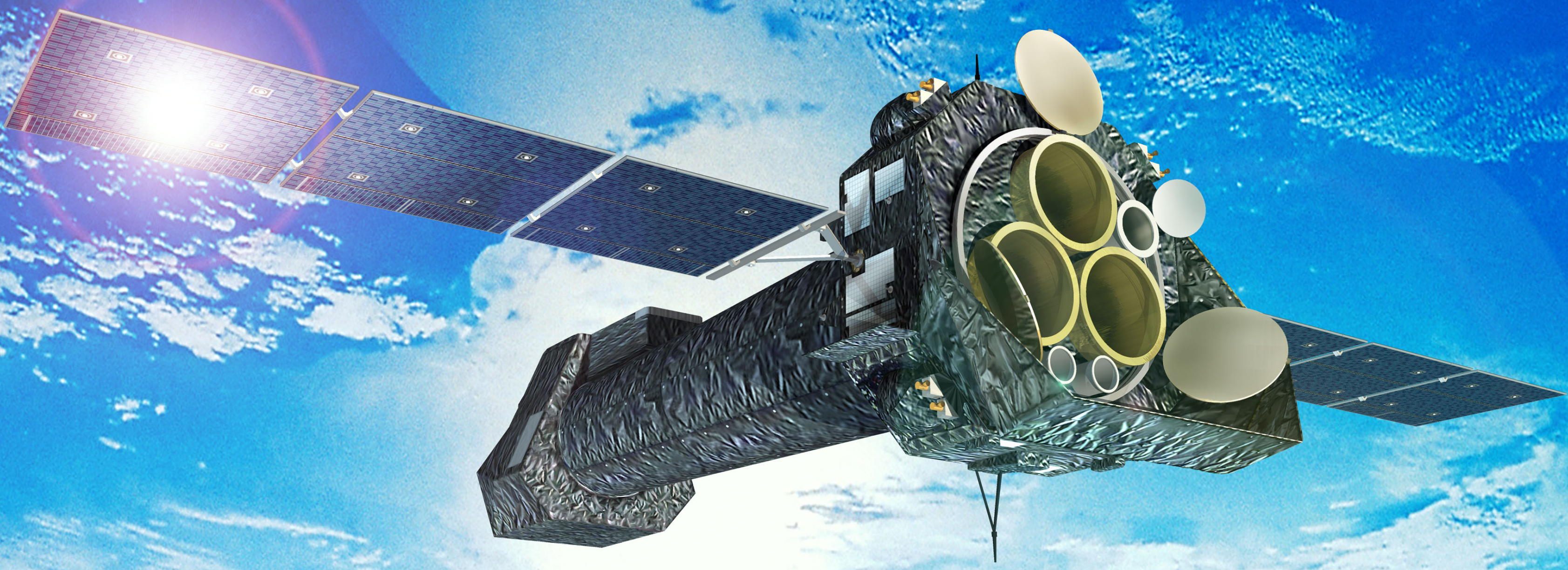
An empirical method for improving the XMM-Newton/EPIC-pn RMF and ARFs

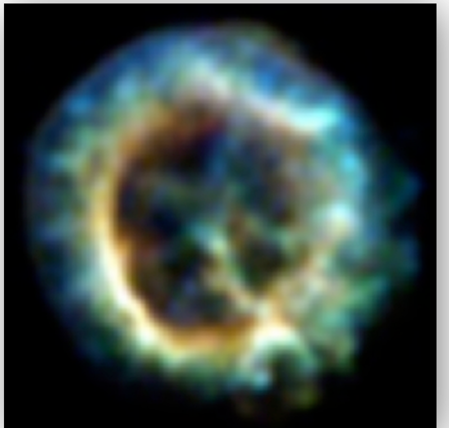


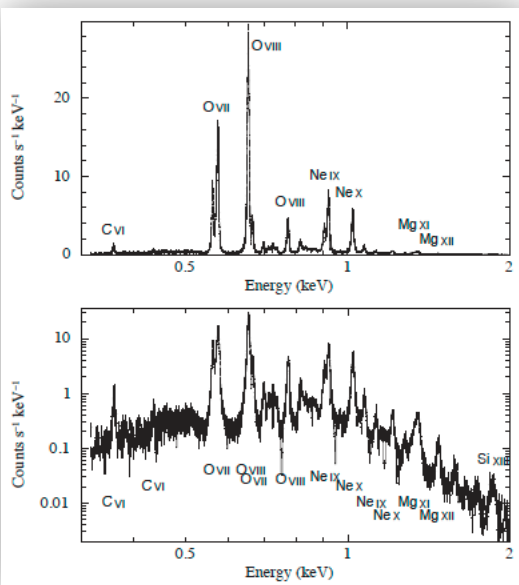
Konrad Dennerl - Max Planck Institute for extraterrestrial Physics – Garching - Germany

A&A 597, A35 (2017)

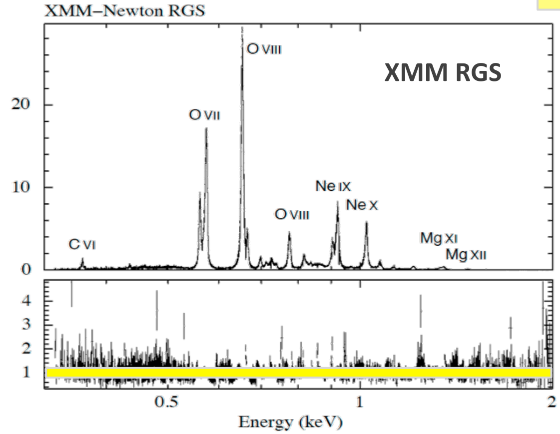
SNR 1E 0102.2-7219 as an X-ray calibration standard in the 0.5–1.0 keV bandpass and its application to the CCD instruments aboard *Chandra*, *Suzaku*, *Swift* and *XMM-Newton*

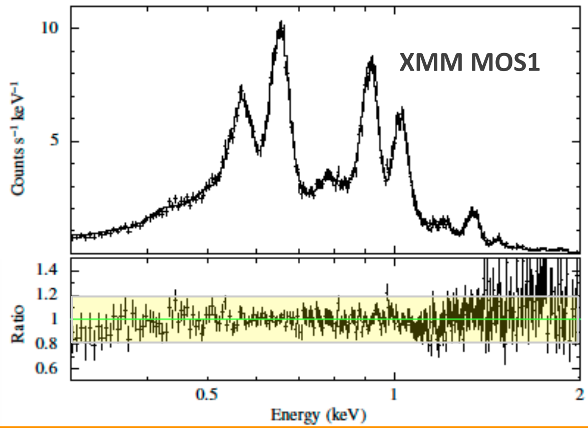
Paul P. Plucinsky[1], Andrew P. Beardmore[2], Adam Foster[1], Frank Haberl[3], Eric D. Miller[4], Andrew M. T. Pollock[5], and Steve Sembay[2]

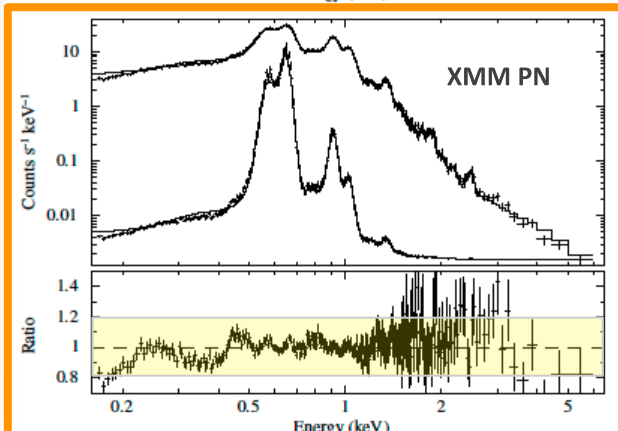


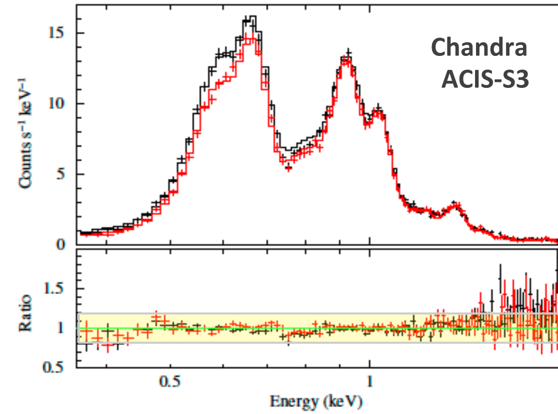


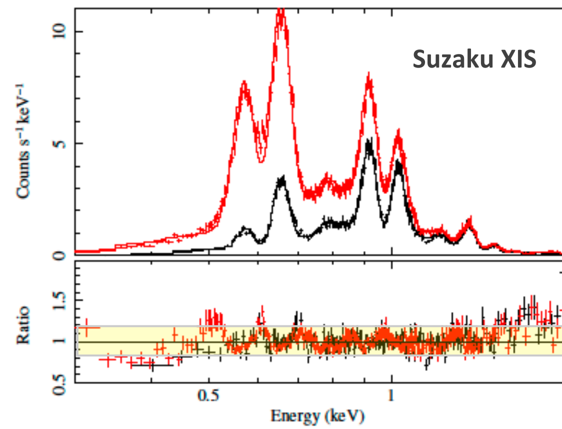
± 20%

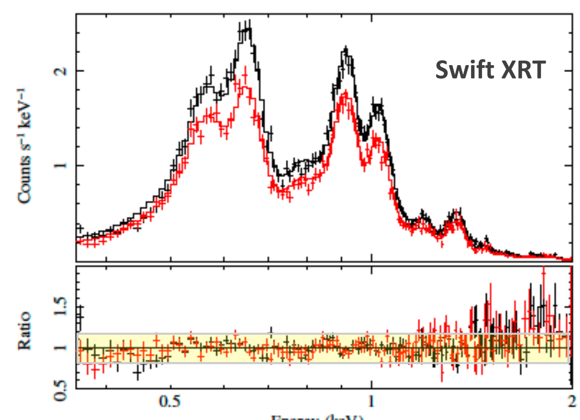






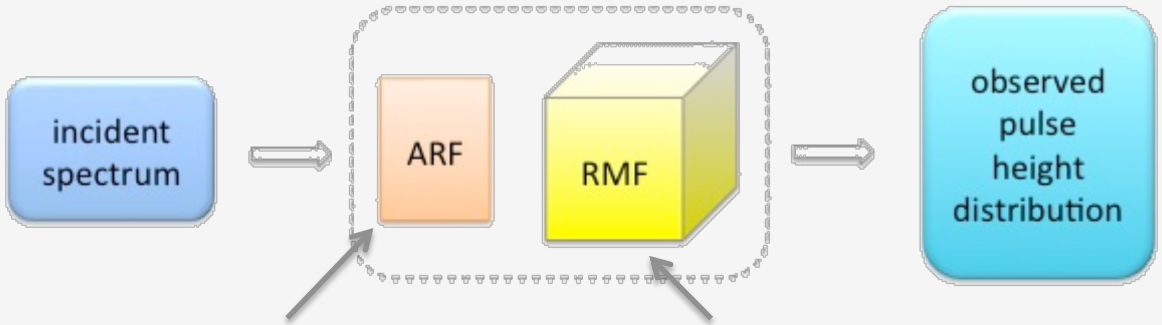






General properties of the ARF and RMF

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



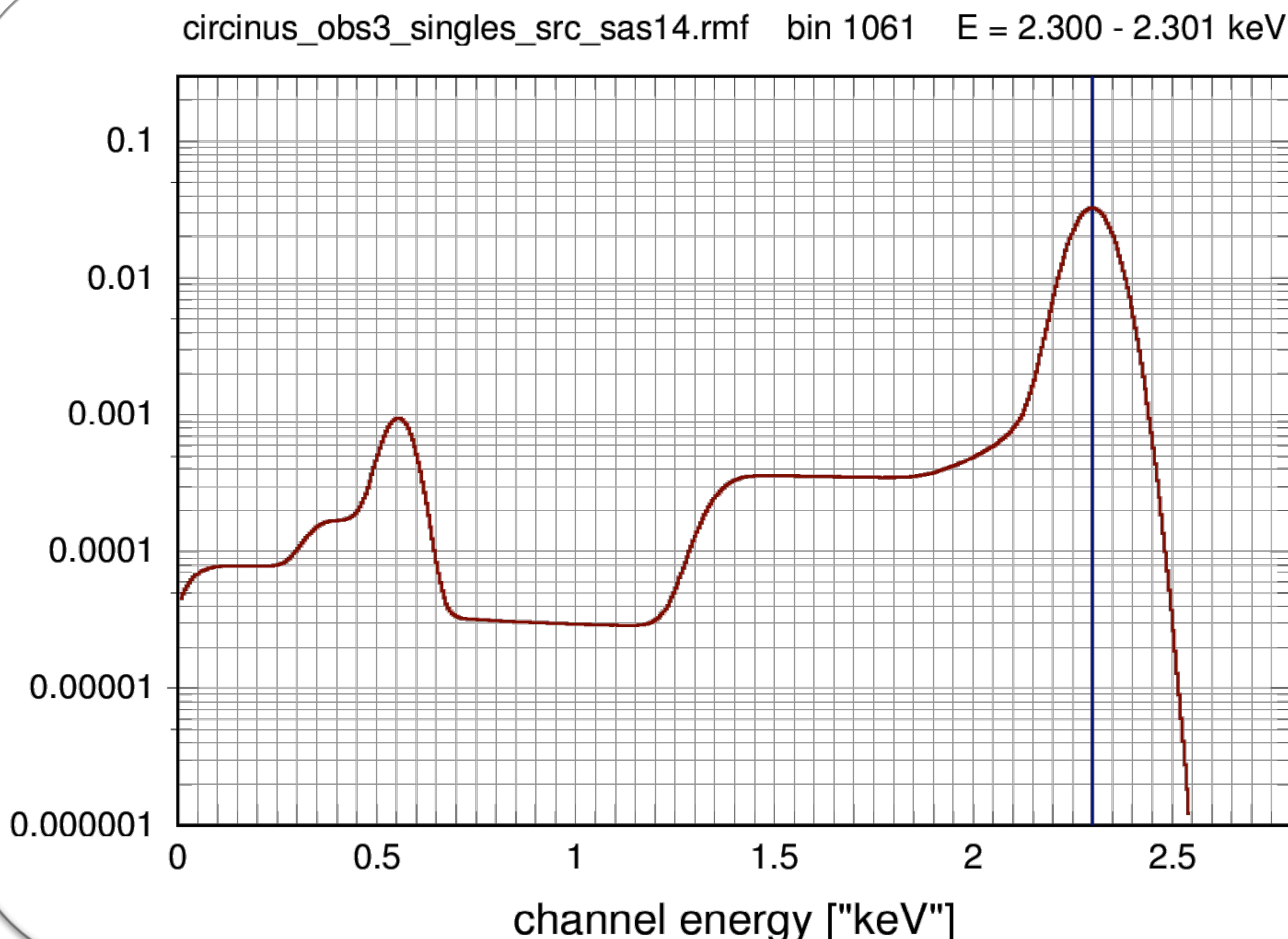
EPIC pn: 2067 vector elements | 2067 x 4096 = 8 446 432 matrix elements

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

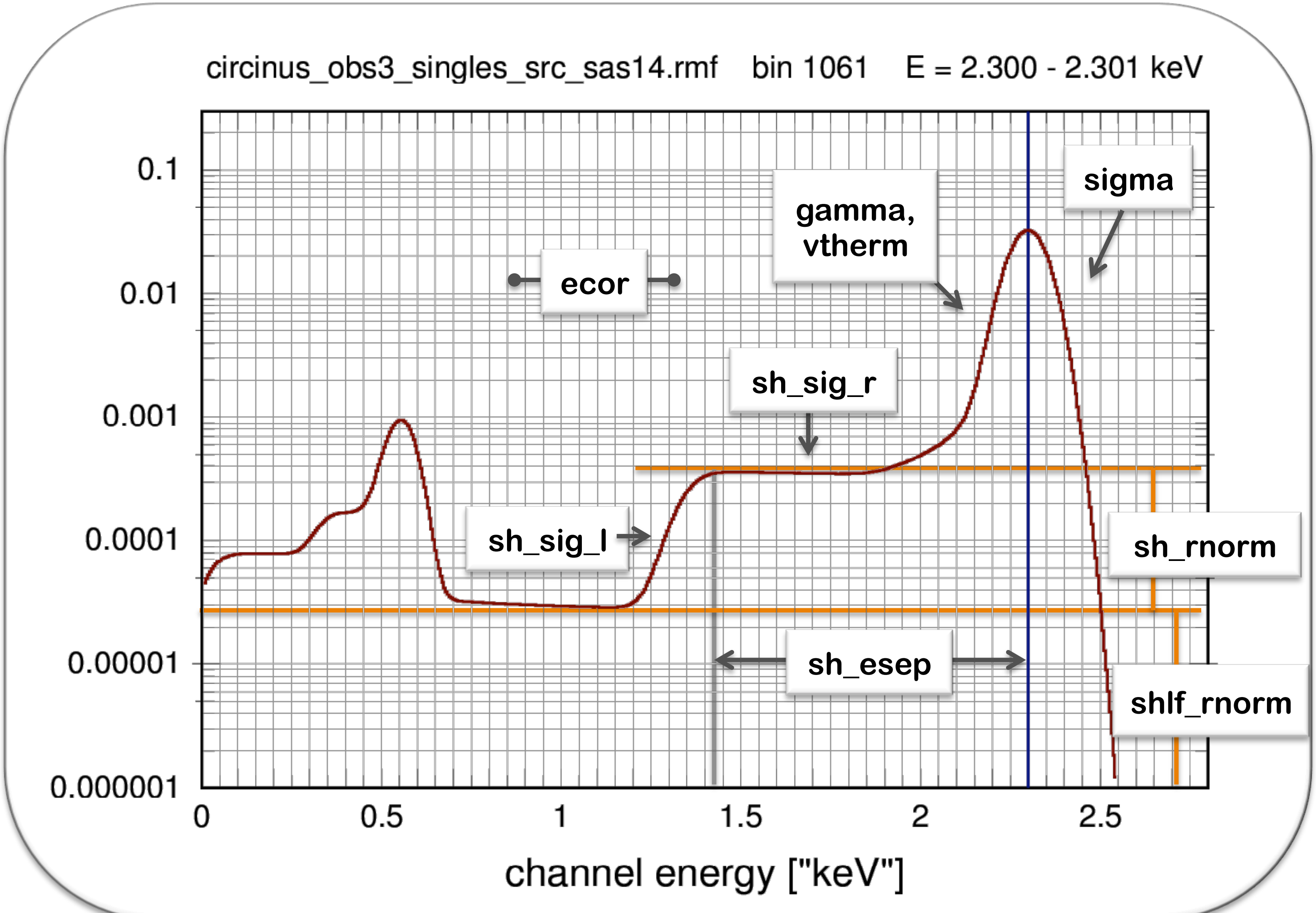
EPIC pn RMF: 8.5 million matrix elements → **HUGE** parameter space!
EPIC pn ARFs: 3 x 2067 elements → comparatively trivial

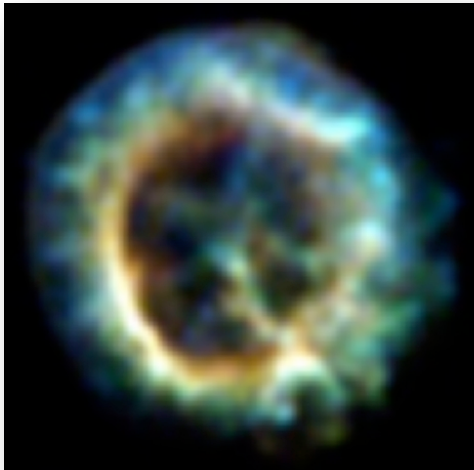
→ find appropriate RMF parametrization and try to optimize it..

Model Parameters for the EPIC pn RMF



Model Parameters for the EPIC pn RMF

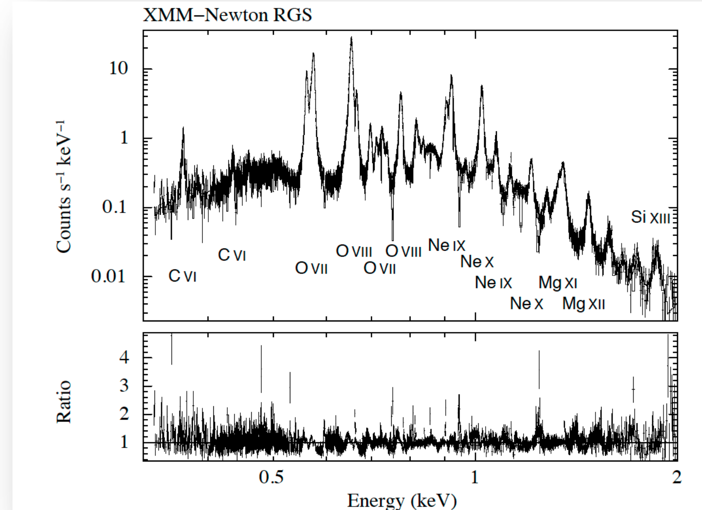


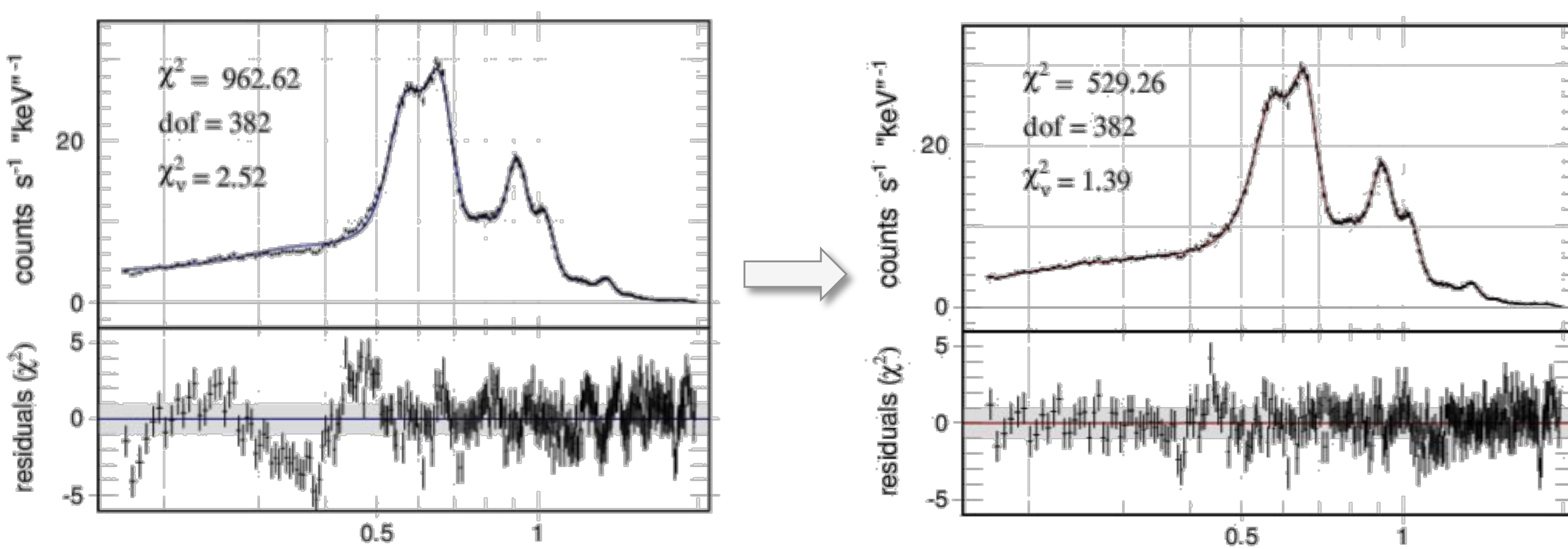


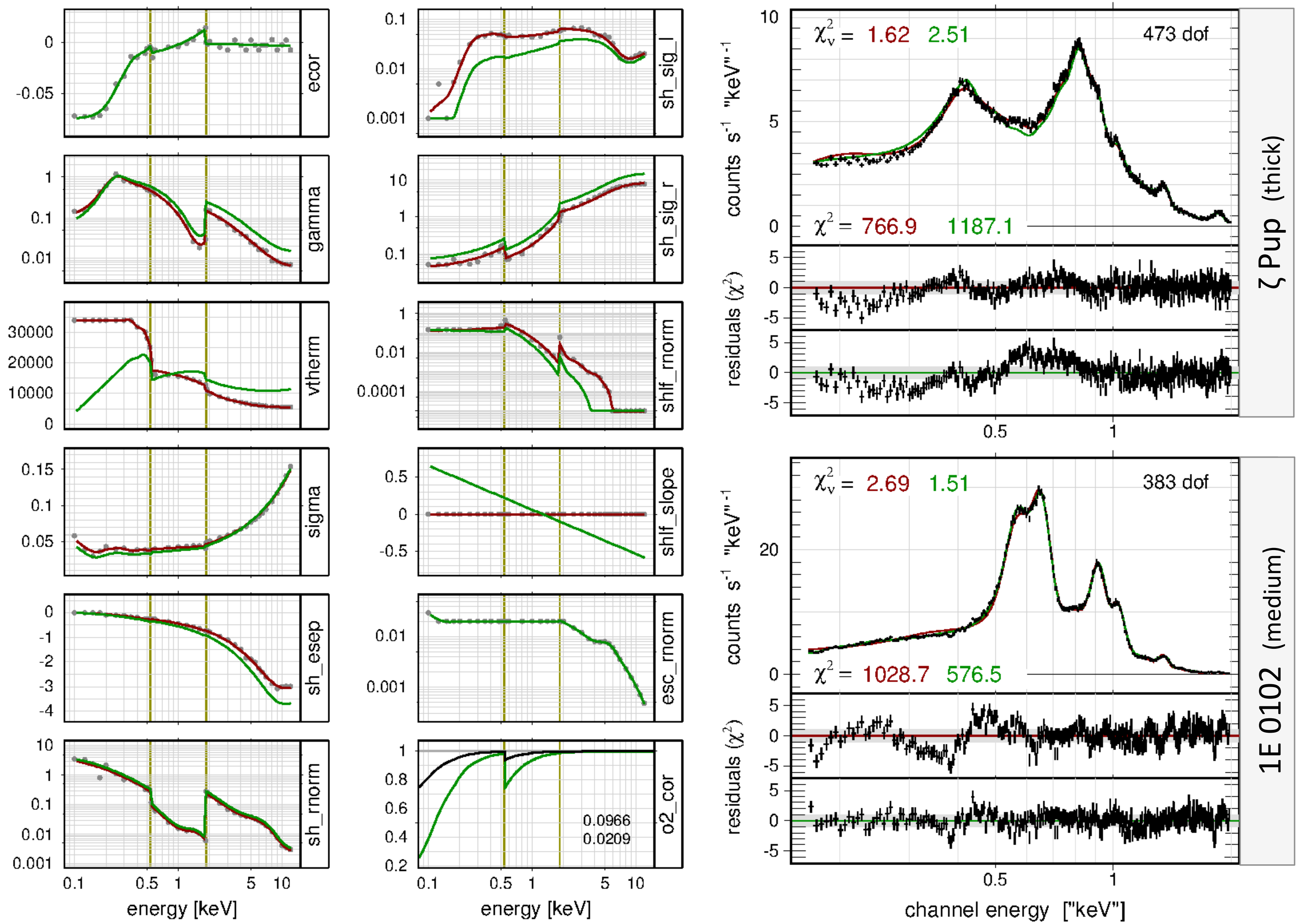
Improving the EPIC pn RMF

SNR 1E 0102

proof of concept







ecor
gamma
vtherm
sigma
sh_esep
sh_rnorm
sh_sig_l
sh_sig_r
shlf_rnorm
shlf_slope
esc_rnorm
o2_cor
0.0966
0.0209
energy [keV]
energy [keV]
χ^2_ν = 1.62 2.51
473 dof
χ^2 = 766.9 1187.1
ζ Pup (thick)
χ^2_ν = 2.69 1.51
383 dof
χ^2 = 1028.7 576.5
1E 0102 (medium)
counts s^{-1} "keV"$^{-1}$
residuals (χ^2)
channel energy ["keV"]

Interim result:

algorithm works well, but resulting RMF depends heavily on assumed spectral models

Is there any possibility to expose the CCD to a known X-ray spectrum ?

Currently no, but for XMM/EPIC we can modify the incident spectrum in a controlled way!

There is a filter wheel..

Idea: observe the same
(temporally constant, soft, non piled-up)
X-ray source(s) with all available filters
and fit the spectra
simultaneously with the same RMF

General strategy:

- make this calib…
  by minimizi…
- ➢ at (almost) … l experiment"
- ➢ at the **same** … : check of the ARF
- ➢ with the **san**…

- to make this … changes),
  repeat the filter sequence immediately afterwards, e.g.
  thick – medium – thin -- thick – medium – thin

XMM rev 2995: **RXJ 1856**, SW
18.0 ks thick – 9.3 ks medium – 6.2 ks thin
18.9 ks thick – 8.5 ks medium – 16.0 ks thick

XMM rev 3000: **1E 0102**, SW
30.5 ks thick – 12.5 ks medium – 12.5 ks thin
30.5 ks thick – 14.2 ks medium – 17.5 ks thick

Simultaneous fit to
RXJ 1856 and 1E0102
in three filters each

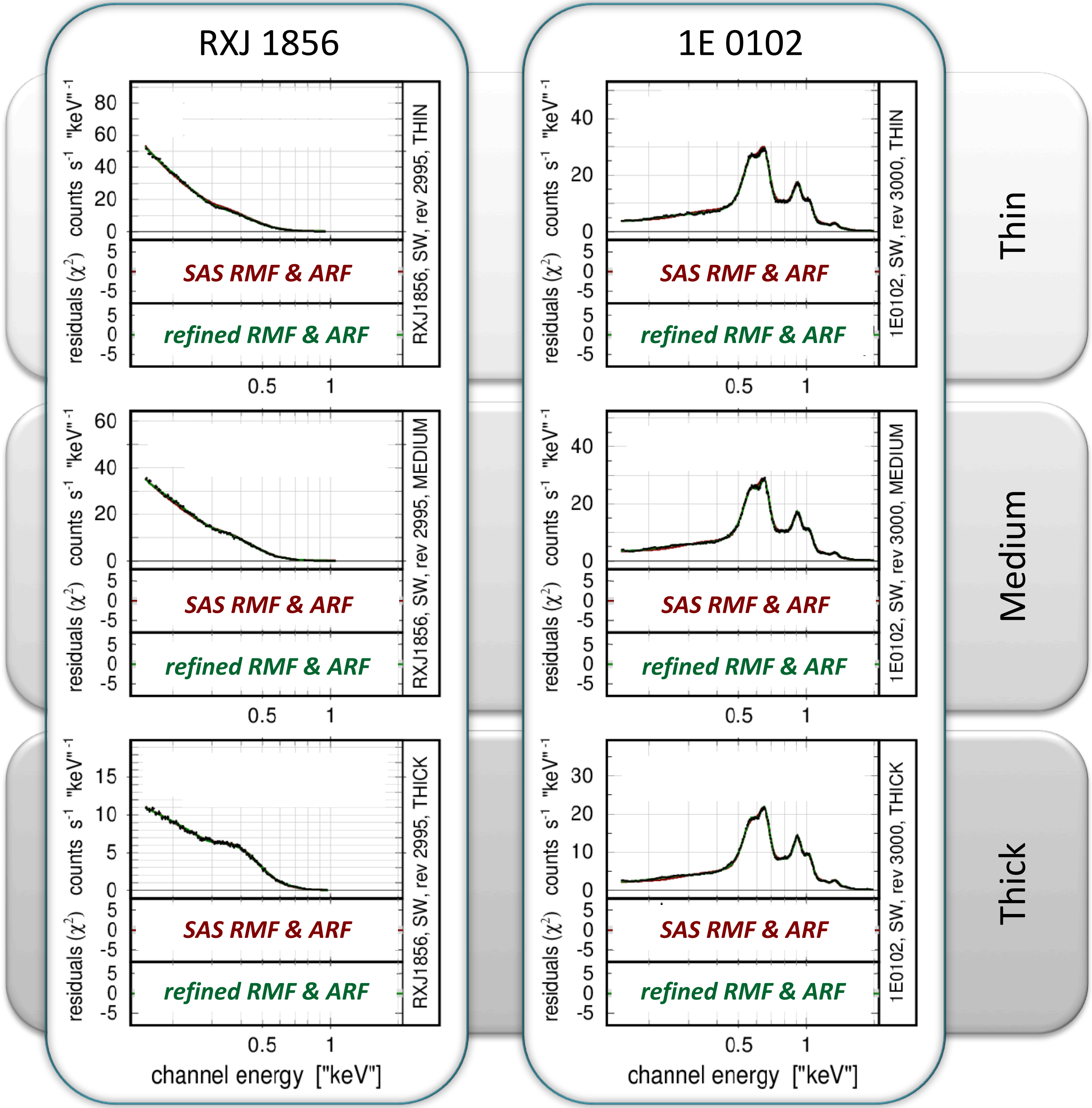
using the same
model spectrum
for each source,
with no normalization
between the filters

and

1 RMF + 3 ARFs

⇩

significant
improvement
possible !



Simultaneous fit to
RXJ 1856 and 1E0102
in three filters each

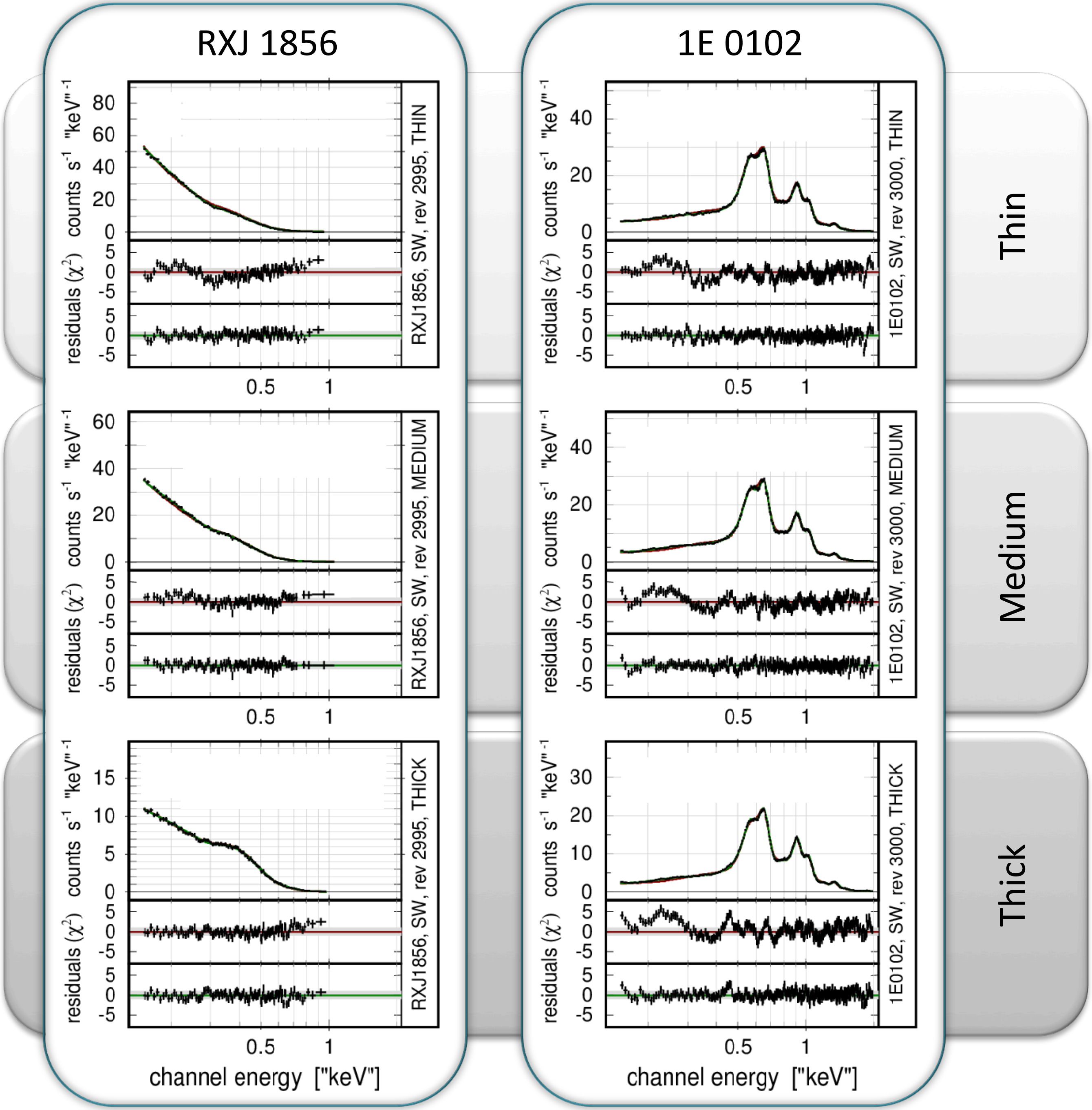
using the same
model spectrum
for each source,
with no normalization
between the filters

and

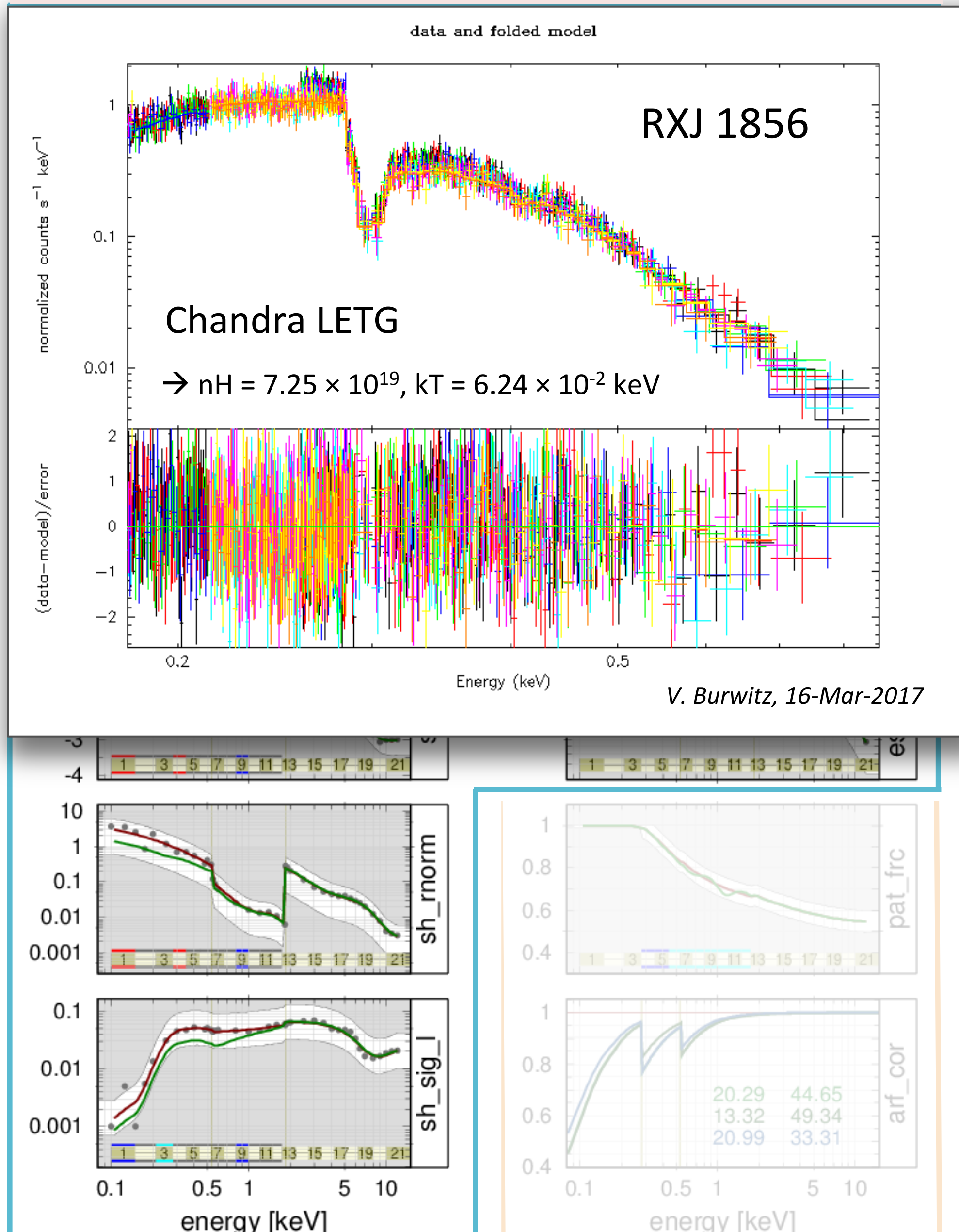
1 RMF + 3 ARFs

⇩

significant
improvement
possible !



XMM/EPIC-pn: bbodyrad: norm = 1.89 x 10^5
Chandra LETGS: bbodyrad: norm = 1.58 x 10^5 } 20 %



X-ray spectra: model, data, results

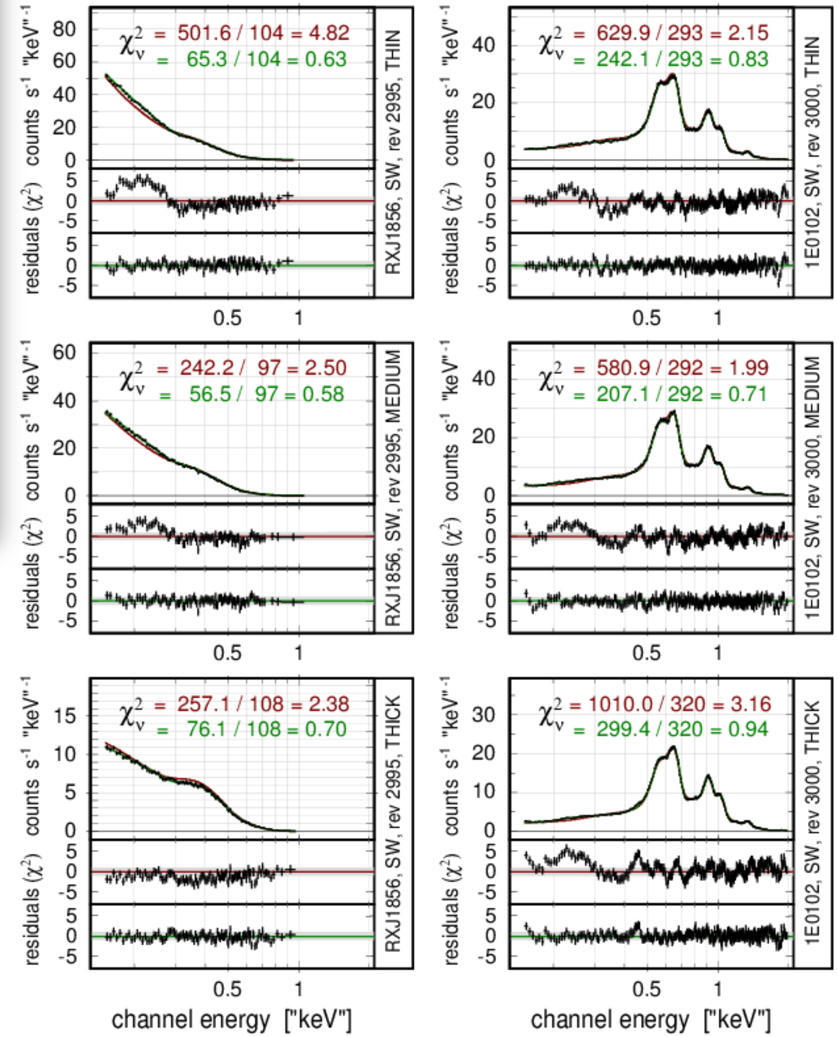
Chandra LETG

RXJ1856

bbodyrad: norm = 0.189E+06
gain: offset = -3.4 eV
n_H == 7.25 x 10^{19} cm^{-2}
kT == 62.4 eV

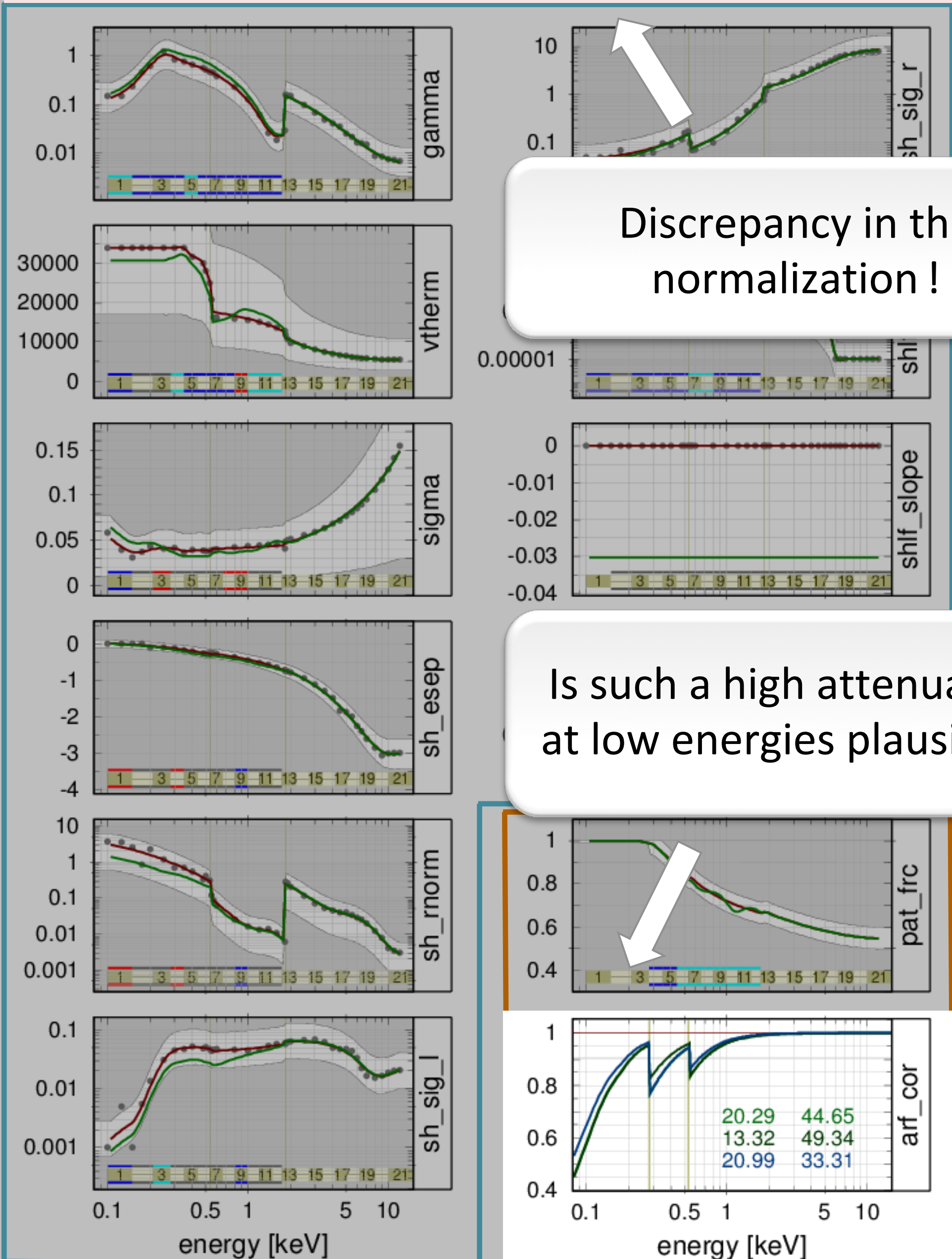
1E0102

constant: factor = 0.995
gaussian: norm = 0.139E-02
gaussian: norm = 0.135E-02
gaussian: norm = 0.474E-02
gain: offset = +2.1 eV



X-ray spectra: model, data, results

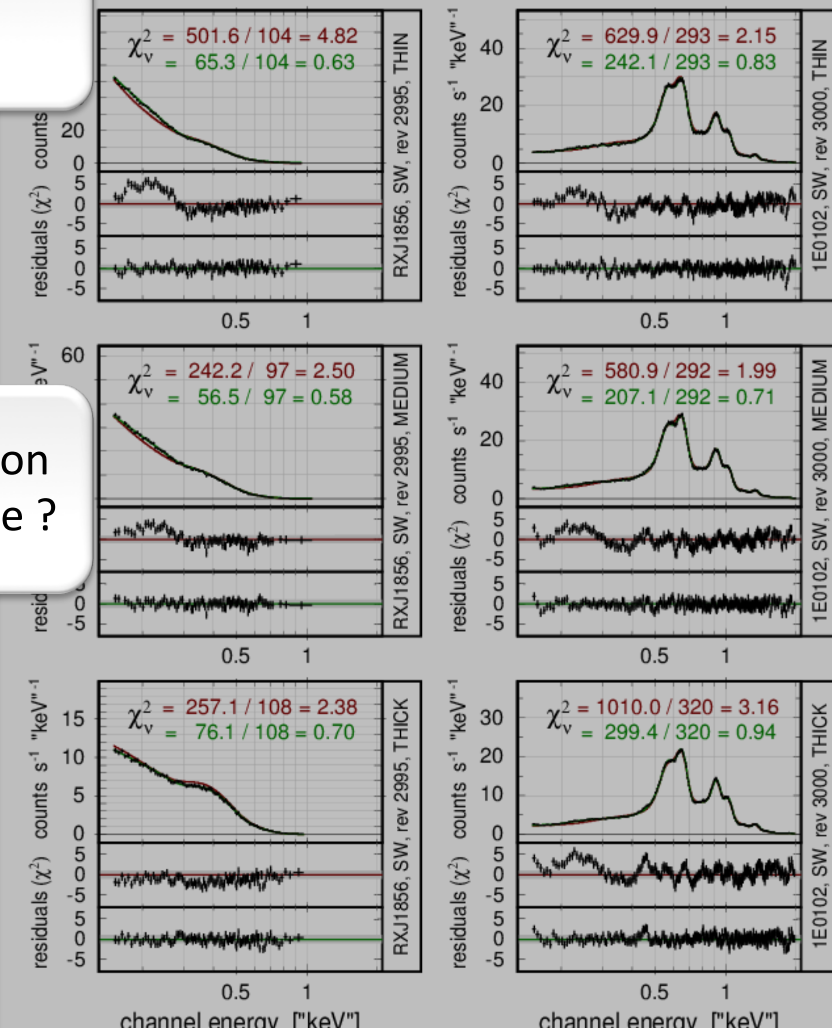
XMM/EPIC-pn: bbodyrad: norm = 1.89 x 10^5
Chandra LETGS: bbodyrad: norm = 1.58 x 10^5 } 20 %



Discrepancy in the normalization !

Is such a high attenuation at low energies plausible ?

RXJ1856	1E0102
bbodyrad: norm = 0.189E+06	constant: factor = 0.995
gain: offset = -3.4 eV	gaussian: norm = 0.139E-02
n_H == 7.25 x 10^{19} cm^{-2}	gaussian: norm = 0.135E-02
kT == 62.4 eV	gaussian: norm = 0.474E-02
	gain: offset = +2.1 eV



ARF components

Calibration of the first XMM Flight Mirror Module
II - Effective Area

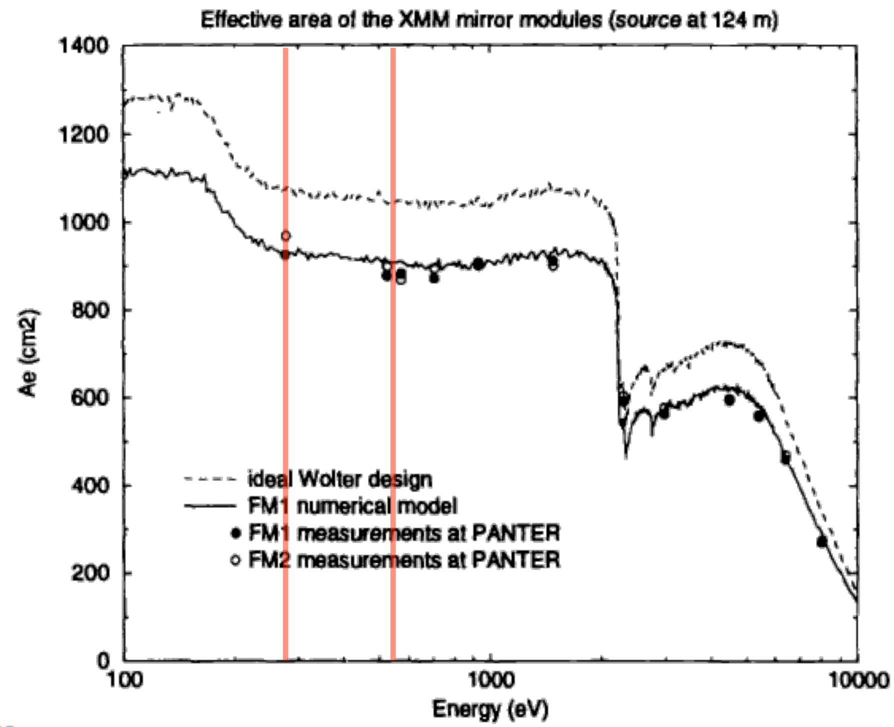
Ph. Gondoin[a], B. Aschenbach[b], M. Beijersbergen[a], R. Egger[b]
F. Jansen[a], Y. Stockman[c], J.P. Tock[c]

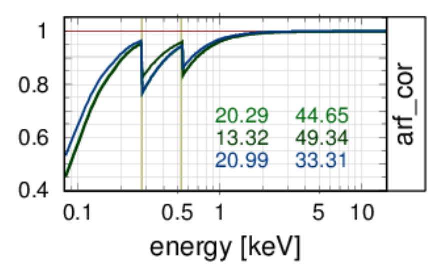
[a] European Space Research and Technology Center, 2200 AG Noordwijk zh, the Netherlands
[b] Max-Planck Institute fur Extraterrestrische Physik, 8046 Garching, Germany
[c] Centre Spatial de Liege, B-4031 Liege, Belgium

ARF („Ancillary Response File“)

= mirror effective area

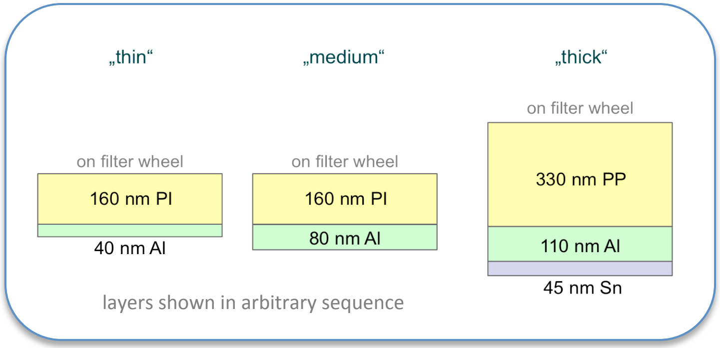
- * filter transmission
- * CCD quantum efficiency
- * fraction of single pixel events
- * threshold induced sensitivity drop





ARF change modeled by absorption from C and O

ARF components



ARF („Ancillary Response File“)

= mirror effective area

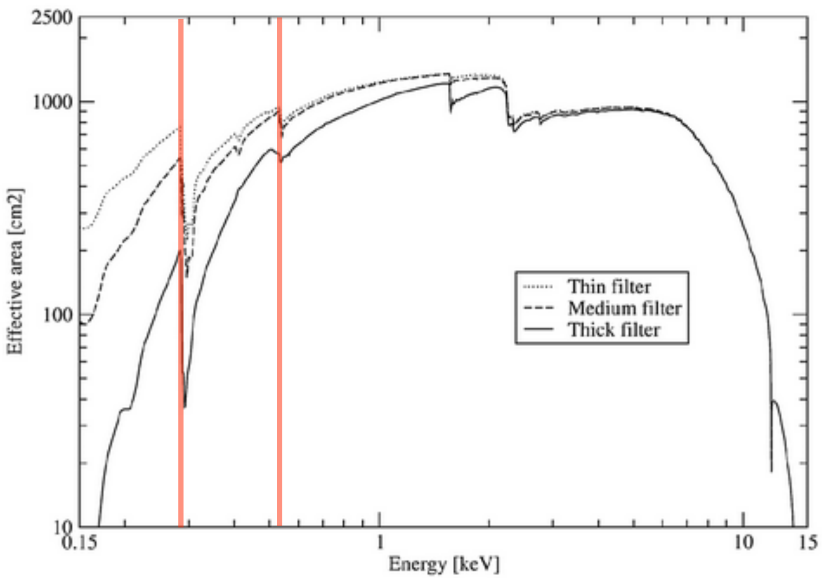
* filter transmission

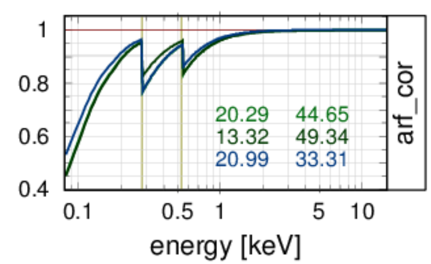
* CCD quantum efficiency

* fraction of single pixel events

* threshold induced sensitivity drop

https://www.cosmos.esa.int/web/xmm-newton/technical-details-epic





ARF change modeled by absorption from C and O

ARF components

ARF („Ancillary Response File")

= mirror effective area

* filter transmission

* **CCD quantum efficiency**

* fraction of single pixel events

* threshold induced sensitivity drop

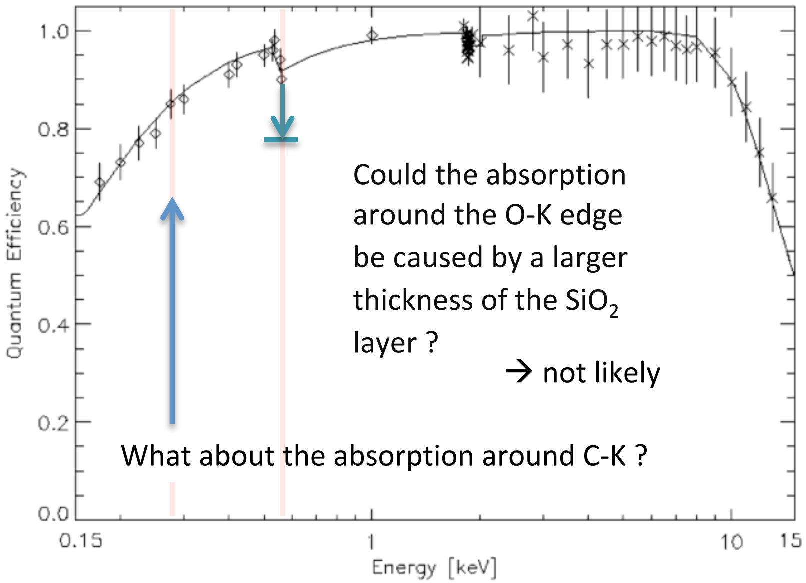
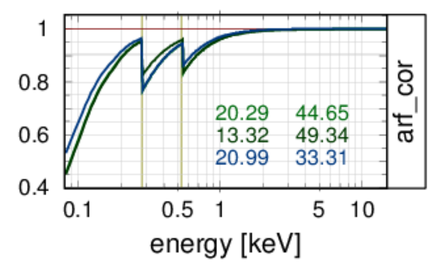


Figure 28: *Quantum efficiency of the EPIC pn CCD chips as a function of photon energy (Strüder et al., 2001, A&A, 365, L18, Fig. 5).*



ARF change modeled by absorption from C and O

ARF components

ARF („Ancillary Response File“)

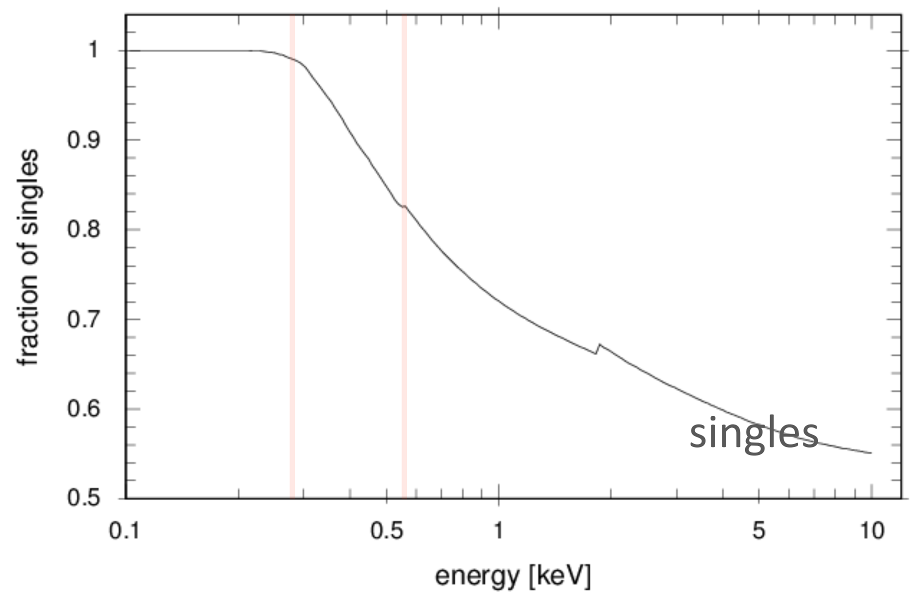
= **mirror effective area**

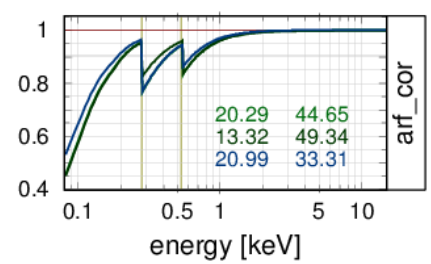
* **filter transmission**

* **CCD quantum efficiency**

* **fraction of single pixel events**

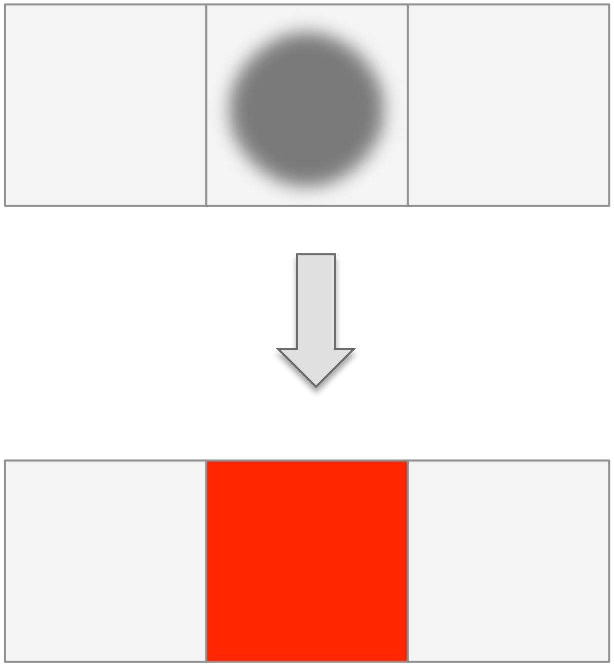
* **threshold induced sensitivity drop**





ARF change modeled by absorption from C and O

ARF components



ARF („Ancillary Response File“)

= mirror effective area

* filter transmission

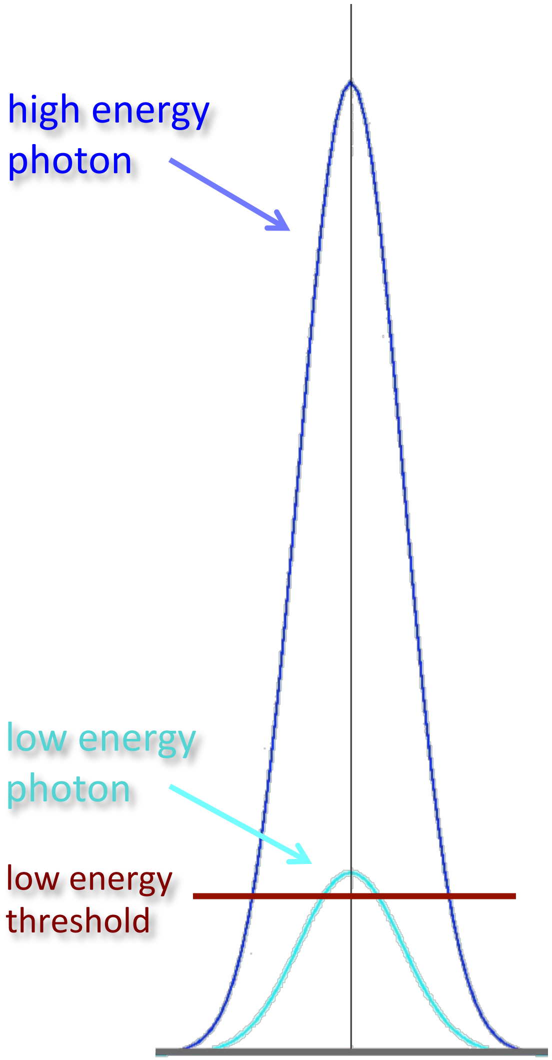
* CCD quantum efficiency

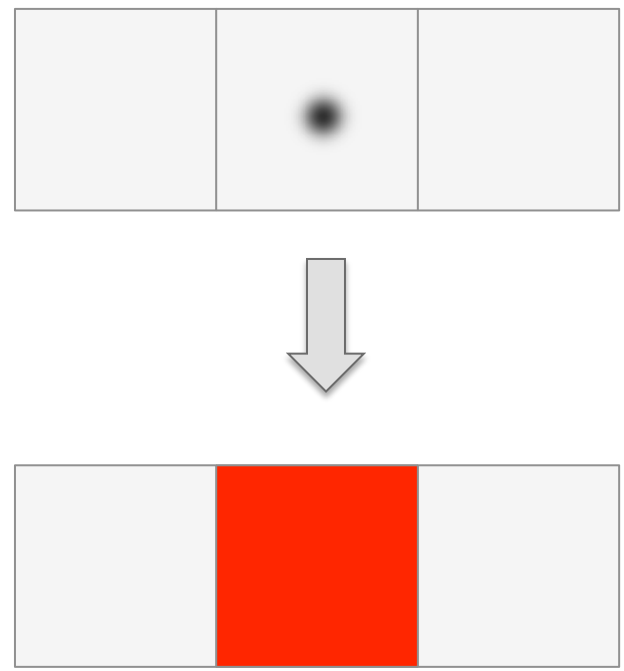
* fraction of single pixel events

* **threshold induced sensitivity drop**

→ sensitivity should drop near low energy threshold

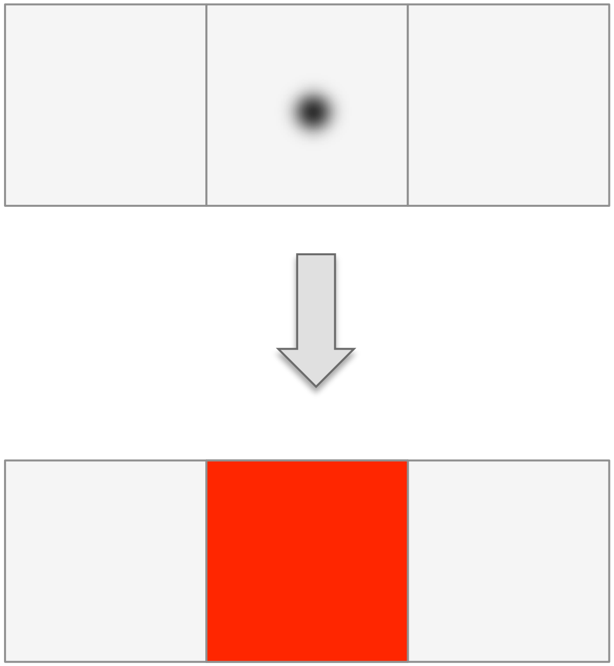
Threshold induced sensitivity drop ?





→ sensitivity should drop near low energy threshold**, but not that much**

Threshold induced sensitivity drop ?



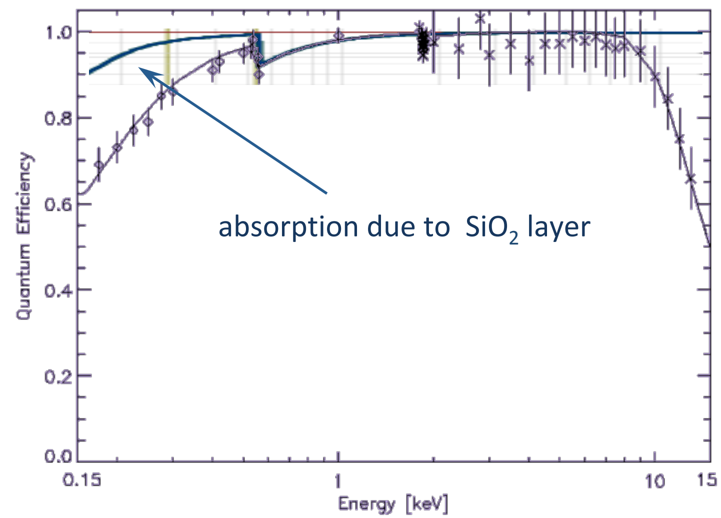


Figure 28: *Quantum efficiency of the EPIC pn CCD chips as a function of photon energy (Strüder et al., 2001, A&A, 365, L18, Fig. 5).*

→ sensitivity should drop near low energy threshold**, but not that much**

.. and in the QE determination, this effect should already have been implicitely considered

(approximately, depending on the low energy threshold used in the QE measurement)

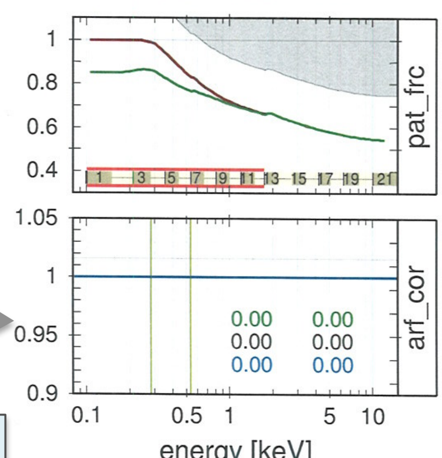
How to modify the ARF ?

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

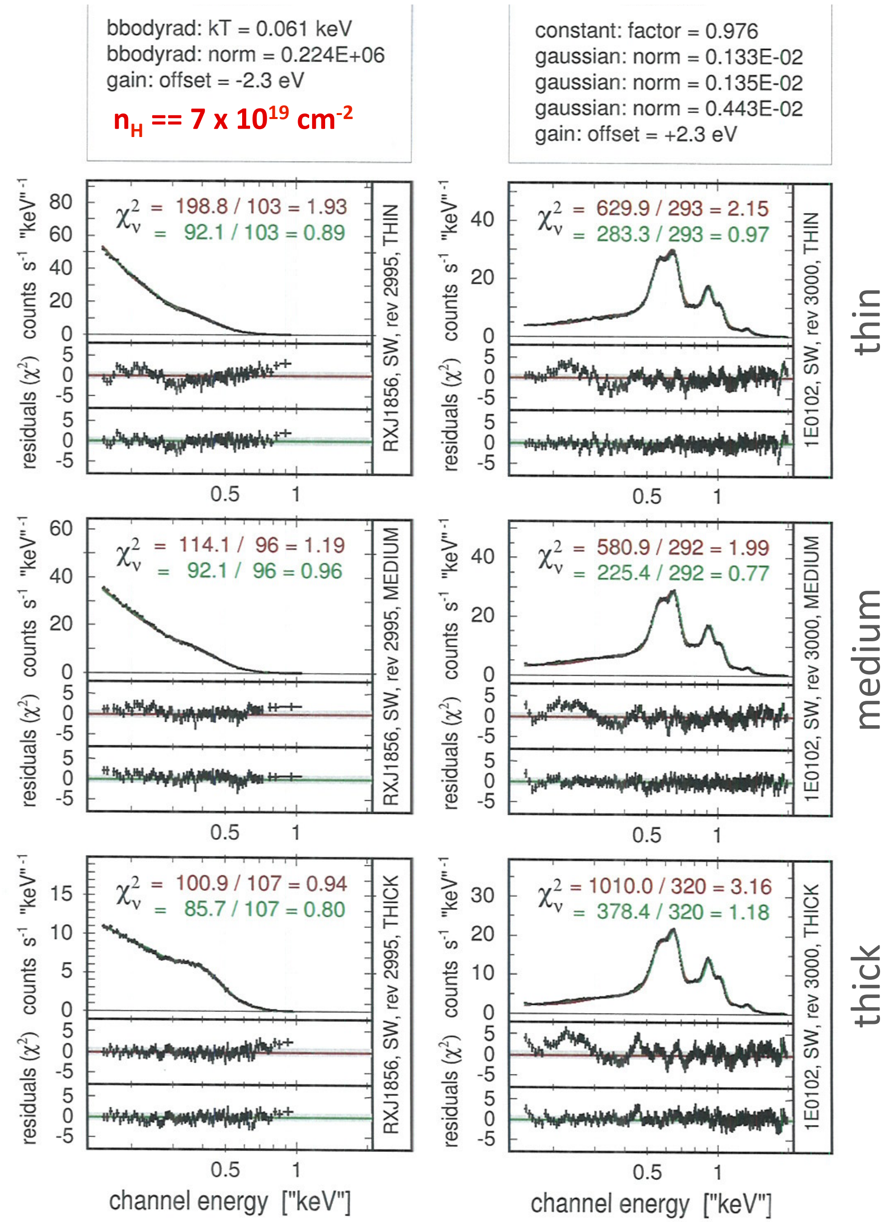
filter dependent ARF correction	correction for **carbon** thickness	correction for **oxygen** thickness
thin	= 0 (fixed)	= 0 (fixed)
medium	= 0 (fixed)	= 0 (fixed)
thick	= 0 (fixed)	= 0 (fixed)

reasonable fits

neither C nor O absorption



RXJ 1856 | 1E 0102



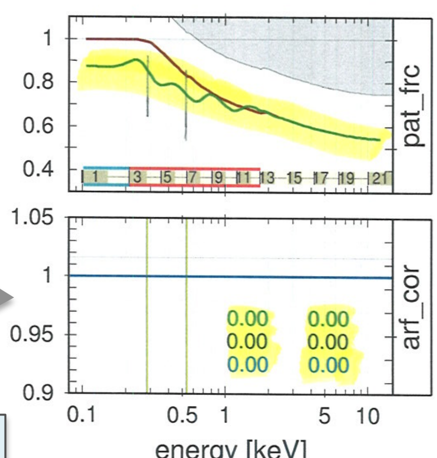
How to modify the ARF ?

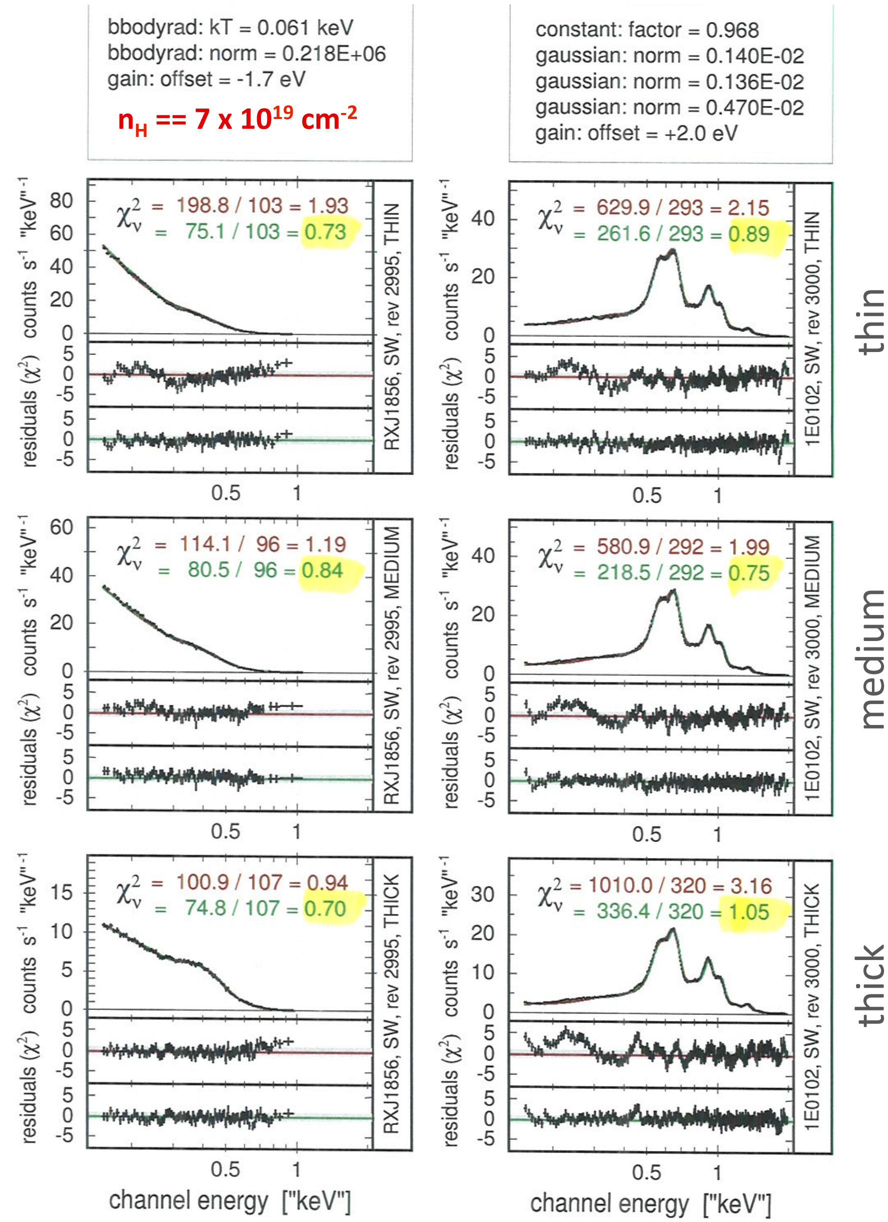
correction for threshold induced sensitivity drop		
0.10 – 0.28 keV free	0.28 – 1.74 keV free	1.74 – 16.0 keV fixed
low stiffness		

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

better fits
but pat_frc
too wavy

neither C nor O absorption





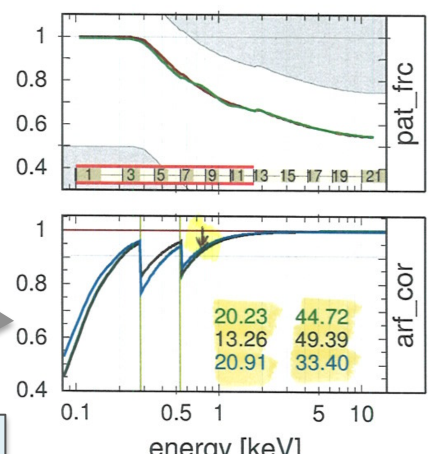
How to modify the ARF ?

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

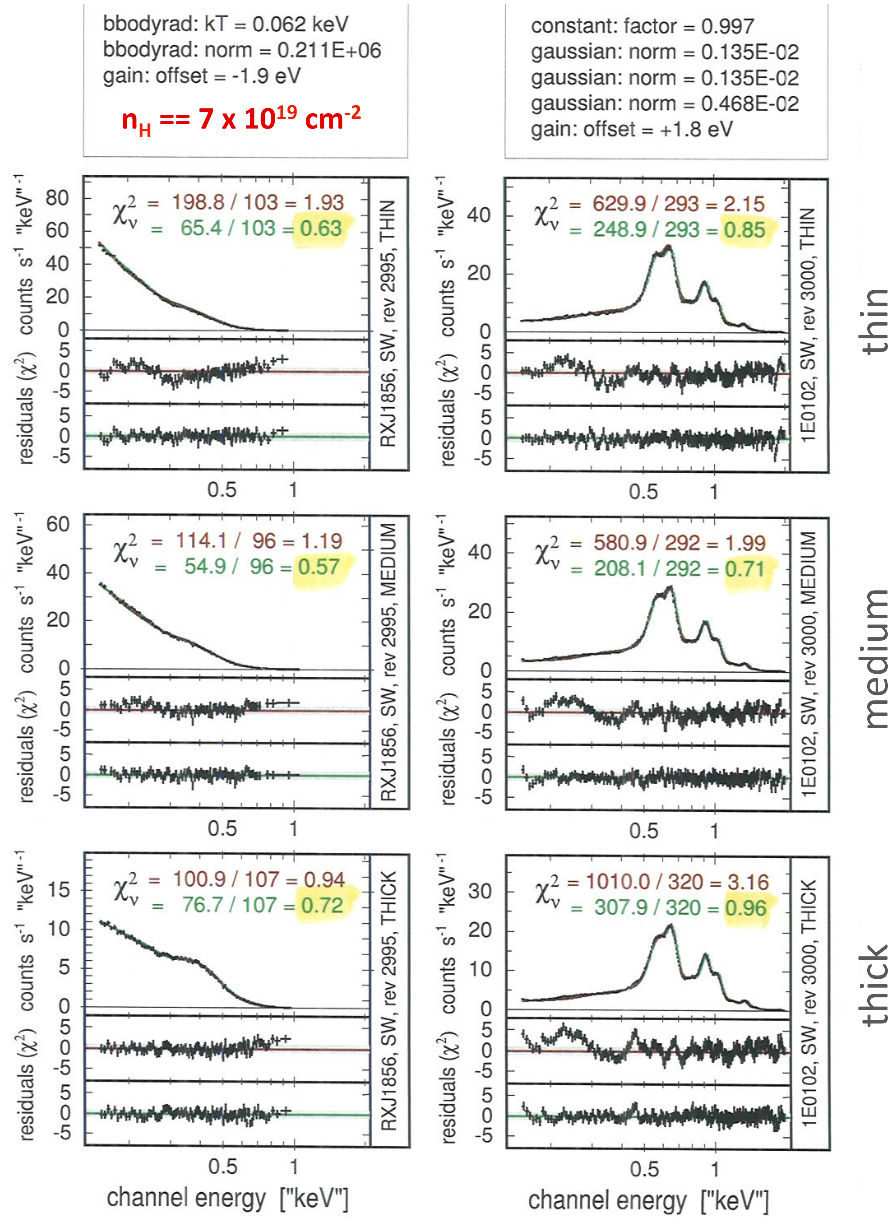
filter dependent ARF correction	correction for **carbon** thickness	correction for **oxygen** thickness
thin	= 20.23 (fixed)	= 44.72 (fixed)
medium	= 13.26 (fixed)	= 49.39 (fixed)
thick	= 20.91 (fixed)	= 33.40 (fixed)

excellent fits, but high absorption required

ind. C + O absorption for each filter



RXJ 1856 | 1E 0102



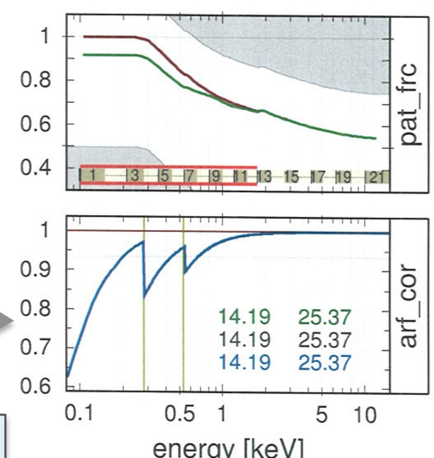
How to modify the ARF ?

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	free	free
medium	= C_cor(thin)	= O_cor(thin)
thick	= C_cor(thin)	= O_cor(thin)

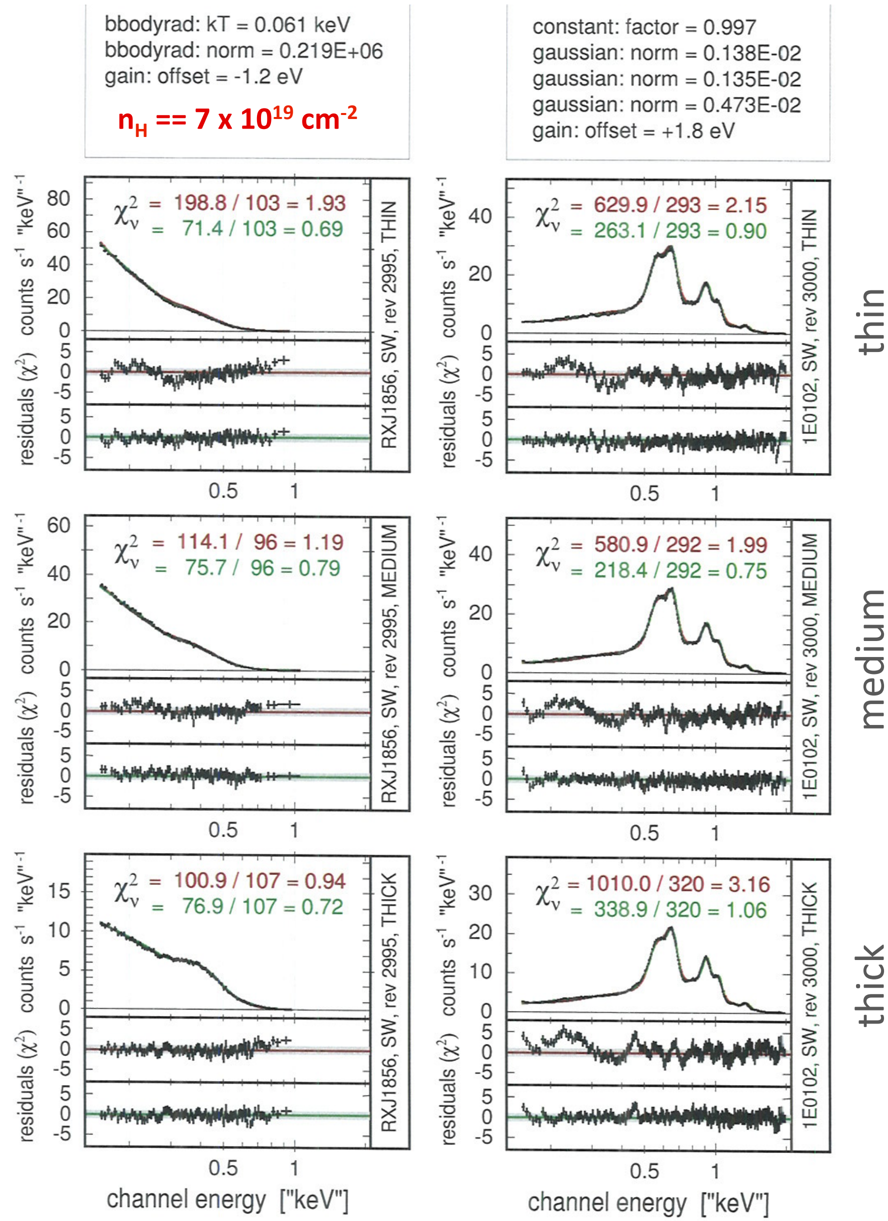
good fits
but absorption
quite high

same C + O absorption for all filters



RXJ 1856

1E 0102



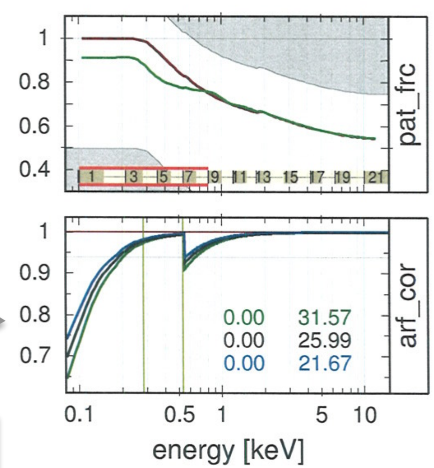
How to modify the ARF ?

correction for threshold induced sensitivity drop		
0.10 – 0.80 keV free	0.80 – 1.74 keV fixed	1.74 – 16.0 keV fixed

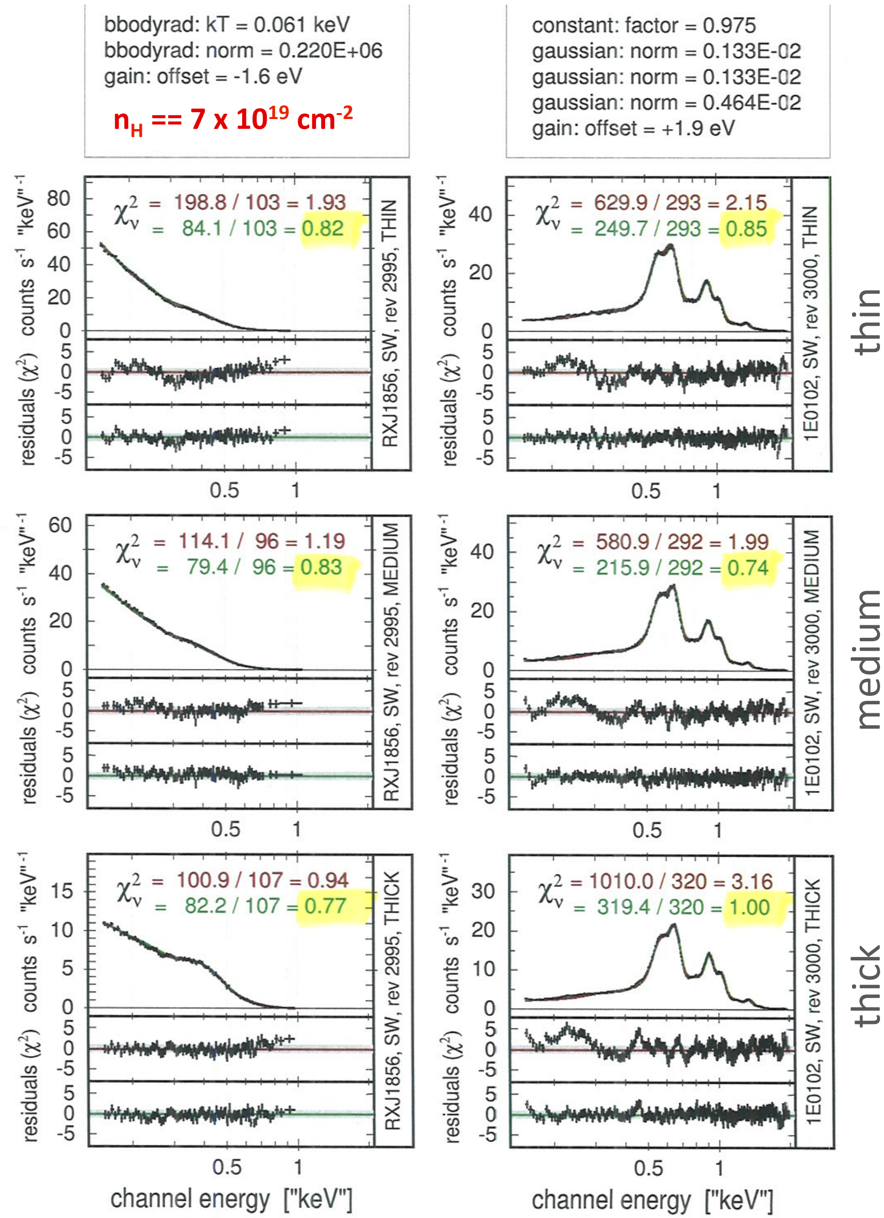
filter dependent ARF correction	correction for carbon thickness	correction for oxygen thickness
thin	= 0 (fixed)	free
medium	= 0 (fixed)	free
thick	= 0 (fixed)	free

good fits, similar values for oxygen thickness

only absorption by oxygen



RXJ 1856 | 1E 0102



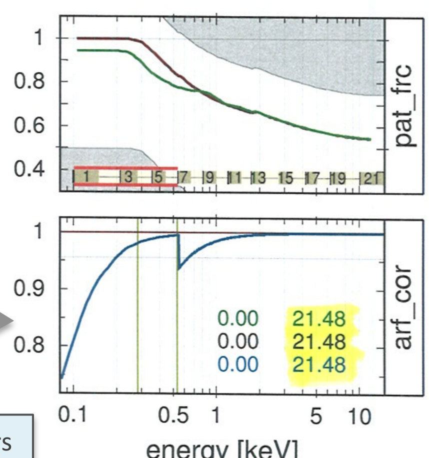
How to modify the ARF ?

correction for threshold induced sensitivity drop		
0.10 – 0.53 keV free	0.53 – 1.74 keV fixed	1.74 – 16.0 keV fixed

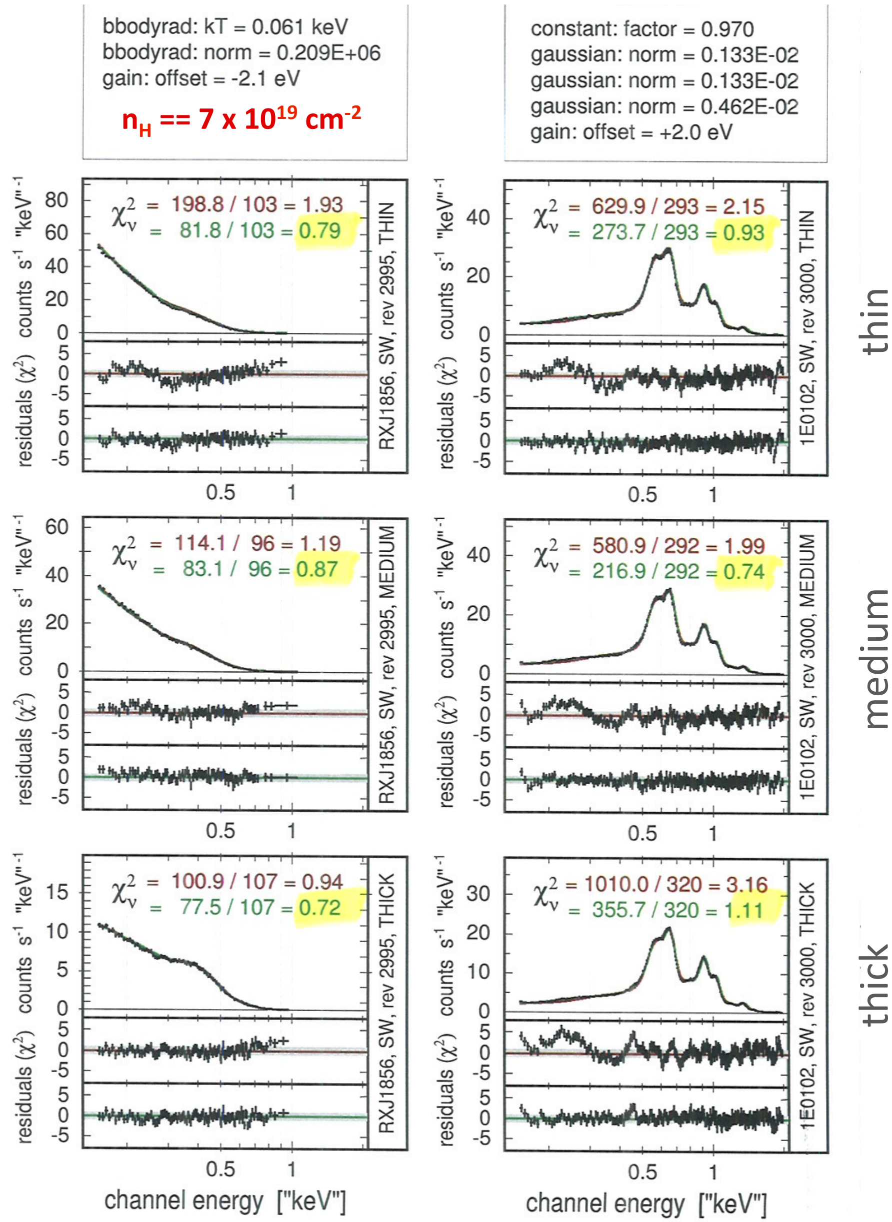
filter dependent ARF correction	correction for carbon thickness	correction for oxygen thickness
thin	= 0 (fixed)	free
medium	= 0 (fixed)	= O_cor(thin)
thick	= 0 (fixed)	= O_cor(thin)

reasonable fits, only moderate absorption by O

same O absorption (only) for all filters



RXJ 1856 1E 0102



Considering also the normalization

The fits with

- n_H = 7.25 x 10^{19} cm^{-2}
- kT = 62.4 eV
- norm = 178

worked well

→ would norm = 158 also work ?

but Chandra LETG yields

- n_H = 7.25 x 10^{19} cm^{-2}
- kT = 62.4 eV
- norm = 158

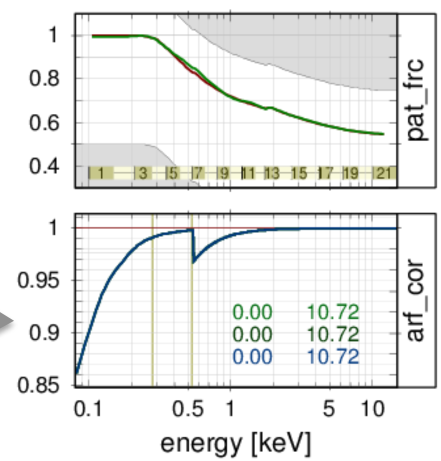
In the following fits, the model spectrum for RXJ 1856 is fixed to exactly the Chandra LETG values ..

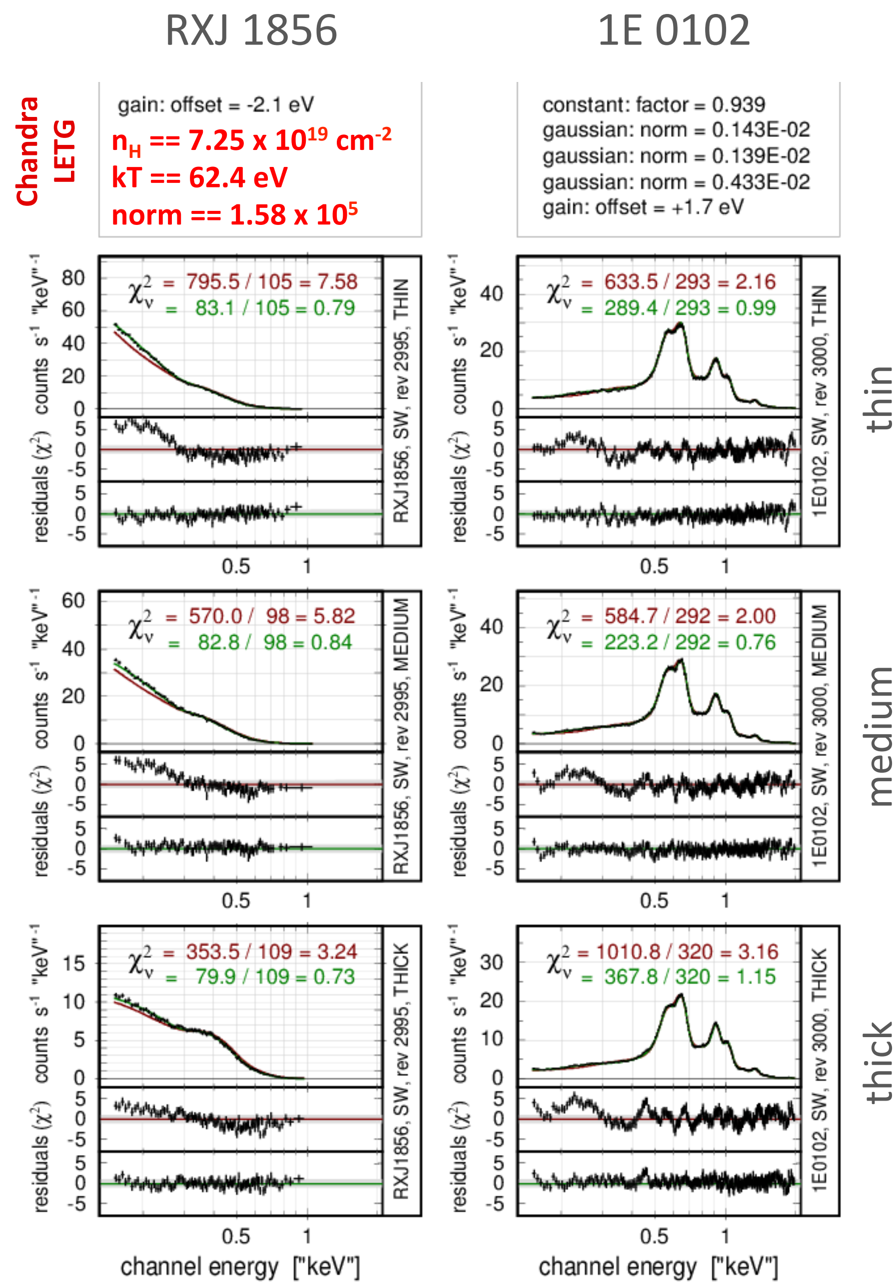
How to modify the ARF ?

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

RXJ 1856:

gain: offset = -2.1 eV

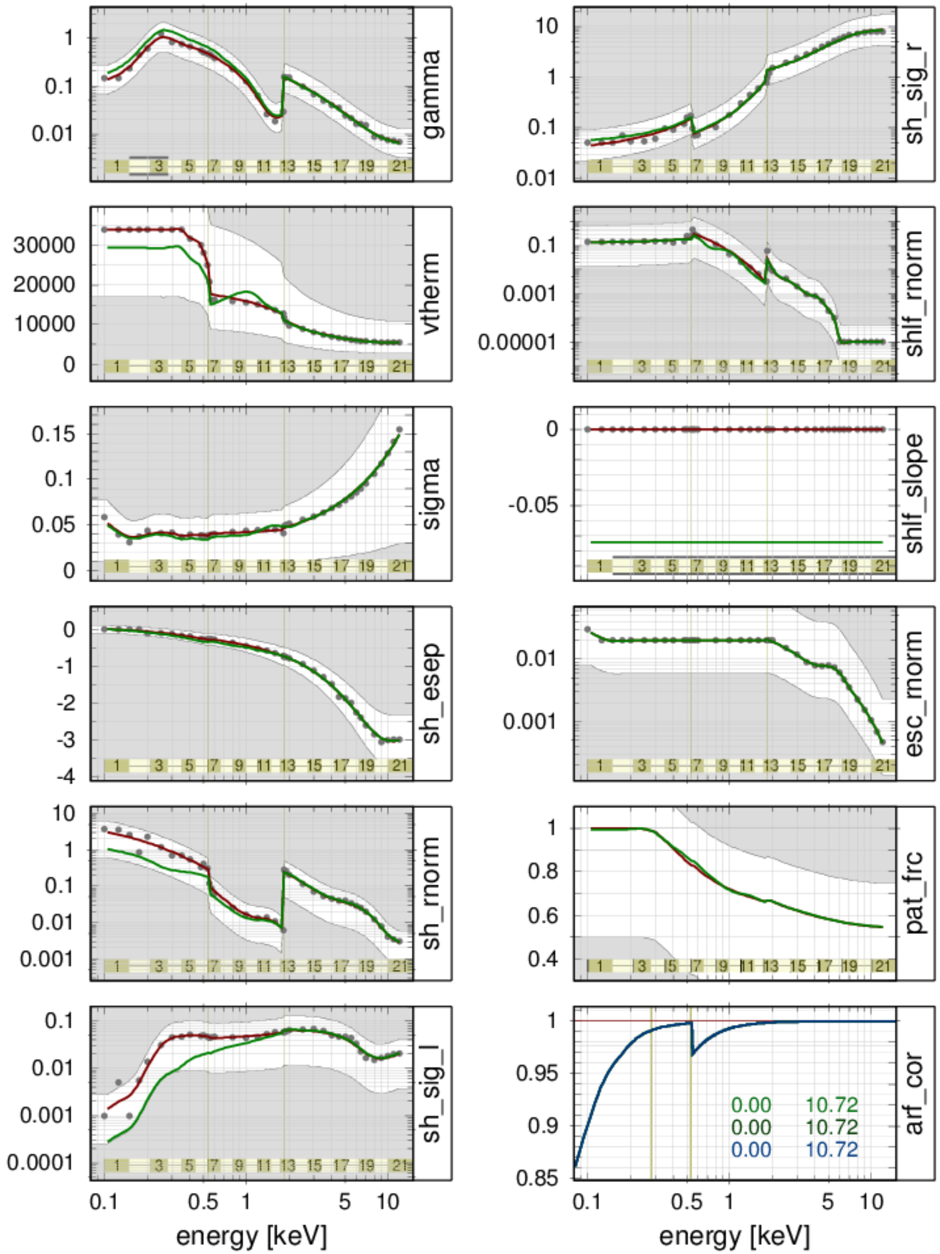
n_H == 7.25 x 10^{19} cm^{-2}

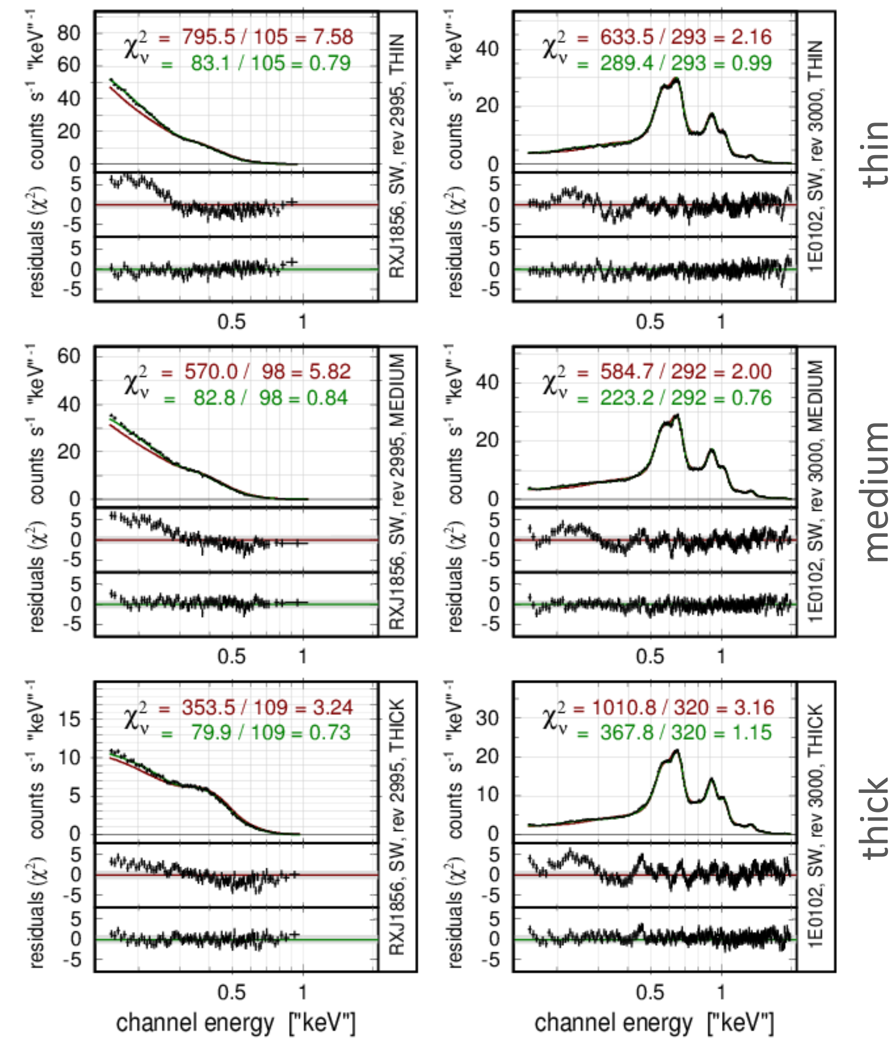
kT == 62.4 eV

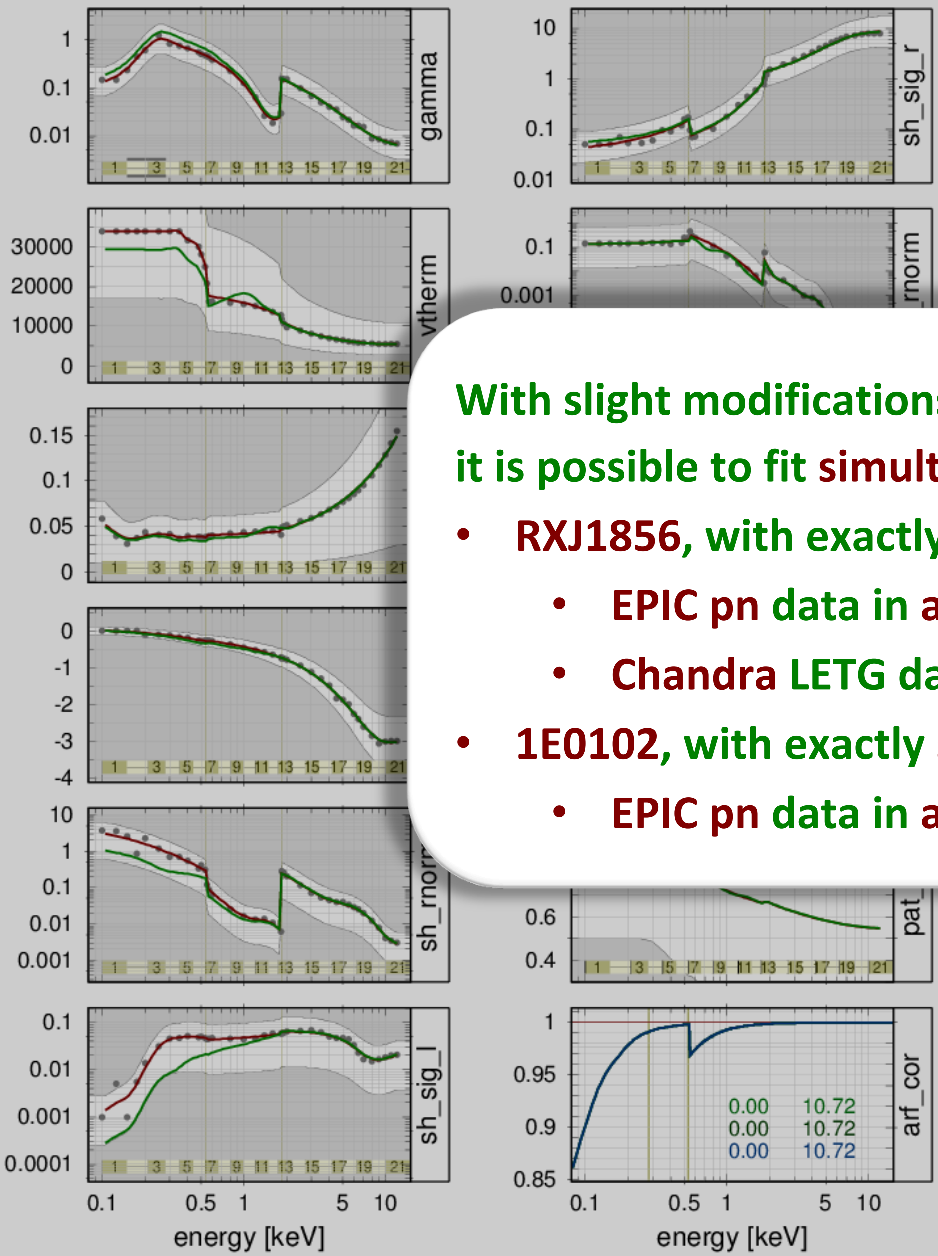
norm == 1.58 x 10^5

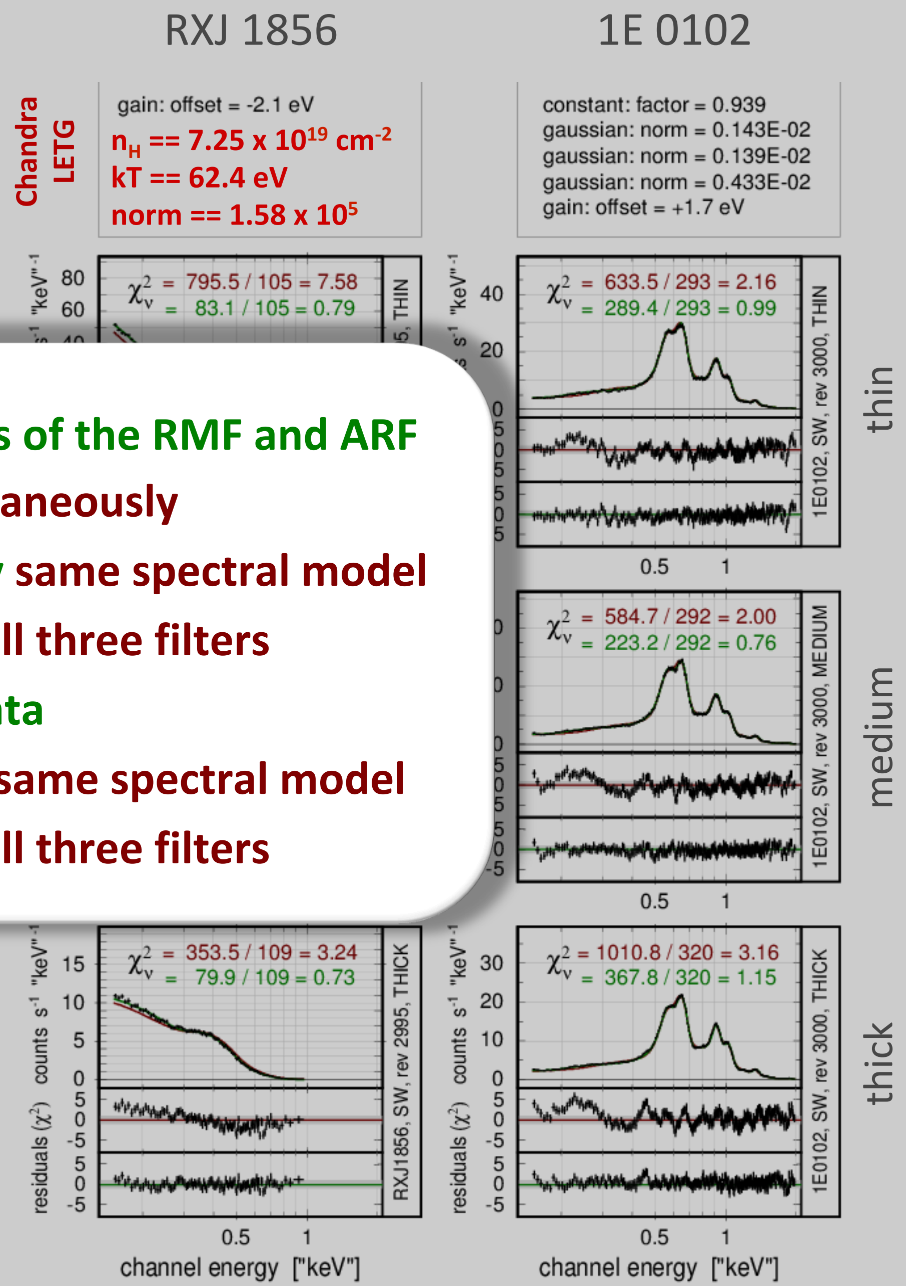
1E 0102:

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









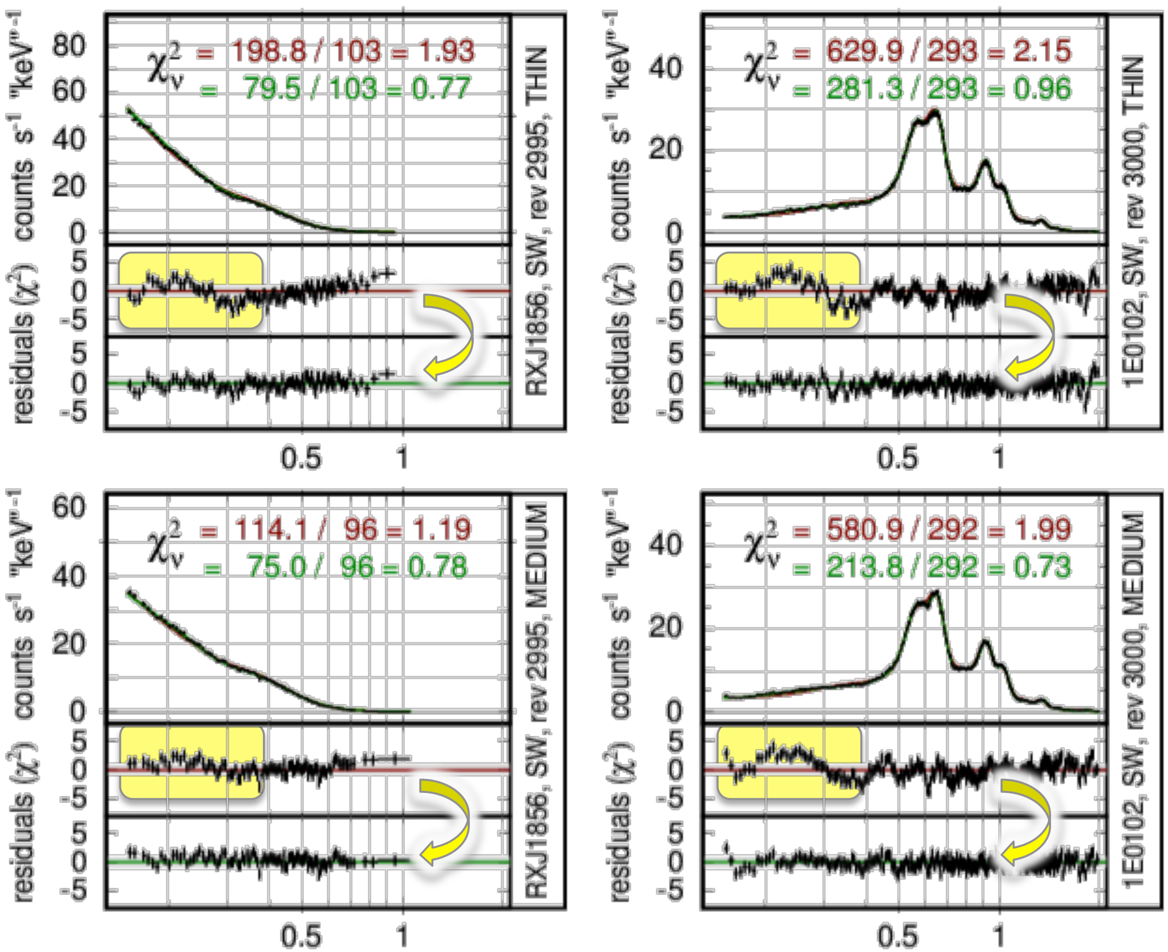
With slight modifications of the RMF and ARF it is possible to fit simultaneously

- **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**

Warning: ARF adjustments alone may be dangerous !

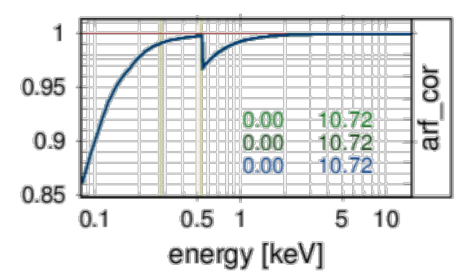
Example: XMM/EPIC-pn, simultaneous fit to RXJ 1856 and 1E0102 in three filters each, using the same model spectrum for each source, with no normalization between the filters

RXJ 1856 1E 0102

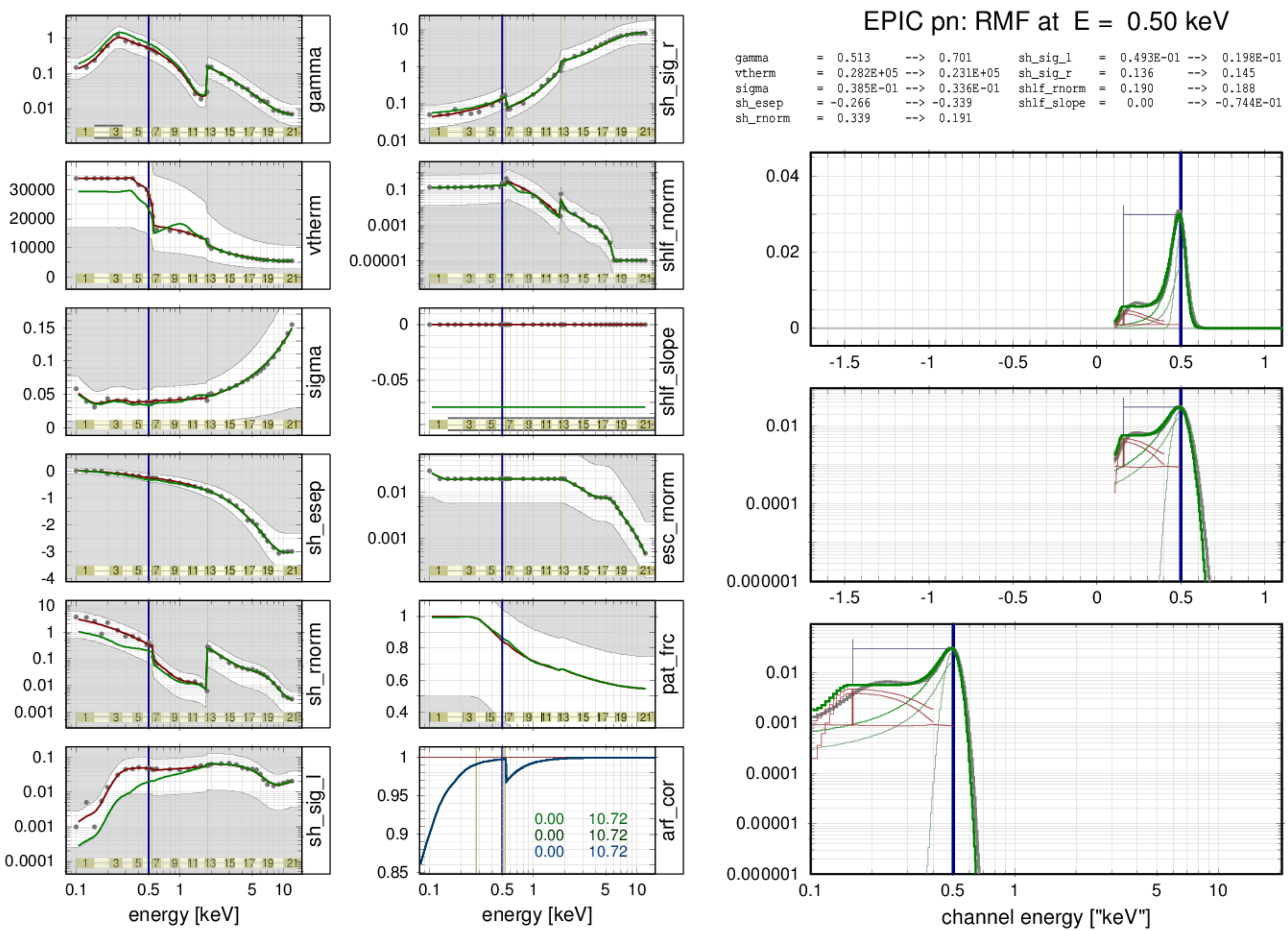


The apparent excess in residuals below 0.4 keV could be „repaired“ by **increasing the ARF** at low energies ..

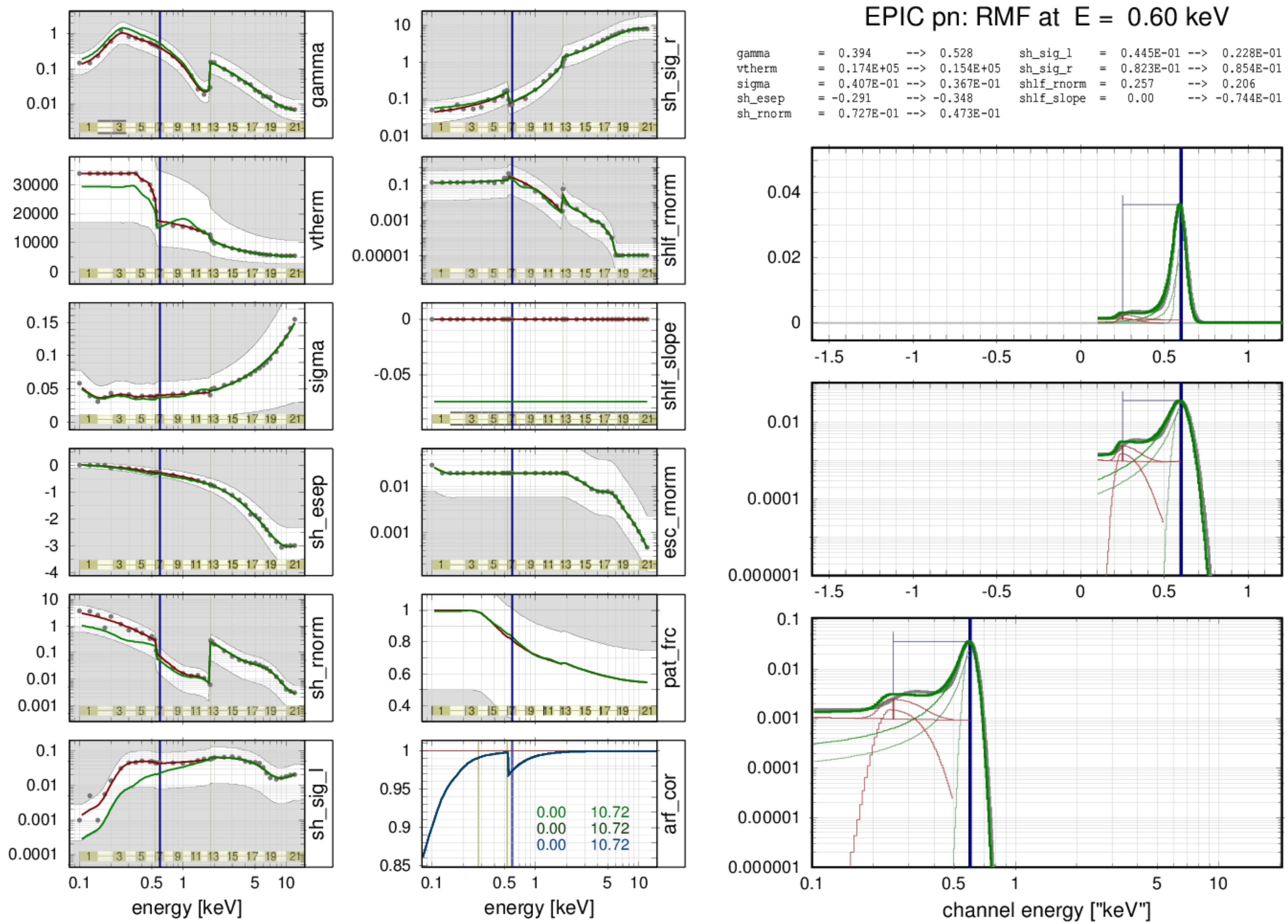
Work on the RMF refinement, however, suggests to **increase the redistribution** and to **decrease the ARF** at low energies !



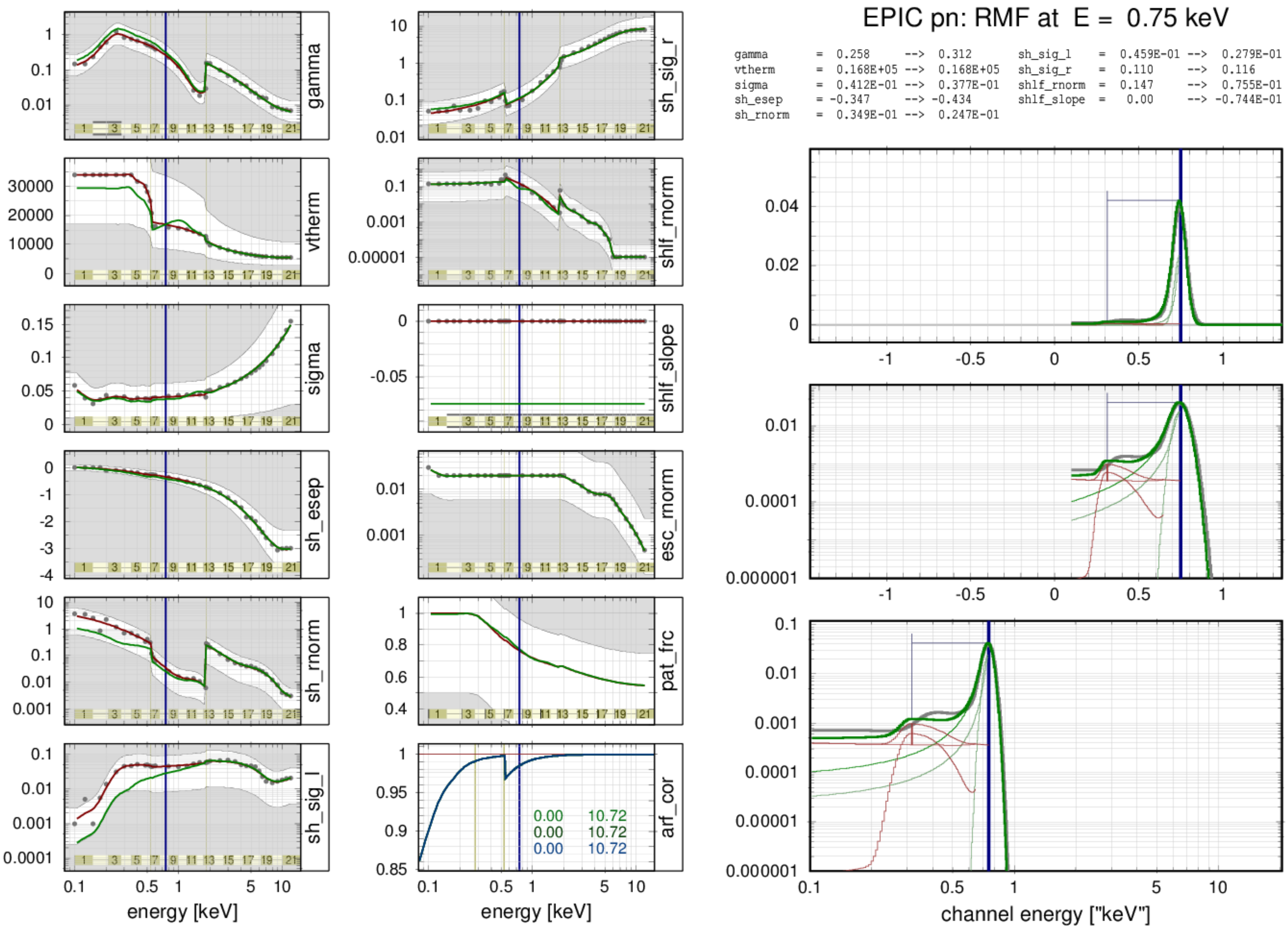
What has changed in the RMF ?



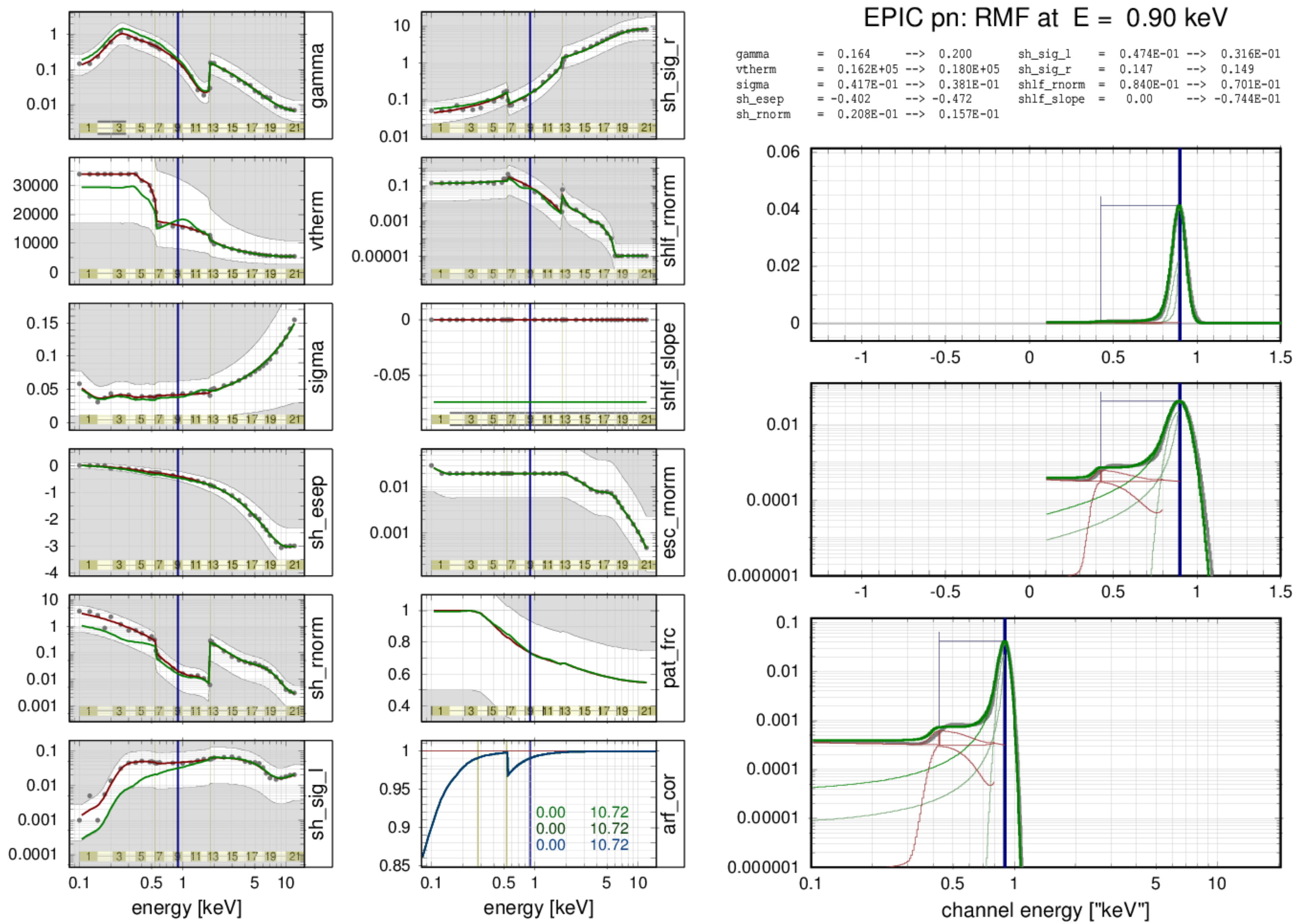
What has changed in the RMF ?



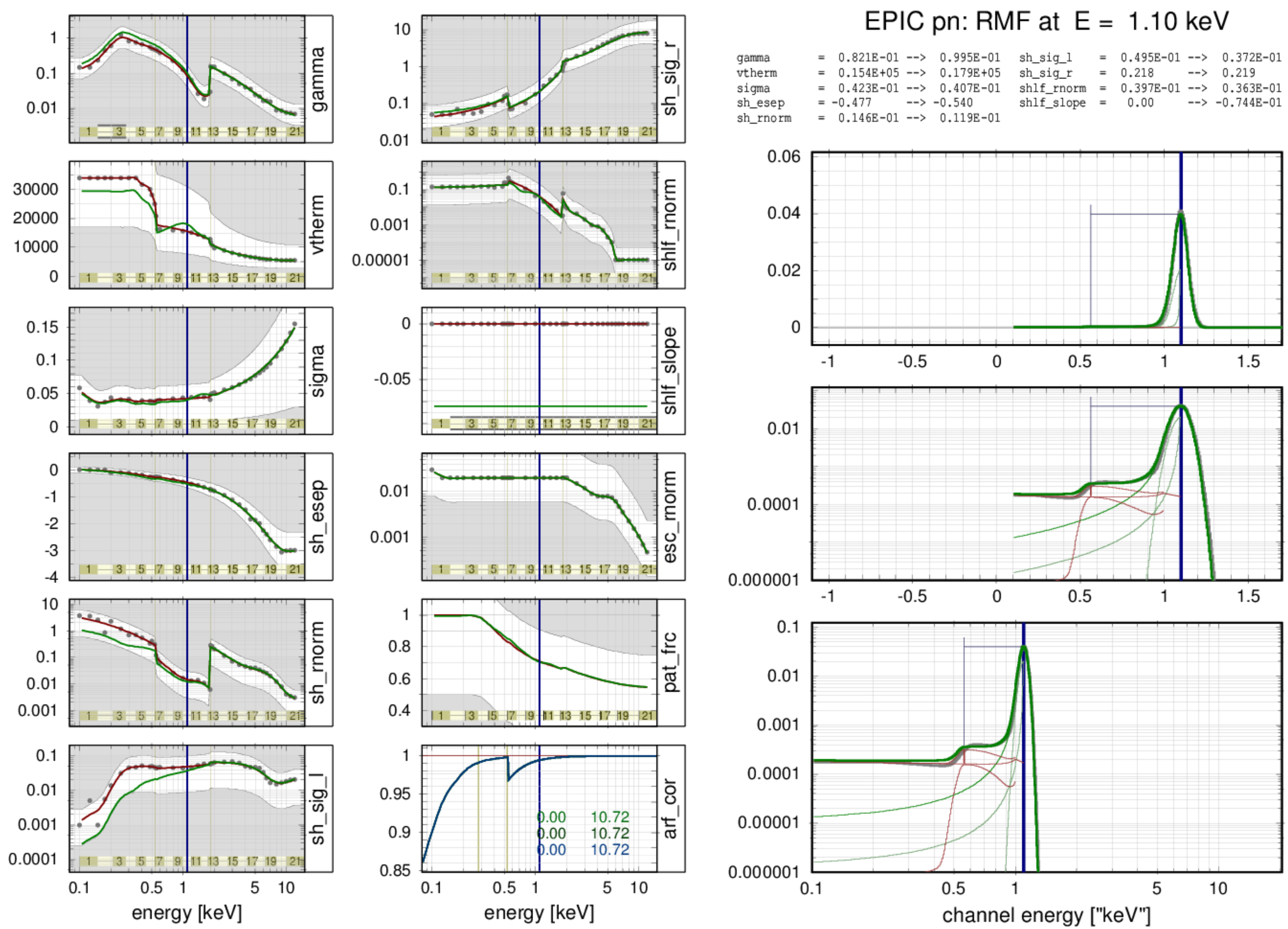
What has changed in the RMF ?



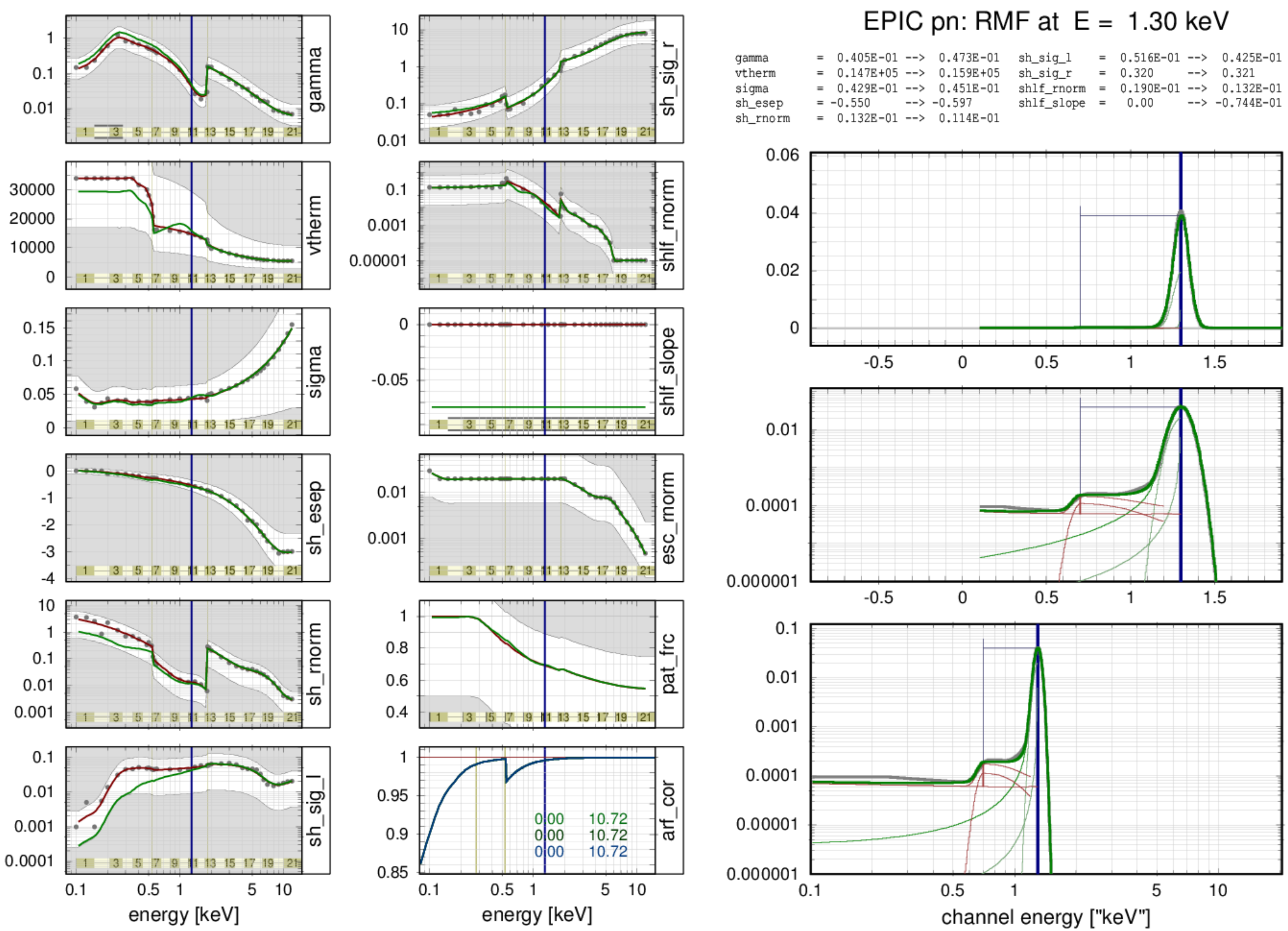
What has changed in the RMF ?



What has changed in the RMF ?



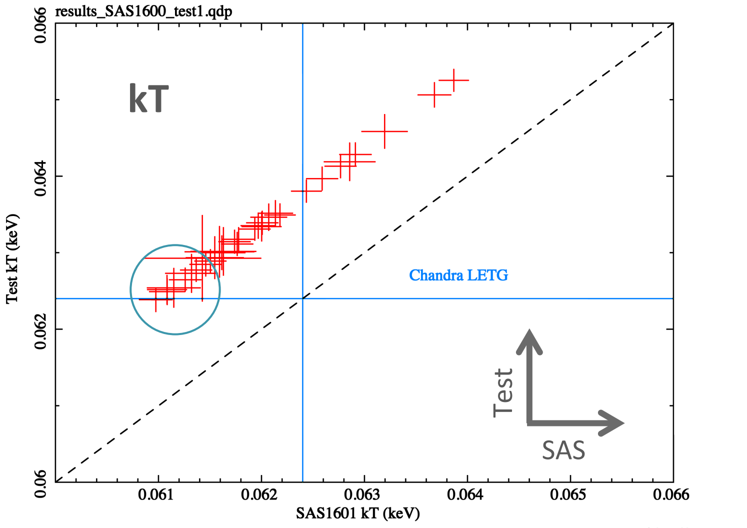
What has changed in the RMF ?

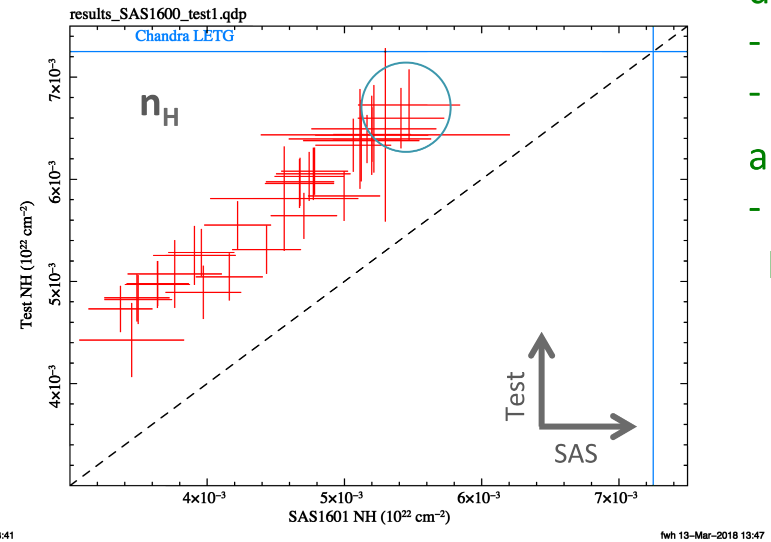


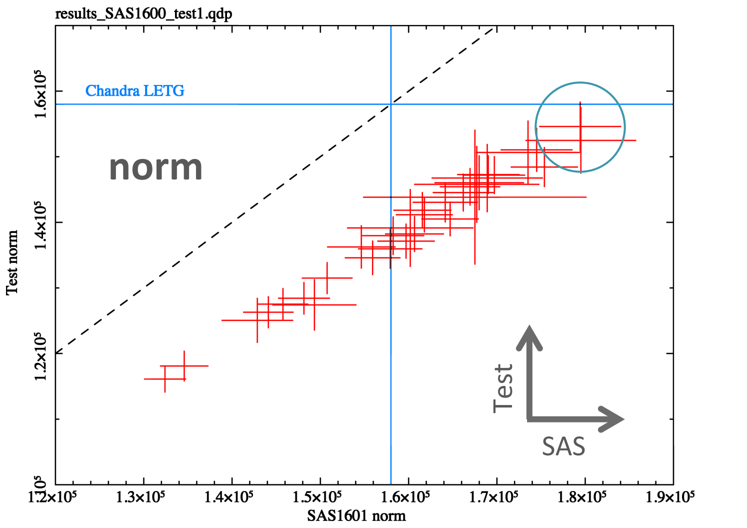
First tests of the modified RMF & ARF

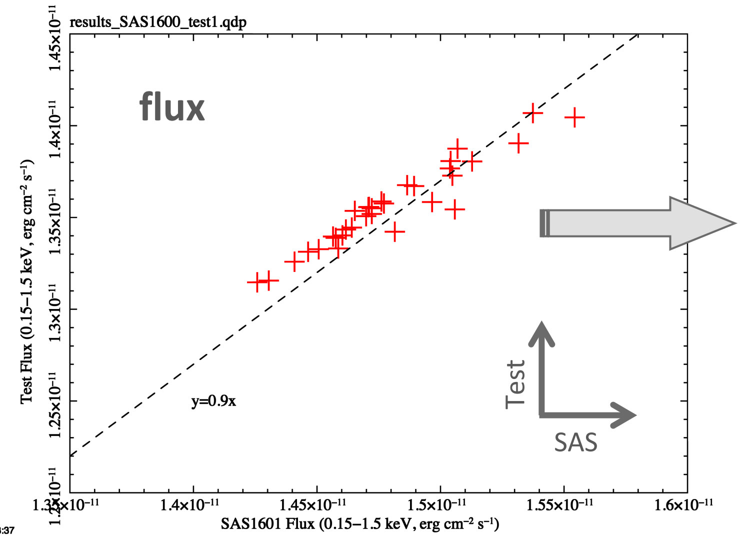
by Frank Haberl

RXJ 1856, EPIC pn, **SW, thin filter***: comparison with SAS 16.01 results







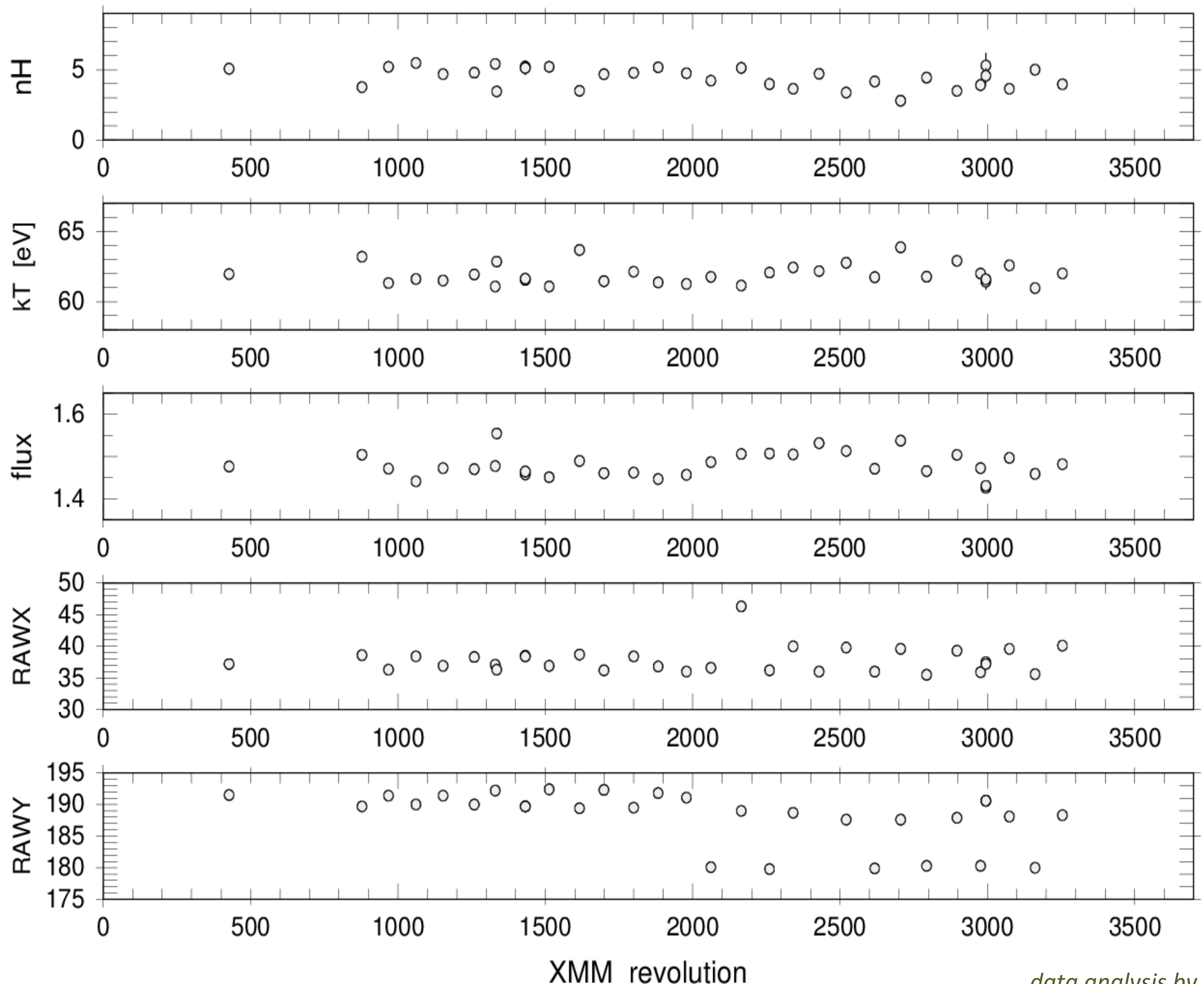


(*) but:
distribution in
- obs times
- coordinates

and:
- coupling of parameters

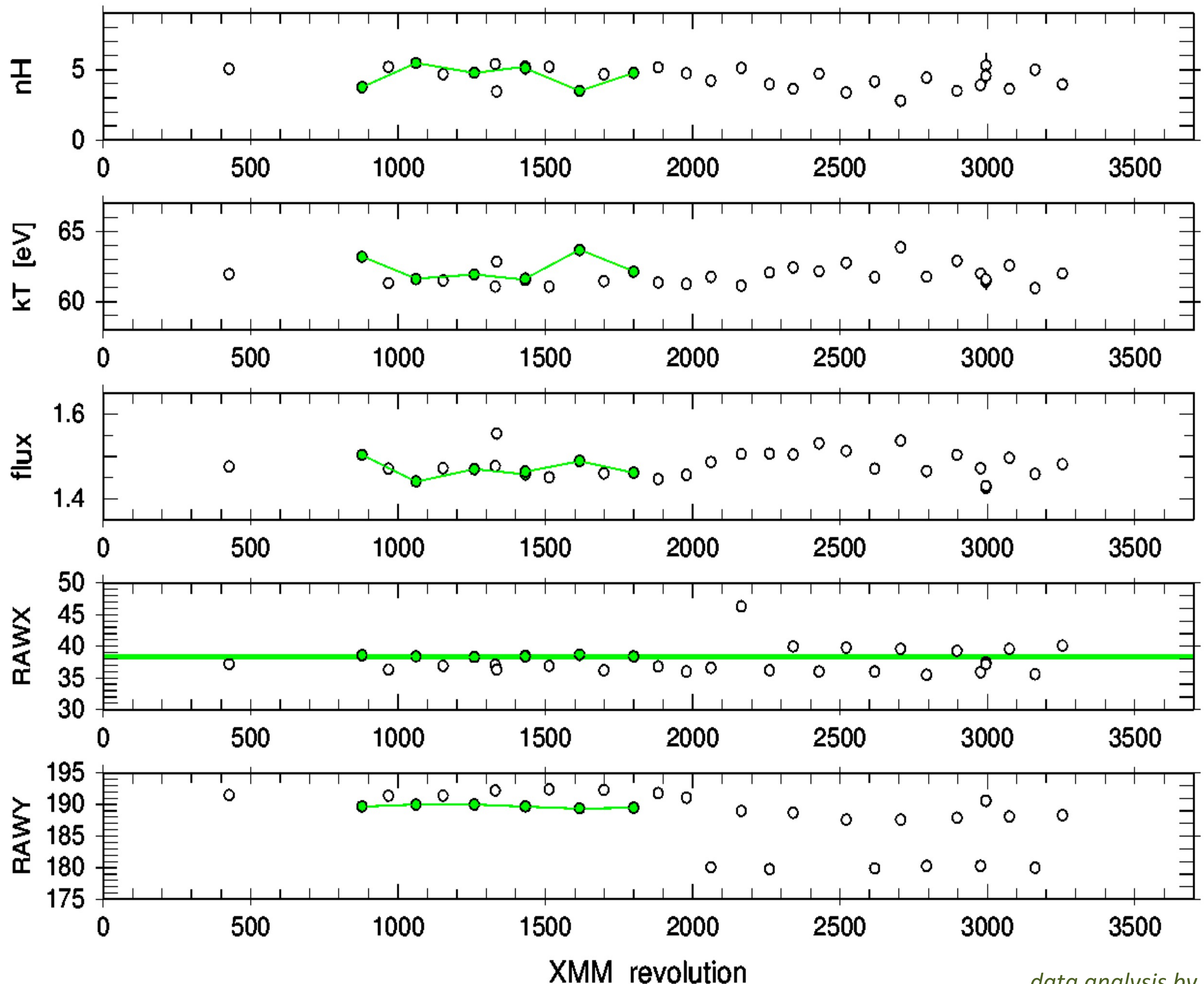
the modified RMF & ARF reduce the derived 0.15 – 1.5 keV flux by ~10%

RXJ1856: temporal and spatial dependencies (SW, thin, SAS 16.0.1)



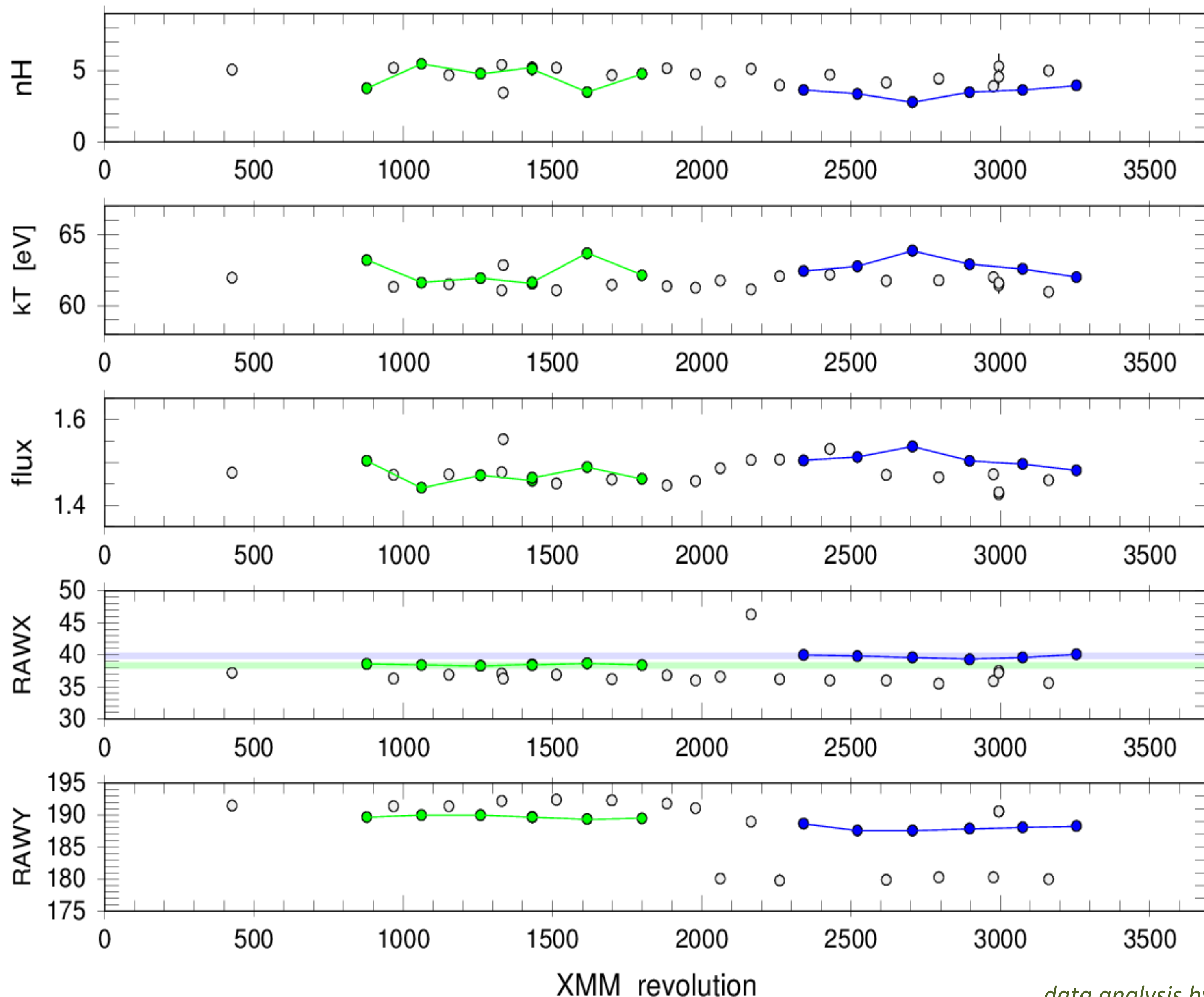
data analysis by Frank Haberl

RXJ1856: temporal and spatial dependencies (SW, thin, SAS 16.0.1)



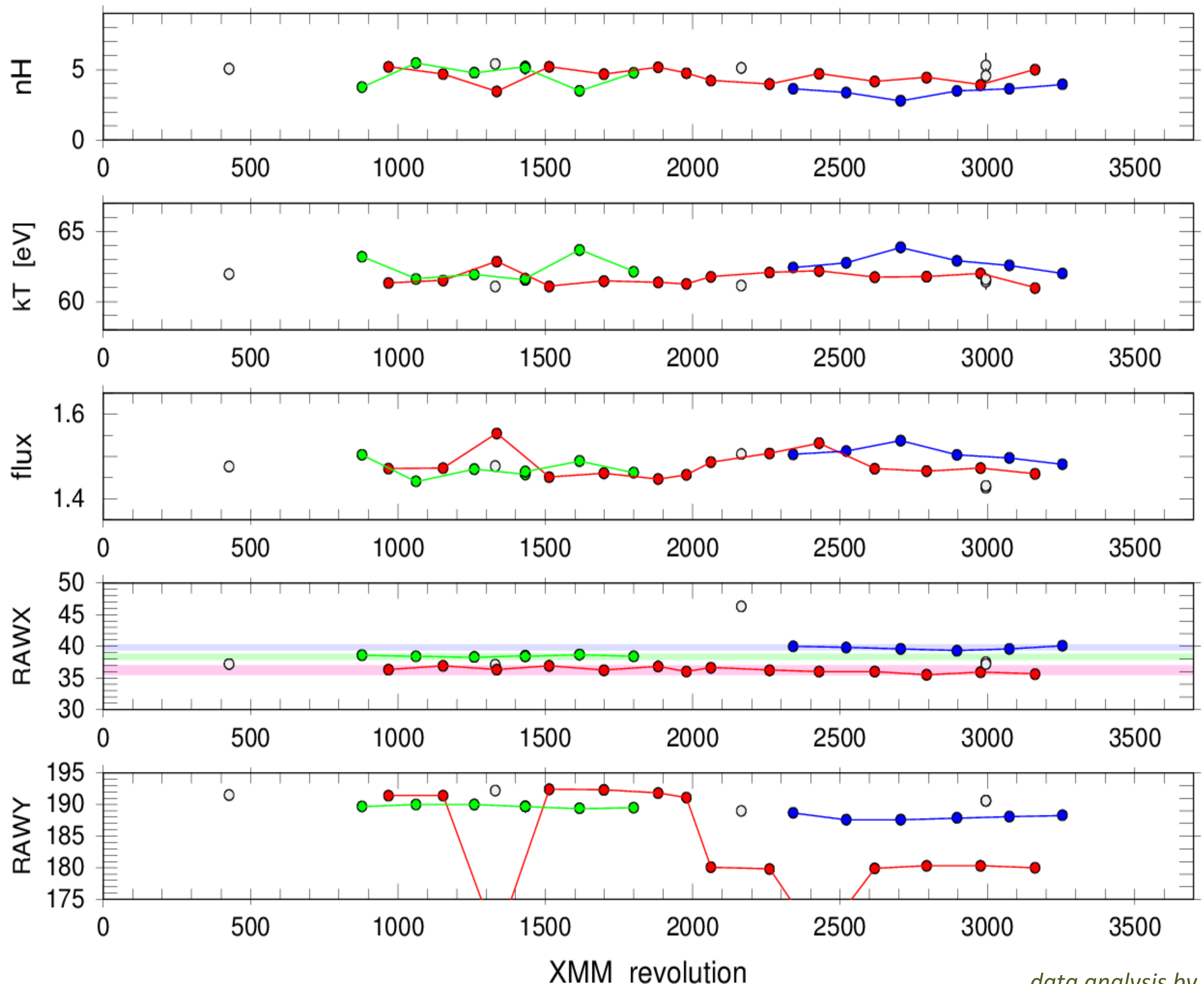
data analysis by Frank Haberl

RXJ1856: temporal and spatial dependencies (SW, thin, SAS 16.0.1)



data analysis by Frank Haberl

RXJ1856: temporal and spatial dependencies (SW, thin, SAS 16.0.1)



data analysis by Frank Haberl

Current status

With the current RMF and ARF adjustments it is now possible to fit simultaneously spectra of **RXJ1856** and **1E0102** obtained with **all three EPIC pn filters** in revs 2995 – 3000 in SW mode at the aimpoint **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 **aimpoint** region analysed (to minimise spatial dependencies)
- only **rev 2995 – 3000** period analysed (to minimise temporal dependencies)

Extensions needed:

- full spectral range
- other readout modes: FF, eFF, LW, TI, BU
- full field of view
- full time span

How to proceed..

energy range	③	➢ **E < 1.7 keV** ➢ **E > 1.7 keV**	below 1.7 keV no photon escape RMF must be available for full energy range
readout mode	④	➢ **SW** ➢ LW ➢ **FF** ➢ eFF ➢ TI ➢ BU	SW is useful for initial studies (high source flux, good statistics) FF is the standard mode
detector position	②	➢ **aimpoint** ➢ **aimpoint area** ➢ full FoV	in most of the observations the target is located at the aimpoint in order to analyse existing observations, the aimpoint area must be calibrated
observation time	①	➢ **rev 2995 – 3000** ➢ **full time span**	temporal dependence must be known in order to analyse more observations