EPIC Calibration and Operations Meeting

ESAC, Spain, 2016 April 12 - 13
2016 EPIC Calibration and Operations Meeting, ESAC, April 12-13

Tuesday April 12

"B" Building, Room B005

09:30 Welcome and logistics  M. Smith  10
09:40 XMM-Newton mission operations  J. Martin & N. Pfeil  60
10:40 Status of instrument operations  P. Calderon  20

11:00 Coffee Break

11:30 Status of science operations  M. Santos-Lleo  15
11:45 Review of relevant SAS SCRS  M. Smith  10
11:55 News and plans on the SAS front  C. Gabriel  20
12:15 Pipeline status and plans  P. Rodriguez  15
12:30 On the need for an intra-exposure time-dependent HK interface in the EPIC-pn pipeline  M. Freyberg  10

12:40 Lunch

14:00 EPIC-MOS monitoring  M. Stuhlinger  20
14:20 EPIC-pn monitoring and energy scale  M. Smith  20
14:40 Monitoring of EPIC-pn timing  J. Ferrero  30
15:10 Update on the MOS contamination  S. Semkay  15

15:30 Coffee Break

16:00 Improving the EPIC-pn RMF  K. Dennerl  30
16:30 Cross-calibrating effective areas for a default empirical correction  C. Heinitz  20
16:50 XRT PSF investigations  M. Smith  20

Wednesday April 13

"B" Building, Room B005

09:30 On EPIC-pn mode efficiencies (in particular Burst mode)  M. Freyberg  10
09:40 Background maps  N. de la Calle  20
10:00 Status of EPIC cross-calibration  M. Stuhlinger  20
10:20 RGS calibration status overview  C. Gonzalez  10
Improving the EPIC-pn RMF (and ARF)

Konrad Dennerl - Max Planck Institute for extraterrestrial Physics – Garching - Germany
Cross-calibration of the X-ray Instruments onboard the Chandra, Suzaku, Swift, and XMM-Newton Observatories using the SNR 1E 0102.2-7219


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


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

Plucinsky et al. 2012

\[ \chi^2 = 962.62 \]
\[ \text{dof} = 382 \]
\[ \chi^2_v = 2.52 \]
General properties of the ARF and RMF


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?
$E_{\text{in}} = 1.840 \text{ keV}$
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

circinus_obs3_singles_src_sas14.rmf  bin 1065  E = 2.304 - 2.305 keV

EPIC PN  singles

EPIC MOS1

circinus_obs3_doubles_src_sas14.rmf  bin 1065  E = 2.304 - 2.305 keV

EPIC PN  doubles

acis_2_rmf.fits  bin 0201  E = 2.300 - 2.310 keV

ACIS I2
EPIC pn RMF in comparison with other RMFs
Model Parameters for the EPIC pn RMF

circinus_obs3_singles_src_sas14.rmf  bin 1061  E = 2.300 - 2.301 keV

channel energy ["keV"]
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)
Model Parameters for the EPIC pn RMF

circinus_obs3_singles_src_sas14.rmf  bin 1061  E = 2.300 - 2.301 keV

channel energy ["keV"]
Modeling the EPIC pn RMF at individual energies

circinus_obs3_singles_src_sas14.rmf  bin 1061  E = 2.300 - 2.301 keV

channel energy ['"keV"']

0 0.5 1 1.5 2 2.5

0.000001 0.00001 0.0001 0.001 0.01 0.1

gamma, vtherm

sigma

esc_rnorm

sh_rnorm

shlf_rnorm

sh_esep

sh_sig_l

sh_sig_r

cor

1.74 keV
Modeling the EPIC pn RMF at individual energies

circinus_obs3_singles_src_sas14.rmf  bin 1061  E = 2.300 - 2.301 keV

channel energy ["keV"]
Comparison: original and recomputed RMF @ 2.3 keV

E = 2.302 - 2.303 keV

original RMF

recomputed RMF
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

\[ \text{gamma, vtherm} \]

\[ \text{sigma} \]

\[ \text{sh_sig_r} \]

\[ \text{sh_esep} \]

\[ \text{sh_sig_l} \]

\[ \text{sh_rnorm} \]

\[ \text{shf_rnorm} \]

channel energy ["keV"]

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Recomputing the EPIC pn RMF

EPIC pn: RMF for single pixel events

- E = 2.302 - 2.303 keV
- E = 2.302 - 2.303 keV
- E = 2.302 - 2.303 keV

energy [keV]

channel energy ["keV"]

K. Dennerl / MPE
**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
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- 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
Structural 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

\[ \chi^2 = 947.07 \]
\[ \text{dof} = 382 \]
\[ \chi^2_\nu = 2.48 \]

1E0102
(SW, medium filter)
Improving the EPIC pn RMF

\[ \chi^2 = 947.07 \]

channel energy ["keV"]

residuals ($\chi^2$)

sh \_ sig \_ r

sh \_ sig \_ l

gamma

vtherm

sigma

0.05

0.1

0.15

0.5

1

5

10

0.1

0.5

1

5

10
Comparison old ↔ new RMF

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K. Dennerl / MPE
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 $\chi^2 \rightarrow$ spectrum with best statistical quality wins
   ➢ sum of reduced $\chi^2 \rightarrow$ better balance, but still some spectra may win at the expense of others
   ➢ sum of reduced $\chi^2$, but with boundary condition that all spectra must improve $\rightarrow$ 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
- thin filter medium filter thick filter
- time of the observation
- position on the CCD

example: 1E 0102

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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
ζ Puppis  (SW, thick filter)
Before

\( \chi^2 = 1092.18 \)
\( \text{dof} = 487 \)
\( \chi^2_{\nu} = 2.24 \)

After

\( \chi^2 = 1023.02 \)
\( \text{dof} = 487 \)
\( \chi^2_{\nu} = 2.10 \)

\( \zeta \, \text{Pup (SW, thick filter)} \)
RXJ 1856.6-3754 (SW, thin filter)
RXJ 1856 (SW, thin filter)

before

\[ \chi^2 = 203.65 \]

\[ \text{dof} = 129 \]

\[ \chi^2 < 1.58 \]

after

\[ \chi^2 = 128.32 \]

\[ \text{dof} = 129 \]

\[ \chi^2 < 0.99 \]
RXJ 1856 (SW, thin filter)
ζ Puppis (SW, thick filter)

&

1E 0102-72 (SW, medium filter)
RXJ 1856.6-3754 (SW, thin filter) & ζ Puppis (SW, thick filter) & 1E 0102-72 (SW, medium filter)
1E 0102-72 (SW, thin filter)
&
1E 0102-72 (SW, medium filter)
# !XSPEC12>show free;
#
#Free parameters defined:
#---------------------------------------------------------------
#Model constant<1>(gaussian<2> + gaussian<3> + gaussian<4> + gaussian<5> + gaussian<6>)
#Model Model Component Parameter  Unit       Value
# par comp
#  1   1 constant  factor       0.581934  +/-  2.92526E-03
#  61  21 gaussian  norm        1.28559E-03 +/-  1.51837E-05
#  67  23 gaussian  norm        1.43469E-03 +/-  1.33642E-05
# 118 40 gaussian  norm        5.21139E-03 +/-  3.54326E-05
#
#
Challenge: finding appropriate models

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

Is there any possibility to avoid the dependence on the reliability of spectral models? .. the EPICs have several filters..

Idea: observe the same (constant, non piled-up) source at the same position on the CCD with the same readout mode and at (almost) the same time, but with different filters, and fit the ratio of the (detector-background subtracted) spectra with the ratio of the filter transmissions ..
Is it possible to avoid the dependence on the reliability of spectral models?
Is it possible to avoid the dependence on the reliability of spectral models?

- Source spectrum
- Source spectrum, multiplied with ARF
- Flux ratio of ARF-weighted source spectra
- Thin, medium, thick
- Medium/thin, thick/thin
- Ratio of ARF-weighted source spectra
- Count rate ratio
- Channel energy [“keV”]

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Is it possible to avoid the dependence on the reliability of spectral models?

**Source Spectrum**

- Flux vs. photon energy [keV]
- Multiplied with ARF and convolved with RMF ratio of ARF-weighted source spectra

**Count Rate**

- Thin, Medium, Thick
- Medium/Thin, Thick/Thin
- Ratio of ARF-weighted and RMF-convolved source spectra

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Is it possible to avoid the dependence on the reliability of spectral models?

**source spectrum**

**source spectrum, multiplied with ARF**

**source spectrum, multiplied with ARF and convolved with RMF**

**ratio of ARF-weighted source spectra**

**ratio of ARF-weighted and RMF-convolved source spectra**
Is it possible to avoid the dependence on the reliability of spectral models?
Is it possible to avoid the dependence on the reliability of spectral models?

No, but it is possible to minimize this dependence!
Outlook (near future)

- implement a „spectral stabilizer“ into the RMF fits (as done for eROSITA)
- implement more flexible constraints on the parameters of the shaping functions (as done for eROSITA)
- investigate the possibility of fitting flux ratios (obtained with different filters) instead of the fluxes
- check for/propose calibration observations obtained at „identical“ conditions with all the three filters (no pile-up, stable background)
- check the filter transmission in the ARFs
- check the other ARF components: mirror, pattern frequencies, QE
1. EPIC pn:
- 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, MOS2, RGS1, RGS2\} RMFs
- in-orbit fine-tuning of the eROSITA RMFs
- cross calibration with other instruments by simultaneously fitting their RMFs
Improving the EPIC-pn RMF (and ARF)

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