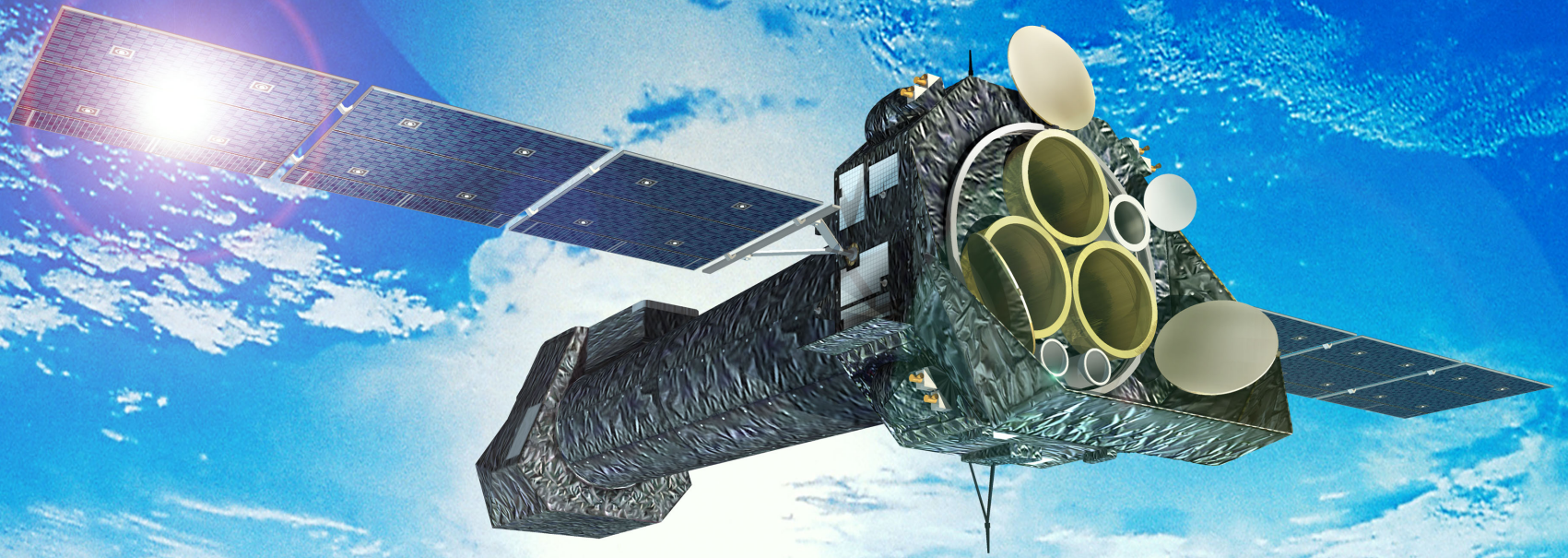


# An empirical method for improving the XMM-Newton/EPIC-pn RMF and ARFs

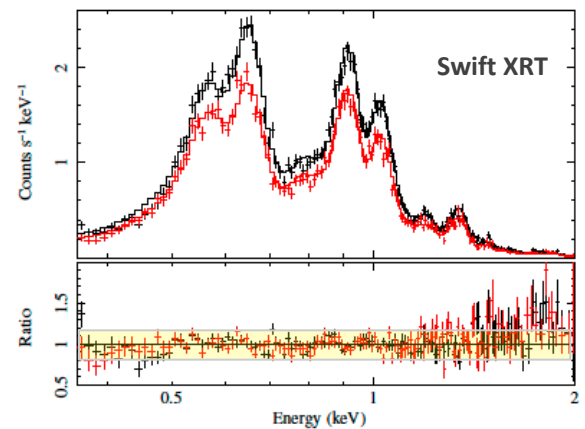
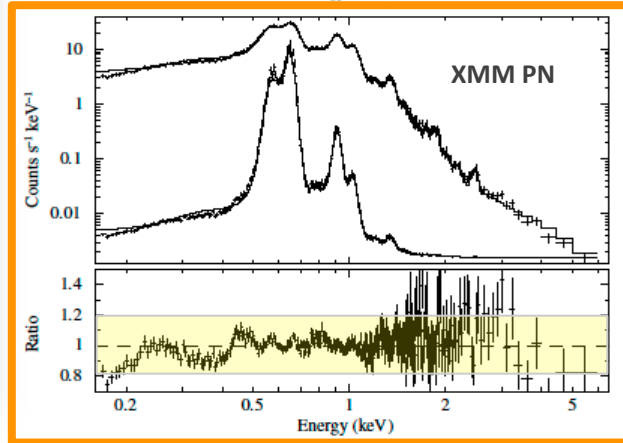
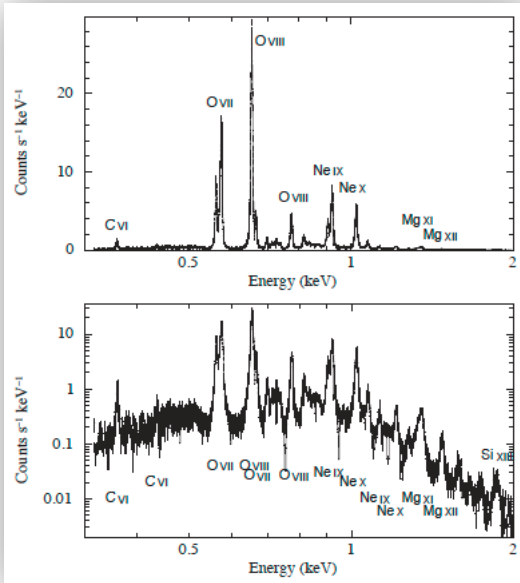
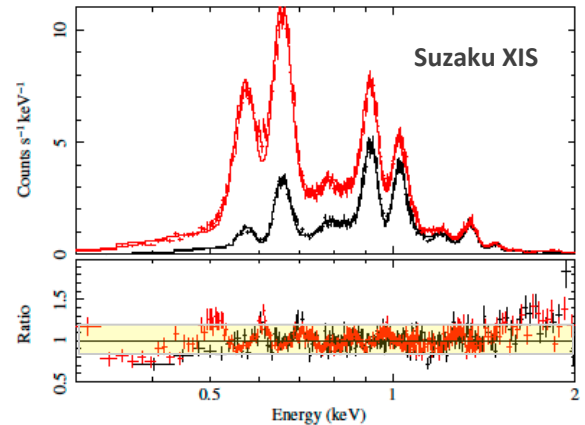
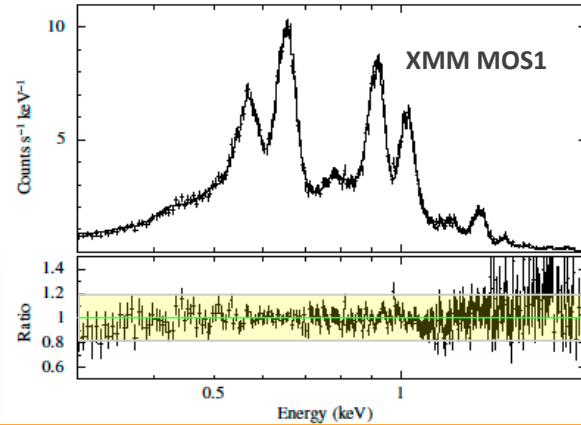
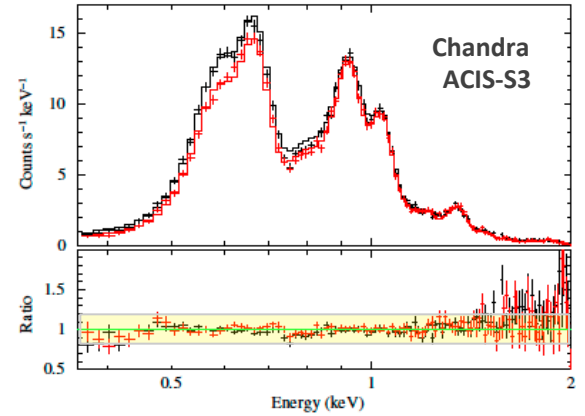
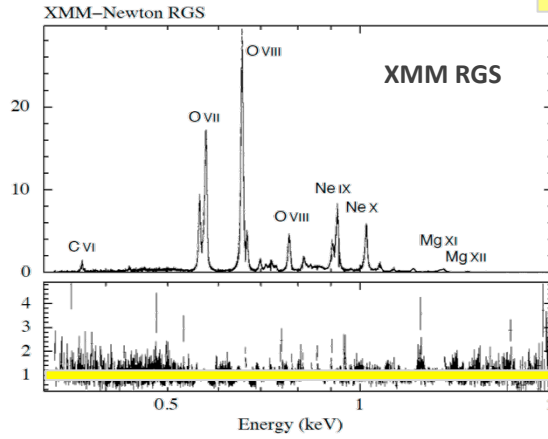
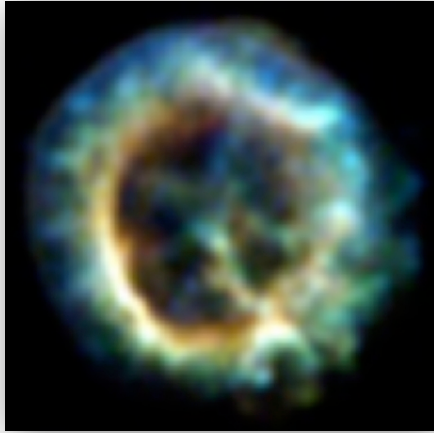




$\pm 20\%$

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<sup>1</sup>, Andrew P. Beardmore<sup>2</sup>, Adam Foster<sup>1</sup>, Frank Haber<sup>3</sup>,  
Eric D. Miller<sup>4</sup>, Andrew M. T. Pollock<sup>5</sup>, and Steve Sembay<sup>2</sup>

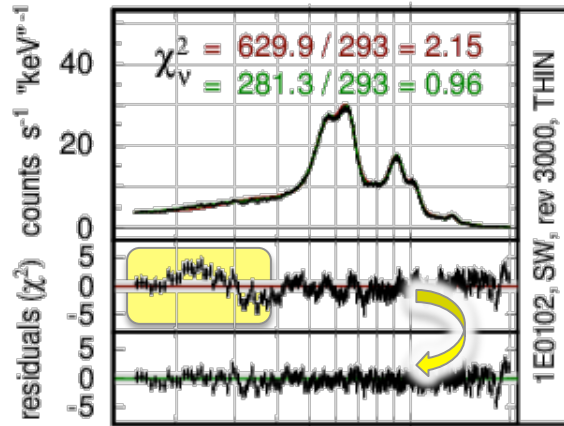
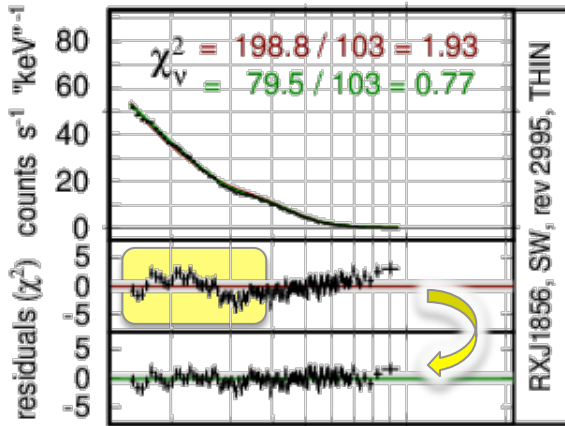


# Warning: ARF adjustments alone may be dangerous !

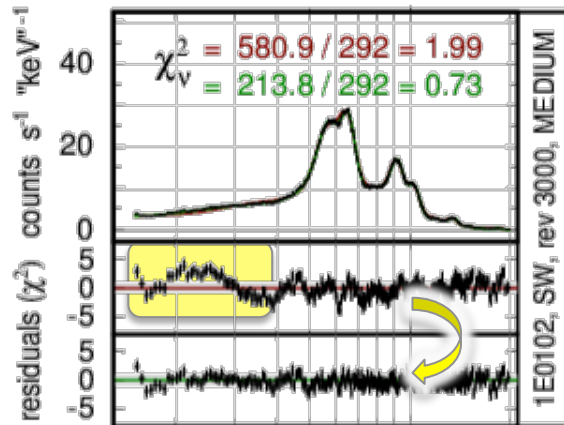
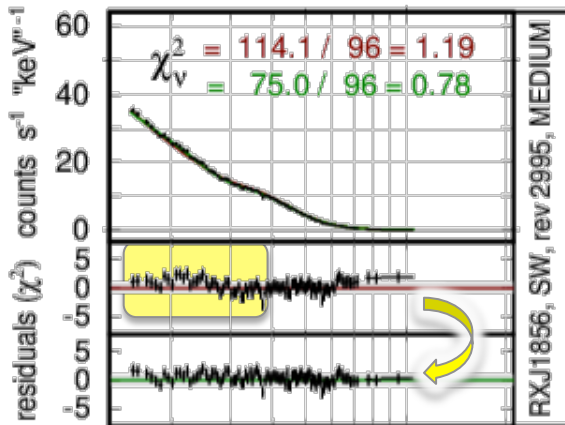
**Example:** XMM/EPIC-pn, simultaneous fit to RXJ 1856 and 1E0102 in three filters each, using the same model spectrum for each source, with no normalization between the filters

RXJ 1856

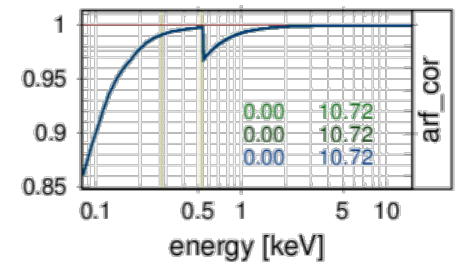
1E 0102



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

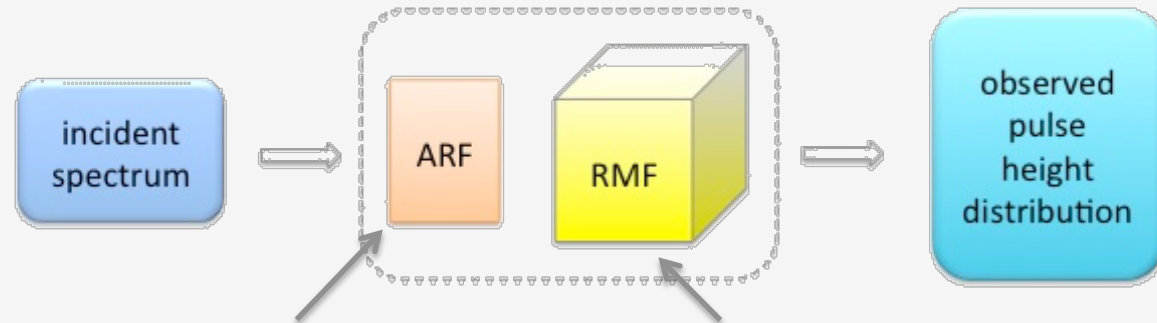


Work on the RMF refinement, however, suggests to **increase the redistribution** and to **decrease the ARF** at low energies !



# General properties of the ARF and RMF

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



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

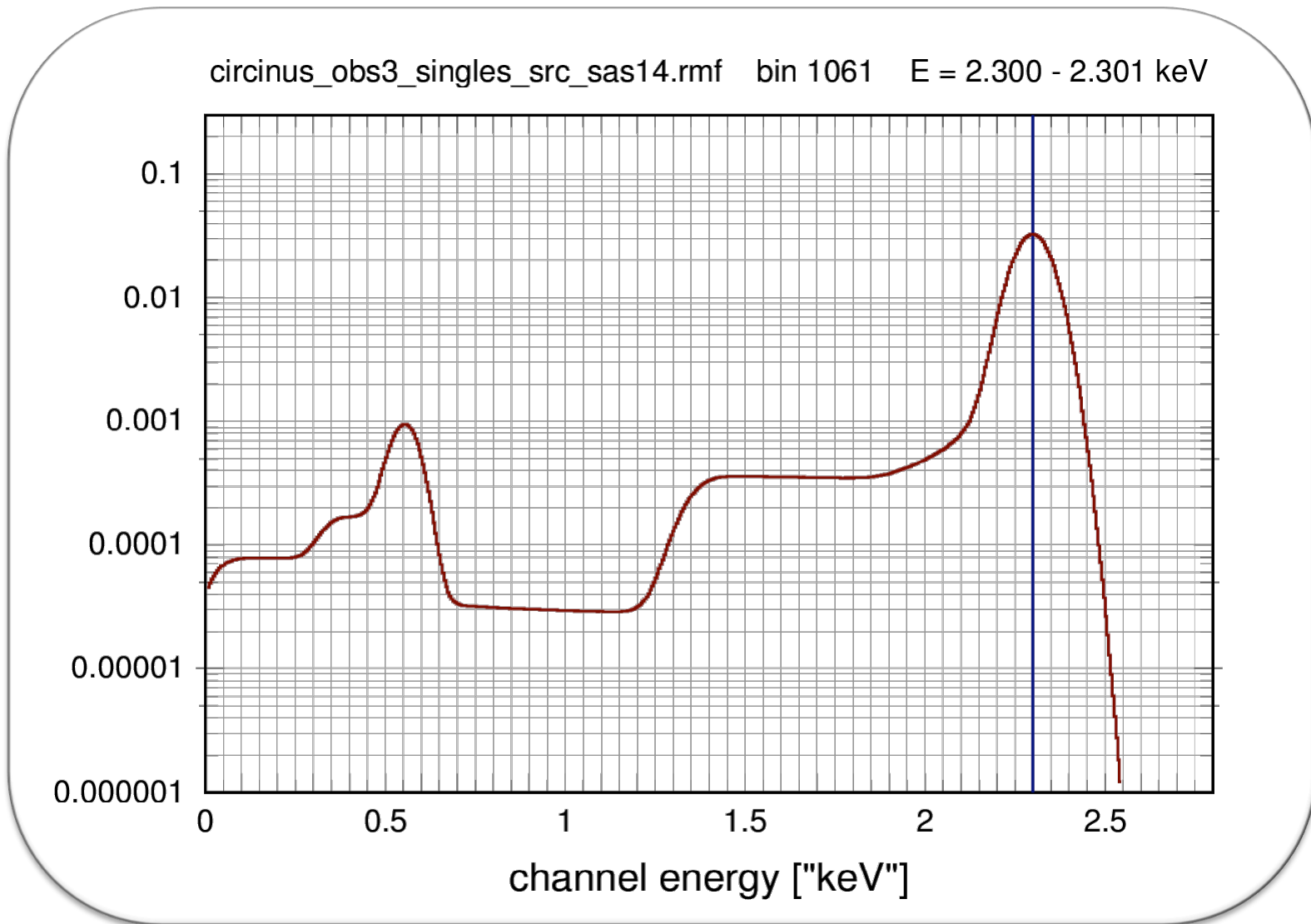
RMF @ EPIC pn: 4096 adu bins from 0.0 to 20.5 ,keV' („EBOUNDS“)  
   2067 eV bins from 50 eV to 16 keV

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

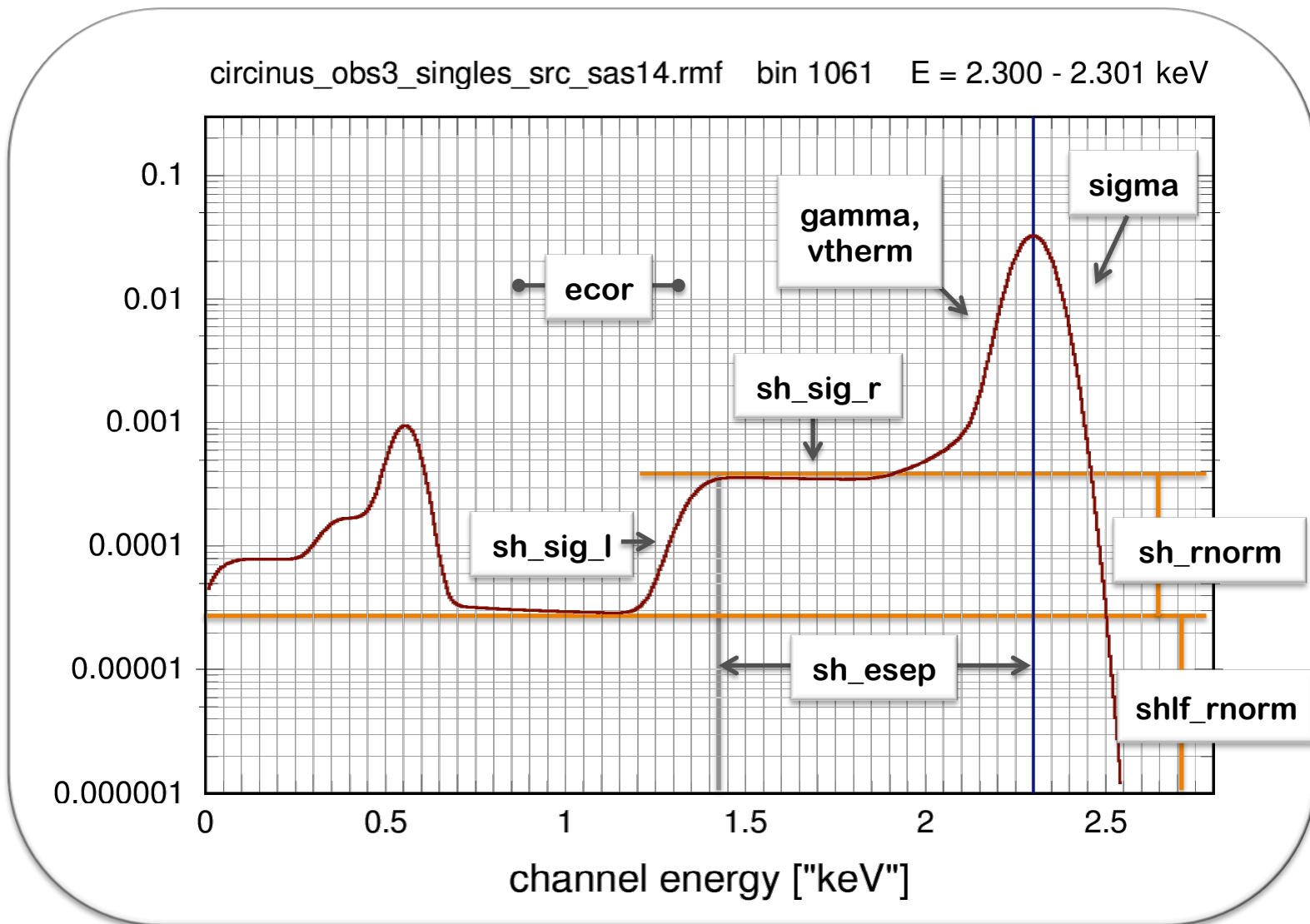
→ find appropriate RMF parameterization and try to optimize it..



# Model Parameters for the EPIC pn RMF

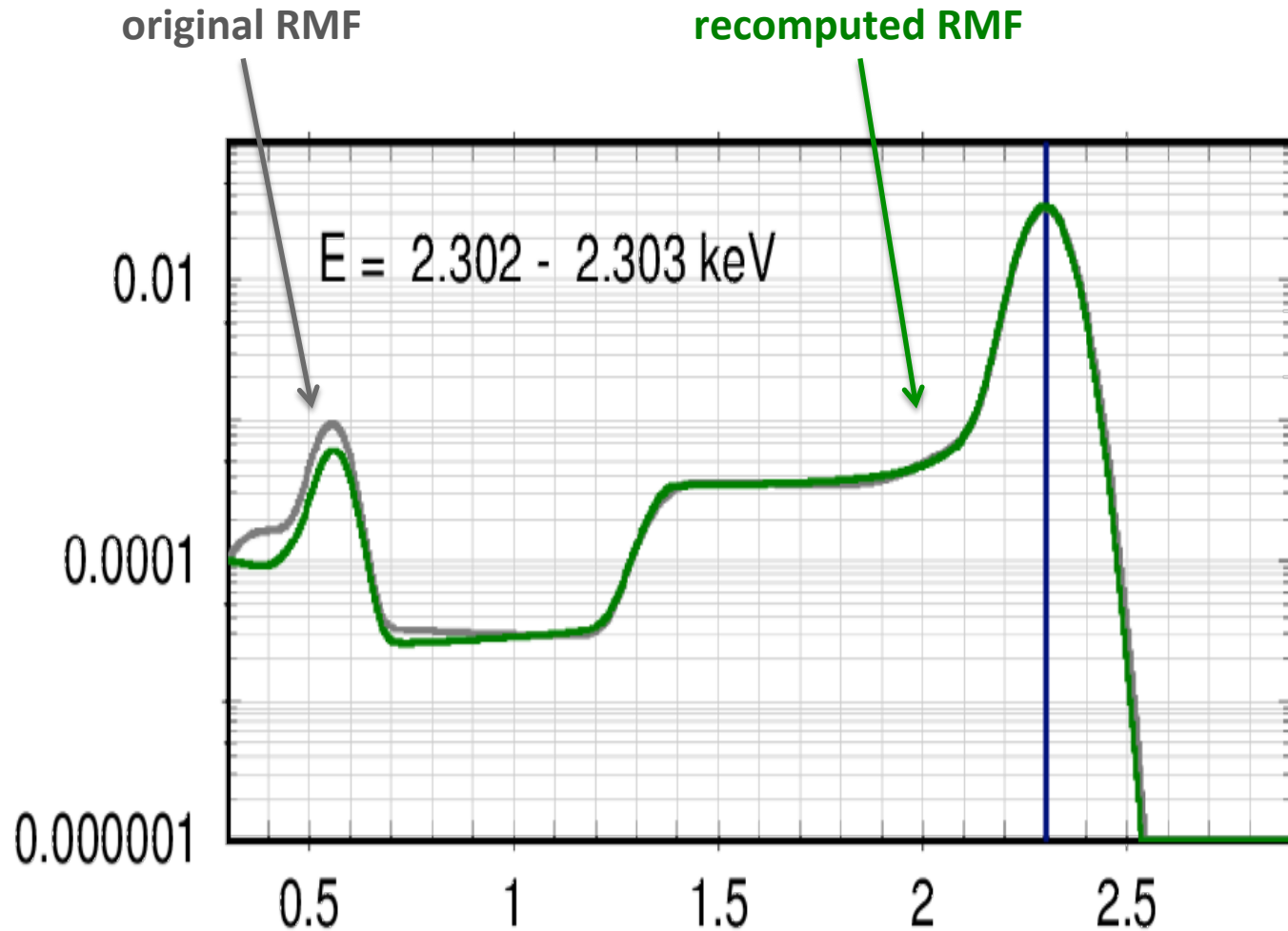


# Model Parameters for the EPIC pn RMF

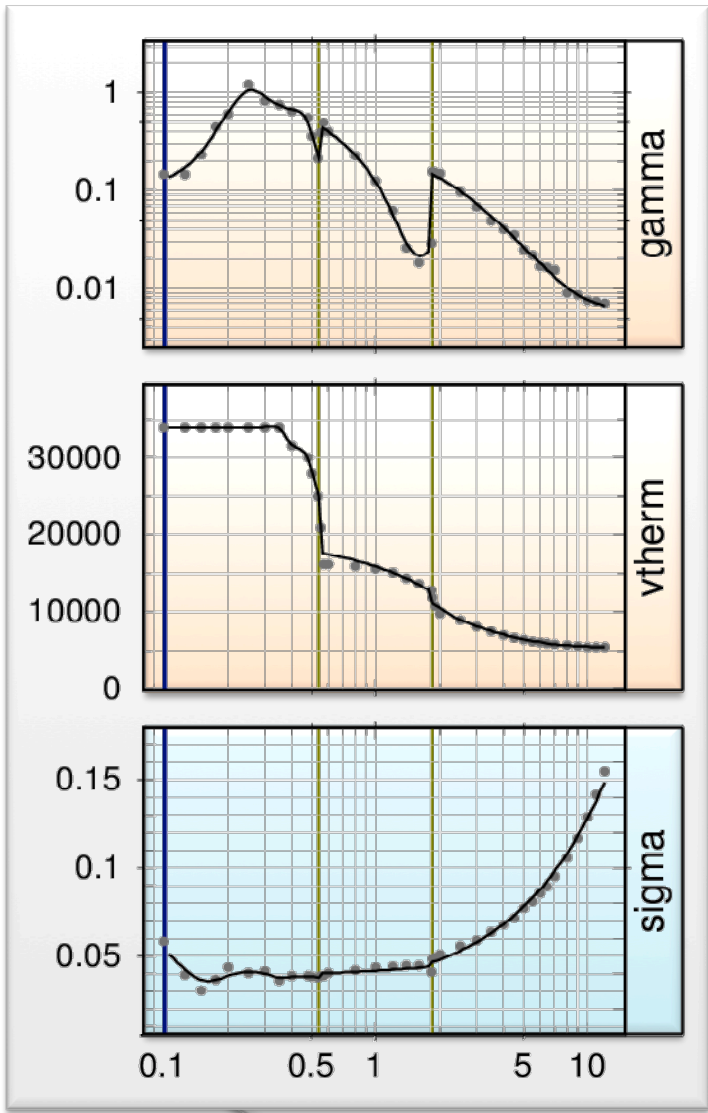




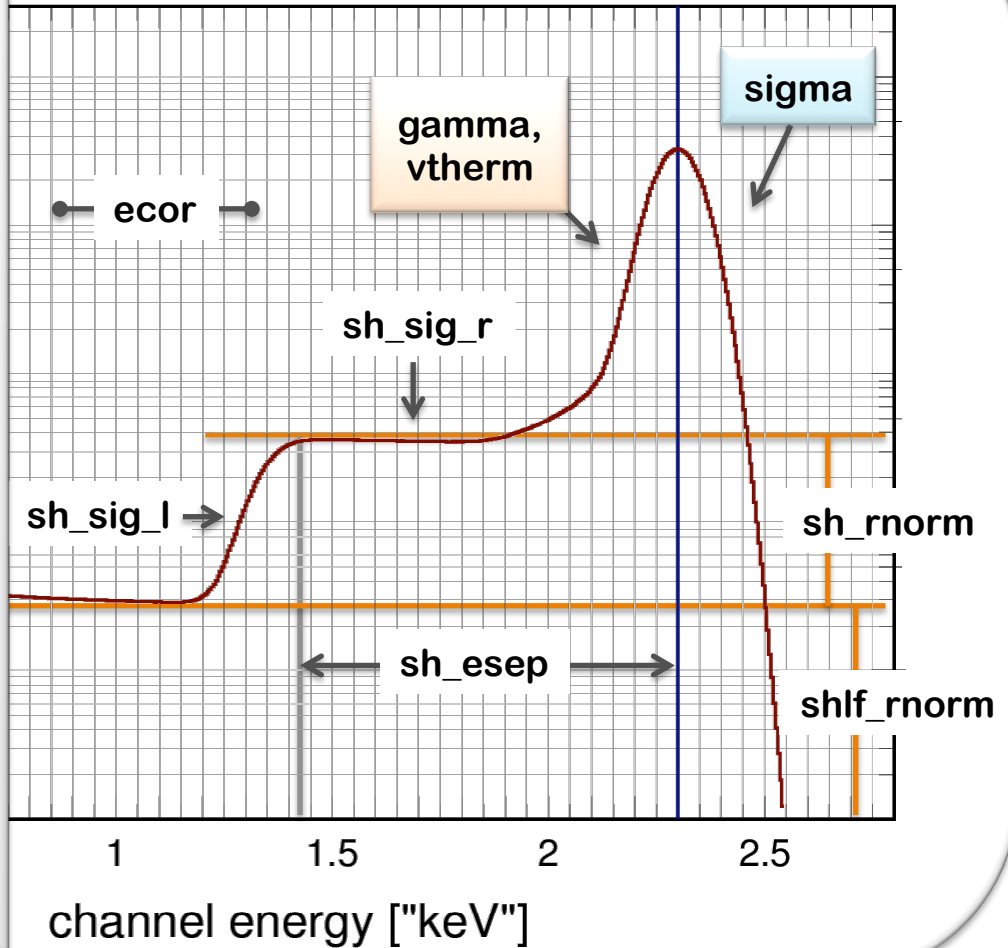
# Comparison: original and recomputed RMF @ 2.3 keV



# Modeling the EPIC pn RMF at individual energies

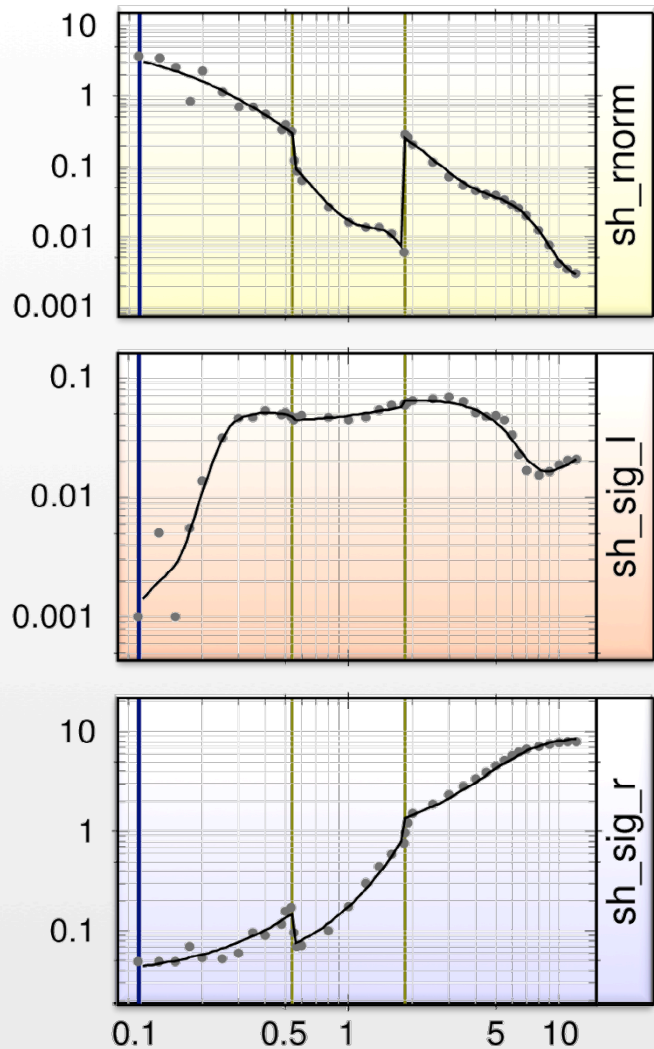


es\_src\_sas14.rmf bin 1061 E = 2.300 - 2.301 keV

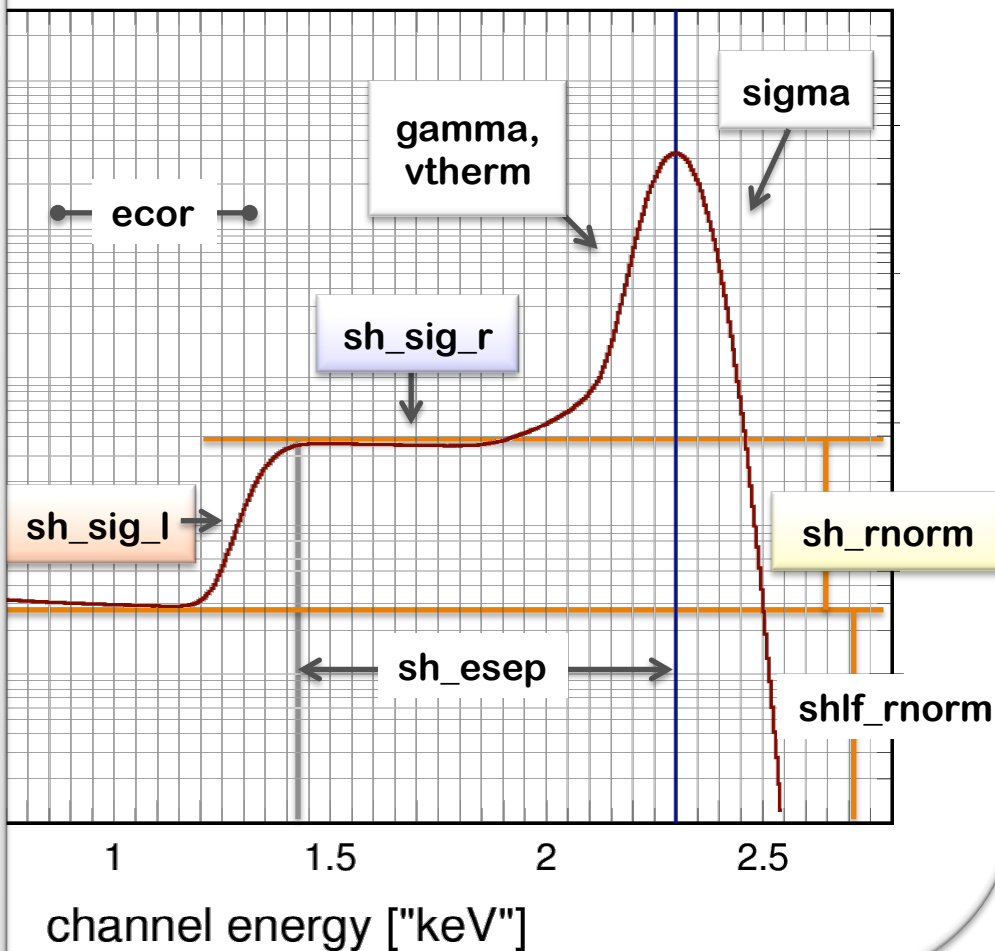




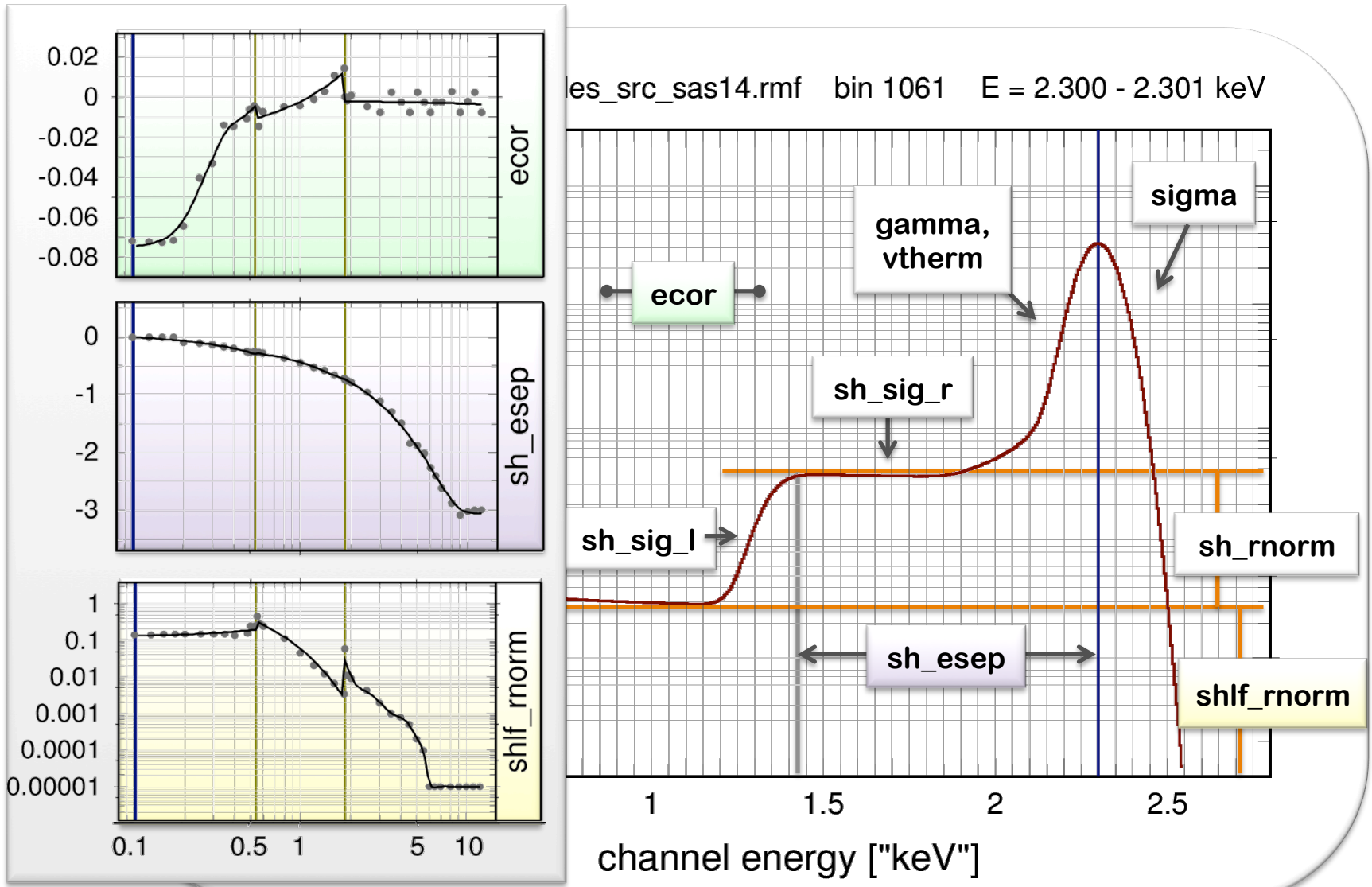
# Modeling the EPIC pn RMF at individual energies



es\_src\_sas14.rmf bin 1061 E = 2.300 - 2.301 keV



# Modeling the EPIC pn RMF at individual energies





# RMF refinement method

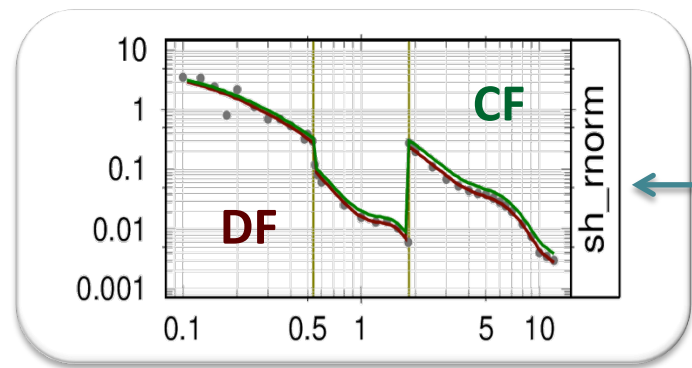
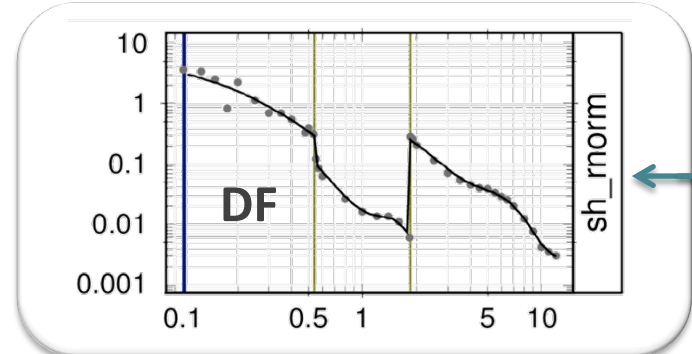
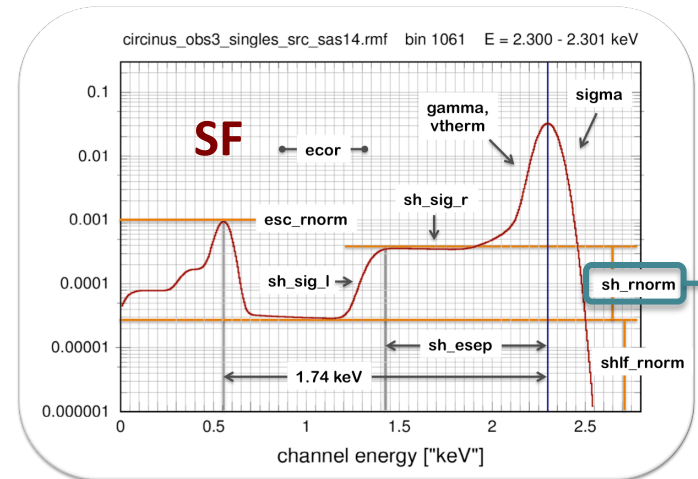
(ARF refinement comparatively trivial)

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

- **main peak**:  $\gamma$ ,  $v_{therm}$ ,  $\sigma$
- **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.



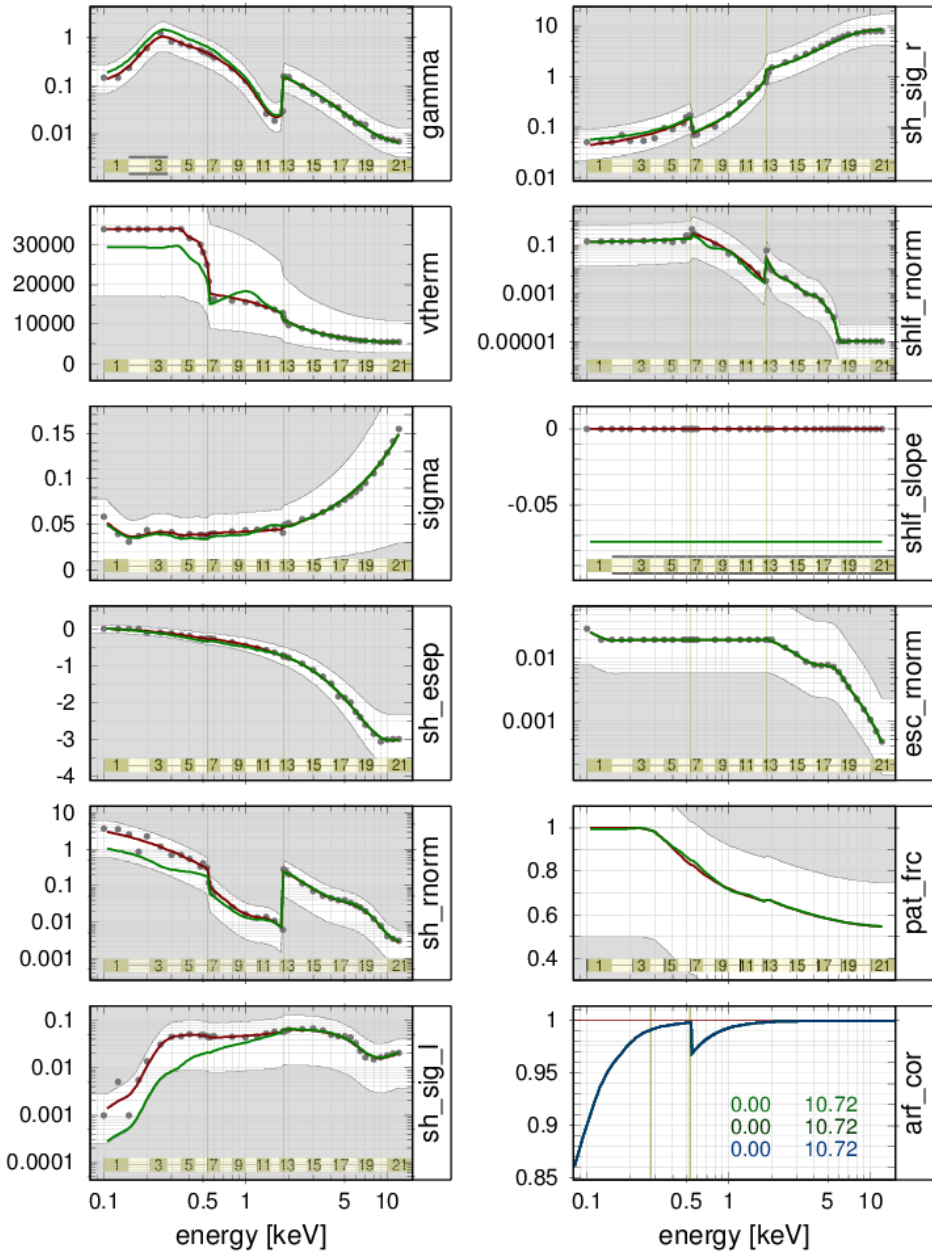
# RMF refinement method

**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<sub>1</sub>**, with 4 of them free + **gain offset**
    - RXJ 1856: **3 model parameters MP<sub>2</sub>**, 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



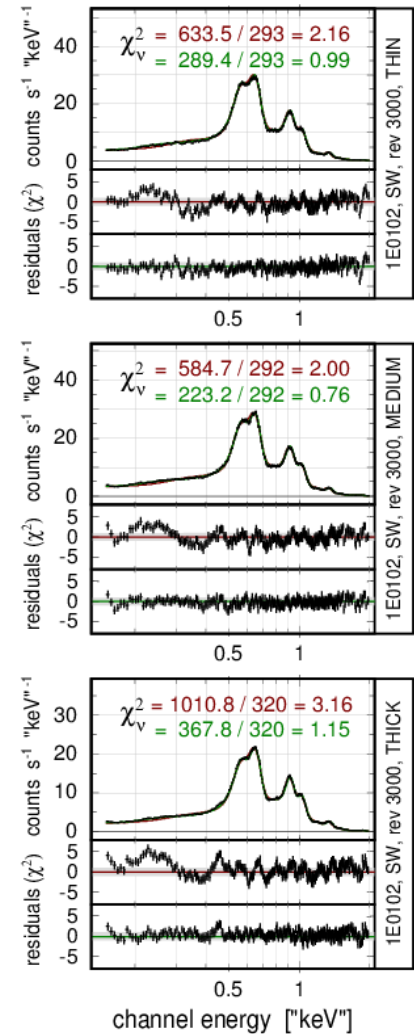
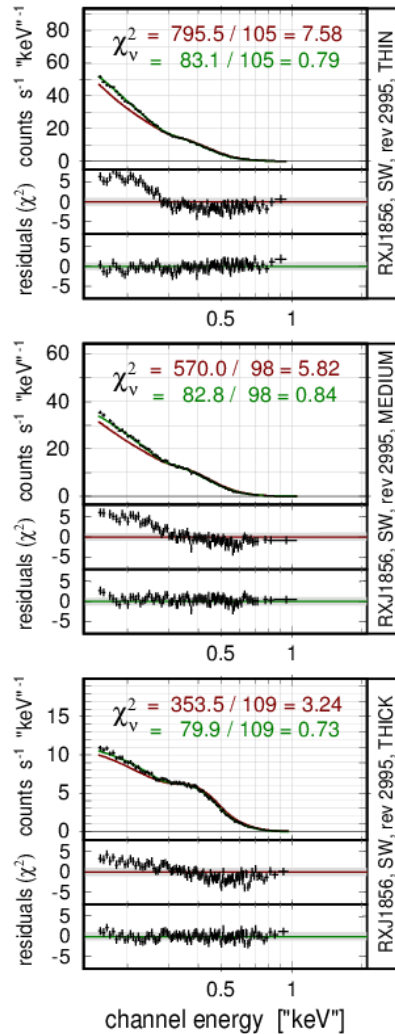
RXJ 1856

1E 0102

**Chandra**  
**LETG**

gain: offset = -2.1 eV  
 $n_H == 7.25 \times 10^{19} \text{ cm}^{-2}$   
 $kT == 62.4 \text{ eV}$   
 $norm == 1.58 \times 10^5$

constant: factor = 0.939  
 gaussian: norm = 0.143E-02  
 gaussian: norm = 0.139E-02  
 gaussian: norm = 0.433E-02  
 gain: offset = +1.7 eV



thin

medium

thick

# Status @ IACHEC-2018

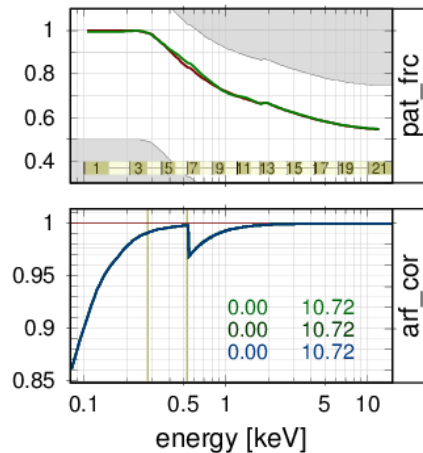
## ARF correction

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 (!)



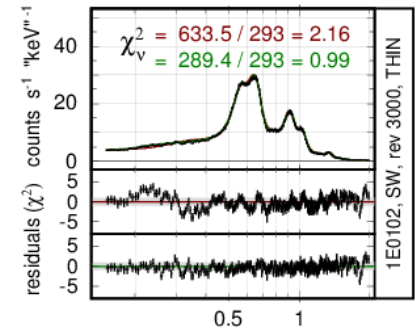
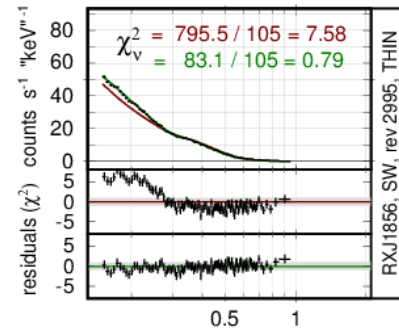
RXJ 1856

1E 0102

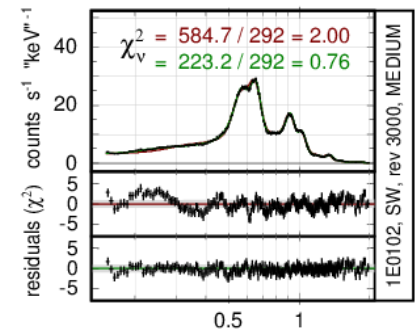
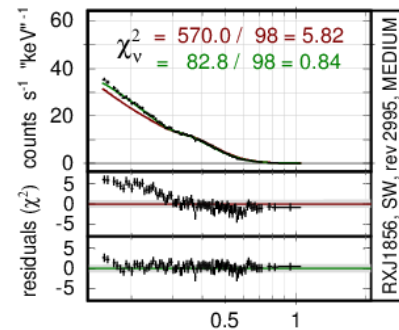
Chandra  
LETG

gain: offset = -2.1 eV  
 $n_H == 7.25 \times 10^{19} \text{ cm}^{-2}$   
 $kT == 62.4 \text{ eV}$   
 $norm == 1.58 \times 10^5$

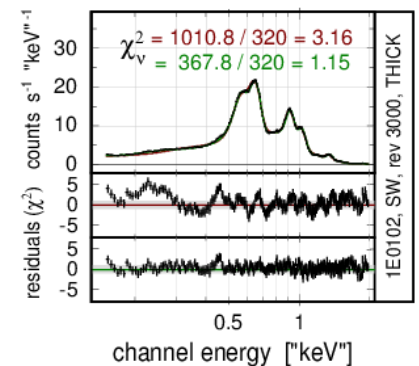
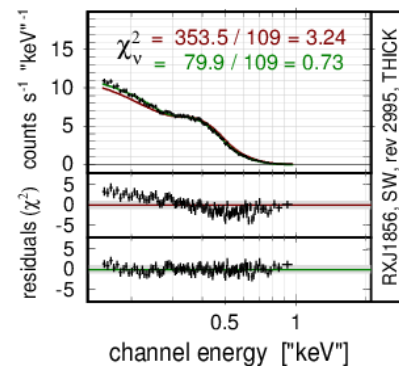
constant: factor = 0.939  
 gaussian: norm = 0.143E-02  
 gaussian: norm = 0.139E-02  
 gaussian: norm = 0.433E-02  
 gain: offset = +1.7 eV



thin



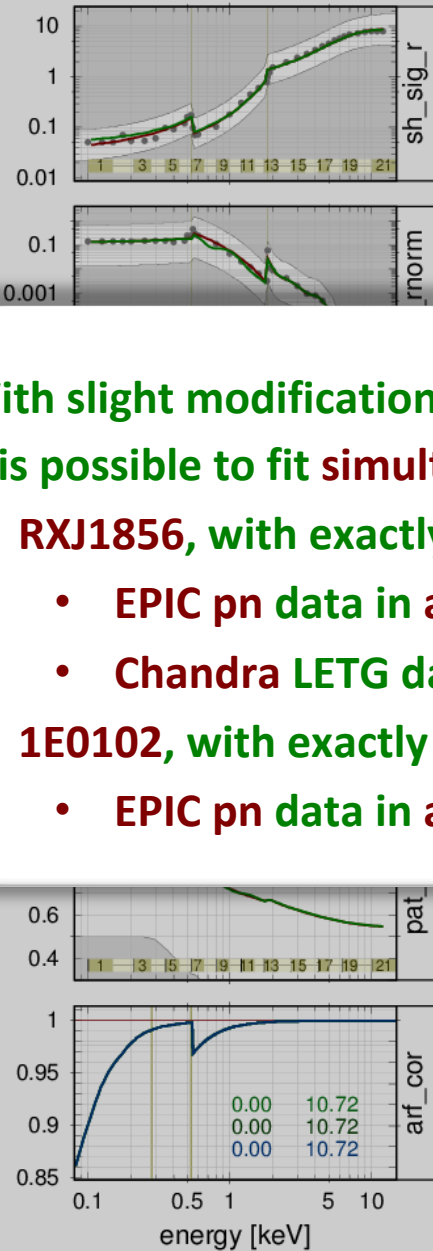
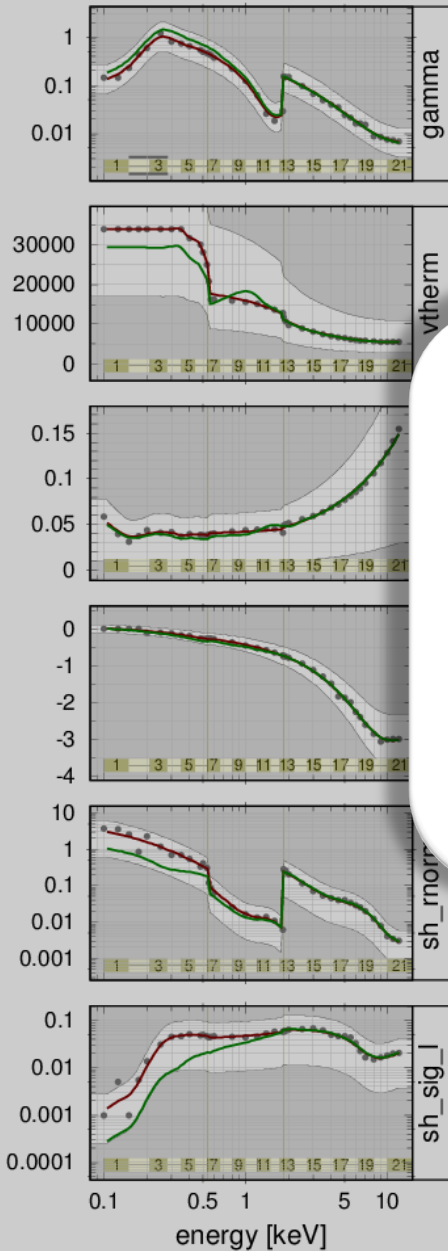
medium



thick



# Status @ IACHEC-2018



Chandra  
LETG

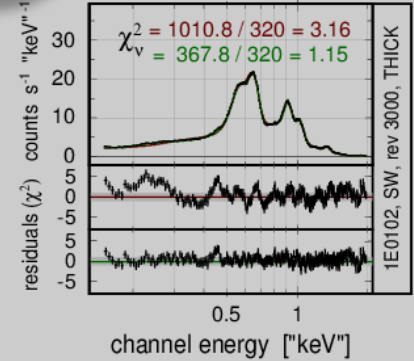
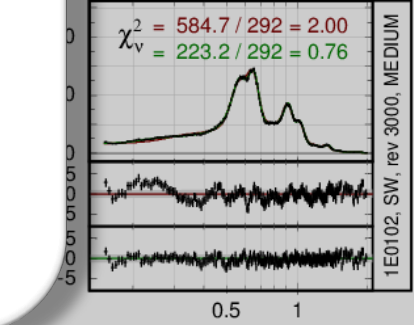
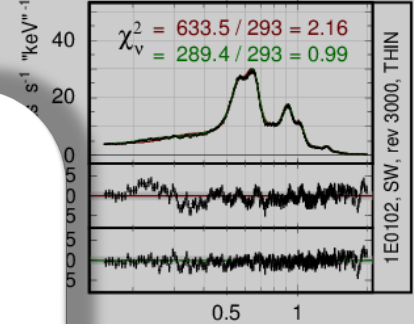
gain: offset = -2.1 eV  
 $n_H == 7.25 \times 10^{19} \text{ cm}^{-2}$   
 $kT == 62.4 \text{ eV}$   
 $norm == 1.58 \times 10^5$

$\chi^2_v = 795.5 / 105 = 7.58$   
 $= 83.1 / 105 = 0.79$

RXJ 1856

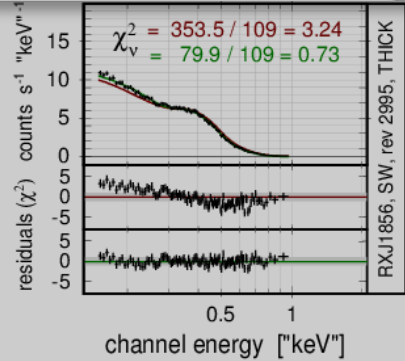
1E 0102

constant: factor = 0.939  
 gaussian: norm = 0.143E-02  
 gaussian: norm = 0.139E-02  
 gaussian: norm = 0.433E-02  
 gain: offset = +1.7 eV



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



thin

medium

thick

# 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!)

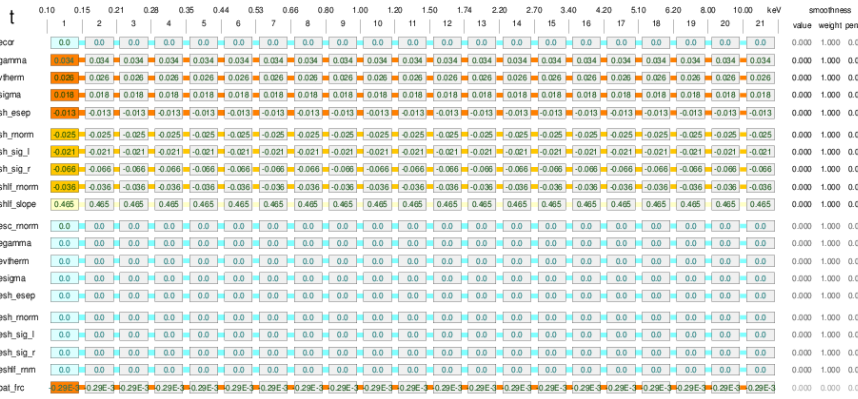
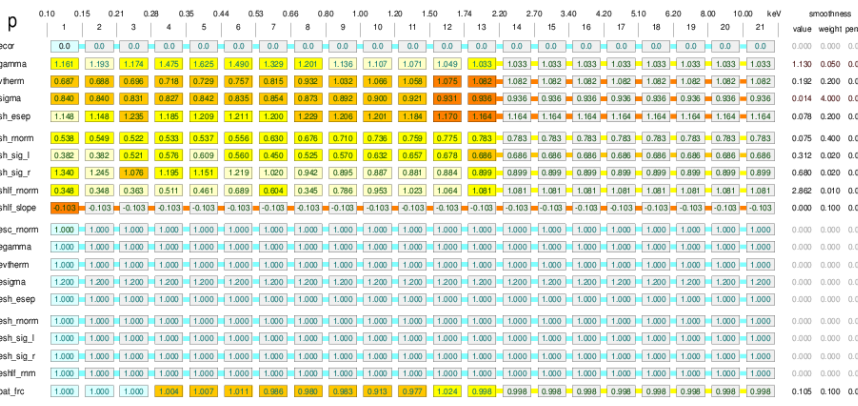
→ **major restructuring of the program**  
(also opportunity to clean the code)

→ ≈ 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 thermal RMF changes: sample output

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



parameter constraints:

parameter	p	t
ecor	[rel: 1.00 - 0.02, ref: 1.00 + 0.02]	[rel: 0.00 - 0.05, ref: 0.00 + 0.05]
gamma	[rel: 0.50 - 0.02, ref: 1.00 + 0.02]	[rel: 0.00 - 0.05, ref: 0.00 + 0.05]
vtherm	[rel: 0.50 - 0.00, ref: 1.10 + 0.00]	[rel: 0.00 - 0.05, ref: 0.00 + 0.05]
sigma	[rel: 0.70 - 0.00, ref: 1.00 + 0.00]	[rel: 0.00 - 0.05, ref: 0.00 + 0.05]
sh_skep	[rel: 0.50 - 0.10, ref: 1.20 + 0.00]	[rel: 0.00 - 0.05, ref: 0.00 + 0.05]
sh_sig_l	[rel: 0.50 - 0.01, ref: 1.50 + 0.00]	[rel: 0.00 - 0.05, ref: 0.00 + 0.05]
sh_sig_r	[rel: 0.40 - 0.00, ref: 2.00 + 0.00]	[rel: 0.00 - 0.05, ref: 0.00 + 0.05]
shl_norm	[rel: 0.50 - 0.00, ref: 1.00 + 0.00]	[rel: 0.00 - 0.05, ref: 0.00 + 0.05]
shl_slope	[rel: 1.00 - 0.30, ref: 1.00 + 0.30]	[rel: 0.00 - 0.05, ref: 0.00 + 0.05]
esc_norm	[rel: 0.30 - 0.00, ref: 5.00 + 0.00]	[rel: 0.00 - 0.05, ref: 0.00 + 0.05]
egamma	[rel: 0.01 - 0.00, ref: 2.00 + 0.00]	[rel: 0.00 - 0.05, ref: 0.00 + 0.05]
evtherm	[rel: 0.50 - 0.00, ref: 2.00 + 0.00]	[rel: 0.00 - 0.05, ref: 0.00 + 0.05]
esigma	[rel: 0.50 - 0.00, ref: 2.00 + 0.00]	[rel: 0.00 - 0.05, ref: 0.00 + 0.05]
esh_skep	[rel: 0.80 - 0.00, ref: 1.20 + 0.00]	[rel: 0.00 - 0.05, ref: 0.00 + 0.05]
esh_norm	[rel: 0.50 - 0.00, ref: 2.00 + 0.00]	[rel: 0.00 - 0.05, ref: 0.00 + 0.05]
esh_sig_l	[rel: 0.08 - 0.00, ref: 2.00 + 0.00]	[rel: 0.00 - 0.05, ref: 0.00 + 0.05]
esh_sig_r	[rel: 0.50 - 0.00, ref: 2.00 + 0.00]	[rel: 0.00 - 0.05, ref: 0.00 + 0.05]
eshl_norm	[rel: 0.10 - 0.00, ref: 5.00 + 0.00]	[rel: 0.00 - 0.05, ref: 0.00 + 0.05]
pat_rc	[rel: 1.00 - 0.10, ref: 1.00 + 0.10]	[rel: 0.00 - 0.05, ref: 0.00 + 0.00]
chi_cor	[rel: 0.01 - 1.00, ref: 10.00 + 1.00]	[rel: 0.00 - 0.05, ref: 0.00 + 0.05]
ecor	[rel: 0.01 - 1.00, ref: 10.00 + 1.00]	[rel: 0.00 - 0.05, ref: 0.00 + 0.05]

1e0102 spectra:

rev	chid	SW	Th
1	1e0102rev_0375	P01357280PN01	SW Th1
2	1e0102rev_0521	P01357210PN01	SW Th1
3	1e0102rev_0552	P01357210PN01	SW Th1
4	1e0102rev_0619	P01357240PN02	SW Th1
5	1e0102rev_0801	P01357200PN01	SW Medium
6	1e0102rev_0818	P01357280PN01	SW Medium
7	1e0102rev_1165	P01357270PN01	SW Medium
8	1e0102rev_1265	P04128010PN01	SW Th1
9	1e0102rev_1511	P04128010PN01	SW Th1
10	1e0102rev_1431	P04128030PN01	SW Medium
11	1e0102rev_1543	P04128050PN01	SW Th1
12	1e0102rev_1837	P04128010PN01	SW Medium
13	1e0102rev_1711	P04128010PN01	SW Th1
14	1e0102rev_1878	P04128060PN01	SW Th1
15	1e0102rev_1888	P04128010PN01	SW Th1
16	1e0102rev_2065	P04128040PN01	SW Th1
17	1e0102rev_2304	P04128010PN01	SW Th1
18	1e0102rev_2309	P04128010PN12	SW Th1
19	1e0102rev_2300	P04128010PN13	SW Th1
20	1e0102rev_2568	P04128010PN01	SW Th1
21	1e0102rev_2722	P04128020PN01	SW Medium
22	1e0102rev_2729	P04128020PN01	SW Medium
23	1e0102rev_3003	P04128010PN01	SW Th1
24	1e0102rev_3004	P04128010PN01	SW Th1
25	1e0102rev_3006	P09158000PN01	SW Medium
26	1e0102rev_3007	P09158000PN01	SW Medium
27	1e0102rev_3008	P09158000PN01	SW Th1
28	1e0102rev_3009	P09158000PN01	SW Th1
29	1e0102rev_3010	P09158000PN01	SW Th1
30	1e0102rev_3032	P04128020PN01	SW Medium
31	1e0102rev_3111	P04128030PN01	SW Th1
32	1e0102rev_3278	P04128030PN01	SW Medium
33	1e0102rev_3279	P04128030PN01	SW Medium

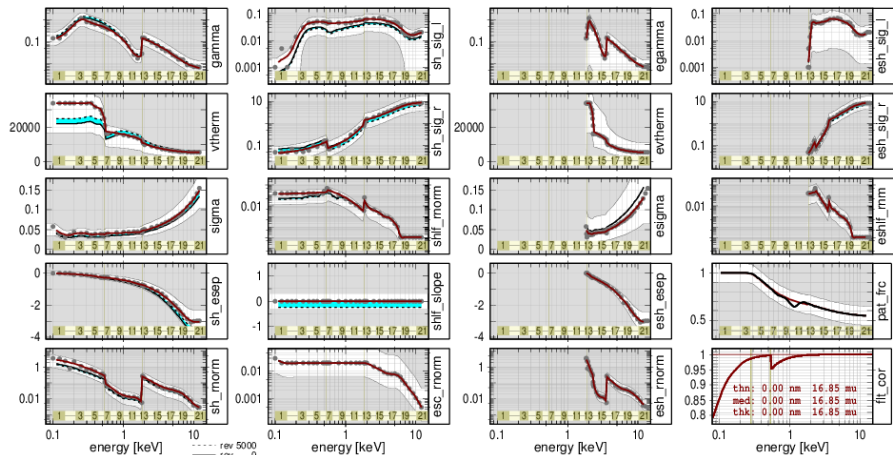
rxj1856 spectra:

rev	chid	SW	Th
1	rxj1856rev_0427	P01026010PN01	SW Th1
2	rxj1856rev_0521	P01026010PN01	SW Th1
3	rxj1856rev_0988	P01026010PN01	SW Th1
4	rxj1856rev_1031	P01026010PN01	SW Th1
5	rxj1856rev_1058	P01026010PN01	SW Th1
6	rxj1856rev_1258	P01026010PN01	SW Th1
7	rxj1856rev_1330	P04126020PN02	SW Th1
8	rxj1856rev_1335	P04158010PN01	SW Th1
9	rxj1856rev_1424	P04126020PN01	SW Th1
10	rxj1856rev_1432	P04126020PN02	SW Th1
11	rxj1856rev_1513	P04126040PN02	SW Th1
12	rxj1856rev_1616	P04126060PN02	SW Th1
13	rxj1856rev_1696	P04126070PN02	SW Th1
14	rxj1856rev_1800	P04126010PN02	SW Th1
15	rxj1856rev_1879	P04126010PN02	SW Th1
16	rxj1856rev_1916	P04126010PN03	SW Th1
17	rxj1856rev_2054	P04126010PN03	SW Th1
18	rxj1856rev_2165	P04126010PN02	SW Th1
19	rxj1856rev_2159	P04126020PN03	SW Th1
20	rxj1856rev_2241	P04126020PN03	SW Th1
21	rxj1856rev_2321	P02776010PN01	SW Th1
22	rxj1856rev_2318	P02776020PN01	SW Th1
23	rxj1856rev_2307	P02776030PN01	SW Th1
24	rxj1856rev_2374	P02776040PN01	SW Th1
25	rxj1856rev_2796	P02776050PN01	SW Th1
26	rxj1856rev_2977	P02776060PN01	SW Th1
27	rxj1856rev_2975	P02776070PN01	SW Th1
28	rxj1856rev_2986	P02776080PN01	SW Th1
29	rxj1856rev_3075	P0277610PN01	SW Th1
30	rxj1856rev_3162	P0277611PN01	SW Th1
31	rxj1856rev_3355	P0277612PN01	SW Th1

object: 1e0102(33)  
 modeid: home/iod/data/1epic/RMF/FT/rtms/wal/  
 dname: home/iod/data/1epic/RMF/FT/rtms/wal/  
 wname: home/iod/data/epic/RMF/FT/rtms/wal/1/  
 spectral mode:  
 1e0102: mode1=rgp,mod\_babs\_bvabsa\_2psec\_line\_ratio\_v1\_xcm  
 rxj1856: mode=3,rv=856,mod\_bbody\_xcm  
 function used for evaluating the shaping parameters: vahave\_25  
 XMM reference revolution: rev 2000  
 level: -10 th\_low = 0.10E-5 th\_high = -20 th\_high = -0.001

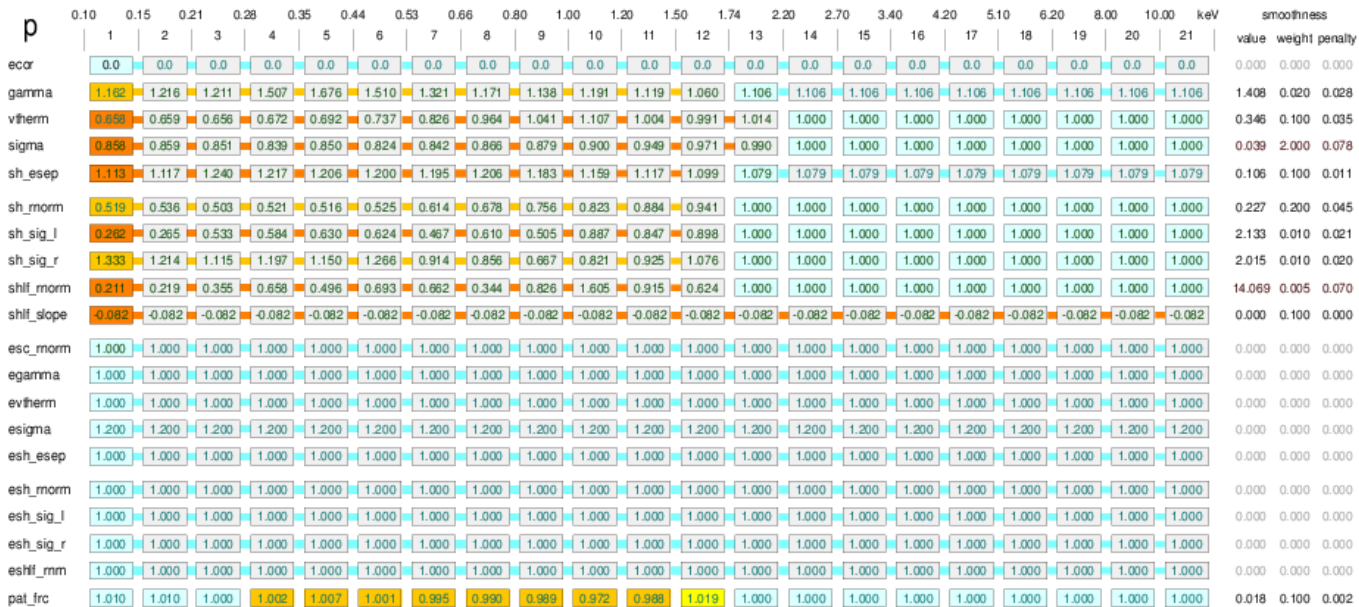
XMM / EPIC-pn RMF and ARF parameterization Small Window Mode

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





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



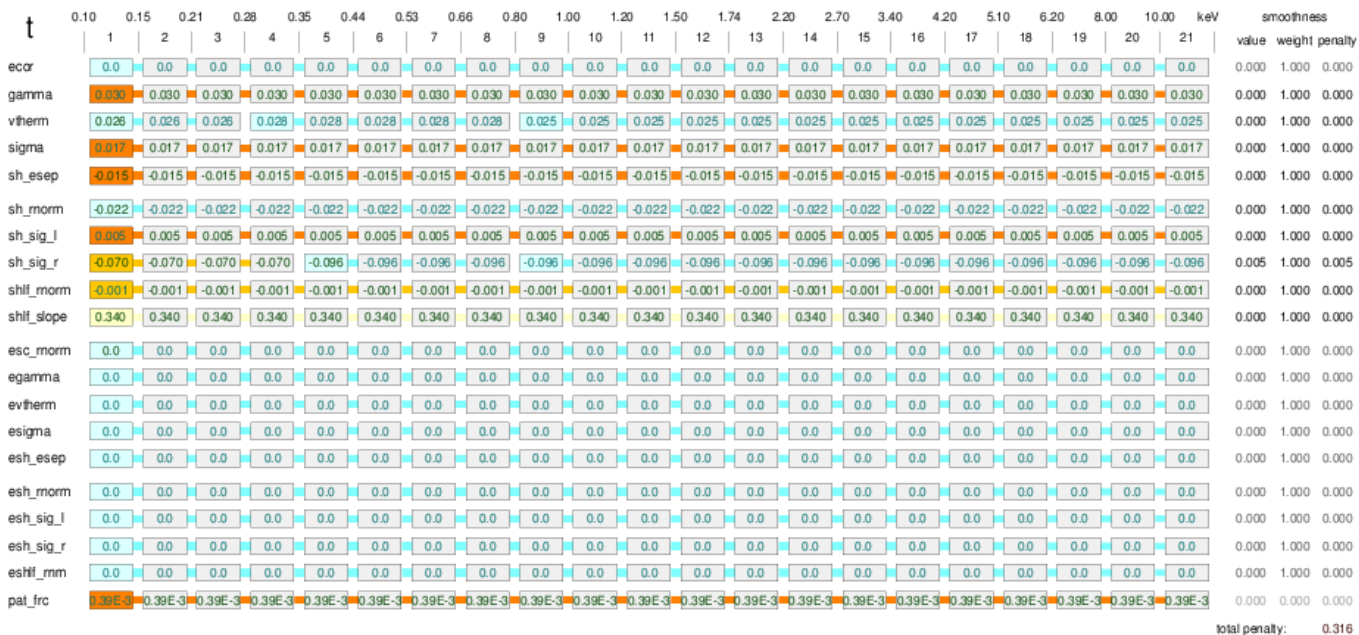
19 RMF shaping functions with 21 parameters each  
 → 399 RMF parameters

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

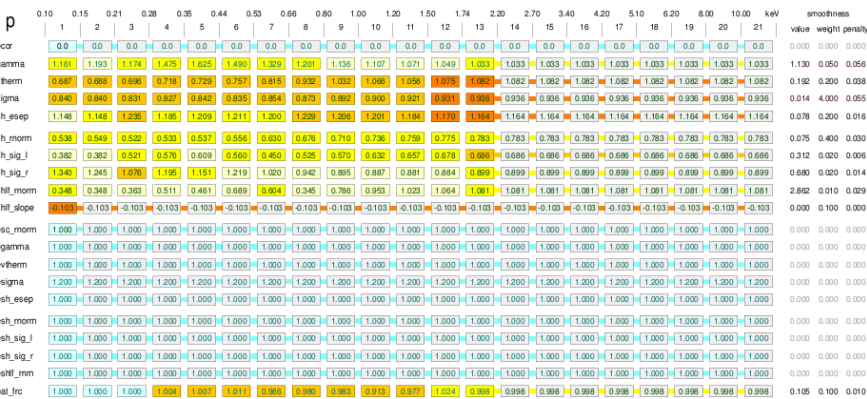
→ 852 parameters

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

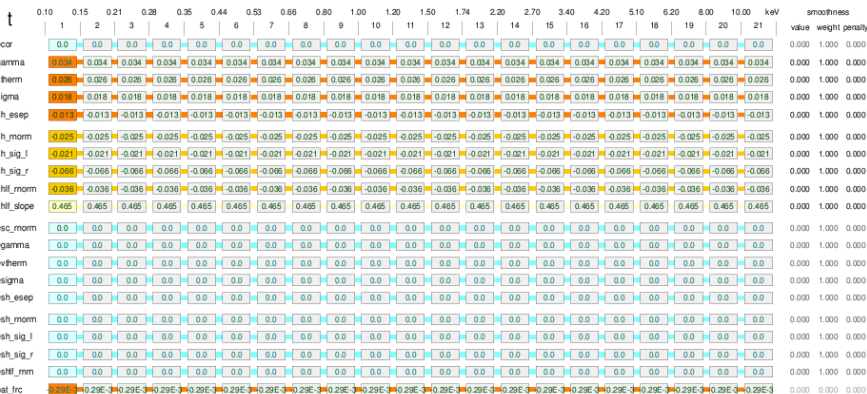
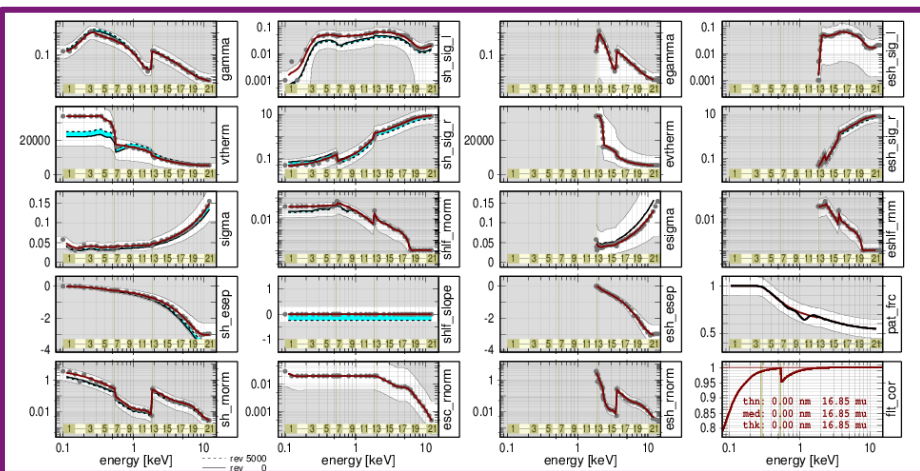


# Modelling thermal RMF changes: sample output

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



XMM / EPIC-pn RMF and ARF parameterization Small Window Mode  
 targets: 1e0102 (33) rxj1856 (31) 20190312\_134952



parameter constraints:

parameter	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 -0.02, ref: 2.00 +0.02]	[ref: 0.00 -0.05, ref: 0.00 +0.05]
vtherm	[ref: 0.50 -0.02, ref: 1.20 +0.00]	[ref: 0.00 -0.05, ref: 0.00 +0.05]
sigma	[ref: 0.70 -0.02, ref: 1.30 +0.00]	[ref: 0.00 -0.05, ref: 0.00 +0.05]
sh_slop	[ref: 0.10 -0.02, ref: 1.20 +0.00]	[ref: 0.00 -0.05, ref: 0.00 +0.05]
sh_sigm	[ref: 0.20 -0.02, ref: 1.00 +0.00]	[ref: 0.00 -0.05, ref: 0.00 +0.05]
sh_sig_r	[ref: 0.50 -0.01, ref: 1.50 +0.00]	[ref: 0.00 -0.05, ref: 0.00 +0.05]
shl_norm	[ref: 0.40 -0.00, ref: 2.00 +0.00]	[ref: 0.00 -0.05, ref: 0.00 +0.05]
shl_slope	[ref: 0.10 -0.02, ref: 1.20 +0.00]	[ref: 0.00 -0.05, ref: 0.00 +0.05]
esc_norm	[ref: 0.30 -0.00, ref: 1.00 +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 -0.02, ref: 2.00 +0.00]	[ref: 0.00 -0.05, ref: 0.00 +0.05]
esigma	[ref: 0.50 -0.02, 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_norm	[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 -0.02, ref: 2.00 +0.00]	[ref: 0.00 -0.05, ref: 0.00 +0.05]
eshl_norm	[ref: 0.10 -0.00, ref: 5.00 +0.00]	[ref: 0.00 -0.05, ref: 0.00 +0.05]
eshl_rm	[ref: 0.10 -0.10, ref: 1.00 +0.10]	[ref: 0.00 -0.05, ref: 0.00 +0.05]
pat_rc	[ref: 0.01 -1.00, ref: 10.00 +1.00]	[ref: 0.00 -0.05, ref: 0.00 +0.05]
chi_cor	[ref: 0.01 -1.00, ref: 10.00 +1.00]	[ref: 0.00 -0.05, ref: 0.00 +0.05]

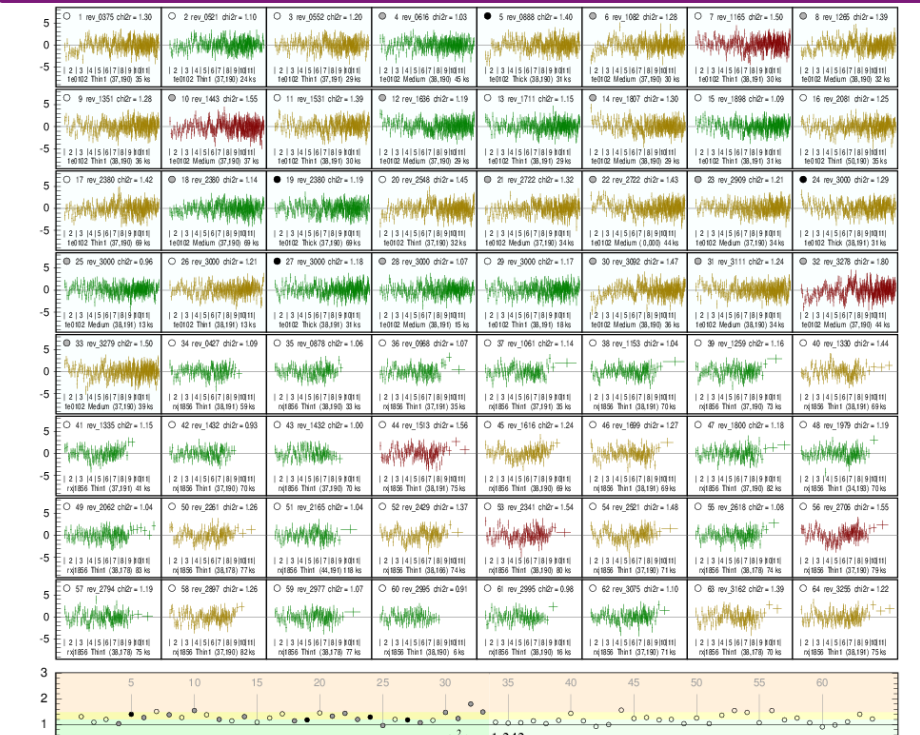
1e0102 spectra:

id	name	model	SW	Med
1	1e0102rev_0375	P01357290P1NS01	SW Thick	Med
2	1e0102rev_0521	P01357210P1NS01	SW Thick	Med
3	1e0102rev_0579	P01357210P1NS01	SW Thick	Med
4	1e0102rev_0619	P01357210P1NS02	SW Medium	Med
5	1e0102rev_0681	P01357200P1NS01	SW Medium	Med
6	1e0102rev_0812	P01357220P1NS01	SW Medium	Med
7	1e0102rev_1165	P01357220P1NS01	SW Medium	Med
8	1e0102rev_1265	P01280101P1NS01	SW Medium	Med
9	1e0102rev_1321	P01280101P1NS01	SW Thick	Med
10	1e0102rev_1431	P01280301P1NS01	SW Medium	Med
11	1e0102rev_1531	P01280501P1NS01	SW Thick	Med
12	1e0102rev_1637	P01280701P1NS01	SW Medium	Med
13	1e0102rev_1711	P01280901P1NS01	SW Thick	Med
14	1e0102rev_1829	P01280901P1NS01	SW Medium	Med
15	1e0102rev_1888	P01280101P1NS01	SW Medium	Med
16	1e0102rev_2061	P01280101P1NS01	SW Thick	Med
17	1e0102rev_2306	P01280101P1NS01	SW Thick	Med
18	1e0102rev_2306b	P01280101P1NS12	SW Thick	Med
19	1e0102rev_2306c	P01280101P1NS13	SW Thick	Med
20	1e0102rev_2560	P01282101P1NS01	SW Thick	Med
21	1e0102rev_2722a	P01282201P1NS01	SW Medium	Med
22	1e0102rev_2722b	P01282201P1NS01	SW Medium	Med
23	1e0102rev_2903	P01282101P1NS01	SW Thick	Med
24	1e0102rev_3006a	P01915801P1NS01	SW Thick	Med
25	1e0102rev_3006b	P01915801P1NS01	SW Medium	Med
26	1e0102rev_3006c	P01915801P1NS01	SW Medium	Med
27	1e0102rev_3006d	P01915801P1NS01	SW Thick	Med
28	1e0102rev_3006e	P01915801P1NS01	SW Thick	Med
29	1e0102rev_3006f	P01915801P1NS01	SW Thick	Med
30	1e0102rev_3006g	P01915801P1NS01	SW Thick	Med
31	1e0102rev_3006h	P01915801P1NS01	SW Thick	Med
32	1e0102rev_3279	P01280301P1NS01	SW Medium	Med
33	1e0102rev_3279f	P01280301P1NS01	SW Medium	Med

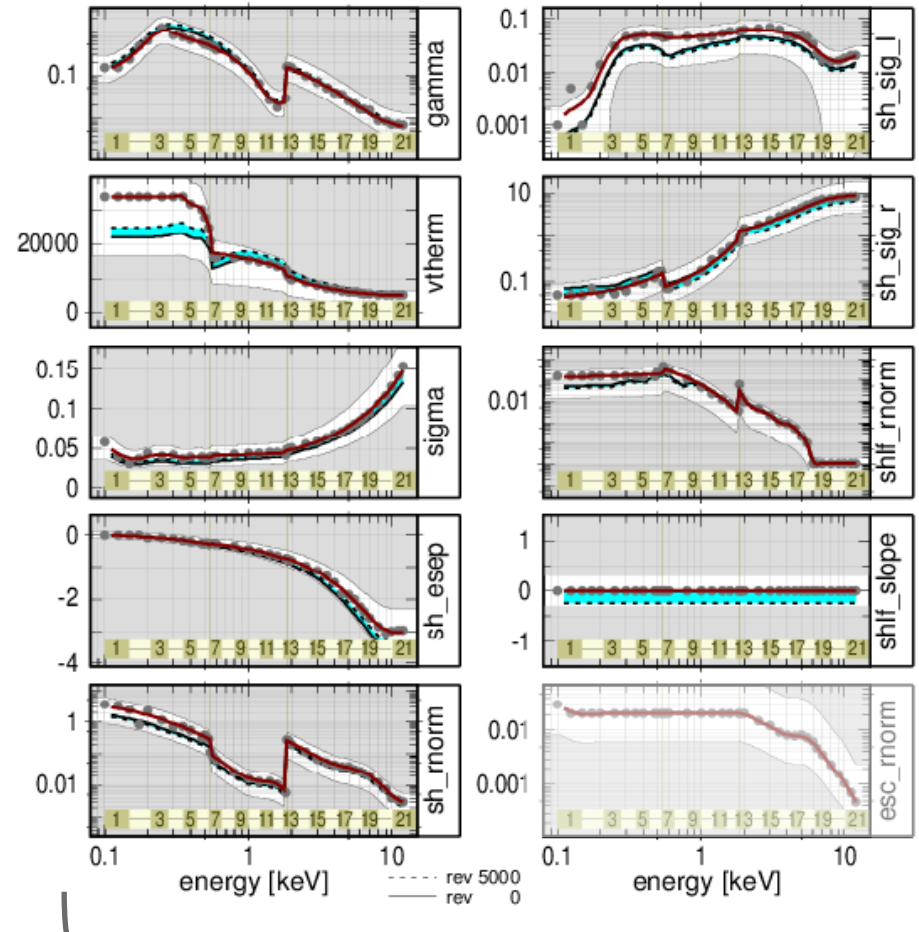
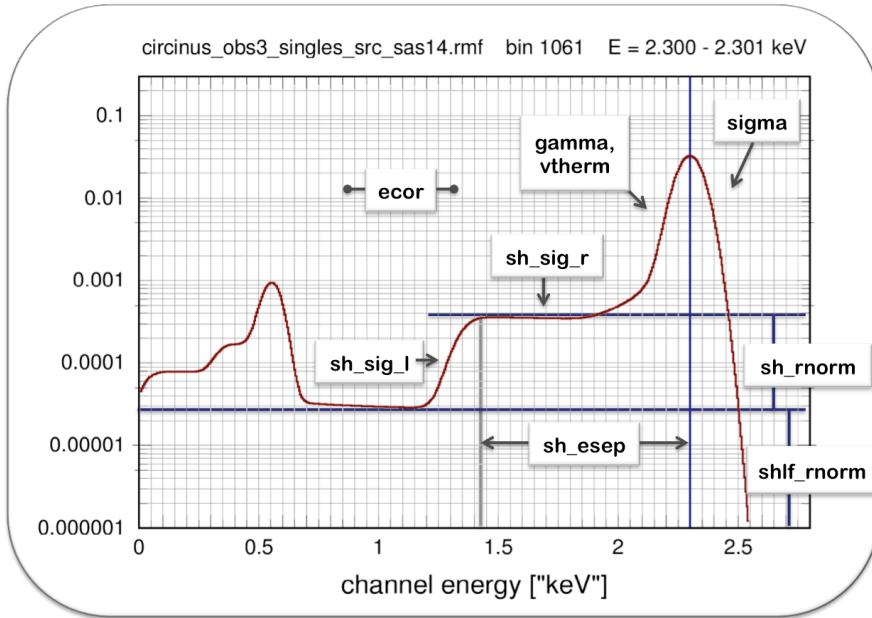
rxj1856 spectra:

id	name	model	SW	Med
1	rxj1856rev_0427	P01026010P1NS01	SW Thick	Med
2	rxj1856rev_0517	P01026010P1NS01	SW Thick	Med
3	rxj1856rev_0980	P01026010P1NS03	SW Thick	Med
4	rxj1856rev_1031	P01026010P1NS03	SW Thick	Med
5	rxj1856rev_1150	P01026010P1NS03	SW Thick	Med
6	rxj1856rev_1250	P01026010P1NS03	SW Thick	Med
7	rxj1856rev_1330	P01260201P1NS02	SW Thick	Med
8	rxj1856rev_1335	P01260201P1NS01	SW Thick	Med
9	rxj1856rev_1424a	P01260201P1NS03	SW Thick	Med
10	rxj1856rev_1432a	P01260201P1NS02	SW Thick	Med
11	rxj1856rev_1513	P01260401P1NS02	SW Thick	Med
12	rxj1856rev_1616	P01260601P1NS02	SW Thick	Med
13	rxj1856rev_1699	P01260701P1NS03	SW Thick	Med
14	rxj1856rev_1800	P01260701P1NS02	SW Thick	Med
15	rxj1856rev_1879	P01280101P1NS02	SW Thick	Med
16	rxj1856rev_1916	P01280101P1NS03	SW Thick	Med
17	rxj1856rev_2056	P01280101P1NS01	SW Thick	Med
18	rxj1856rev_2165	P01280101P1NS02	SW Thick	Med
19	rxj1856rev_2169	P01260201P1NS03	SW Thick	Med
20	rxj1856rev_2274	P01260201P1NS01	SW Thick	Med
21	rxj1856rev_2321	P02776010P1NS01	SW Thick	Med
22	rxj1856rev_2318	P02776201P1NS01	SW Thick	Med
23	rxj1856rev_2376	P02776301P1NS01	SW Thick	Med
24	rxj1856rev_2374	P02776401P1NS01	SW Thick	Med
25	rxj1856rev_2401	P02776501P1NS01	SW Thick	Med
26	rxj1856rev_2497	P02776601P1NS01	SW Thick	Med
27	rxj1856rev_2575	P02776801P1NS01	SW Thick	Med
28	rxj1856rev_2693	P02776901P1NS01	SW Thick	Med
29	rxj1856rev_2696	P02777001P1NS01	SW Thick	Med
30	rxj1856rev_3175	P02777101P1NS01	SW Thick	Med
31	rxj1856rev_3052	P02777101P1NS01	SW Thick	Med
32	rxj1856rev_3111	P01280301P1NS01	SW Thick	Med
33	rxj1856rev_3255	P02777201P1NS01	SW Thick	Med

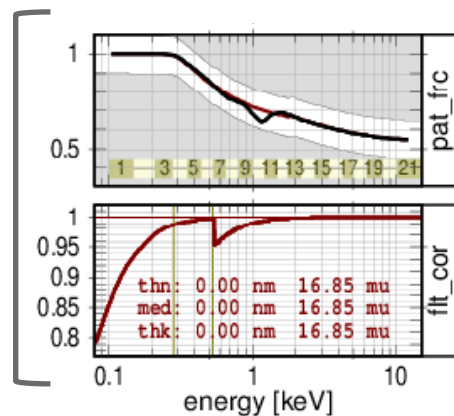
total penalty: 0.255



# Modelling temporal RMF changes: shaping functions



ARF parameters



RMF parameters

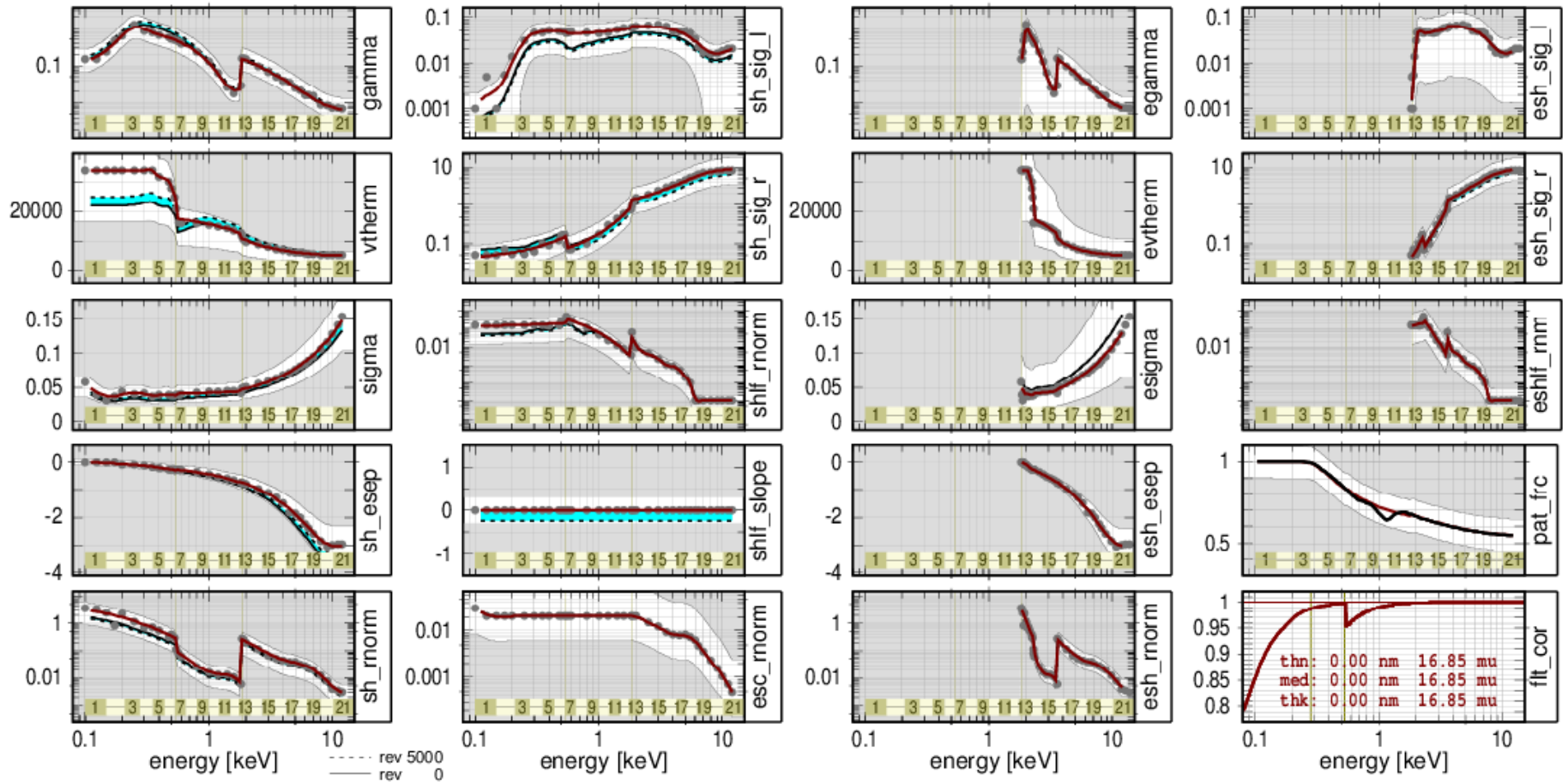
# Modelling temporal RMF changes: shaping functions

XMM / EPIC-pn RMF and ARF parameterization

Small Window Mode

targets: 1e0102 (33) rxj1856 (29)

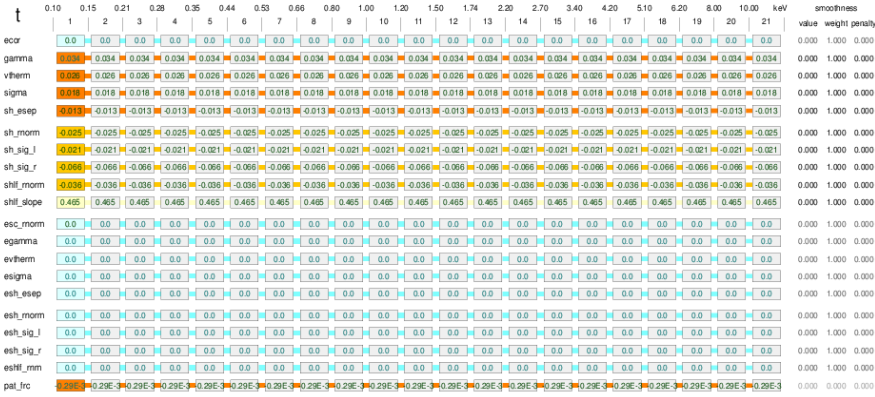
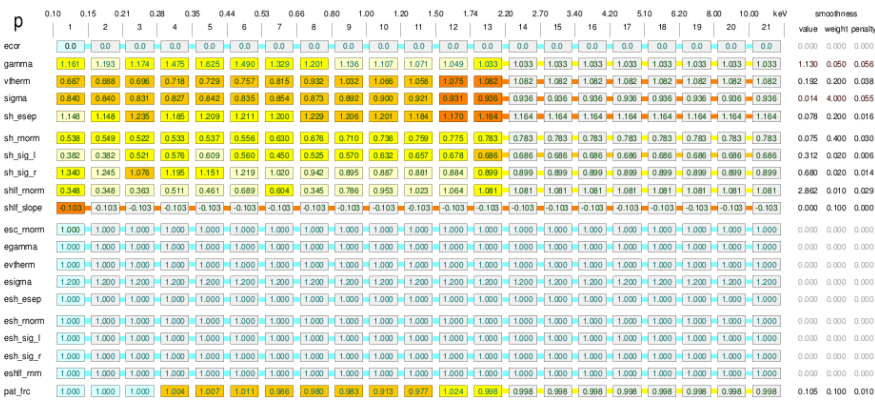
20190312\_111448





# Modelling temporal RMF changes: sample output

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



parameter constraints: p t

ecor	[ref: 1.00 -0.05, ref: 1.00 +0.02]	[ref: 0.00 -0.05, ref: 0.00 +0.05]
gamma	[ref: 0.50 -0.05, ref: 1.00 +0.05]	[ref: 0.00 -0.05, ref: 0.00 +0.05]
vtherm	[ref: 0.50 -0.05, ref: 1.20 +0.00]	[ref: 0.00 -0.05, ref: 0.00 +0.05]
sigma	[ref: 0.70 -0.05, ref: 1.30 +0.00]	[ref: 0.00 -0.05, ref: 0.00 +0.05]
sh_slop	[ref: 0.10 -0.10, ref: 1.20 +0.00]	[ref: 0.00 -0.05, ref: 0.00 +0.05]
sh_sig	[ref: 0.20 -0.05, ref: 1.00 +0.05]	[ref: 0.00 -0.05, ref: 0.00 +0.05]
sh_sig_r	[ref: 0.50 -0.05, ref: 1.50 +0.00]	[ref: 0.00 -0.05, ref: 0.00 +0.05]
shl_norm	[ref: 0.40 -0.05, ref: 2.00 +0.00]	[ref: 0.00 -0.05, ref: 0.00 +0.05]
shl_slope	[ref: 0.10 -0.10, ref: 1.00 +0.00]	[ref: 0.00 -0.05, ref: 0.00 +0.05]
esc_norm	[ref: 0.30 -0.05, 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 -0.05, ref: 2.00 +0.00]	[ref: 0.00 -0.05, ref: 0.00 +0.05]
esigma	[ref: 0.50 -0.05, 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_mom	[ref: 0.50 -0.05, ref: 2.00 +0.00]	[ref: 0.00 -0.05, ref: 0.00 +0.05]
esh_sig	[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 -0.05, ref: 2.00 +0.00]	[ref: 0.00 -0.05, ref: 0.00 +0.05]
eshl_rm	[ref: 0.10 -0.10, ref: 5.00 +0.00]	[ref: 0.00 -0.05, ref: 0.00 +0.05]
pat_rc	[ref: 1.00 -0.10, ref: 1.00 +0.10]	[ref: 0.00 -0.05, ref: 0.00 +0.05]
chi_cor	[ref: 0.01 -1.00, ref: 10.00 +1.00]	[ref: 0.00 -0.05, ref: 0.00 +0.05]
cor_cor	[ref: 0.01 -1.00, ref: 10.00 +1.00]	[ref: 0.00 -0.05, ref: 0.00 +0.05]

1e0102 spectra: rj1856 spectra:

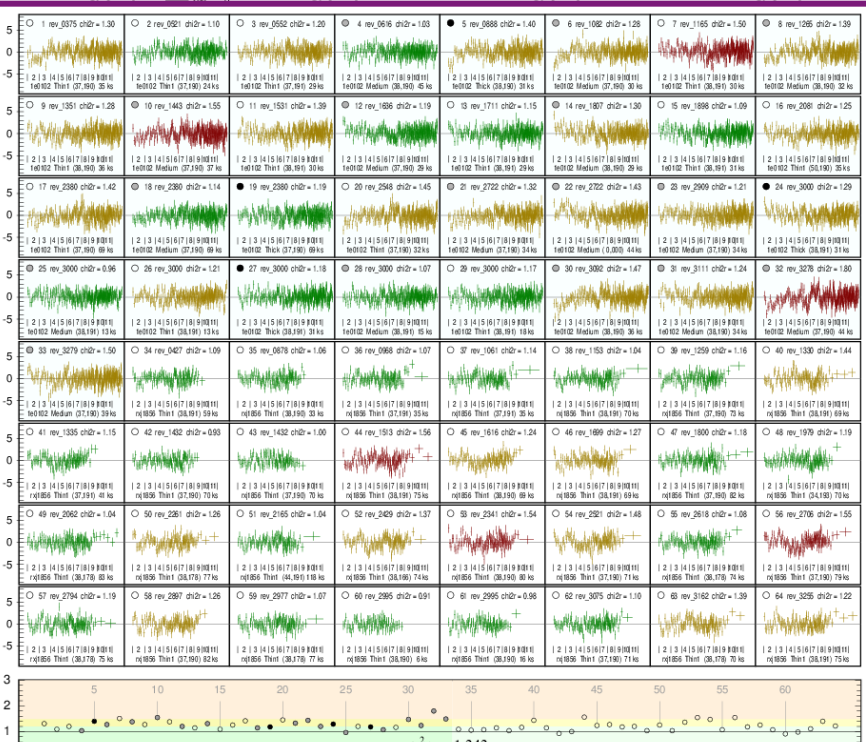
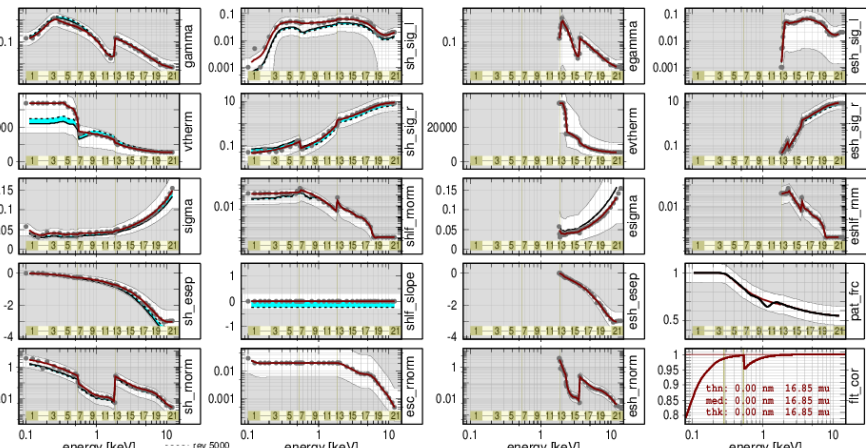
1 1e0102rev_0379	P01357200PN01 SW Thet	1 rj1856rev_0427	P01026010PN01 SW Thet
2 1e0102rev_0521	P01357210PN01 SW Thet	2 rj1856rev_0701	P01026010PN01 SW Thet
3 1e0102rev_0552	P01357210PN01 SW Thet	3 rj1856rev_0988	P01026010PN01 SW Thet
4 1e0102rev_0819	P01357210PN01 SW Medium	4 rj1856rev_1031	P01026010PN01 SW Thet
5 1e0102rev_0861	P01357200PN01 SW Medium	5 rj1856rev_1250	P01026010PN01 SW Thet
6 1e0102rev_0916	P01357220PN01 SW Medium	6 rj1856rev_1589	P01026010PN01 SW Thet
7 1e0102rev_1165	P01357220PN01 SW Medium	7 rj1856rev_1330	P01260201PN002 SW Thet
8 1e0102rev_1261	P04128010PN01 SW Medium	8 rj1856rev_1335	P04158010PN01 SW Thet
9 1e0102rev_1321	P04128010PN01 SW Thet	9 rj1856rev_1424	P04126000PN003 SW Thet
10 1e0102rev_1431	P04128030PN01 SW Medium	10 rj1856rev_1432	P04126000PN002 SW Thet
11 1e0102rev_1543	P04128050PN01 SW Thet	11 rj1856rev_1513	P04126040PN002 SW Thet
12 1e0102rev_1637	P04128070PN01 SW Medium	12 rj1856rev_1616	P04126000PN002 SW Thet
13 1e0102rev_1711	P04128080PN01 SW Medium	13 rj1856rev_1696	P04126000PN002 SW Thet
14 1e0102rev_1829	P04128090PN01 SW Medium	14 rj1856rev_1800	P04126000PN002 SW Thet
15 1e0102rev_1888	P04128010PN01 SW Medium	15 rj1856rev_1979	P04128010PN002 SW Thet
16 1e0102rev_2081	P04128040PN01 SW Thet	16 rj1856rev_2032	P04128010PN003 SW Thet
17 1e0102rev_2304	P04128010PN01 SW Thet	17 rj1856rev_2241	P04126000PN003 SW Thet
18 1e0102rev_2300	P04128010PN01 SW Thet	18 rj1856rev_2165	P04128010PN002 SW Thet
19 1e0102rev_2300	P04128010PN01 SW Thet	19 rj1856rev_2429	P04126020PN003 SW Thet
20 1e0102rev_2568	P04128010PN01 SW Thet	20 rj1856rev_2568	P04126020PN003 SW Thet
21 1e0102rev_2722	P04128020PN01 SW Medium	21 rj1856rev_2511	P02776010PN001 SW Thet
22 1e0102rev_2722	P04128020PN01 SW Medium	22 rj1856rev_2818	P02776020PN002 SW Thet
23 1e0102rev_2903	P04128050PN01 SW Medium	23 rj1856rev_2737	P02776030PN001 SW Thet
24 1e0102rev_3006	P09158001PN01 SW Thet	24 rj1856rev_2784	P02776040PN001 SW Thet
25 1e0102rev_3006	P09158001PN01 SW Medium	25 rj1856rev_2901	P02776050PN001 SW Thet
26 1e0102rev_3006	P09158001PN01 SW Thet	26 rj1856rev_2975	P02776060PN001 SW Thet
27 1e0102rev_3006	P09158001PN01 SW Thet	27 rj1856rev_2993	P02776070PN001 SW Thet
28 1e0102rev_3006	P09158001PN01 SW Thet	28 rj1856rev_2996	P02776080PN001 SW Thet
29 1e0102rev_3006	P09158010PN01 SW Thet	29 rj1856rev_3175	P02776101PN001 SW Thet
30 1e0102rev_3006	P09158010PN01 SW Thet	30 rj1856rev_3062	P02776110PN001 SW Thet
31 1e0102rev_3032	P04128030PN01 SW Medium	31 rj1856rev_3355	P02776120PN001 SW Thet
32 1e0102rev_3278	P04128030PN01 SW Medium		
33 1e0102rev_3278	P04128030PN01 SW Medium		

total penalty: 0.255

object: 1e01021856  
modeldir: home/keck/data/1epic/RMF/FTITrms/walwei/  
data\_dir: home/keck/data/1epic/RMF/FTITrms/walwei/  
workdir: home/keck/data/1epic/RMF/FTITrms/walwei/1  
spectral mode:  
1e0102: mode1=lypnp\_mod\_babs\_bvabsa\_2apec\_line\_ratio\_v1\_xzm  
rj1856: mode=3n=856\_mod\_bbody\_xzm  
function used for evaluating the shaping parameters: vahnev\_25  
XMM reference version: rev 2000  
lnlvl: -10 th\_low = 0.10E-5 th\_high = -20 th\_high = -0.001

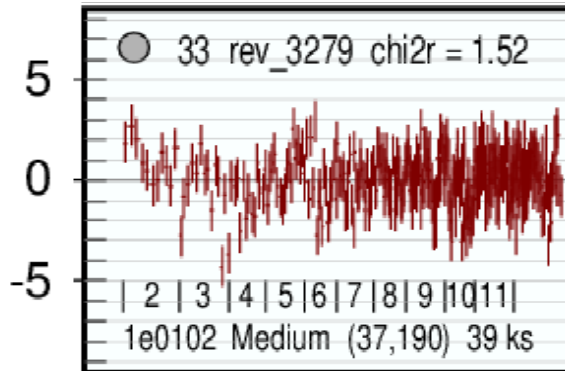
XMM / EPIC-pn RMF and ARF parameterization Small Window Mode

targets: 1e0102 (33) rj1856 (31) 20190312\_134952

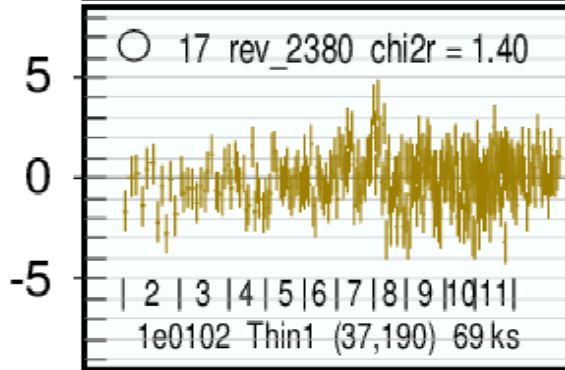




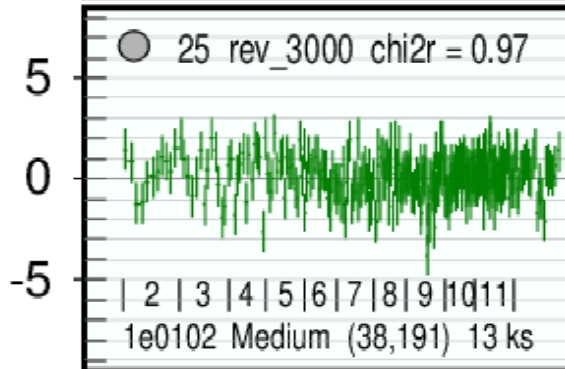
# Modelling temporal RMF changes: residuals



red: reduced  $\chi^2 > 1.5$



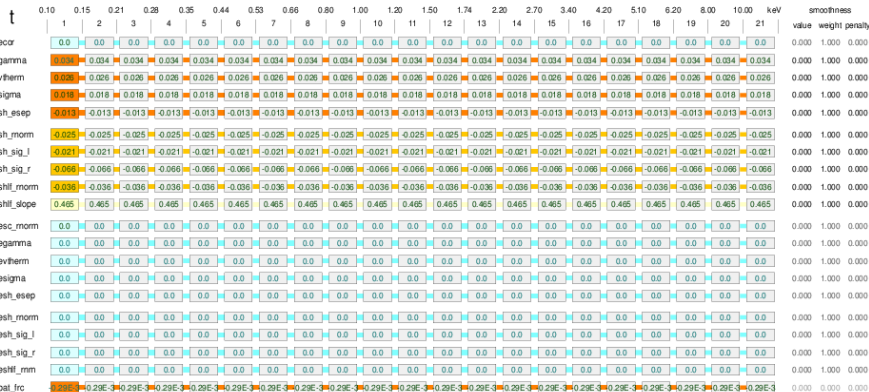
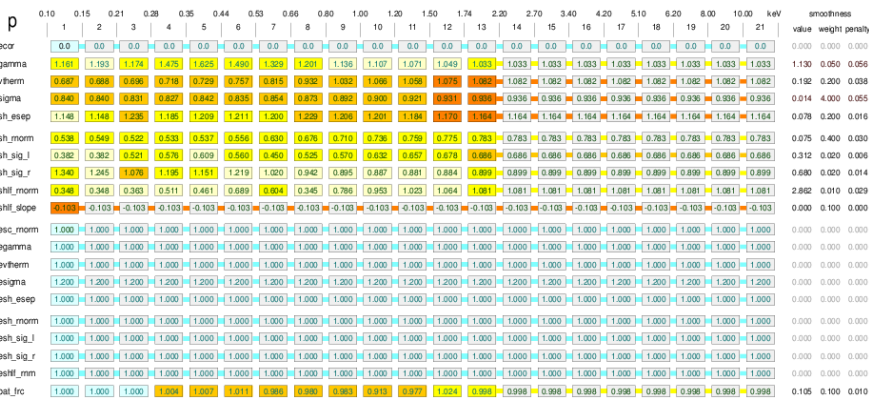
yellow:  $1.2 \leq$  reduced  $\chi^2 \leq 1.5$



green: reduced  $\chi^2 < 1.2$

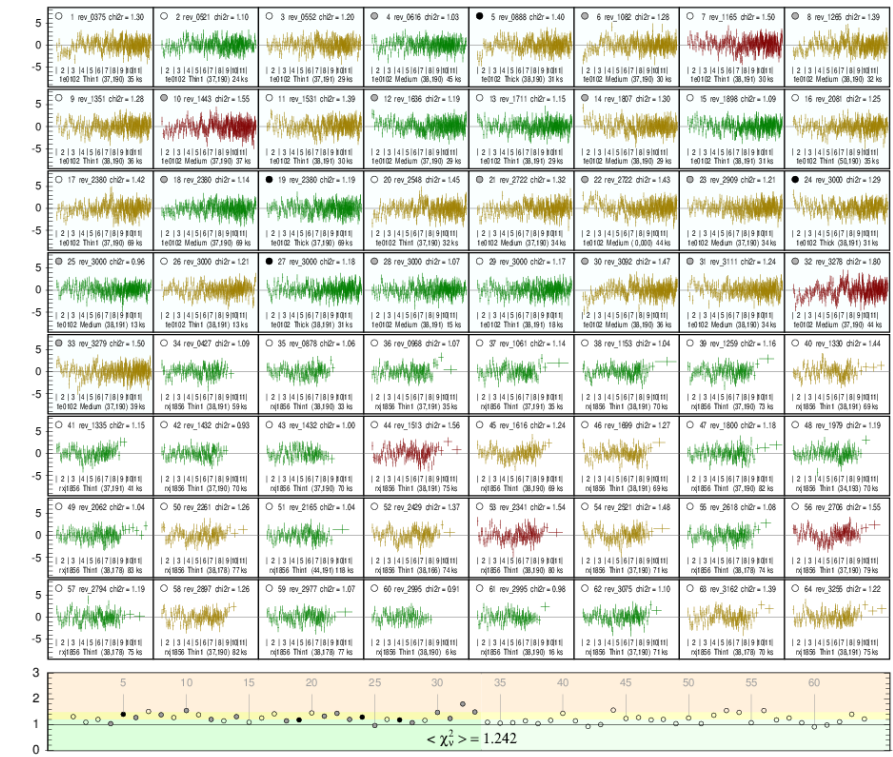
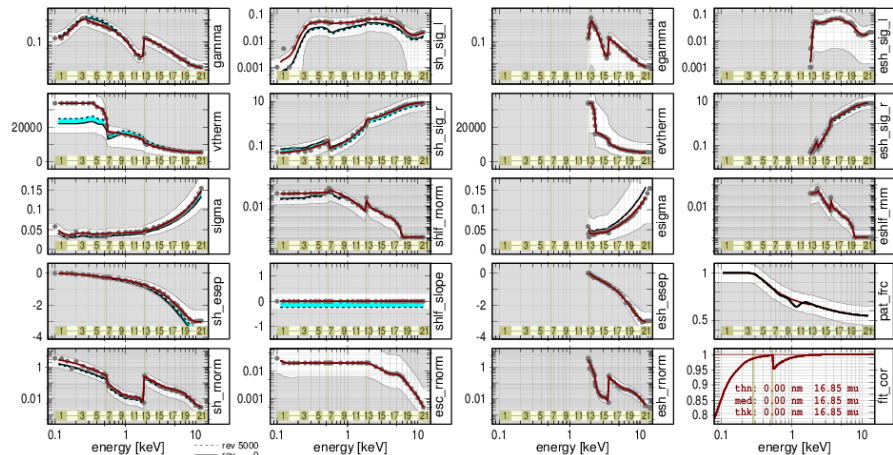
# Modelling thermal RMF changes: sample output

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



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

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



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_skep	[ref: 0.50, 0.00, ref: 1.20, 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]
shl_norm	[ref: 1.00, 0.00, ref: 1.00, 0.00]	[ref: 0.00, 0.05, ref: 0.00, 0.05]
shl_slope	[ref: 1.00, 0.00, ref: 1.00, 0.00]	[ref: 0.00, 0.05, ref: 0.00, 0.05]
esc_norm	[ref: 0.50, 0.00, ref: 1.00, 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_mom	[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]
eshl_norm	[ref: 0.10, 0.00, ref: 5.00, 0.00]	[ref: 0.00, 0.05, ref: 0.00, 0.05]
eshl_slope	[ref: 1.00, 0.10, ref: 1.00, 0.10]	[ref: 0.00, 0.05, ref: 0.00, 0.05]
pat_rc	[ref: 0.01, 1.00, ref: 1.00, 0.00]	[ref: 0.00, 0.05, ref: 0.00, 0.05]
chi_cor	[ref: 0.01, 1.00, ref: 1.00, 0.00]	[ref: 0.00, 0.05, ref: 0.00, 0.05]
ecor	[ref: 0.01, 1.00, ref: 1.00, 0.00]	[ref: 0.00, 0.05, ref: 0.00, 0.05]

1e0102 spectra:

ObsID	Model	SW	Th
1	1e0102rev_0379	SW Thick	1.1
2	1e0102rev_0521	SW Thick	1.1
3	1e0102rev_0552	SW Thick	1.1
4	1e0102rev_0619	SW Medium	1.1
5	1e0102rev_0801	SW Medium	1.1
6	1e0102rev_0818	SW Medium	1.1
7	1e0102rev_1165	SW Medium	1.1
8	1e0102rev_1265	SW Medium	1.1
9	1e0102rev_1321	SW Thick	1.1
10	1e0102rev_1431	SW Medium	1.1
11	1e0102rev_1531	SW Thick	1.1
12	1e0102rev_1631	SW Medium	1.1
13	1e0102rev_1711	SW Thick	1.1
14	1e0102rev_1831	SW Thick	1.1
15	1e0102rev_1881	SW Thick	1.1
16	1e0102rev_2001	SW Thick	1.1
17	1e0102rev_2201	SW Thick	1.1
18	1e0102rev_2301	SW Thick	1.1
19	1e0102rev_2301	SW Thick	1.1
20	1e0102rev_2561	SW Thick	1.1
21	1e0102rev_2721	SW Medium	1.1
22	1e0102rev_2721	SW Medium	1.1
23	1e0102rev_2901	SW Thick	1.1
24	1e0102rev_3001	SW Thick	1.1
25	1e0102rev_3001	SW Medium	1.1
26	1e0102rev_3001	SW Medium	1.1
27	1e0102rev_3001	SW Thick	1.1
28	1e0102rev_3001	SW Thick	1.1
29	1e0102rev_3001	SW Thick	1.1
30	1e0102rev_3001	SW Thick	1.1
31	1e0102rev_3031	SW Medium	1.1
32	1e0102rev_3111	SW Medium	1.1
33	1e0102rev_3271	SW Medium	1.1
34	1e0102rev_3271	SW Medium	1.1

rxj1856 spectra:

ObsID	Model	SW	Th
1	rxj1856rev_0427	SW Thick	1.1
2	rxj1856rev_0427	SW Thick	1.1
3	rxj1856rev_0991	SW Thick	1.1
4	rxj1856rev_1031	SW Thick	1.1
5	rxj1856rev_1051	SW Thick	1.1
6	rxj1856rev_1251	SW Thick	1.1
7	rxj1856rev_1331	SW Thick	1.1
8	rxj1856rev_1335	SW Thick	1.1
9	rxj1856rev_1421	SW Thick	1.1
10	rxj1856rev_1432	SW Thick	1.1
11	rxj1856rev_1513	SW Thick	1.1
12	rxj1856rev_1616	SW Thick	1.1
13	rxj1856rev_1696	SW Thick	1.1
14	rxj1856rev_1800	SW Thick	1.1
15	rxj1856rev_1879	SW Thick	1.1
16	rxj1856rev_1916	SW Thick	1.1
17	rxj1856rev_2021	SW Thick	1.1
18	rxj1856rev_2165	SW Thick	1.1
19	rxj1856rev_2165	SW Thick	1.1
20	rxj1856rev_2241	SW Thick	1.1
21	rxj1856rev_2321	SW Thick	1.1
22	rxj1856rev_2318	SW Thick	1.1
23	rxj1856rev_2391	SW Thick	1.1
24	rxj1856rev_2734	SW Thick	1.1
25	rxj1856rev_2737	SW Thick	1.1
26	rxj1856rev_2737	SW Thick	1.1
27	rxj1856rev_2975	SW Thick	1.1
28	rxj1856rev_2975	SW Thick	1.1
29	rxj1856rev_3012	SW Thick	1.1
30	rxj1856rev_3162	SW Thick	1.1
31	rxj1856rev_3355	SW Thick	1.1

object: 1e0102(1856)  
 detector: home/iod/data/1epic/RMF/FTITrms/waldev/  
 model: home/iod/data/1epic/RMF/FTITrms/waldev/  
 working: home/iod/data/1epic/RMF/FTITrms/waldev/1  
 spectral mode:  
 1e0102: mode=1nrgp\_mod\_Babs\_Bvabsa\_2apeec\_val\_ratio\_xl\_v1\_xzm  
 rxj1856: mode=3nrgp\_mod\_Babs\_Bvabsa\_2apeec\_val\_ratio\_xl\_v1\_xzm  
 function used for evaluating the shaping parameters: vahnev\_25  
 XMM reference revolution: rev 2000  
 lnvbl = -10 thl = 0.10E-5 lthap = -20 lthamb = -10 thb = -0.001

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_norm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	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
eshif_rmm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	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: 0.25

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]
viherm	[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_norm	[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]
shif_norm	[ref * 0.10 + 0.00 , ref * 2.00 + 0.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
shif_slope	[ref * 1.00 - 0.30 , ref * 1.00 + 0.30]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]
esc_norm	[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_norm	[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]
eshif_rmm	[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]
c2_cor	[ref * 0.01 - 1.00 , ref * 10.00 + 1.00]	[ref * 0.00 - 0.05 , ref * 0.00 + 0.05]

1e0102 spectra:			rxj1856 spectra:		
1	1e0102/rev_0375/	P0135720801PNS001 SW Thin1	1	rxj1856/rev_0427/	P0106260101PNS001 SW Thin1
2	1e0102/rev_0521/	P0135721101PNS001 SW Thin1	2	rxj1856/rev_0878/	P0165971601PNS003 SW Thin1
3	1e0102/rev_0552/	P0135721301PNS001 SW Thin1	3	rxj1856/rev_0968/	P0165971901PNS003 SW Thin1
4	1e0102/rev_0616/	P0135721401PNU002 SW Medium	4	rxj1856/rev_1061/	P0165972001PNS003 SW Thin1
5	1e0102/rev_0888/	P0135722401PNS001 SW Thick	5	rxj1856/rev_1153/	P0165972101PNS003 SW Thin1
6	1e0102/rev_1082/	P0135722601PNS001 SW Medium	6	rxj1856/rev_1259/	P0412600101PNS003 SW Thin1
7	1e0102/rev_1165/	P0135722701PNS001 SW Thin1	7	rxj1856/rev_1330/	P0412600201PNU002 SW Thin1
8	1e0102/rev_1265/	P0412980101PNS001 SW Medium	8	rxj1856/rev_1335/	P0415180101PNS001 SW Thin1
9	1e0102/rev_1351/	P0412980201PNS001 SW Thin1	9	rxj1856/rev_1432a/	P0412600301PNS003 SW Thin1
10	1e0102/rev_1443/	P0412980301PNS001 SW Medium	10	rxj1856/rev_1432b/	P0412600301PNU002 SW Thin1
11	1e0102/rev_1531/	P0412980501PNS001 SW Thin1	11	rxj1856/rev_1513/	P0412600401PNU002 SW Thin1
12	1e0102/rev_1636/	P0412980701PNS001 SW Medium	12	rxj1856/rev_1616/	P0412600601PNU002 SW Thin1
13	1e0102/rev_1711/	P0412980801PNS001 SW Thin1	13	rxj1856/rev_1699/	P0412600701PNS003 SW Thin1
14	1e0102/rev_1807/	P0412980901PNS001 SW Medium	14	rxj1856/rev_1800/	P0412600801PNU002 SW Thin1
15	1e0102/rev_1898/	P0412981001PNS001 SW Thin1	15	rxj1856/rev_1979/	P0412601101PNU002 SW Thin1
16	1e0102/rev_2081/	P0412981401PNS001 SW Thin1	16	rxj1856/rev_2062/	P0412601301PNS003 SW Thin1
17	1e0102/rev_2380a/	P0412981701PNS001 SW Thin1	17	rxj1856/rev_2261/	P0412601401PNS003 SW Thin1
18	1e0102/rev_2380b/	P0412981701PNS012 SW Medium	18	rxj1856/rev_2165/	P0412601501PNS002 SW Thin1
19	1e0102/rev_2380c/	P0412981701PNS013 SW Thick	19	rxj1856/rev_2429/	P0412602201PNS003 SW Thin1
20	1e0102/rev_2548/	P0412982101PNS001 SW Thin1	20	rxj1856/rev_2341/	P0412602301PNS003 SW Thin1
21	1e0102/rev_2722a/	P0412982201PNS001 SW Medium	21	rxj1856/rev_2521/	P0727760101PNS001 SW Thin1
22	1e0102/rev_2722b/	P0412982301PNS001 SW Medium	22	rxj1856/rev_2618/	P0727760201PNS001 SW Thin1
23	1e0102/rev_2909/	P0412982501PNS001 SW Medium	23	rxj1856/rev_2706/	P0727760301PNS001 SW Thin1
24	1e0102/rev_3000a/	P0791580701PNS001 SW Thick	24	rxj1856/rev_2794/	P0727760401PNS001 SW Thin1
25	1e0102/rev_3000b/	P0791580801PNS001 SW Medium	25	rxj1856/rev_2897/	P0727760501PNS001 SW Thin1
26	1e0102/rev_3000c/	P0791580901PNS001 SW Thin1	26	rxj1856/rev_2977/	P0727760601PNS001 SW Thin1
27	1e0102/rev_3000d/	P0791581001PNS001 SW Thick	27	rxj1856/rev_2995a/	P0791580301PNS001 SW Thin1
28	1e0102/rev_3000e/	P0791581101PNS001 SW Medium	28	rxj1856/rev_2995b/	P0791580601PNS001 SW Thin1
29	1e0102/rev_3000f/	P0791581201PNS001 SW Thin1	29	rxj1856/rev_3075/	P0727761001PNS001 SW Thin1
30	1e0102/rev_3092/	P0412983201PNS001 SW Medium	30	rxj1856/rev_3162/	P0727761101PNS001 SW Thin1
31	1e0102/rev_3111/	P0412983301PNS001 SW Medium	31	rxj1856/rev_3255/	P0727761201PNS001 SW Thin1
32	1e0102/rev_3278/	P0412983401PNS001 SW Medium			
33	1e0102/rev_3279/	P0412983501PNS001 SW Medium			

```

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_ibabs_ibvarabs_2apeac_line_ratios_id_v1.9.xcm
rxj1856: model-3/rxj1856_model_bbody.xcm
function used for evaluating the shaping parameters: valnew_25
XMM reference revolution: rev 2000
lrvtol = 10 fltol = 0.10E-5 ltmxpr = 20 ltmxbr = 10 tolbr = 0.001

```

# 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:**

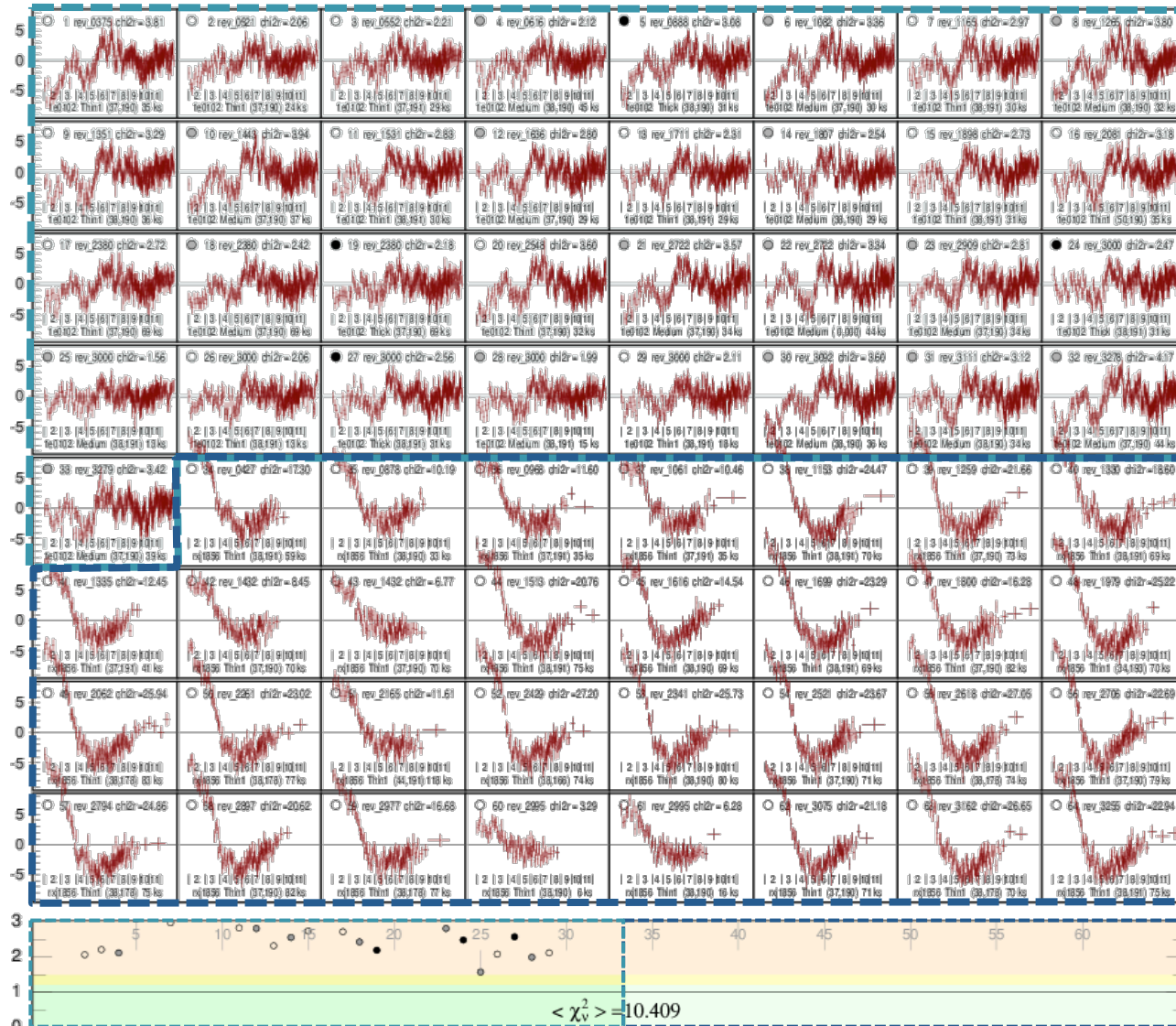
IACHEC model  
with only 1 free parameter:  
global normalization  
+ gain fit (offset)

### **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  $\chi^2 = 10.409$

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!)

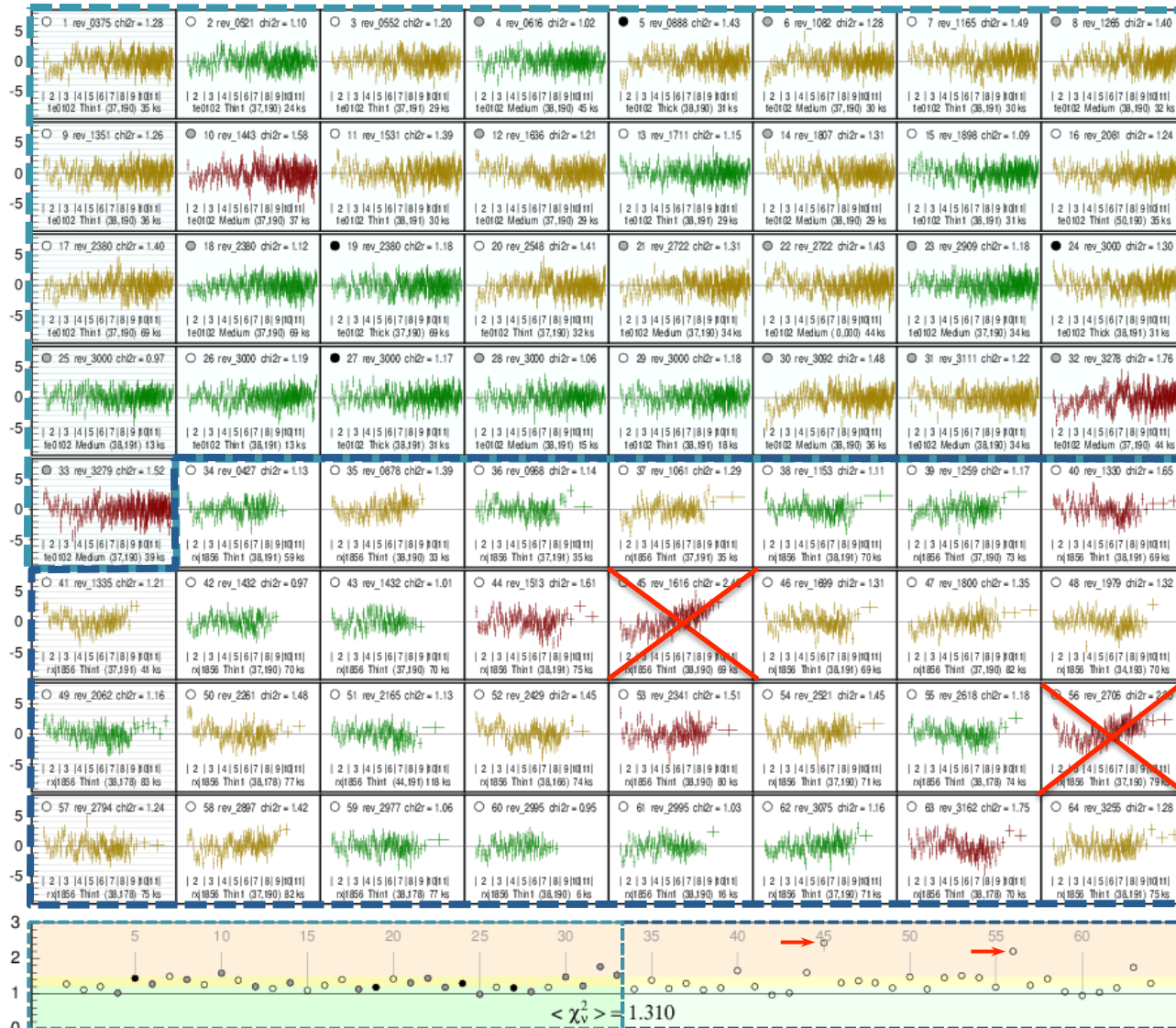
$nH == 7.25 \cdot 10^{-19} \text{ cm}^{-2}$

$kT == 62.4 \text{ eV}$

$\text{norm} == 1.58 \cdot 10^5$

+ gain fit (offset)

# Residuals obtained with parameterized RMF



average reduced  $\chi^2 = 1.310$

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!)

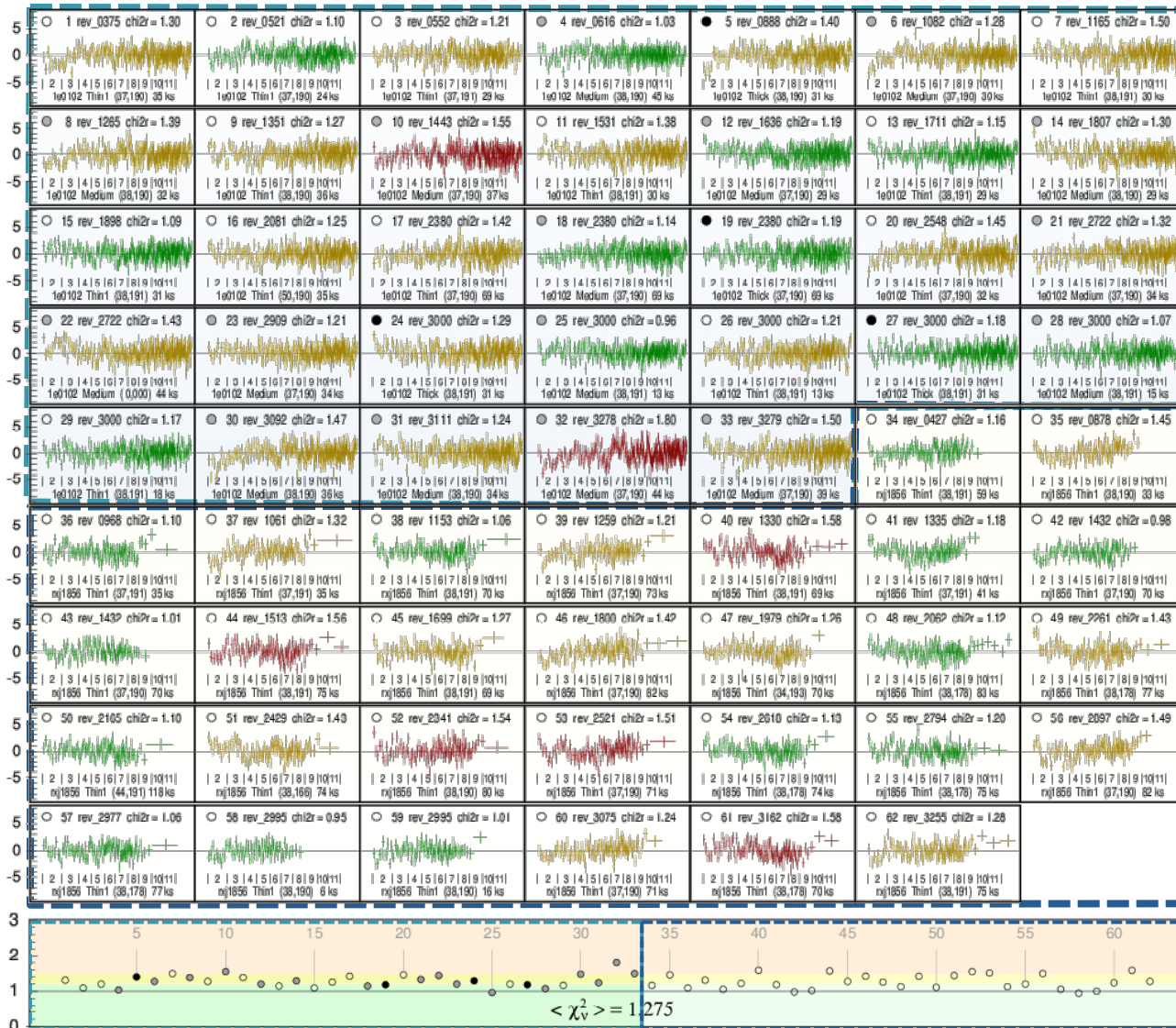
$nH == 7.25 \cdot 10^{-19} \text{ cm}^{-2}$

$kT == 62.4 \text{ eV}$

$\text{norm} == 1.58 \cdot 10^5$

+ gain fit (offset)

# Residuals obtained with parameterized RMF



average reduced  $\chi^2 = 1.275$

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 ==  $7.25 \cdot 10^{-19} \text{ cm}^{-2}$

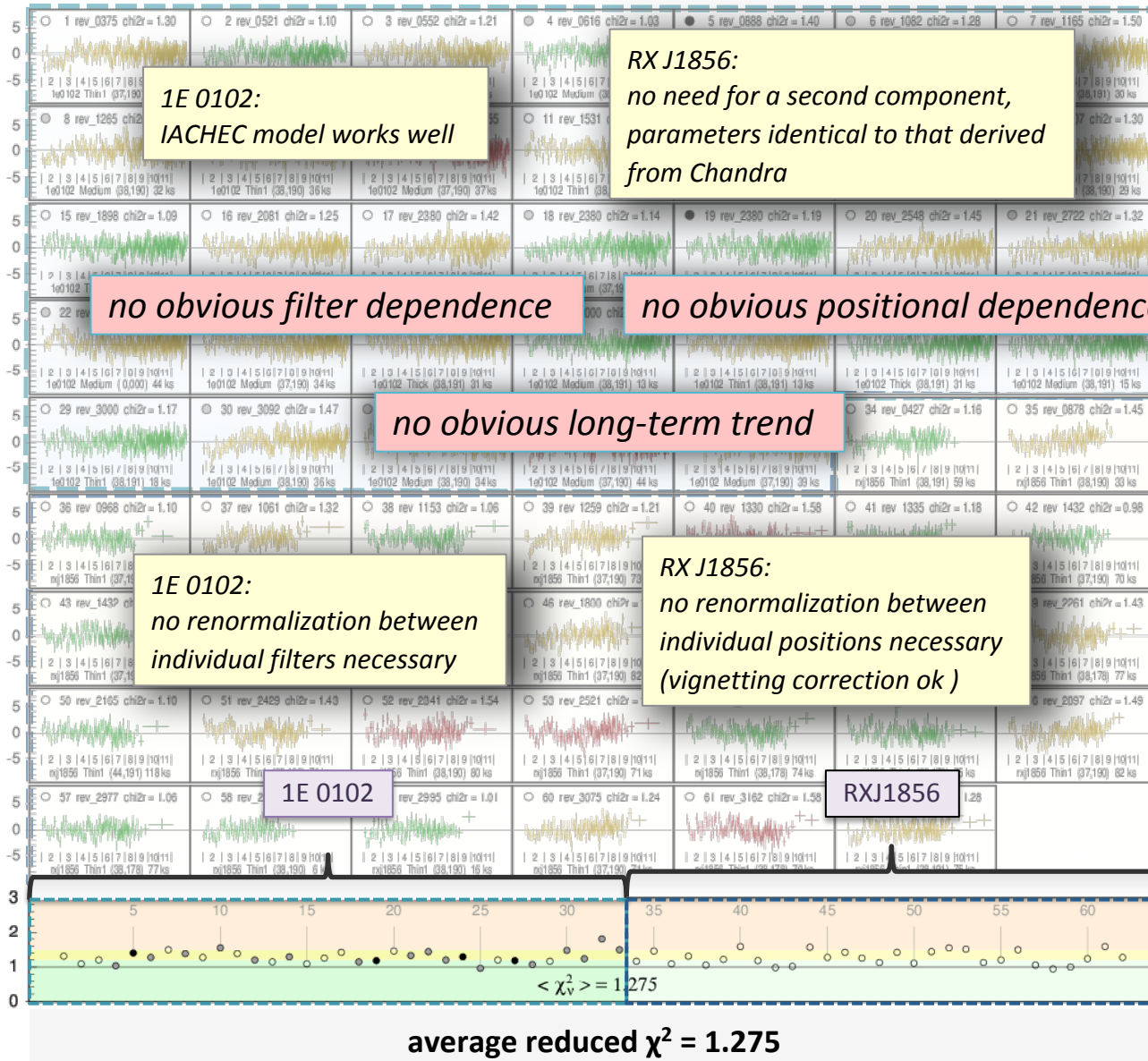
kT == 62.4 eV

norm ==  $1.58 \cdot 10^5$

+ 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!)

$nH == 7.25 \cdot 10^{-19} \text{ cm}^{-2}$

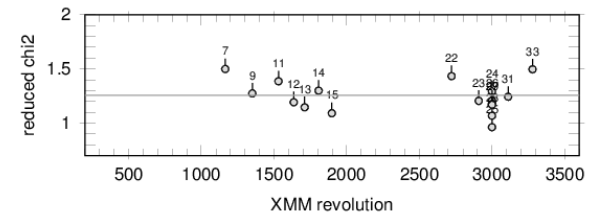
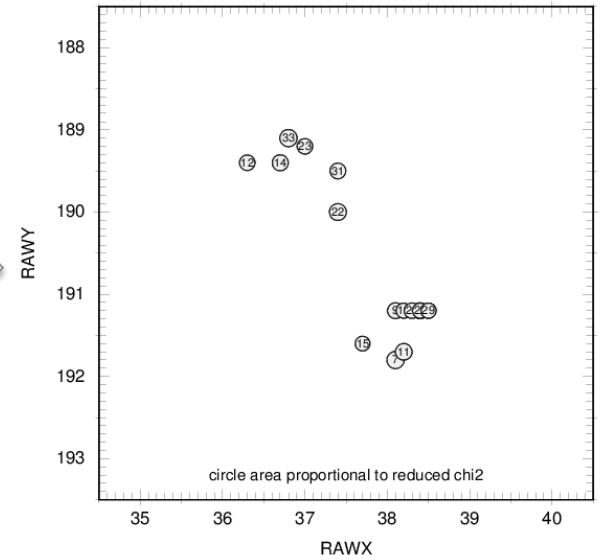
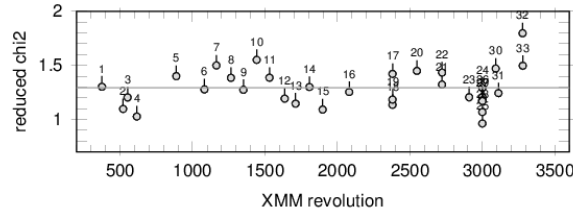
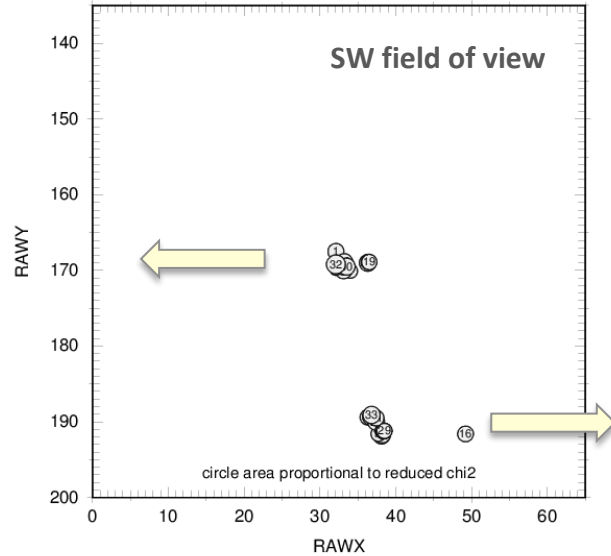
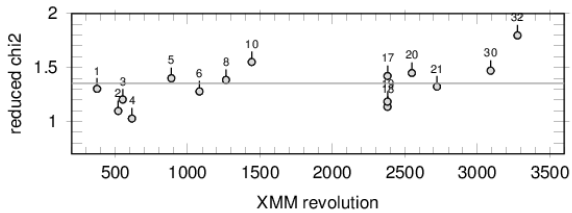
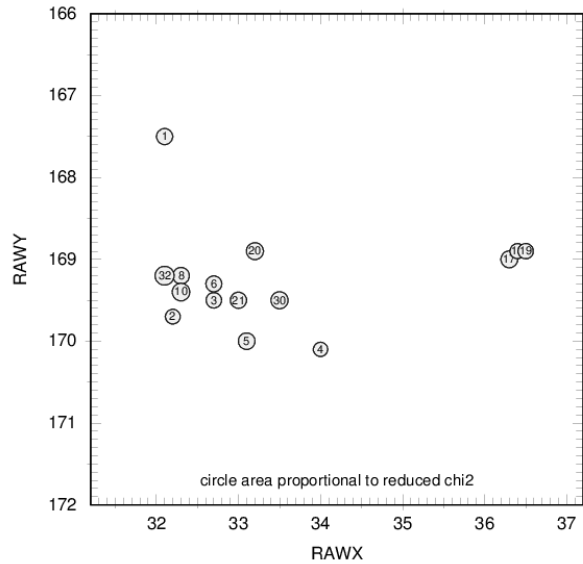
$kT == 62.4 \text{ eV}$

$norm == 1.58 \cdot 10^5$

+ gain fit (offset)

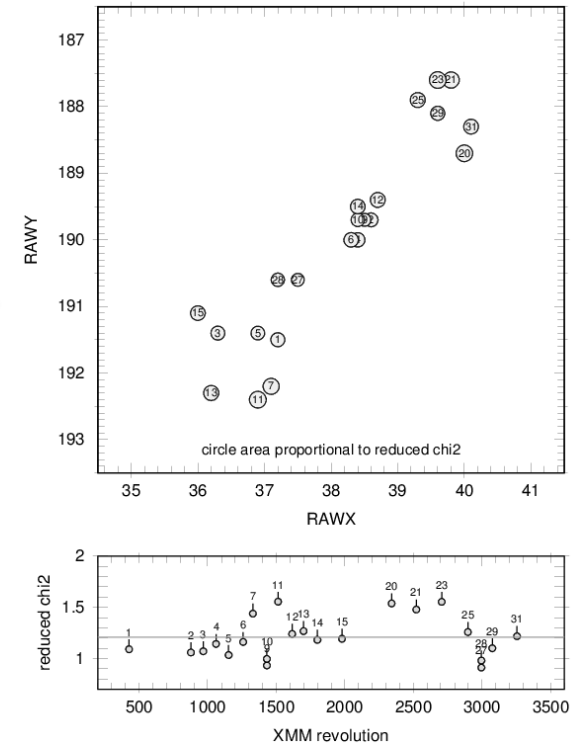
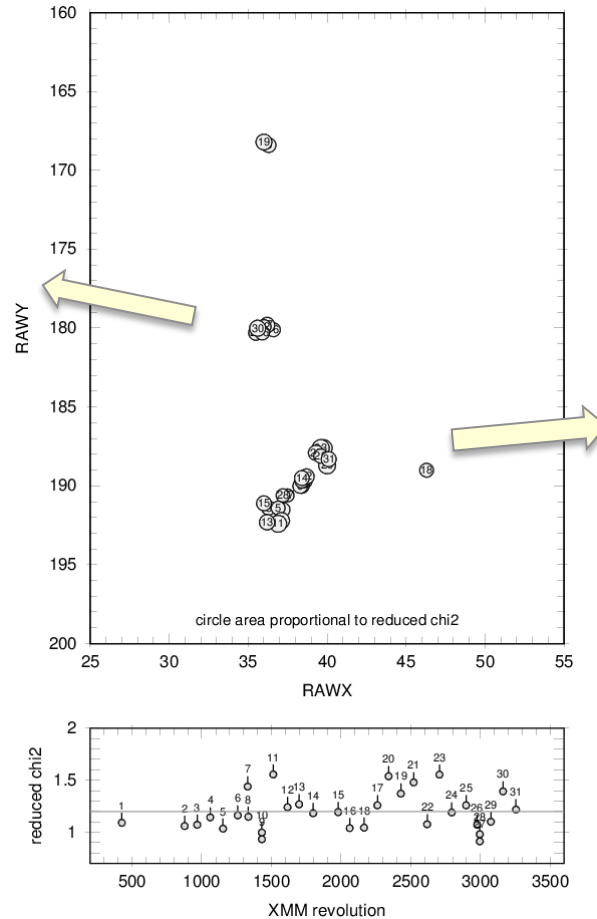
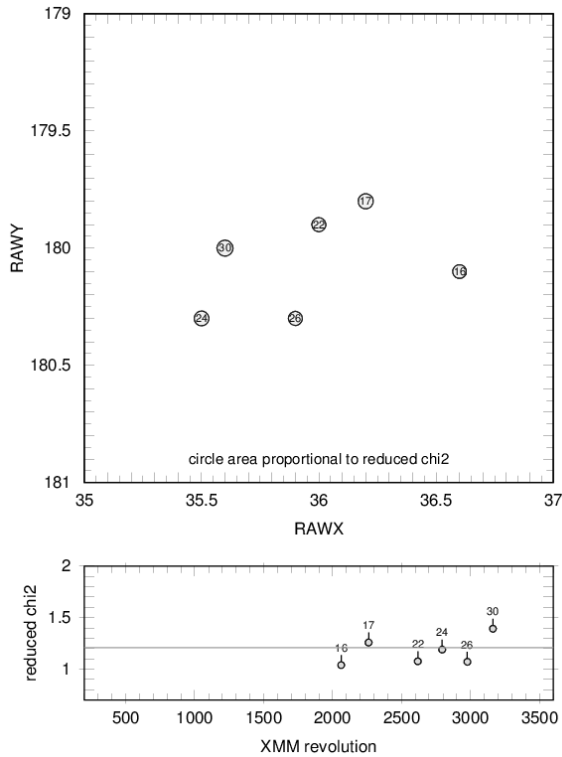


# 1E 0102: Fit quality over position and time



→ 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](https://doi.org/10.1051/0004-6361/201118489)  
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**Astronomy  
&  
Astrophysics**

## **Spectral monitoring of RX J1856.5-3754 with *XMM-Newton* Analysis of EPIC-pn data**

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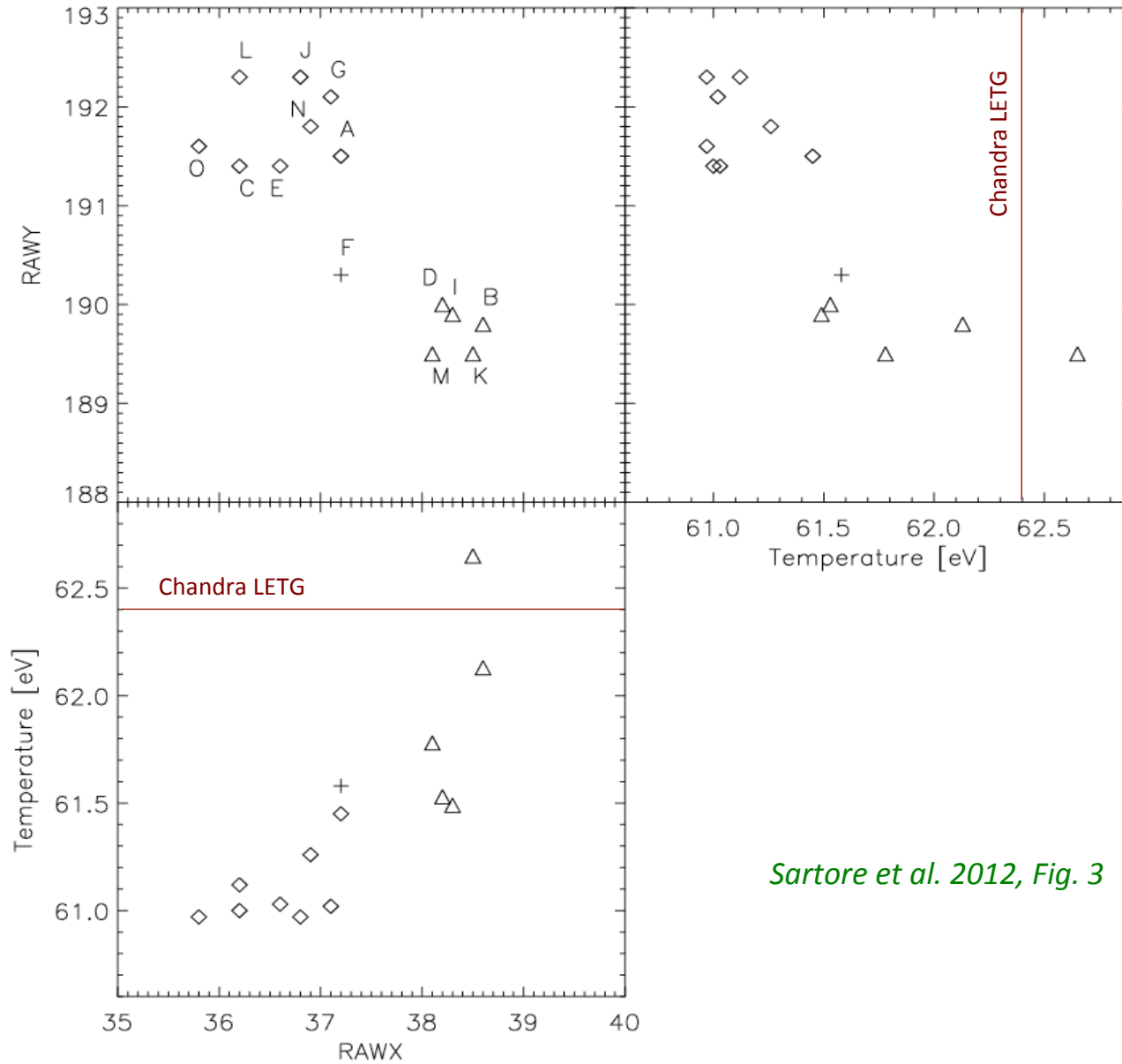
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<sup>5</sup> Mullard Space Science Laboratory, University College London, Holmbury St. Mary, Dorking, Surrey, RH5 6NT, UK

<sup>6</sup> Max-Planck-Institut für extraterrestrische Physik, Giessenbachstraße, 85748 Garching bei München, Germany

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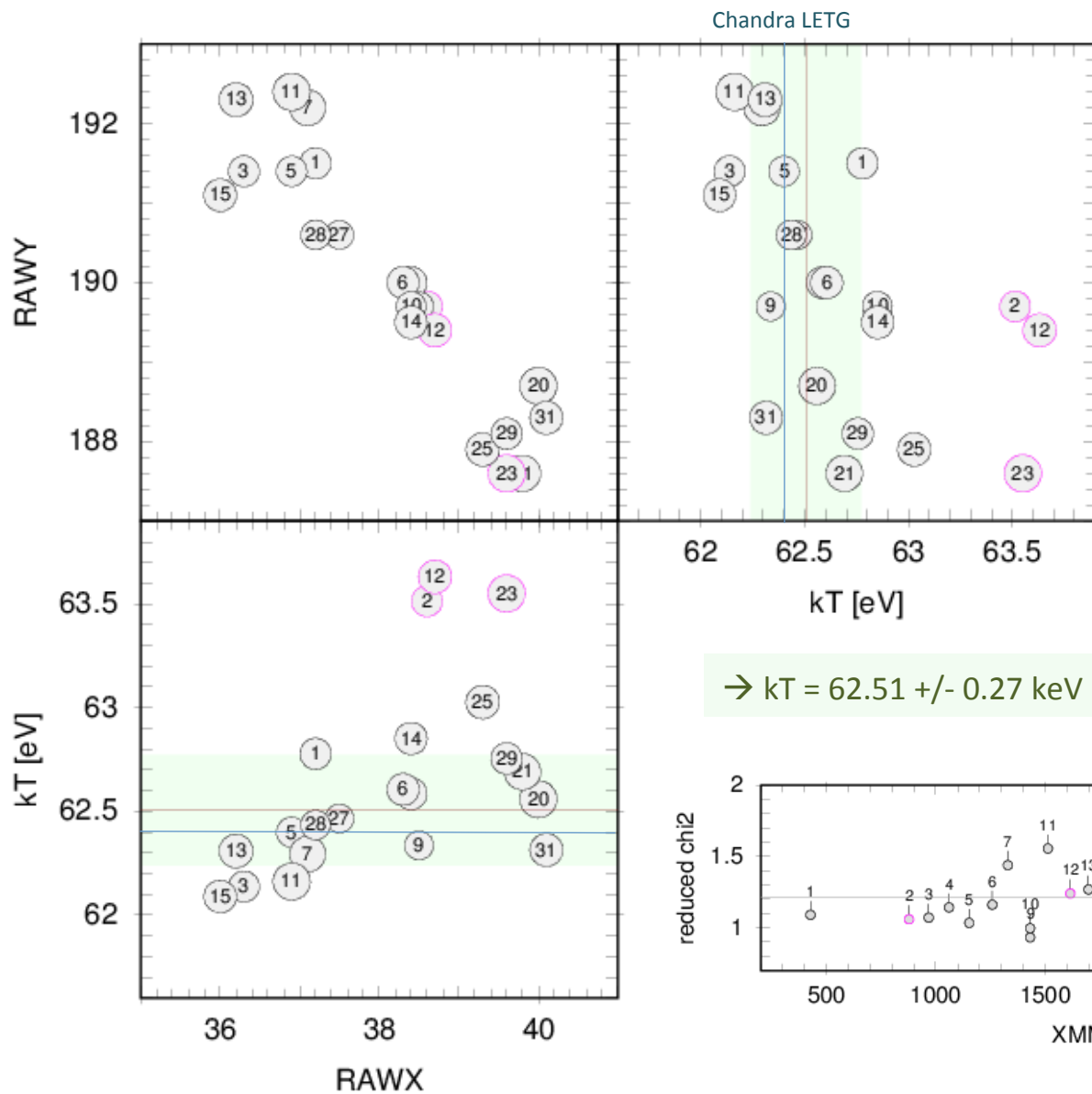
# Previous spectral studies of RX J1856



*Sartore et al. 2012, Fig. 3*



# RX J1856: spectral fit results from new RMF

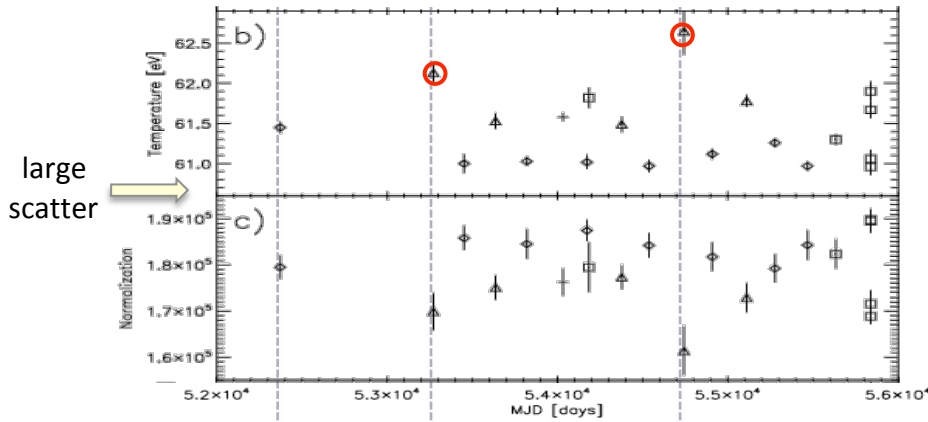


- $\rightarrow$  kT consistent with Chandra LETG
- $\rightarrow$  deviation in 3 observations (but no long-term trend and no positional trend)

Chandra:  $kT = (62.4 \pm 0.4) \text{ eV}$

$\rightarrow kT = 62.51 \pm 0.27 \text{ keV}$  (excluding 2,12,23)

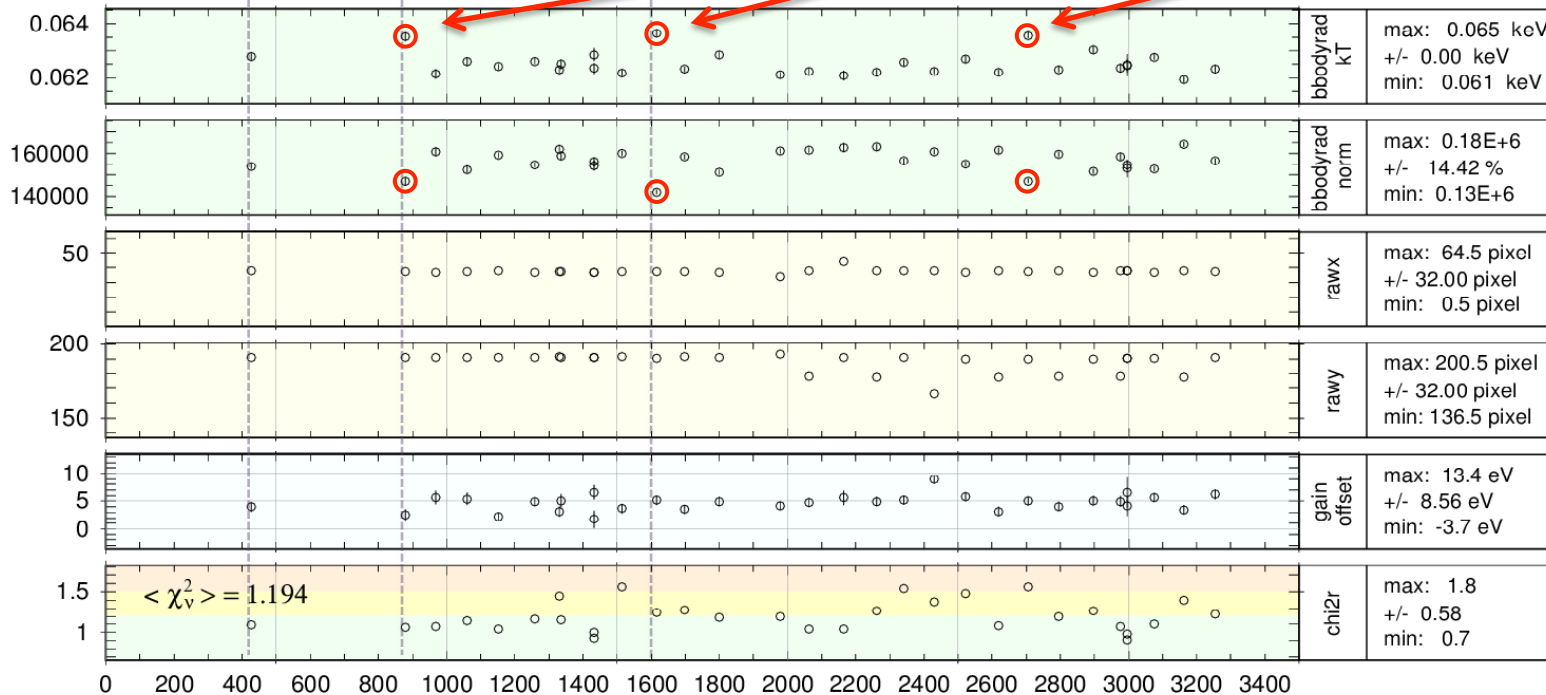
# RX J1856: new RMF highlights sporadic spectral changes



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

*Sartore et al. 2012, Fig. 2*

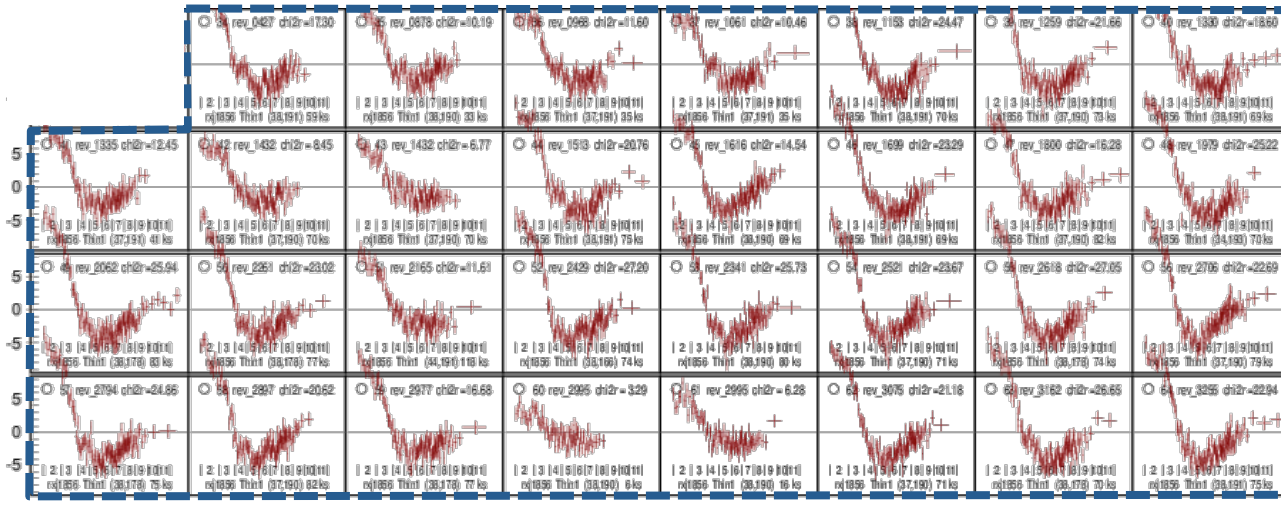
evidence for sporadic spectral changes



rxj1856

$\chi_v^2 = 1.19$

# Previous spectral studies of RX J1856



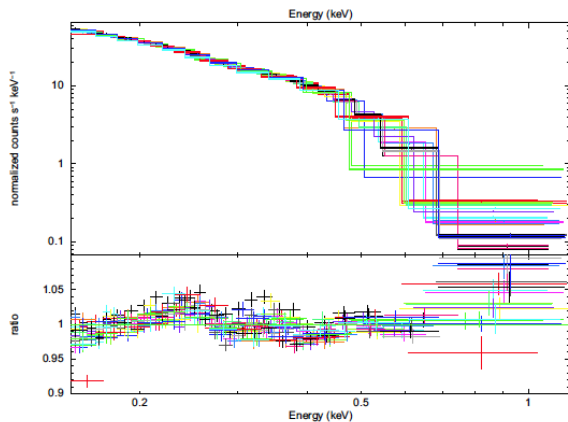
**TBabs \* bbodyrad**

with all parameters from Chandra  
(no free parameter!)

$n_H == 7.25 \cdot 10^{-19} \text{ cm}^{-2}$   
 $kT == 62.4 \text{ eV}$   
 $\text{norm} == 1.58 \cdot 10^5$

+ gain fit (offset)

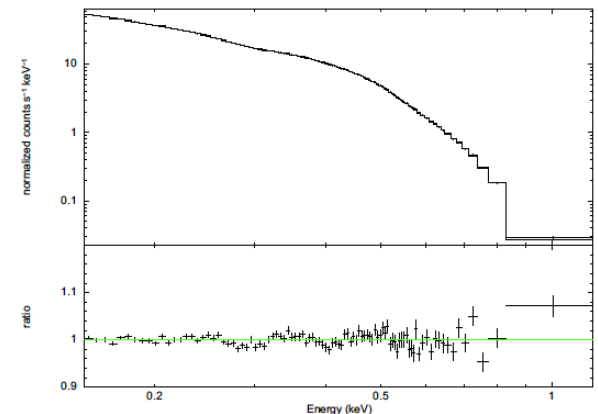
→ necessity to adopt significantly different parameters and/or to introduce a second component



*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

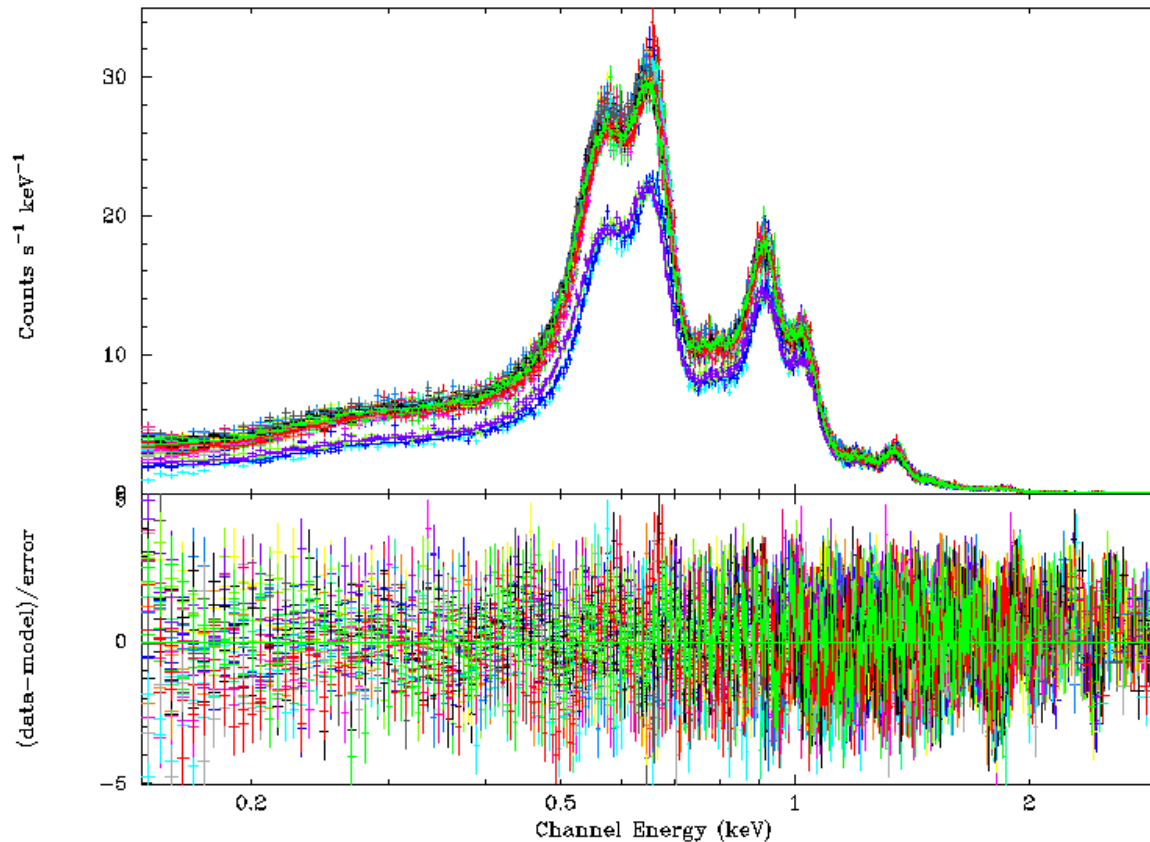
→  $n_H = (5.84 \pm 0.04) \times 10^{19} \text{ cm}^{-2}$   
→  $kT = 61.30 \pm 0.04 \text{ eV}$



*Sartore et al. 2012, Fig. 5*

RX J1856: major discrepancies to Chandra results with xmmas RMF

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

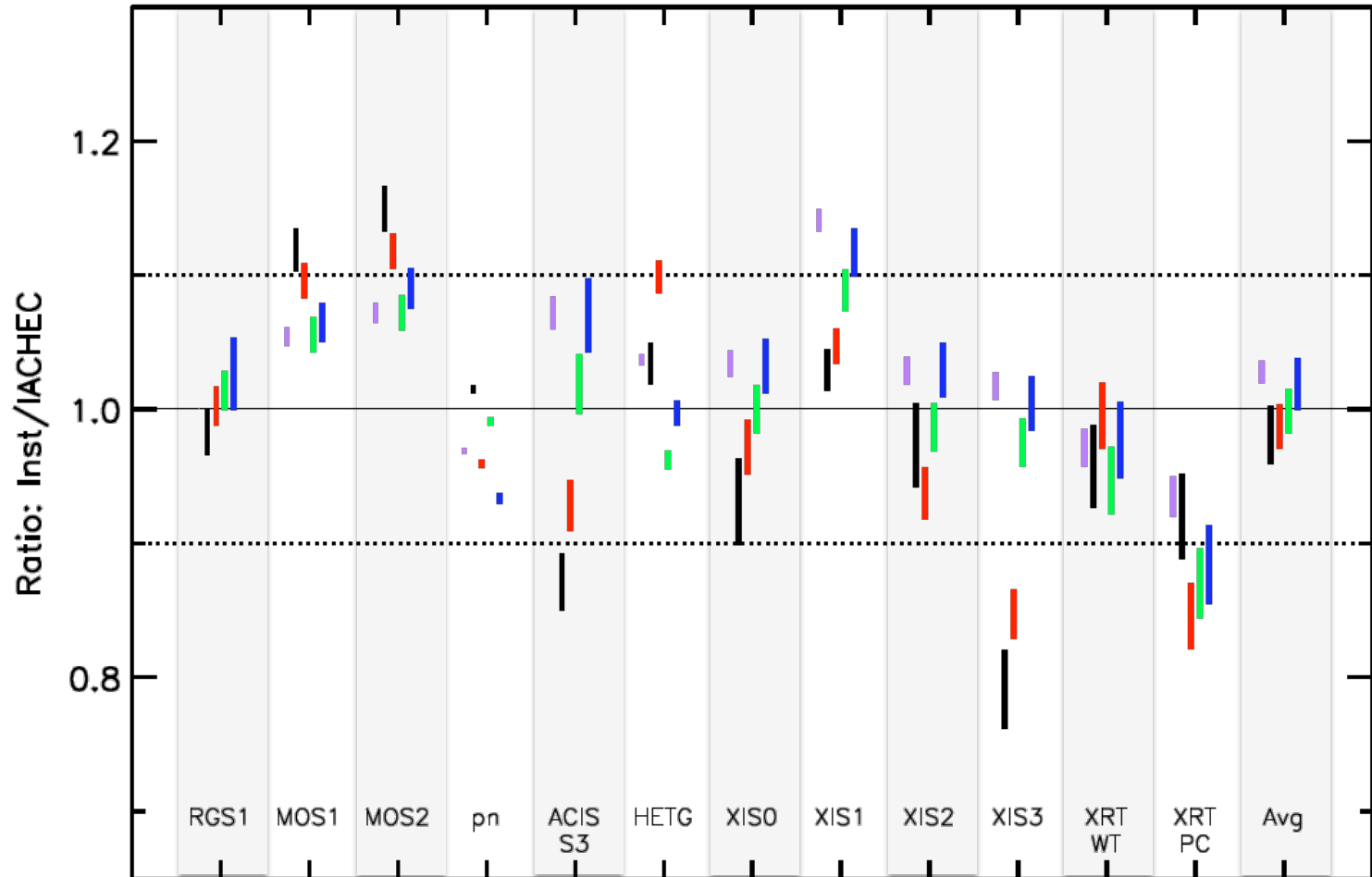


$E = 0.15 - 3.0$  keV, extraction radius: 30 arcsec, small window mode, singles only  
each spectrum fit with time dependent parameterized RMF  
reduced  $\chi^2 = 1.382$ ,  $\chi^2 = 15\,482$ , 11 206 PHA bins, 11 201 degrees of freedom



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

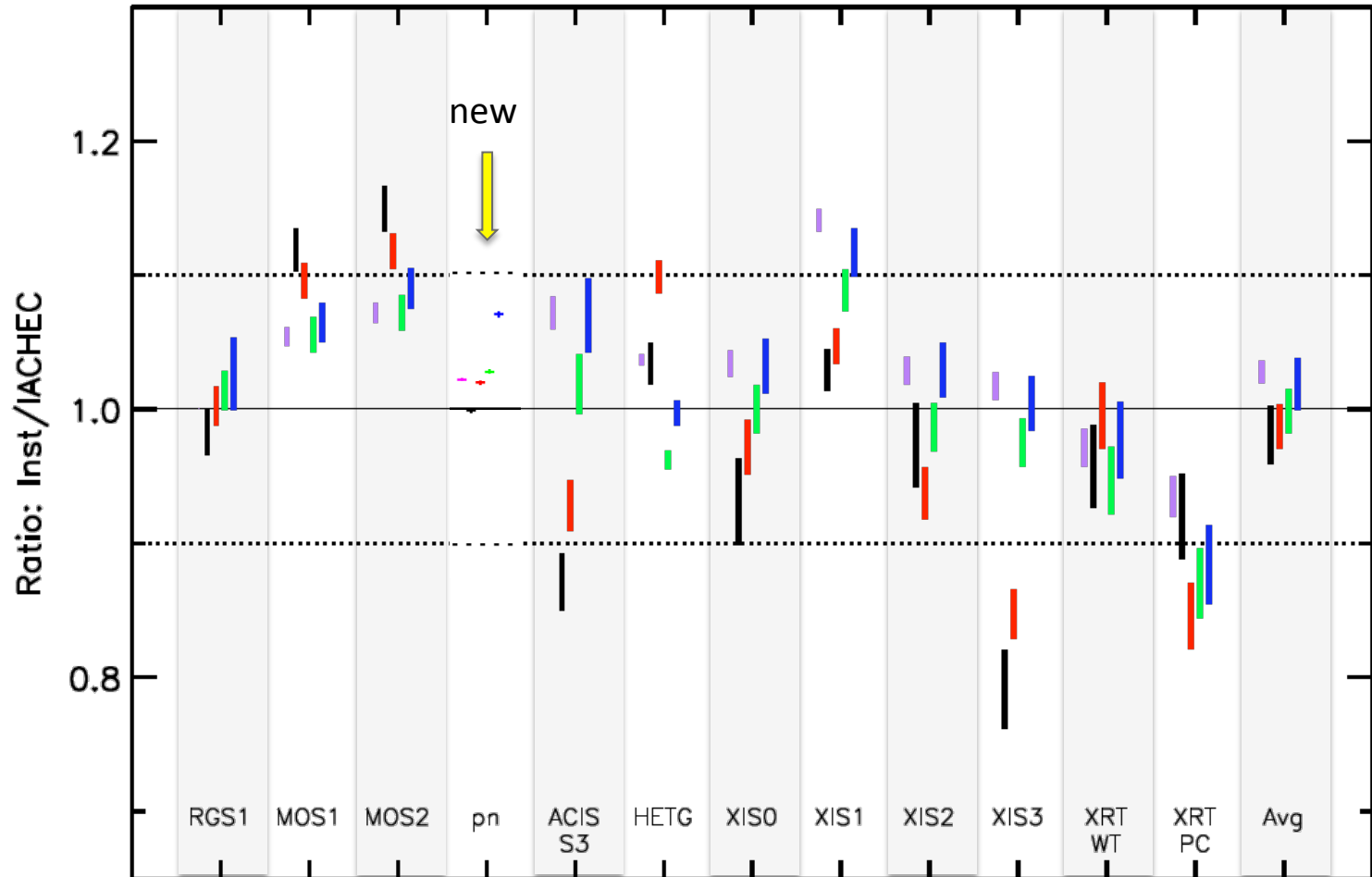
A&A 597, A35 (2017)



**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  $1.0\sigma$  CL for the scaled normalization.

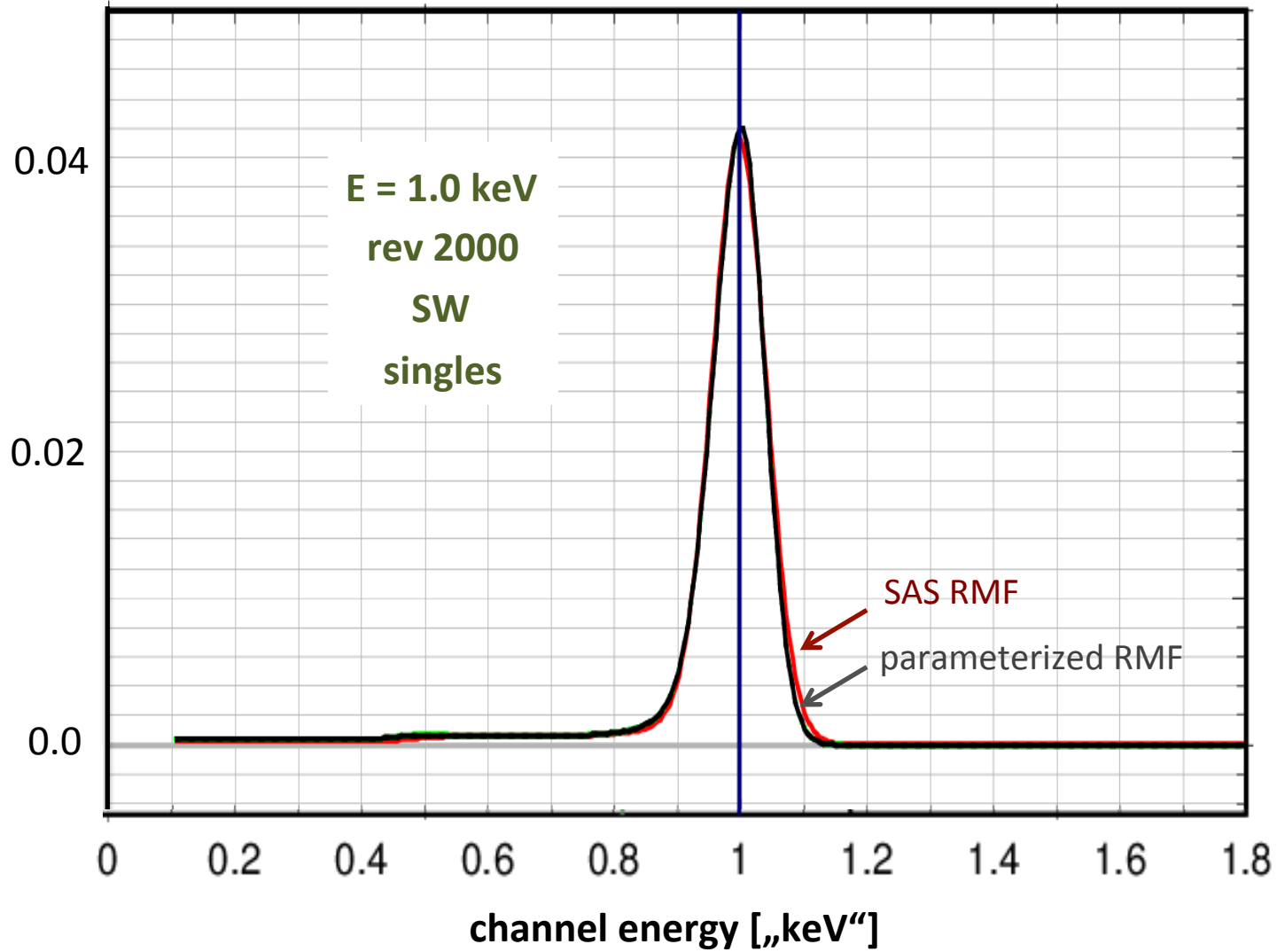
# 1E 0102: IACHEC model & XMM-Newton / EPIC-pn

A&A 597, A35 (2017)

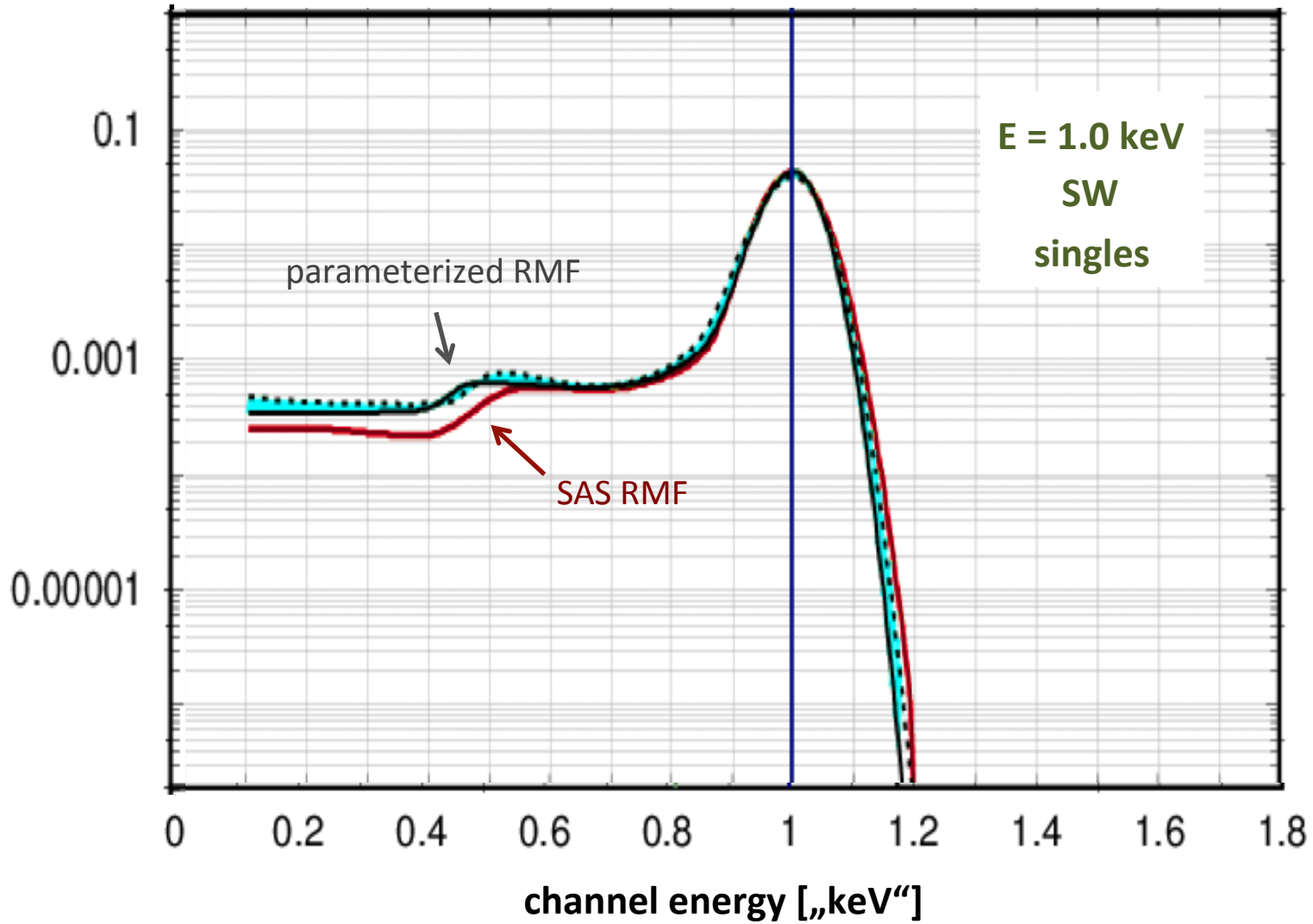


**Fig. 14.** Comparison of the scaled normalizations for each instrument to the IACHEC model values and the average. There are four or five points for each instrument which are from left to right, global normalization (purple), O VII Heα r (black), O VIII Lyα (red), Ne IX Heα r (green), and Ne X Lyα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

# What has changed in the RMF ?

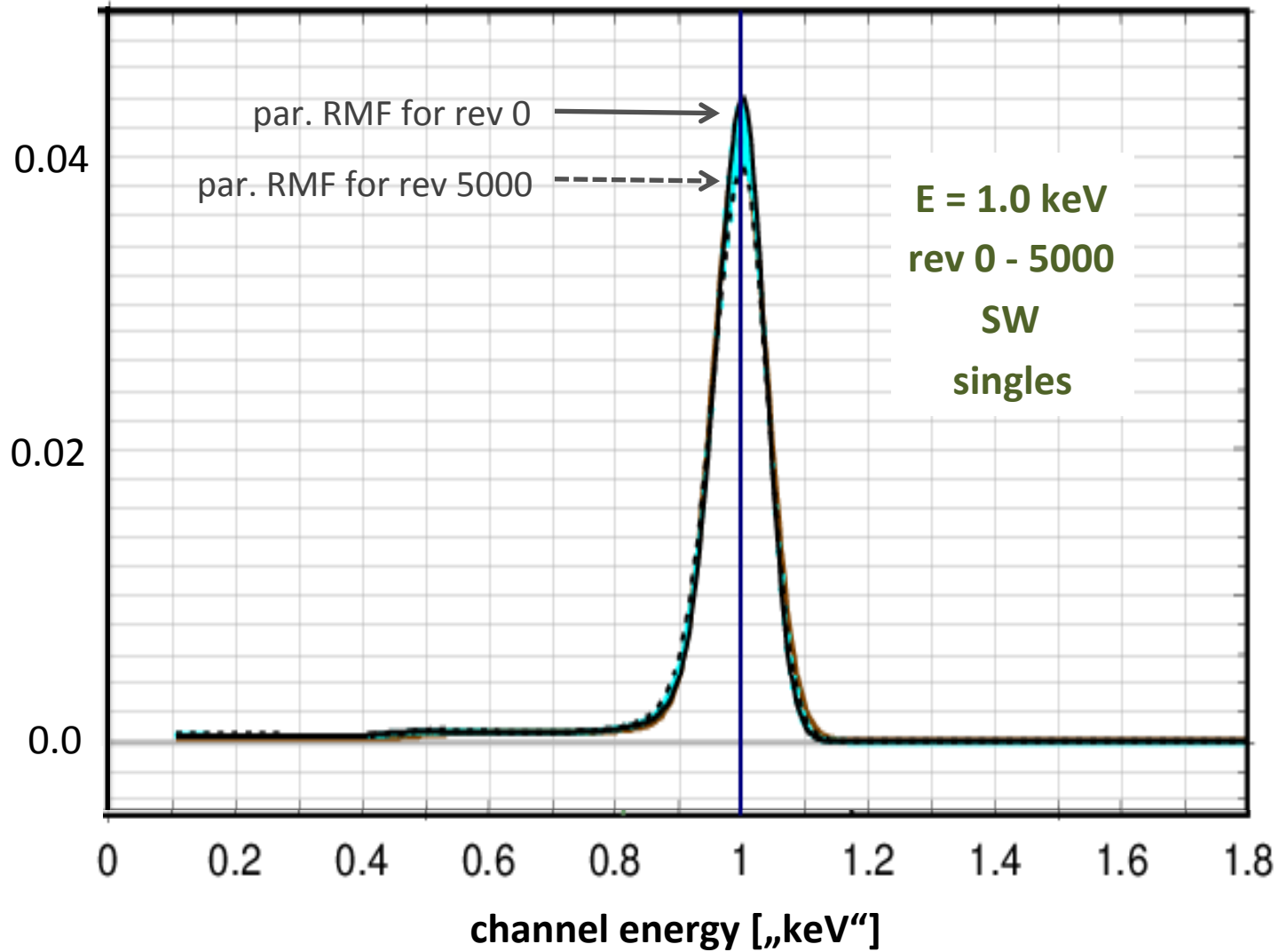


# What has changed in the RMF ?

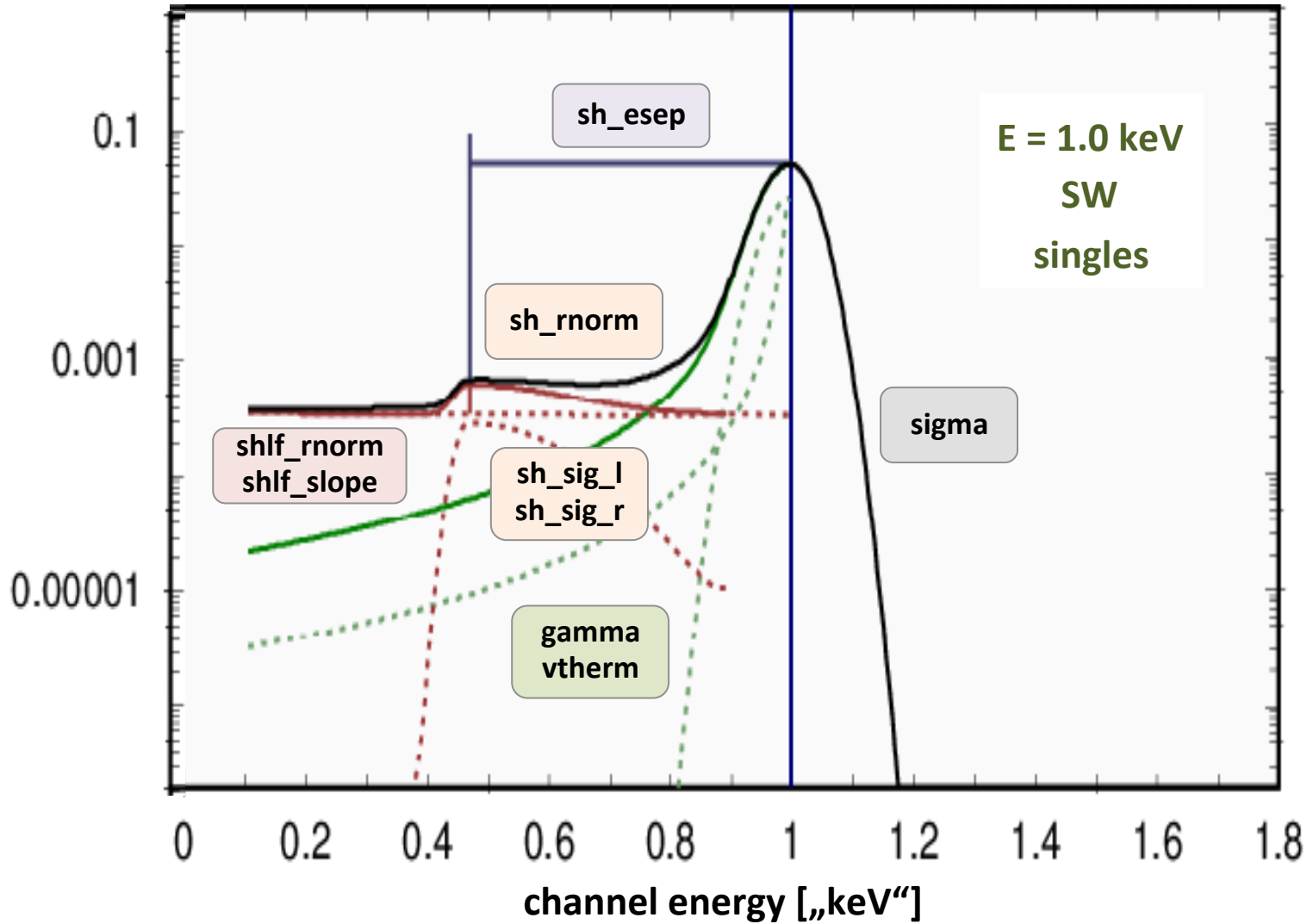




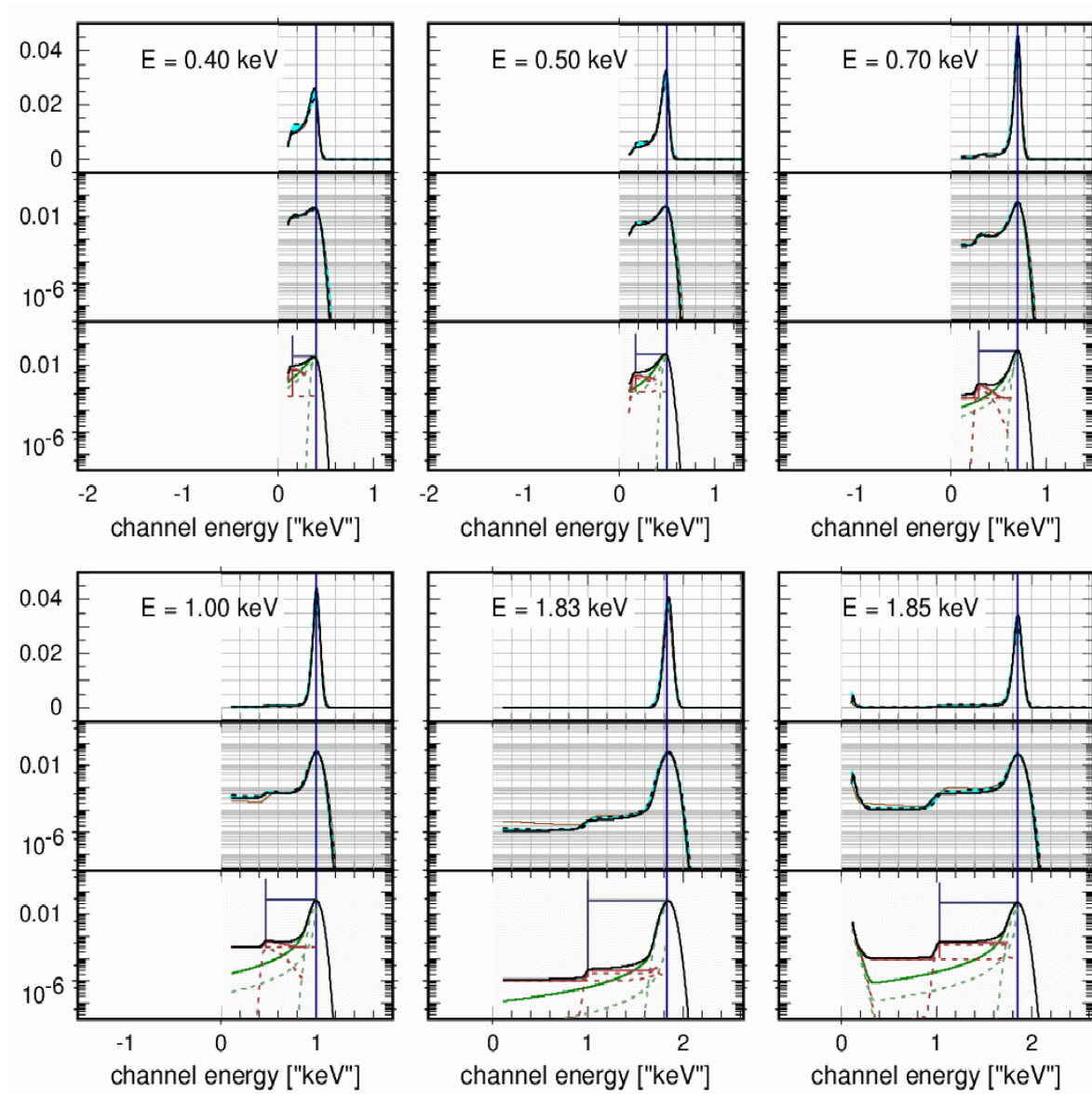
# Temporal trend in the parameterized RMF



# 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

