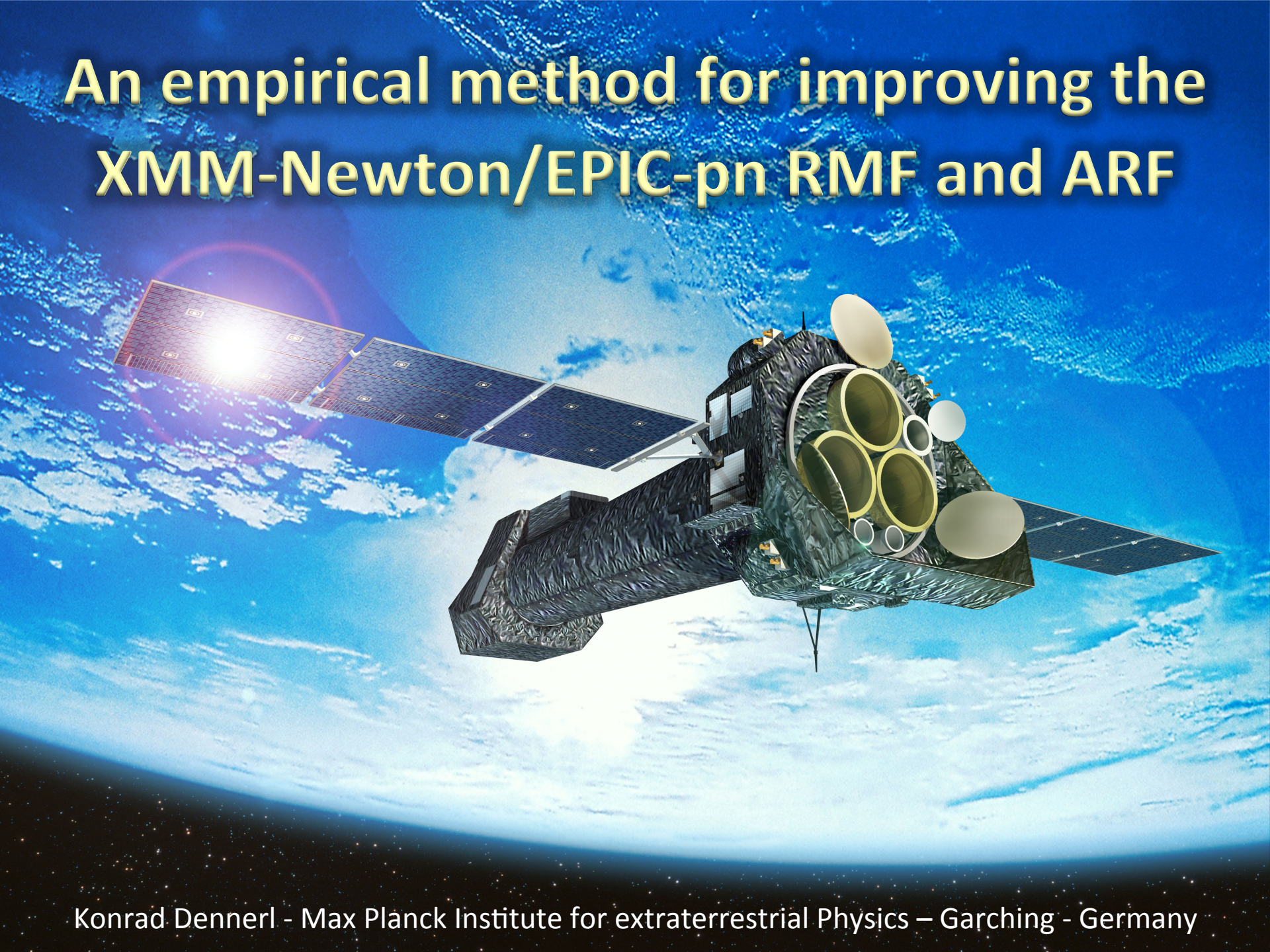
IACHEC

International Astronomical Consortium for High Energy Calibration

11th IACHEC meeting

29 February – 3 March 2016, IUCAA (Pune, India)

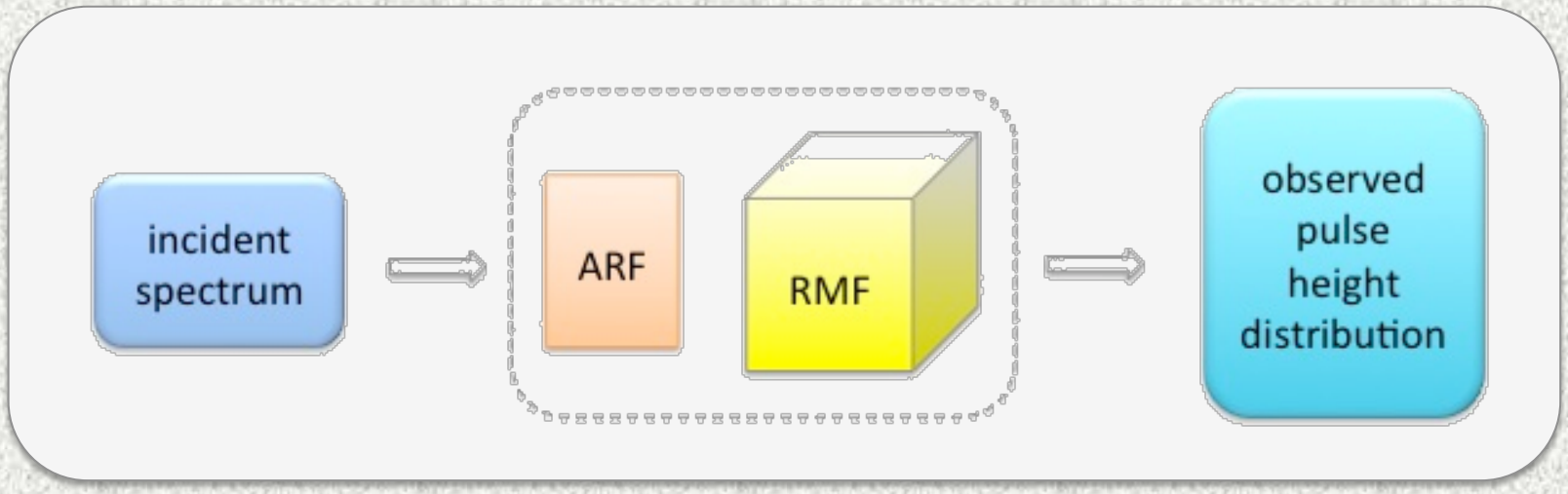
An empirical method for improving the XMM-Newton/EPIC-pn RMF and ARF



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

ARF and RMF

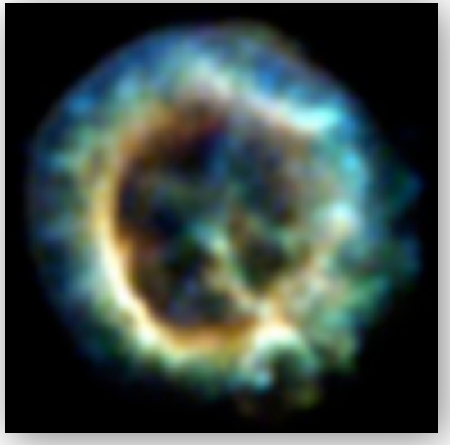
ARF: „Ancillary Response File“, RMF: „Redistribution Matrix File“

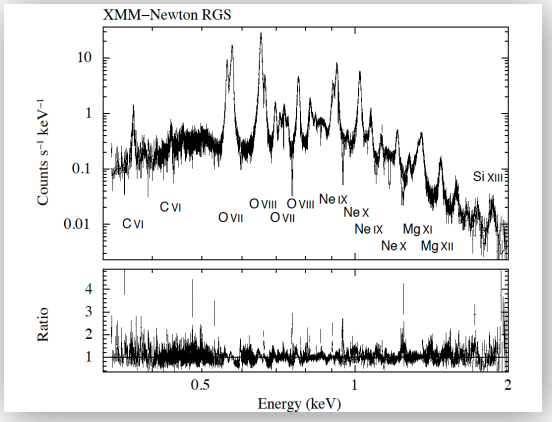


± 20%

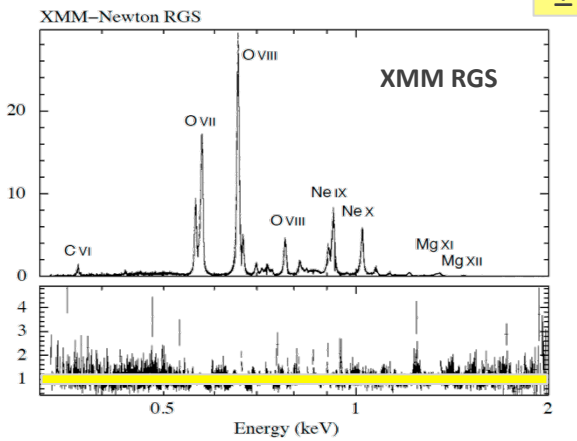
Cross-calibration of the X-ray Instruments onboard the Chandra, Suzaku, Swift, and XMM-Newton Observatories using the SNR 1E 0102.2-7219

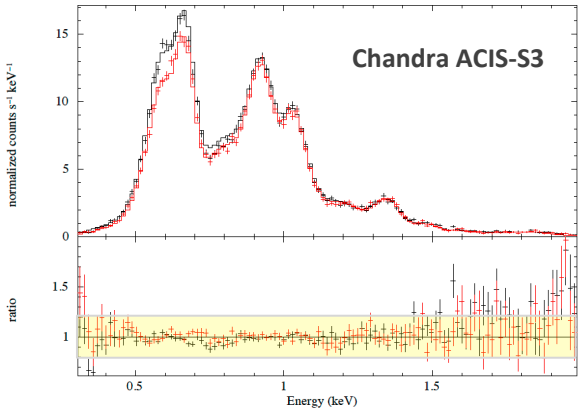
Paul P. Plucinsky[a], Andrew P. Beardmore[b], Joseph M. DePasquale[a], Daniel Dewey[c], Adam Foster[a], Frank Haberl[d], Eric D. Miller[c], A.M.T. Pollock[e], Jennifer L.L. Posson-Brown[a], Steve Sembay[b], & Randall K. Smith[a]

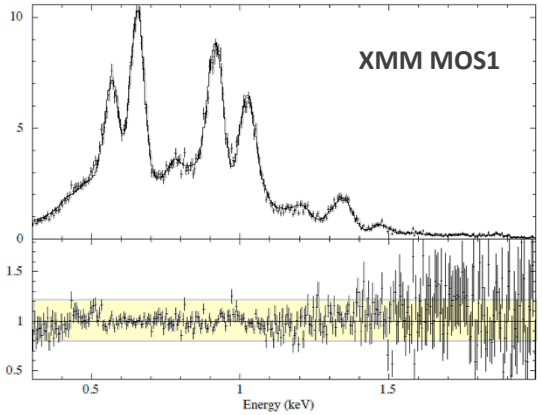


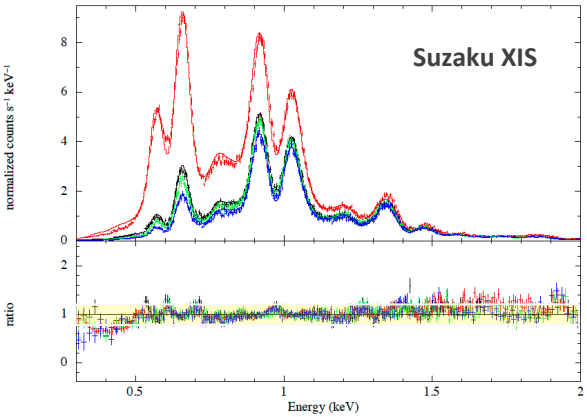


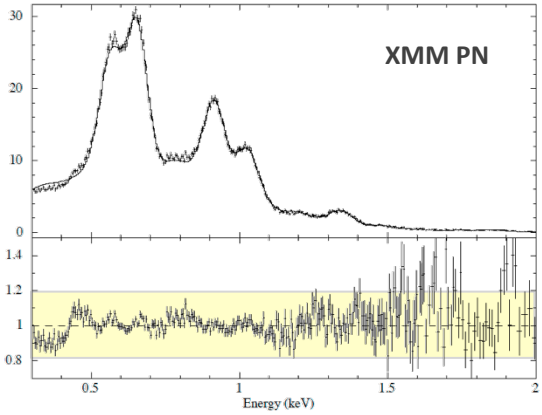
Plucinsky et al. 2012

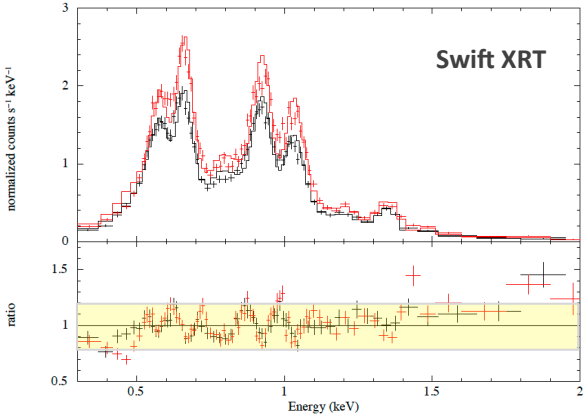






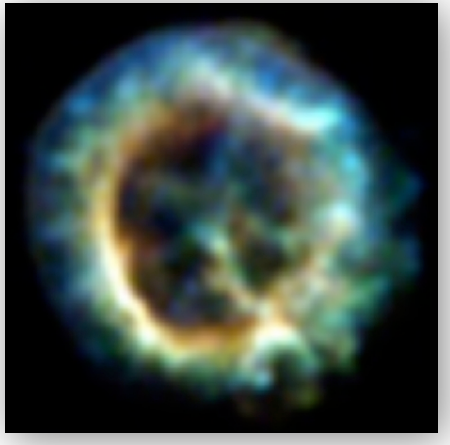


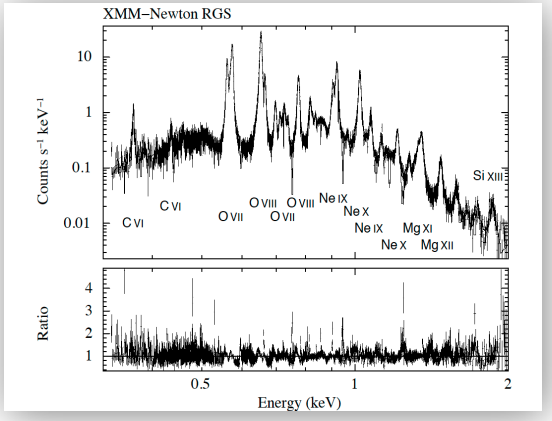




Cross-calibration of the X-ray Instruments onboard the Chandra, Suzaku, Swift, and XMM-Newton Observatories using the SNR 1E 0102.2-7219

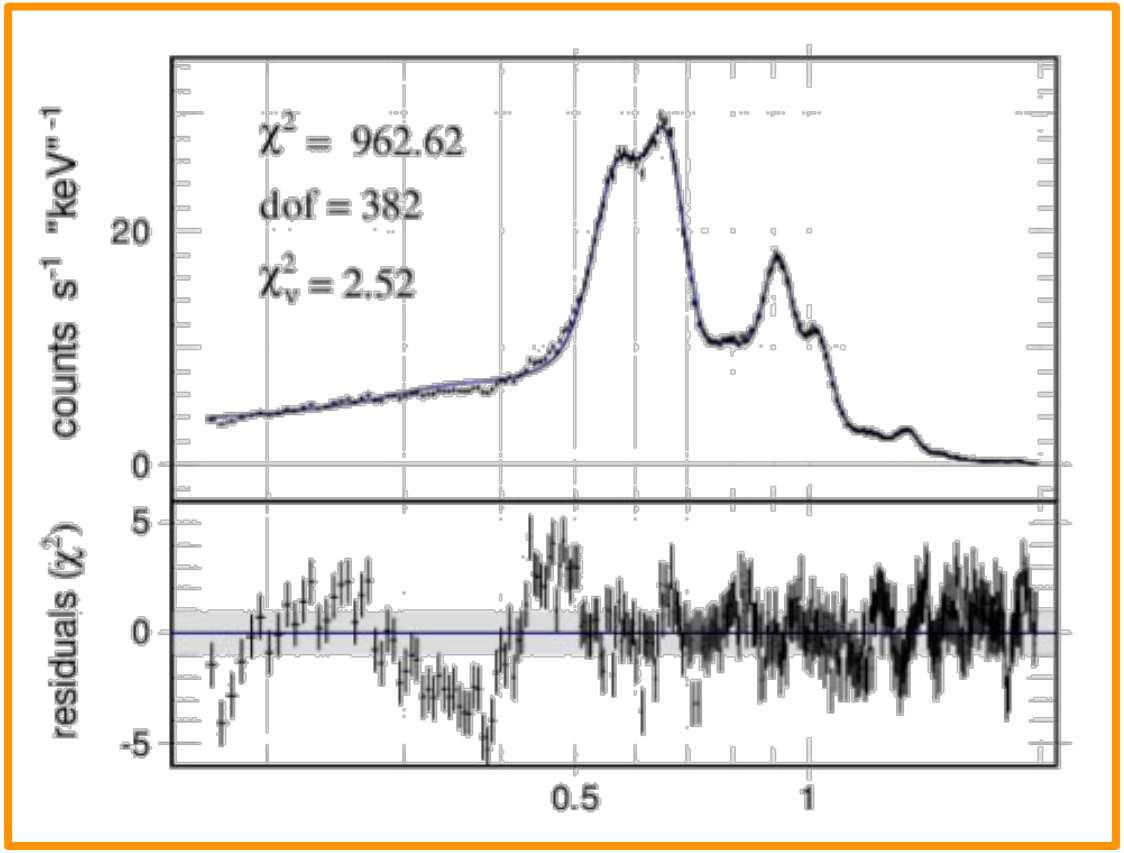
Paul P. Plucinsky[a], Andrew P. Beardmore[b], Joseph M. DePasquale[a], Daniel Dewey[c], Adam Foster[a], Frank Haberl[d], Eric D. Miller[c], A.M.T. Pollock[e], Jennifer L.L. Posson-Brown[a], Steve Sembay[b], & Randall K. Smith[a]





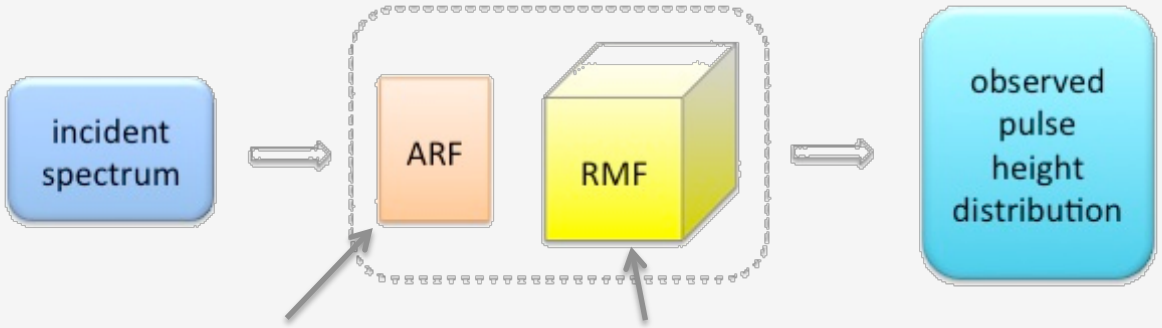
Plucinsky et al. 2012

1E 0102 (XMM-Newton / EPIC-pn, SW, medium filter)



General properties of the ARF and RMF

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



EPIC pn: 2067 vector elements; 2067 x 4096 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!

how to improve ?

Empirical modeling of the EPIC pn RMF

Step 1

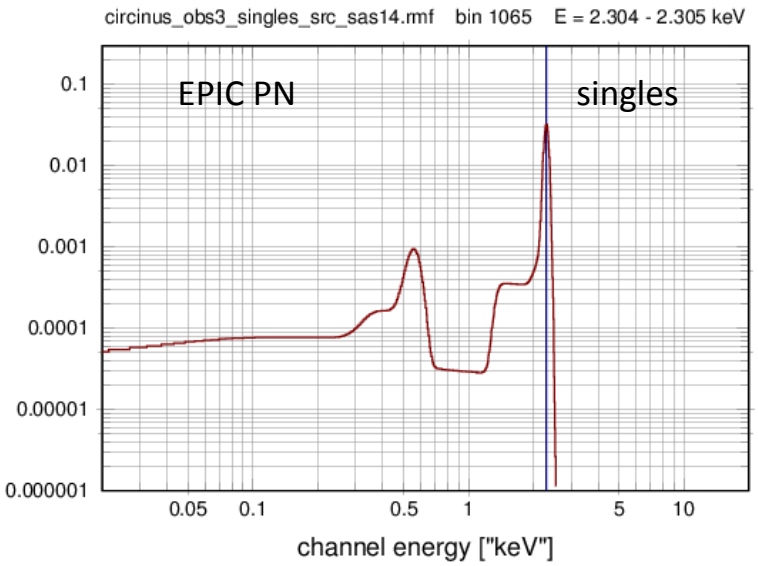
- extract a suitable number (39) of „spectra“ from an EPIC pn RMF
- find a generic mathematical function which is capable of reproducing all of them
- determine the fit parameters individually for each of the 39 spectra
- tighten their energy dependence by applying a „spectral stabilizer“
- find for each parameter a mathematical function which reproduces its energy dependence
- compose the empirical RMF by evaluating this function at each (channel,energy) bin

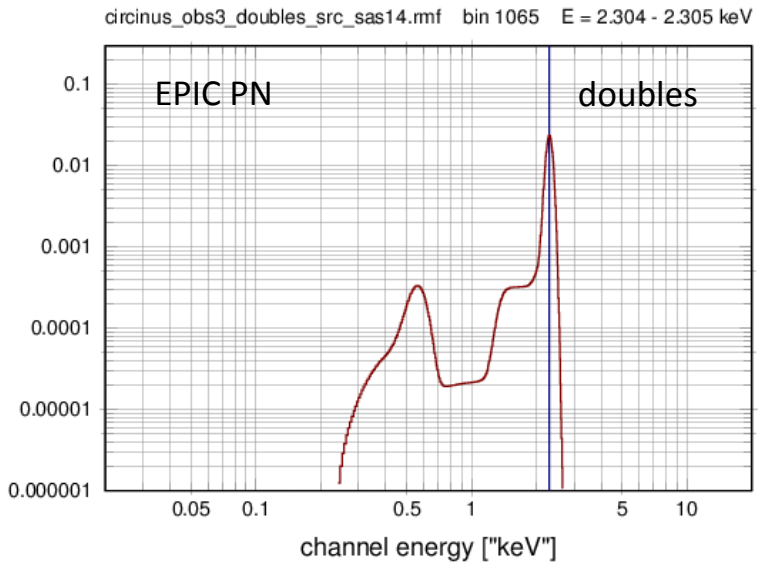
→ faster computation of the RMF
→ direct access to its „shaping components“

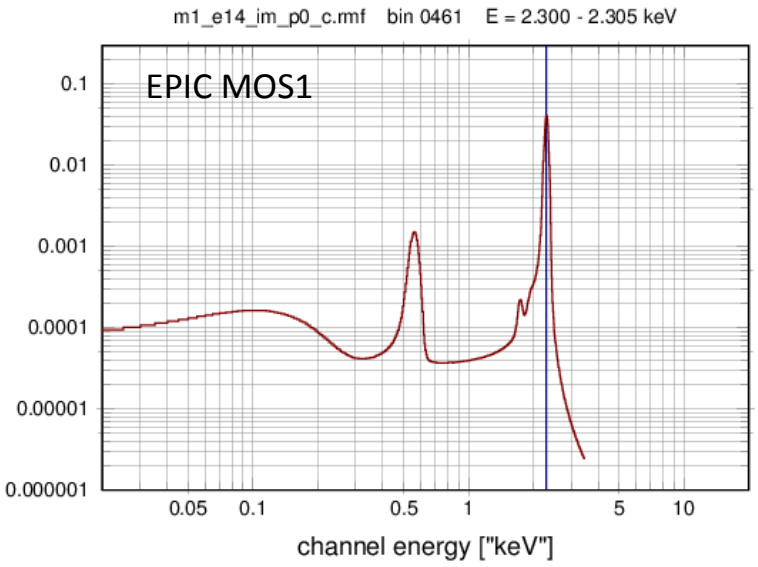
Step 2

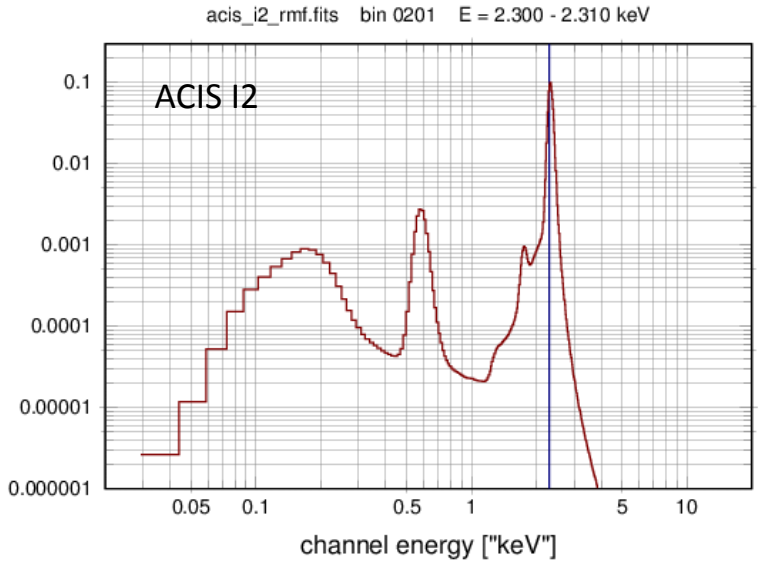
- change the energy dependence of the parameters
- compute modified RMFs
- fit them to pairs of „reliable“ model spectra and observed spectra
- improve the RMF

EPIC pn RMF in comparison with other RMFs

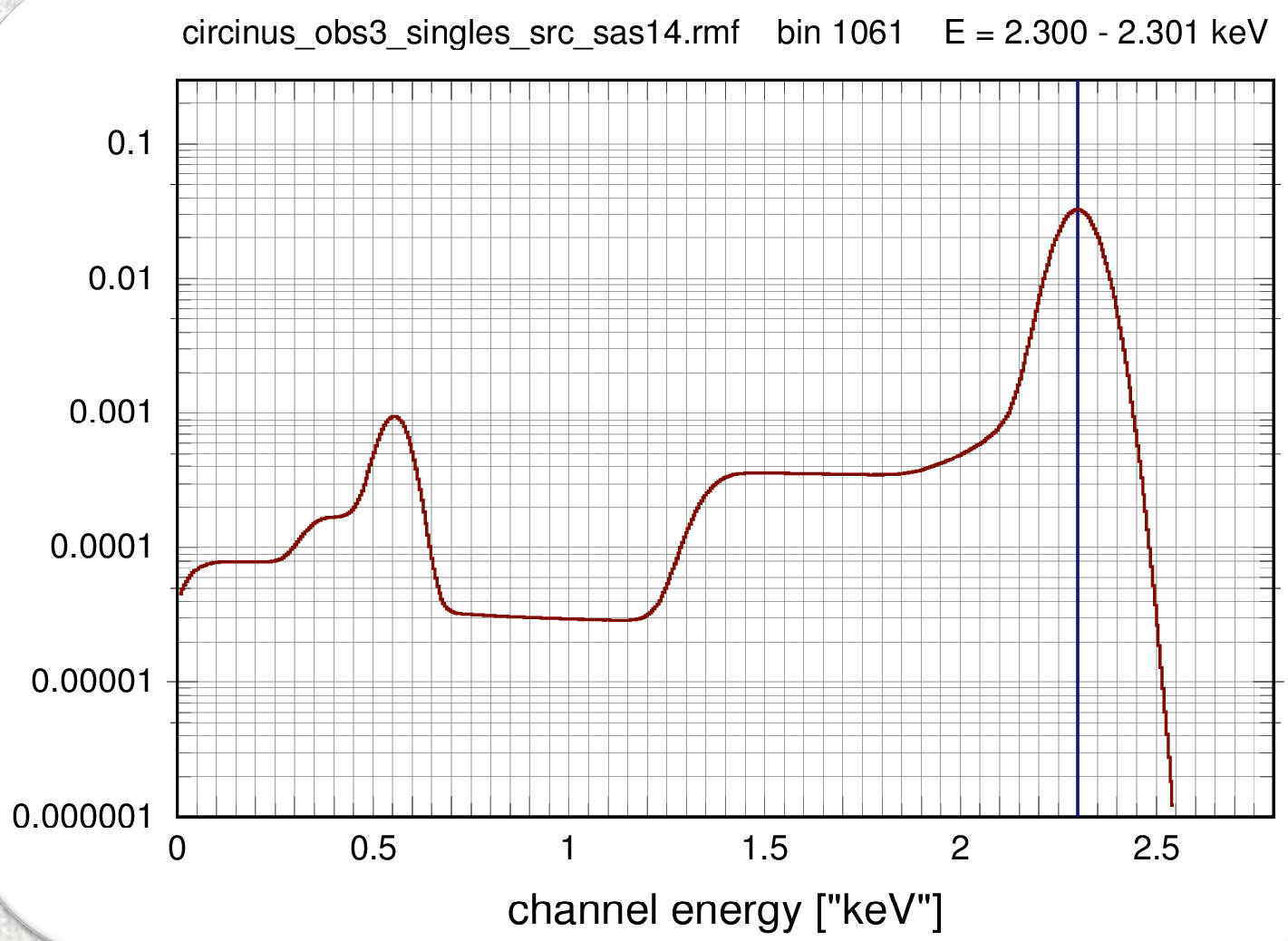




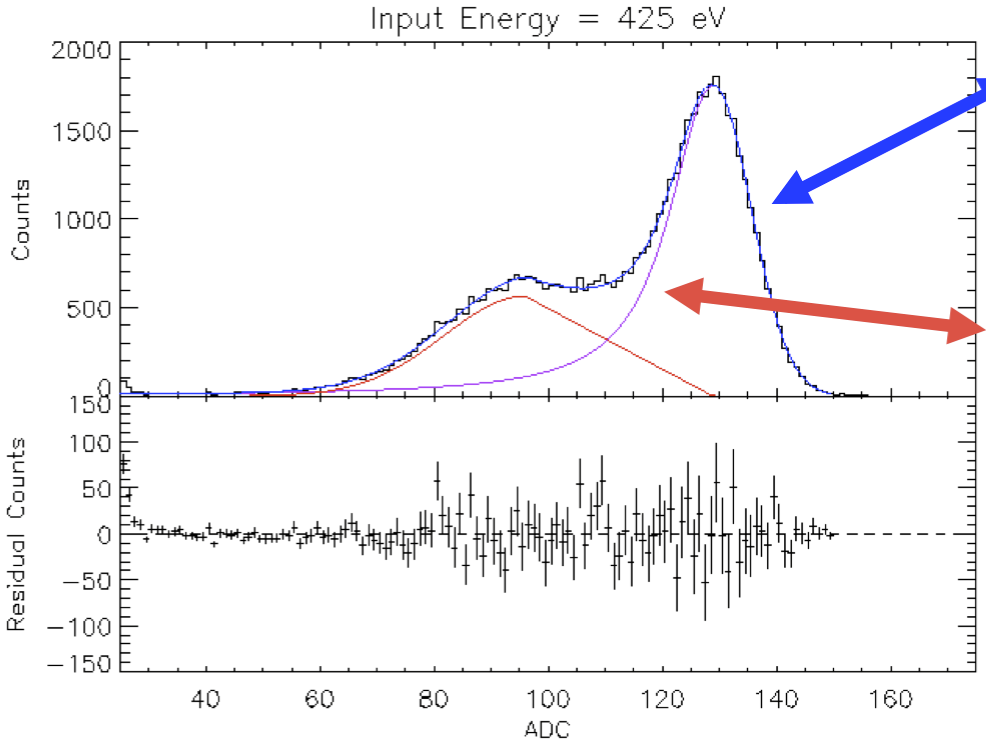




Model Parameters for the EPIC pn RMF



Descriptive Model: The VRMF Model



Main Peak

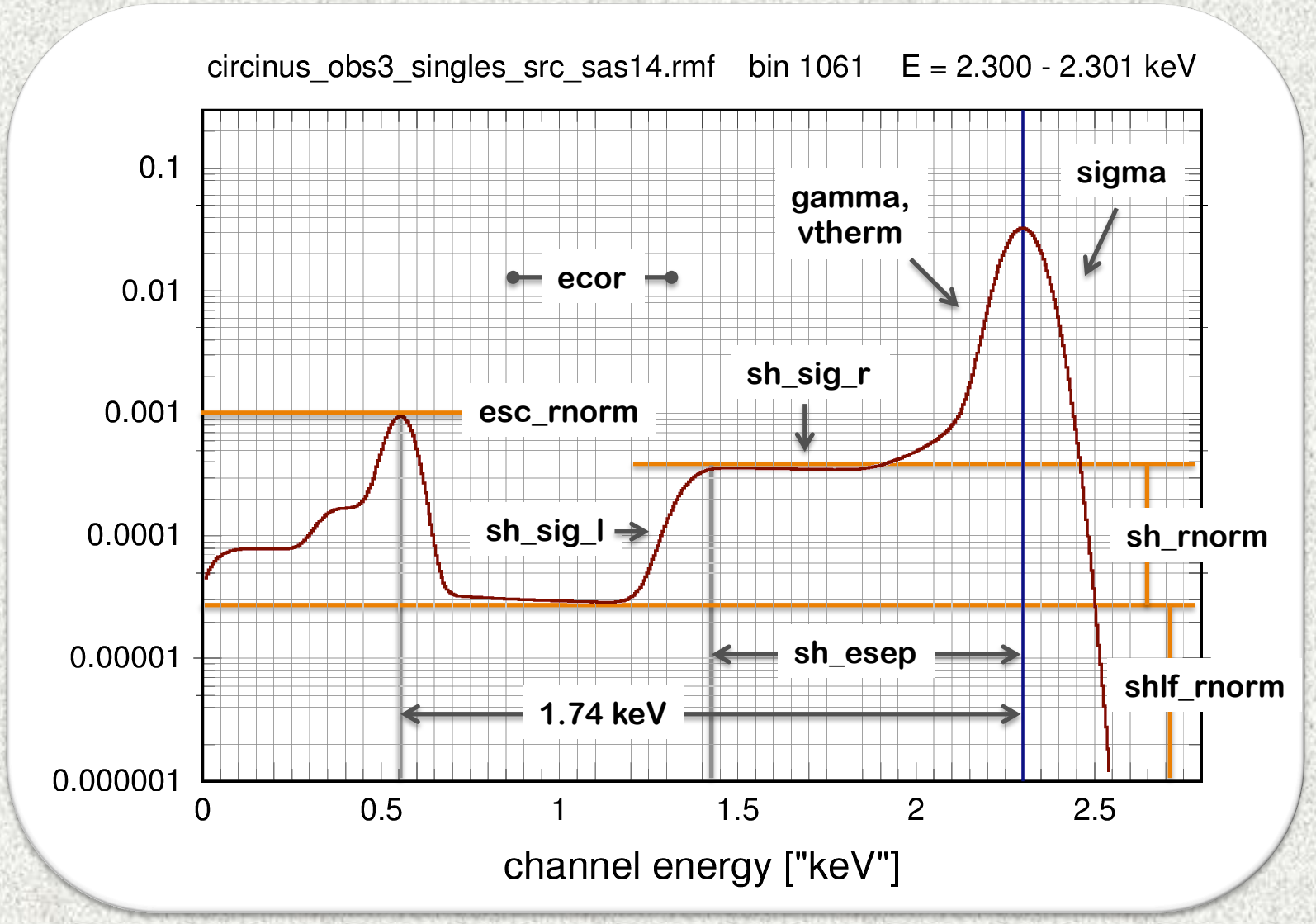
Blue Wing:
Gaussian

Red Wing:
Voigt Function

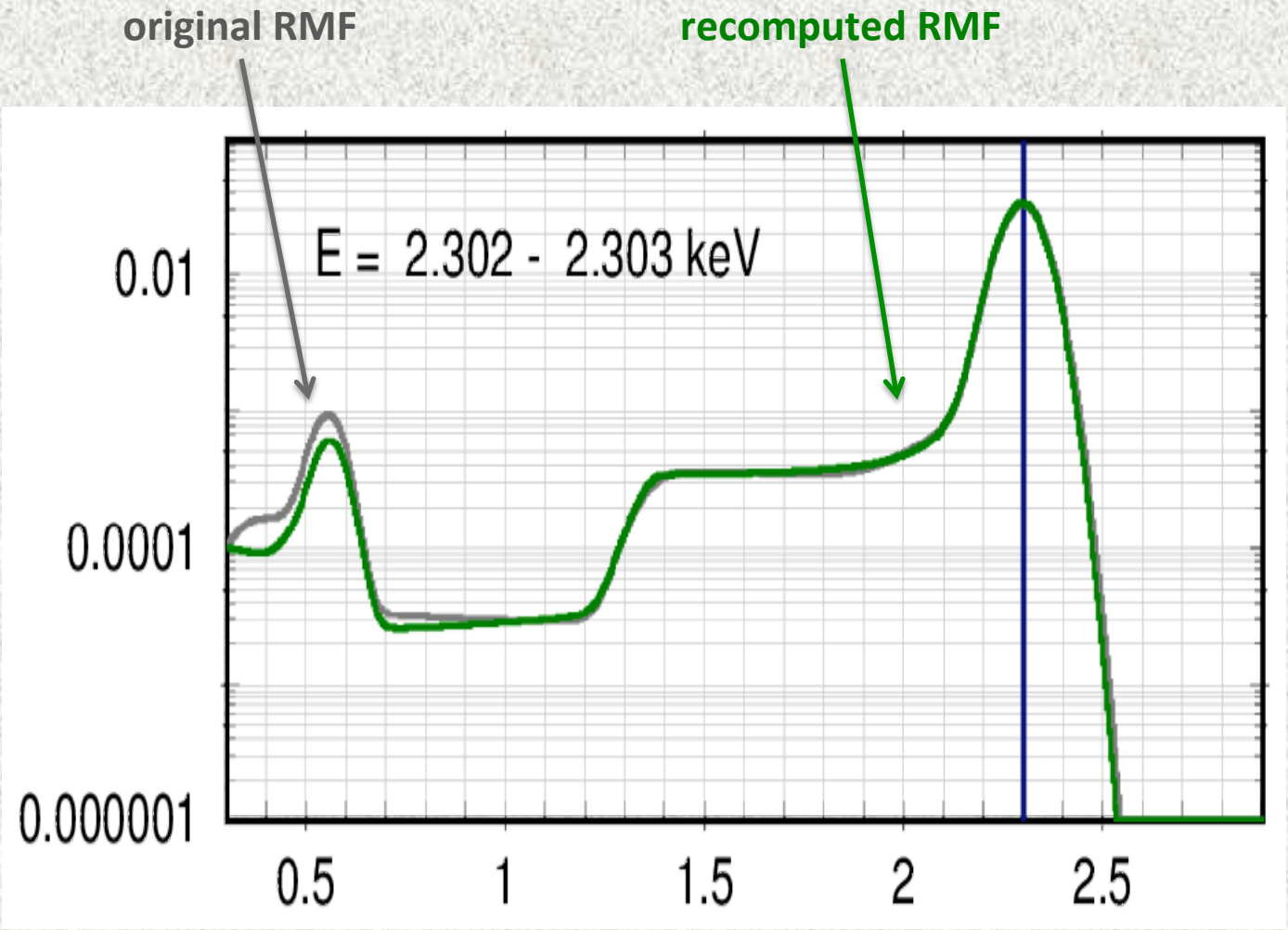
= Gaussian convolved with a Lorentian.

Dampening factor
= 0 (Gaussian)
> 0 (Lorentz-like)

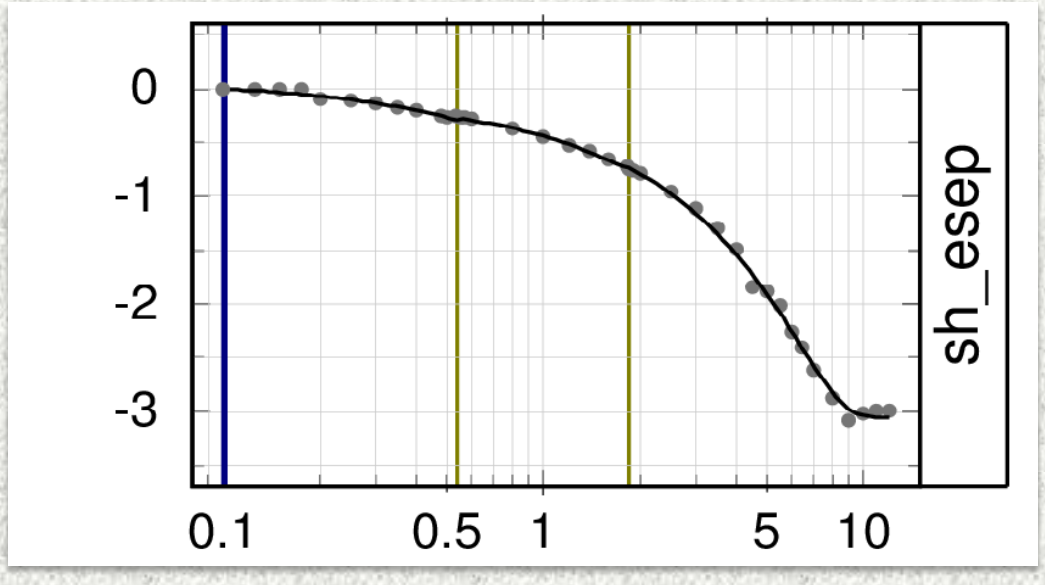
Modeling the EPIC pn RMF at individual energies



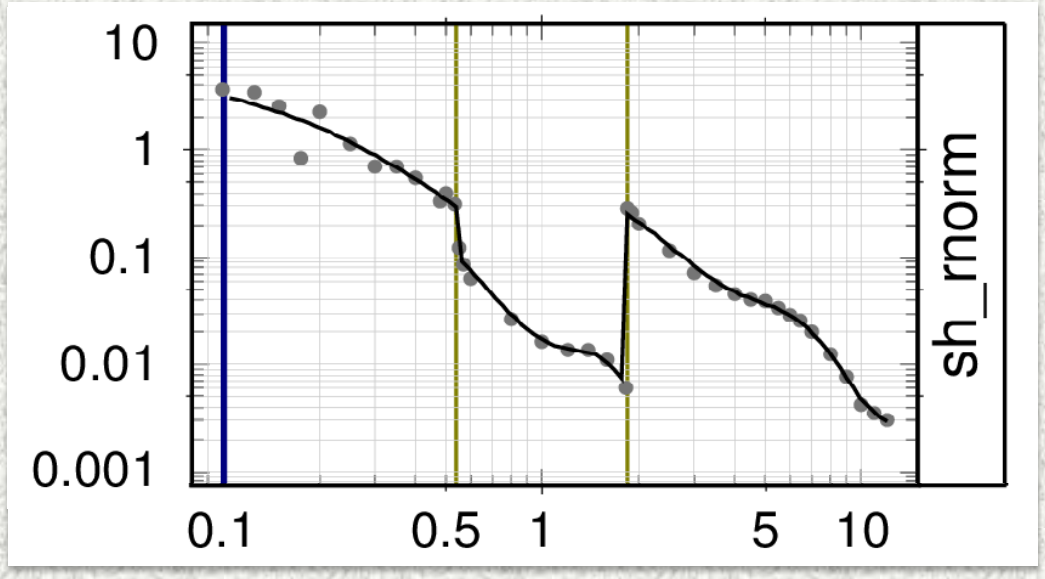
Comparison: original and recomputed RMF @ 2.3 keV



Modeling the energy dependence of the RMF parameters for EPIC pn

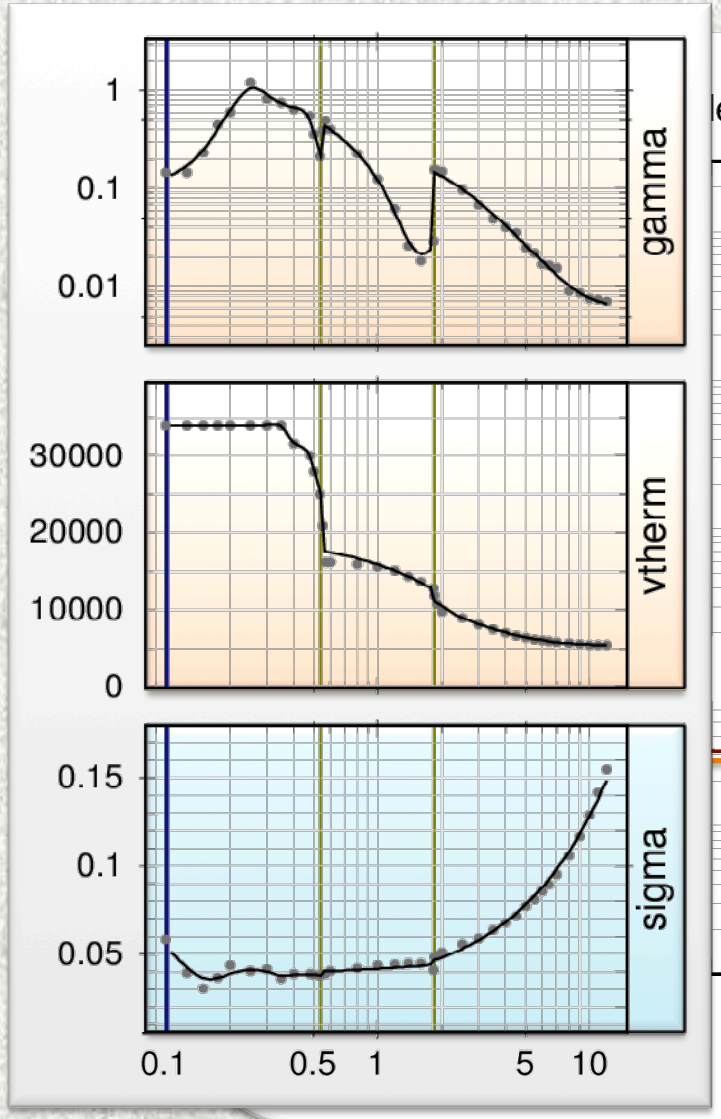


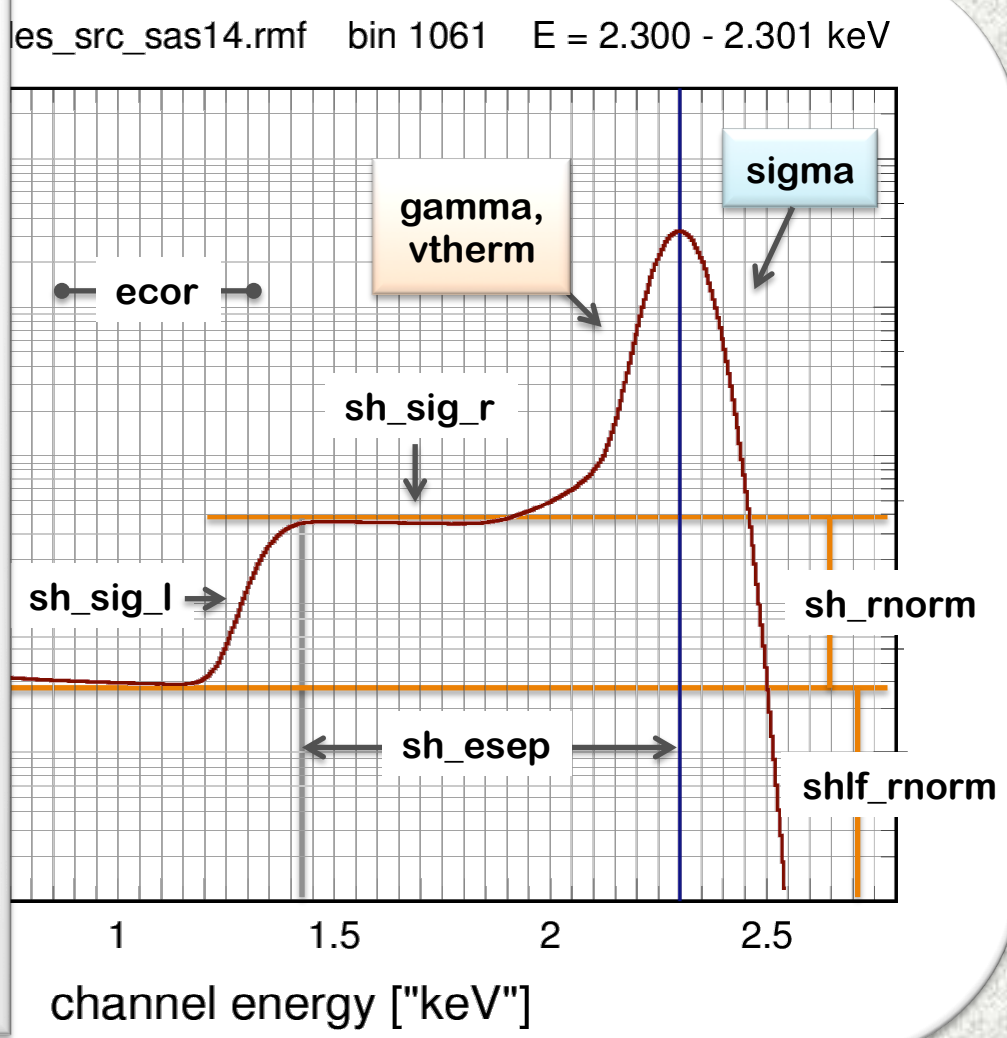
approximating spline



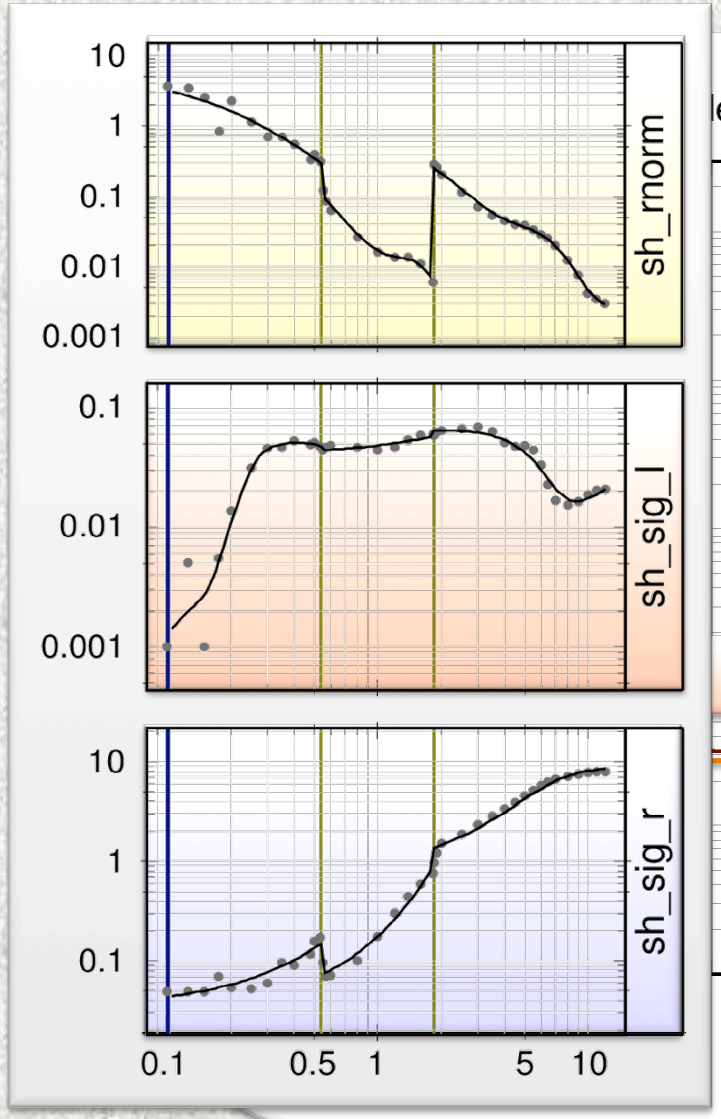
approximating segmented spline

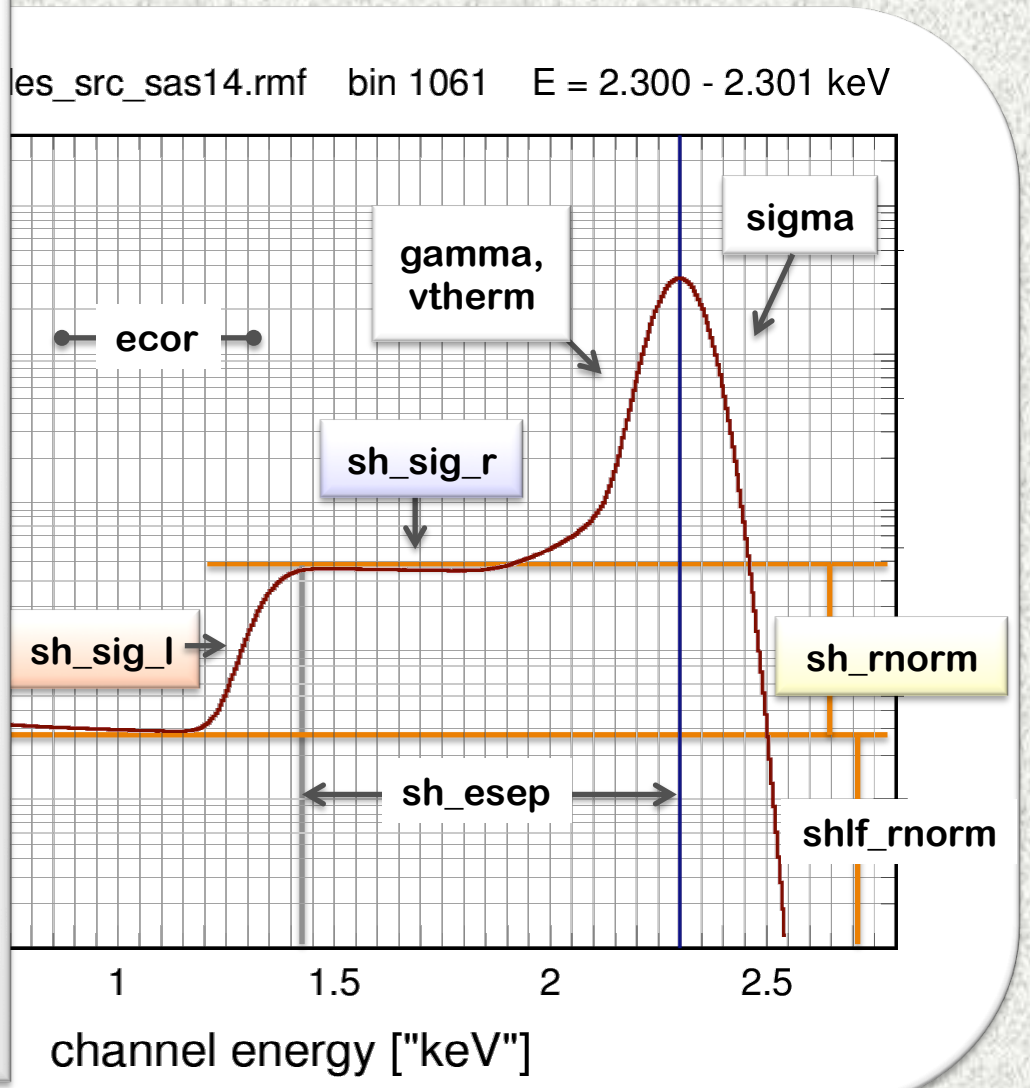
Modeling the EPIC pn RMF at individual energies



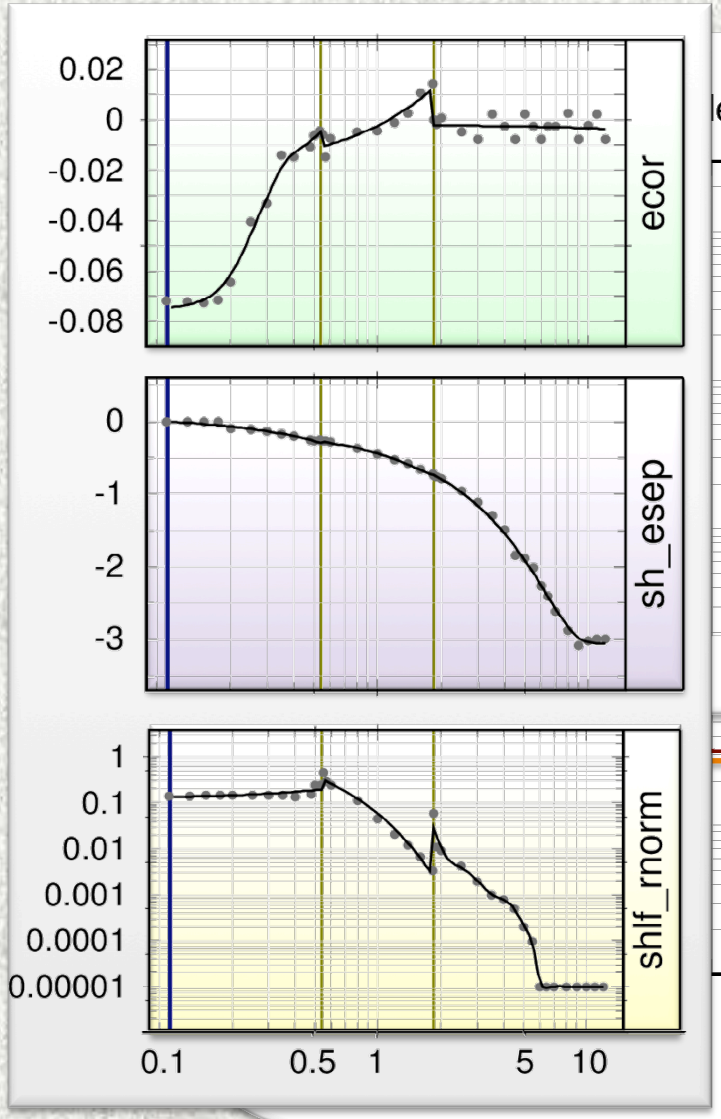


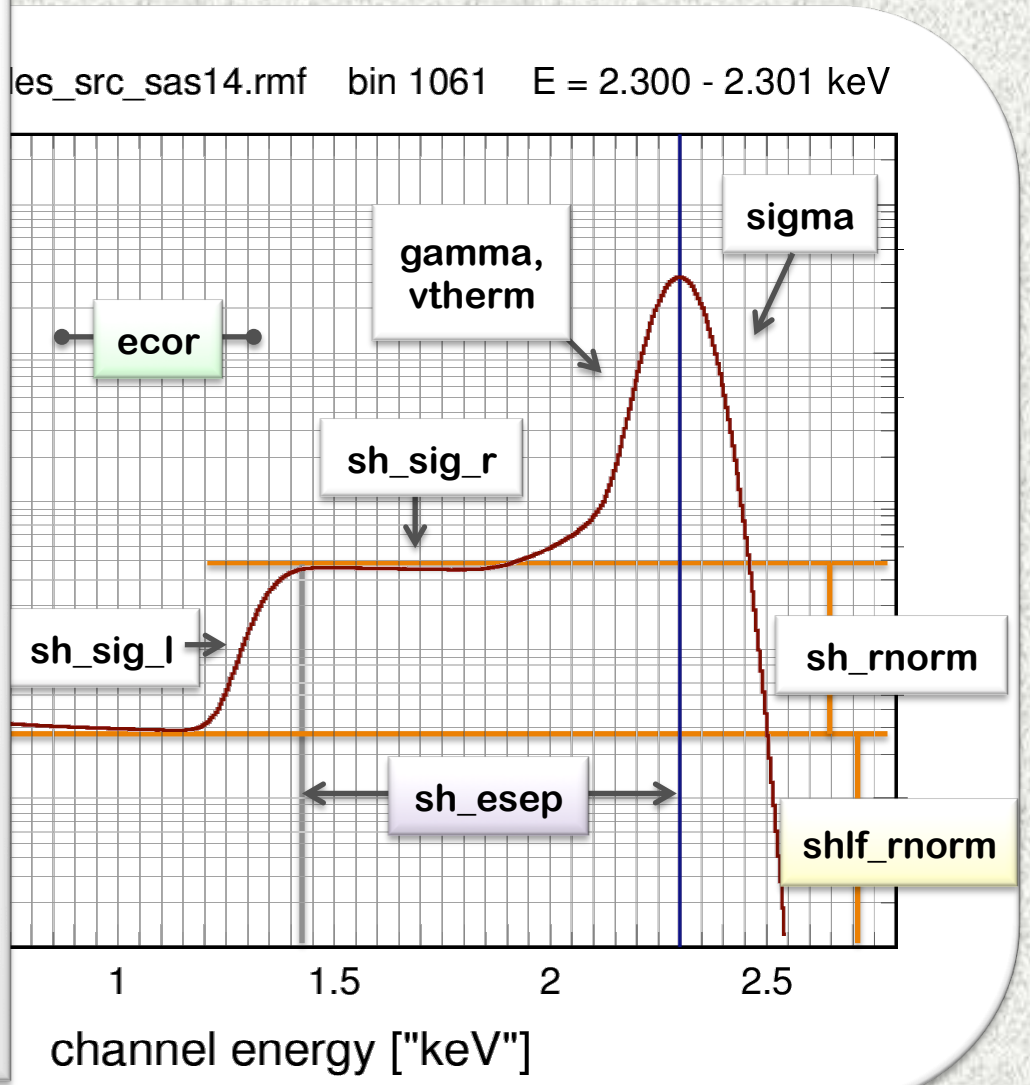
Modeling the EPIC pn RMF at individual energies





Modeling the EPIC pn RMF at individual energies





Empirical modeling of the EPIC pn RMF

Step 1

- extract a suitable number (39) of „spectra“ from an EPIC pn RMF
- find a generic mathematical function which is capable of reproducing all of them
- determine the fit parameters individually for each of the 39 spectra
- tighten their energy dependence by applying a „spectral stabilizer“
- find for each parameter a mathematical function which reproduces its energy dependence
- compose the empirical RMF by evaluating this function at each (channel,energy) bin

→ faster computation of the RMF
→ direct access to its „shaping components“

Step 2

- change the energy dependence of the parameters
- compute modified RMFs
- fit them to pairs of „reliable“ model spectra and observed spectra
- improve the RMF

Empirical modeling of the EPIC pn RMF

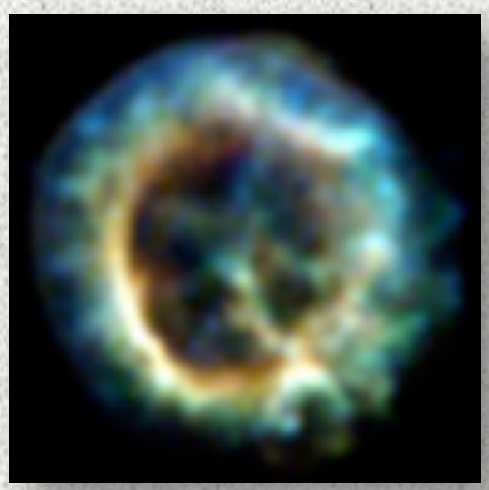
Step 1

- extract a suitable number (39) of „spectra“ from an EPIC pn RMF
- find a generic mathematical function which is capable of reproducing all of them
- determine the fit parameters individually for each of the 39 spectra
- tighten their energy dependence by applying a „spectral stabilizer“
- find for each parameter a mathematical function which reproduces its energy dependence
- compose the empirical RMF by evaluating this function at each (channel,energy) bin

→ faster computation of the RMF
→ direct access to its „shaping components“

Step 2

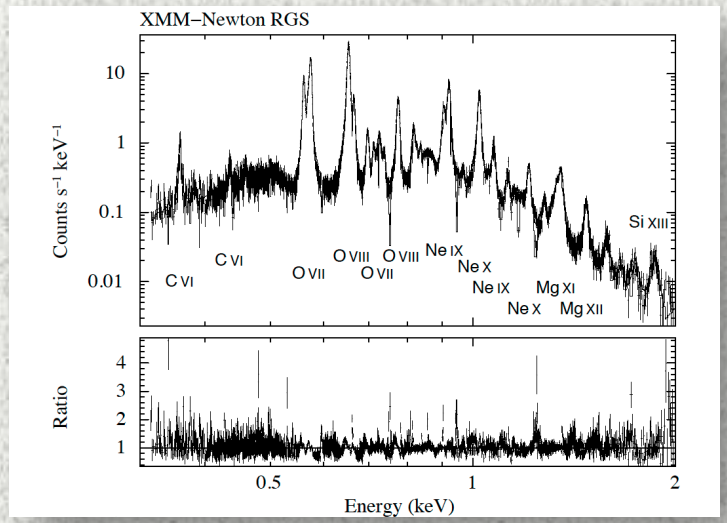
- change the energy dependence of the parameters
- compute modified RMFs
- fit them to pairs of „reliable“ model spectra and observed spectra
- improve the RMF

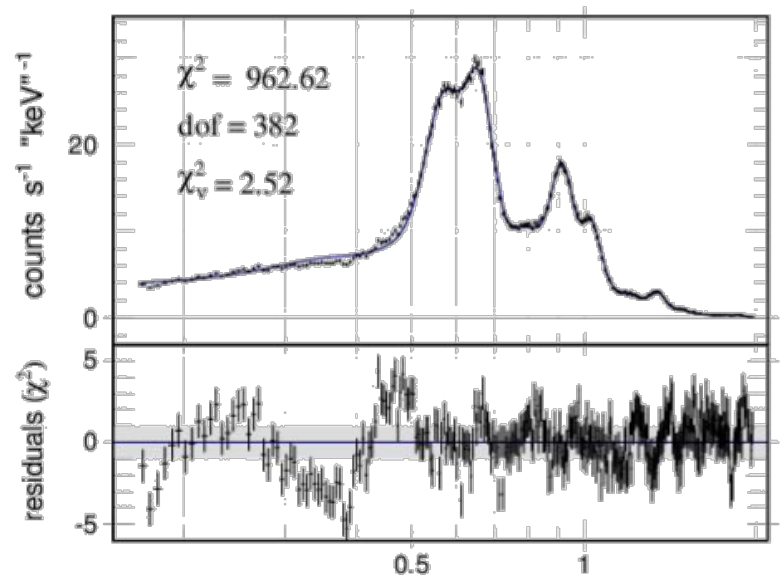


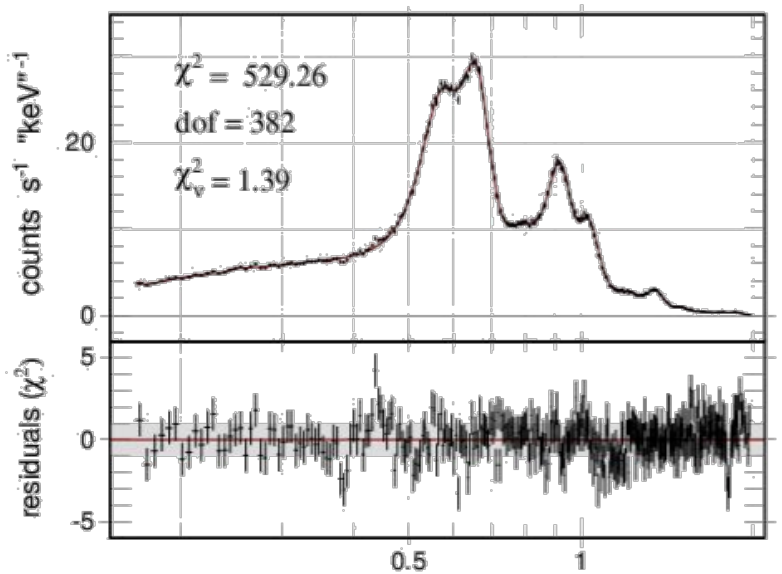
Improving the EPIC pn RMF

SNR 1E0102

proof of concept







Simultaneous Fits

✓ avoid the danger that the ARF/RMF is adjusted to the specific properties of the selected source and the spectral model

- what should be optimized ?
  - sum of χ^2 → spectrum with best statistical quality wins
  - sum of reduced χ^2 → better balance, but still some spectra may win at the expense of others
  - sum of reduced χ^2, but with boundary condition that all spectra must improve → necessity to fit all spectra, even if first spectrum gets worse

Challenge: finding appropriate models

The quality of RMF/ARF improvement is directly related to the confidence of spectral models

e.g. is there a second thermal component in the spectrum of RXJ 1856 ?

Reliable „technical“ reference models are essential

→ IACHEC !

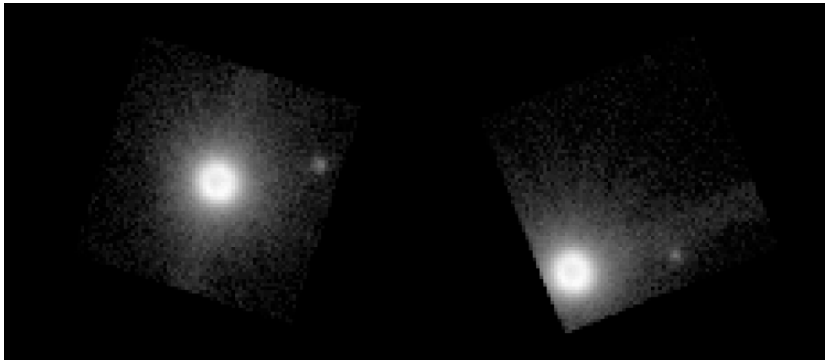
Challenge: finding suitable data

XMM-Newton / EPIC-pn

full frame ext. full frame large window **small window** timing burst	thin filter medium filter thick filter	time of the observation	position on the CCD

example: 1E 0102

2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1x	2x	1x	1x	1x	2x	2x	2x	2x	1x	1x	3x	2x	2x	2x

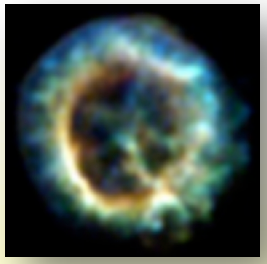


thin
medium
thick

centered position
boresight position

Selected calibration observations

general strategy: start at low energies, below the escape peak of Si (1.7 keV)



1E 0102-72

SW, **medium**, 2011-04-20, 23 ks

SW, **thin**, 2014-10-20, 30 ks

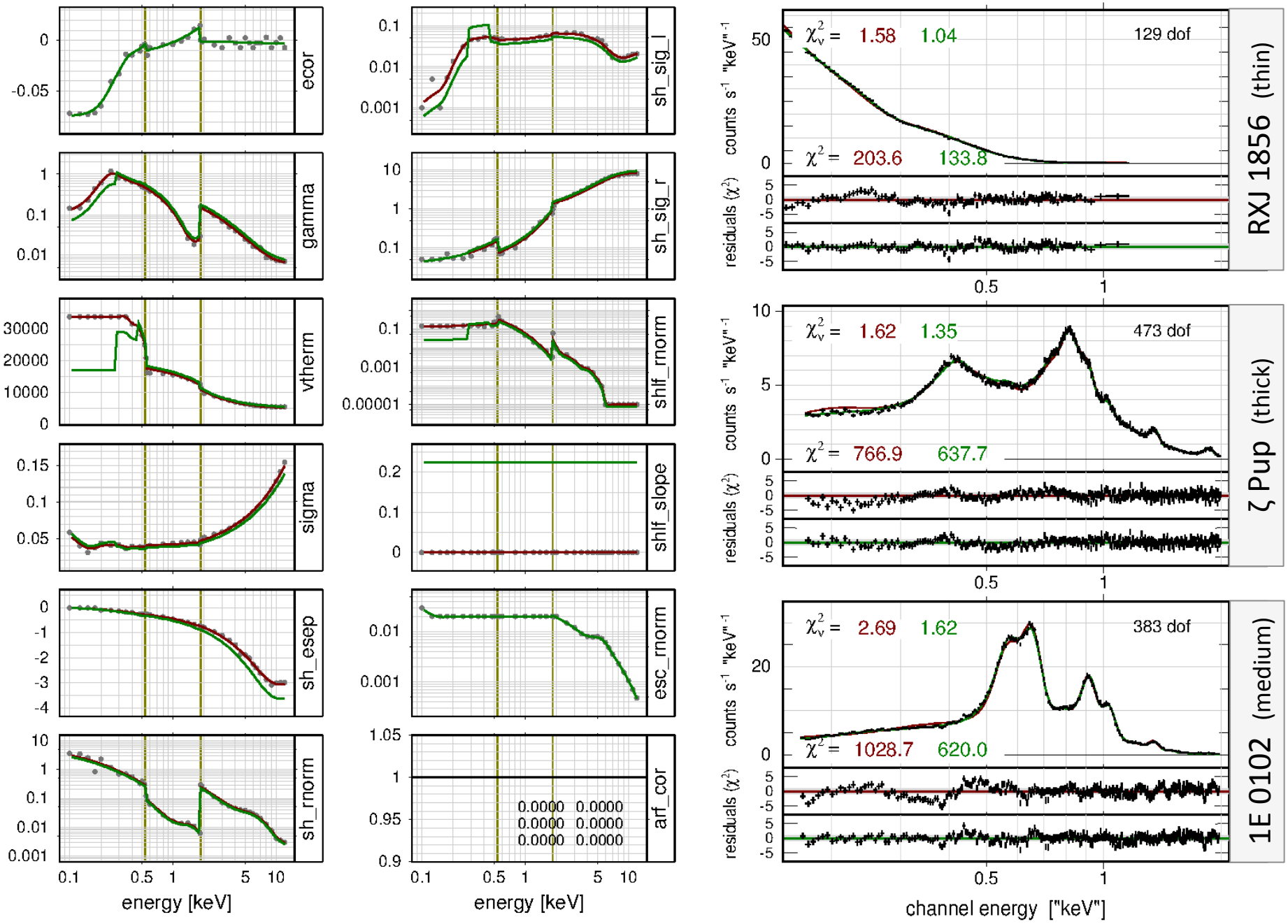
SW, **medium**, 2014-10-20, 30 ks

RXJ 1856.6-3754

SW, **thin**, 2014-09-18/19, 78 ks

ζ Puppis

SW, **thick**, 2013-10-08, 67 ks


ecor
gamma
vtherm
sigma
sh_esep
sh_rnorm
sh_sig_l
sh_sig_r
shlf_rnorm
shlf_slope
esc_rnorm
arf_cor
0.0000 0.0000
0.0000 0.0000
0.0000 0.0000
energy [keV]
energy [keV]
RXJ 1856 (thin)
χ^2_ν = 1.58 1.04
129 dof
χ^2 = 203.6 133.8
ζ Pup (thick)
χ^2_ν = 1.62 1.35
473 dof
χ^2 = 766.9 637.7
1E 0102 (medium)
χ^2_ν = 2.69 1.62
383 dof
χ^2 = 1028.7 620.0
counts s^{-1} "keV"$^{-1}$
residuals (χ^2)
channel energy ["keV"]

Outlook

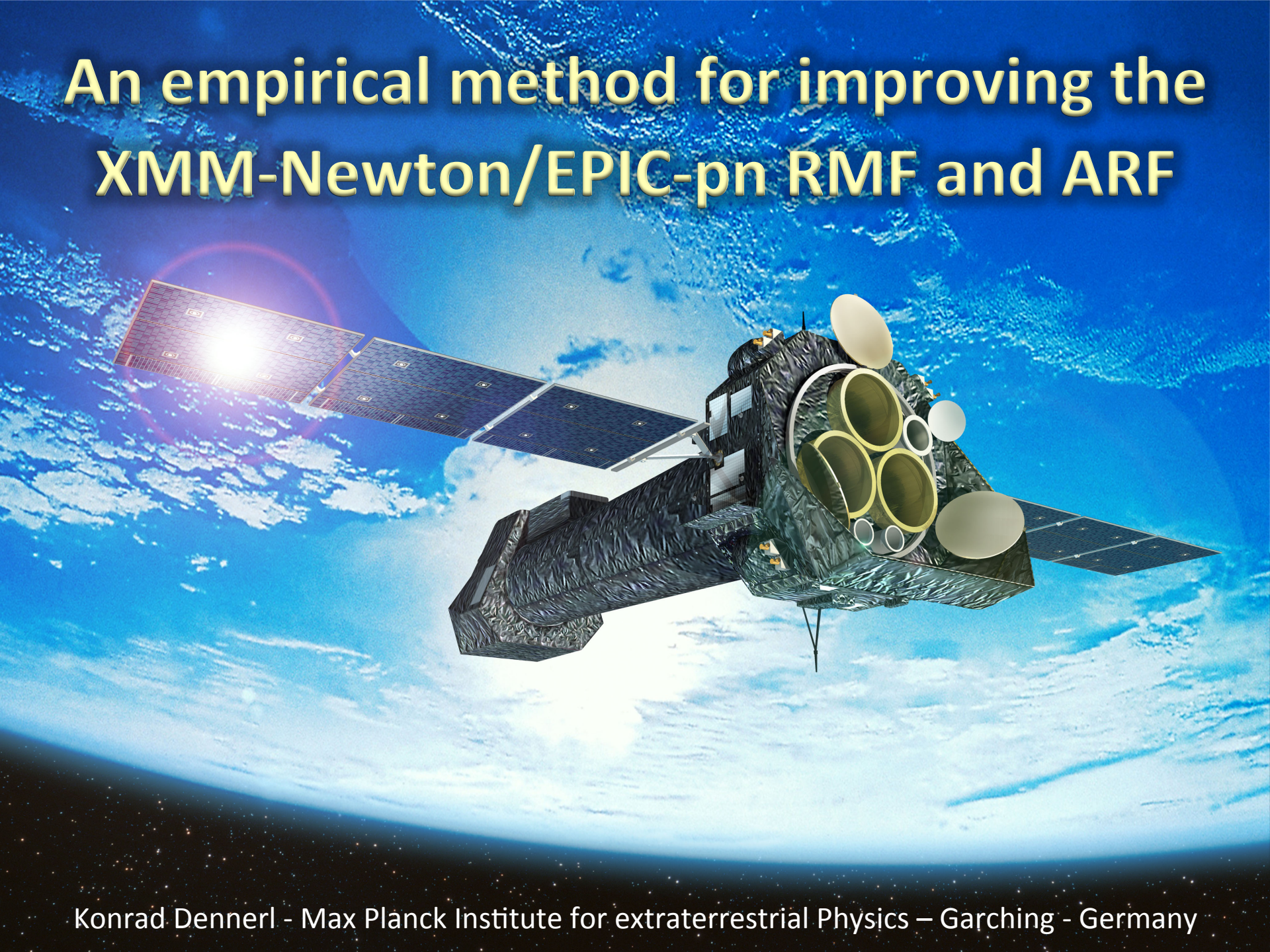
1**. EPIC pn** (presence and near future):

- more tests with „IACHEC spectra“
- simultaneous fits of complementary spectra
- temporal, spatial, and mode dependencies of the RMF:
  parameter determination and interpolation by suitable functions

2. **XMM-Newton and beyond** (if first step successful):

- cross calibration within XMM-Newton:
  simultaneous fits of the EPIC PN, MOS1, and MOS2 RMFs
- in-orbit fine-tuning of the eROSITA RMFs
- cross calibration with other instruments by simultaneous fitting of their RMFs

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



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