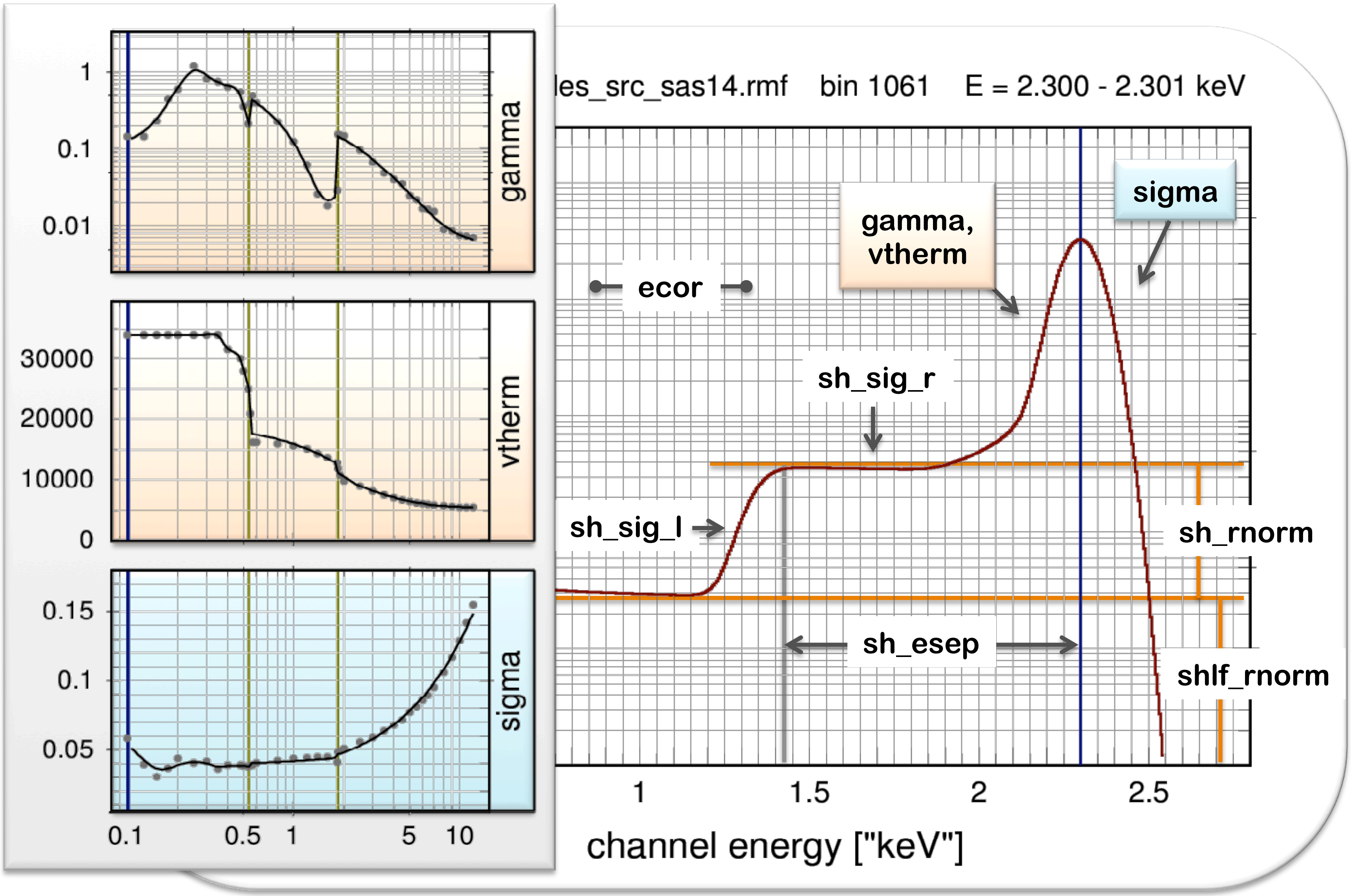
Model Parameters for the EPIC pn RMF



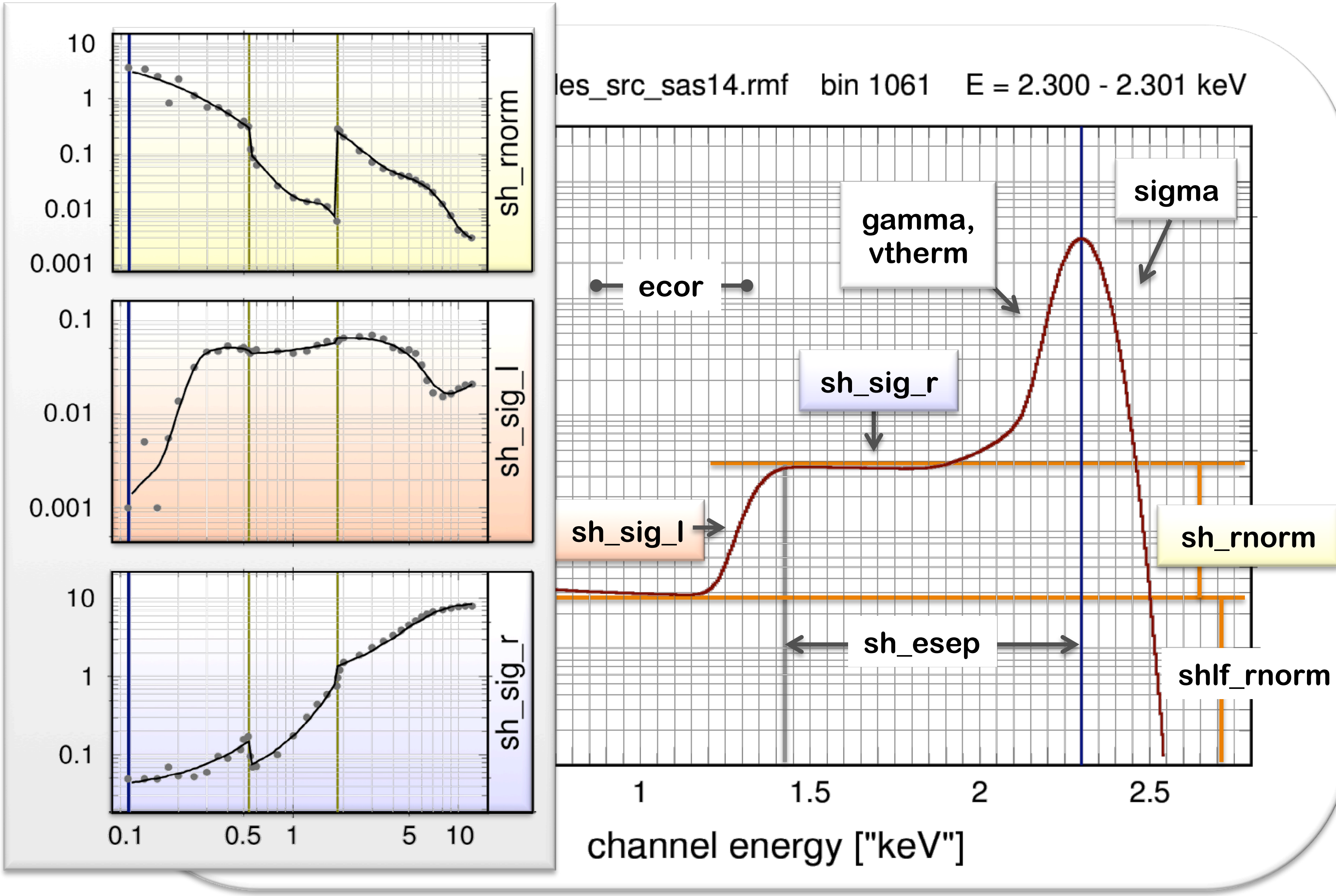
Comparison: original and recomputed RMF @ 2.3 keV



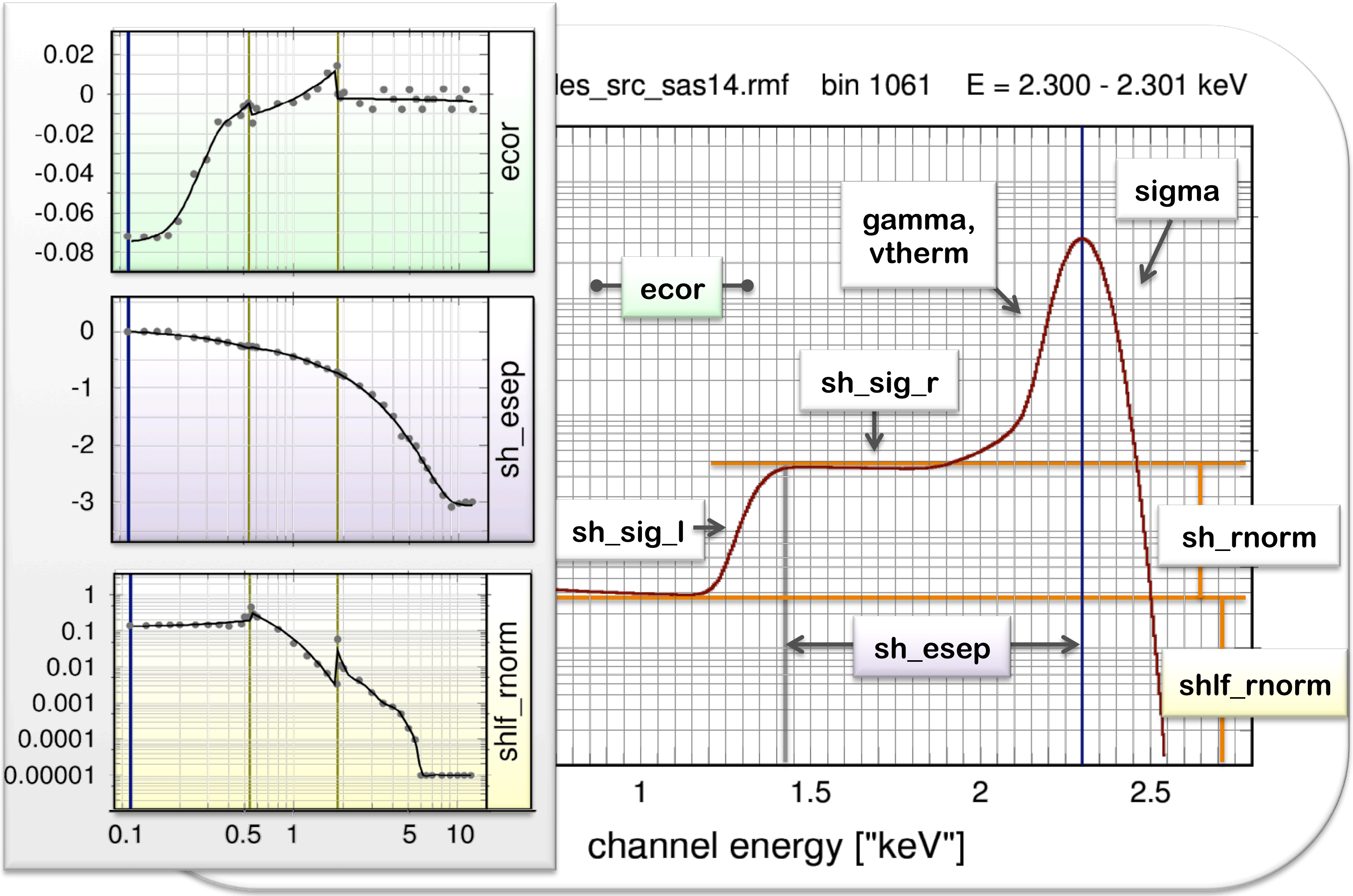
Modeling the EPIC pn RMF at individual energies



Modeling the EPIC pn RMF at individual energies



Modeling the EPIC pn RMF at individual energies



RMF refinement method

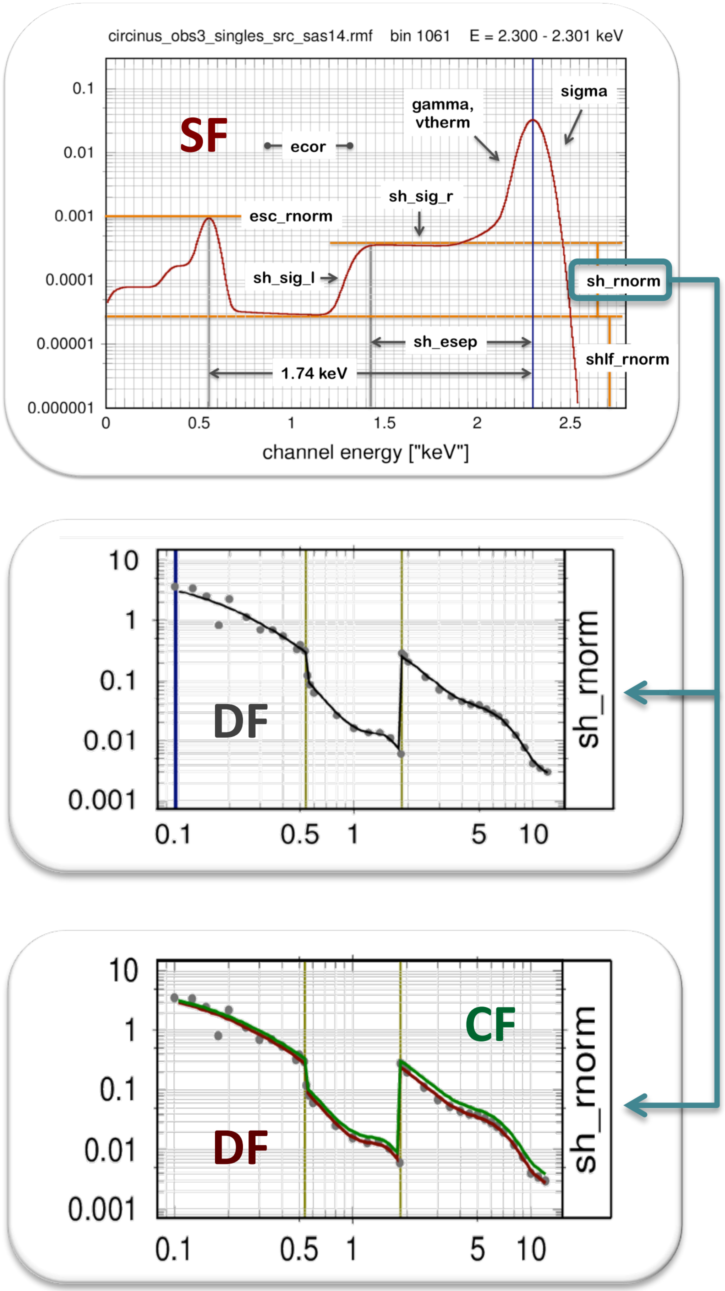
(ARF refinement comparatively trivial)

1) Compose the RMF of (19) **shaping functions SF** which are determined by **shaping parameters SP**:

- **main peak**: *gamma, vtherm, sigma*
- **shoulder**: *sh_rnorm, sh_sigl, sh_sigr, sh_esep*
- **shelf**: *shlf_rnorm, shlf_slope*
- **escape peak**: *another 9 parameters*

and determine **deformation functions DF** to model the energy dependence of each shaping parameter, and to reproduce an existing RMF

2) Apply **correction functions CF** to the deformation functions DF, recompute the RMF, use this RMF for (simultaneously) fitting X-ray spectra with spectral **model functions MF** (using plausible spectral **model parameters MP**), and compute the goodness of the fit. Vary the **correction parameters CP** (and the correction functions CF) in order to maximize the goodness of the fit.



RMF refinement method

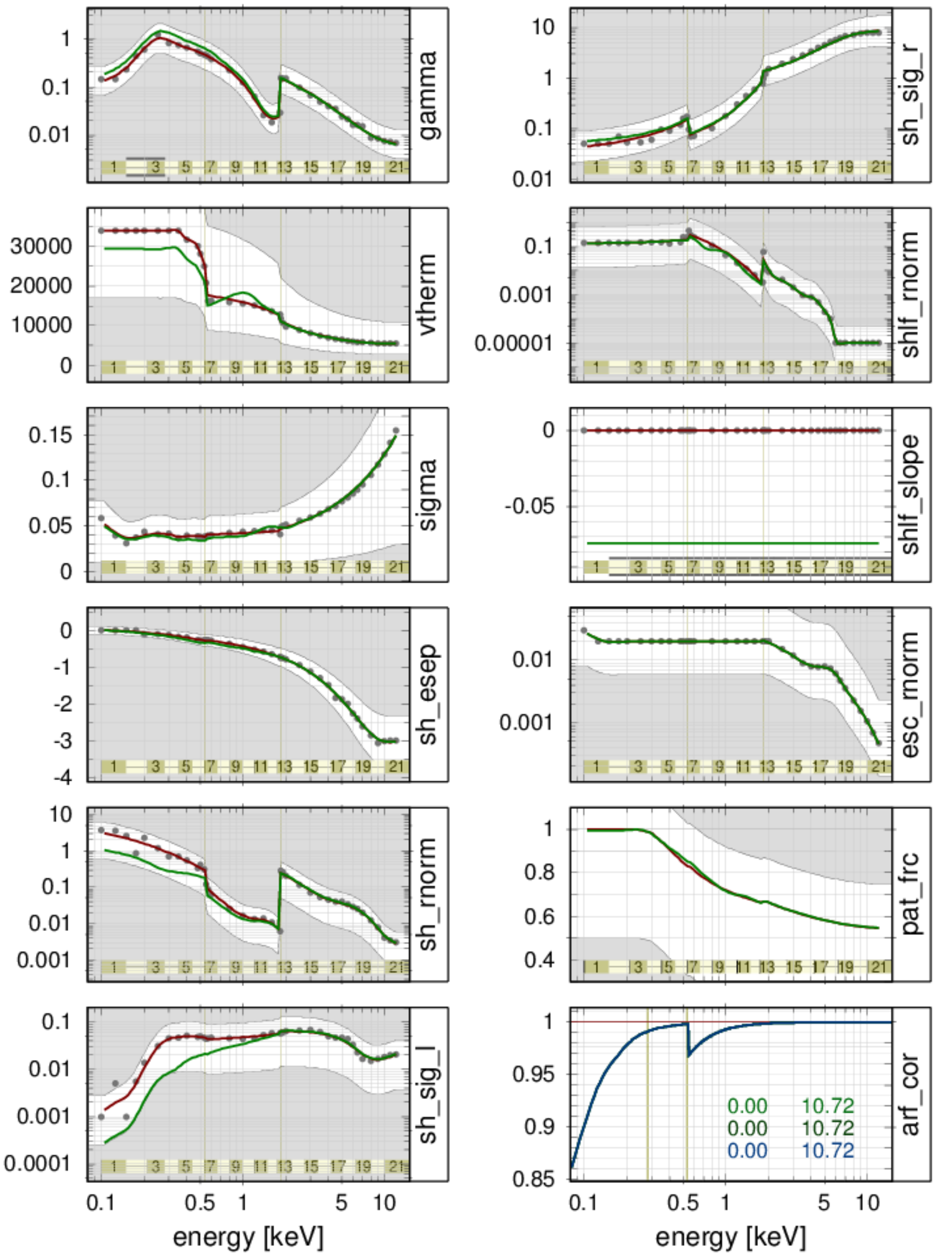
Challenge: how to keep an **overview** (in total ~1000 parameters!)

- **19 shaping functions SF** with a total of **19 shaping parameter SP**;
  the energy dependence of each SP is determined by a deformation function DF
- the **19 DFs** are computed from a total of **555 deformation parameters DP**,
  which were derived by simultaneously fitting 39 EPIC-pn „RMF samples“
  with 117 free and 438 fixed/tied parameters
- **19 correction functions CF**, each determined by up to 21 adjustable **CPs**,
  yielding a total of **399 correction parameters CPs**
- spectral fits:
  - 1E 0102: **208 model parameters MP_1**, with 4 of them free + **gain offset**
  - RXJ 1856: **3 model parameters MP_2,** with 1-3 of them free + **gain offset**
- in addition for the 3 ARFs: (thick, medium, thin):
  - **3 x 2 adjustable parameters** for C-K and O-K absorption
  - **up to 21 adjustable parameters** for correcting the fraction of singles

→ up to **19 x 21 + 6 = 405 adjustable correction parameters** in total
→ necessity to **fix/tie/couple** a subset of the correction parameters
→ necessity to **constrain** the correction functions
→ necessity to **control** the spectral fit results

very useful: concise graphical overview

Status @ IACHEC-2018



RXJ 1856

1E 0102

Chandra LETG

gain: offset = -2.1 eV

n_H == 7.25 x 10^{19} cm^{-2}

kT == 62.4 eV

norm == 1.58 x 10^5

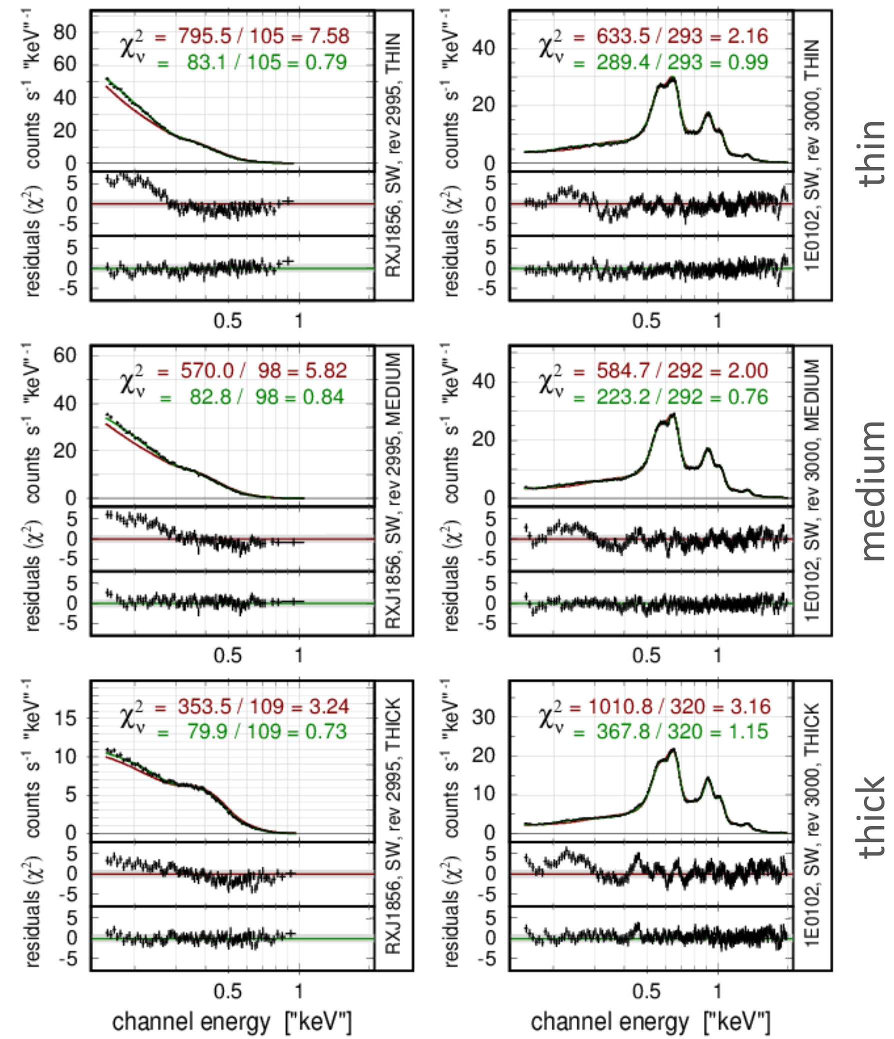
constant: factor = 0.939

gaussian: norm = 0.143E-02

gaussian: norm = 0.139E-02

gaussian: norm = 0.433E-02

gain: offset = +1.7 eV



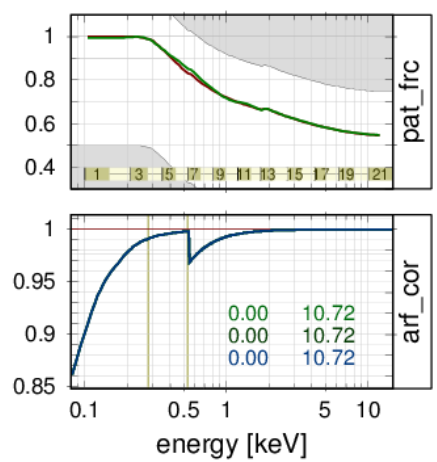
Status @ IACHEC-2018

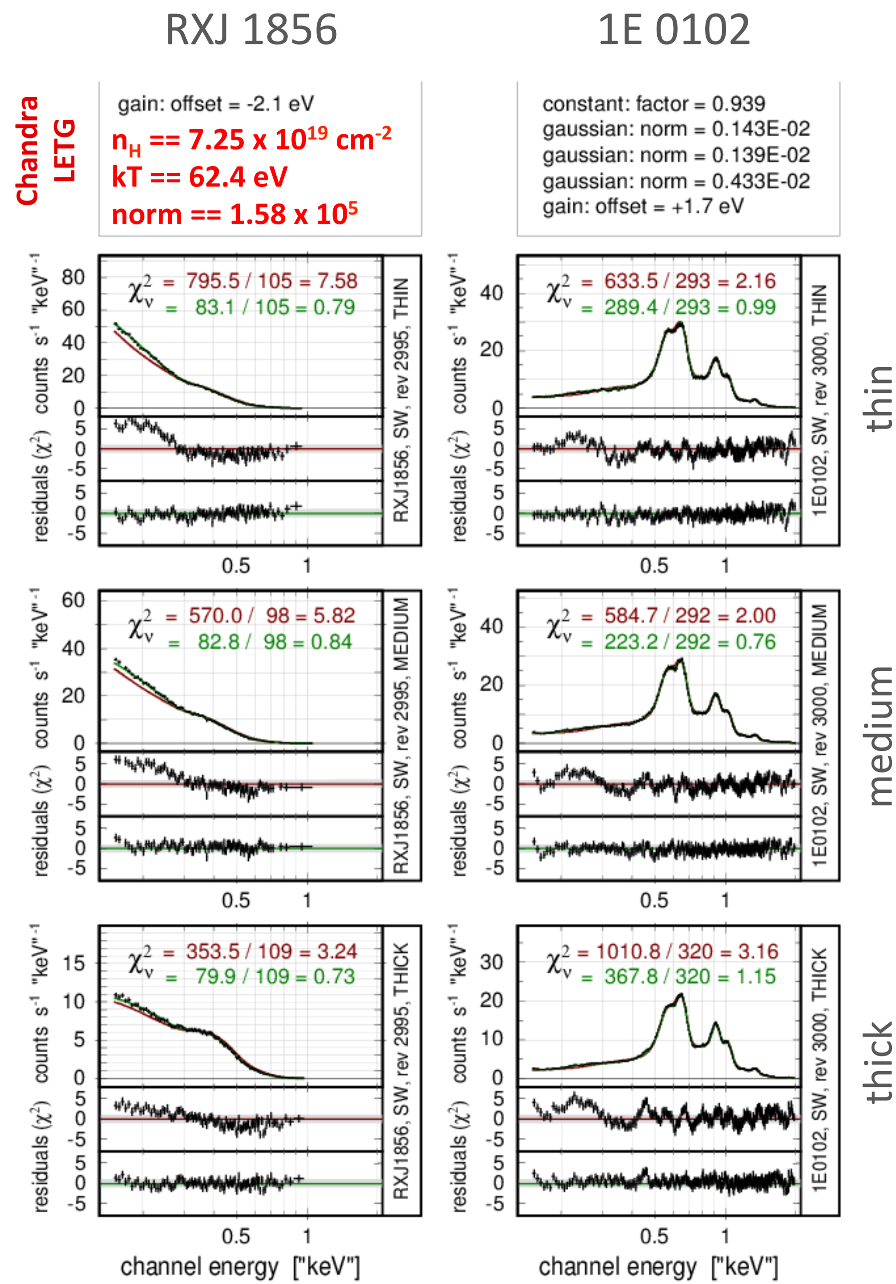
ARF correction

correction for threshold induced sensitivity drop		
0.10 – 0.28 keV free	0.28 – 1.74 keV free	1.74 – 16.0 keV fixed

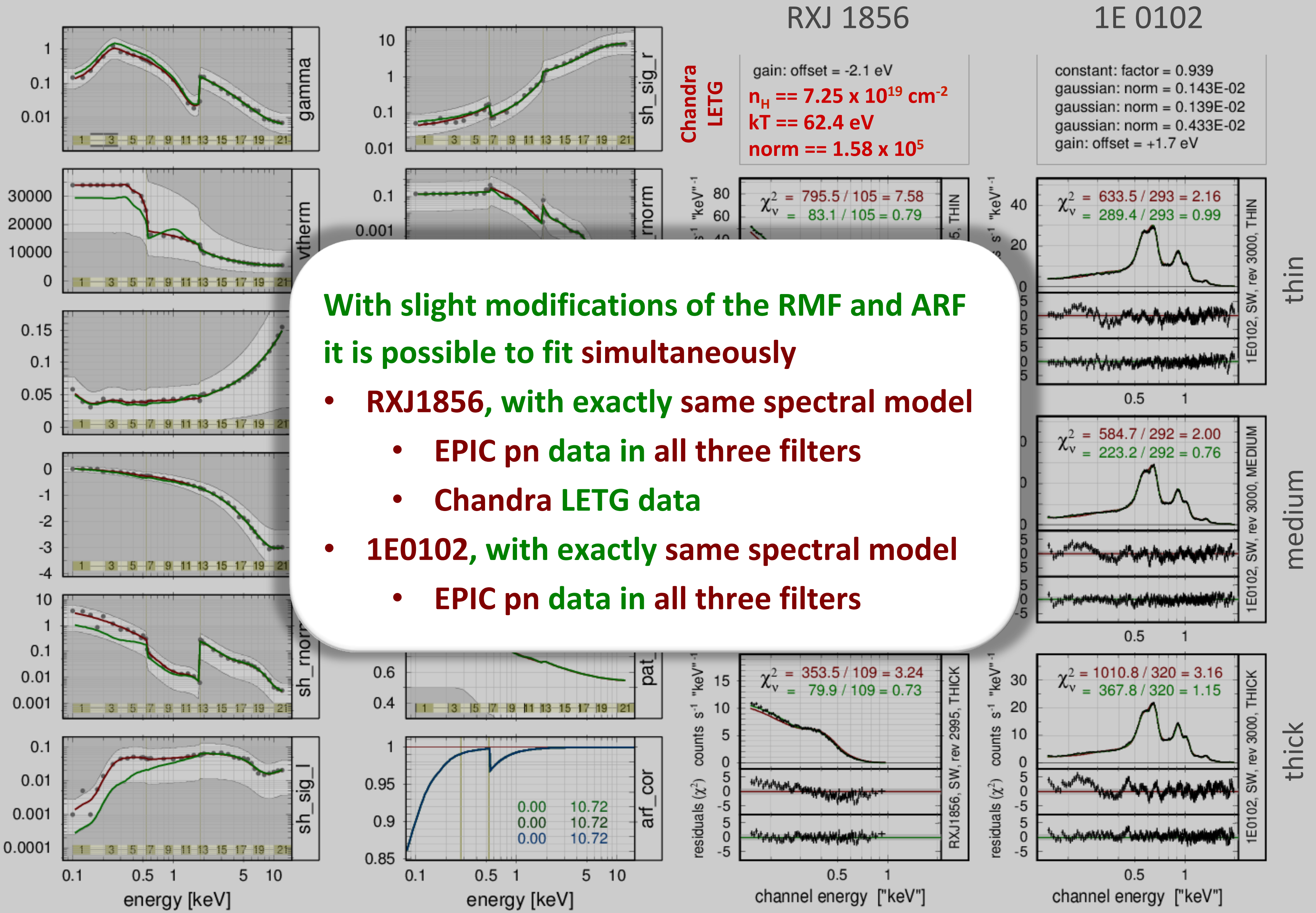
filter dependent ARF correction	correction for **carbon** thickness	correction for **oxygen** thickness
thin	= 0 (fixed)	free
medium	= 0 (fixed)	= O_cor(thin)
thick	= 0 (fixed)	= O_cor(thin)

good fits (!)





Status @ IACHEC-2018



With slight modifications of the RMF and ARF it is possible to fit simultaneously

- **RXJ1856, with exactly same spectral model**
  - **EPIC pn data in all three filters**
  - **Chandra LETG data**
- **1E0102, with exactly same spectral model**
  - **EPIC pn data in all three filters**

Modelling temporal changes

software upgrade:

1. treat **temporal dependencies as new fit parameters**, individually for each shaping component
2. utilize **parallel processing** (→ ≈ 10-100 times faster!)

→ **major restructuring of the program**
(also opportunity to clean the code)

→ ≈ 14 000 lines of code, ~100 programs/modules/subroutines
852 RMF + ARF shaping parameters

also: various possibilities for monitoring, checks and documentation, e.g. highly compressed summary plots

Modelling temporal RMF changes: sample output

XMM / EPIC-pn RMF and ARF parameterization Small Window Mode

p (bin edges, keV: 0.10 0.15 0.21 0.28 0.35 0.44 0.53 0.66 0.80 1.00 1.20 1.50 1.74 2.20 2.70 3.40 4.20 5.10 6.20 8.00 10.00)

p	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	smoothness value	weight	penalty
ecor	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000
gamma	1.161	1.193	1.174	1.475	1.625	1.490	1.329	1.201	1.136	1.107	1.071	1.049	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.130	0.050	0.056
vtherm	0.687	0.688	0.696	0.718	0.729	0.757	0.815	0.932	1.032	1.066	1.058	1.075	1.082	1.082	1.082	1.082	1.082	1.082	1.082	1.082	1.082	0.192	0.200	0.038
sigma	0.840	0.840	0.831	0.827	0.842	0.835	0.854	0.873	0.892	0.900	0.921	0.931	0.936	0.936	0.936	0.936	0.936	0.936	0.936	0.936	0.936	0.014	4.000	0.055
sh_esep	1.148	1.148	1.235	1.185	1.209	1.211	1.200	1.229	1.206	1.201	1.184	1.170	1.164	1.164	1.164	1.164	1.164	1.164	1.164	1.164	1.164	0.078	0.200	0.016
sh_rnorm	0.538	0.549	0.522	0.533	0.537	0.556	0.630	0.676	0.710	0.736	0.759	0.775	0.783	0.783	0.783	0.783	0.783	0.783	0.783	0.783	0.783	0.075	0.400	0.030
sh_sig_l	0.382	0.382	0.521	0.576	0.609	0.560	0.450	0.525	0.570	0.632	0.657	0.678	0.686	0.686	0.686	0.686	0.686	0.686	0.686	0.686	0.686	0.312	0.020	0.006
sh_sig_r	1.340	1.245	1.076	1.195	1.151	1.219	1.020	0.942	0.895	0.887	0.881	0.884	0.899	0.899	0.899	0.899	0.899	0.899	0.899	0.899	0.899	0.680	0.020	0.014
shlf_rnorm	0.348	0.348	0.363	0.511	0.461	0.689	0.604	0.345	0.786	0.953	1.023	1.064	1.081	1.081	1.081	1.081	1.081	1.081	1.081	1.081	1.081	2.862	0.010	0.029
shlf_slope	-0.103	-0.103	-0.103	-0.103	-0.103	-0.103	-0.103	-0.103	-0.103	-0.103	-0.103	-0.103	-0.103	-0.103	-0.103	-0.103	-0.103	-0.103	-0.103	-0.103	-0.103	0.000	0.100	0.000
esc_rnorm	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000
egamma	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000
evtherm	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000
esigma	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	0.000	0.000	0.000
esh_esep	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000
esh_rnorm	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000
esh_sig_l	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000
esh_sig_r	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000
eshlf_rnm	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000
pat_frc	1.000	1.000	1.000	1.004	1.007	1.011	0.986	0.980	0.983	0.913	0.977	1.024	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.105	0.100	0.010

t (bin edges, keV: 0.10 0.15 0.21 0.28 0.35 0.44 0.53 0.66 0.80 1.00 1.20 1.50 1.74 2.20 2.70 3.40 4.20 5.10 6.20 8.00 10.00)

t	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	smoothness value	weight	penalty
ecor	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
gamma	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.000	1.000	0.000
vtherm	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.000	1.000	0.000
sigma	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.000	1.000	0.000
sh_esep	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	0.000	1.000	0.000
sh_rnorm	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	0.000	1.000	0.000
sh_sig_l	-0.021	-0.021	-0.021	-0.021	-0.021	-0.021	-0.021	-0.021	-0.021	-0.021	-0.021	-0.021	-0.021	-0.021	-0.021	-0.021	-0.021	-0.021	-0.021	-0.021	-0.021	0.000	1.000	0.000
sh_sig_r	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	0.000	1.000	0.000
shlf_rnorm	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036	0.000	1.000	0.000
shlf_slope	0.465	0.465	0.465	0.465	0.465	0.465	0.465	0.465	0.465	0.465	0.465	0.465	0.465	0.465	0.465	0.465	0.465	0.465	0.465	0.465	0.465	0.000	1.000	0.000
esc_rnorm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
egamma	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
evtherm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
esigma	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
esh_esep	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
esh_rnorm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
esh_sig_l	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
esh_sig_r	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
eshlf_rnm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
pat_frc	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	0.000	0.000	0.000

parameter constraints:

	p	t
ecor	[ref * 1.00 - 0.02 , ref * 1.00 + 0.02]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
gamma	[ref * 0.50 + 0.00 , ref * 2.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
vtherm	[ref * 0.50 + 0.00 , ref * 1.20 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
sigma	[ref * 0.70 + 0.00 , ref * 1.30 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
sh_esep	[ref * 0.80 - 0.10 , ref * 1.20 + 0.10]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
sh_rnorm	[ref * 0.30 + 0.00 , ref * 2.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
sh_sig_l	[ref * 0.50 - 0.01 , ref * 1.50 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
sh_sig_r	[ref * 0.40 + 0.00 , ref * 2.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
shlf_rnorm	[ref * 0.10 + 0.00 , ref * 2.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
shlf_slope	[ref * 1.00 - 0.30 , ref * 1.00 + 0.30]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
esc_rnorm	[ref * 0.30 + 0.00 , ref * 5.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
egamma	[ref * 0.01 + 0.00 , ref * 2.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
evtherm	[ref * 0.50 + 0.00 , ref * 2.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
esigma	[ref * 0.50 + 0.00 , ref * 2.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
esh_esep	[ref * 0.80 + 0.00 , ref * 1.20 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
esh_rnorm	[ref * 0.50 + 0.00 , ref * 2.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
esh_sig_l	[ref * 0.08 + 0.00 , ref * 2.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
esh_sig_r	[ref * 0.50 + 0.00 , ref * 2.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
eshlf_rnm	[ref * 0.10 + 0.00 , ref * 5.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
pat_frc	[ref * 1.00 - 0.10 , ref * 1.00 + 0.10]	[ref * 0.00 + 0.00 , ref * 0.00 + 0.00]
c2_cor	[ref * 0.01 - 1.00 , ref *10.00 + 1.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
o2_cor	[ref * 0.01 - 1.00 , ref *10.00 + 1.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]

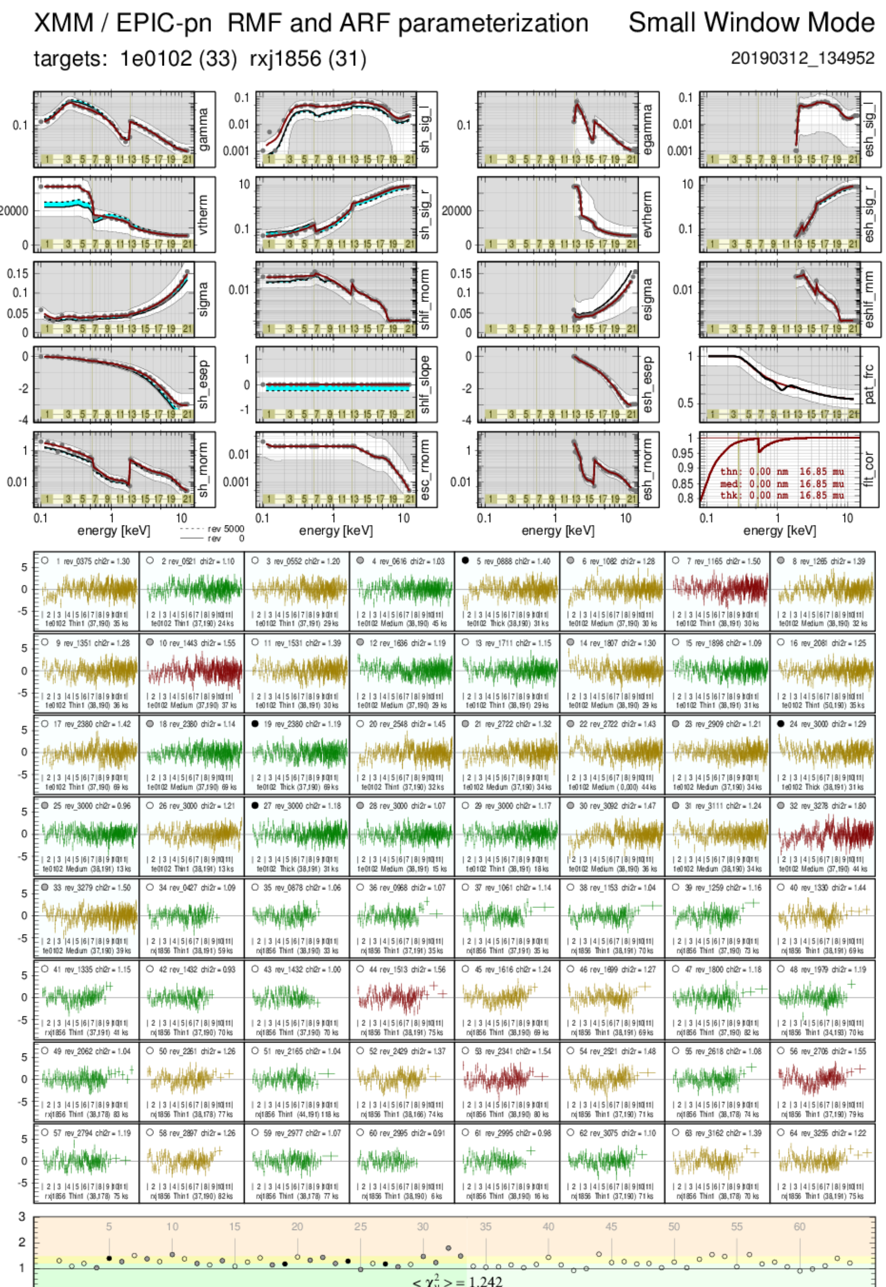
objects: 1e0102 rxj1856
modeldir: /home/kod/data1/epic/RMF-FIT/rmf/sw/model/
datadir: /home/kod/data1/epic/RMF-FIT/rmf/sw/data/
workdir: /home/kod/data1/epic/RMF-FIT/rmf/sw/work/v01/
spectral models:
1e0102: model-1/rgspn_mod_fbabs_fbvarabs_2apec_line_ratios_jd_v1.9.xcm
rxj1856: model-3/rxj1856_model_bbody.xcm
function used for evaluating the shaping parameters: valnew_25
XMM reference revolution: rev 2000
invtol_ = 10 ftol_ = 0.10E-5 itmaxp_ = 20 itmaxb_ = 10 tolb_ = 0.001

1e0102 spectra:

1	1e0102/rev_0375/	P0135720801PNS001	SW	Thin1
2	1e0102/rev_0521/	P0135721101PNS001	SW	Thin1
3	1e0102/rev_0552/	P0135721301PNS001	SW	Thin1
4	1e0102/rev_0616/	P0135721401PNU002	SW	Medium
5	1e0102/rev_0888/	P0135722401PNS001	SW	Thick
6	1e0102/rev_1082/	P0135722601PNS001	SW	Medium
7	1e0102/rev_1165/	P0135722701PNS001	SW	Thin1
8	1e0102/rev_1265/	P0412980101PNS001	SW	Medium
9	1e0102/rev_1351/	P0412980201PNS001	SW	Thin1
10	1e0102/rev_1443/	P0412980301PNS001	SW	Medium
11	1e0102/rev_1531/	P0412980501PNS001	SW	Thin1
12	1e0102/rev_1636/	P0412980701PNS001	SW	Medium
13	1e0102/rev_1711/	P0412980801PNS001	SW	Thin1
14	1e0102/rev_1807/	P0412980901PNS001	SW	Medium
15	1e0102/rev_1898/	P0412981001PNS001	SW	Thin1
16	1e0102/rev_2081/	P0412981401PNS001	SW	Thin1
17	1e0102/rev_2380a/	P0412981701PNS001	SW	Thin1
18	1e0102/rev_2380b/	P0412981701PNS012	SW	Medium
19	1e0102/rev_2380c/	P0412981701PNS013	SW	Thick
20	1e0102/rev_2548/	P0412982101PNS001	SW	Thin1
21	1e0102/rev_2722a/	P0412982201PNS001	SW	Medium
22	1e0102/rev_2722b/	P0412982301PNS003	SW	Medium
23	1e0102/rev_2909/	P0412982501PNS001	SW	Medium
24	1e0102/rev_3000a/	P0791580701PNS001	SW	Thick
25	1e0102/rev_3000b/	P0791580801PNS001	SW	Medium
26	1e0102/rev_3000c/	P0791580901PNS001	SW	Thin1
27	1e0102/rev_3000d/	P0791581001PNS001	SW	Thick
28	1e0102/rev_3000e/	P0791581101PNS001	SW	Medium
29	1e0102/rev_3000f/	P0791581201PNS001	SW	Thin1
30	1e0102/rev_3092/	P0412983201PNS001	SW	Medium
31	1e0102/rev_3111/	P0412983301PNS001	SW	Medium
32	1e0102/rev_3278/	P0412983401PNS001	SW	Medium
33	1e0102/rev_3279/	P0412983501PNS001	SW	Medium

rxj1856 spectra:

1	rxj1856/rev_0427/	P0106260101PNS001	SW	Thin1
2	rxj1856/rev_0878/	P0165971601PNS003	SW	Thin1
3	rxj1856/rev_0968/	P0165971901PNS003	SW	Thin1
4	rxj1856/rev_1061/	P0165972001PNS003	SW	Thin1
5	rxj1856/rev_1153/	P0165972101PNS003	SW	Thin1
6	rxj1856/rev_1259/	P0412600101PNS003	SW	Thin1
7	rxj1856/rev_1330/	P0412600201PNU002	SW	Thin1
8	rxj1856/rev_1335/	P0415180101PNS001	SW	Thin1
9	rxj1856/rev_1432a/	P0412600301PNS003	SW	Thin1
10	rxj1856/rev_1432b/	P0412600301PNU002	SW	Thin1
11	rxj1856/rev_1513/	P0412600401PNU002	SW	Thin1
12	rxj1856/rev_1616/	P0412600601PNU002	SW	Thin1
13	rxj1856/rev_1699/	P0412600701PNS003	SW	Thin1
14	rxj1856/rev_1800/	P0412600801PNU002	SW	Thin1
15	rxj1856/rev_1979/	P0412601101PNU002	SW	Thin1
16	rxj1856/rev_2062/	P0412601301PNS003	SW	Thin1
17	rxj1856/rev_2261/	P0412601401PNS003	SW	Thin1
18	rxj1856/rev_2165/	P0412601501PNS002	SW	Thin1
19	rxj1856/rev_2429/	P0412602201PNS003	SW	Thin1
20	rxj1856/rev_2341/	P0412602301PNS003	SW	Thin1
21	rxj1856/rev_2521/	P0727760101PNS001	SW	Thin1
22	rxj1856/rev_2618/	P0727760201PNS001	SW	Thin1
23	rxj1856/rev_2706/	P0727760301PNS001	SW	Thin1
24	rxj1856/rev_2794/	P0727760401PNS001	SW	Thin1
25	rxj1856/rev_2897/	P0727760501PNS001	SW	Thin1
26	rxj1856/rev_2977/	P0727760601PNS001	SW	Thin1
27	rxj1856/rev_2995a/	P0791580301PNS001	SW	Thin1
28	rxj1856/rev_2995b/	P0791580601PNS001	SW	Thin1
29	rxj1856/rev_3075/	P0727761001PNS001	SW	Thin1
30	rxj1856/rev_3162/	P0727761101PNS001	SW	Thin1
31	rxj1856/rev_3255/	P0727761201PNS001	SW	Thin1



XMM / EPIC-pn RMF and ARF parameterization Small Window Mode

Energy grid (keV): 0.10 | 0.15 | 0.21 | 0.28 | 0.35 | 0.44 | 0.53 | 0.66 | 0.80 | 1.00 | 1.20 | 1.50 | 1.74 | 2.20 | 2.70 | 3.40 | 4.20 | 5.10 | 6.20 | 8.00 | 10.00 keV

p	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	smoothness value	weight	penalty
ecor	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000
gamma	1.162	1.216	1.211	1.507	1.676	1.510	1.321	1.171	1.138	1.191	1.119	1.060	1.106	1.106	1.106	1.106	1.106	1.106	1.106	1.106	1.106	1.408	0.020	0.028
vtherm	0.658	0.659	0.656	0.672	0.692	0.737	0.826	0.964	1.041	1.107	1.004	0.991	1.014	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.346	0.100	0.035
sigma	0.858	0.859	0.851	0.839	0.850	0.824	0.842	0.866	0.879	0.900	0.949	0.971	0.990	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.039	2.000	0.078
sh_esep	1.113	1.117	1.240	1.217	1.206	1.200	1.195	1.206	1.183	1.159	1.117	1.099	1.079	1.079	1.079	1.079	1.079	1.079	1.079	1.079	1.079	0.106	0.100	0.011
sh_rnorm	0.519	0.536	0.503	0.521	0.516	0.525	0.614	0.678	0.756	0.823	0.884	0.941	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.227	0.200	0.045
sh_sig_l	0.262	0.265	0.533	0.584	0.630	0.624	0.467	0.610	0.505	0.887	0.847	0.898	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	2.133	0.010	0.021
sh_sig_r	1.333	1.214	1.115	1.197	1.150	1.266	0.914	0.856	0.667	0.821	0.925	1.076	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	2.015	0.010	0.020
shlf_rnorm	0.211	0.219	0.355	0.658	0.496	0.693	0.662	0.344	0.826	1.605	0.915	0.624	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	14.069	0.005	0.070
shlf_slope	-0.082	-0.082	-0.082	-0.082	-0.082	-0.082	-0.082	-0.082	-0.082	-0.082	-0.082	-0.082	-0.082	-0.082	-0.082	-0.082	-0.082	-0.082	-0.082	-0.082	-0.082	0.000	0.100	0.000
esc_rnorm	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000
egamma	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000
evtherm	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000
esigma	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	0.000	0.000	0.000
esh_esep	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000
esh_rnorm	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000
esh_sig_l	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000
esh_sig_r	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000
eshlf_rnm	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000
pat_frc	1.010	1.010	1.000	1.002	1.007	1.001	0.995	0.990	0.989	0.972	0.988	1.019	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.018	0.100	0.002

Energy grid (keV): 0.10 | 0.15 | 0.21 | 0.28 | 0.35 | 0.44 | 0.53 | 0.66 | 0.80 | 1.00 | 1.20 | 1.50 | 1.74 | 2.20 | 2.70 | 3.40 | 4.20 | 5.10 | 6.20 | 8.00 | 10.00 keV

t	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	smoothness value	weight	penalty
ecor	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
gamma	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.000	1.000	0.000
vtherm	0.026	0.026	0.026	0.028	0.028	0.028	0.028	0.028	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.000	1.000	0.000
sigma	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.000	1.000	0.000
sh_esep	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	0.000	1.000	0.000
sh_rnorm	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	0.000	1.000	0.000
sh_sig_l	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.000	1.000	0.000
sh_sig_r	-0.070	-0.070	-0.070	-0.070	-0.096	-0.096	-0.096	-0.096	-0.096	-0.096	-0.096	-0.096	-0.096	-0.096	-0.096	-0.096	-0.096	-0.096	-0.096	-0.096	-0.096	0.005	1.000	0.005
shlf_rnorm	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	0.000	1.000	0.000
shlf_slope	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.000	1.000	0.000
esc_rnorm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
egamma	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
evtherm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
esigma	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
esh_esep	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
esh_rnorm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
esh_sig_l	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
esh_sig_r	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
eshlf_rnm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
pat_frc	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.000	0.000	0.000

total penalty: 0.316

19 RMF shaping functions with 21 parameters each → 399 RMF parameters

21 parameters for correcting the energy dependence of the fraction of singles

2 correction functions for the filter transmission (O and C thickness) for each filter → 6 parameters

→ 27 ARF parameters

→ 426 parameters

(linear) temporal dependence of each parameter

→ 852 parameters

parameters can be fixed, coupled, tied, constrained, and determined for a given smoothness of the shaping function

Modelling temporal RMF changes: sample output

XMM / EPIC-pn RMF and ARF parameterization Small Window Mode

p	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	smoothness value	weight	penalty
keV	0.10	0.15	0.21	0.28	0.35	0.44	0.53	0.66	0.80	1.00	1.20	1.50	1.74	2.20	2.70	3.40	4.20	5.10	6.20	8.00	10.00			
ecor	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000
gamma	1.161	1.193	1.174	1.475	1.625	1.490	1.329	1.201	1.136	1.107	1.071	1.049	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.130	0.050	0.056
vtherm	0.687	0.688	0.696	0.718	0.729	0.757	0.815	0.932	1.032	1.066	1.058	1.075	1.082	1.082	1.082	1.082	1.082	1.082	1.082	1.082	1.082	0.192	0.200	0.038
sigma	0.840	0.840	0.831	0.827	0.842	0.835	0.854	0.873	0.892	0.900	0.921	0.931	0.936	0.936	0.936	0.936	0.936	0.936	0.936	0.936	0.936	0.014	4.000	0.055
sh_esep	1.148	1.148	1.235	1.185	1.209	1.211	1.200	1.229	1.206	1.201	1.184	1.170	1.164	1.164	1.164	1.164	1.164	1.164	1.164	1.164	1.164	0.078	0.200	0.016
sh_rnorm	0.538	0.549	0.522	0.533	0.537	0.556	0.630	0.676	0.710	0.736	0.759	0.775	0.783	0.783	0.783	0.783	0.783	0.783	0.783	0.783	0.783	0.075	0.400	0.030
sh_sig_l	0.382	0.382	0.521	0.576	0.609	0.560	0.450	0.525	0.570	0.632	0.657	0.678	0.686	0.686	0.686	0.686	0.686	0.686	0.686	0.686	0.686	0.312	0.020	0.006
sh_sig_r	1.340	1.245	1.076	1.195	1.151	1.219	1.020	0.942	0.895	0.887	0.881	0.884	0.899	0.899	0.899	0.899	0.899	0.899	0.899	0.899	0.899	0.680	0.020	0.014
shlf_rnorm	0.348	0.348	0.363	0.511	0.461	0.689	0.604	0.345	0.786	0.953	1.023	1.064	1.081	1.081	1.081	1.081	1.081	1.081	1.081	1.081	1.081	2.862	0.010	0.029
shlf_slope	-0.103	-0.103	-0.103	-0.103	-0.103	-0.103	-0.103	-0.103	-0.103	-0.103	-0.103	-0.103	-0.103	-0.103	-0.103	-0.103	-0.103	-0.103	-0.103	-0.103	-0.103	0.000	0.100	0.000
esc_rnorm	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000
egamma	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000
evtherm	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000
esigma	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	0.000	0.000	0.000
esh_esep	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000
esh_rnorm	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000
esh_sig_l	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000
esh_sig_r	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000
eshlf_rnm	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000
pat_frc	1.000	1.000	1.000	1.004	1.007	1.011	0.986	0.980	0.983	0.913	0.977	1.024	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.105	0.100	0.010

t	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	smoothness value	weight	penalty
keV	0.10	0.15	0.21	0.28	0.35	0.44	0.53	0.66	0.80	1.00	1.20	1.50	1.74	2.20	2.70	3.40	4.20	5.10	6.20	8.00	10.00			
ecor	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
gamma	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.000	1.000	0.000
vtherm	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.000	1.000	0.000
sigma	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.000	1.000	0.000
sh_esep	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	-0.013	0.000	1.000	0.000
sh_rnorm	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	0.000	1.000	0.000
sh_sig_l	-0.021	-0.021	-0.021	-0.021	-0.021	-0.021	-0.021	-0.021	-0.021	-0.021	-0.021	-0.021	-0.021	-0.021	-0.021	-0.021	-0.021	-0.021	-0.021	-0.021	-0.021	0.000	1.000	0.000
sh_sig_r	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	-0.066	0.000	1.000	0.000
shlf_rnorm	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036	-0.036	0.000	1.000	0.000
shlf_slope	0.465	0.465	0.465	0.465	0.465	0.465	0.465	0.465	0.465	0.465	0.465	0.465	0.465	0.465	0.465	0.465	0.465	0.465	0.465	0.465	0.465	0.000	1.000	0.000
esc_rnorm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
egamma	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
evtherm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
esigma	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
esh_esep	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
esh_rnorm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
esh_sig_l	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
esh_sig_r	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
eshlf_rnm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
pat_frc	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	0.000	0.000	0.000

total penalty: 0.255

parameter constraints:	p	t
ecor	[ref * 1.00 - 0.02 , ref * 1.00 + 0.02]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
gamma	[ref * 0.50 + 0.00 , ref * 2.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
vtherm	[ref * 0.50 + 0.00 , ref * 1.20 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
sigma	[ref * 0.70 + 0.00 , ref * 1.30 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
sh_esep	[ref * 0.80 - 0.10 , ref * 1.20 + 0.10]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
sh_rnorm	[ref * 0.30 + 0.00 , ref * 2.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
sh_sig_l	[ref * 0.50 - 0.01 , ref * 1.50 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
sh_sig_r	[ref * 0.40 + 0.00 , ref * 2.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
shlf_rnorm	[ref * 0.10 + 0.00 , ref * 2.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
shlf_slope	[ref * 1.00 - 0.30 , ref * 1.00 + 0.30]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
esc_rnorm	[ref * 0.30 + 0.00 , ref * 5.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
egamma	[ref * 0.01 + 0.00 , ref * 2.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
evtherm	[ref * 0.50 + 0.00 , ref * 2.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
esigma	[ref * 0.50 + 0.00 , ref * 2.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
esh_esep	[ref * 0.80 + 0.00 , ref * 1.20 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
esh_rnorm	[ref * 0.50 + 0.00 , ref * 2.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
esh_sig_l	[ref * 0.08 + 0.00 , ref * 2.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
esh_sig_r	[ref * 0.50 + 0.00 , ref * 2.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
eshlf_rnm	[ref * 0.10 + 0.00 , ref * 5.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
pat_frc	[ref * 1.00 - 0.10 , ref * 1.00 + 0.10]	[ref * 0.00 + 0.00 , ref * 0.00 + 0.00]
c2_cor	[ref * 0.01 - 1.00 , ref *10.00 + 1.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
d2_cor	[ref * 0.01 - 1.00 , ref *10.00 + 1.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]

objects:1e0102rxj1856
modeldir: /home/kod/data1/epic/RMF-FIT/rmf/sw/model/
datadir: /home/kod/data1/epic/RMF-FIT/rmf/sw/data/
workdir: /home/kod/data1/epic/RMF-FIT/rmf/sw/work/v01/
spectral models:
1e0102: model-1/rgspn_mod_tbabs_tbvarabs_2apec_line_ratios_jd_v1.9.xcm
rxj1856: model-3/rxj1856_model_bbody.xcm
function used for evaluating the shaping parameters: valnew_25
XMM reference revolution: rev 2000
irvtol_ = 10 ftol_ = 0.10E-5 itmaxp_ = 20 itmaxb_ = 10 tolb_ = 0.001

1e0102 spectra:

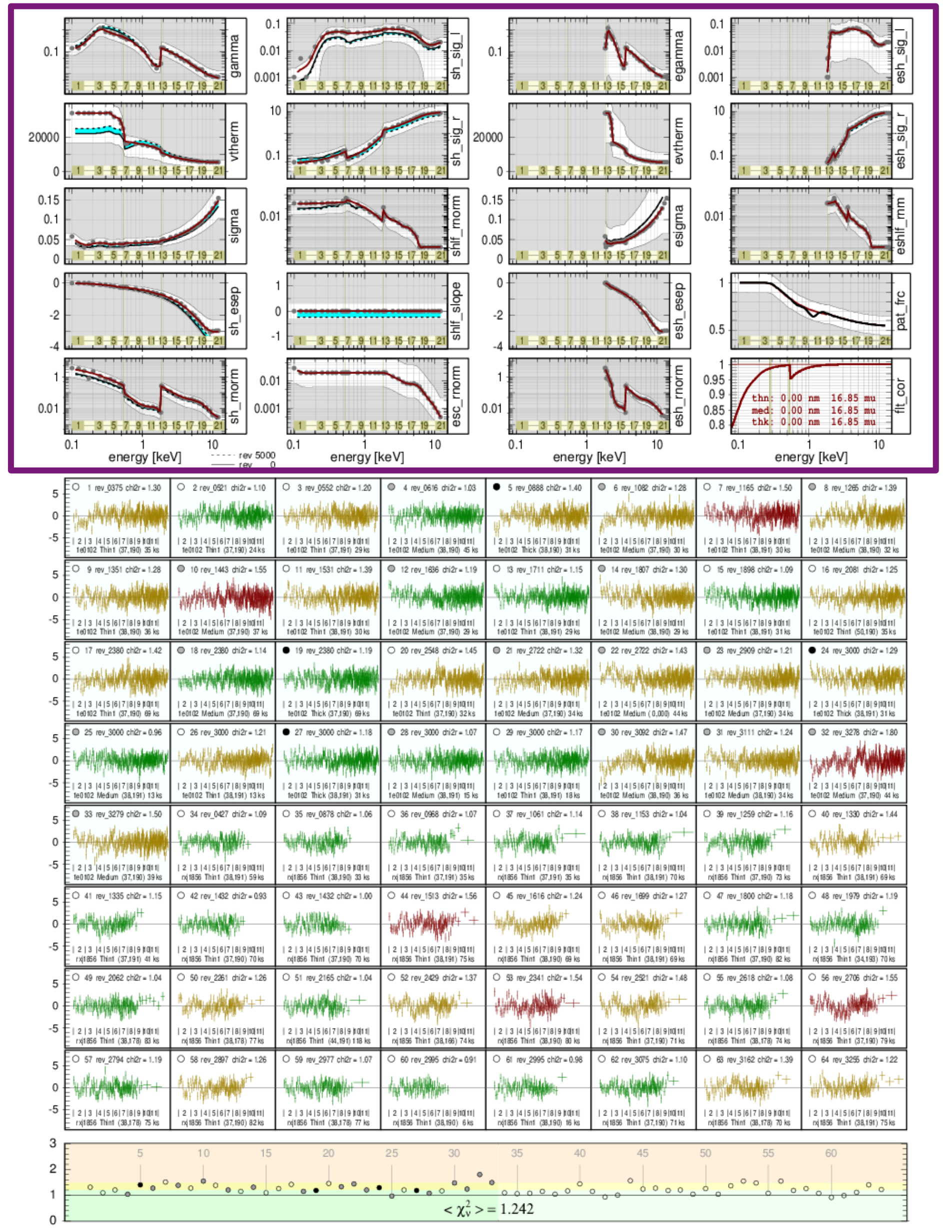
1	1e0102/rev_0375/	P0135720801PNS001	SW Thin1
2	1e0102/rev_0521/	P0135721101PNS001	SW Thin1
3	1e0102/rev_0552/	P0135721301PNS001	SW Thin1
4	1e0102/rev_0616/	P0135721401PNU002	SW Medium
5	1e0102/rev_0888/	P0135722401PNS001	SW Thick
6	1e0102/rev_1082/	P0135722601PNS001	SW Medium
7	1e0102/rev_1165/	P0135722701PNS001	SW Thin1
8	1e0102/rev_1265/	P0412980101PNS001	SW Medium
9	1e0102/rev_1351/	P0412980201PNS001	SW Thin1
10	1e0102/rev_1443/	P0412980301PNS001	SW Medium
11	1e0102/rev_1531/	P0412980501PNS001	SW Thin1
12	1e0102/rev_1636/	P0412980701PNS001	SW Medium
13	1e0102/rev_1711/	P0412980801PNS001	SW Thin1
14	1e0102/rev_1807/	P0412980901PNS001	SW Medium
15	1e0102/rev_1898/	P0412981001PNS001	SW Thin1
16	1e0102/rev_2081/	P0412981401PNS001	SW Thin1
17	1e0102/rev_2380a/	P0412981701PNS001	SW Thin1
18	1e0102/rev_2380b/	P0412981701PNS012	SW Medium
19	1e0102/rev_2380c/	P0412981701PNS013	SW Thick
20	1e0102/rev_2548/	P0412982101PNS001	SW Thin1
21	1e0102/rev_2722a/	P0412982201PNS001	SW Medium
22	1e0102/rev_2722b/	P0412982301PNS001	SW Medium
23	1e0102/rev_2909/	P0412982501PNS001	SW Medium
24	1e0102/rev_3000a/	P0791580701PNS001	SW Thick
25	1e0102/rev_3000b/	P0791580801PNS001	SW Medium
26	1e0102/rev_3000c/	P0791580901PNS001	SW Thin1
27	1e0102/rev_3000d/	P0791581001PNS001	SW Thick
28	1e0102/rev_3000e/	P0791581101PNS001	SW Medium
29	1e0102/rev_3000f/	P0791581201PNS001	SW Thin1
30	1e0102/rev_3092/	P0412983201PNS001	SW Medium
31	1e0102/rev_3111/	P0412983301PNS001	SW Medium
32	1e0102/rev_3278/	P0412983401PNS001	SW Medium
33	1e0102/rev_3279/	P0412983501PNS001	SW Medium

rxj1856 spectra:

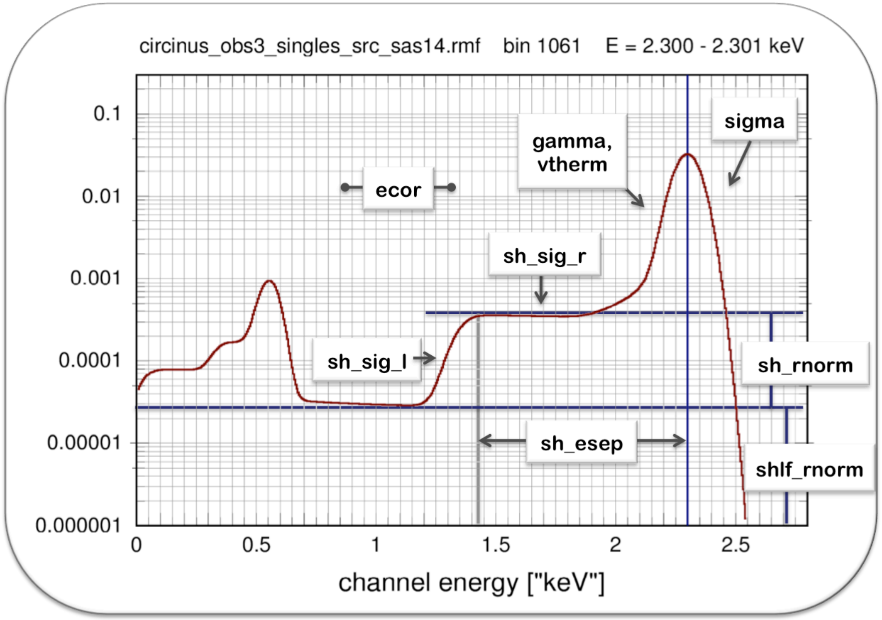
1	rxj1856/rev_0427/	P0106260101PNS001	SW Thin1
2	rxj1856/rev_0878/	P0165971601PNS003	SW Thin1
3	rxj1856/rev_0968/	P0165971901PNS003	SW Thin1
4	rxj1856/rev_1061/	P0165972001PNS003	SW Thin1
5	rxj1856/rev_1153/	P0165972101PNS003	SW Thin1
6	rxj1856/rev_1259/	P0412600101PNS003	SW Thin1
7	rxj1856/rev_1330/	P0412600201PNU002	SW Thin1
8	rxj1856/rev_1335/	P0415180101PNS001	SW Thin1
9	rxj1856/rev_1432a/	P0412600301PNS003	SW Thin1
10	rxj1856/rev_1432b/	P0412600301PNU002	SW Thin1
11	rxj1856/rev_1513/	P0412600401PNU002	SW Thin1
12	rxj1856/rev_1616/	P0412600601PNU002	SW Thin1
13	rxj1856/rev_1699/	P0412600701PNS003	SW Thin1
14	rxj1856/rev_1800/	P0412600801PNU002	SW Thin1
15	rxj1856/rev_1979/	P0412601101PNU002	SW Thin1
16	rxj1856/rev_2062/	P0412601301PNS003	SW Thin1
17	rxj1856/rev_2261/	P0412601401PNS003	SW Thin1
18	rxj1856/rev_2165/	P0412601501PNS602	SW Thin1
19	rxj1856/rev_2429/	P0412602201PNS003	SW Thin1
20	rxj1856/rev_2341/	P0412602301PNS003	SW Thin1
21	rxj1856/rev_2521/	P0727760101PNS001	SW Thin1
22	rxj1856/rev_2618/	P0727760201PNS001	SW Thin1
23	rxj1856/rev_2706/	P0727760301PNS001	SW Thin1
24	rxj1856/rev_2794/	P0727760401PNS001	SW Thin1
25	rxj1856/rev_2897/	P0727760501PNS001	SW Thin1
26	rxj1856/rev_2977/	P0727760601PNS001	SW Thin1
27	rxj1856/rev_2995a/	P0791580301PNS001	SW Thin1
28	rxj1856/rev_2995b/	P0791580601PNS001	SW Thin1
29	rxj1856/rev_3075/	P0727761001PNS001	SW Thin1
30	rxj1856/rev_3162/	P0727761101PNS001	SW Thin1
31	rxj1856/rev_3255/	P0727761201PNS001	SW Thin1

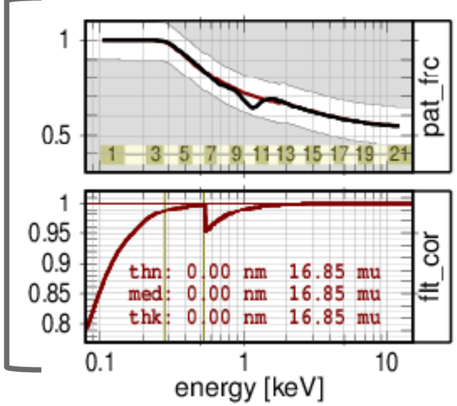
XMM / EPIC-pn RMF and ARF parameterization Small Window Mode

targets: 1e0102 (33) rxj1856 (31) 20190312_134952

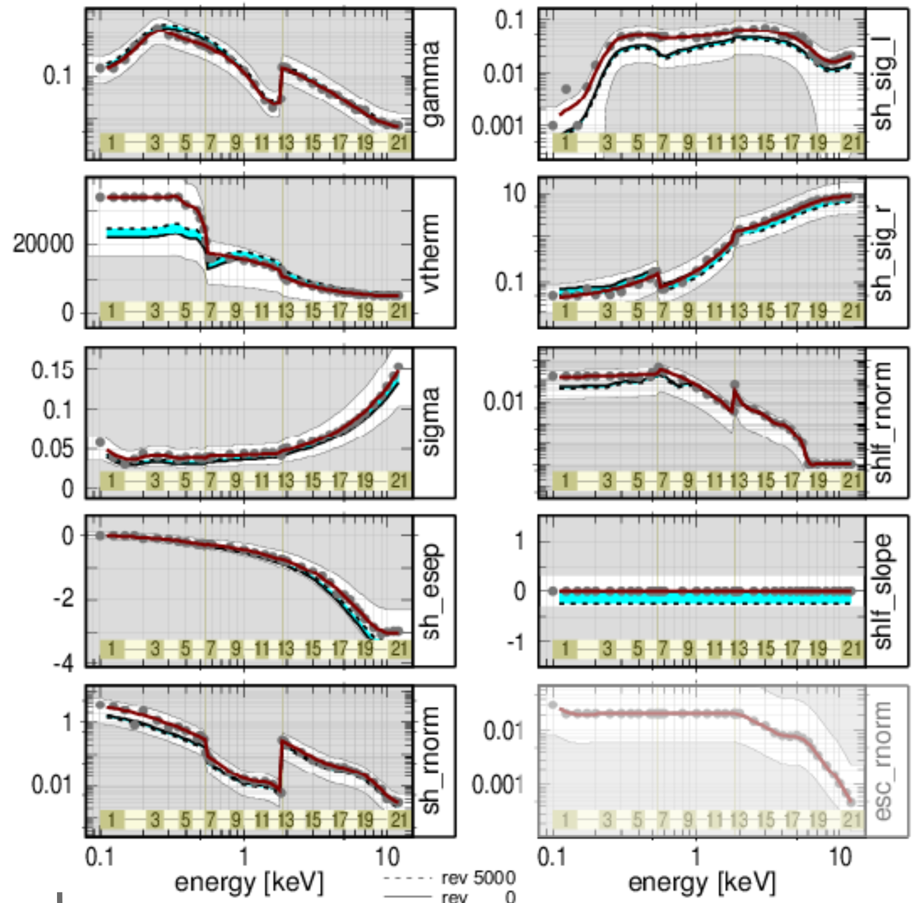


Modelling temporal RMF changes: shaping functions



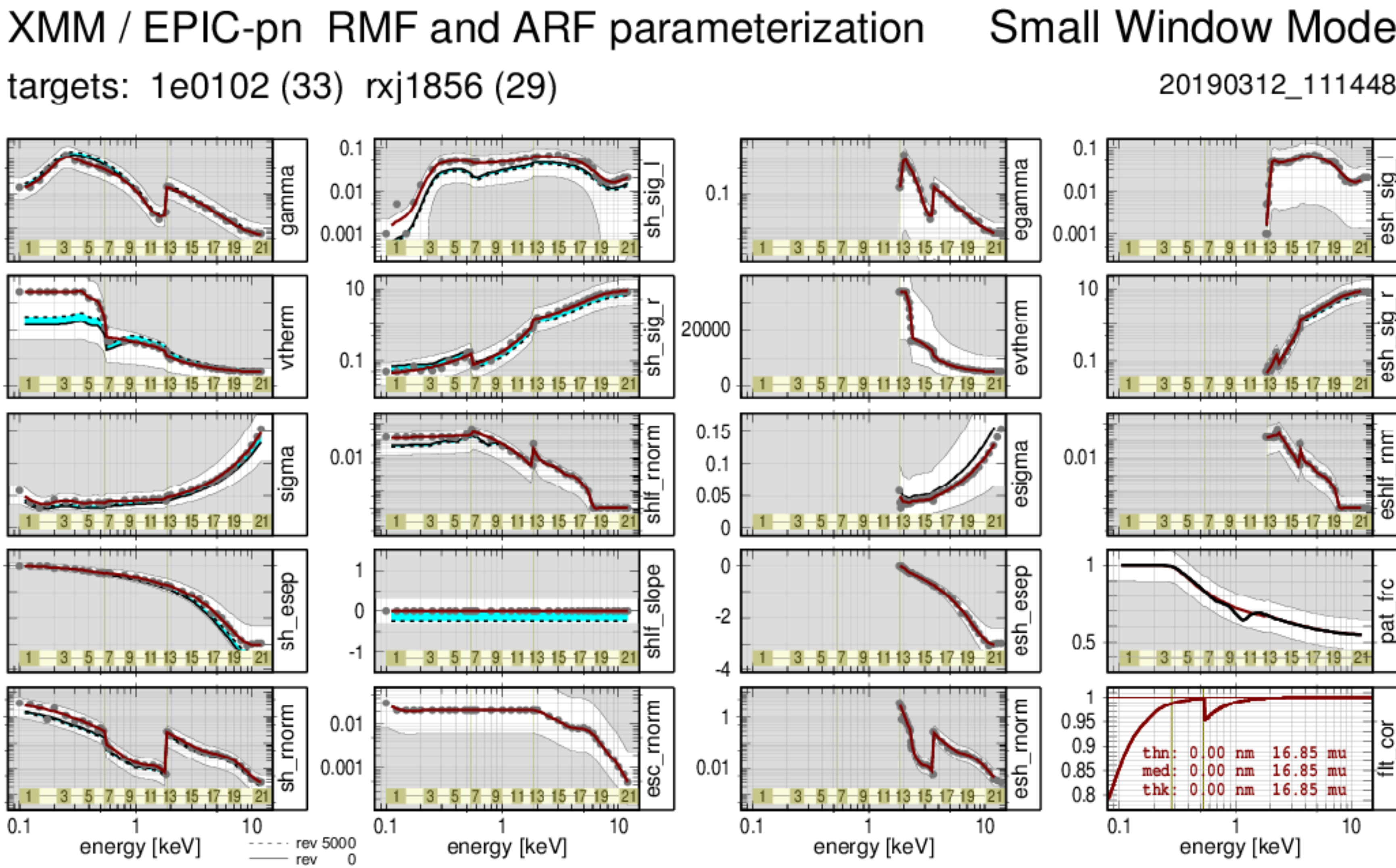


ARF parameters

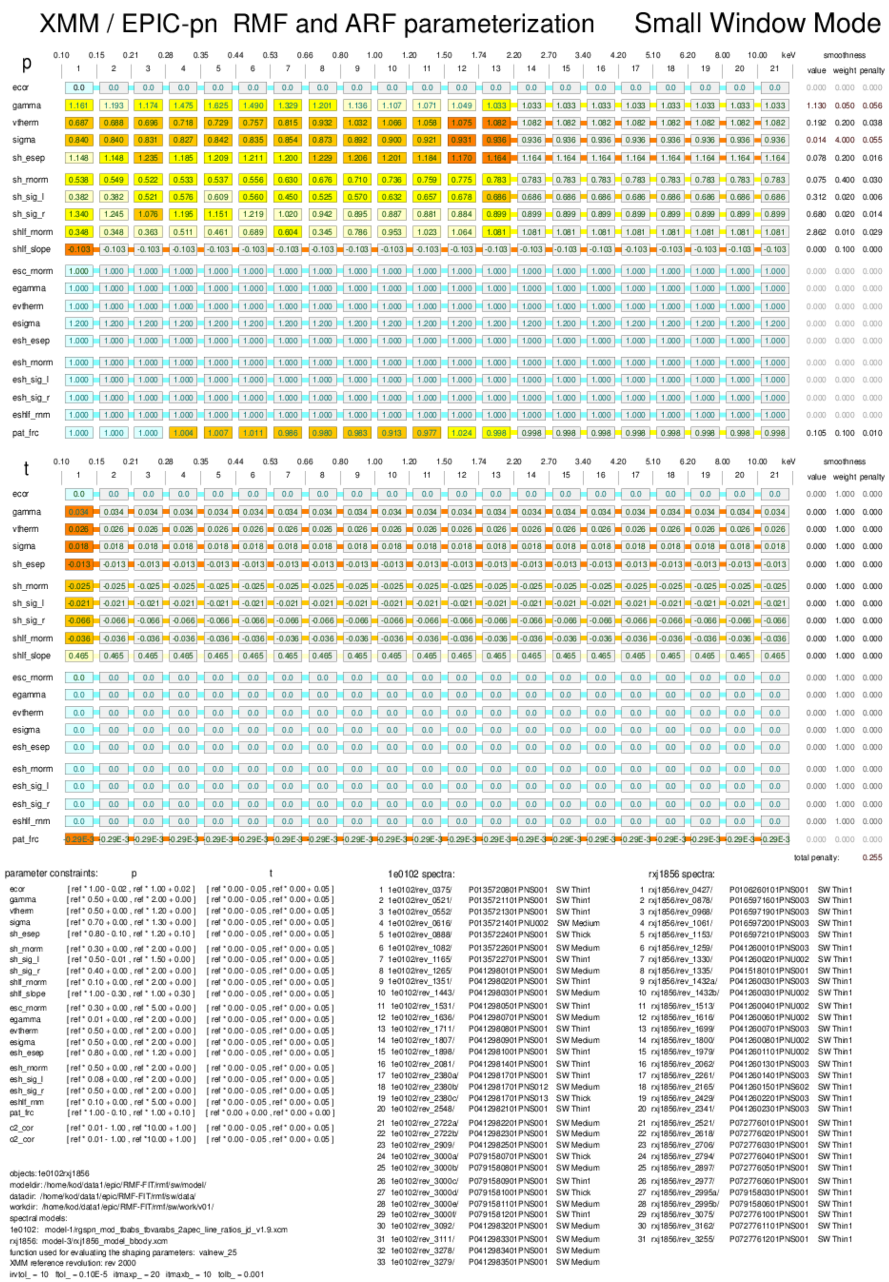


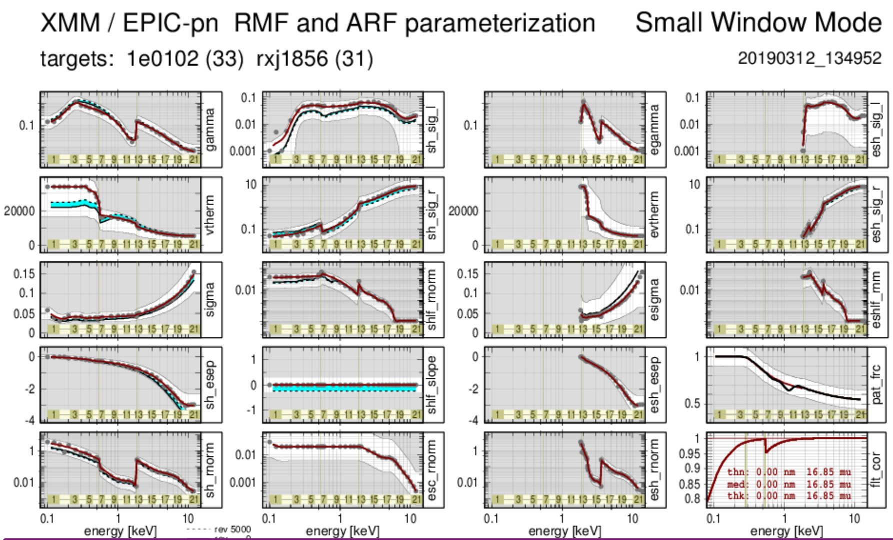
RMF parameters

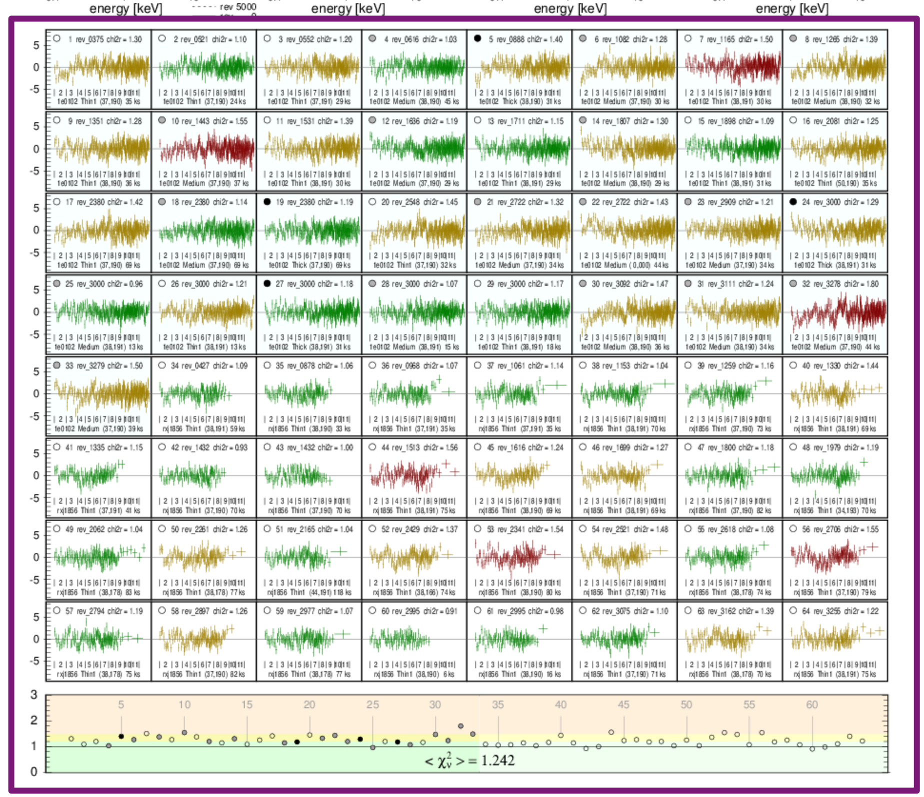
Modelling temporal RMF changes: shaping functions



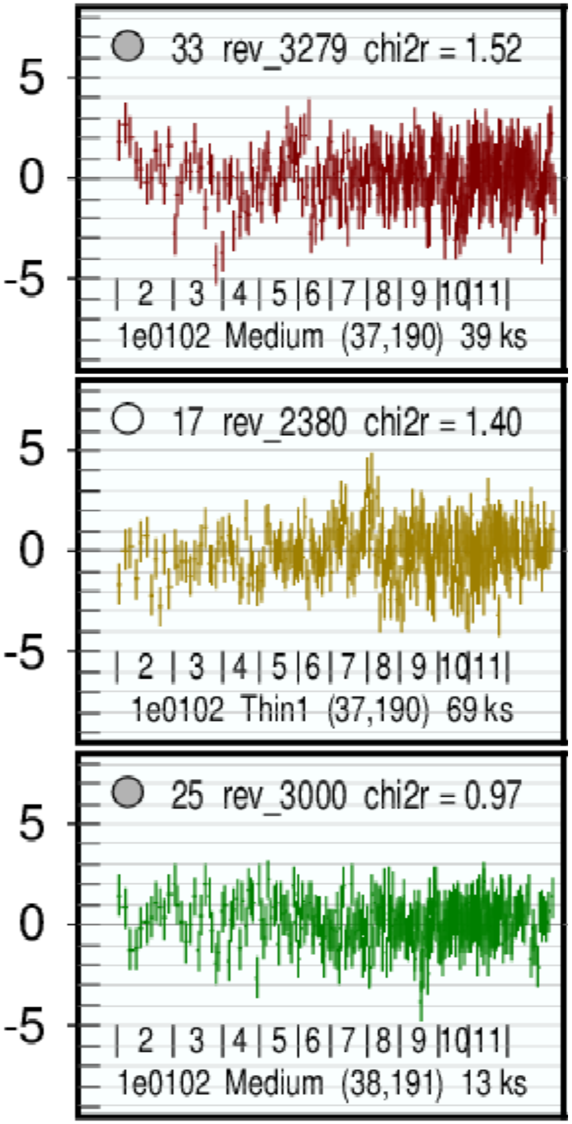
Modelling temporal RMF changes: sample output







Modelling temporal RMF changes: residuals

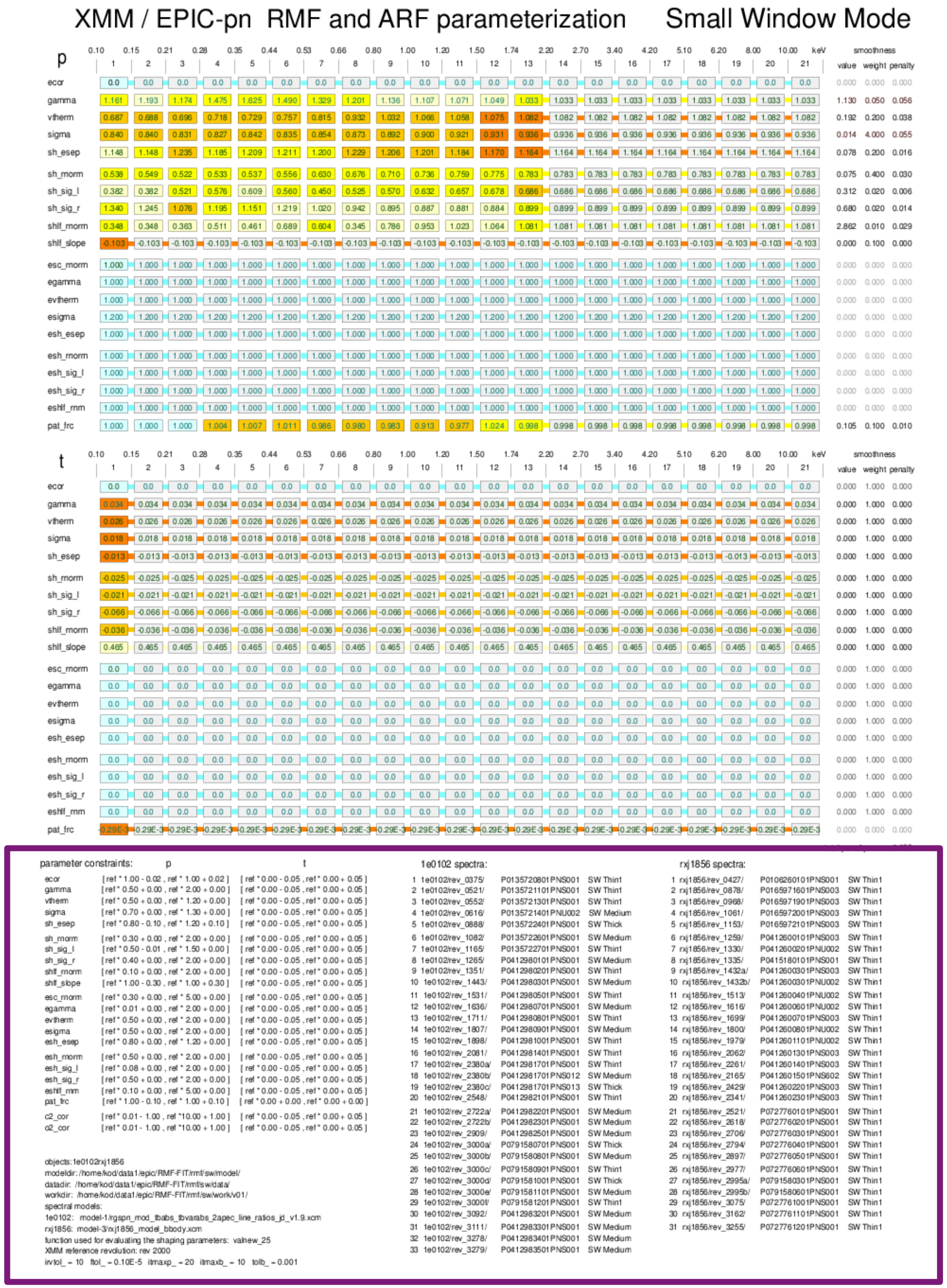


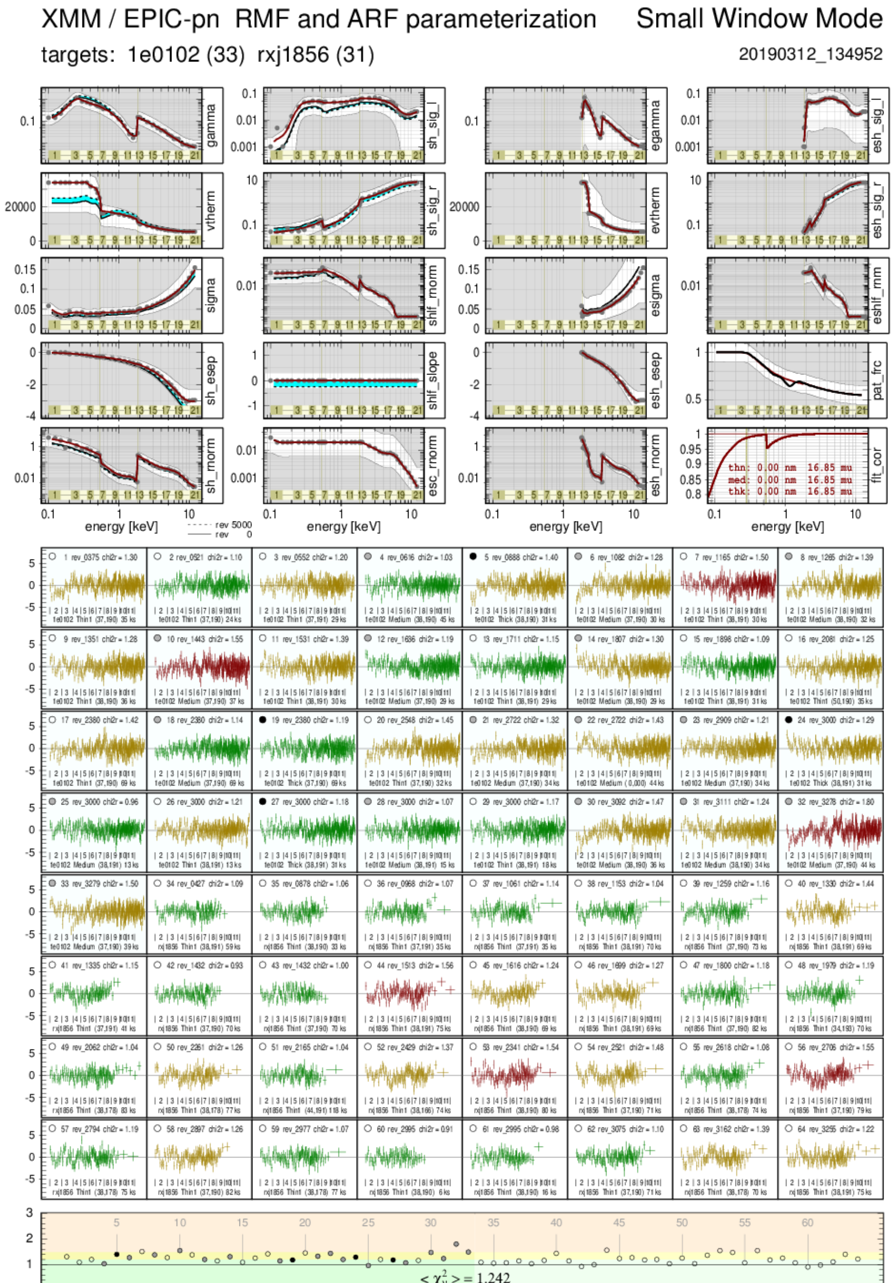
red: reduced $\chi^2 > 1.5$

yellow: $1.2 \leq$ reduced $\chi^2 \leq 1.5$

green: reduced $\chi^2 < 1.2$

Modelling temporal RMF changes: sample output





evtherm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.00
esigma	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.00
esh_esep	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.00
esh_rnorm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.00
esh_sig_l	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.00
esh_sig_r	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.00
eshlf_rnm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.00
pat_frc	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	-0.29E-3	0.000	0.000	0.00

total penalty: 0.25

parameter constraints:

	p	t
ecor	[ref * 1.00 - 0.02 , ref * 1.00 + 0.02]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
gamma	[ref * 0.50 + 0.00 , ref * 2.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
vtherm	[ref * 0.50 + 0.00 , ref * 1.20 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
sigma	[ref * 0.70 + 0.00 , ref * 1.30 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
sh_esep	[ref * 0.80 - 0.10 , ref * 1.20 + 0.10]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
sh_rnorm	[ref * 0.30 + 0.00 , ref * 2.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
sh_sig_l	[ref * 0.50 - 0.01 , ref * 1.50 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
sh_sig_r	[ref * 0.40 + 0.00 , ref * 2.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
shlf_rnorm	[ref * 0.10 + 0.00 , ref * 2.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
shlf_slope	[ref * 1.00 - 0.30 , ref * 1.00 + 0.30]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
esc_rnorm	[ref * 0.30 + 0.00 , ref * 5.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
egamma	[ref * 0.01 + 0.00 , ref * 2.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
evtherm	[ref * 0.50 + 0.00 , ref * 2.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
esigma	[ref * 0.50 + 0.00 , ref * 2.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
esh_esep	[ref * 0.80 + 0.00 , ref * 1.20 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
esh_rnorm	[ref * 0.50 + 0.00 , ref * 2.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
esh_sig_l	[ref * 0.08 + 0.00 , ref * 2.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
esh_sig_r	[ref * 0.50 + 0.00 , ref * 2.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
eshlf_rnm	[ref * 0.10 + 0.00 , ref * 5.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
pat_frc	[ref * 1.00 - 0.10 , ref * 1.00 + 0.10]	[ref * 0.00 + 0.00 , ref * 0.00 + 0.00]
c2_cor	[ref * 0.01 - 1.00 , ref *10.00 + 1.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
o2_cor	[ref * 0.01 - 1.00 , ref *10.00 + 1.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]

objects:1e0102rxj1856
modeldir: /home/kod/data1/epic/RMF-FIT/rmf/sw/model/
datadir: /home/kod/data1/epic/RMF-FIT/rmf/sw/data/
workdir: /home/kod/data1/epic/RMF-FIT/rmf/sw/work/v01/
spectral models:
1e0102: model-1/rgspn_mod_tbabs_tbvarabs_2apec_line_ratios_jd_v1.9.xcm
rxj1856: model-3/rxj1856_model_bbody.xcm
function used for evaluating the shaping parameters: valnew_25
XMM reference revolution: rev 2000
irvtol_ = 10 ftol_ = 0.10E-5 itmaxp_ = 20 itmaxb_ = 10 tolb_ = 0.001

1e0102 spectra:

1	1e0102/rev_0375/	P0135720801PNS001	SW Thin1
2	1e0102/rev_0521/	P0135721101PNS001	SW Thin1
3	1e0102/rev_0552/	P0135721301PNS001	SW Thin1
4	1e0102/rev_0616/	P0135721401PNU002	SW Medium
5	1e0102/rev_0888/	P0135722401PNS001	SW Thick
6	1e0102/rev_1082/	P0135722601PNS001	SW Medium
7	1e0102/rev_1165/	P0135722701PNS001	SW Thin1
8	1e0102/rev_1265/	P0412980101PNS001	SW Medium
9	1e0102/rev_1351/	P0412980201PNS001	SW Thin1
10	1e0102/rev_1443/	P0412980301PNS001	SW Medium
11	1e0102/rev_1531/	P0412980501PNS001	SW Thin1
12	1e0102/rev_1636/	P0412980701PNS001	SW Medium
13	1e0102/rev_1711/	P0412980801PNS001	SW Thin1
14	1e0102/rev_1807/	P0412980901PNS001	SW Medium
15	1e0102/rev_1898/	P0412981001PNS001	SW Thin1
16	1e0102/rev_2081/	P0412981401PNS001	SW Thin1
17	1e0102/rev_2380a/	P0412981701PNS001	SW Thin1
18	1e0102/rev_2380b/	P0412981701PNS012	SW Medium
19	1e0102/rev_2380c/	P0412981701PNS013	SW Thick
20	1e0102/rev_2548/	P0412982101PNS001	SW Thin1
21	1e0102/rev_2722a/	P0412982201PNS001	SW Medium
22	1e0102/rev_2722b/	P0412982301PNS001	SW Medium
23	1e0102/rev_2909/	P0412982501PNS001	SW Medium
24	1e0102/rev_3000a/	P0791580701PNS001	SW Thick
25	1e0102/rev_3000b/	P0791580801PNS001	SW Medium
26	1e0102/rev_3000c/	P0791580901PNS001	SW Thin1
27	1e0102/rev_3000d/	P0791581001PNS001	SW Thick
28	1e0102/rev_3000e/	P0791581101PNS001	SW Medium
29	1e0102/rev_3000f/	P0791581201PNS001	SW Thin1
30	1e0102/rev_3092/	P0412983201PNS001	SW Medium
31	1e0102/rev_3111/	P0412983301PNS001	SW Medium
32	1e0102/rev_3278/	P0412983401PNS001	SW Medium
33	1e0102/rev_3279/	P0412983501PNS001	SW Medium

rxj1856 spectra:

1	rxj1856/rev_0427/	P0106260101PNS001	SW Thin1
2	rxj1856/rev_0878/	P0165971601PNS003	SW Thin1
3	rxj1856/rev_0968/	P0165971901PNS003	SW Thin1
4	rxj1856/rev_1061/	P0165972001PNS003	SW Thin1
5	rxj1856/rev_1153/	P0165972101PNS003	SW Thin1
6	rxj1856/rev_1259/	P0412600101PNS003	SW Thin1
7	rxj1856/rev_1330/	P0412600201PNU002	SW Thin1
8	rxj1856/rev_1335/	P0415180101PNS001	SW Thin1
9	rxj1856/rev_1432a/	P0412600301PNS003	SW Thin1
10	rxj1856/rev_1432b/	P0412600301PNU002	SW Thin1
11	rxj1856/rev_1513/	P0412600401PNU002	SW Thin1
12	rxj1856/rev_1616/	P0412600601PNU002	SW Thin1
13	rxj1856/rev_1699/	P0412600701PNS003	SW Thin1
14	rxj1856/rev_1800/	P0412600801PNU002	SW Thin1
15	rxj1856/rev_1979/	P0412601101PNU002	SW Thin1
16	rxj1856/rev_2062/	P0412601301PNS003	SW Thin1
17	rxj1856/rev_2261/	P0412601401PNS003	SW Thin1
18	rxj1856/rev_2165/	P0412601501PNS602	SW Thin1
19	rxj1856/rev_2429/	P0412602201PNS003	SW Thin1
20	rxj1856/rev_2341/	P0412602301PNS003	SW Thin1
21	rxj1856/rev_2521/	P0727760101PNS001	SW Thin1
22	rxj1856/rev_2618/	P0727760201PNS001	SW Thin1
23	rxj1856/rev_2706/	P0727760301PNS001	SW Thin1
24	rxj1856/rev_2794/	P0727760401PNS001	SW Thin1
25	rxj1856/rev_2897/	P0727760501PNS001	SW Thin1
26	rxj1856/rev_2977/	P0727760601PNS001	SW Thin1
27	rxj1856/rev_2995a/	P0791580301PNS001	SW Thin1
28	rxj1856/rev_2995b/	P0791580601PNS001	SW Thin1
29	rxj1856/rev_3075/	P0727761001PNS001	SW Thin1
30	rxj1856/rev_3162/	P0727761101PNS001	SW Thin1
31	rxj1856/rev_3255/	P0727761201PNS001	SW Thin1

Modelling temporal changes: data and models used

Data:

1E 0102:

33 observations from rev 0375 to rev 3279

13 x thin, 16 x medium, 4 x thick filter

SW mode only, and only singles

total exposure: 1.14 Ms

processed by Frank Haberl

with xmmsas_20170330_1731-17.0.0

using rmfgen-2.5.1, arfgen-1.93.1

RX J1856:

31 observations from rev 0427 to rev 3255

all with thin filter

SW mode only, and only singles

total exposure: 2.05 Ms

processed by Frank Haberl

with xmmsas_20160201_1833-15.0.0

using rmfgen-2.2.1, arfgen-1.92

in total: 3.2 Ms (!), time span: 15.9 years

Models:

1E 0102:

IACHEC model

with only 1 free parameter:

global normalization

+ gain fit (offset)

RX J1856:

TBabs * bbodyrad

with all parameters from Chandra
(no free parameter!)

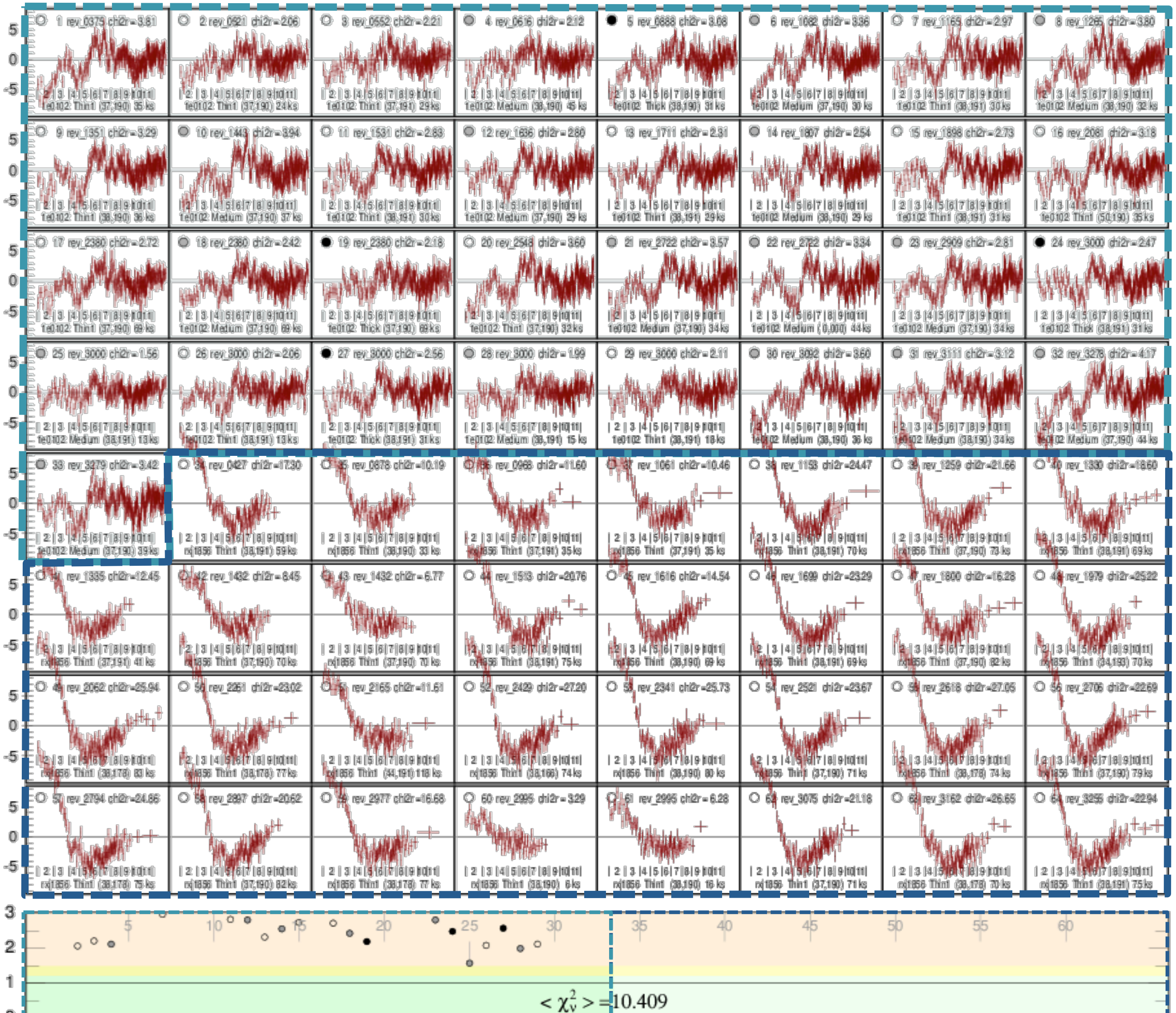
nH == 7.25 e-19 cm-2

kT == 62.4 eV

norm == 1.58 e5

+ gain fit (offset)

Residuals obtained with xmmsas RMF



average reduced χ^2 = 10.409

spectral models:

1E 0102

IACHEC model

with **only 1 free parameter**: global normalization

+ gain fit (offset)

RX J1856

TBabs * bbodyrad

with **all parameters from Chandra**
(no free parameter!)

nH == 7.25 10^{-19} cm^{-2}
kT == 62.4 eV
norm == 1.58 10^{5}

+ gain fit (offset)

Residuals obtained with parameterized RMF

average reduced χ^2 = 1.310

spectral models:

1E 0102

IACHEC model

with **only 1 free parameter**: global normalization

+ gain fit (offset)

RX J1856

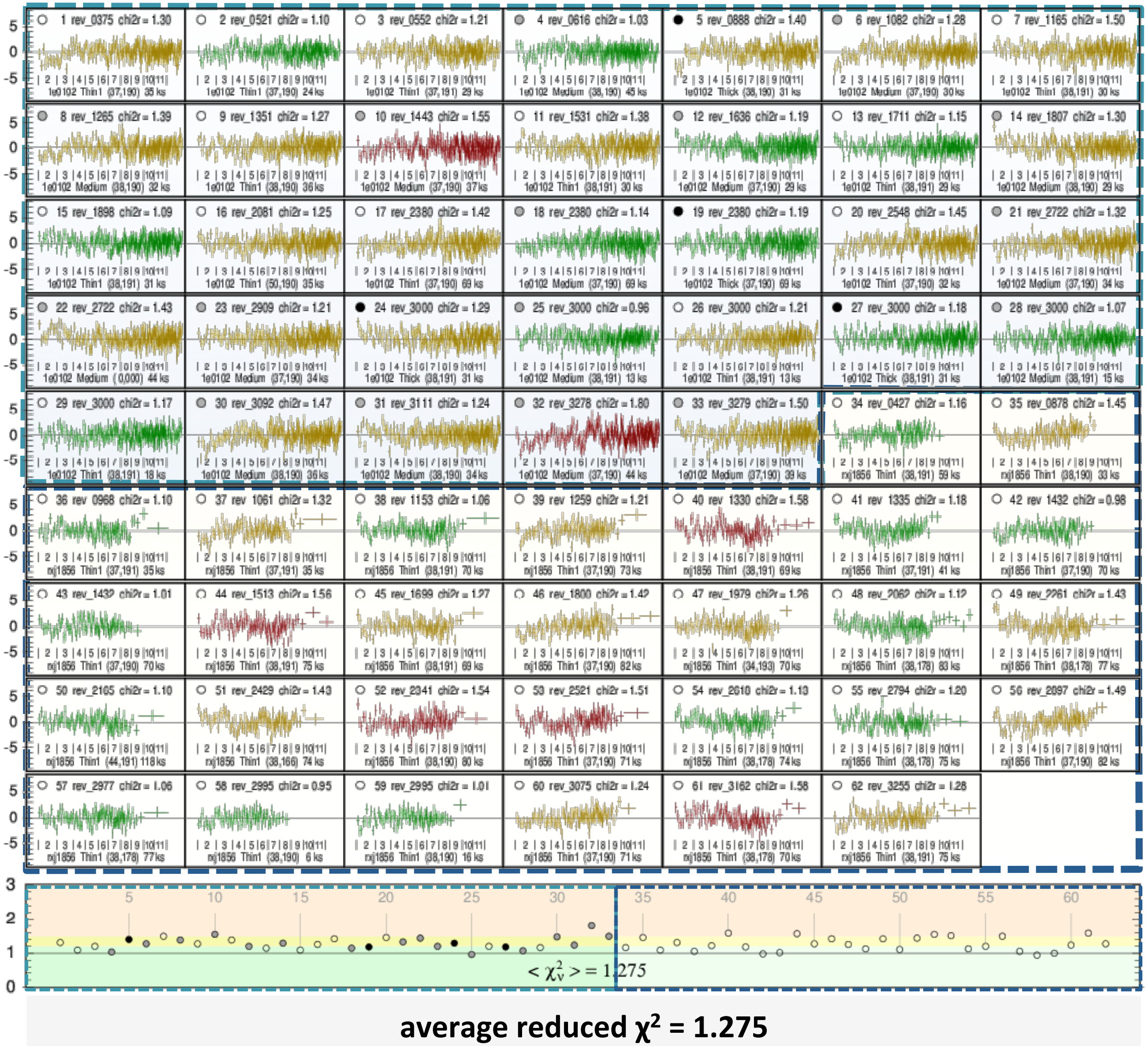
TBabs * bbodyrad

with **all parameters from Chandra**
(no free parameter!)

nH == 7.25 10^{-19} cm^{-2}
kT == 62.4 eV
norm == 1.58 10^{5}

+ gain fit (offset)

Residuals obtained with parameterized RMF



spectral models:

1E 0102

IACHEC model

with **only 1 free parameter**: global normalization

+ gain fit (offset)

RX J1856

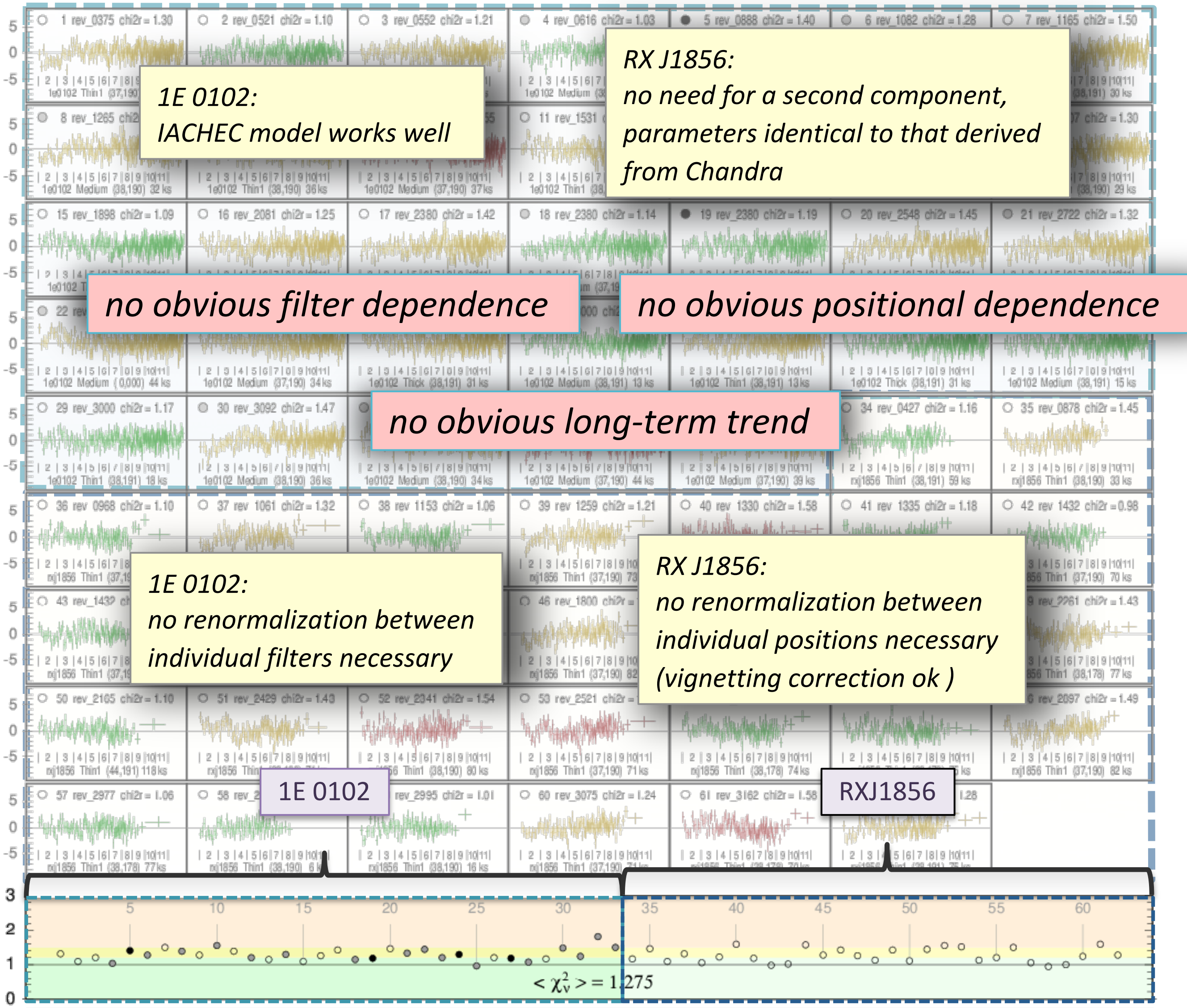
TBabs * bbodyrad

with **all parameters from Chandra**
(no free parameter!)

nH == 7.25 10^{-19} cm^{-2}
kT == 62.4 eV
norm == 1.58 10^{5}

+ gain fit (offset)

Residuals obtained with parameterized RMF



average reduced χ^2 = 1.275

spectral models:

1E 0102

IACHEC model

with **only 1 free parameter**:
global normalization

+ gain fit (offset)

RX J1856

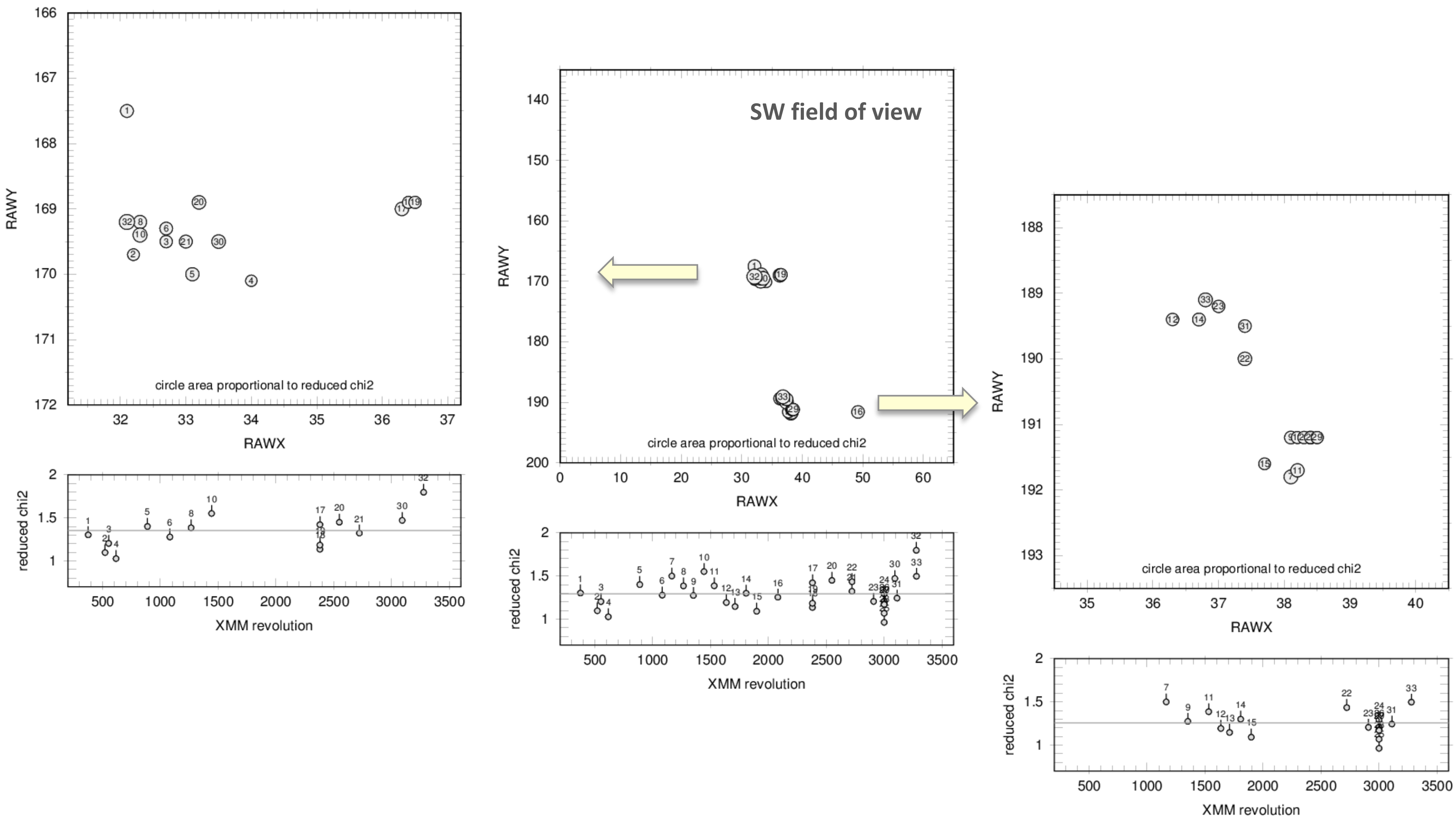
TBabs * bbodyrad

with **all parameters from Chandra**
(no free parameter!)

nH == 7.25 10^{-19} cm^{-2}
kT == 62.4 eV
norm == 1.58 10^{5}

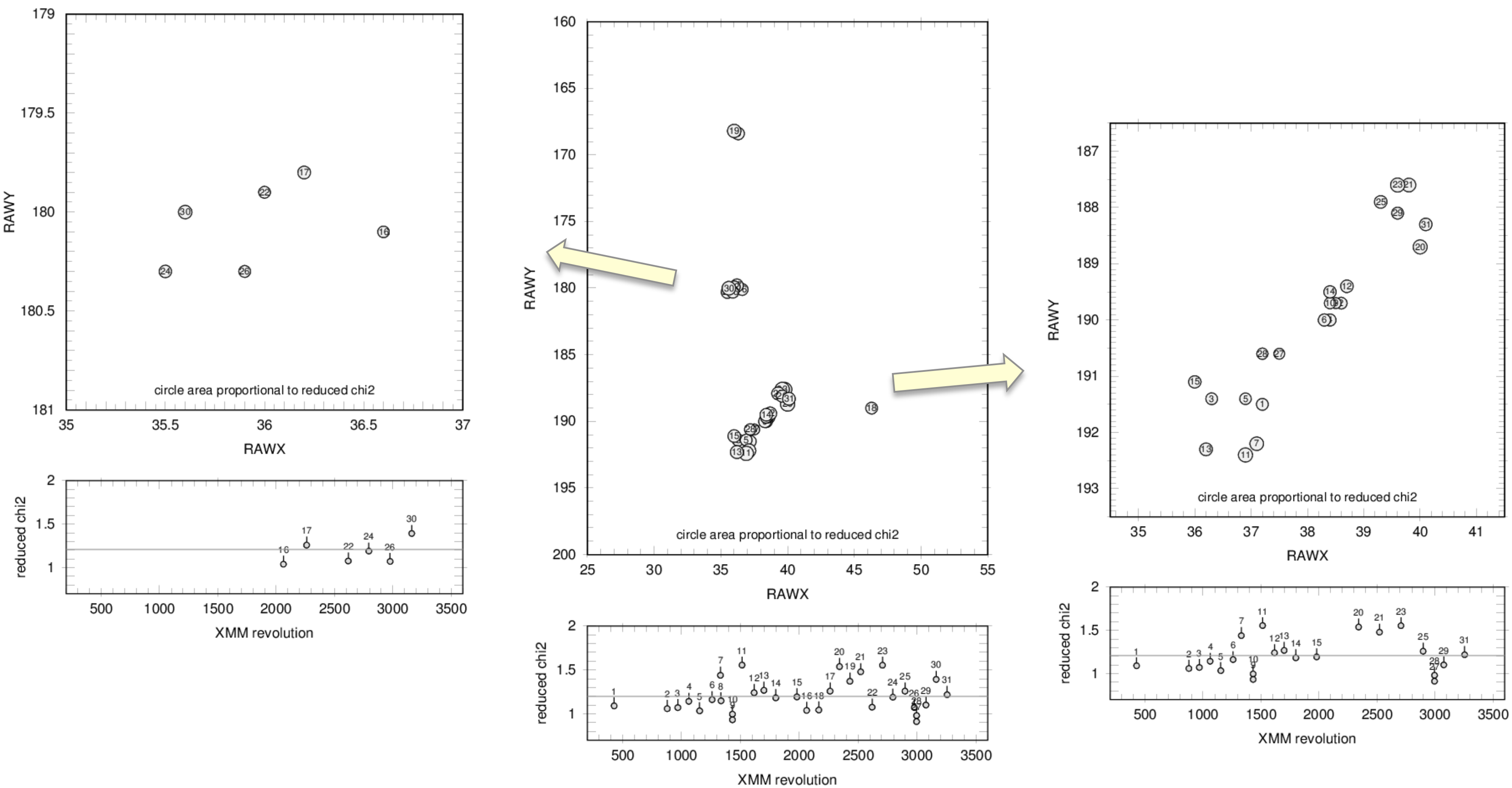
+ gain fit (offset)

1E 0102: Fit quality over position and time



→ no obvious dependence on position or time

RX J1856: Fit quality over position and time



→ no obvious dependence on position, no obvious long-term trend

Previous spectral studies of RX J1856

A&A 541, A66 (2012)
DOI: 10.1051/0004-6361/201118489

Astronomy & Astrophysics

Spectral monitoring of RX J1856.5-3754 with *XMM-Newton*

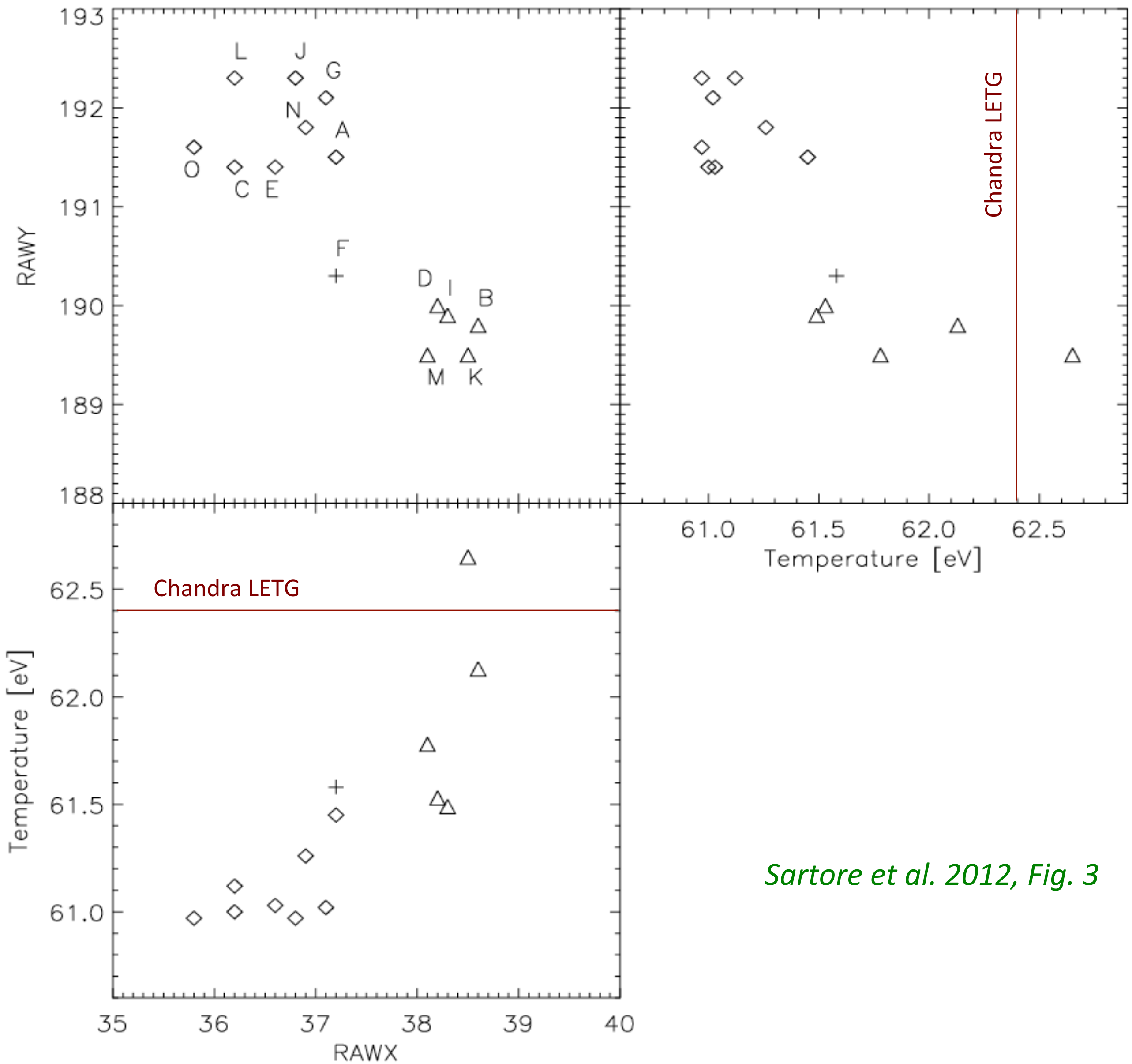
Analysis of EPIC-pn data

N. Sartore[1], A. Tiengo[1,2], S. Mereghetti[1], A. De Luca[1,2,3], R. Turolla[4,5], and F. Haberl[6]

[1] INAF – Istituto di Fisica Spaziale e Fisica Cosmica, via E. Bassini 15, 20133 Milano, Italy
e-mail: sartore@iasf-milano.inaf.it
[2] IUSS – Istituto Universitario di Studi Superiori, viale Lungo Ticino Sforza 56, 27100 Pavia, Italy
[3] INFN – Istituto Nazionale di Fisica Nucleare, sezione di Pavia, via A. Bassi 6, 27100 Pavia, Italy
[4] Dipartimento di Fisica e Astronomia, Università di Padova, via Marzolo 8, 35131 Padova, Italy
[5] Mullard Space Science Laboratory, University College London, Holmbury St. Mary, Dorking, Surrey, RH5 6NT, UK
[6] Max-Planck-Institut für extraterrestrische Physik, Giessenbachstraße, 85748 Garching bei München, Germany

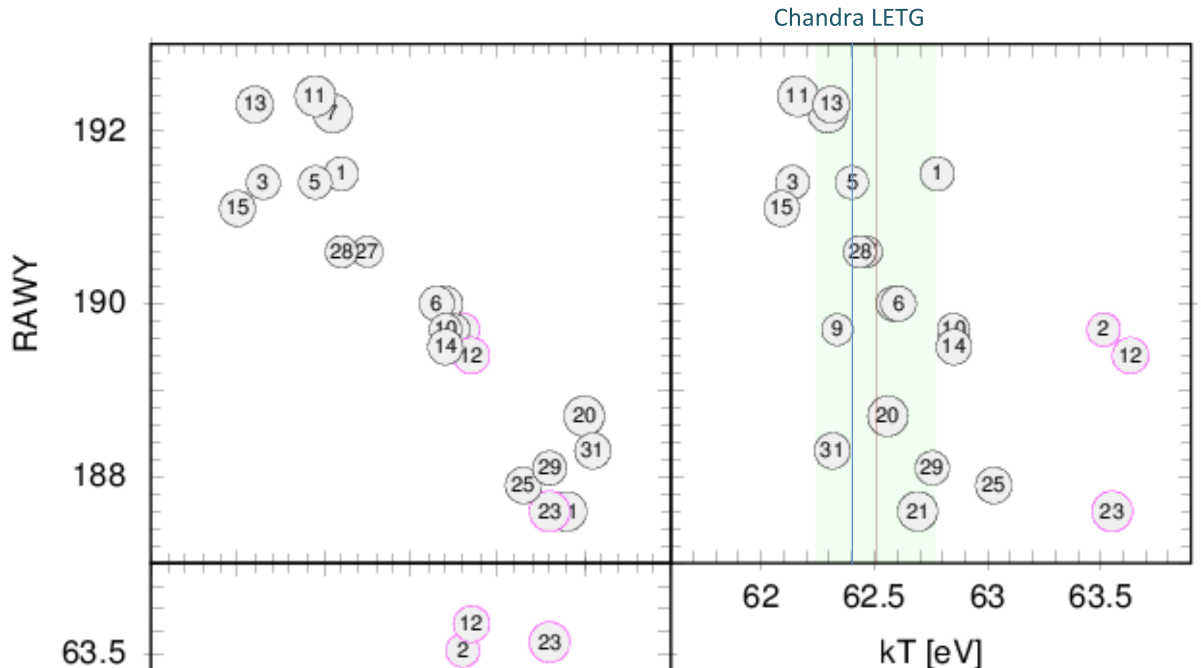
Received 20 November 2011 / Accepted 8 February 2012

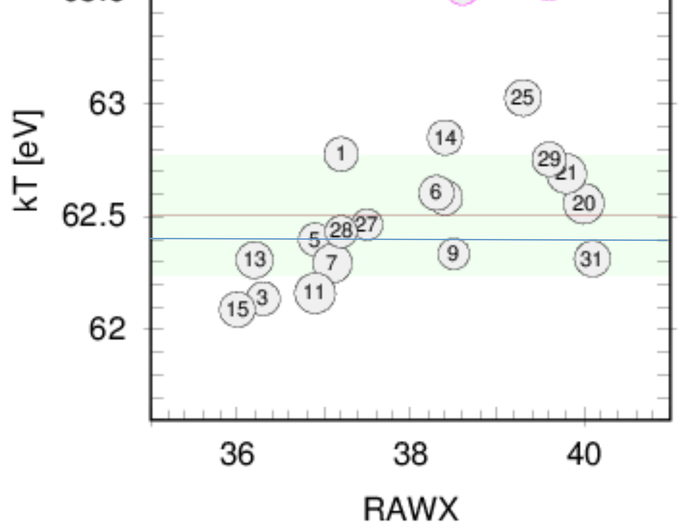
Previous spectral studies of RX J1856



Sartore et al. 2012, Fig. 3

RX J1856: spectral fit results from new RMF



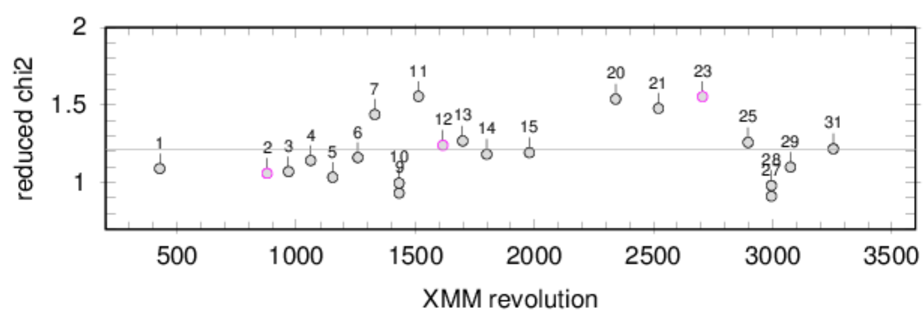


→ kT consistent with Chandra LETG

→ deviation in 3 observations (but no long-term trend and no positional trend)

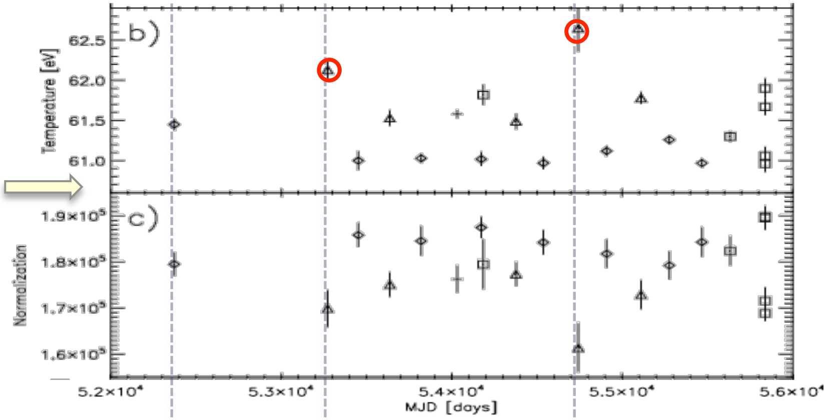
Chandra: kT = (62.4 +/- 0.4) eV

→ kT = 62.51 +/- 0.27 keV (excluding 2,12,23)



RX J1856: new RMF highlights sporadic spectral changes

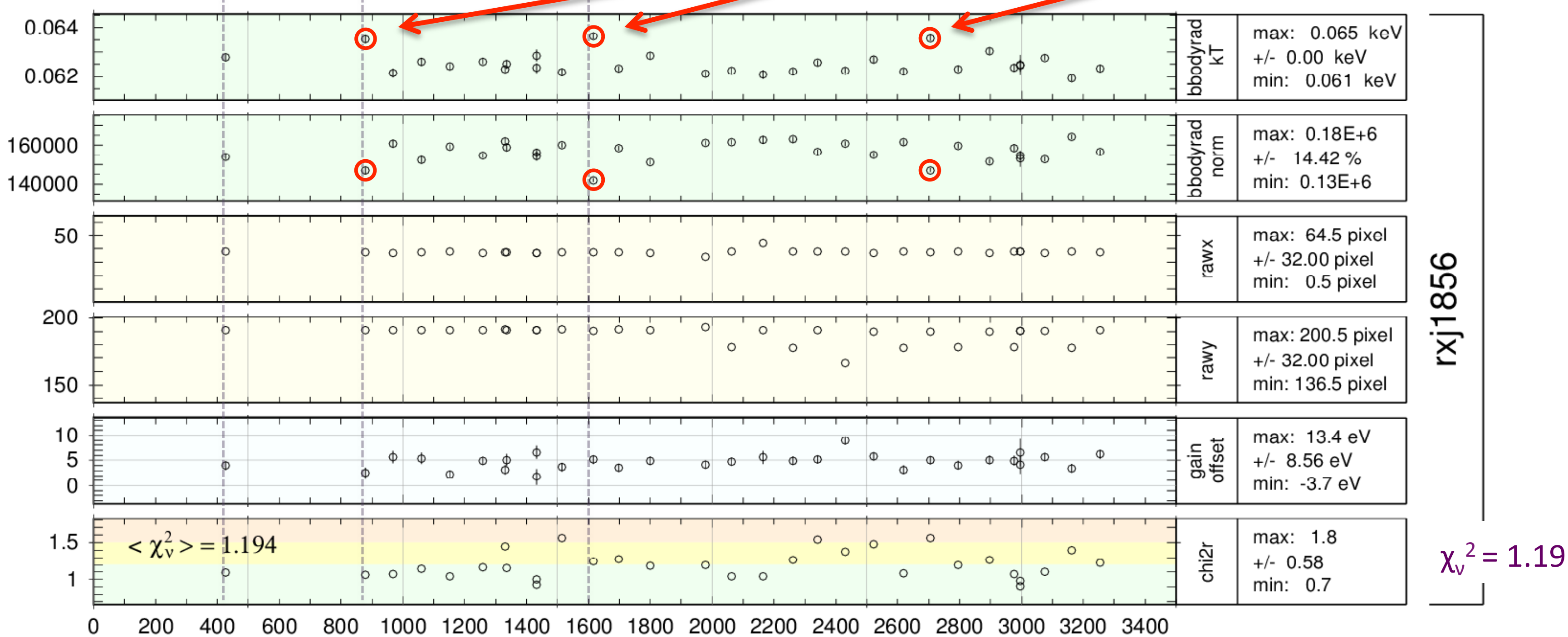
large scatter



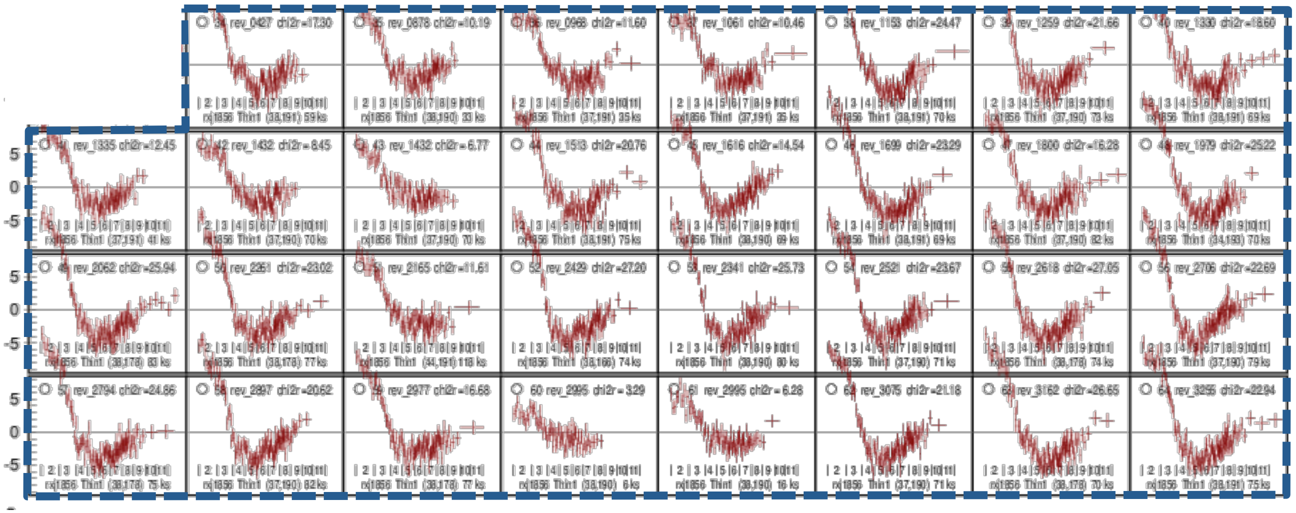
single BB fits (phabs * bbodyrad) to singles within 0.15 – 1.2 „keV“ with n_H fixed to 5.84×10^{19} cm^{-2}, using SAS v11.0: $\chi_\nu^2 = 1.37$

Sartore et al. 2012, Fig. 2

evidence for sporadic spectral changes



Previous spectral studies of RX J1856



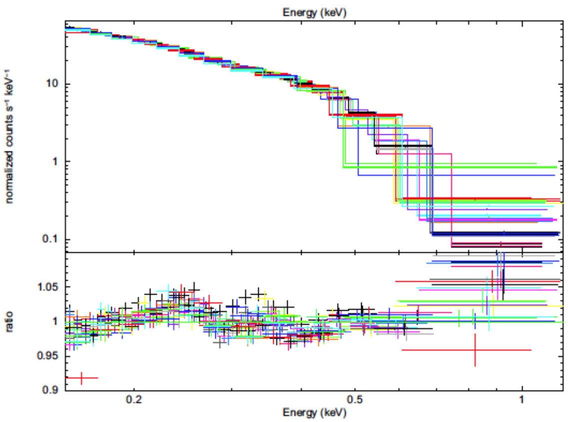
TBabs * bbodyrad

with **all parameters from Chandra**
(no free parameter!)

nH == 7.25 10^{-19} cm^{-2}
kT == 62.4 eV
norm == 1.58 10^{5}

+ gain fit (offset)

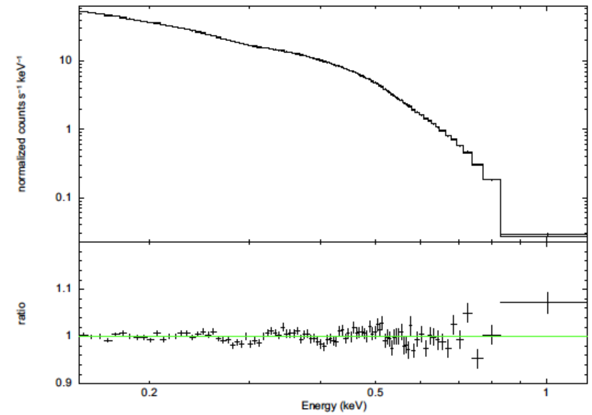
→ necessity to adopt significantly different parameters and/or to introduce a second component



Sartore et al. 2012, Fig. 2

common single BB fit (phabs * bbodyrad) to singles within 0.15 – 1.2 ‚keV'
with all parameters free, using SAS v11.0
+ gain fit

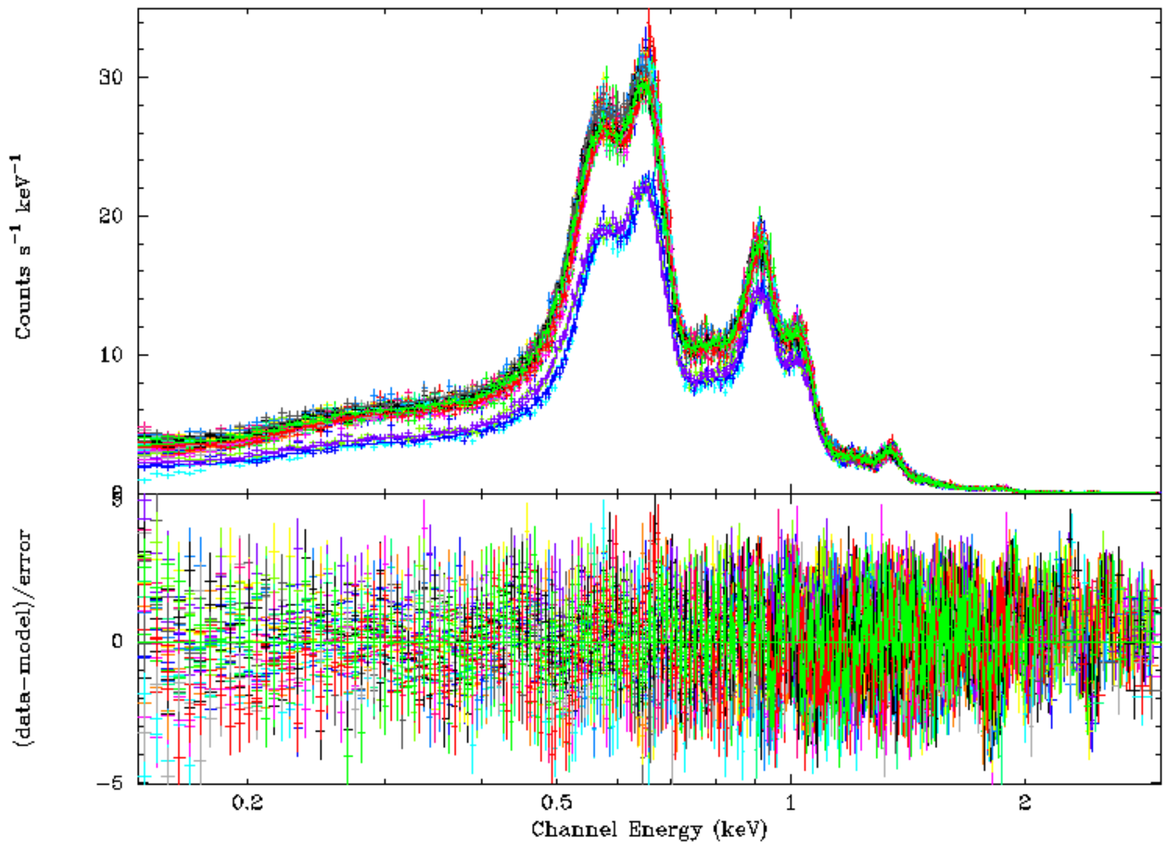
→ $n_H = (5.84 \pm 0.04) \times 10^{19}$ cm^{-2}
→ kT = 61.30 ± 0.04 eV



Sartore et al. 2012, Fig. 5

RX J1856: major discrepancies to Chandra results with xmmsas RMF

1E 0102: Combined fit of 33 EPIC-pn spectra, r = 30“



E = 0.15 − 3.0 keV, extraction radius: 30 arcsec, small window mode, singles only
each spectrum fit with time dependent parameterized RMF
reduced chi2 = 1.382, chi2 = 15 482, 11 206 PHA bins, 11 201 degrees of freedom

1E 0102: IACHEC model & XMM-Newton / EPIC-pn

A&A 597, A35 (2017)

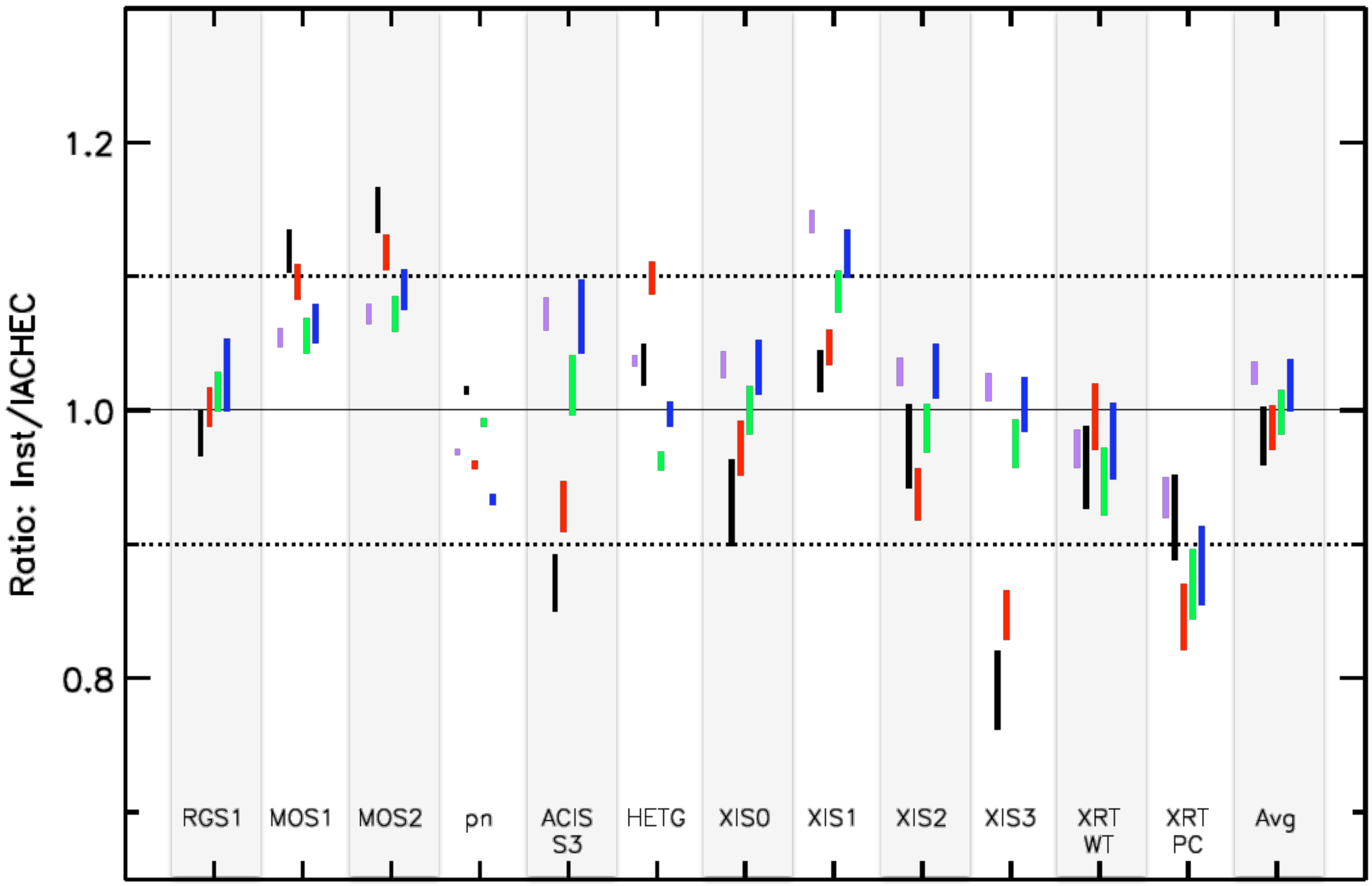


Fig. 14. Comparison of the scaled normalizations for each instrument to the IACHEC model values and the average. There are four or five points for each instrument which are from left to right, global normalization (purple), O VII Heα r (black), O VIII Lyα (red), Ne IX Heα r (green), and Ne X Lyα (blue). The length of the line indicates the 1.0σ CL for the scaled normalization.

1E 0102: IACHEC model & XMM-Newton / EPIC-pn

A&A 597, A35 (2017)

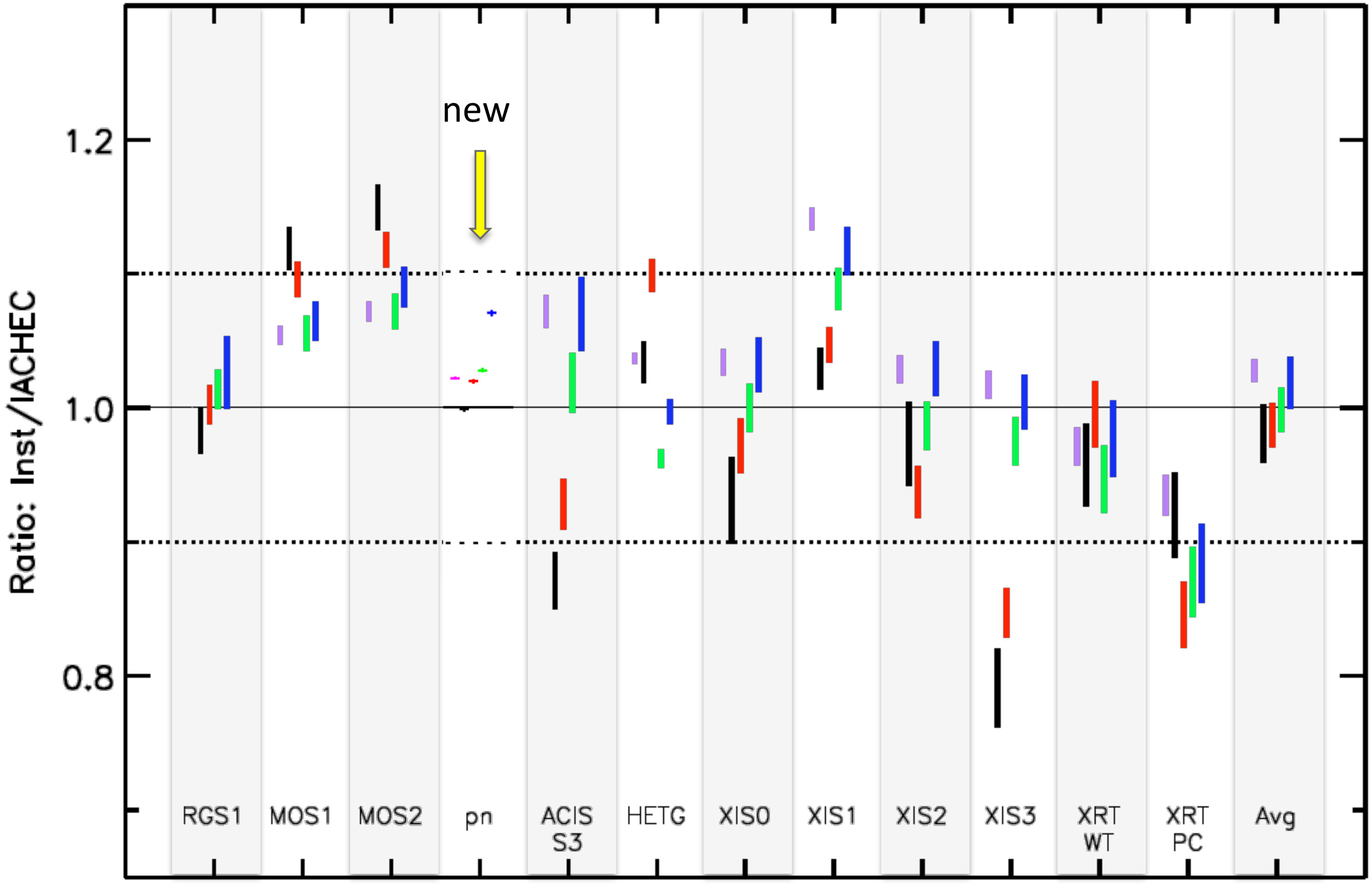
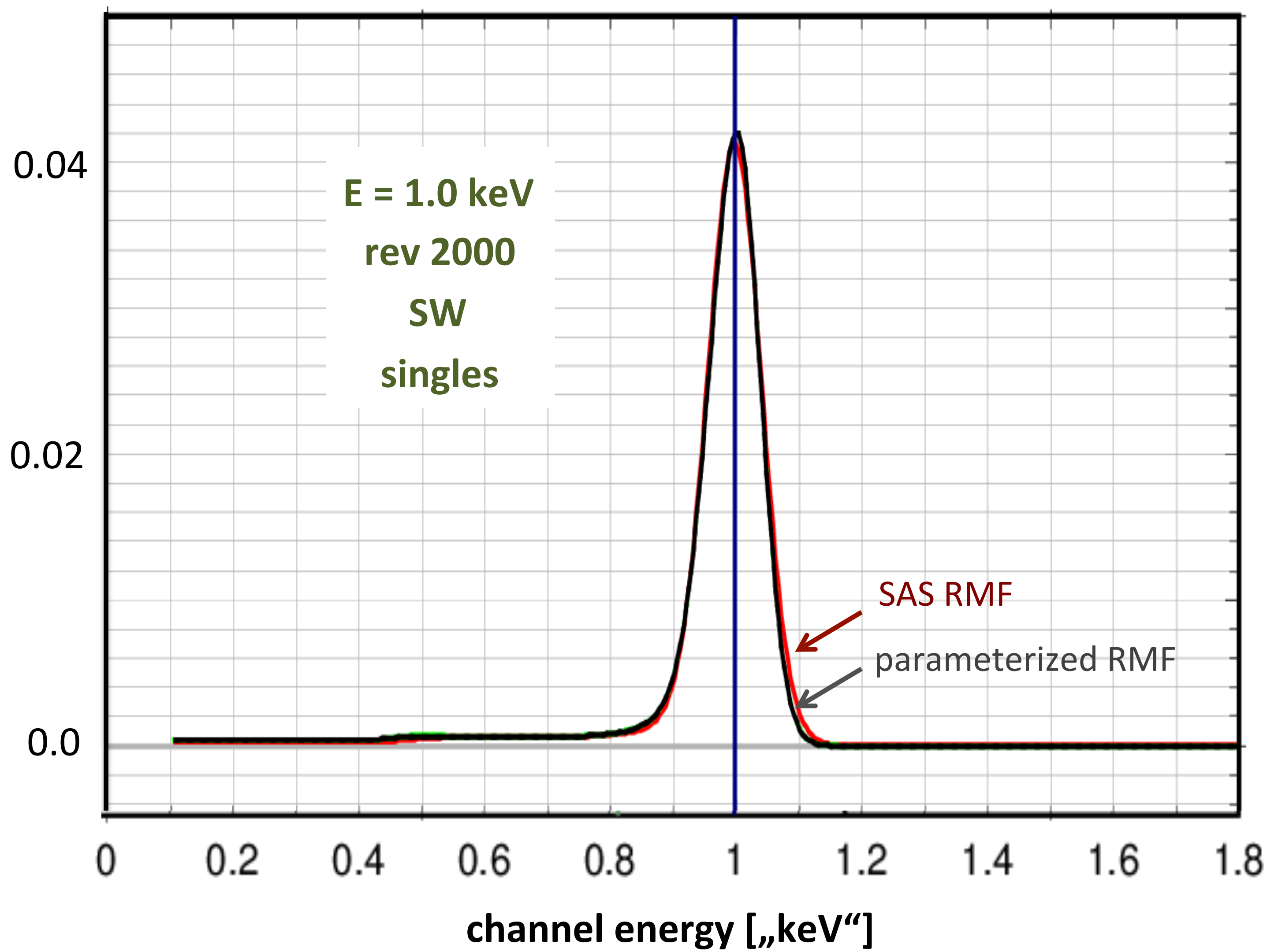
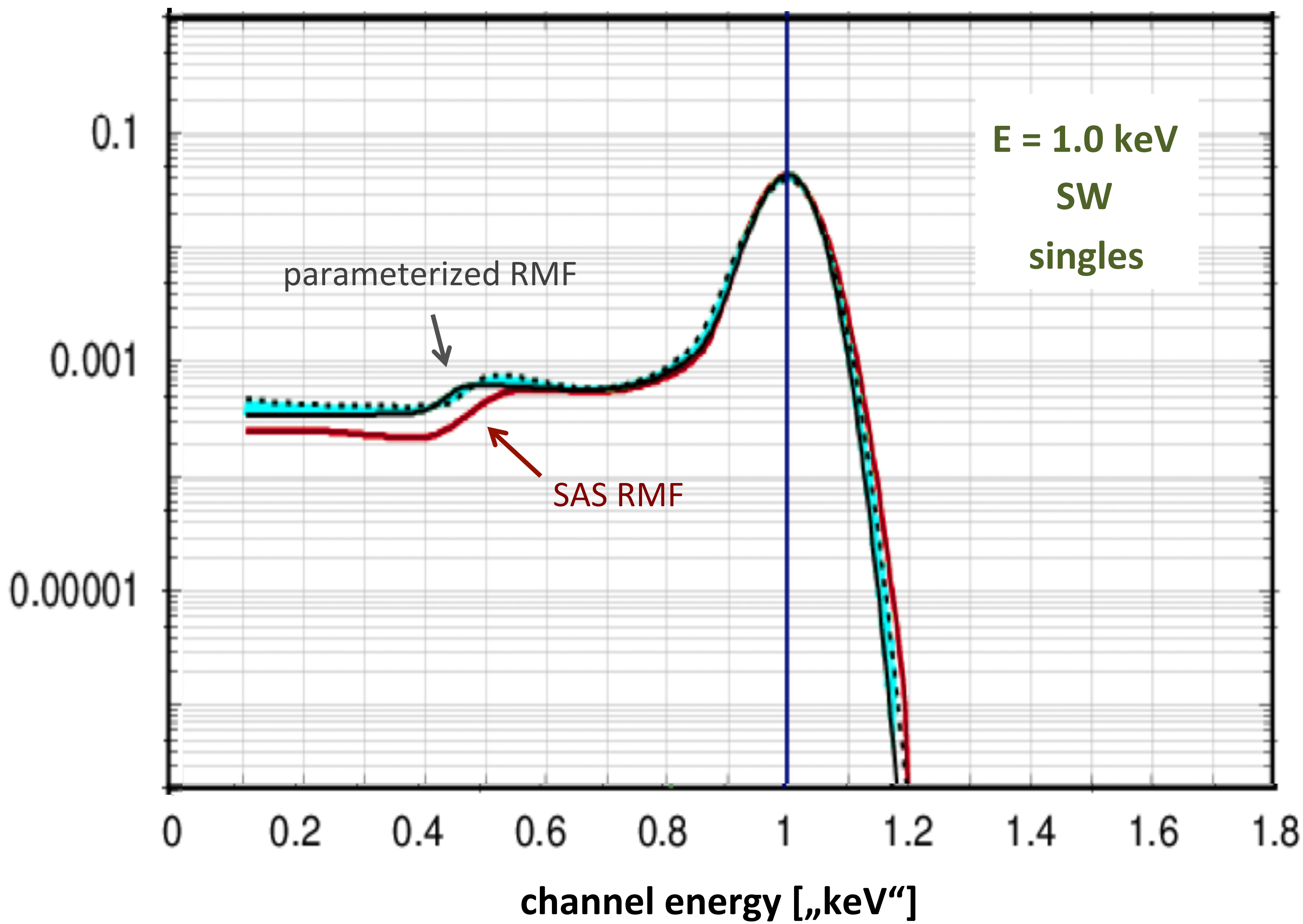


Fig. 14. Comparison of the scaled normalizations for each instrument to the IACHEC model values and the average. There are four or five points for each instrument which are from left to right, global normalization (purple), O VII Heα r (black), O VIII Lyα (red), Ne IX Heα r (green), and Ne X Lyα (blue). The length of the line indicates the 1.0σ CL for the scaled normalization.

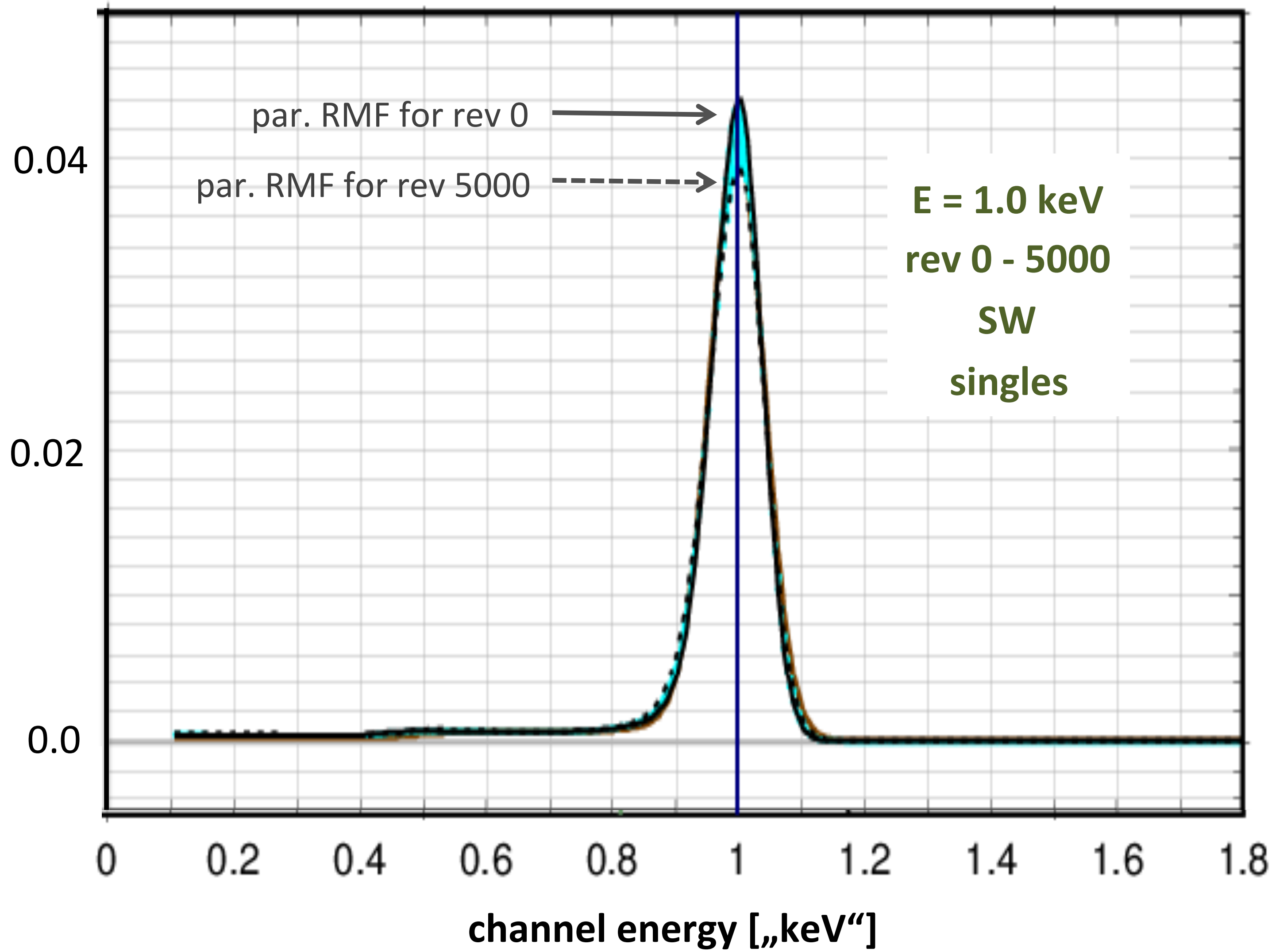
What has changed in the RMF ?



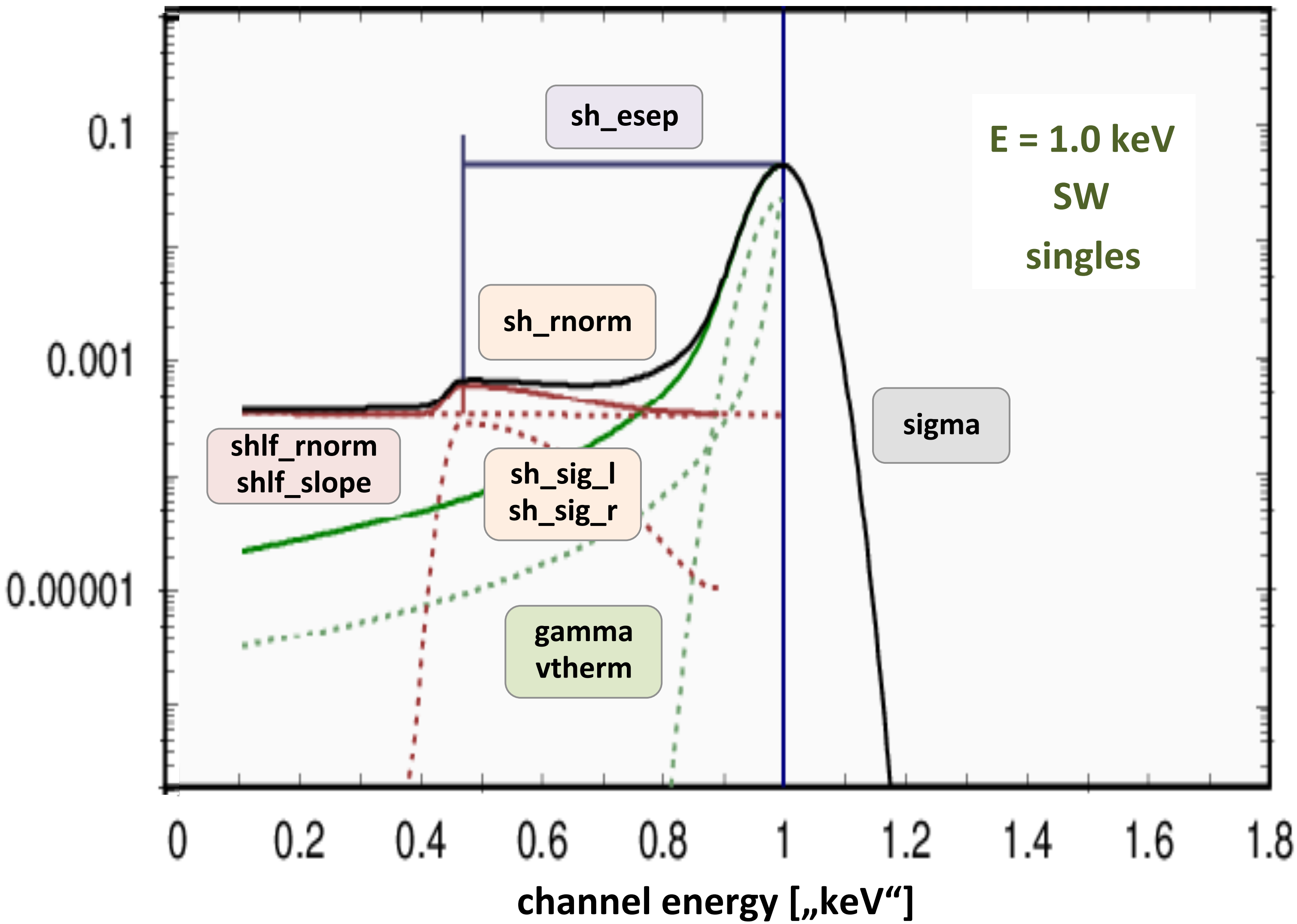
What has changed in the RMF ?



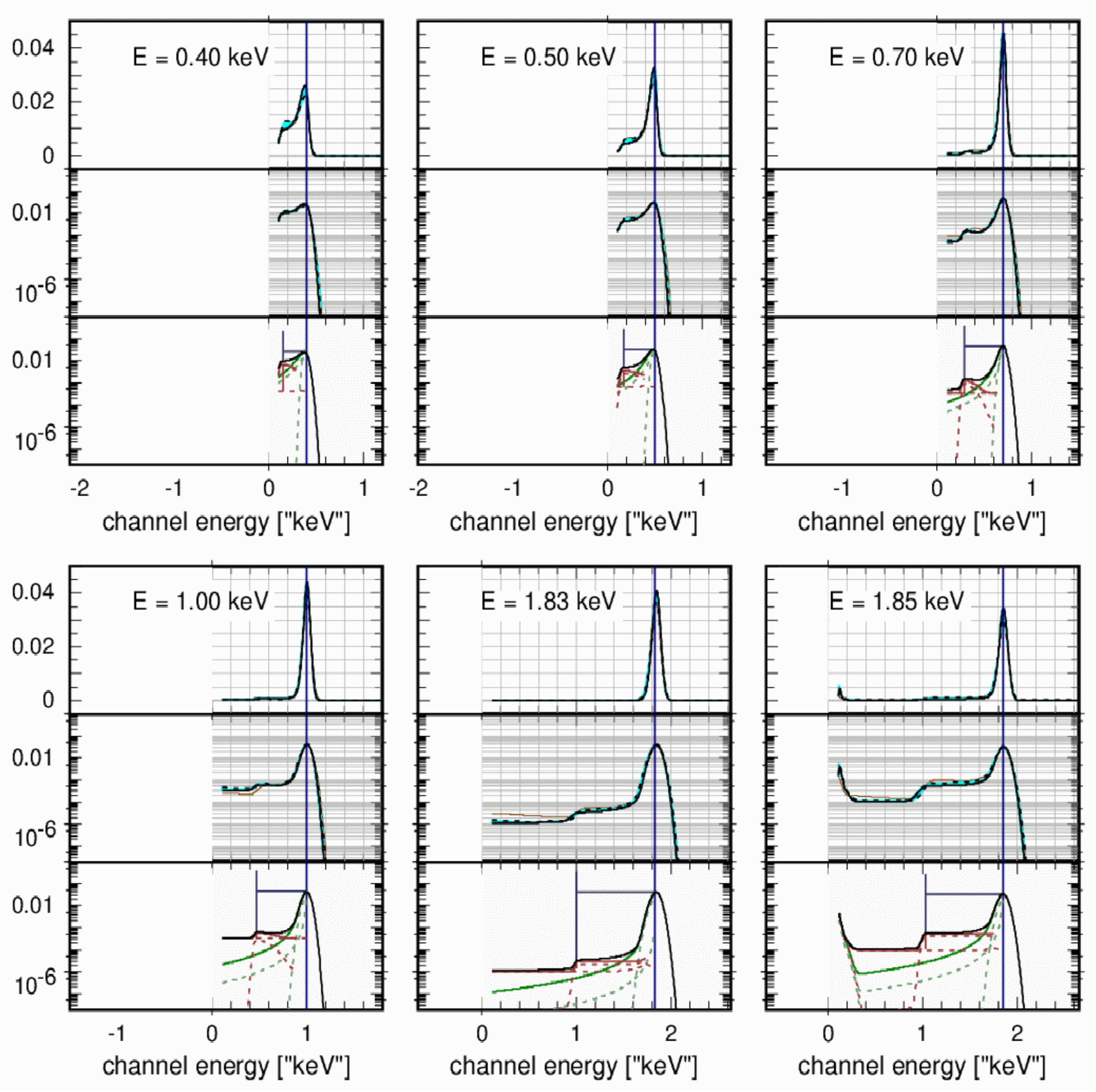
Temporal trend in the parameterized RMF



Composition of the parameterized RMF



Parameterized RMF from 0.40 – 1.85 keV



Current status

With the current RMF and ARF adjustments it is now possible to fit simultaneously the spectra of **RXJ1856** and **1E0102** obtained with **all three EPIC pn filters** in **all revolutions** in SW mode **without any renormalization between the filters**, and using the **unmodified Chandra LETG spectral parameters** for RXJ 1856. The ARF adjustment requires only a slight increase of the oxygen thickness (with the same value for all filters).

Current restrictions:

- only **soft** (< 2 keV) spectra used (to avoid complications with photon escape)
- only **SW** mode spectra analysed (excellent photon statistics, negligible pile-up)
- only **single pixel events** used (to avoid complications with split charges(

Extensions needed:

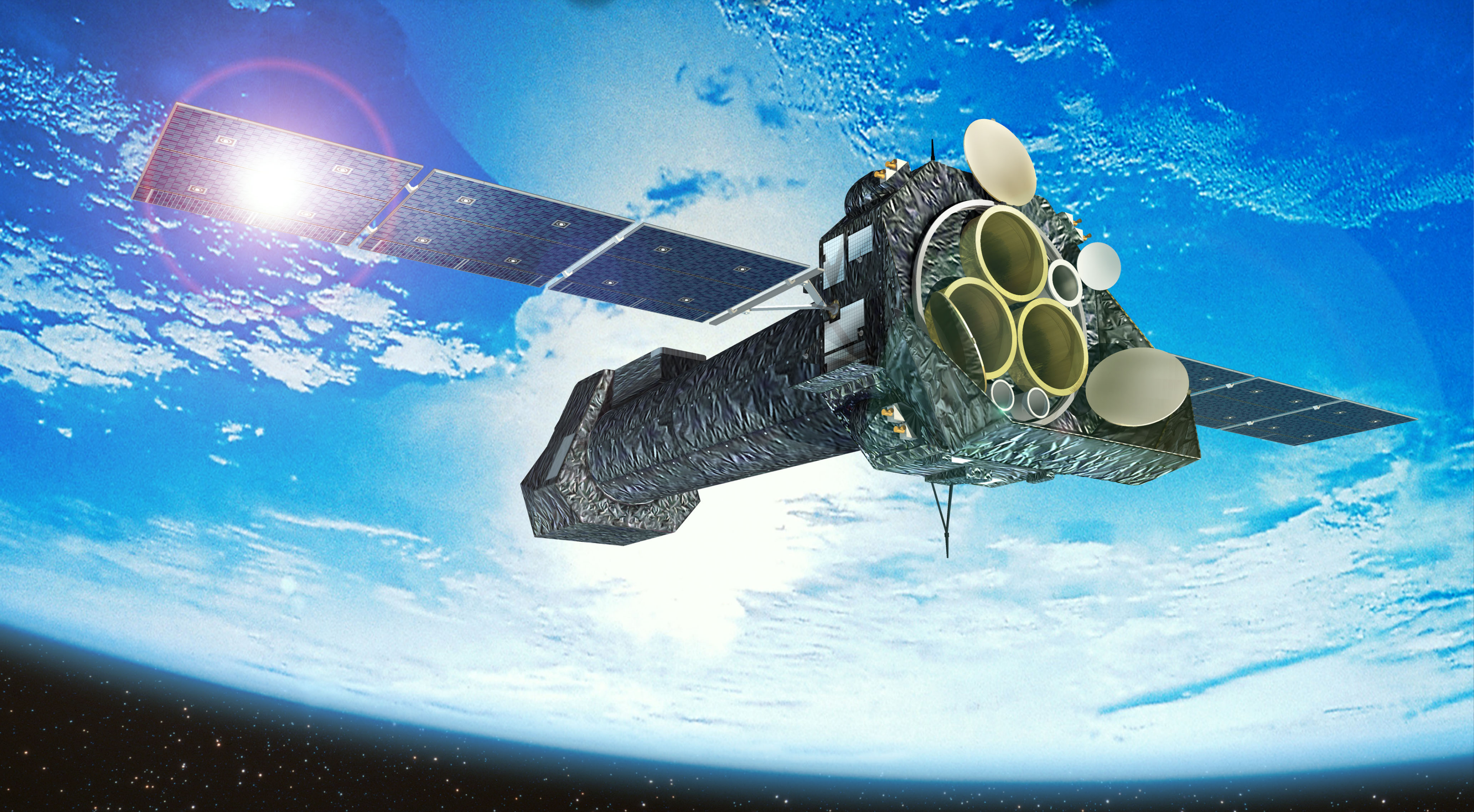
- full spectral range
- other readout modes: FF, eFF, LW, TI, BU
- double pixel events

Scientific by-product of the RMF parameterization:

Spectral monitoring of RX J1856.5-3754 with XMM-Newton / EPIC-pn

- discrepancy with Chandra LETG solved
- no necessity to introduce a second black body
- no obvious long-term trend
- evidence for sporadic spectral changes

EPIC-pn RMF and ARF Improvement: Modelling temporal changes



Konrad Dennerl - Max Planck Institute for extraterrestrial Physics – Garching - Germany