eROSITA On-ground Calibration and beyond..

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MPE

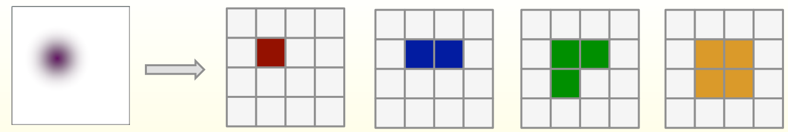
eROSITA Calibration:

Detector

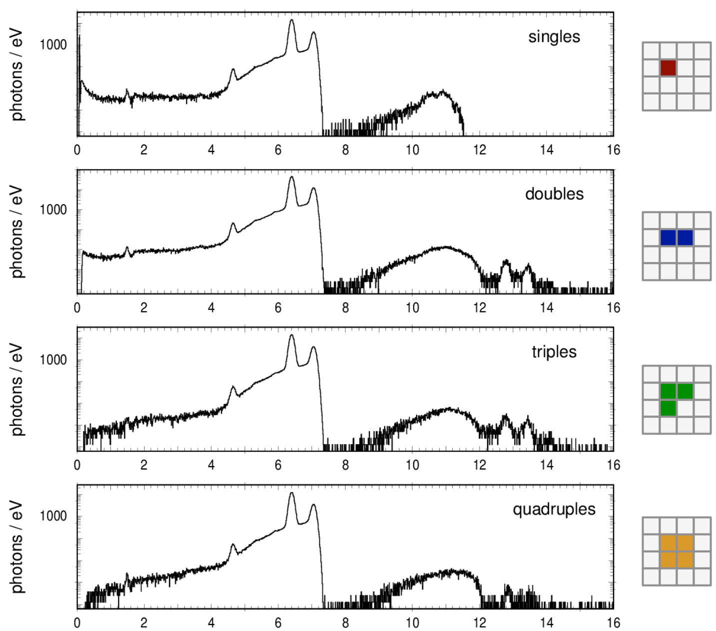
Gain and CTI

Energy Calibration:

extent of charge cloud & 75 µm pixel size
→ 4 pattern types



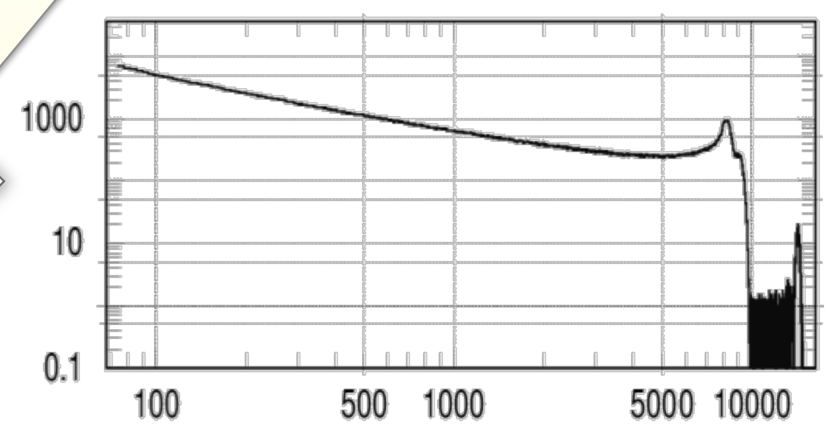
reconstructed spectral distributions



instrumental energy [„keV"]

- superposition of partial charges
- charge transfer losses (CTI)
- gain differences between CCD columns

observed pulse height distribution

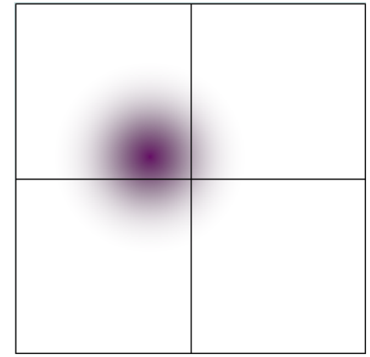


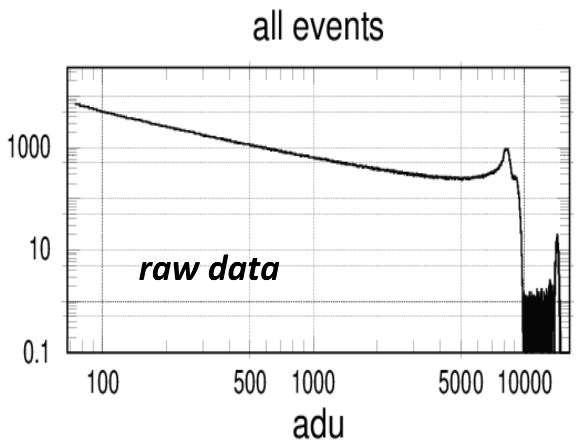
analog-digital-unit [adu]

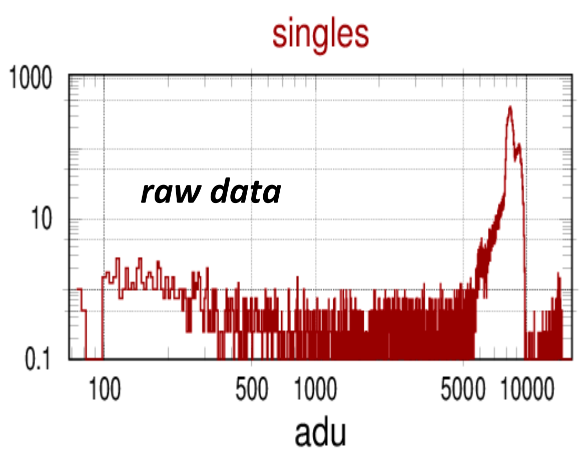
example: Fe-K, measured with FM4

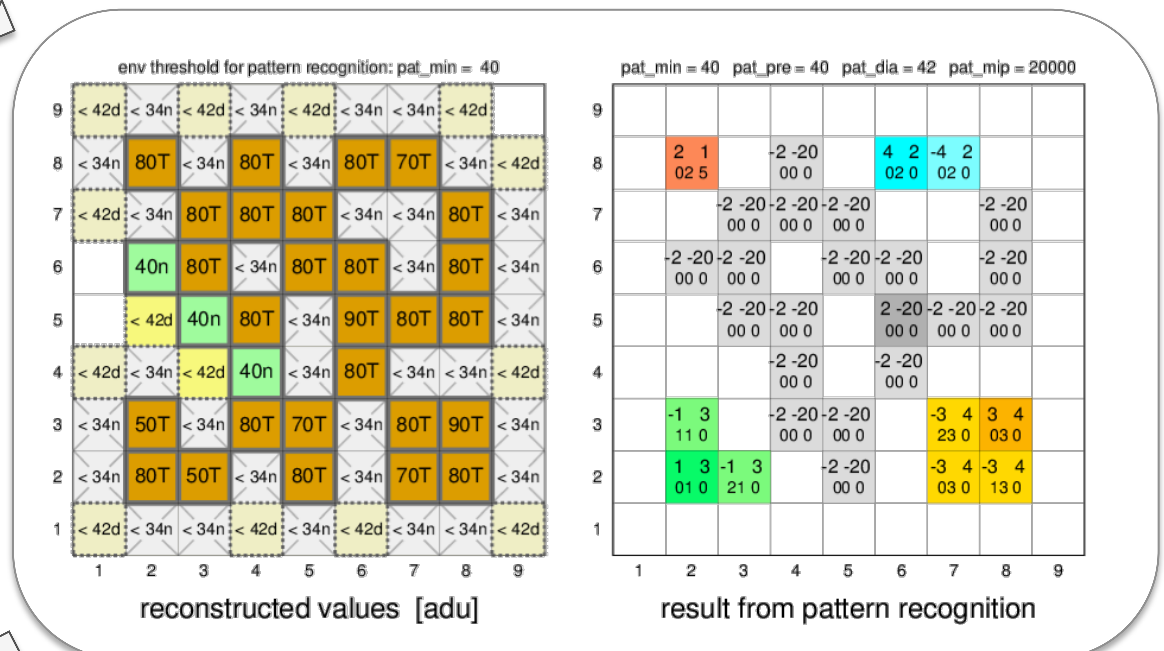
Reconstructing the spectral distribution requires

- **pattern** recognition
- correction for **gain** variations between CCD channels
- correction for charge transfer loss **(CTI)**





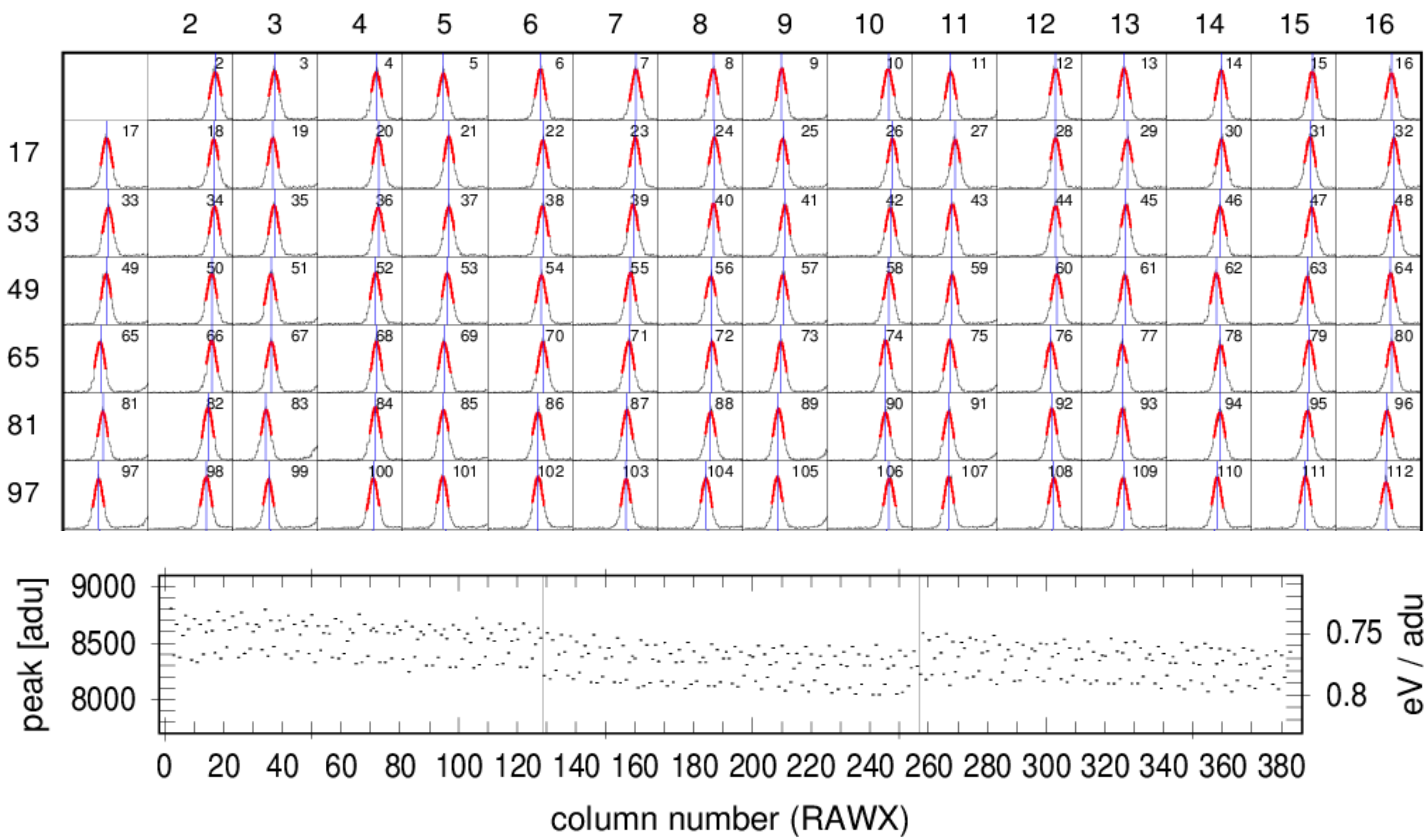




pattern recognition

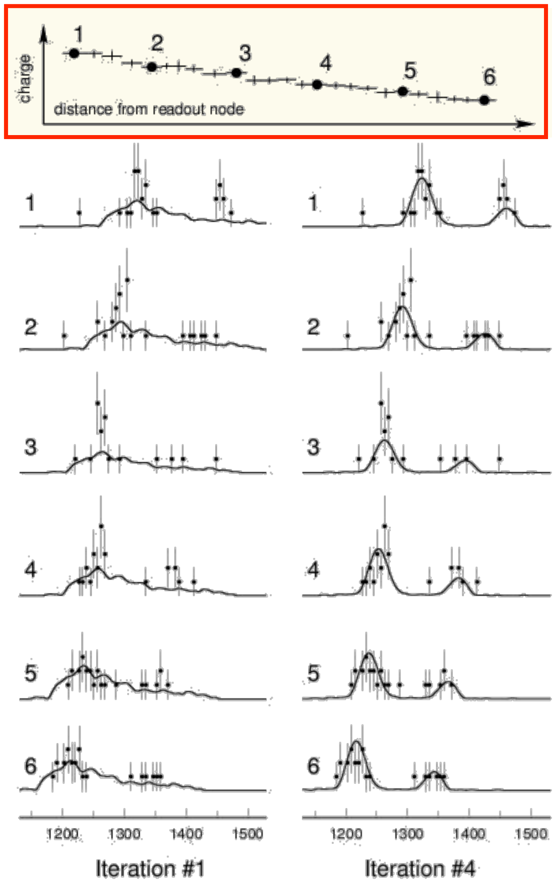
Reconstructing the spectral distribution requires
- **pattern** recognition
- correction for **gain** variations between CCD channels
- correction for charge transfer loss **(CTI)**

example:
Fe-K, measured with FM4



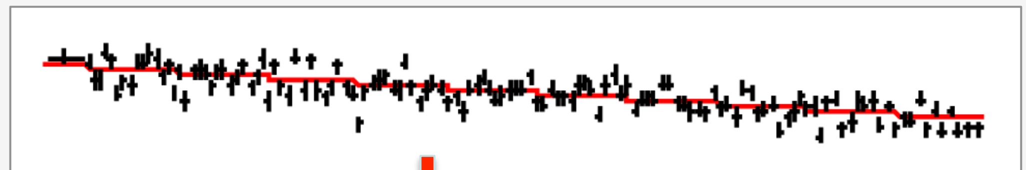
gain determination

Reconstructing the spectral distribution requires
- **pattern** recognition
- correction for **gain** variations between CCD channels
- correction for charge transfer loss **(CTI)**



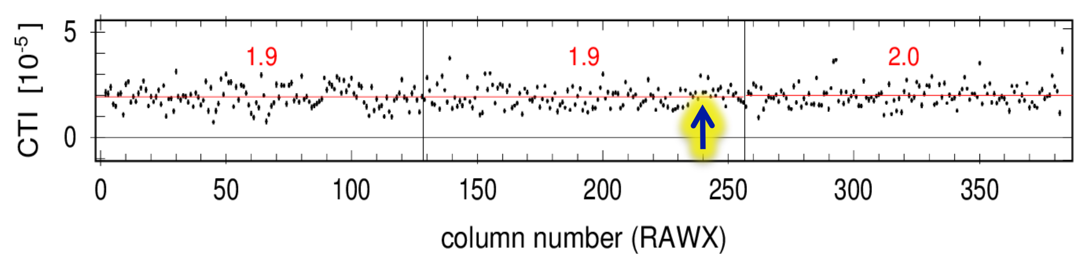
example:
Fe-K, measured with FM4

CCD column 240 (arbitrary choice)

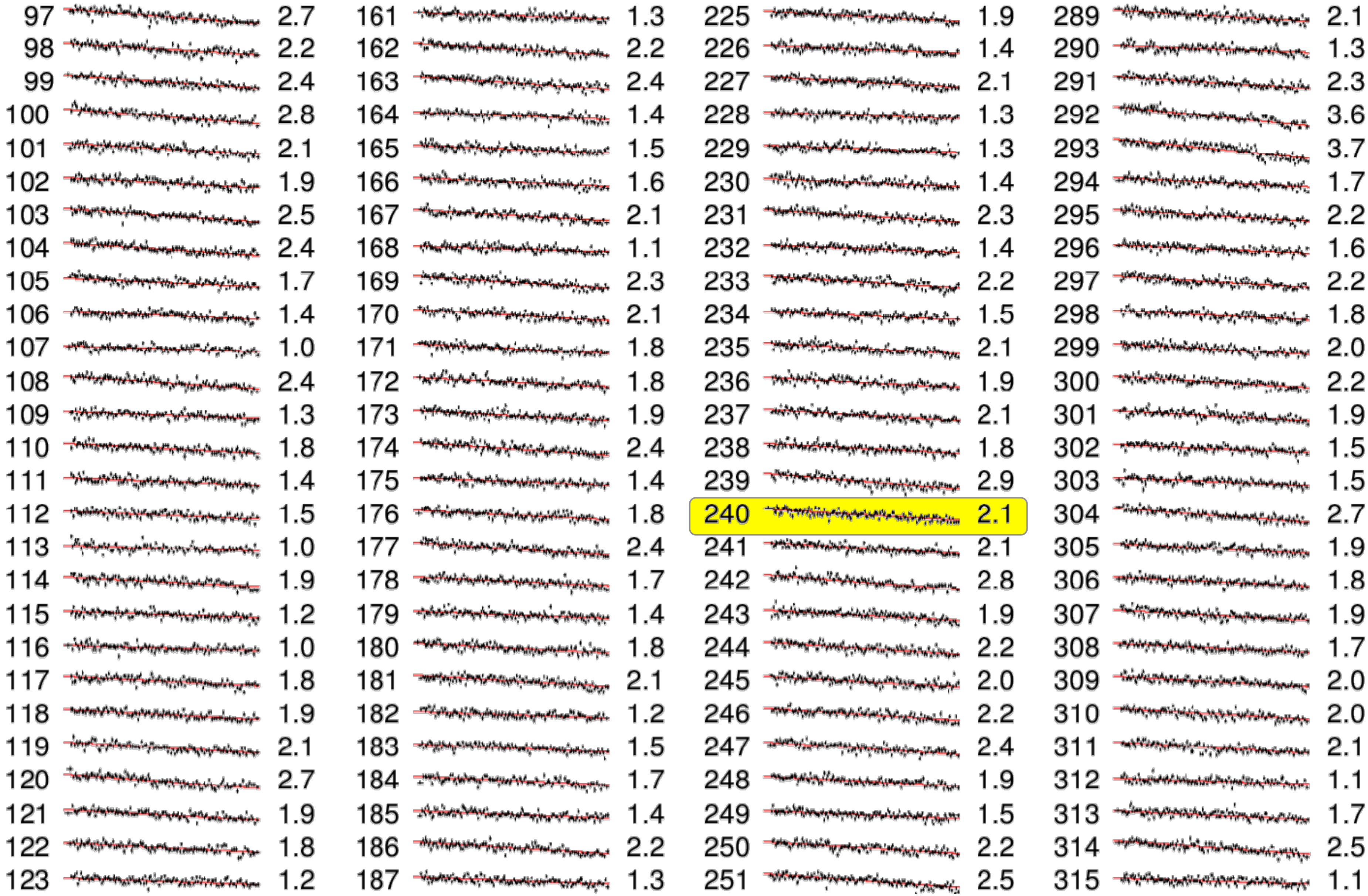


CTI = 2.1 x 10^{-5}

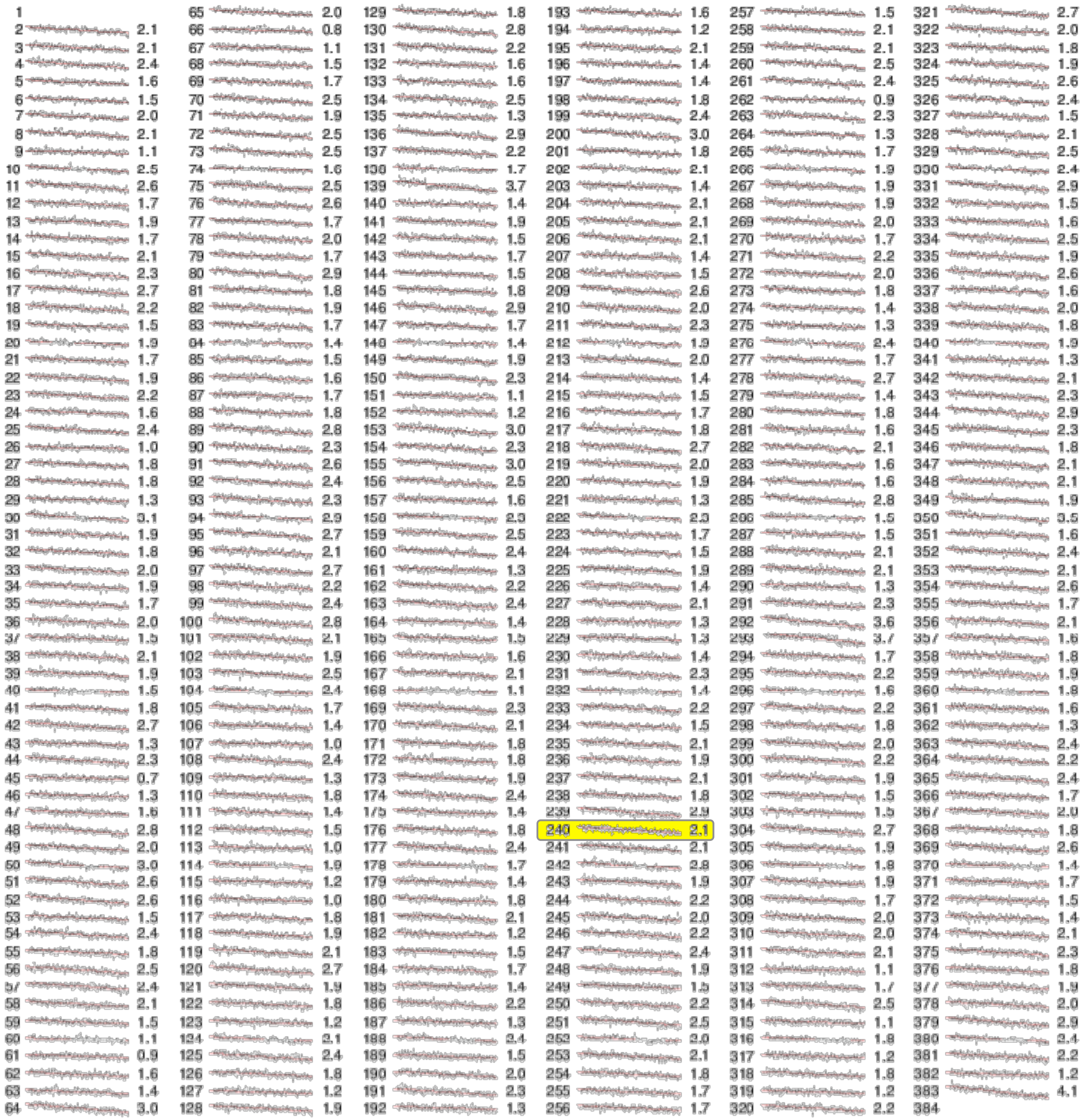
emission line determined in 130 (adaptively computed) macro pixels containing a minimum of 30 first singles around the line



CTI determination



CTI determination

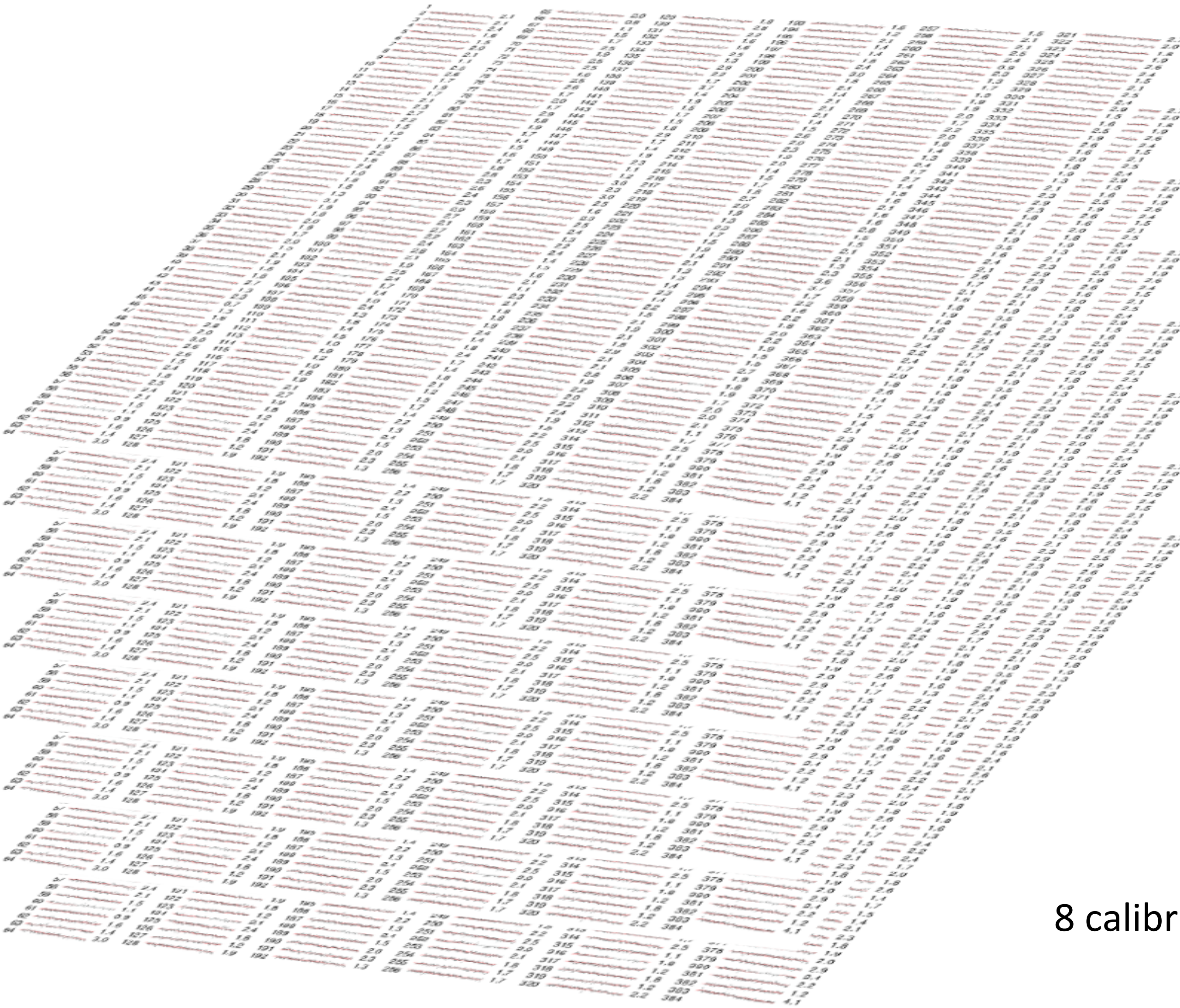


example:
Fe-K, measured with FM4

plot contains
47 267 data points

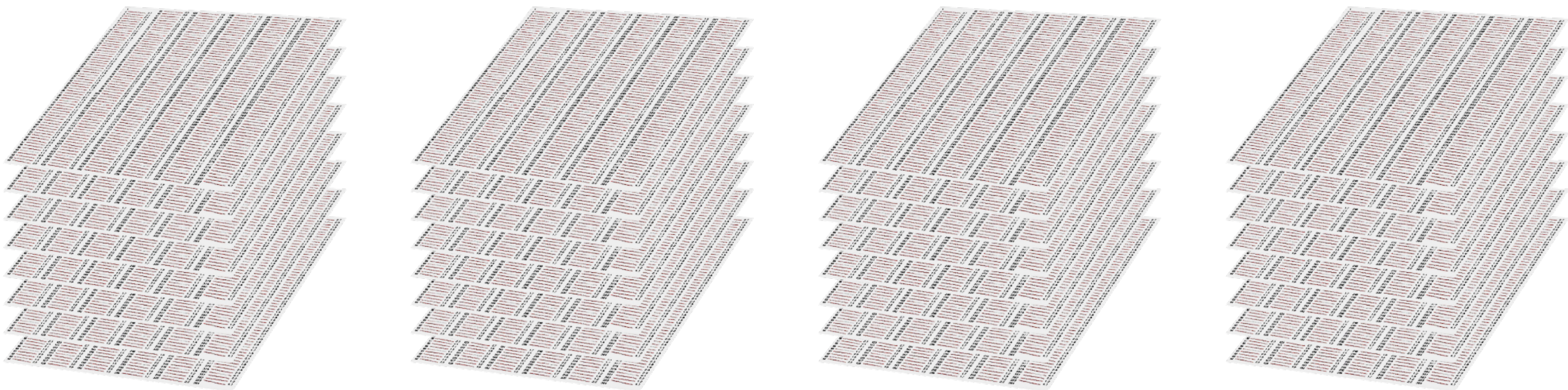
each data point is
the result of several
iterative template fits

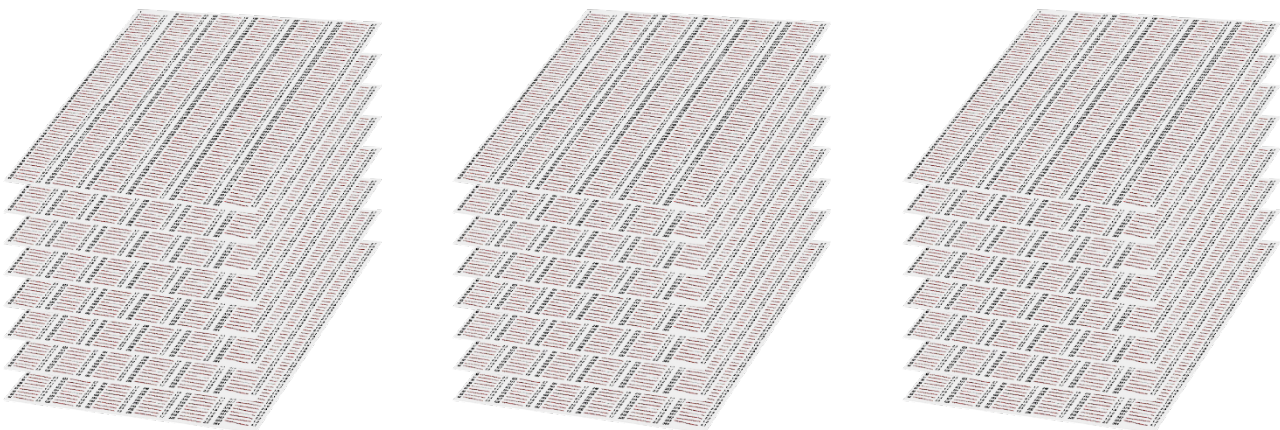
CTI determination



8 calibration energies

CTI determination





8 energies
7 cameras

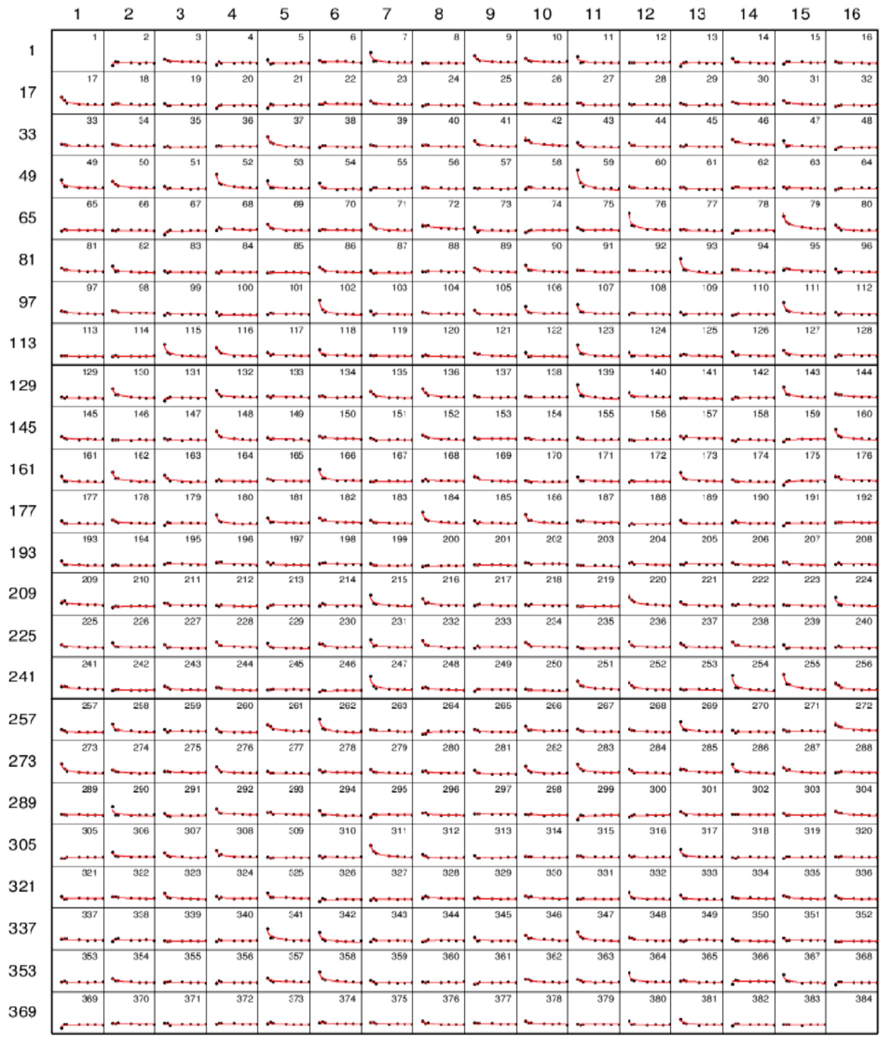
7 CCDs (with 3.3 billion events) calibrated

CTI determination

Energy interpolation of the CTI and gain

individually for each CCD column

CTI



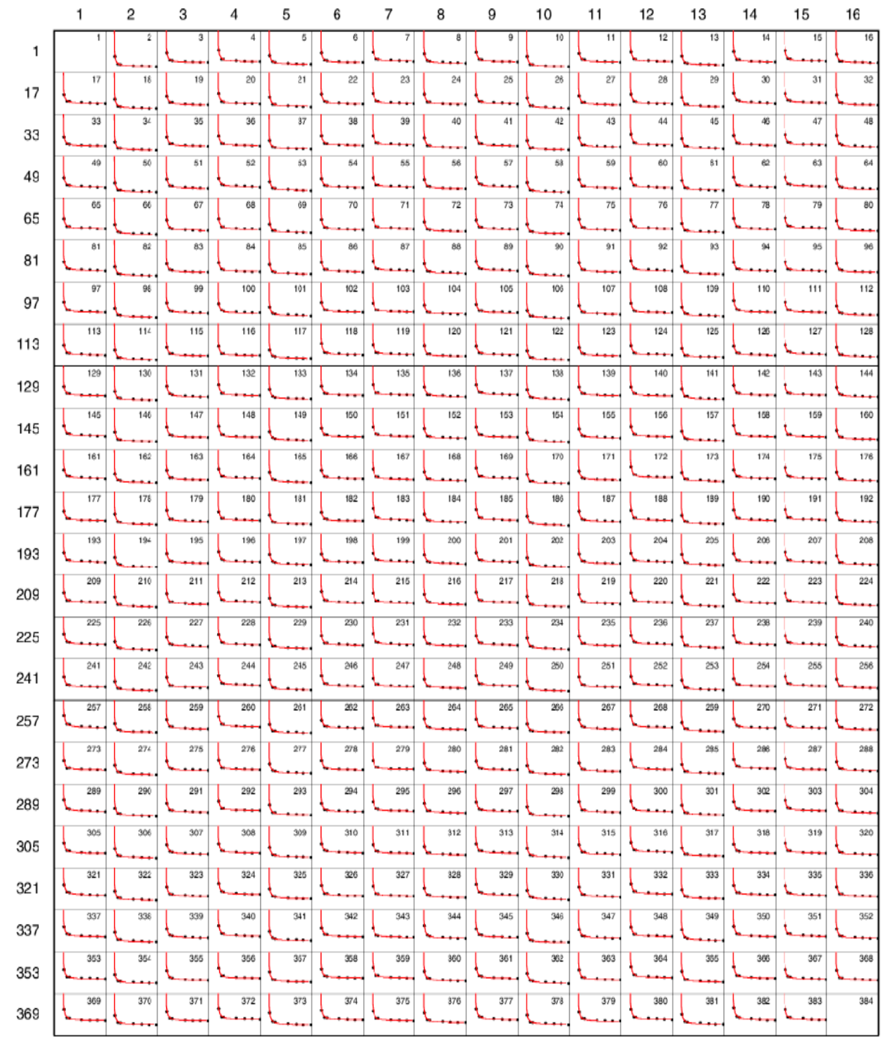
x axis: energy (linear) , min : -2.00 keV, max : 10.00 keV

y axis: CTI (linear) , min : -5.0 e-5 , max : 20.0 e-5

energies [keV] : 0.277 0.277 0.930 1.486 4.508 6 .398 8.040 9.886

transition lines: C-K O-K Cu-L Al-K Ti-K Fe-K Cu-K Ge-K

gain



x axis: energy (linear) , min : -2.0 keV, max : 10.0 keV

y axis: gain (linear) , min : 0.72 eV / adu , max : 0.95 eV / adu

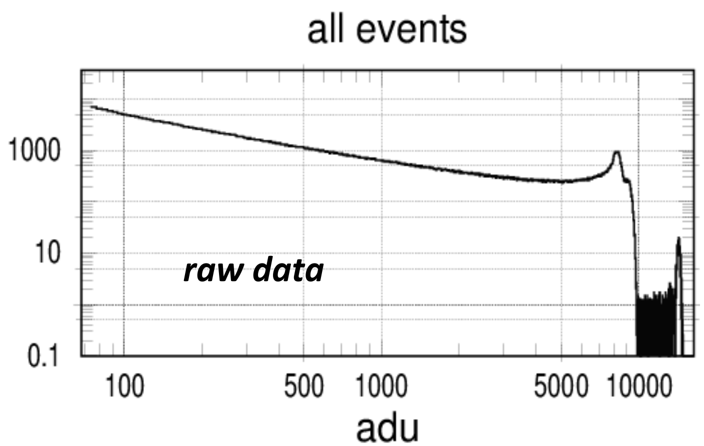
energies [keV] : 0.277 0.277 0.930 1.486 4.508 6 .398 8.040 9.886

transition lines: C-K O-K Cu-L Al-K Ti-K Fe-K Cu-K Ge-K

Reconstructing the spectral distribution requires

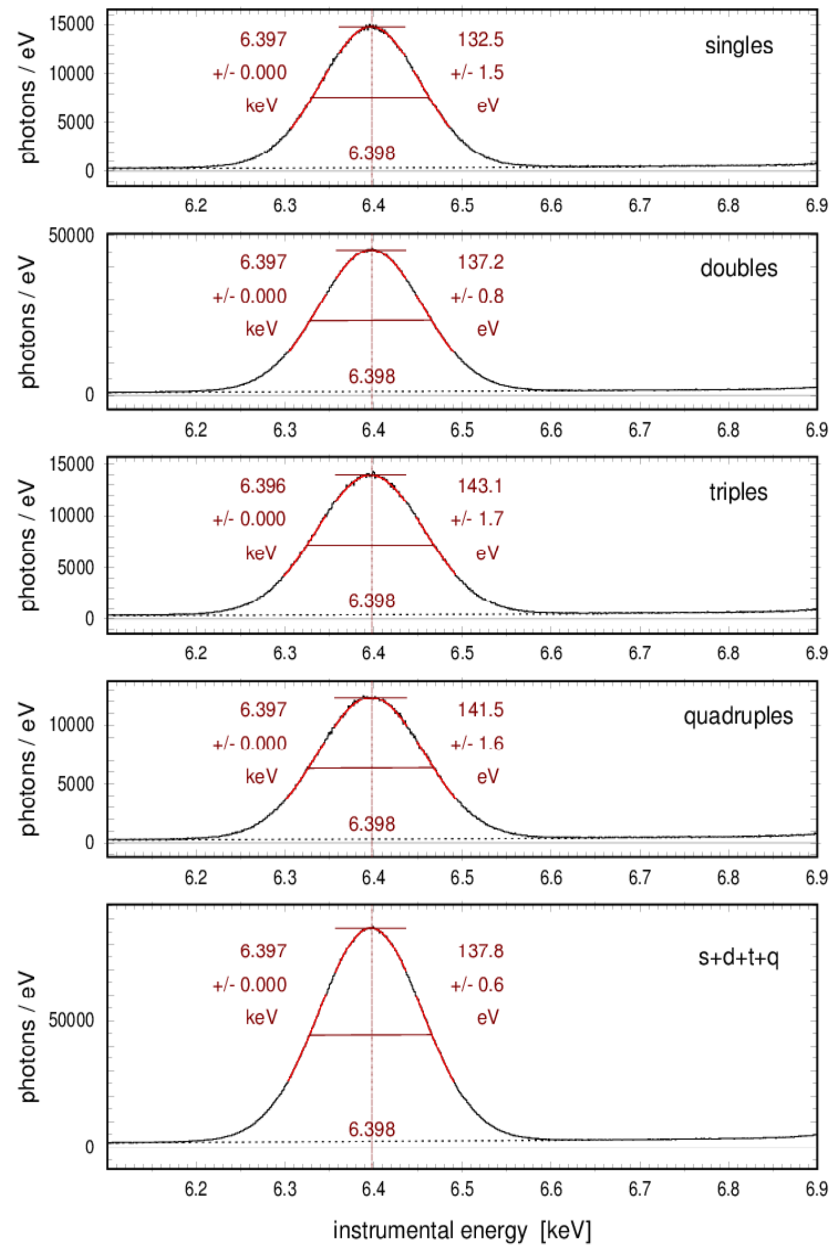
- **pattern** recognition
- correction for **gain** variations between CCD channels
- correction for charge transfer loss **(CTI)**

example: Fe-K, measured with FM4



FWHM = 132.5 – 143.1 eV
all photons: FWHM = 137.8 eV

accuracy of absolute energy scale: 2 eV (0.03%)



reconstructed spectral distribution

Energy Calibration: internal calibration source

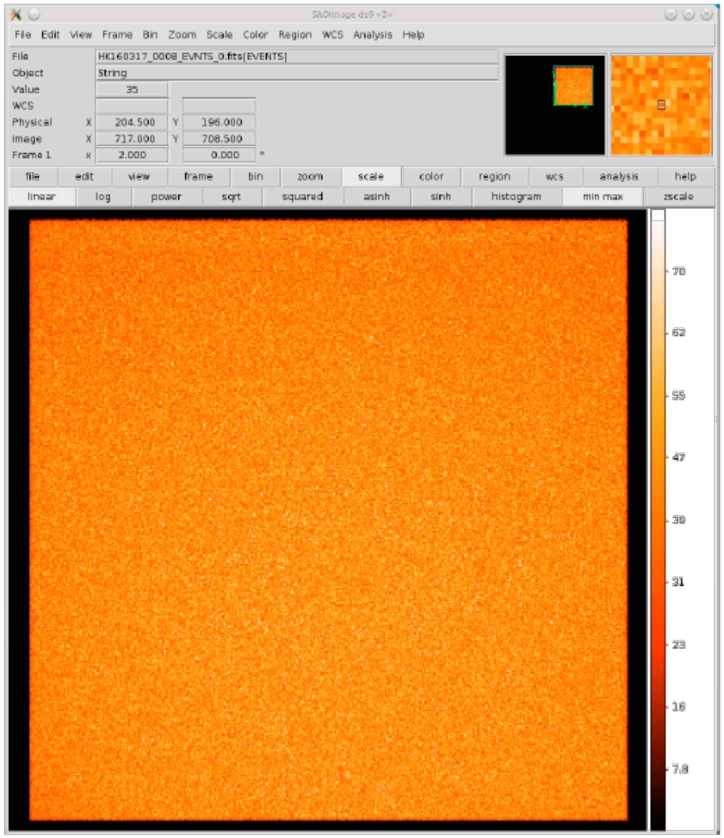


Fig. 76. Distribution of all Ti–K photons with an instrumental energy between 4.3 and 4.7 keV in the exposure with the internal calibration source.

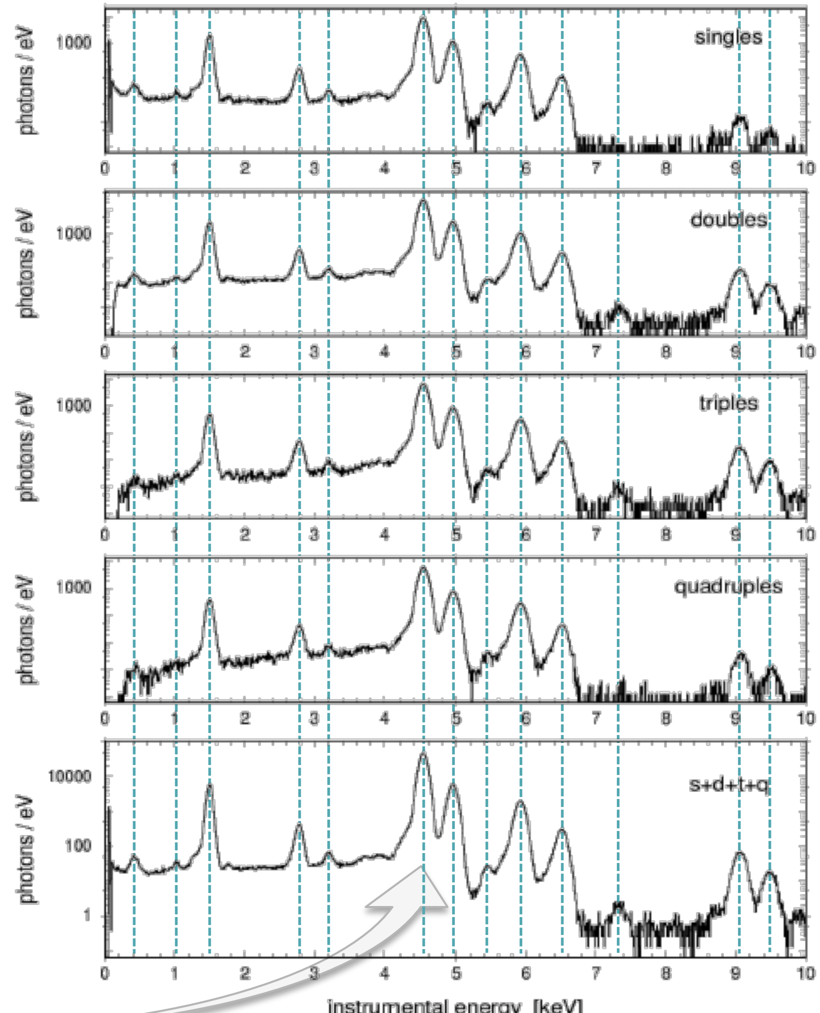
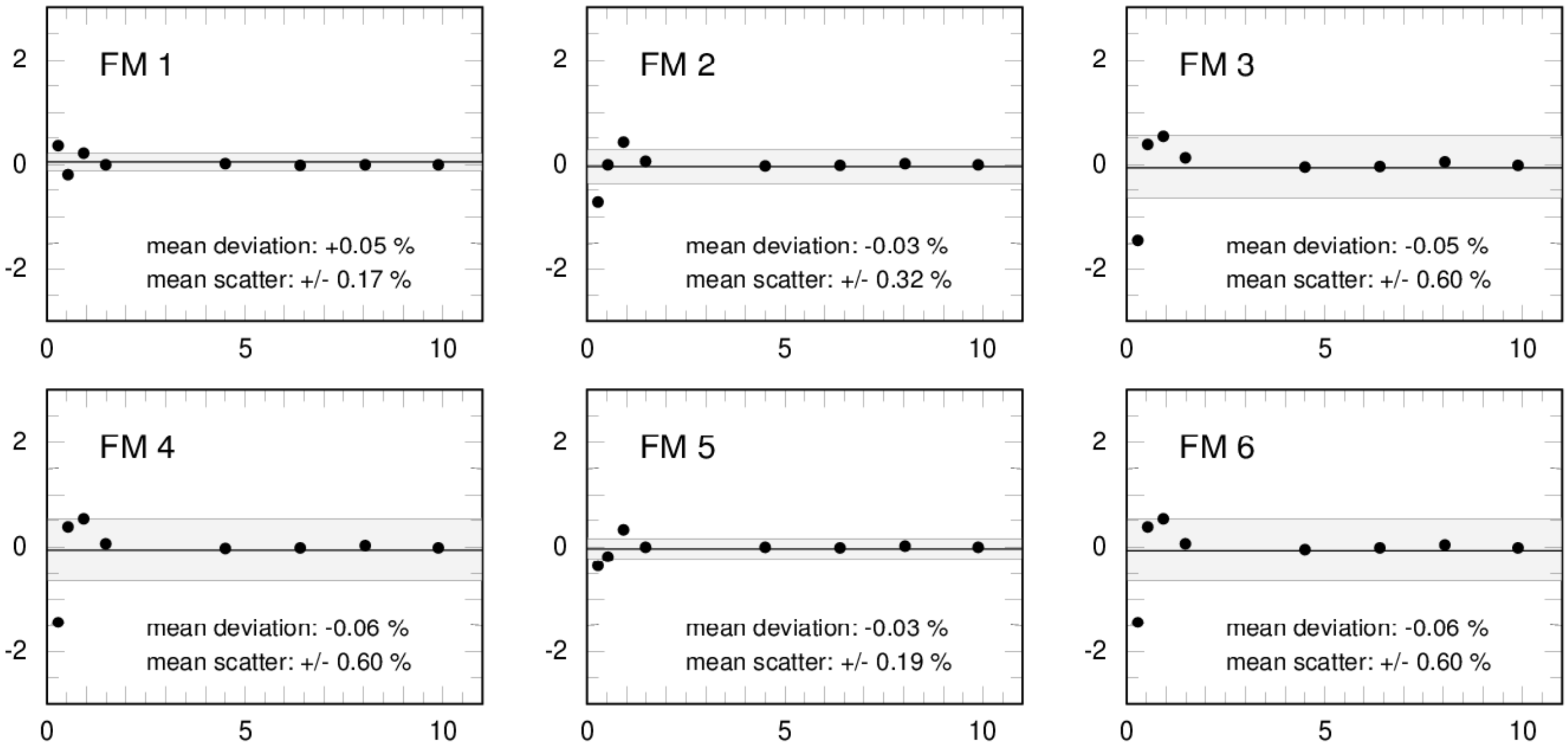
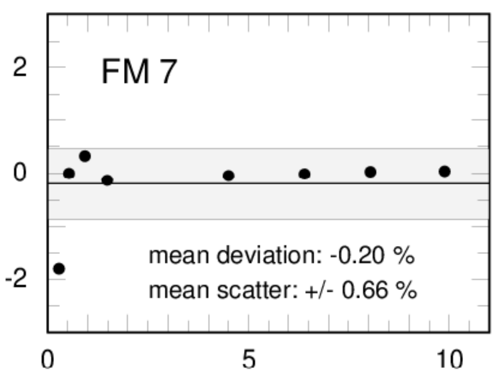


Fig. 80. Reconstructed photon energies for the exposure with the internal calibration source, in a logarithmic scale.

eROSITA flight cameras: absolute energy reconstruction

derived from flatfield measurements at PUMA with a split threshold of 46 adu (~39 eV)





Accuracy of absolute energy reconstruction [%]

for all valid patterns

x axis: photon energy [keV]

y axis: deviation from nominal energy [%]

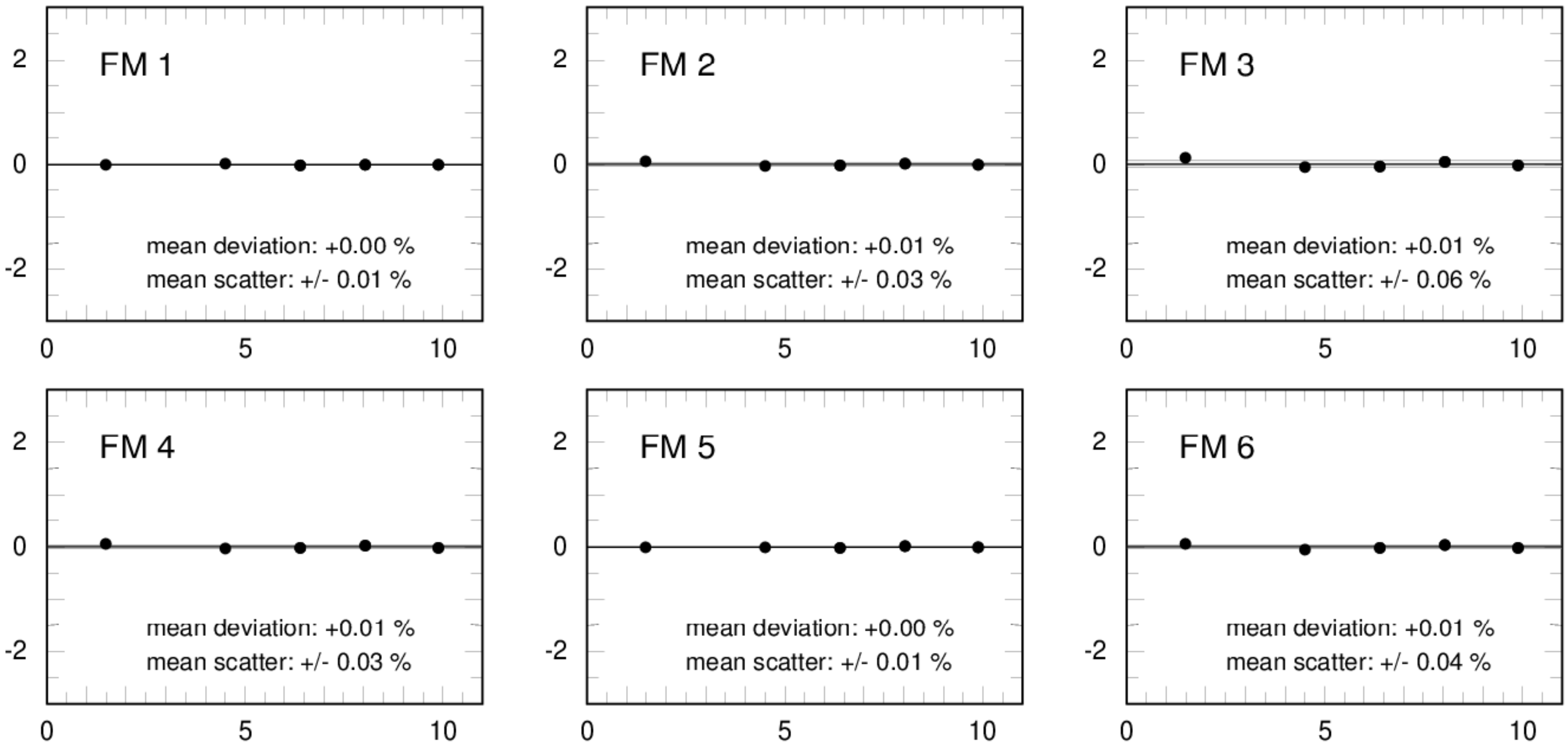
CCDs without on-chip filter: FM1, FM5

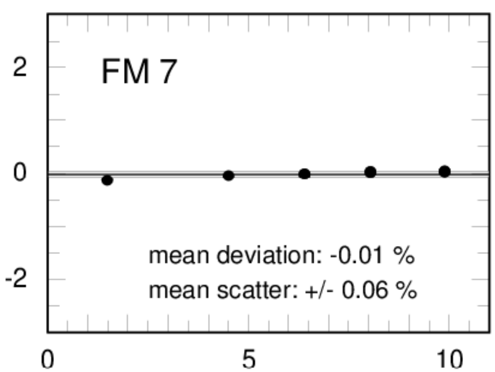
singles
doubles
triples
quadruples
all valid

< ± 0.7%

eROSITA flight cameras: absolute energy reconstruction

derived from flatfield measurements at PUMA with a split threshold of 46 adu (~39 eV)





Accuracy of absolute energy reconstruction [%]

for all valid patterns

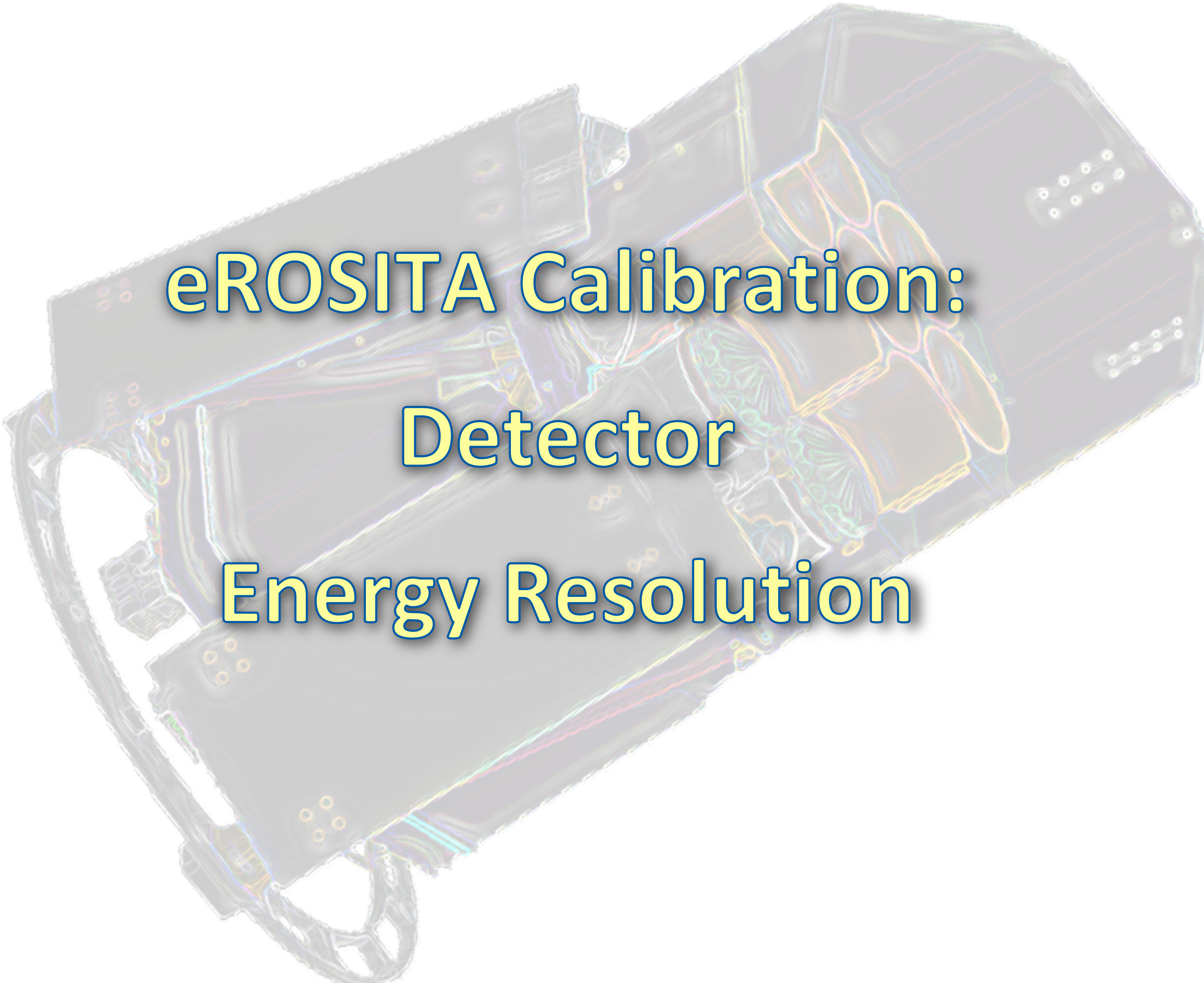
x axis: photon energy [keV]

y axis: deviation from nominal energy [%]

CCDs without on-chip filter: FM1, FM5

singles
doubles
triples
quadruples
all valid

< ± 0.07%



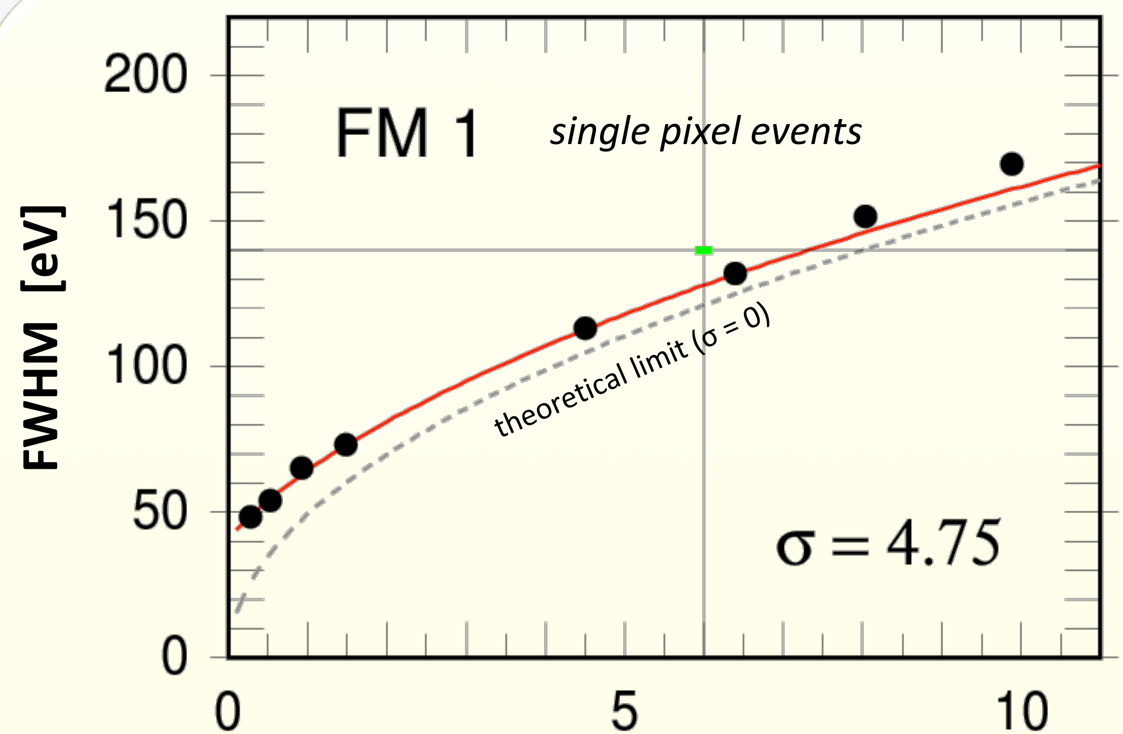
eROSITA Calibration:

Detector

Energy Resolution

Energy resolution of the eROSITA flight cameras

obtained from flatfield measurements at PUMA with a split threshold of 46 adu (~39 eV)
at 8 energies (C-K, O-K, Cu-L, Al-K, Ti-K, Fe-K, Cu-K, and Ge-K)



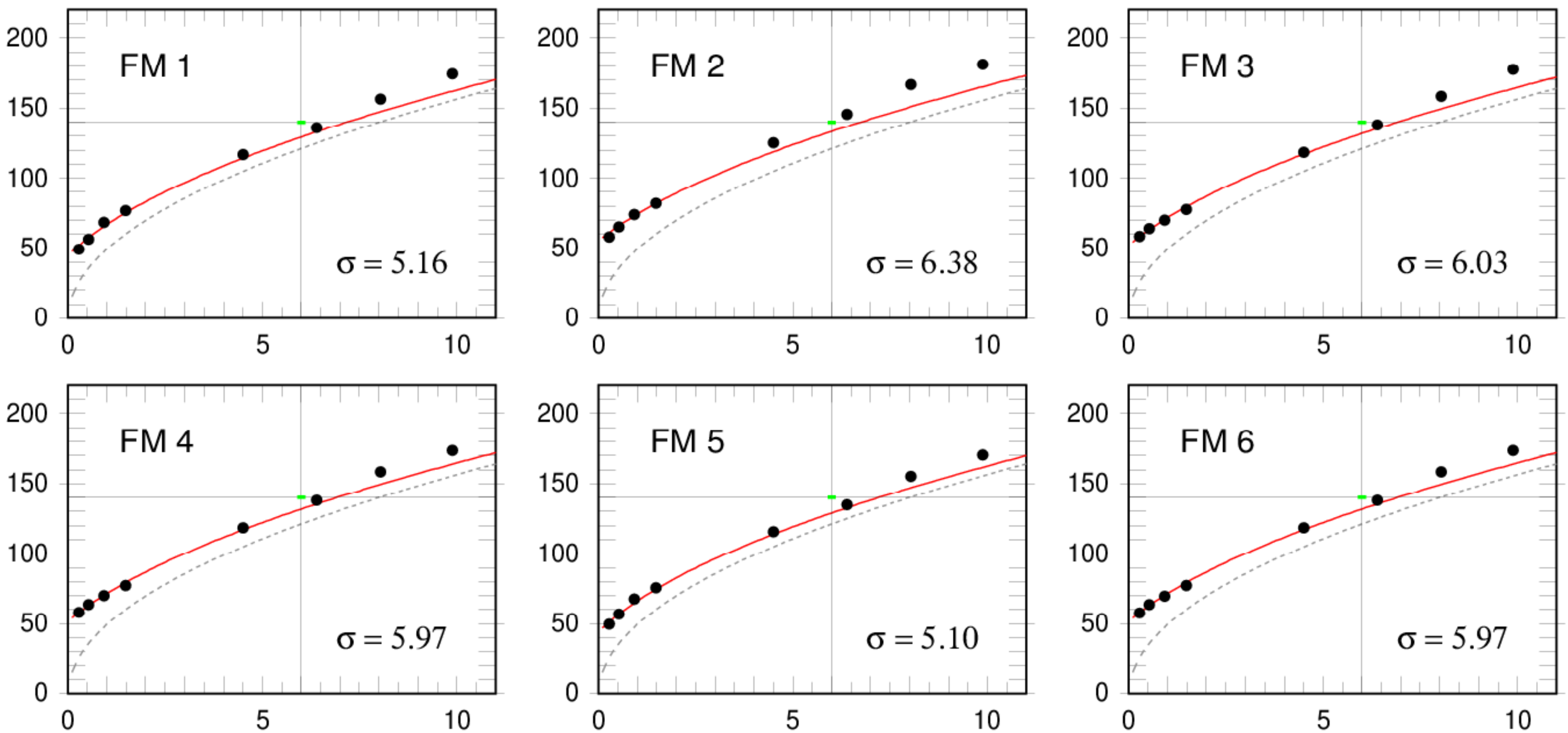
requirement:
FWHM < 140 eV at 6 keV

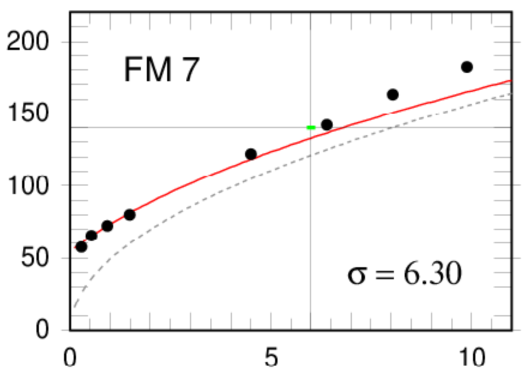
statistical error smaller than dot size

solid curves: $\Delta E_{\rm FWHM} = 2.35\,\omega\sqrt{\sigma^2 + F\frac{E_\gamma}{\omega}}$ with ω = 3.68 eV and F = 0.12

Energy resolution of the eROSITA flight cameras

obtained from flatfield measurements at PUMA with a split threshold of 46 adu (~39 eV)





Energy resolution (FWHM) for all valid patterns

x axis: photon energy [keV]

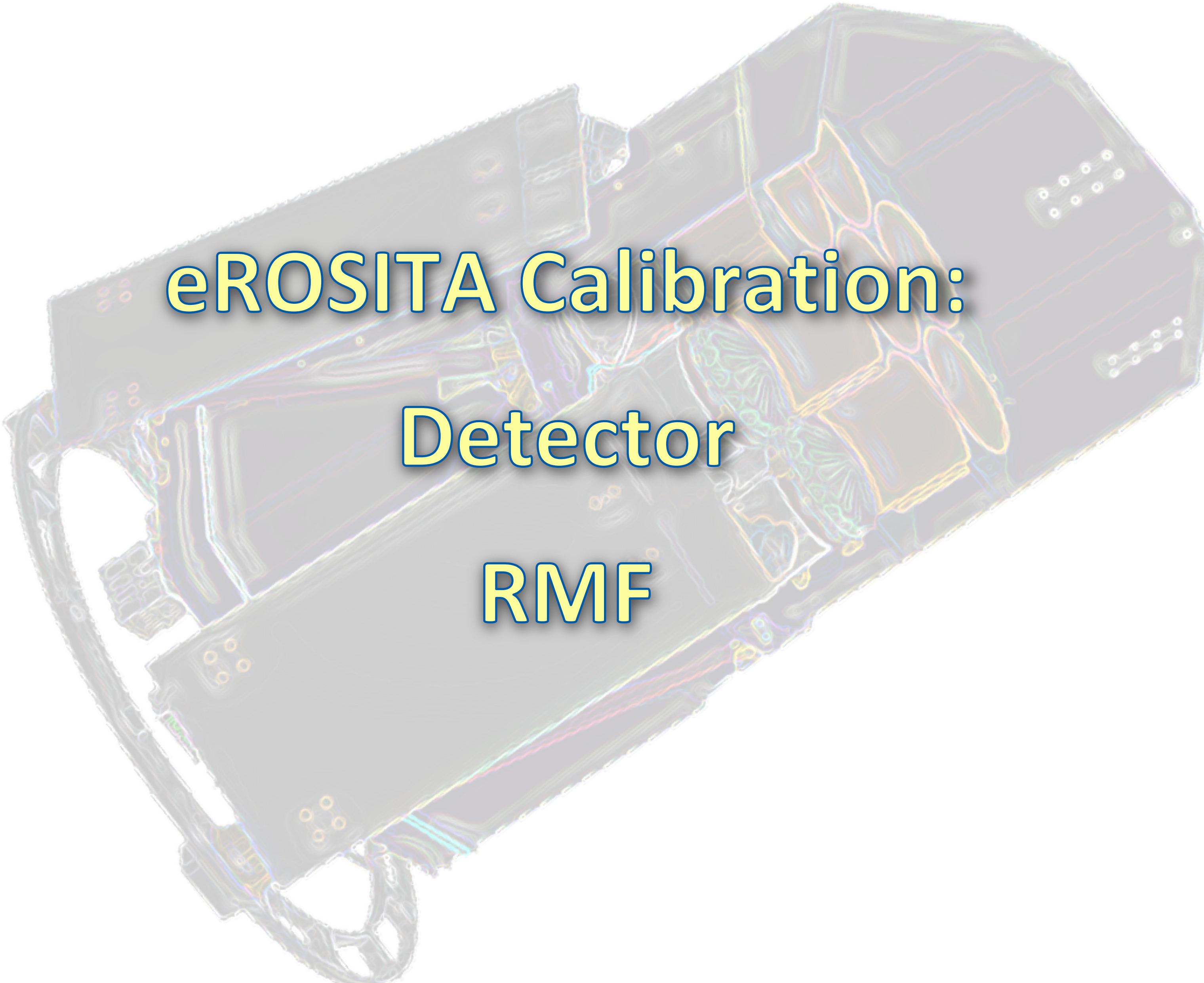
y axis: FWHM [eV]

σ: noise [electrons]

CCDs without on-chip filter: FM1, FM5

requirement: FWHM < 140 eV at 6 keV

singles
doubles
triples
quadruples
all valid

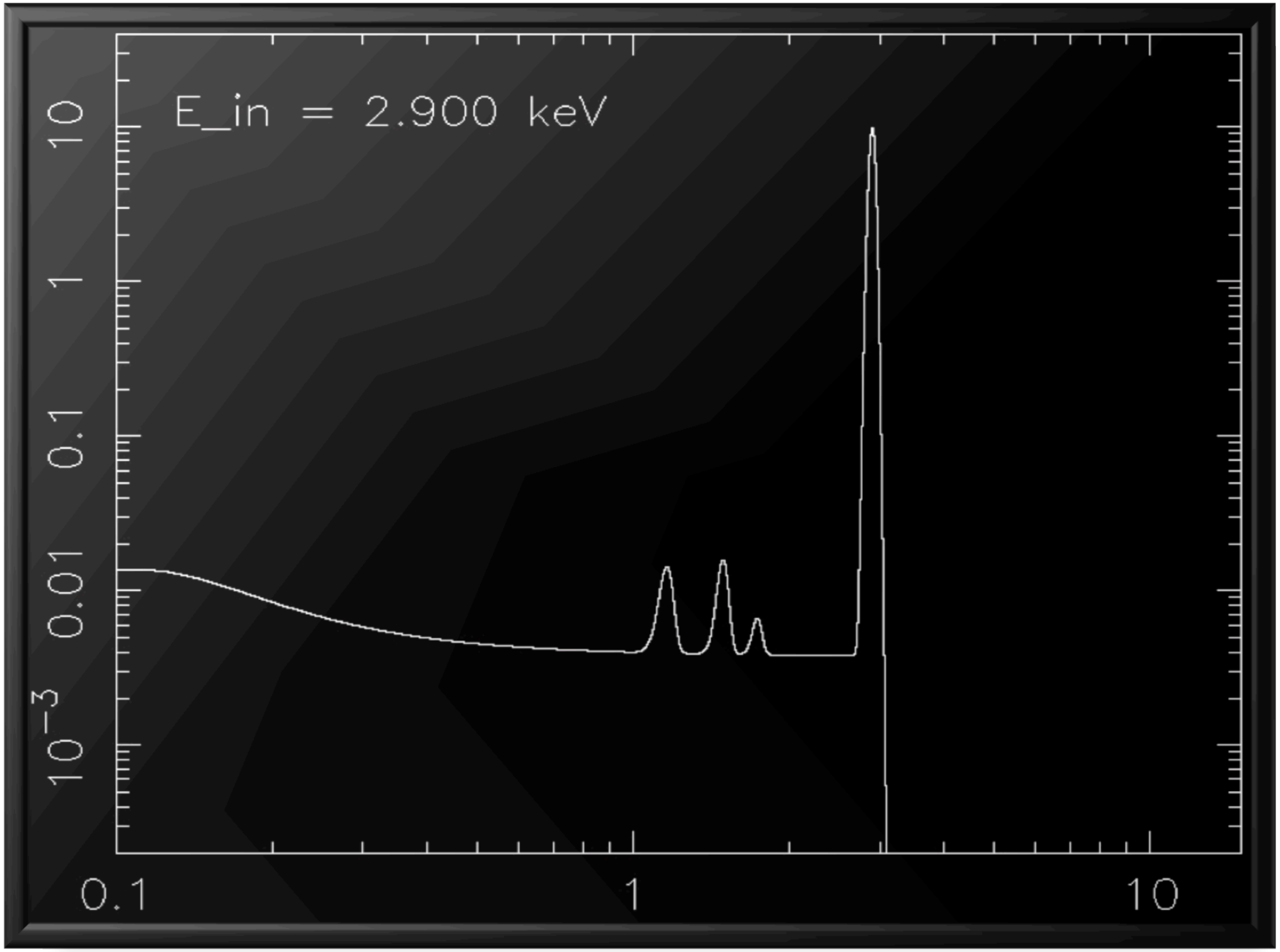


eROSITA Calibration:

Detector

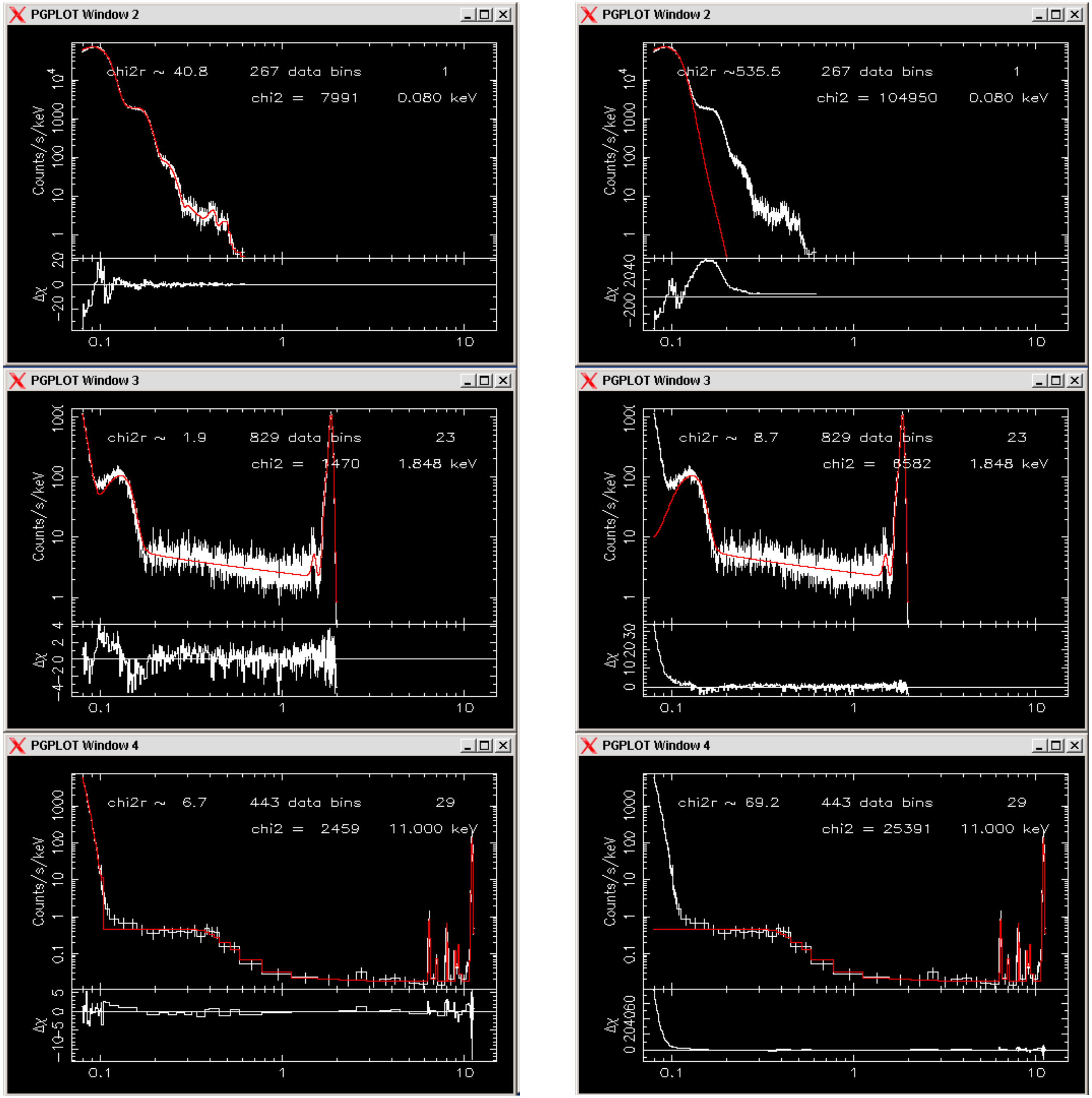
RMF

eROSITA Calibration: Detector Response



normalized flux

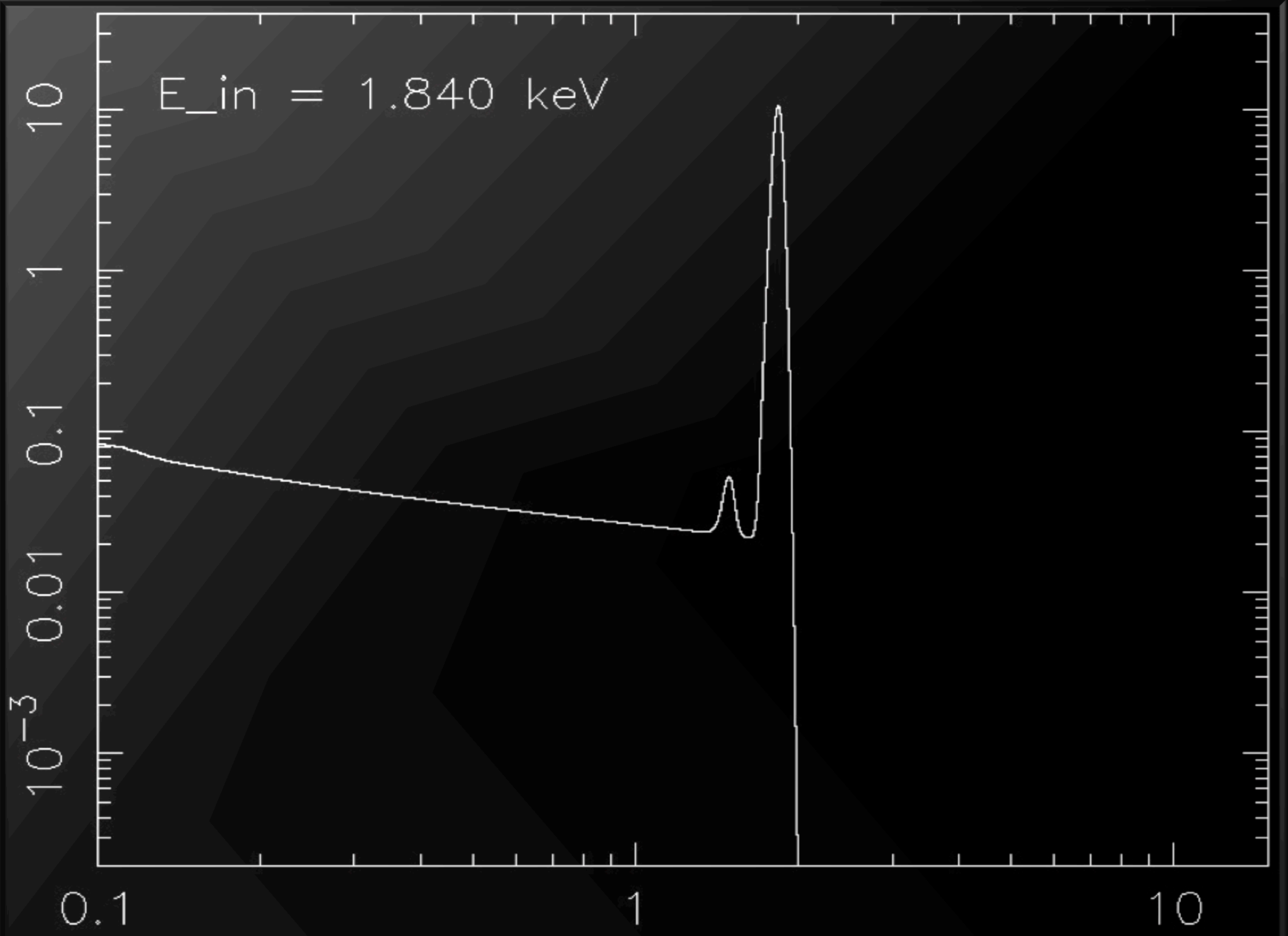
E_out [„keV“]



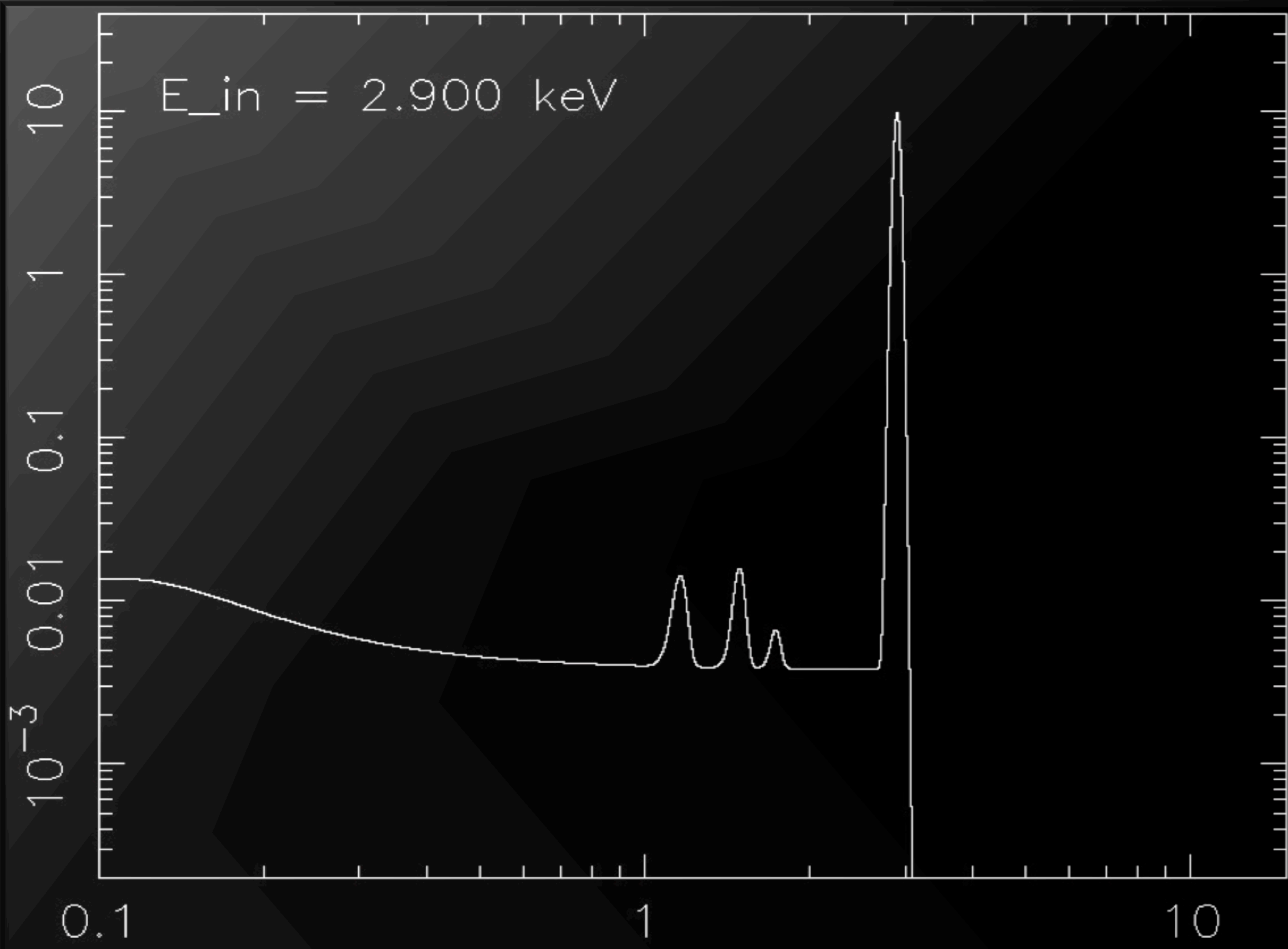
E = 0.800 keV

E = 1.848 keV

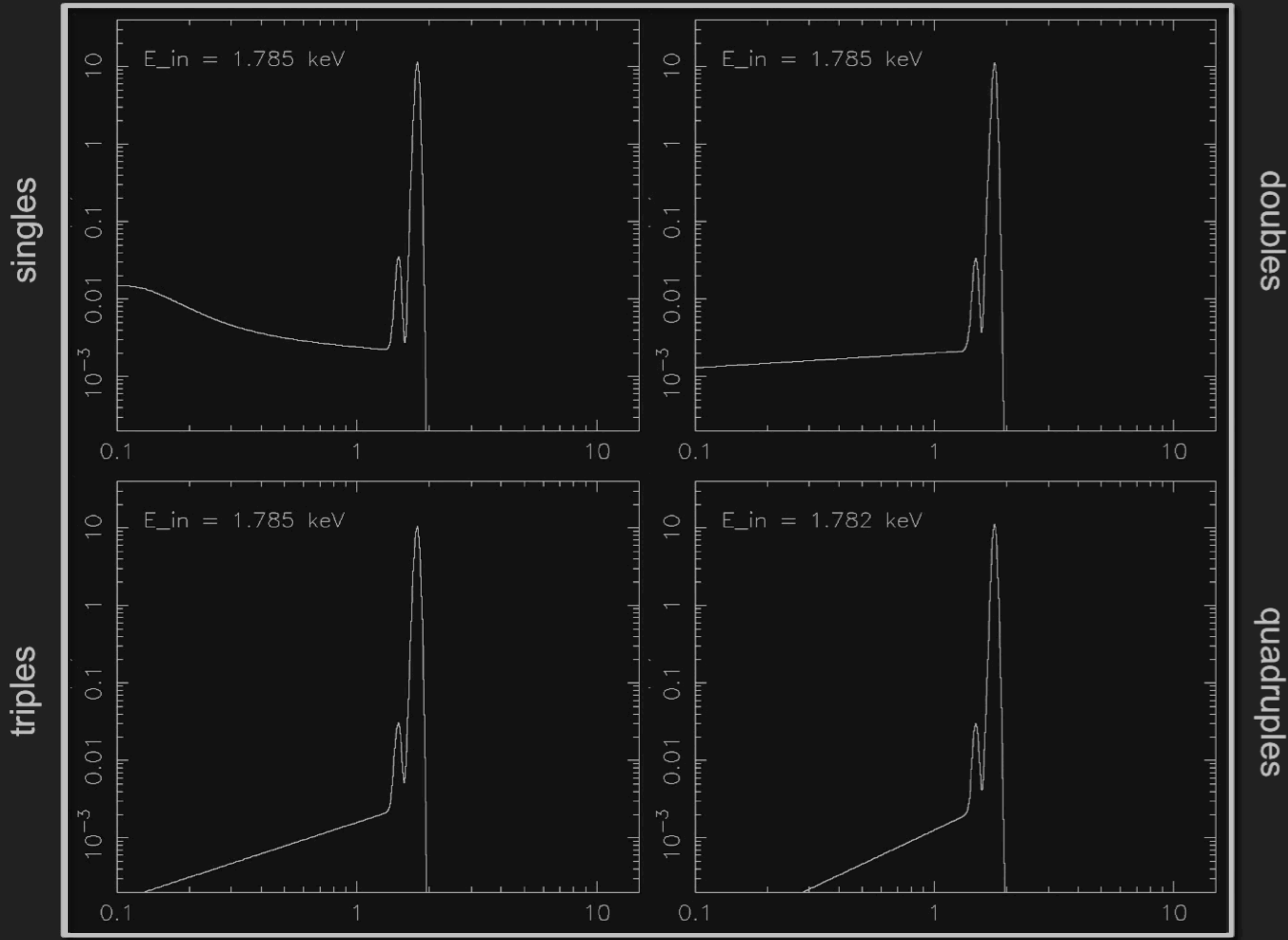
E = 11.0 keV



E_in = 1.840 keV
10
1
0.1
0.01
10^-3
0.1
1
10

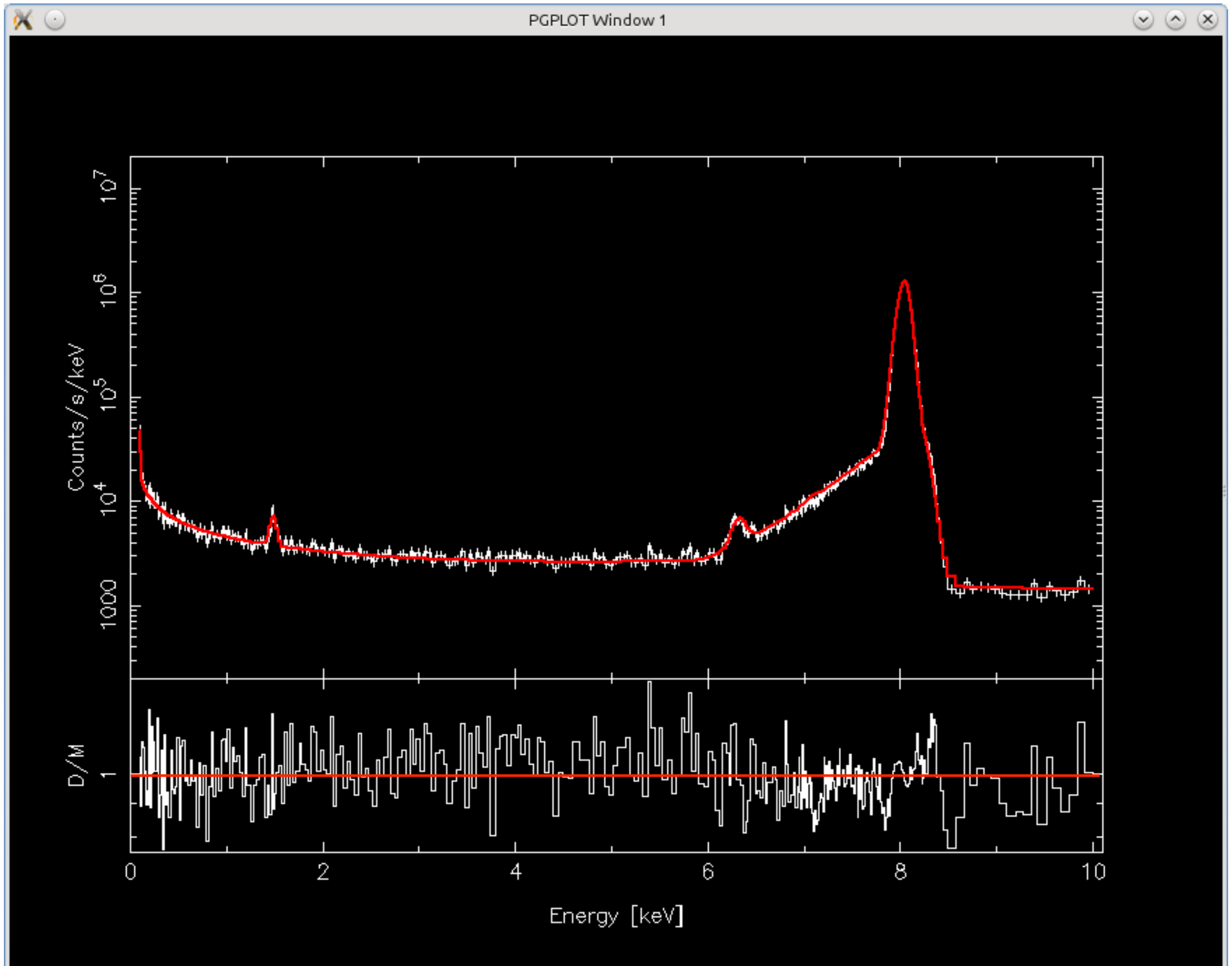

E_in = 2.900 keV
10
1
0.1
0.01
10^{-3}
0.1
1
10

Deriving the spectral response from measured spectra



eROSITA: first spectral fits of observational data

3 ks „observation“ of Cu-K in PUMA at 440 counts/s on 11 Feb 2014 (`QM140211.015`)

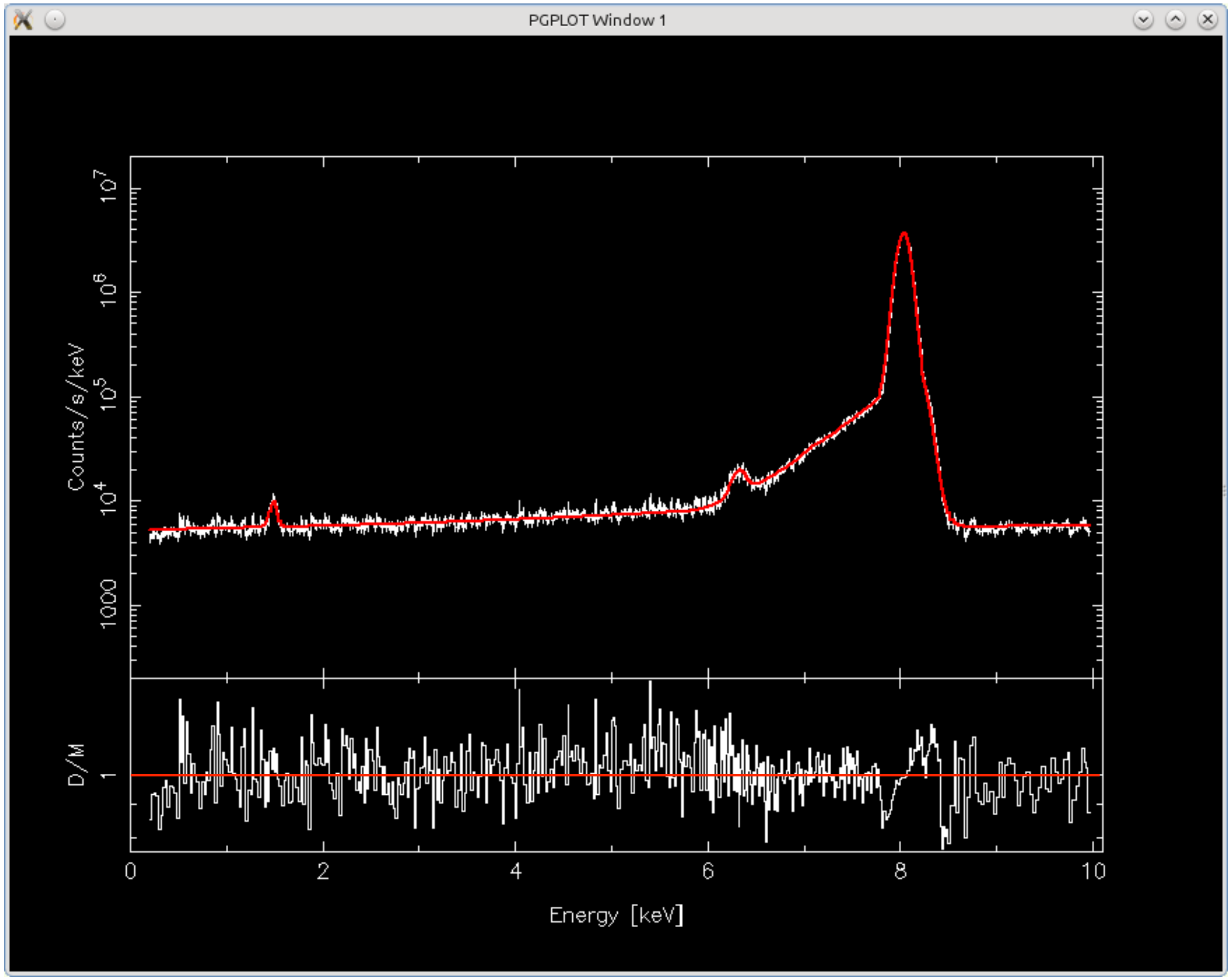


simultaneous fit to spectra from all patterns using appropriate RMFs and ARFs

spectral distribution of **singles**

eROSITA: first spectral fits of observational data

3 ks „observation“ of Cu-K in PUMA at 440 counts/s on 11 Feb 2014 (`QM140211.015`)

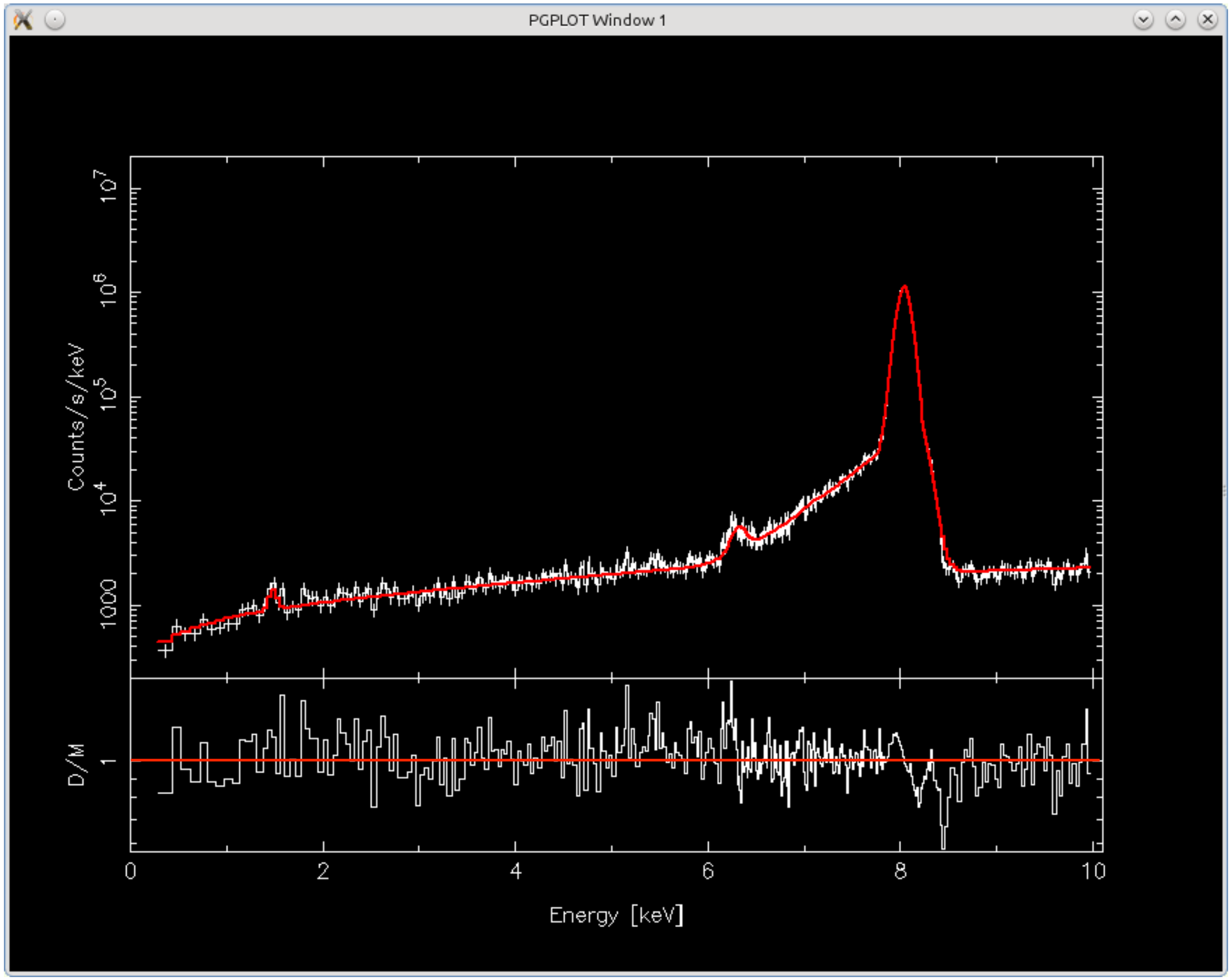


simultaneous fit to spectra from all patterns
using appropriate RMFs and ARFs

spectral distribution of **doubles**

eROSITA: first spectral fits of observational data

3 ks „observation“ of Cu-K in PUMA at 440 counts/s on 11 Feb 2014 (QM140211.015)

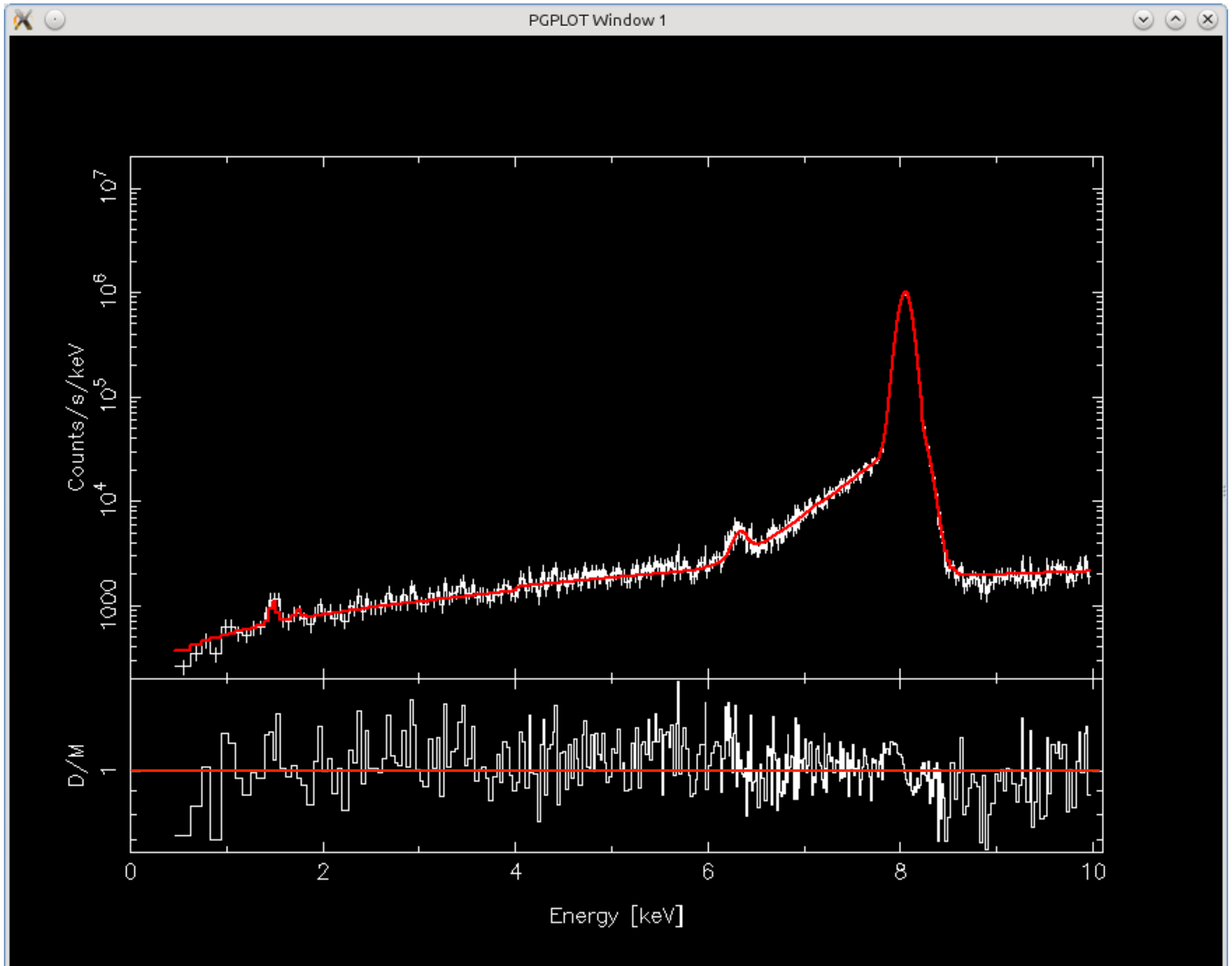


simultaneous fit to spectra from all patterns
using appropriate RMFs and ARFs

spectral distribution of **triples**

eROSITA: first spectral fits of observational data

3 ks „observation“ of Cu-K in PUMA at 440 counts/s on 11 Feb 2014 (QM140211.015)

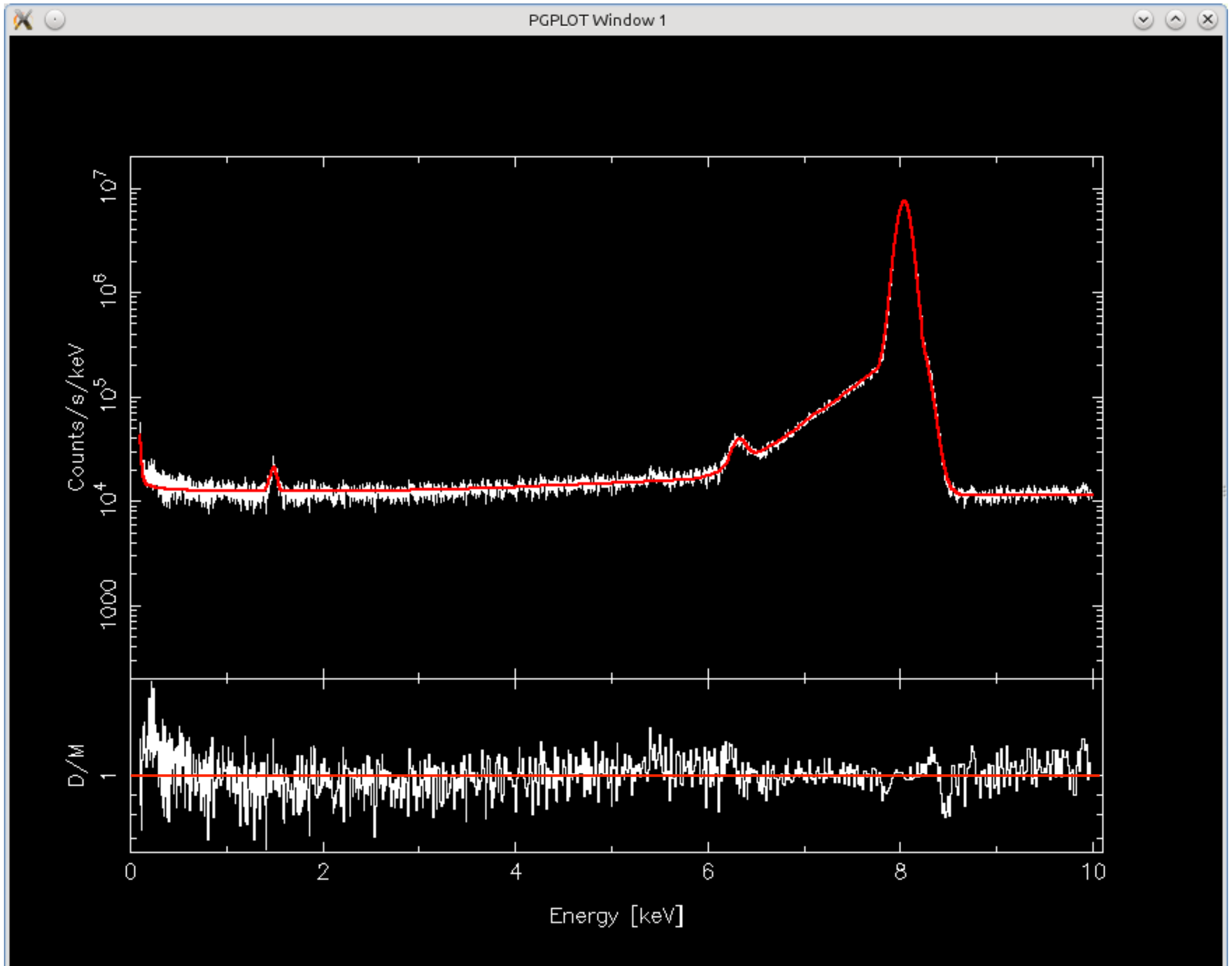


simultaneous fit to spectra from all patterns using appropriate RMFs and ARFs

spectral distribution of **quadruples**

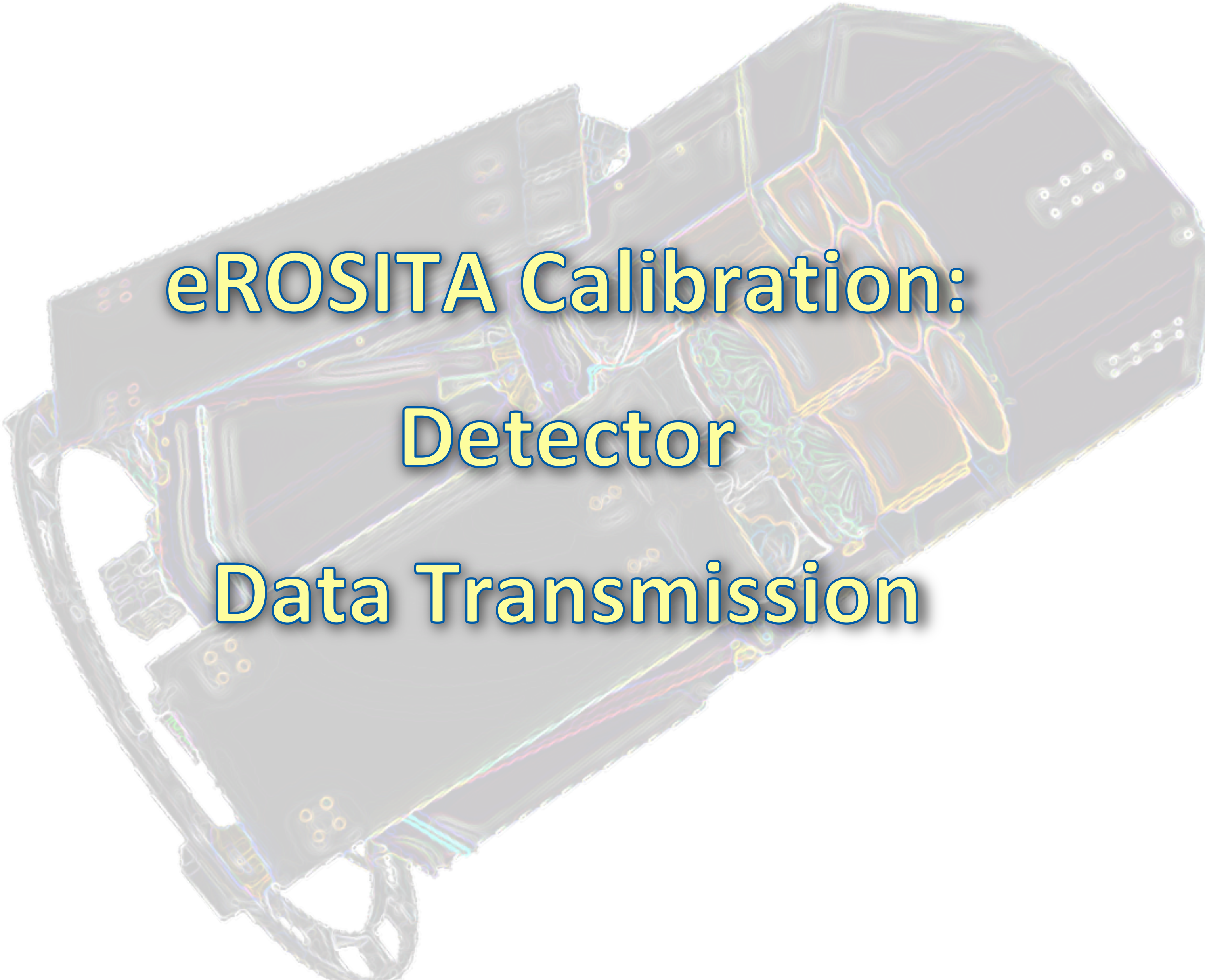
eROSITA: first spectral fits of observational data

3 ks „observation“ of Cu-K in PUMA at 440 counts/s on 11 Feb 2014 (QM140211.015)



simultaneous fit to spectra from all patterns
using appropriate RMFs and ARFs

spectral distribution of **singles**
+ doubles
+ triples
+ quadruples



eROSITA Calibration:

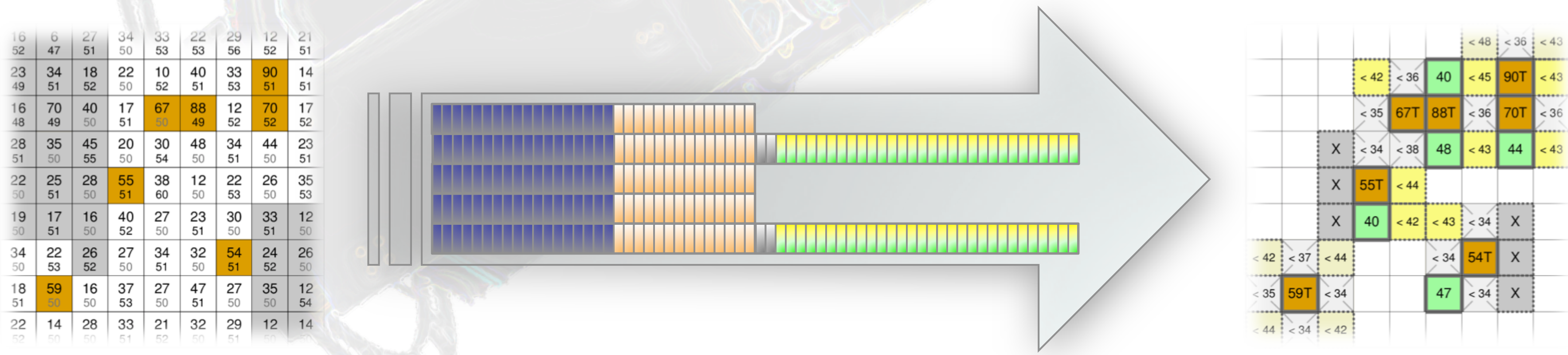
Detector

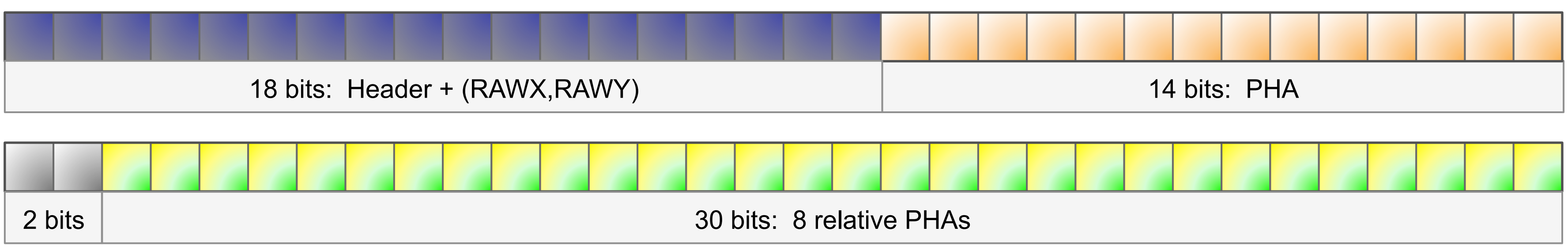
Data Transmission

eROSITA
Event Compression

a novel, fast, efficient compression method

for maximizing the telemetry content





By-product of the Event Compression: information about the spectroscopic quality

New: each reconstructed „photon pattern" will come with **spectroscopic quality information**, indicating

- whether there was a MIP precursor (→ uncertainty about charge transfer loss)
- how „clean" the environment was (→ efficiency of charge collection)

The **additional spectral quality information** will make it possible to adjust the photon selection according to the specific scientific goal:

- if **sensitivity** is of prime importance (e.g. source detection, variability studies), then this flag can be ignored
- if **spectroscopy** is of prime importance and if the photon statistics is sufficient, then low values of this flag should be useful for increasing the spectral resolution

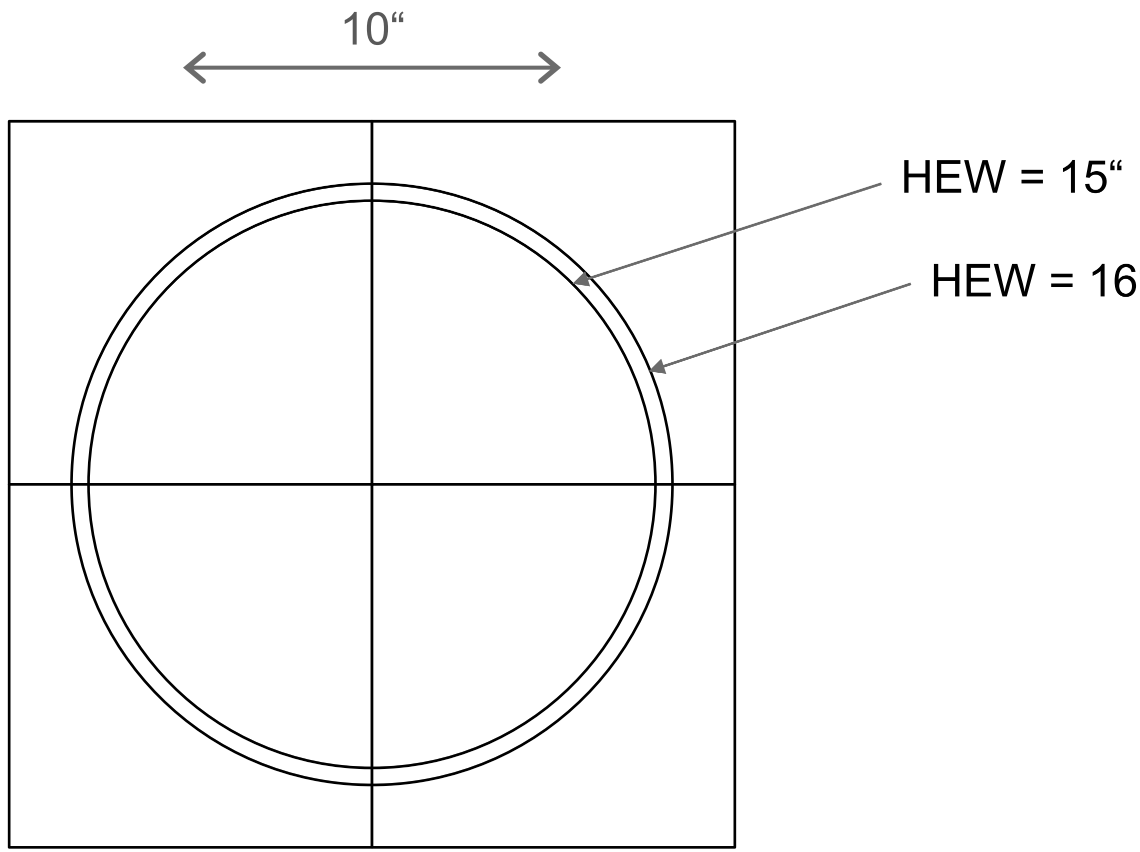
eROSITA Calibration:

Mirror

PSF

Determination of the eROSITA PSF

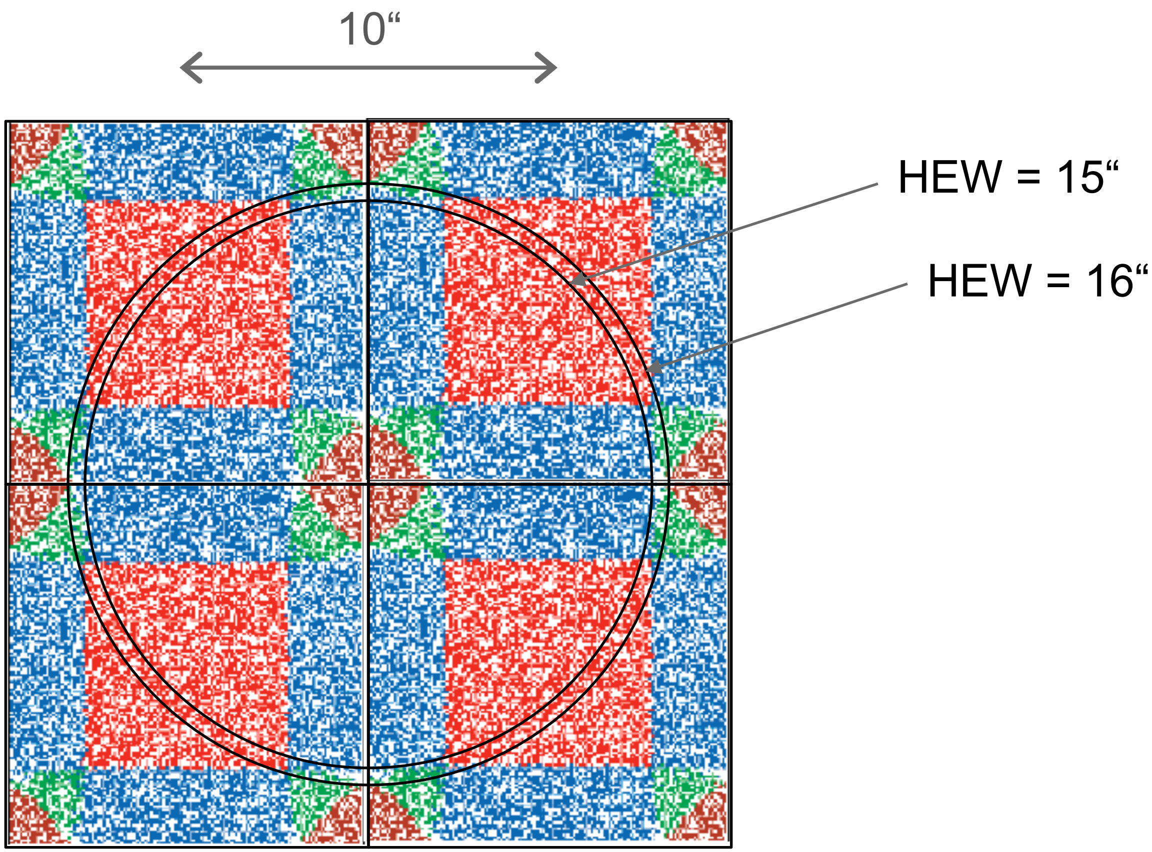
On-axis PSF



1 px = 9.6“ x 9.6“
= 75 µm x 75 µm

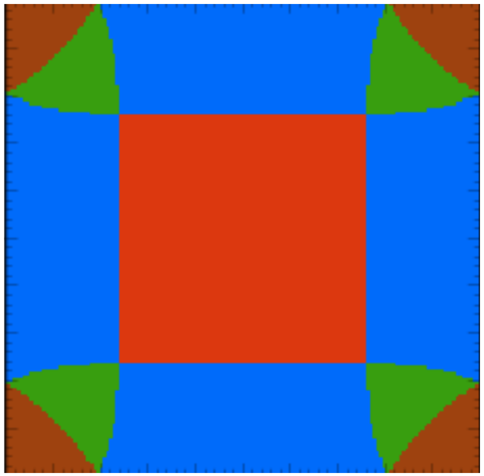
Determination of the eROSITA PSF

On-axis PSF



1 px = 9.6“ x 9.6“
= 75 µm x 75 µm

Effective resolution obtained with „sdtq“ in pixel scans

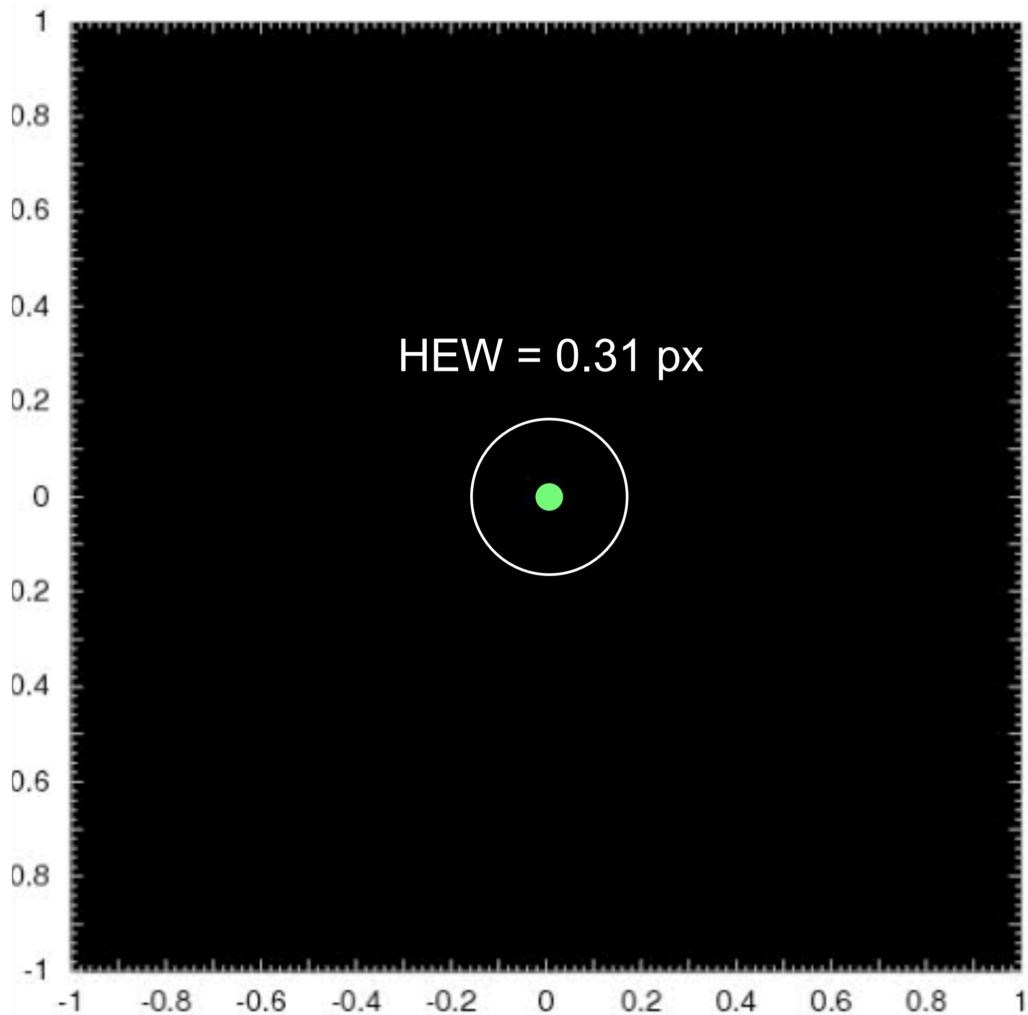


pixel size

using subpixel information for **all valid patterns**

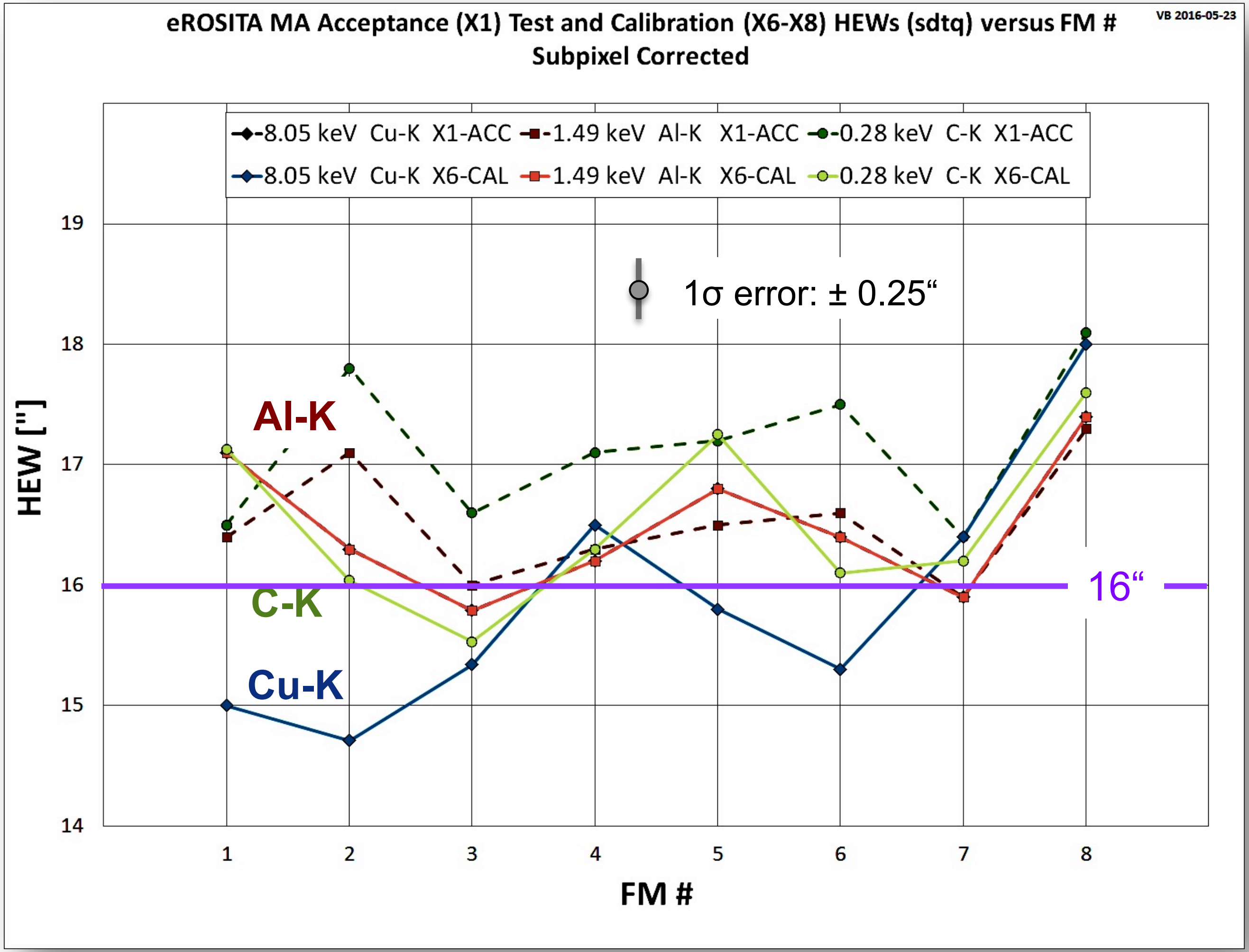
Al-K

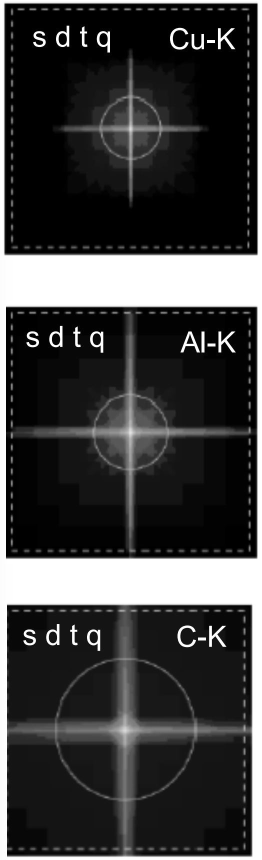
12 x 12 raster



Determination of the eROSITA PSF

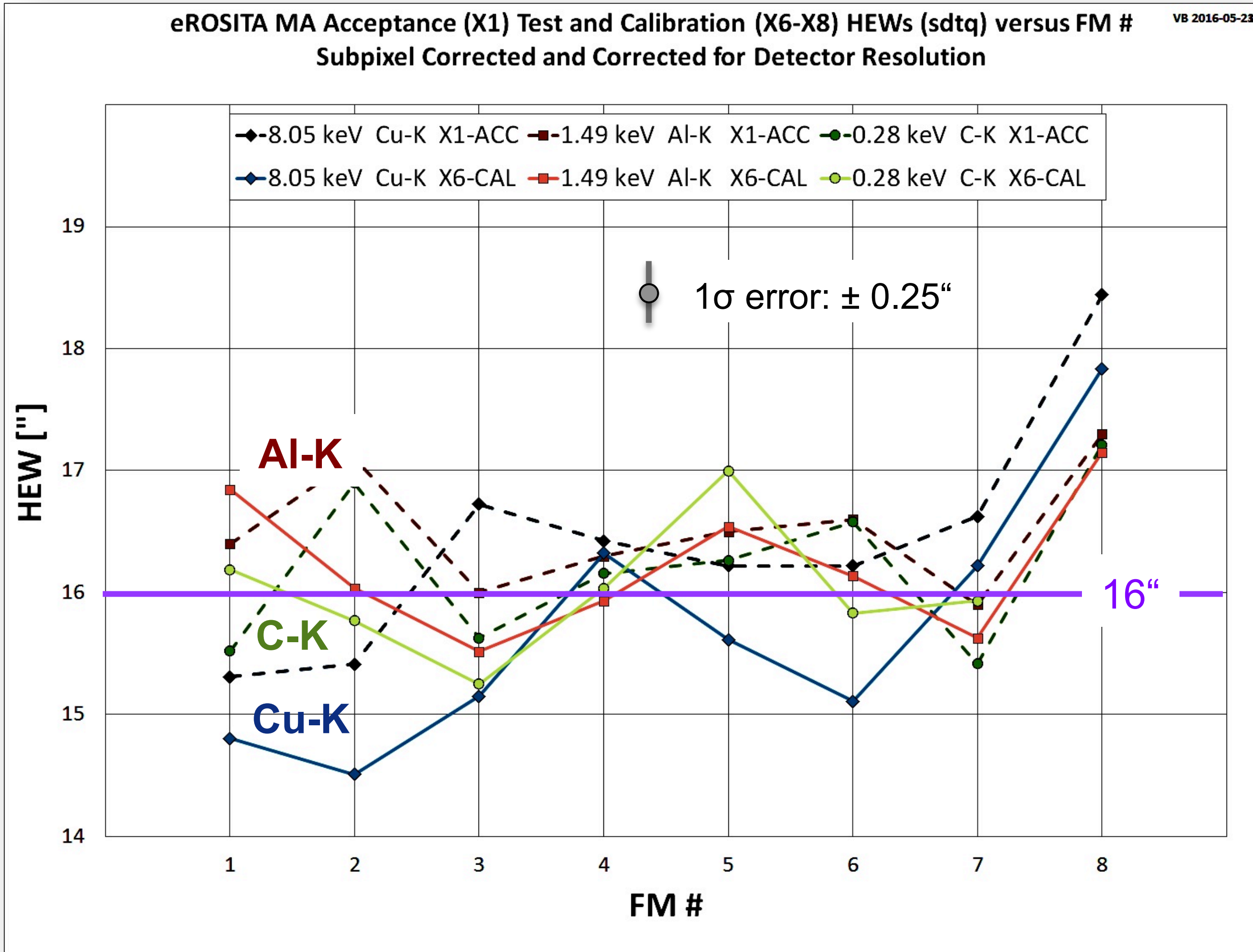
On-axis HEW for all eROSITA mirror modules

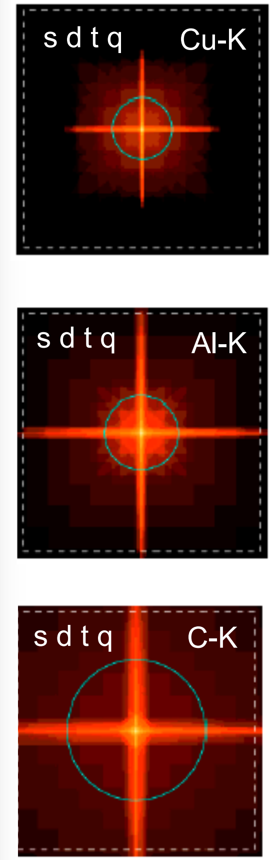




Determination of the eROSITA PSF

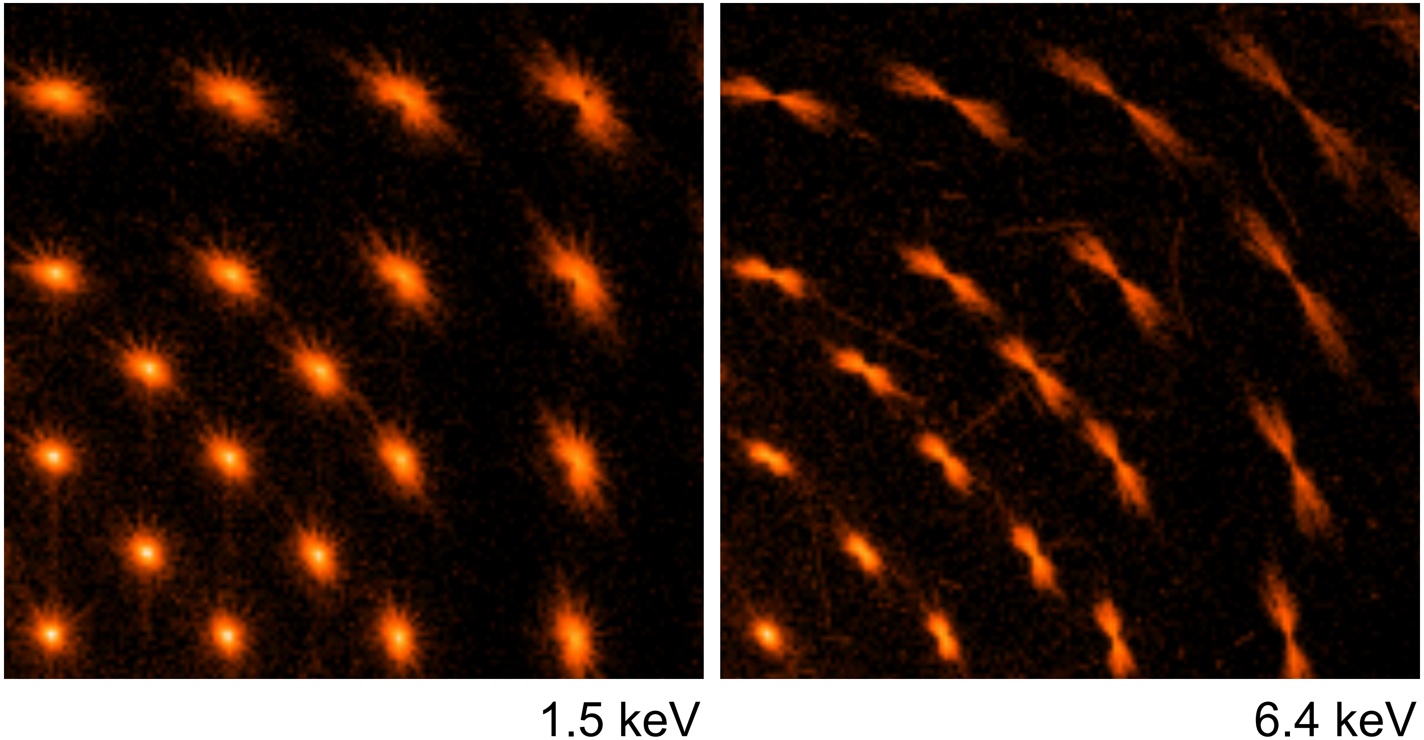
On-axis HEW for all eROSITA mirror modules





Determination of the eROSITA PSF

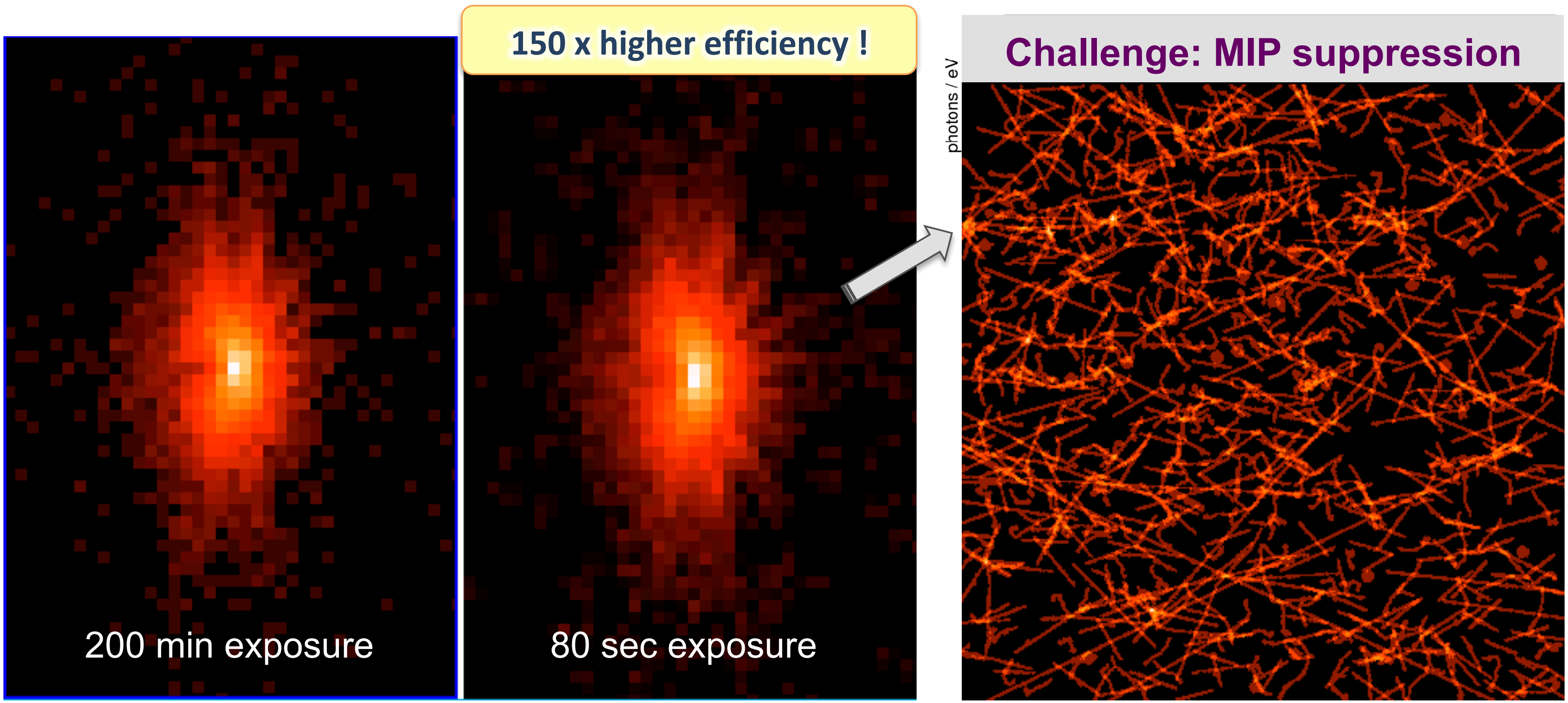
Off-axis PSF



1 pixel scan takes ~ 6-8 hours: how can we shorten the exposure time ?

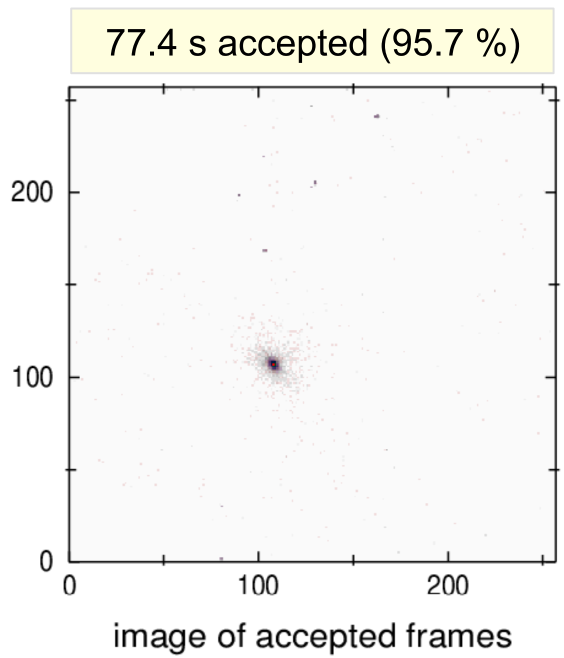
Method : operate the CCD in „charge accumulation mode“

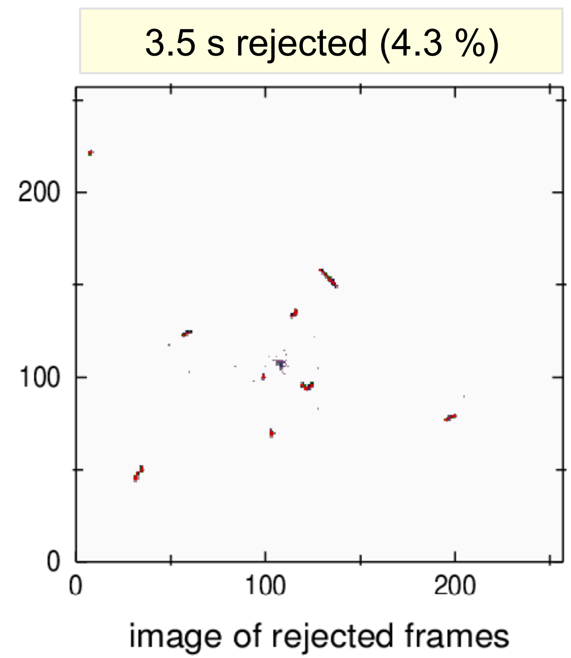
1) utilize the fact that the dominant photon energy is known
2) analyse the accumulated charges (challenge: MIP suppression)
3) abandon subpixel resolution (not required for off-axis PSF)



Method: operate the CCD in „charge accumulation mode“

Challenge: Suppression of MIPs in the case of extreme pile-up





energy: C-K (0.28 keV)
event threshold: 10.0 sigma

C-K

gain: CC
split threshold: 32 adu

total number of frames: 1617
number of accepted frames: 1548
number of rejected frames: 69

total exposure: 80.8 s
exposure used: 77.4 s
exposure lost: 3.5 s

number of accepted photons: ~ 13322
--> rate: ~ 172.1 photons/s
number of photons in brightest PSF pixel: ~ 3109

Method: operate the CCD in „charge accumulation mode“

Challenge: Suppression of MIPs in the case of extreme pile-up

66.7 s accepted (95.0 %) | 3.5 s rejected (5.0 %)

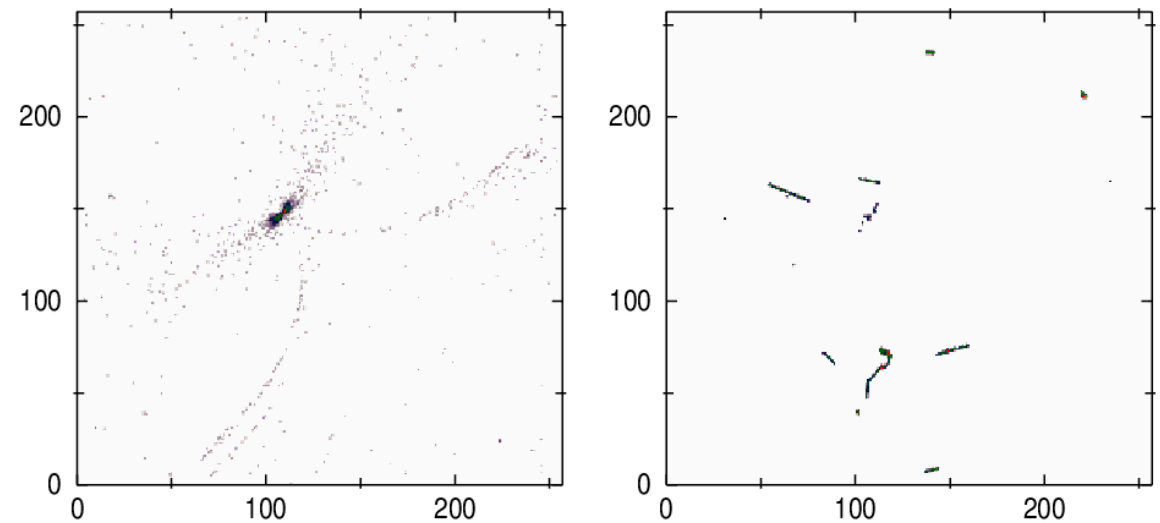


image of accepted frames | image of rejected frames

Cu-K

energy: Cu-K (8.04 keV)
event threshold: 10.0 sigma

gain: "EC" (0.25 x "CC")
split threshold: 32 adu

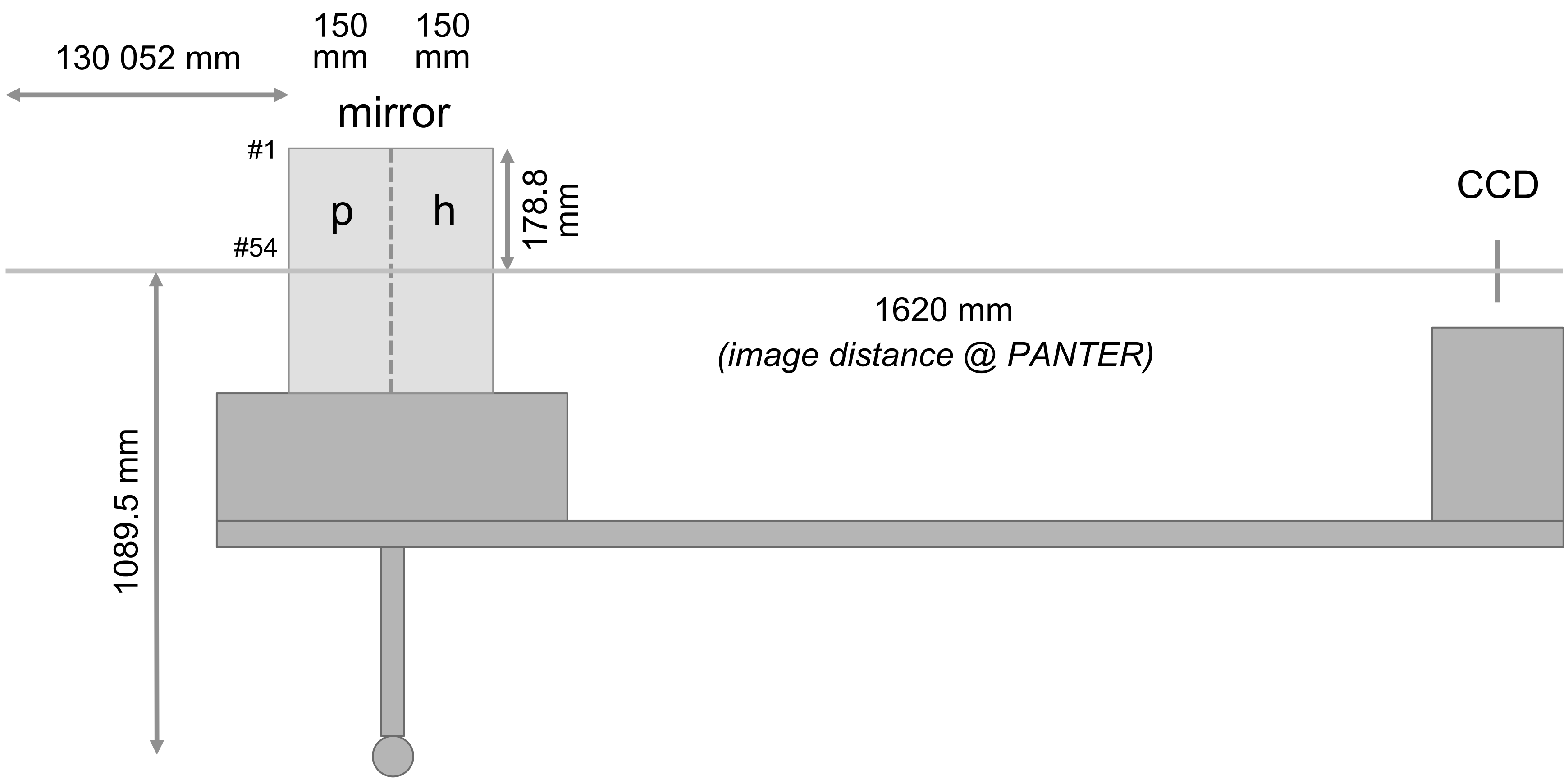
total number of frames: 1403
number of accepted frames: 1334
number of rejected frames: 69

total exposure: 70.2 s
exposure used: 66.7 s
exposure lost: 3.5 s

number of accepted photons: ~ 3612
--> rate: ~ 54.2 photons/s
number of photons in brightest PSF pixel: ~ 174

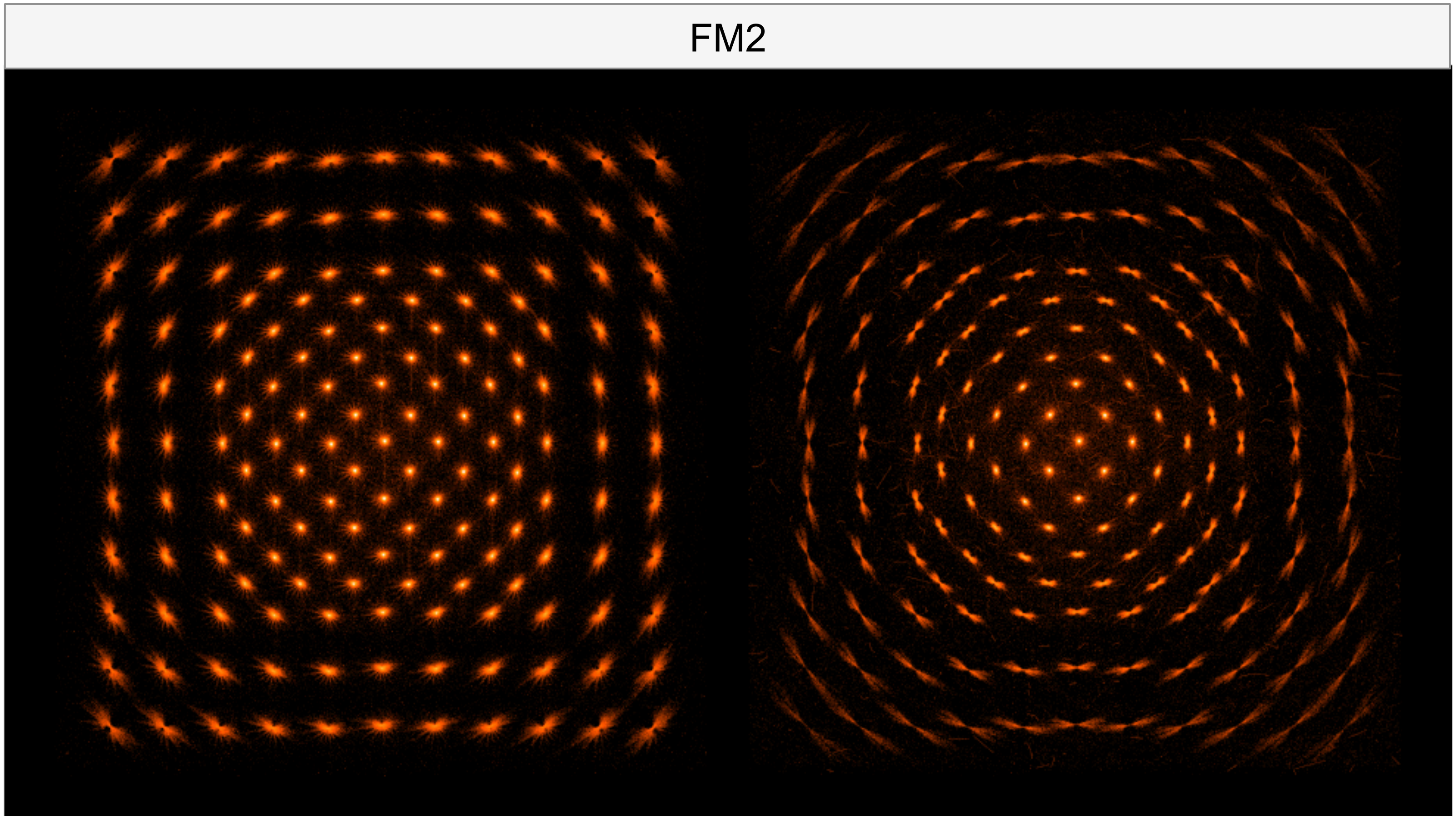
PSF Focal Plane Mapping

PANTER Geometry (overview)



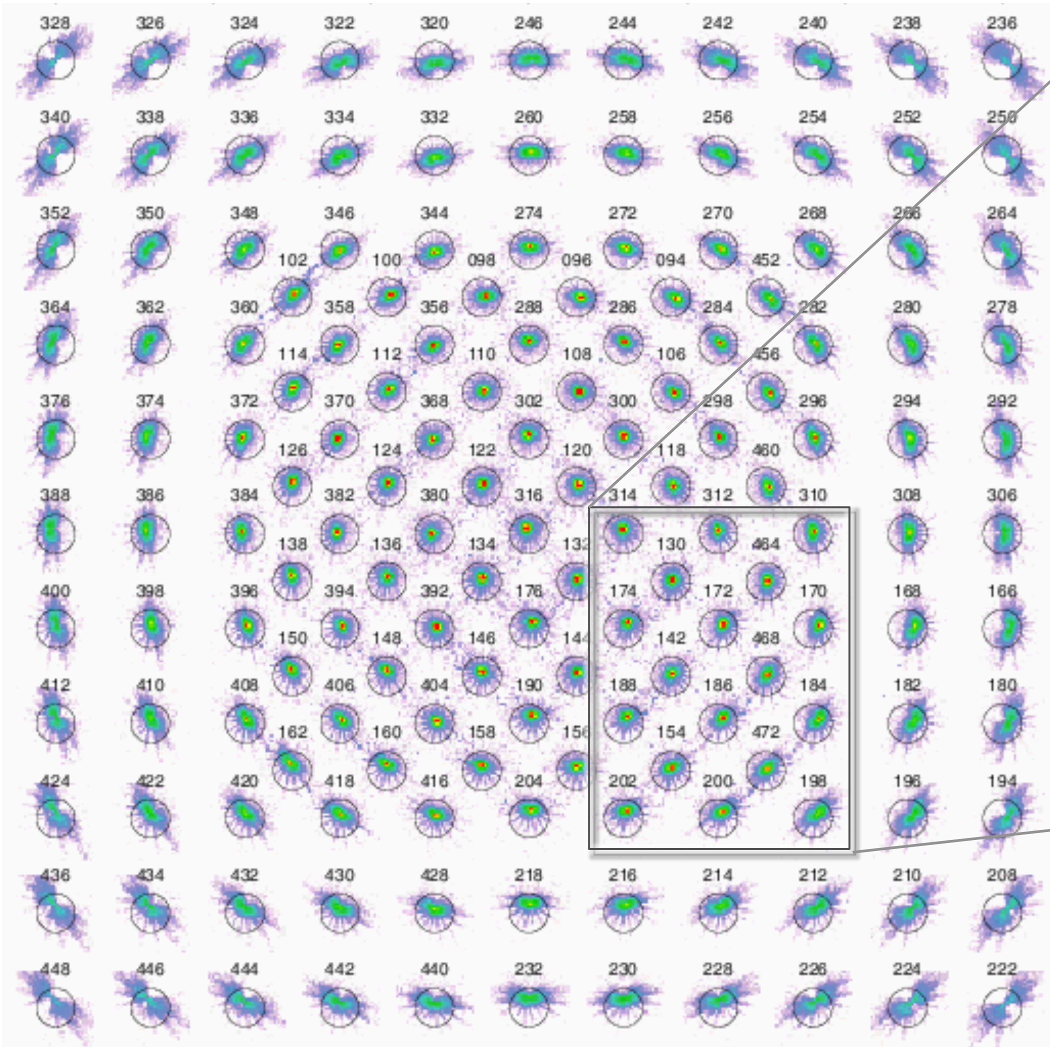
Determination of the eROSITA PSF

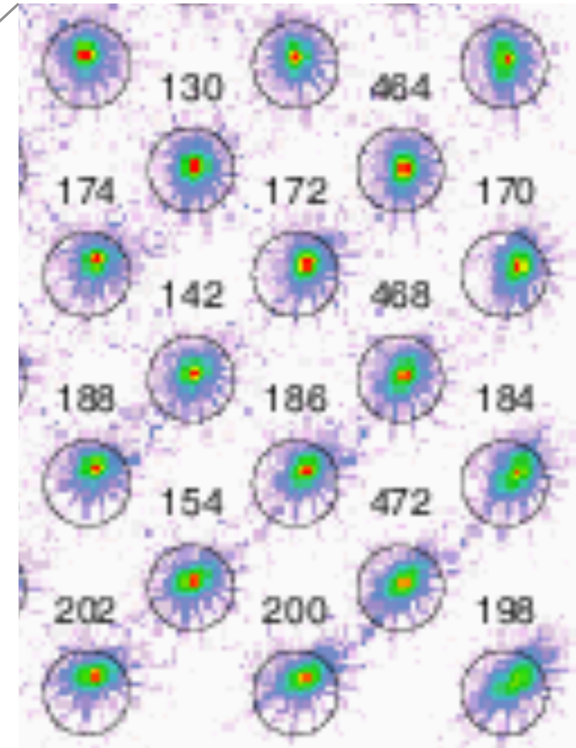
PSF Focal Plane Mapping



1.5 keV **6.4 keV**

PSF Focal Plane Mapping

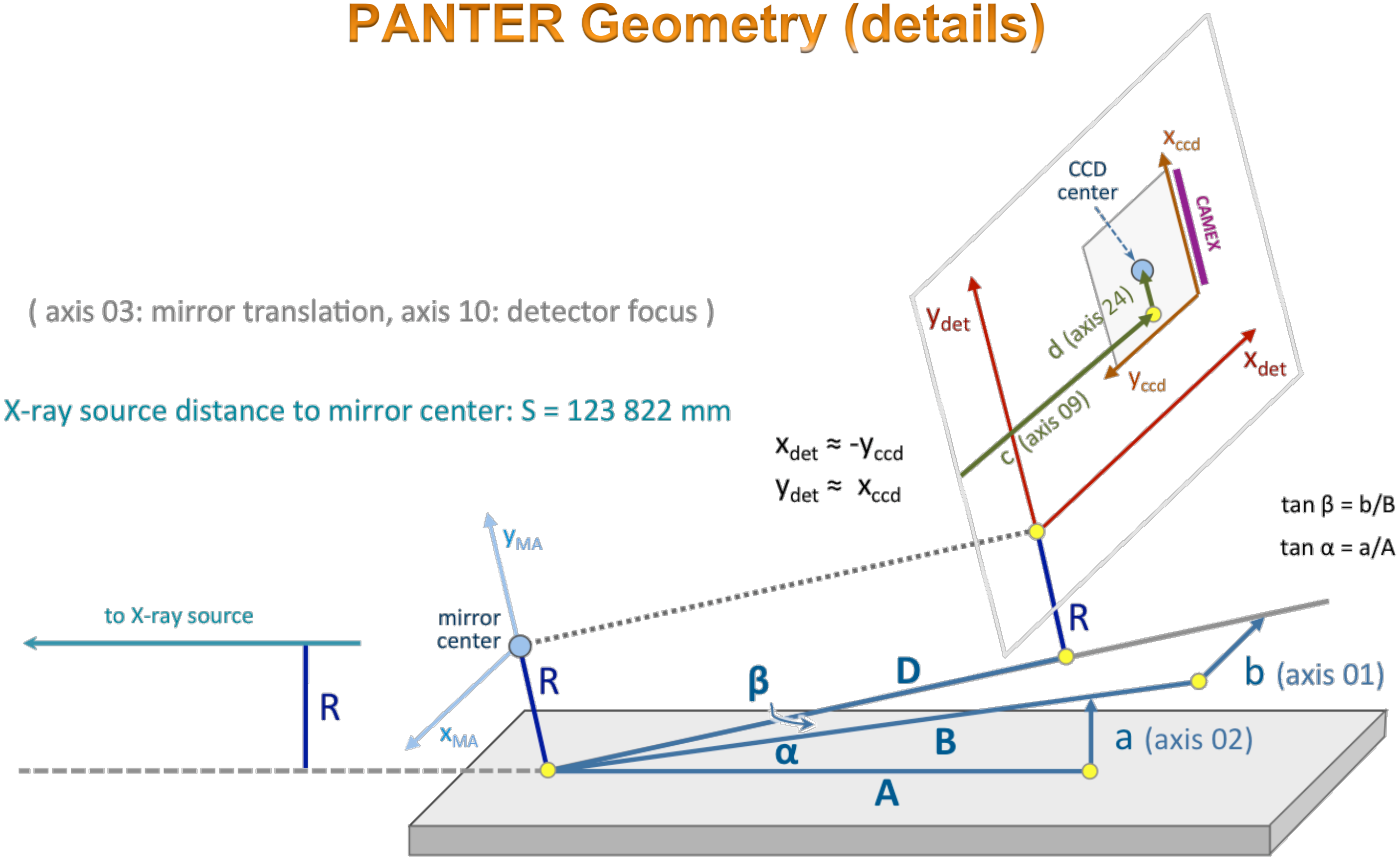




PSFs not exactly at expected positions

PSF Focal Plane Mapping

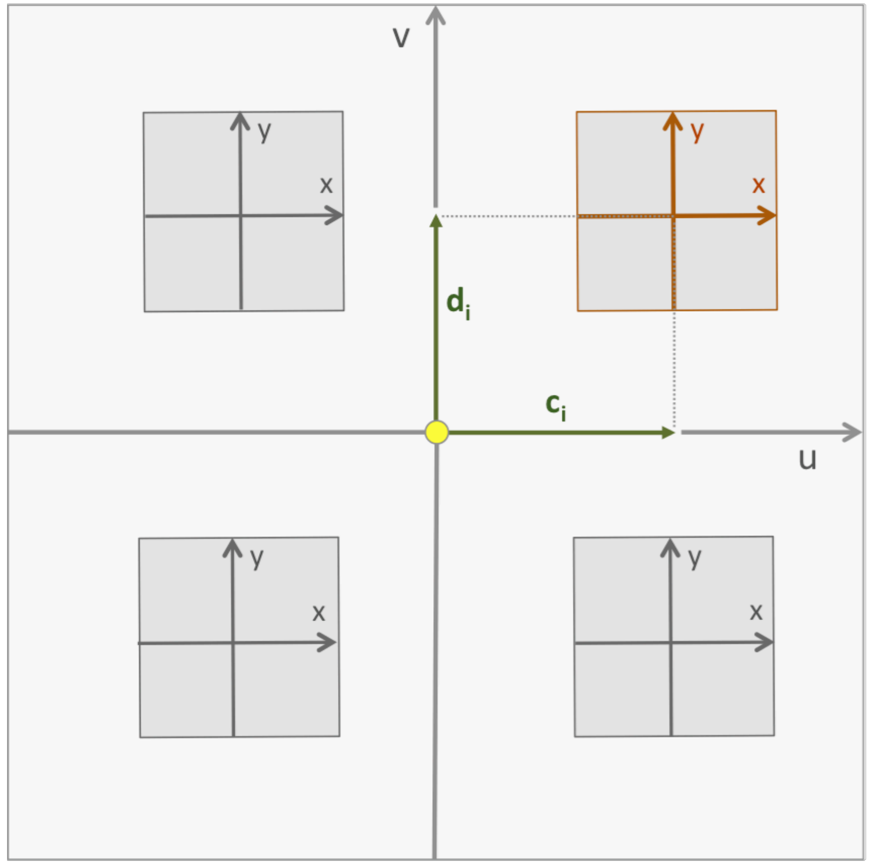
PANTER Geometry (details)



D = 1622.2 mm
A = 3060.4 mm (62.5 nm/step)
B = 3270.0 mm (1.25 µm/step) (+/- 10mm)
R = 1089.5 mm

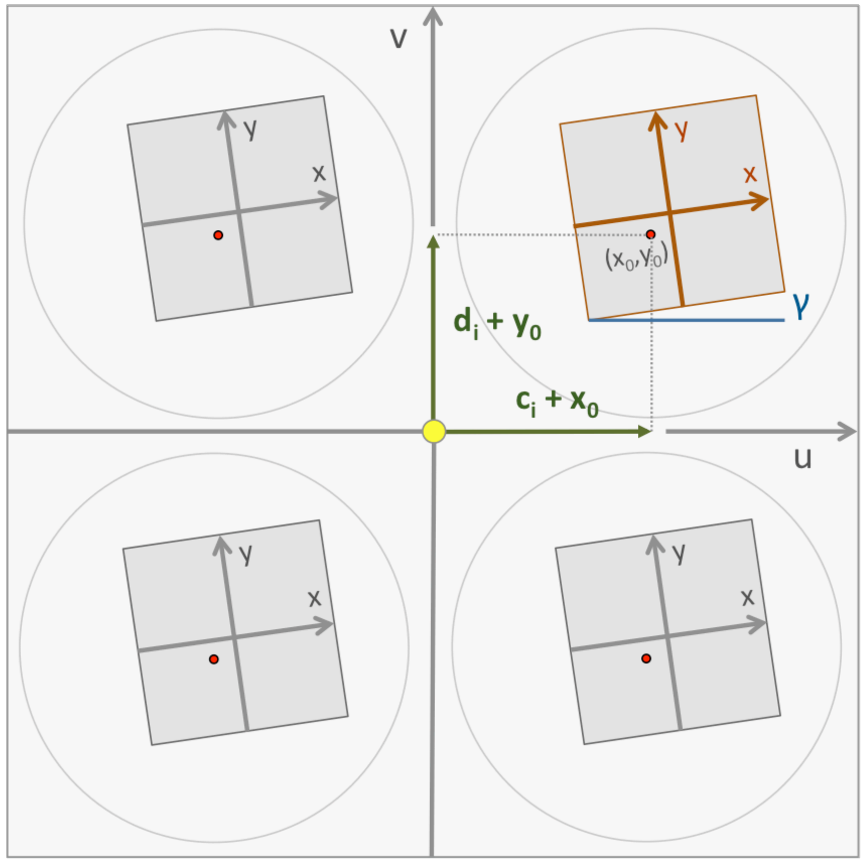
1 step = 62.5 nm
4610017 steps → α = 5.37835 deg
→ a = 288.126 mm
→ A = a / tan α = 3060.4 mm

PSF Focal Plane Mapping



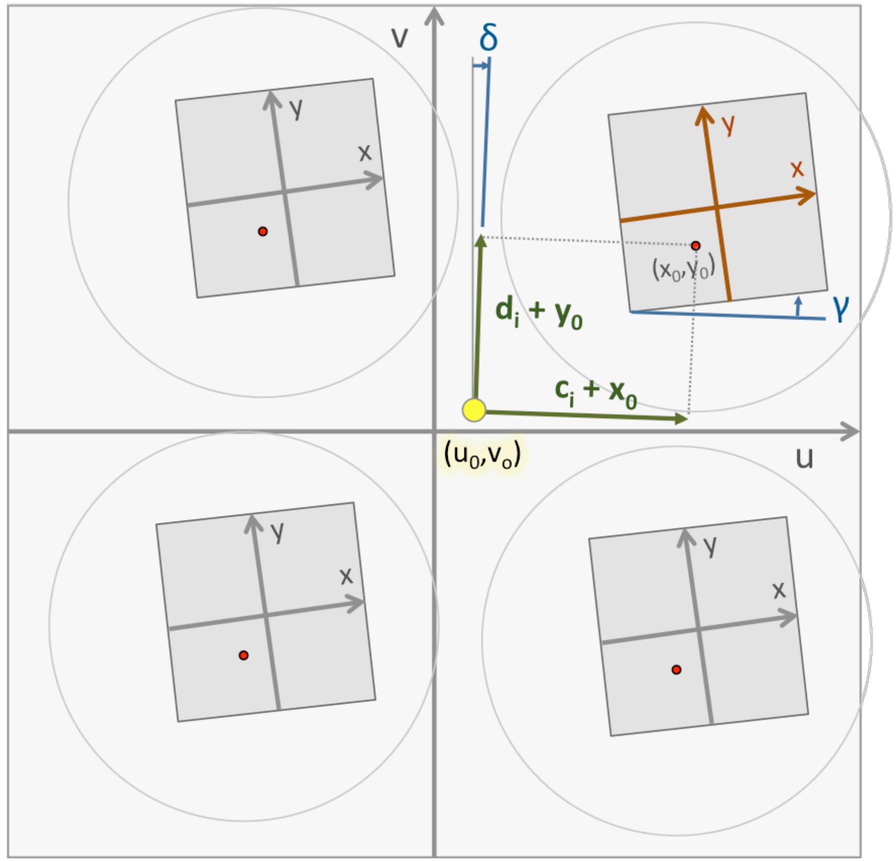
$$u_i = c_i + x$$
$$v_i = d_i + y$$

PSF Focal Plane Mapping



$$u_i = c_i + x_0 + (x-x_0)\cos\gamma - (y-y_0)\sin\gamma$$
$$v_i = d_i + y_0 + (x-x_0)\sin\gamma + (y-y_0)\cos\gamma$$

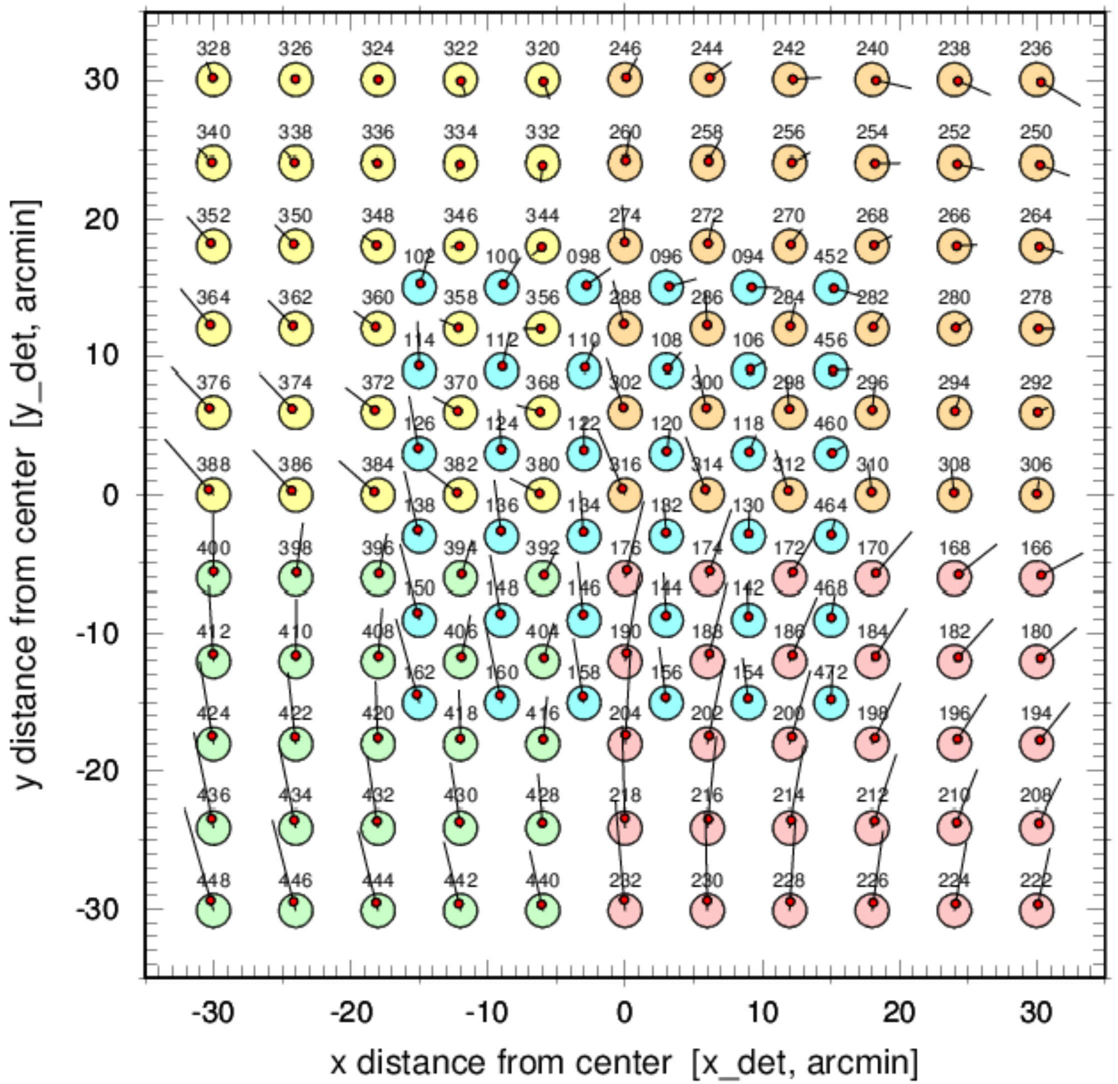
PSF Focal Plane Mapping



$$u_i = c_i + x_0 + (x-x_0)\cos\gamma - (y-y_0)\sin\gamma$$
$$v_i = d_i + y_0 + (x-x_0)\sin\gamma + (y-y_0)\cos\gamma$$

$$u_i' = u_0 + (u_i-u_0)\cos\delta - (v_i-v_0)\sin\delta$$
$$v_i' = v_0 + (u_i-u_0)\sin\delta + (v_i-v_0)\cos\delta$$

PSF Focal Plane Mapping

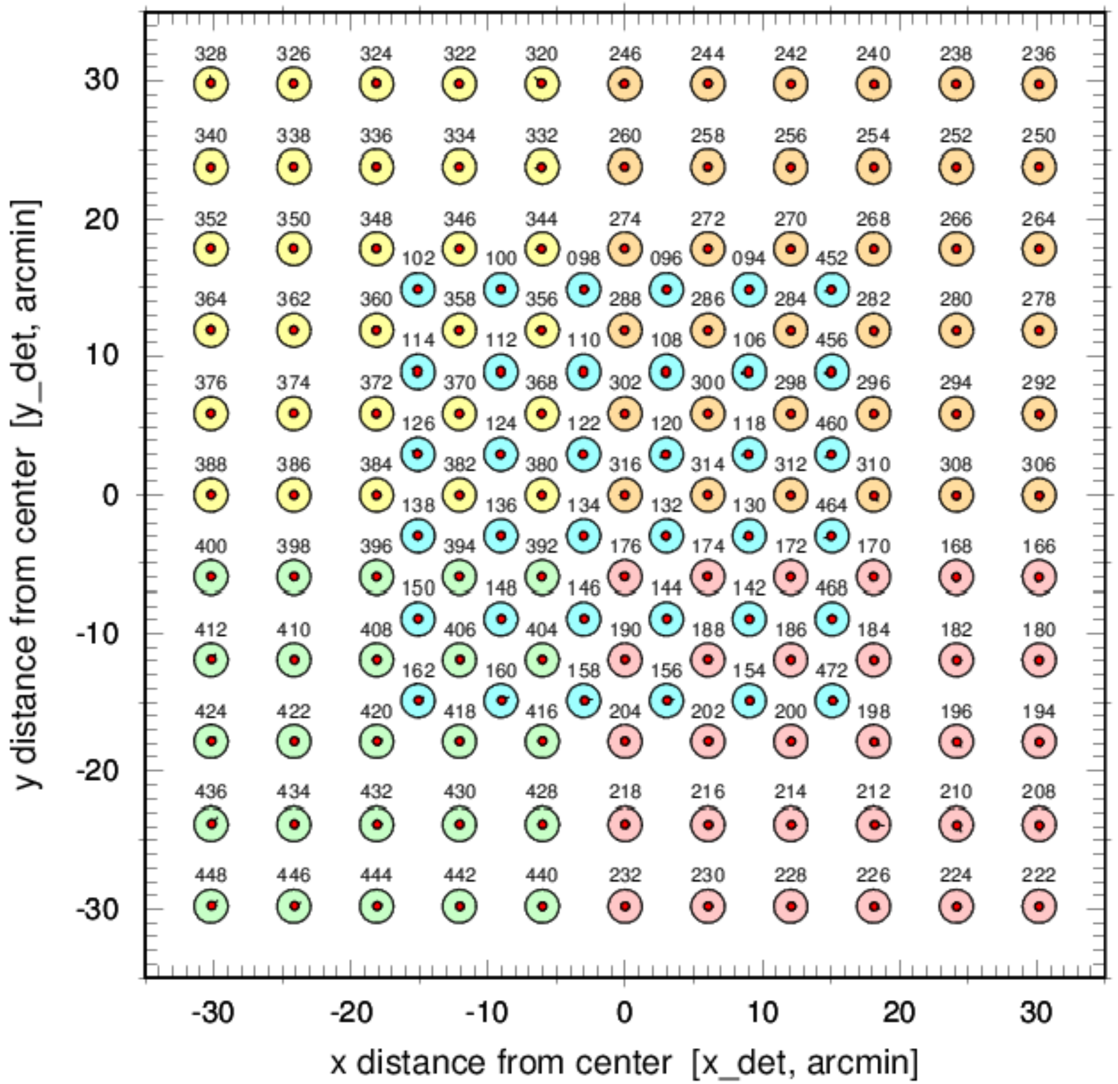


large circles: predicted PSF centers
small circles: corr. measured PSF centers
displacement lines enlarged by factor 10.0

A = 3060.4 mm, B = 3270.0 mm, C = 1621.0 mm
gamma = 0.0 arcmin, delta = 0.0 arcmin
x = (128.0 - y_ccd) , y = (x_ccd - 128.0)

mean positional 1σ deviation: 20.6“

PSF Focal Plane Mapping



Result of geometrical fit with 7 parameters:

A, B, D, γ, δ, x_0, y_0

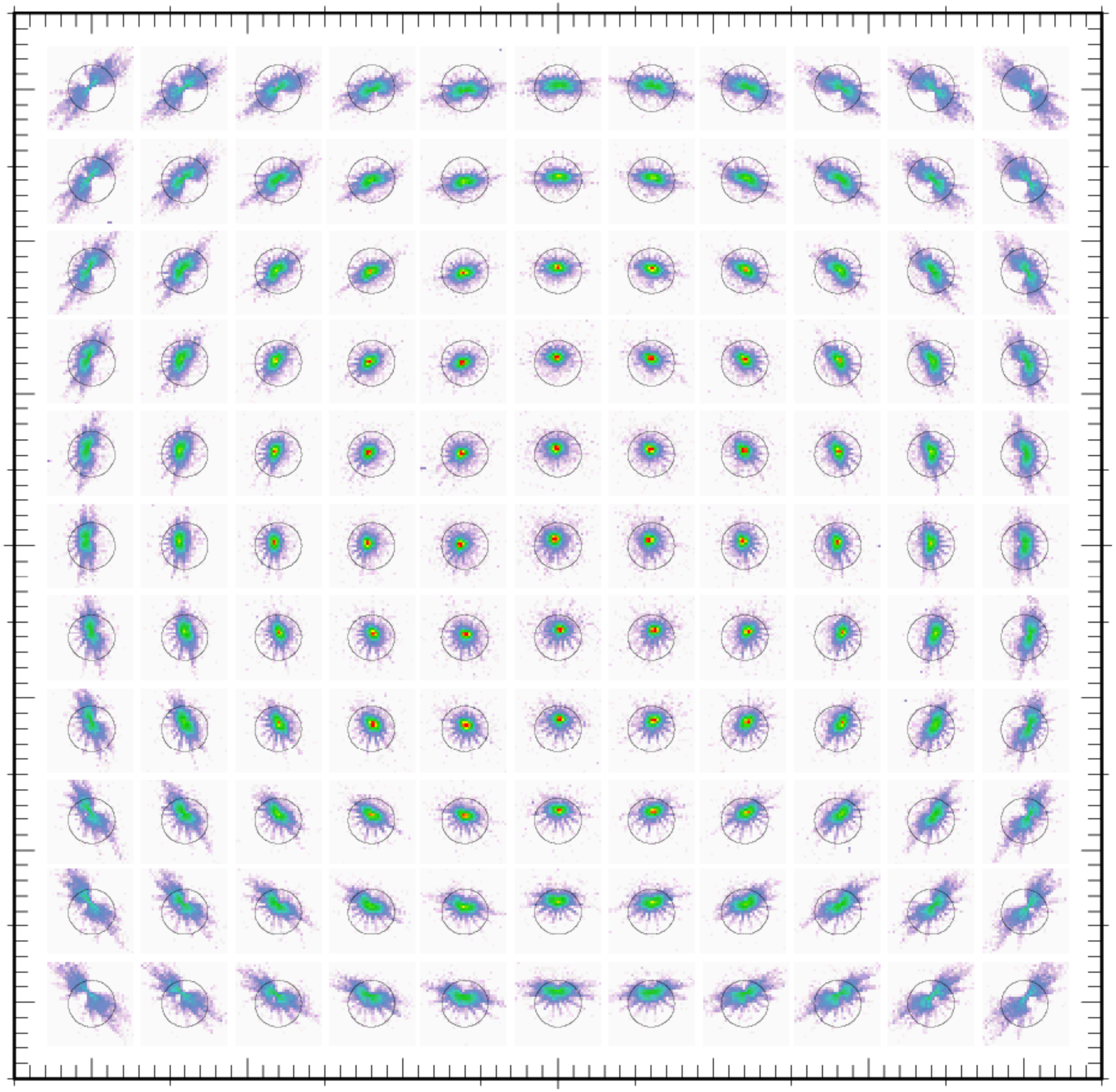
large circles: predicted PSF centers
small circles: corr. measured PSF centers
displacement lines enlarged by factor 10.0

A = 3095.3 mm, B = 3252.7 mm, D = 1622.2 mm
gamma = 46.4 arcmin, delta = -9.9 arcmin
x = (127.8 - y_ccd) , y = (x_ccd - 129.7)

mean positional 1σ deviation: 2.1“

PSF Focal Plane Mapping

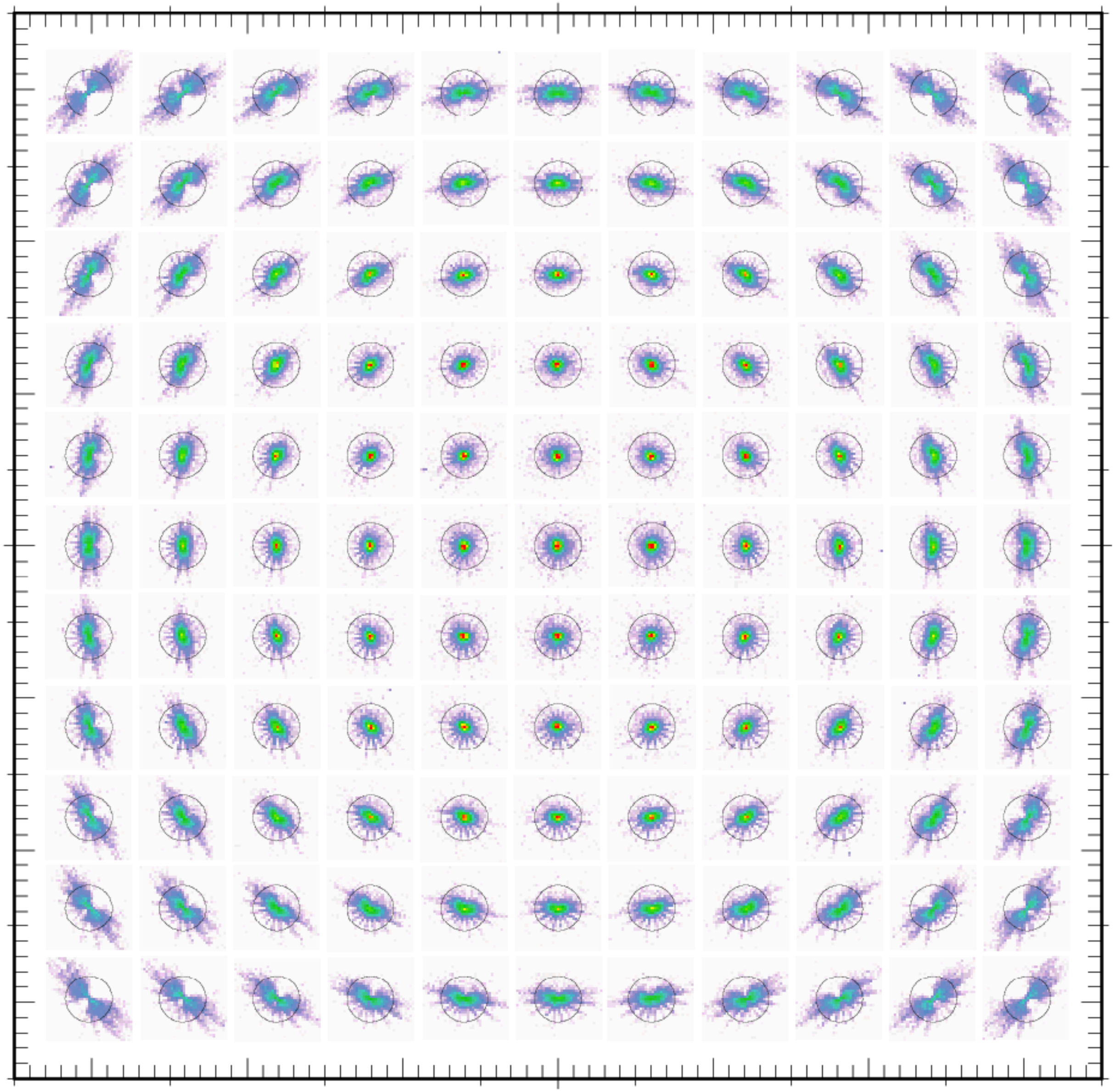
FM2, Al-K



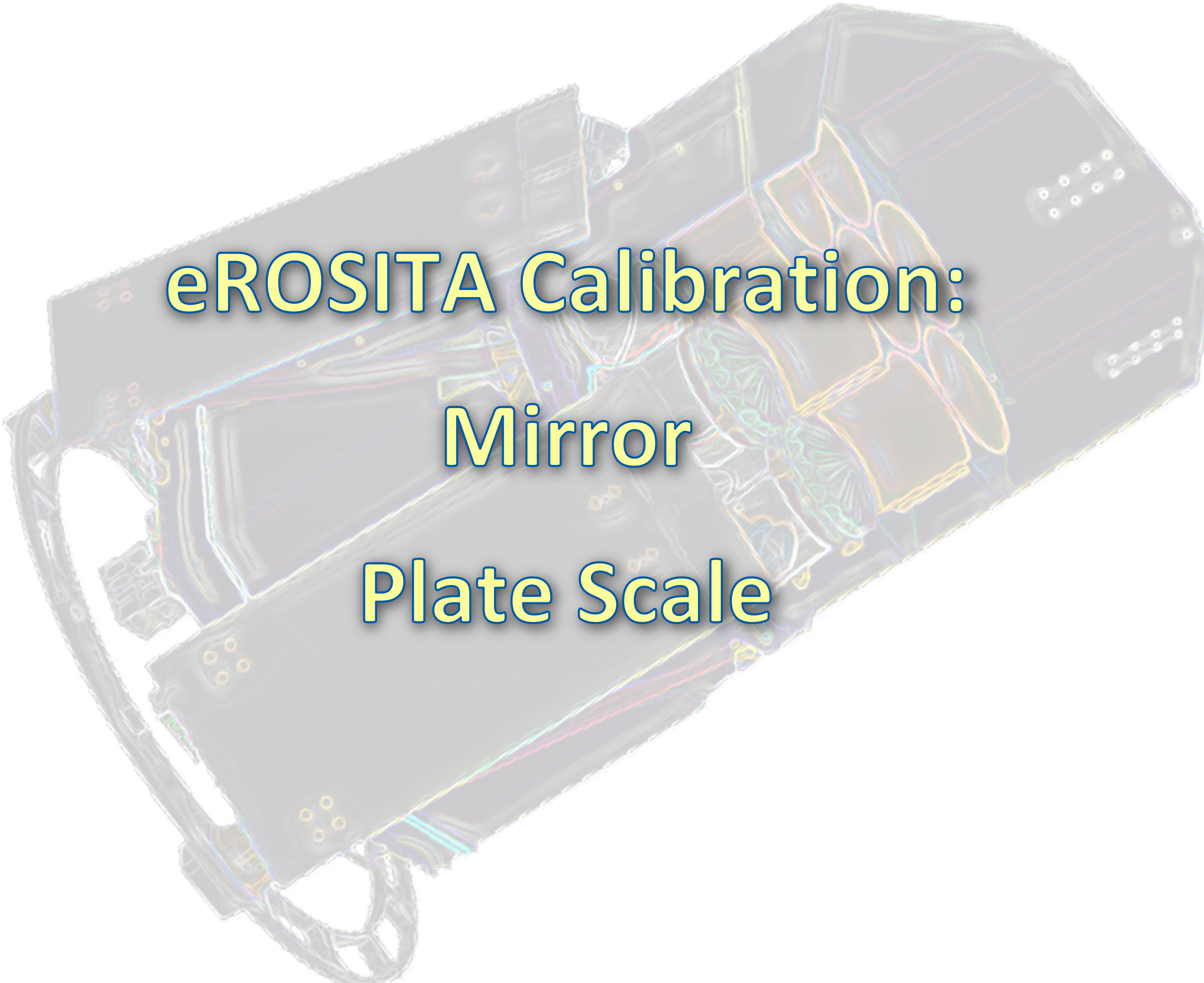
before geometry correction

PSF Focal Plane Mapping

FM2, Al-K



after geometry correction



eROSITA Calibration:

Mirror

Plate Scale

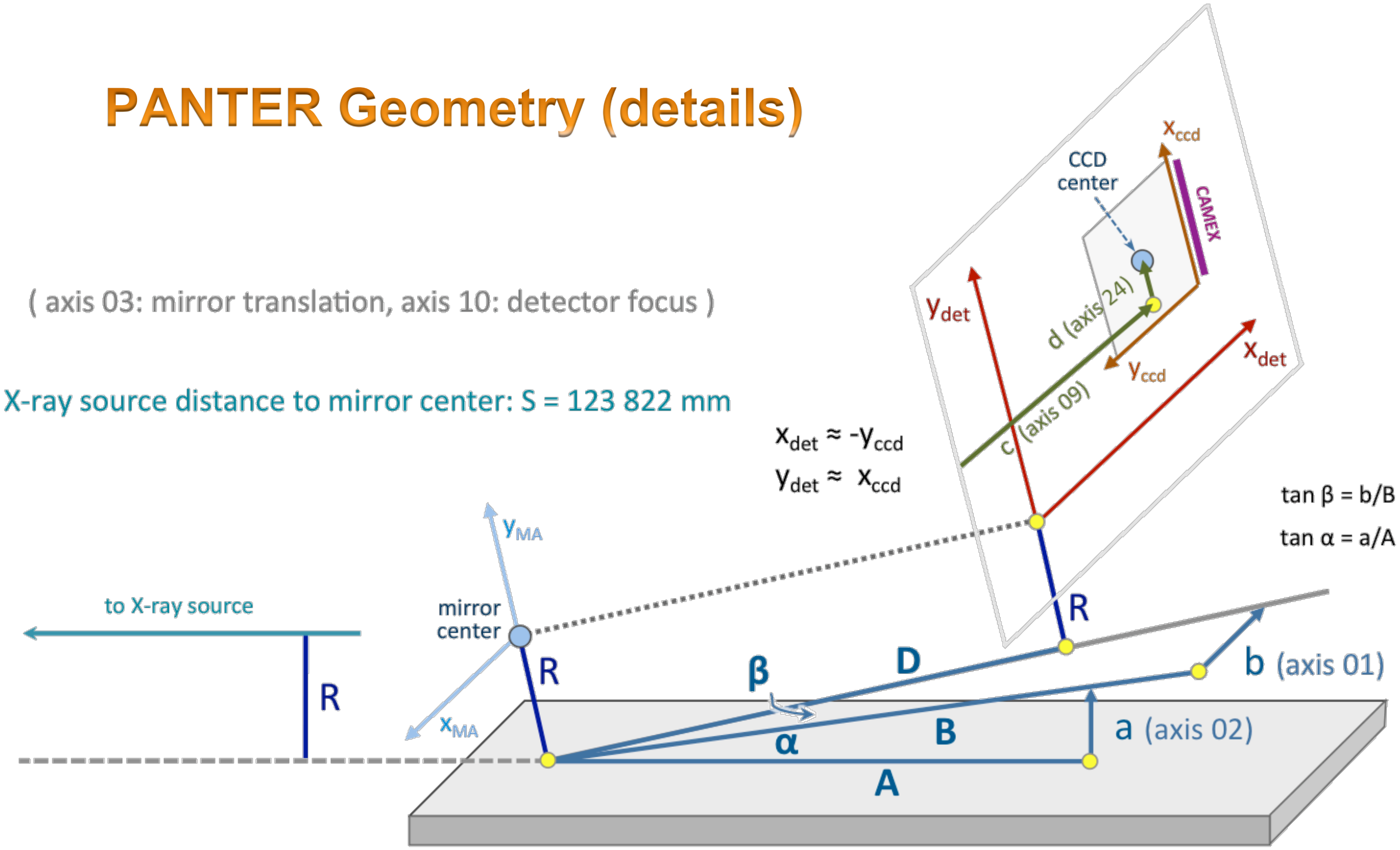
PSF Focal Plane Mapping

FM2, Al-K

PANTER Geometry (details)

(axis 03: mirror translation, axis 10: detector focus)

X-ray source distance to mirror center: S = 123 822 mm



D = 1622.2 mm
A = 3060.4 mm → **3095.3 mm**
B = 3270.0 mm → **3252.7 mm**
R = 1089.5 mm

application to the other energies..

PSF Focal Plane Mapping

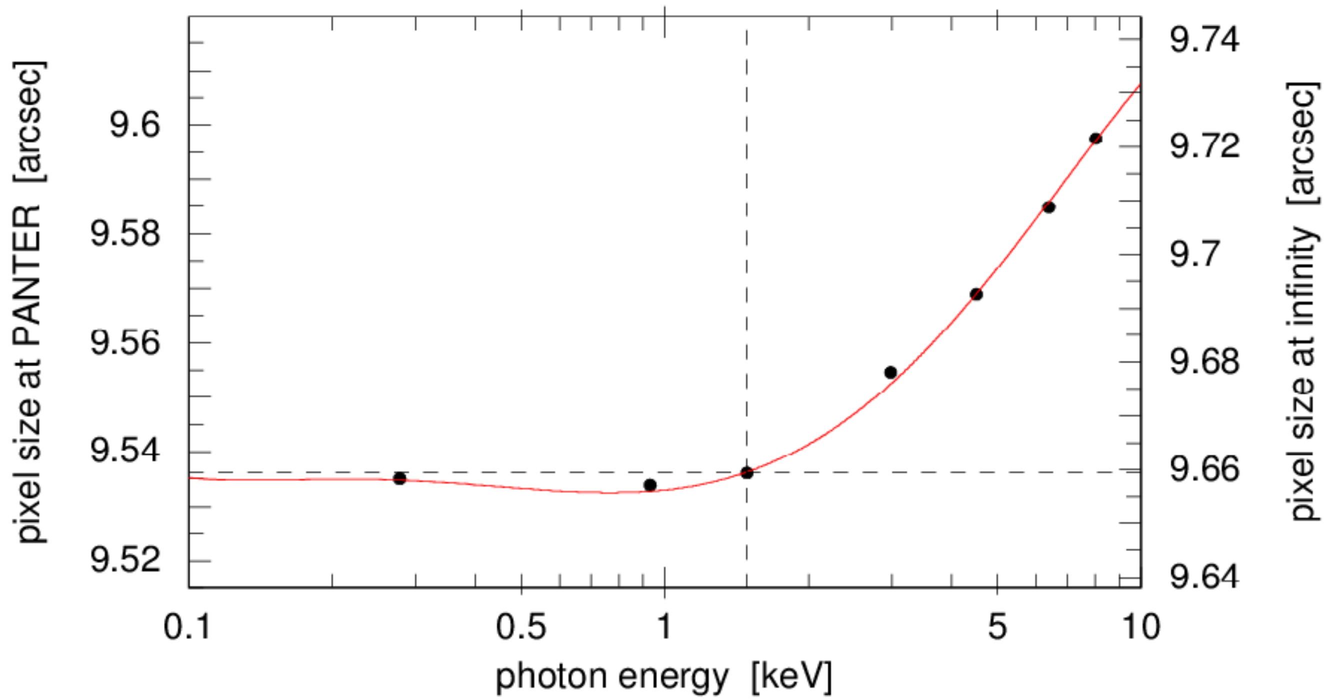
Result from common fit of all energies, with (A, B, γ, δ) fixed

	C-K	Cu-L	Al-K	Ag-L	Ti-K	Fe-K	Cu-K	
A	= 3095.3 mm							fixed
B	= 3252.9 mm							fixed
x_0	126.5	126.2	127.8	126.4	126.6	127.8	126.9	**free**
y_0	129.7	129.6	129.7	129.7	129.7	129.8	129.7	**free**
γ	= 45.8‘							fixed
δ	= -9.7‘							fixed
D	**1622.4**	**1622.6**	**1622.2**	**1619.1**	**1616.7**	**1614.0**	**1611.9**	**free**

The image distance depends on the energy !

PSF Focal Plane Mapping

Result from common fit of all energies, with (A, B, γ, δ) fixed

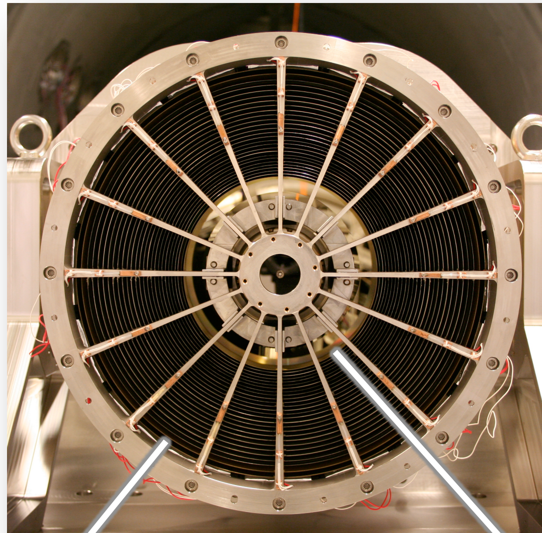


The plate scale depends on the energy !

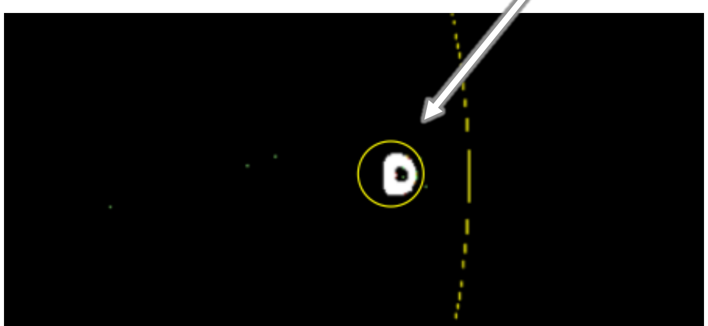
Energy dependence of the eROSITA Plate Scale

Ray-tracing simulation

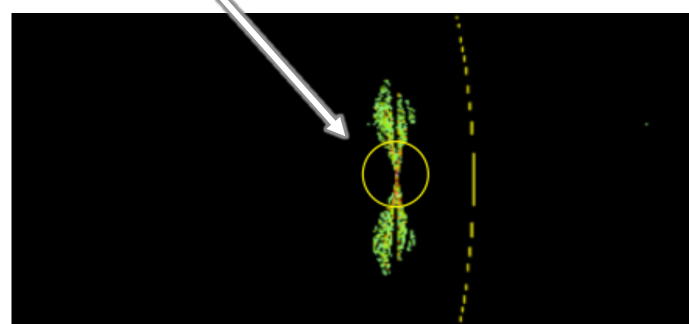
(P. Friedrich, M. Freyberg)



0.1 – 13 keV,
white spectrum,
28 arcmin off-axis

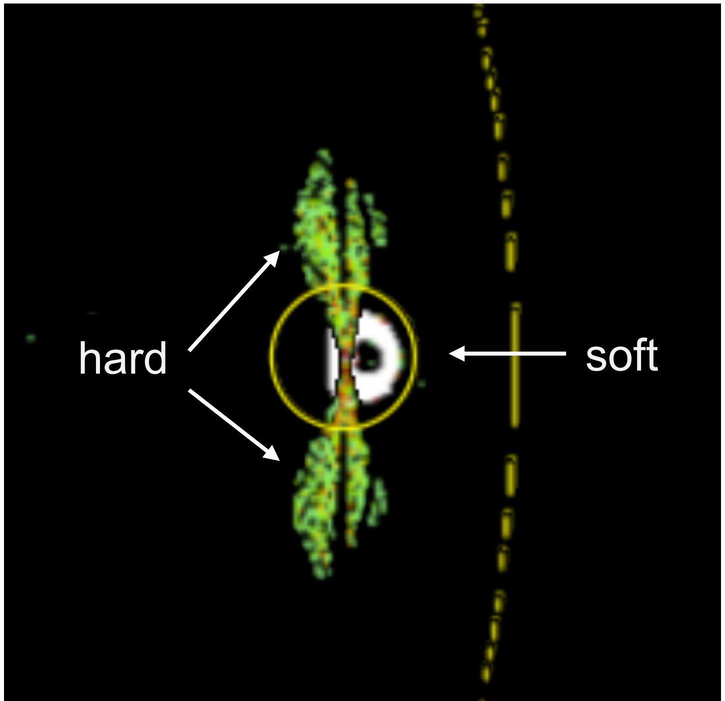


shell 1 (outermost, „soft“)

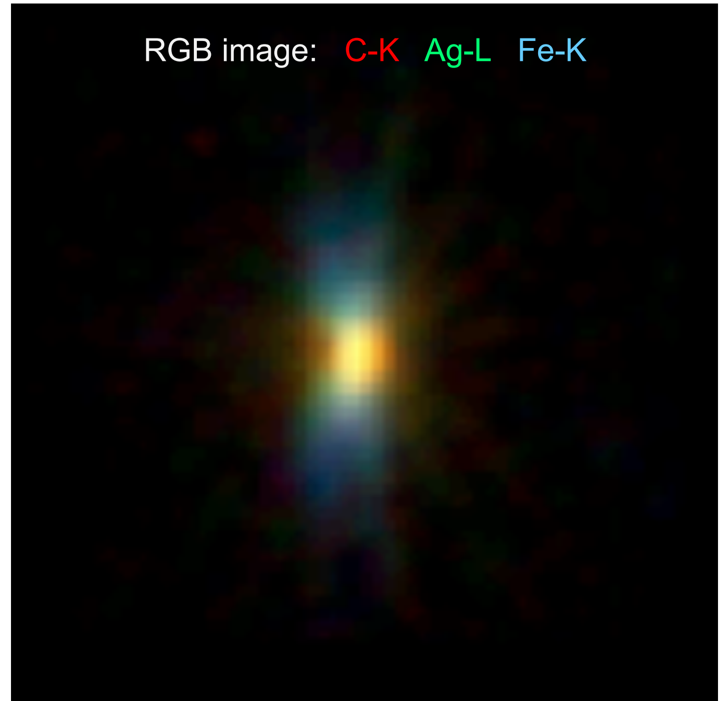


shell 54 (innermost, „hard“)

Energy dependence of the eROSITA Plate Scale

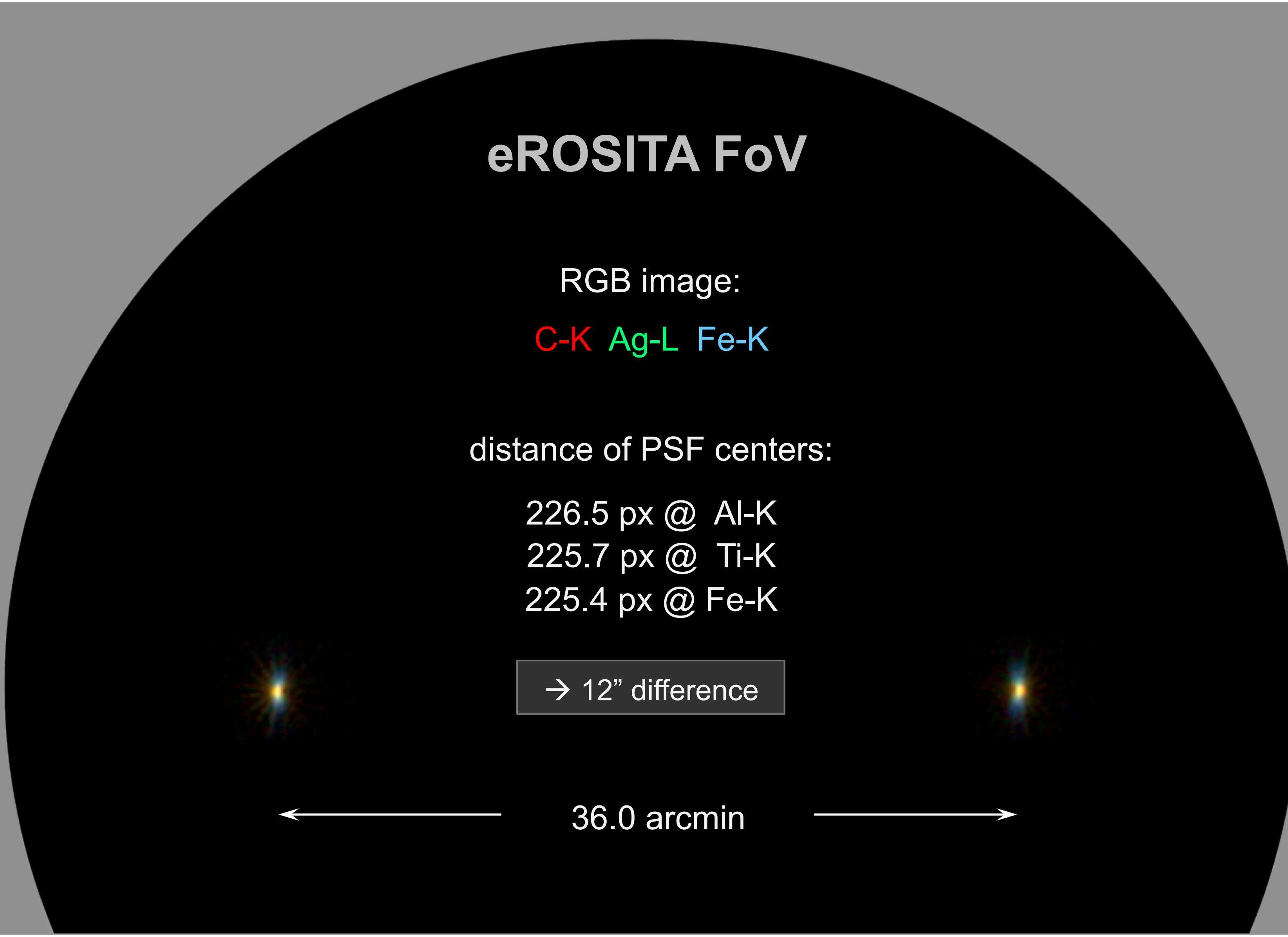


Ray-tracing simulation

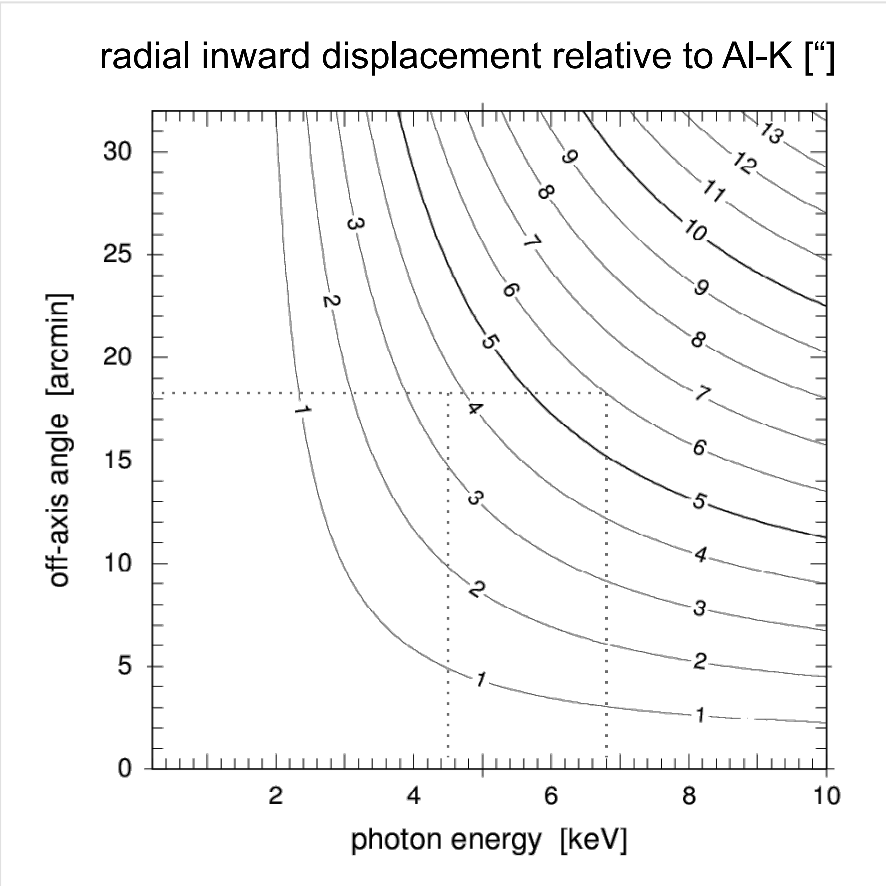


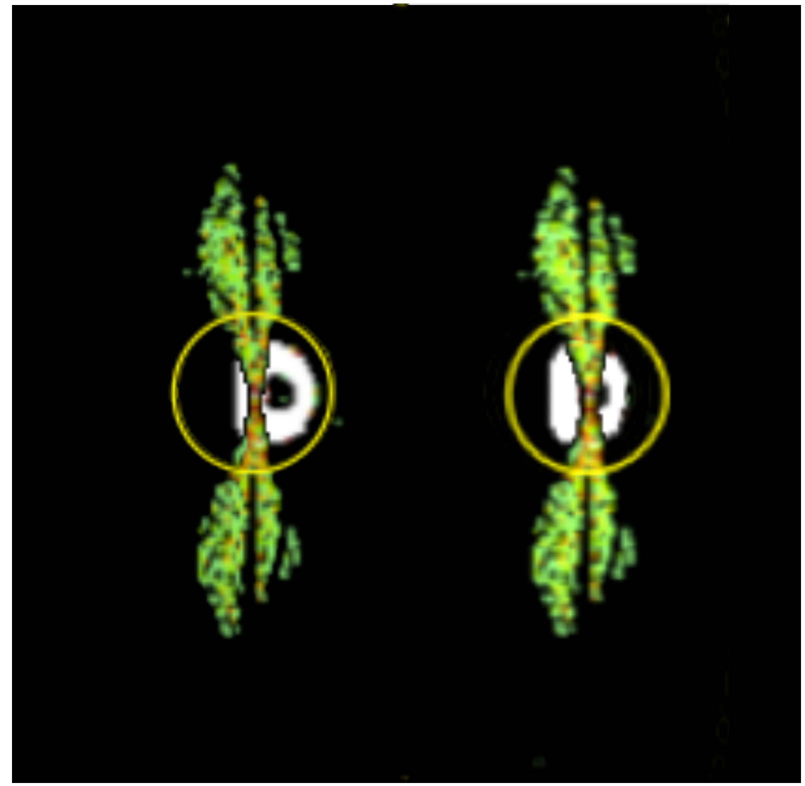
PSF Focal Plane Mapping

PSF Focal Plane Mapping



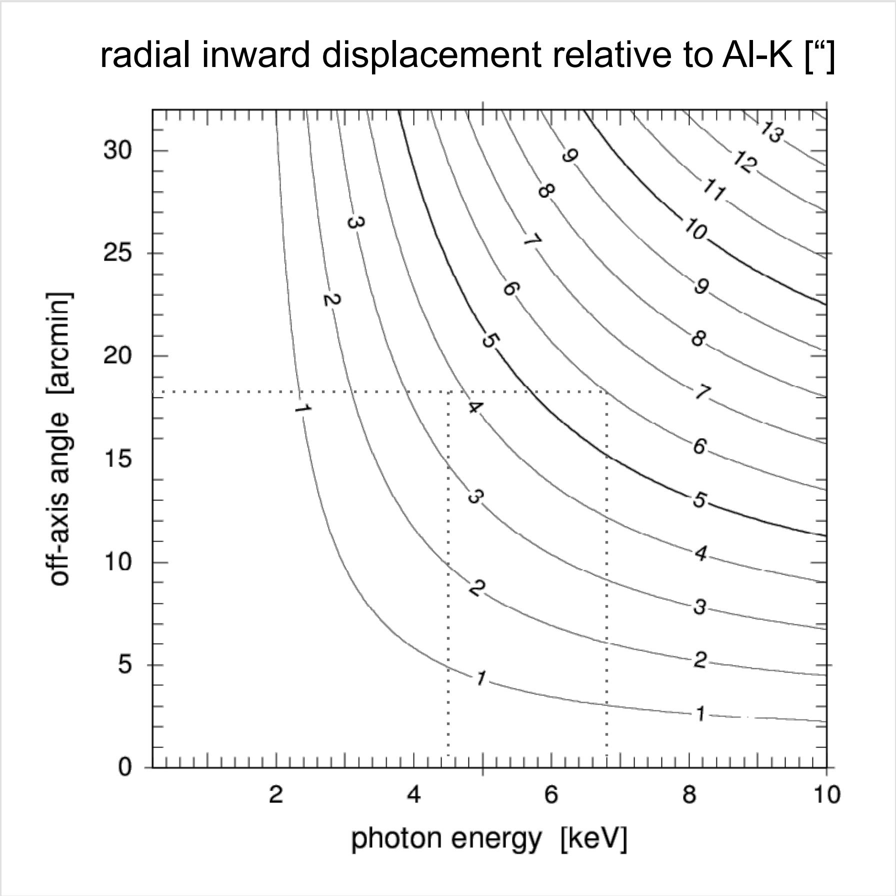
Energy dependence of the eROSITA Plate Scale





If the energy dependence of the plate scale is not taken into account, then the PSF is larger than necessary !

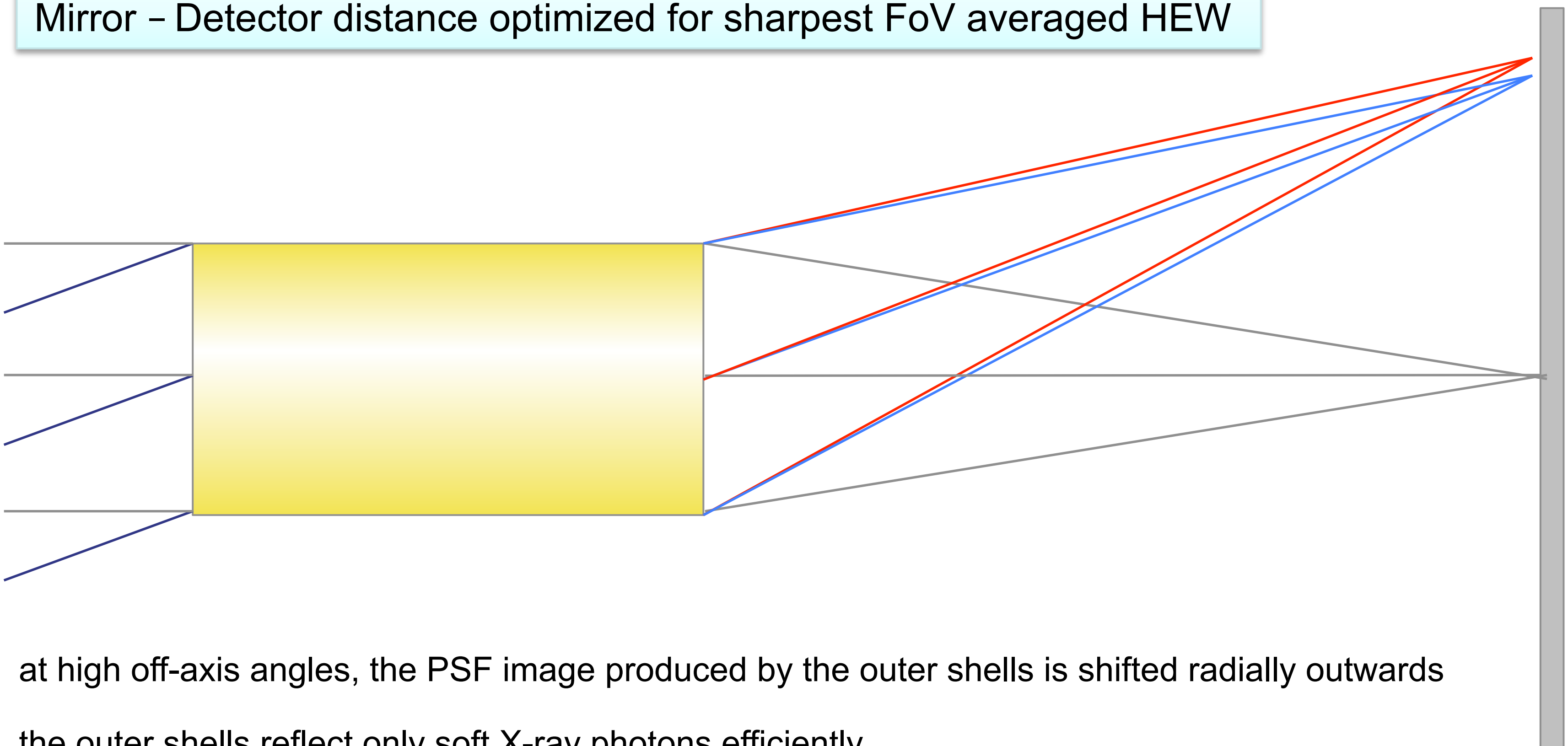
Energy dependence of the eROSITA Plate Scale



If the energy dependence of the plate scale is not taken into account, then sharp boundaries of emission regions may show spectral gradients !

Energy dependence of the eROSITA Plate Scale

Mirror – Detector distance optimized for sharpest FoV averaged HEW



- at high off-axis angles, the PSF image produced by the outer shells is shifted radially outwards
- the outer shells reflect only soft X-ray photons efficiently

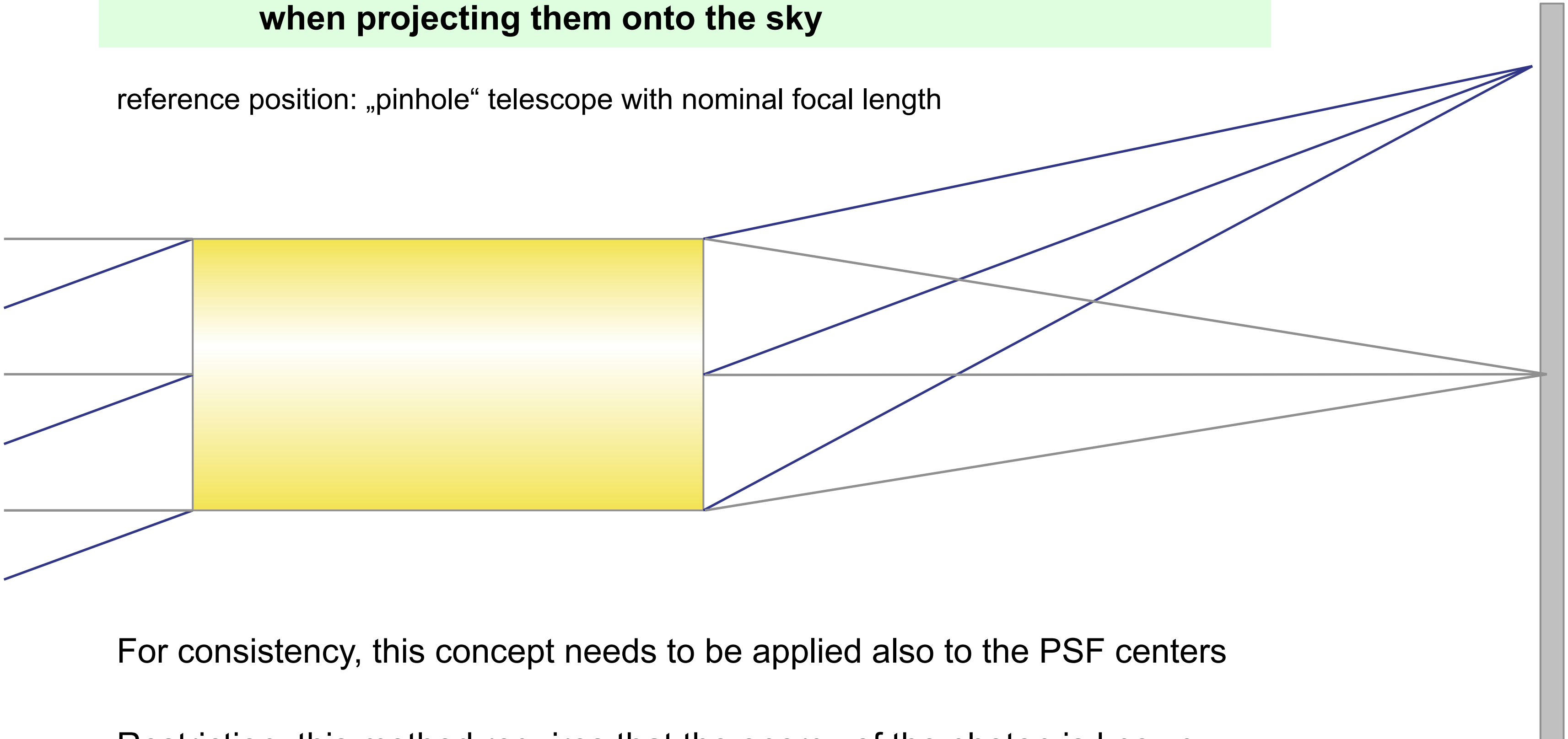
→ **chromatic aberration** (in addition to field curvature)

→ image distance given by focal length and image scale are conceptually different

Energy dependence of the eROSITA Plate Scale

Method: apply radial energy dependent shifts to the photon positions when projecting them onto the sky

reference position: „pinhole“ telescope with nominal focal length

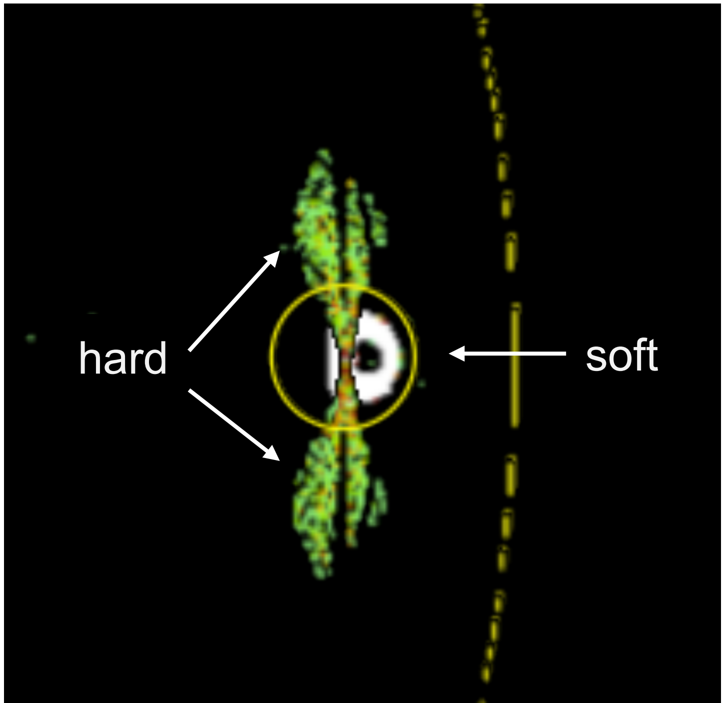


For consistency, this concept needs to be applied also to the PSF centers

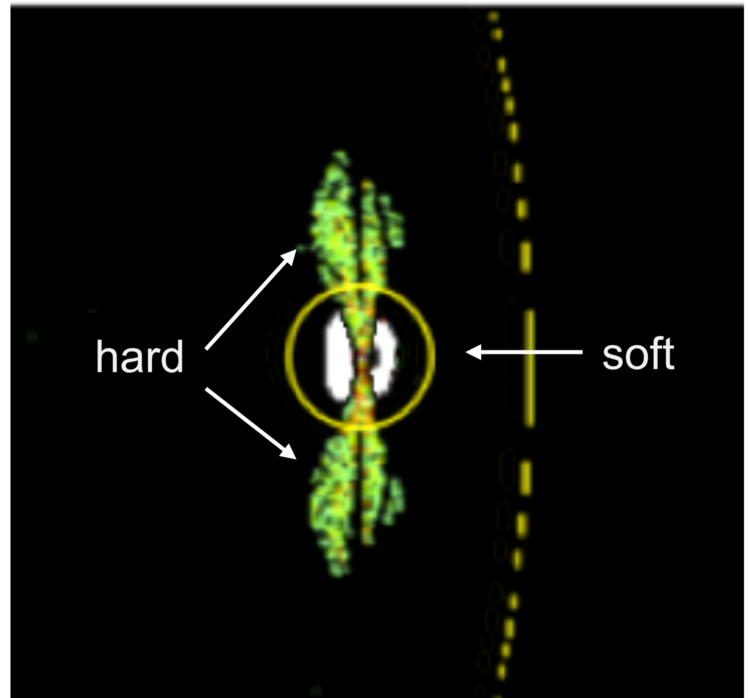
Restriction: this method requires that the energy of the photon is known

→ Problems may occur with escape peak and pile-up,
but there should be an overall improvement

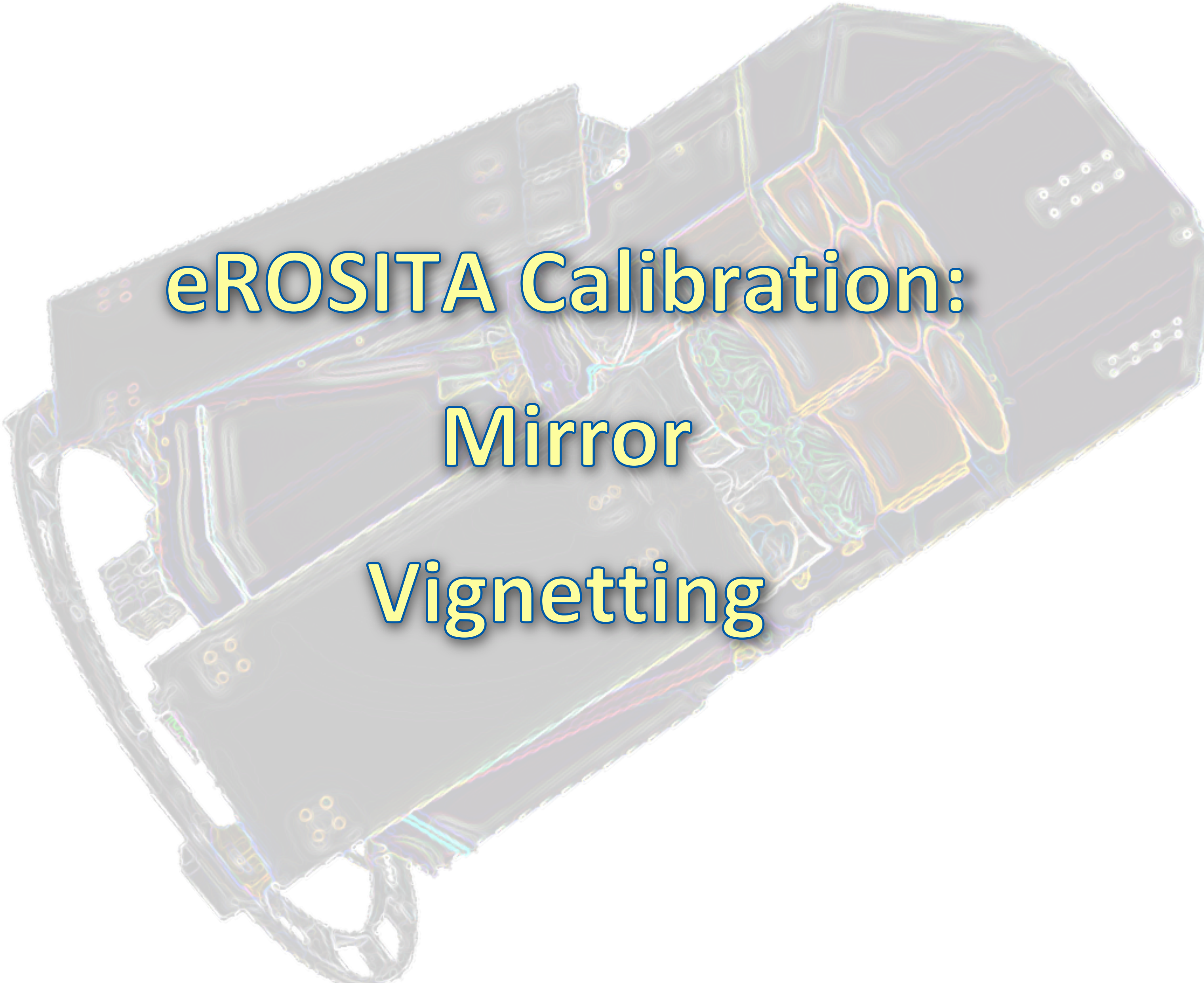
Energy dependence of the eROSITA Plate Scale



constant plate scale



energy dependent plate scale



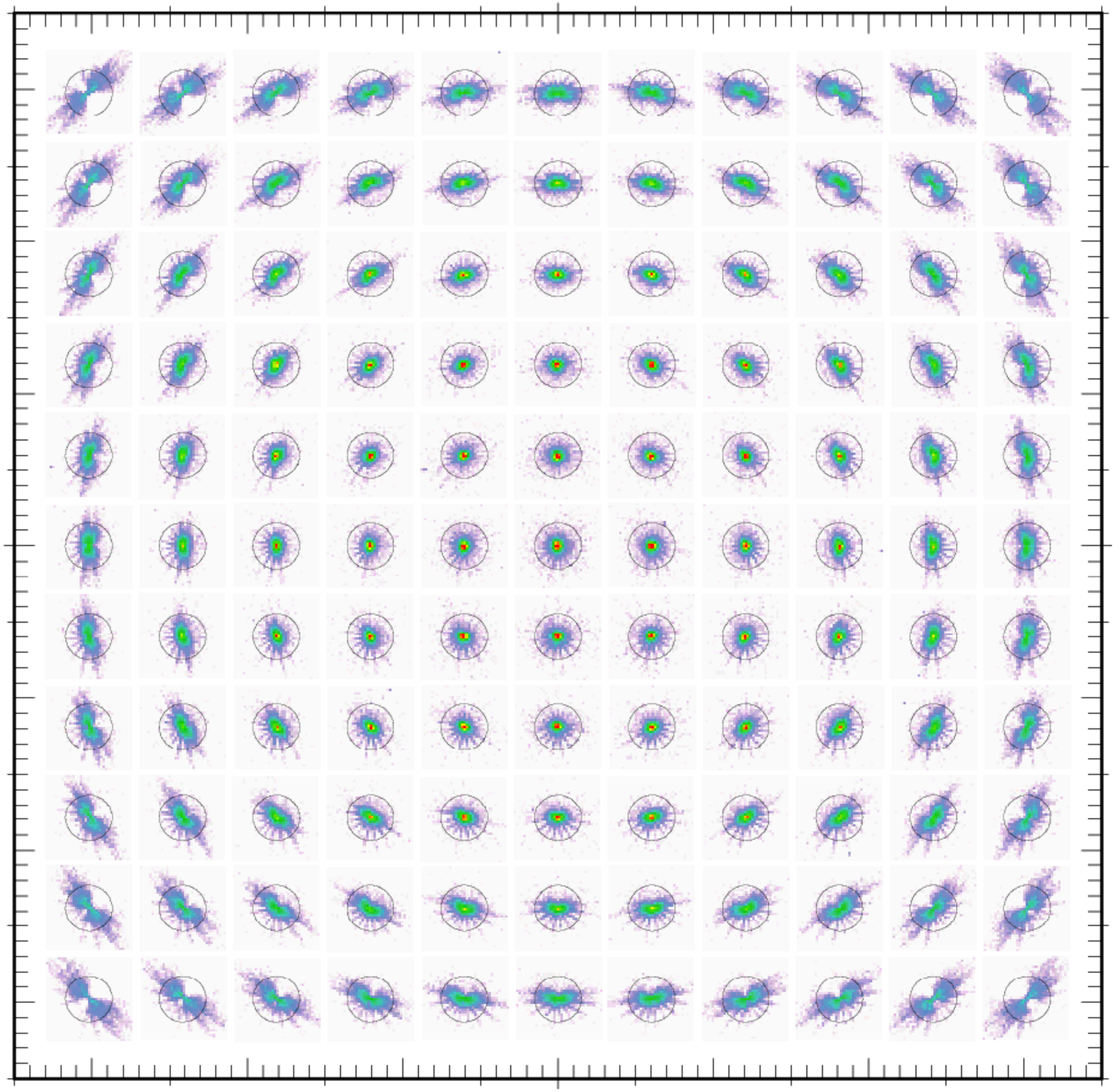
eROSITA Calibration:

Mirror

Vignetting

PSF Focal Plane Mapping

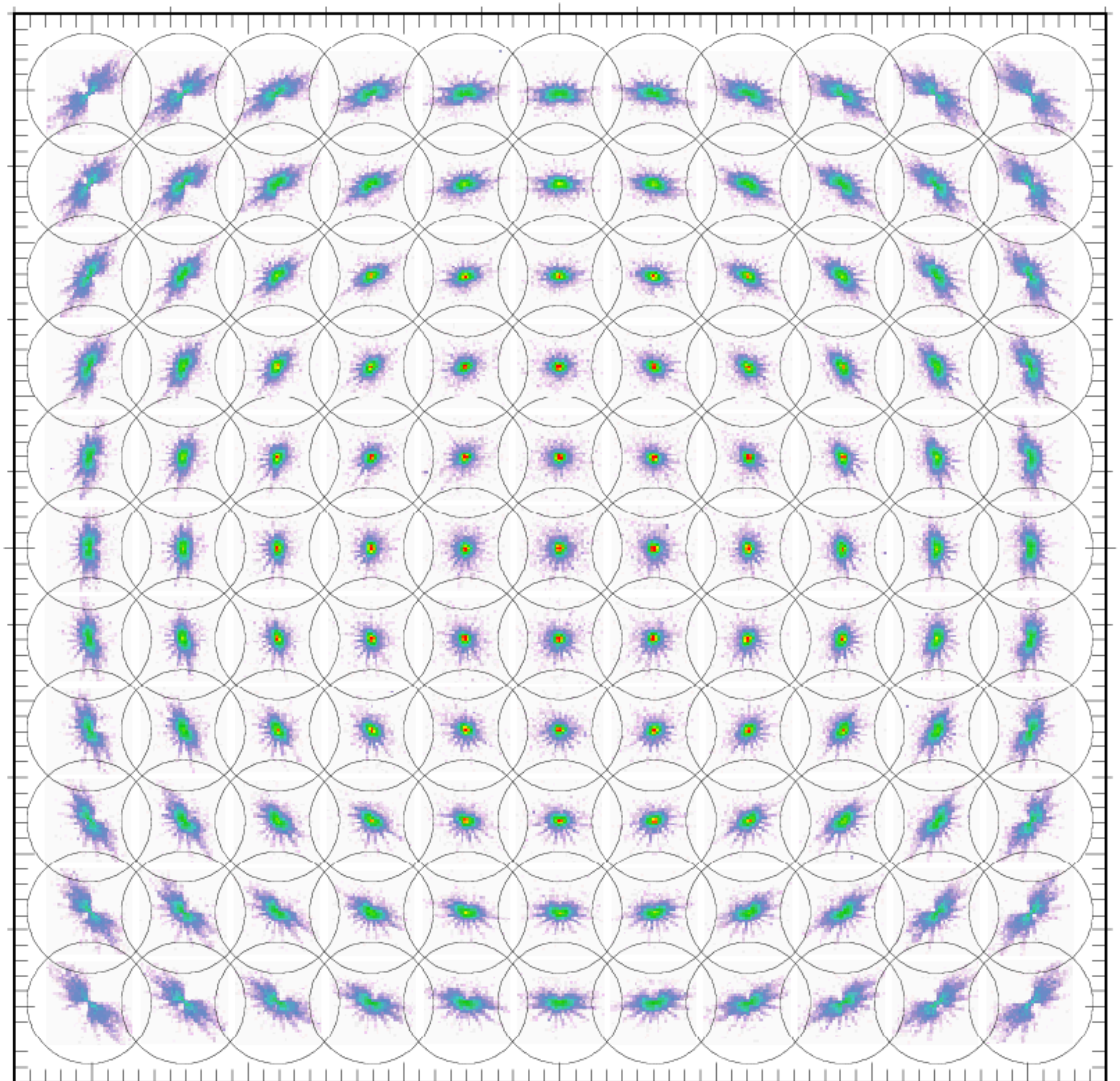
FM2, Al-K



after geometry correction

PSF Focal Plane Mapping

FM2, Al-K



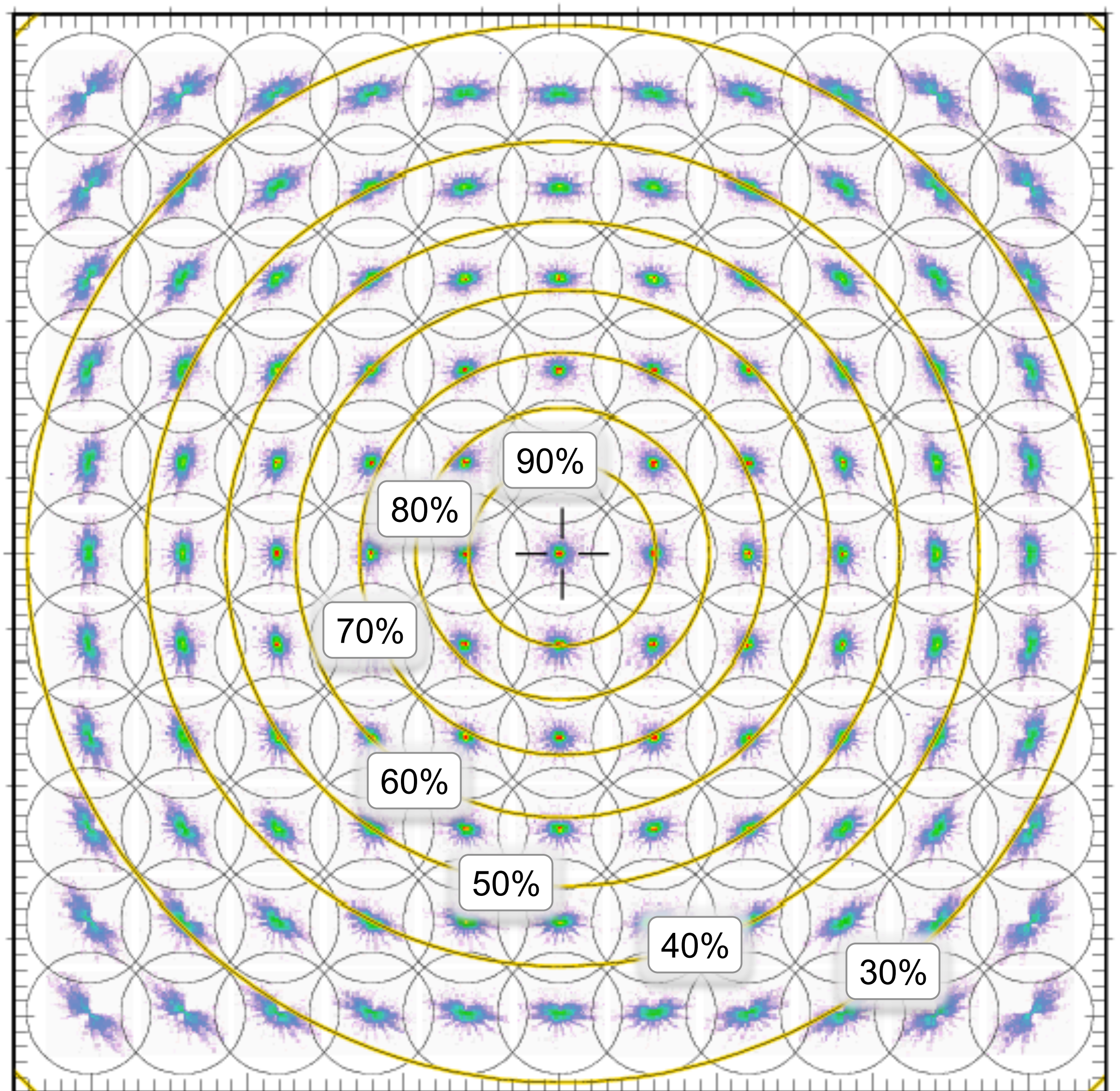
after geometry correction

extraction radius: 4 arcmin

→ vignetting

PSF Focal Plane Mapping

FM2, Al-K

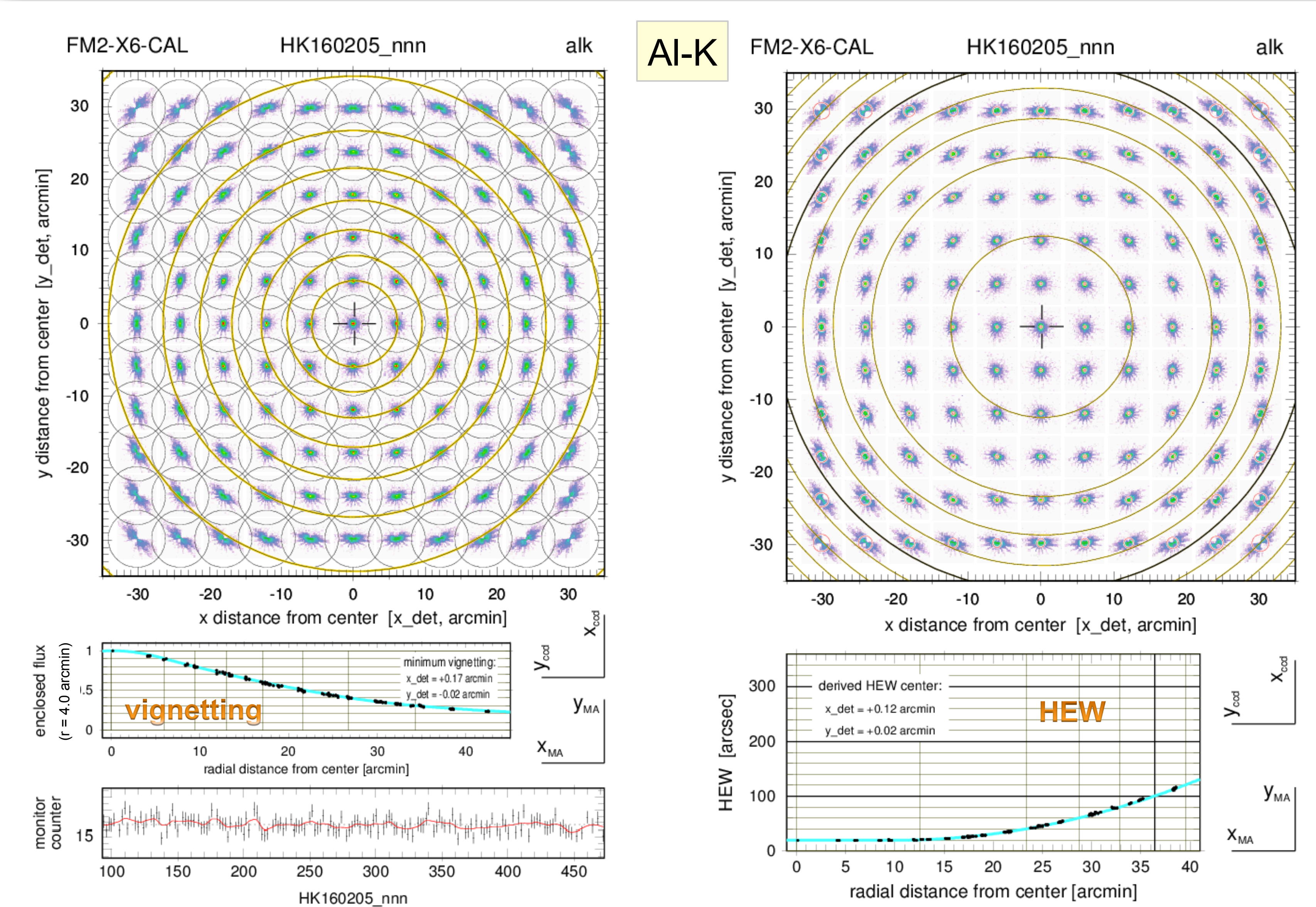


after geometry correction

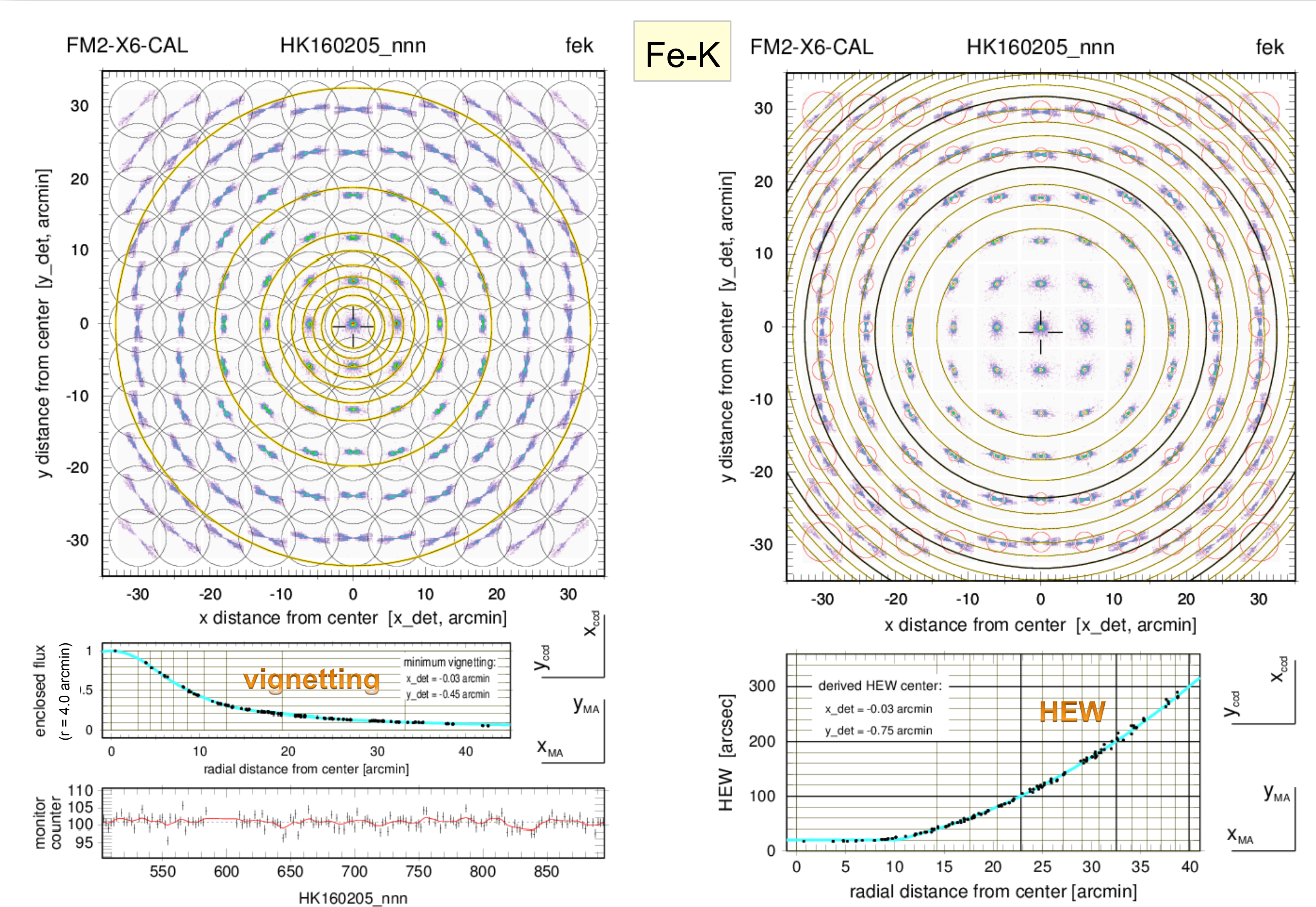
extraction radius: 4 arcmin

→ vignetting

PSF Focal Plane Mapping: Vignetting and HEW



PSF Focal Plane Mapping: Vignetting and HEW

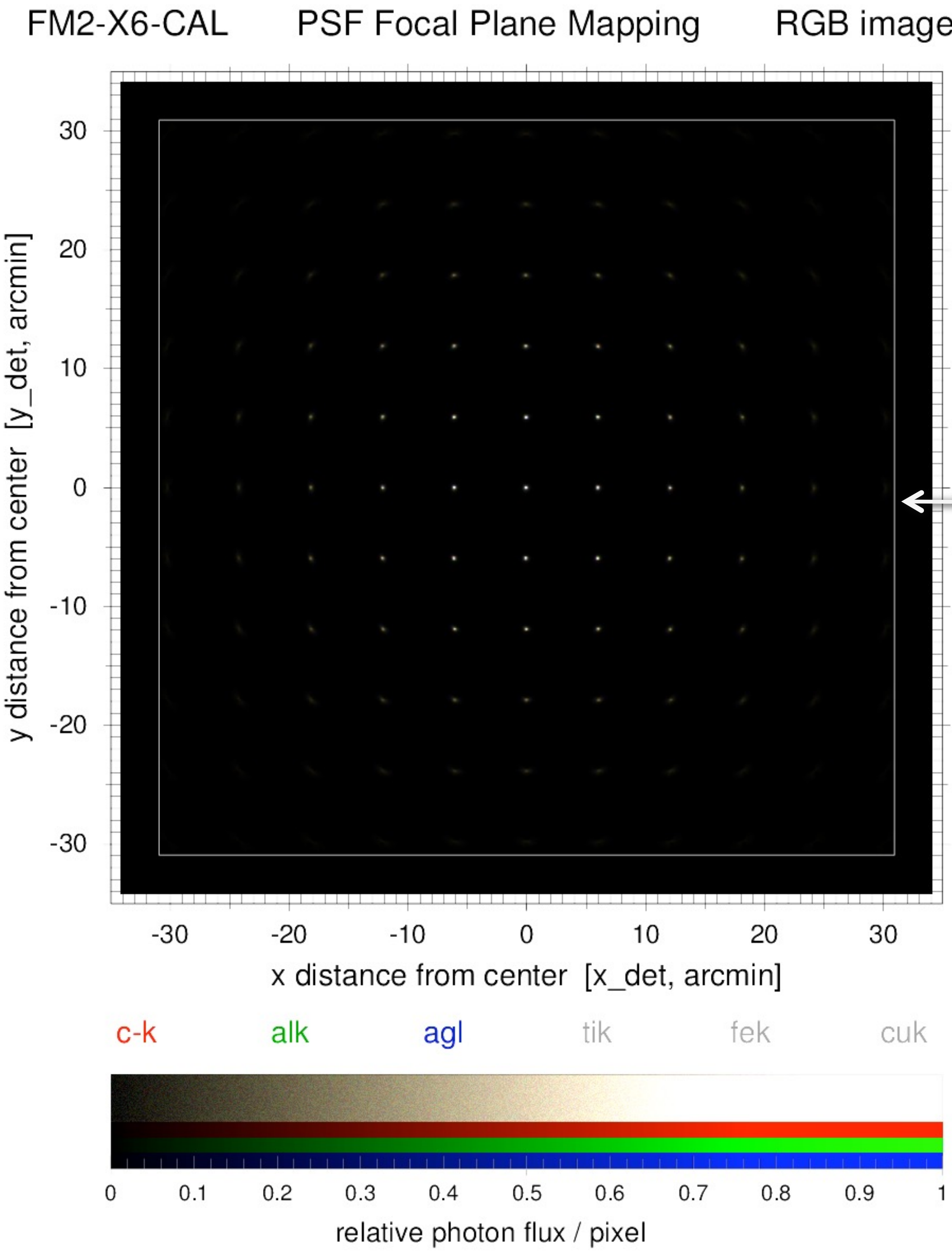


eROSITA Calibration:

mirror

RGB images of PSFs

PSF Focal Plane Mapping: RGB images



eROSITA FoV

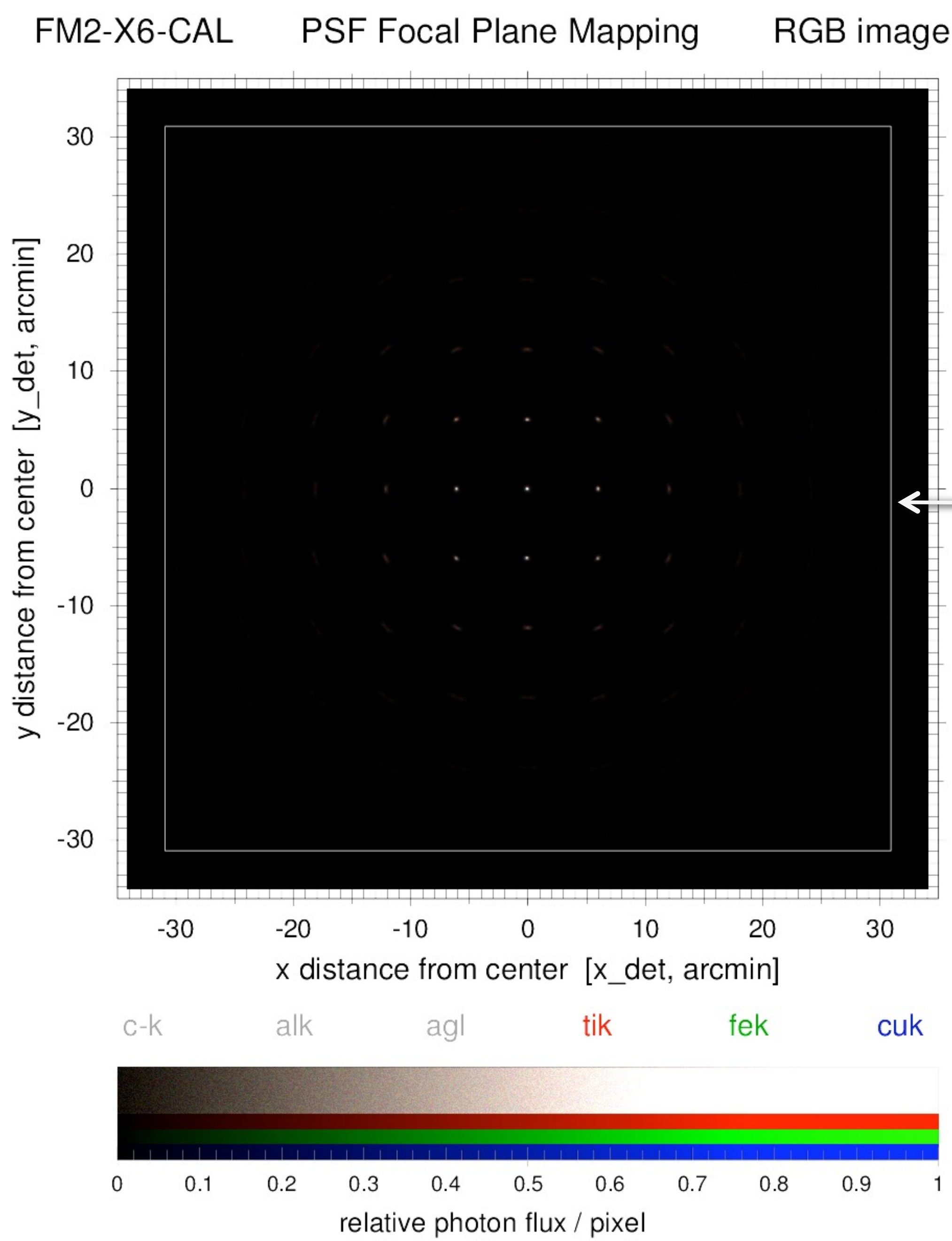
selected RGB energies

121 PSFs from scans 1 – 4, each composed of 3 energies

brightest pixel of all PSFs at each energy normalized to 1.0

linear transfer function, full range: [0.0, 1.0]

PSF Focal Plane Mapping: RGB images



eROSITA FoV

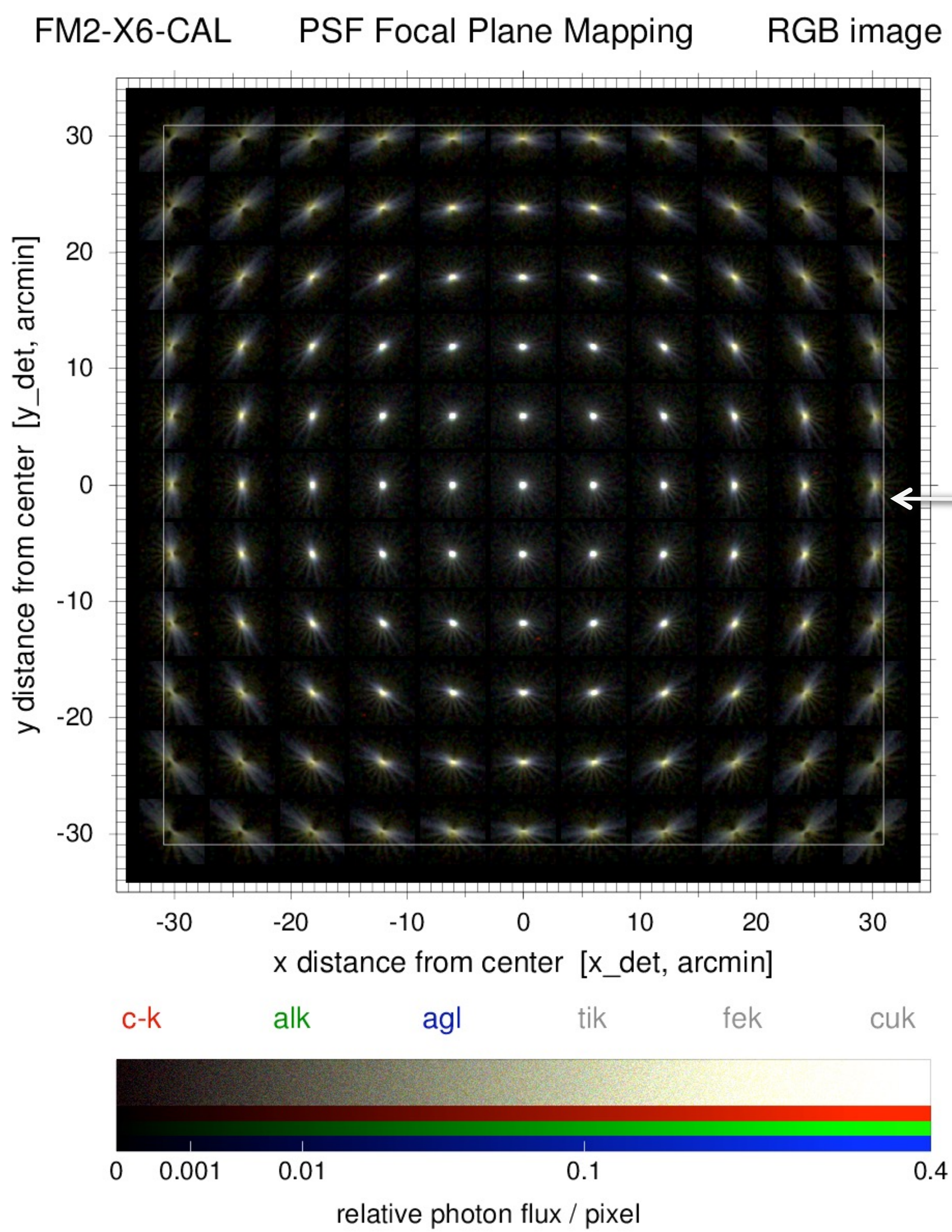
121 PSFs from scans 1 – 4,
each composed of 3 energies

brightest pixel of all PSFs at each energy normalized to 1.0

linear transfer function,
full range: [0.0, 1.0]

selected RGB energies

PSF Focal Plane Mapping: RGB images



eROSITA FoV

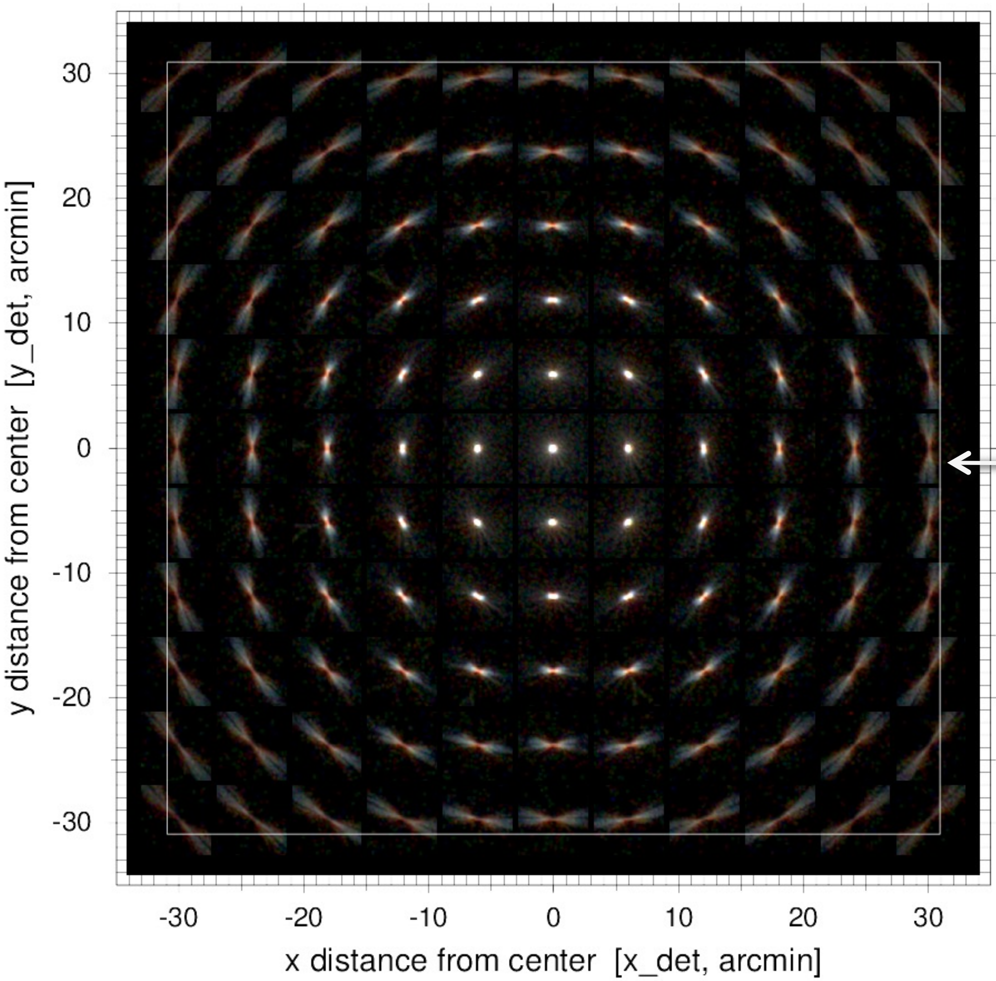
selected RGB energies

121 PSFs from scans 1 – 4, each composed of 3 energies

brightest pixel of all PSFs at each energy normalized to 1.0

transfer function: $f(z) = z^{0.4}$, zoomed to [0.0, 0.4]

FM2-X6-CAL PSF Focal Plane Mapping RGB image



PSF Focal Plane Mapping: RGB images

eROSITA FoV

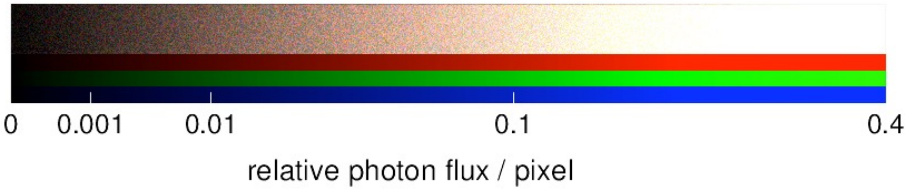
121 PSFs from scans 1 – 4, each composed of 3 energies

brightest pixel of all PSFs at each energy normalized to 1.0

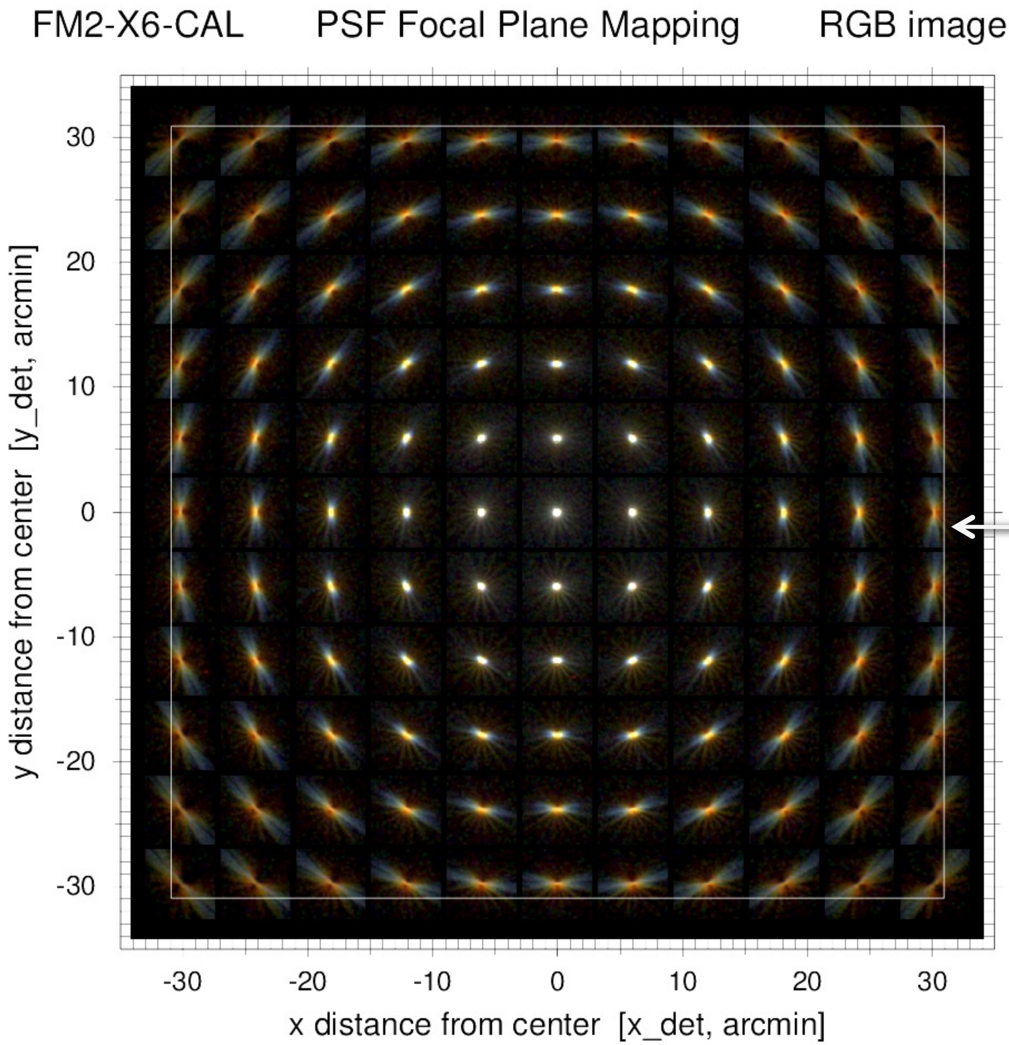
transfer function: $f(z) = z^{0.4}$, zoomed to [0.0, 0.4]

c-k alk agl tik fek cuk

selected RGB energies



PSF Focal Plane Mapping: RGB images

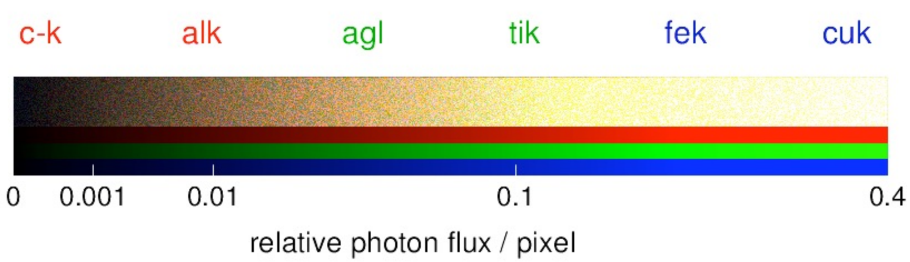


eROSITA FoV

121 PSFs from scans 1 – 4,
each composed of 6 energies

brightest pixel of all PSFs at each energy normalized to 1.0

transfer function: $f(z) = z^{0.4}$,
zoomed to [0.0, 0.4]



selected RGB energies

image contains 6 x 121 = 726 PSFs !

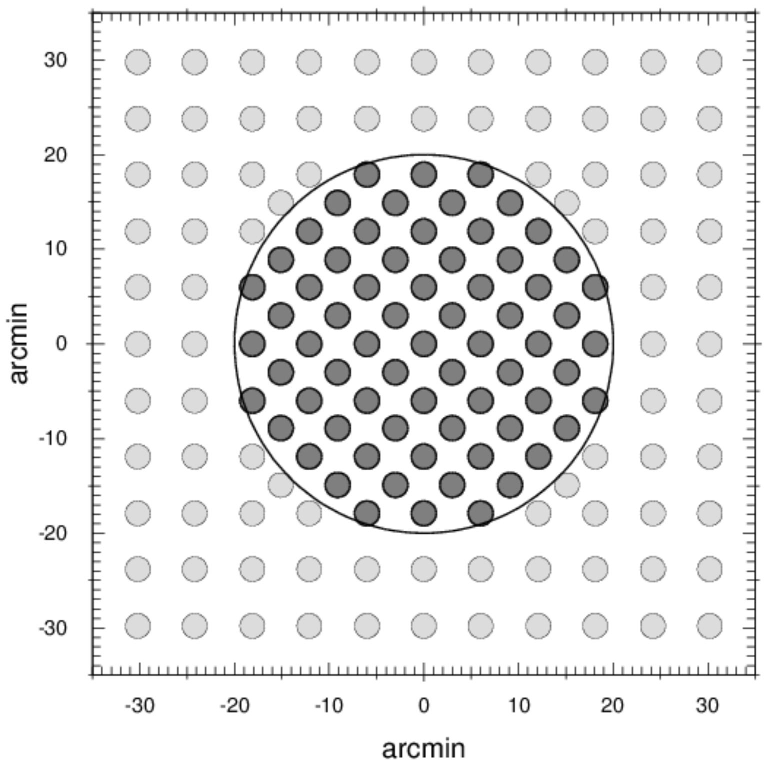
eROSITA Calibration:

mirror

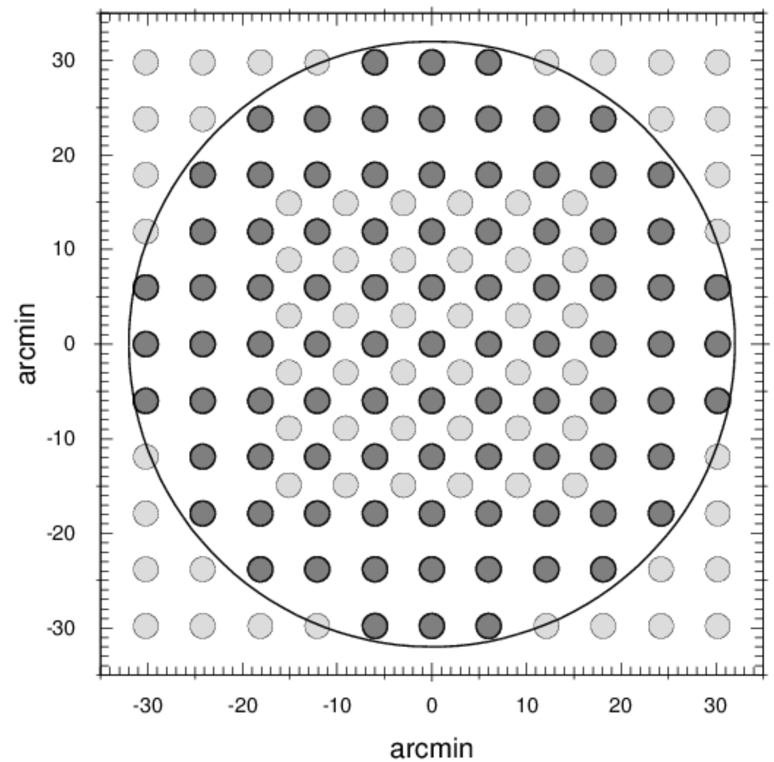
mean PSF during survey

Superposition of PSFs

→ preview of the eROSITA Survey PSF



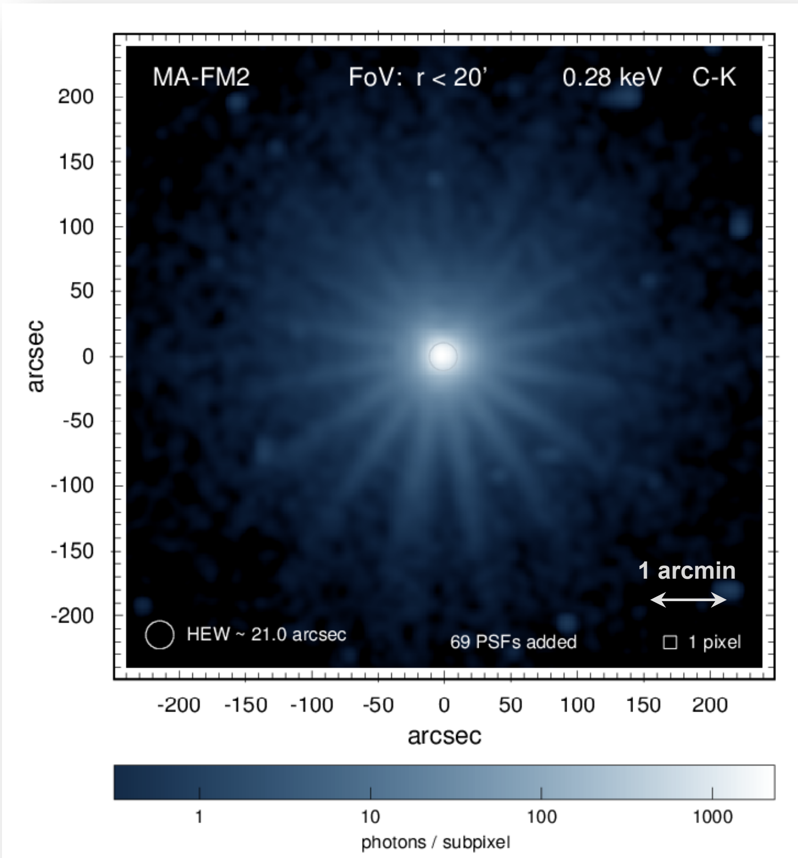
inner FoV (40 arcmin diameter)

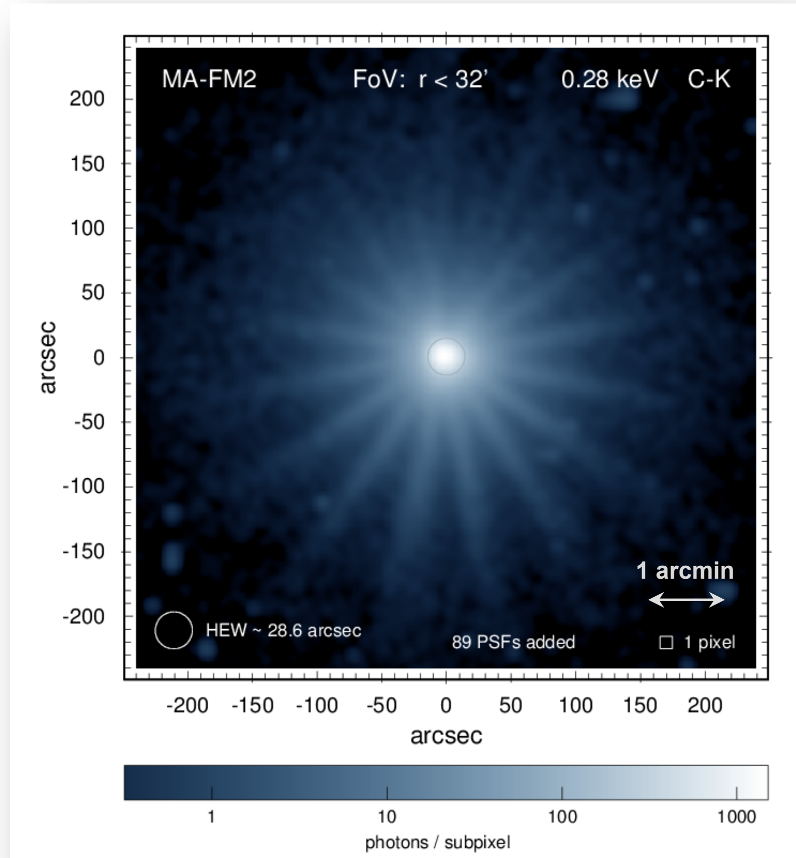


full FoV (60 arcmin diameter)

Preview of the eROSITA Survey PSF

0.28 keV (C-K) 1.49 keV (Al-K) 4.51 keV (Ti-K) 6.40 keV (Fe-K) 8.04 keV (Cu-K)

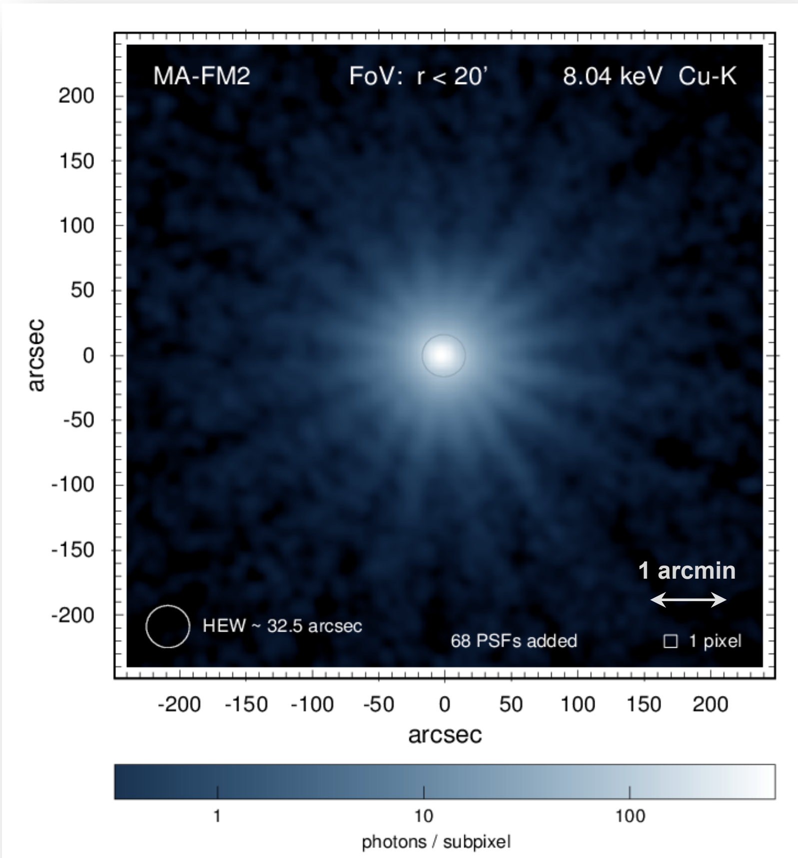




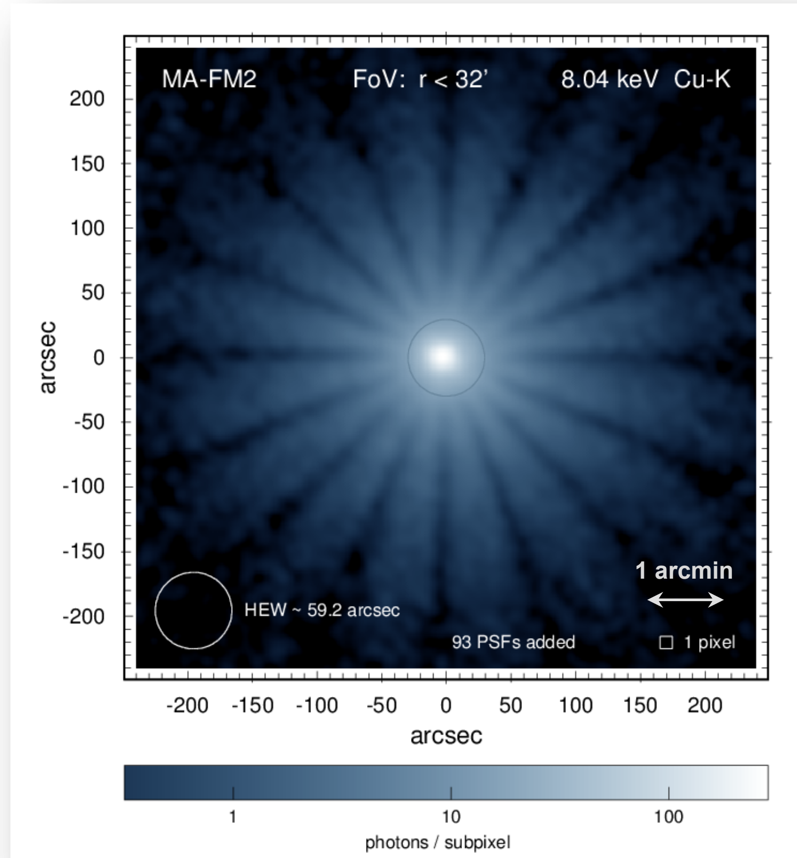
inner FoV (40 arcmin diameter) **full FoV (60 arcmin diameter)**

Preview of the eROSITA Survey PSF

0.28 keV (C-K) 1.49 keV (Al-K) 4.51 keV (Ti-K) 6.40 keV (Fe-K) **8.04 keV (Cu-K)**



inner FoV (40 arcmin diameter)



full FoV (60 arcmin diameter)

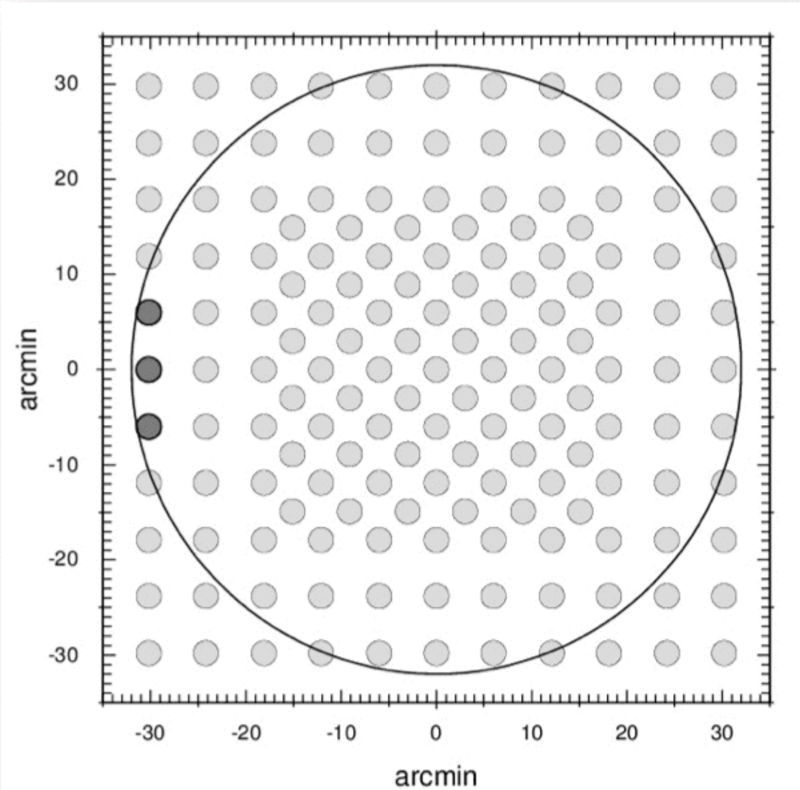
eROSITA Calibration:

mirror

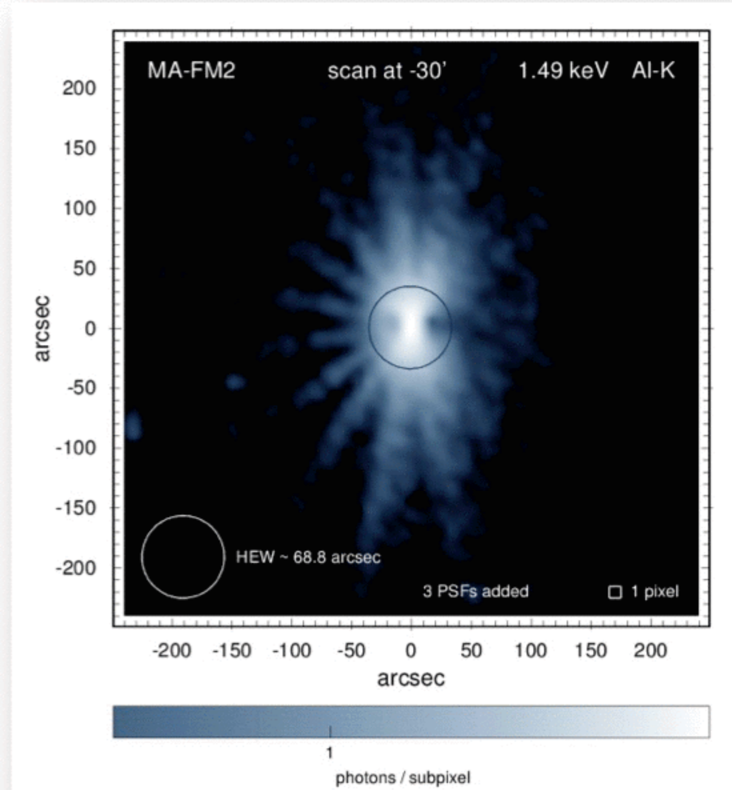
mean PSF during survey scans

Superposition of PSFs

→ preview of the eROSITA Survey PSF



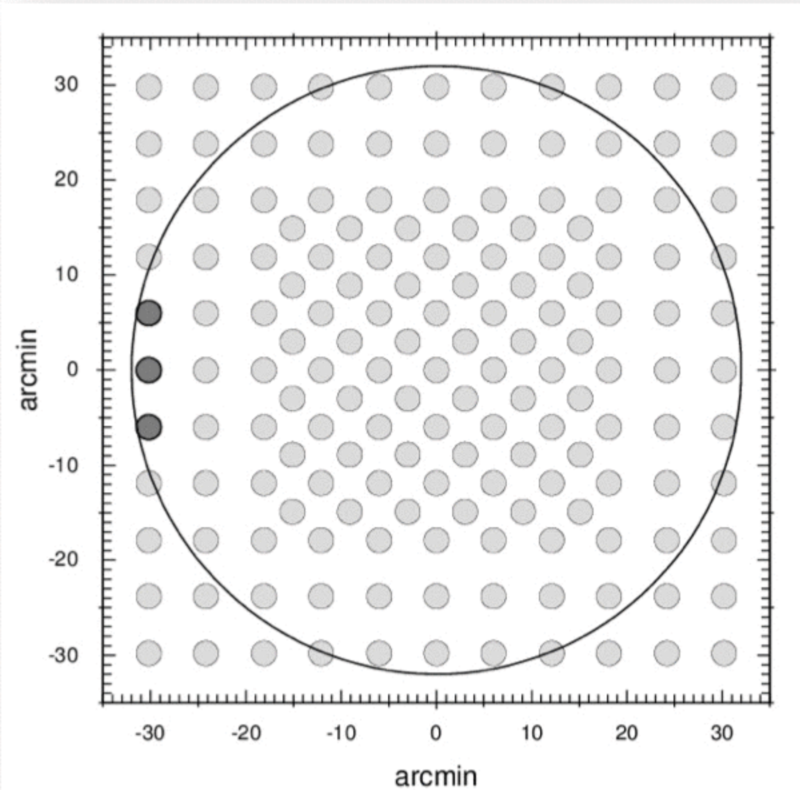
scan at -30 arcmin



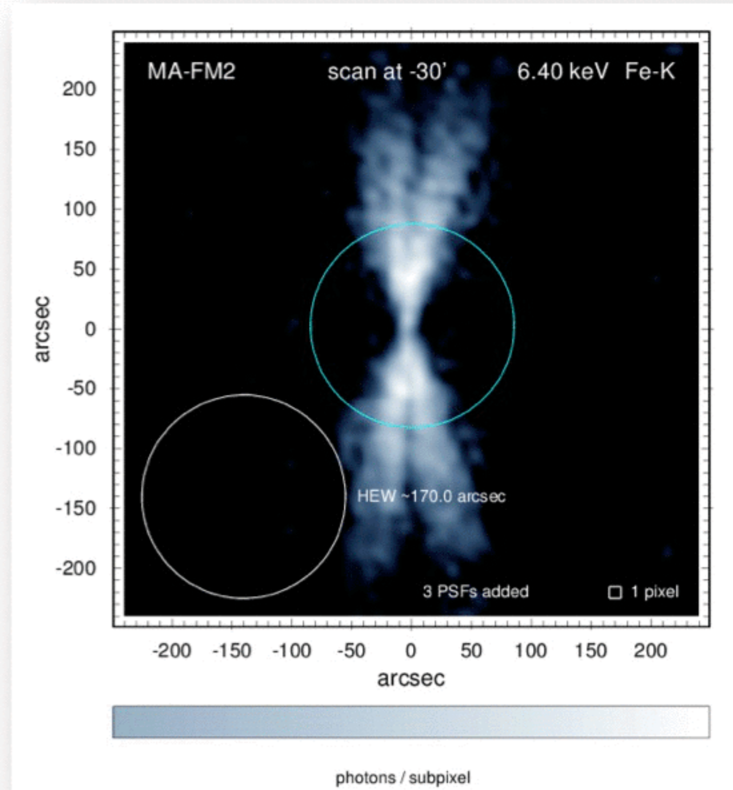
Al-K, 1.49 keV

Superposition of PSFs

→ preview of the eROSITA Survey PSF

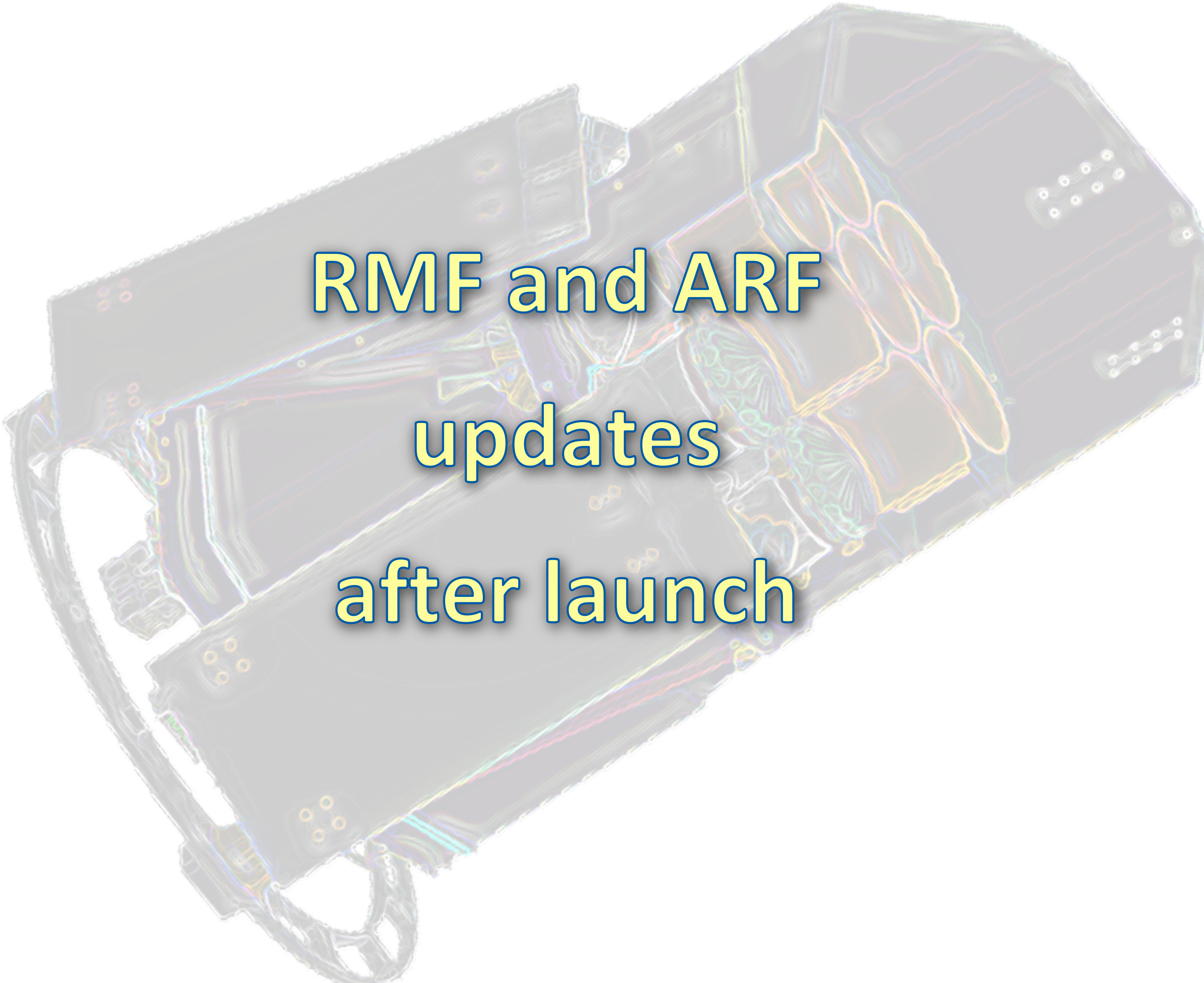


scan at -30 arcmin



Fe-K, 6.40 keV

eROSITA
On-ground Calibration
and beyond..



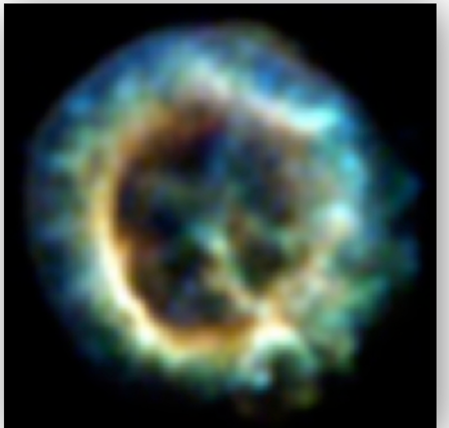
RMF and ARF updates after launch

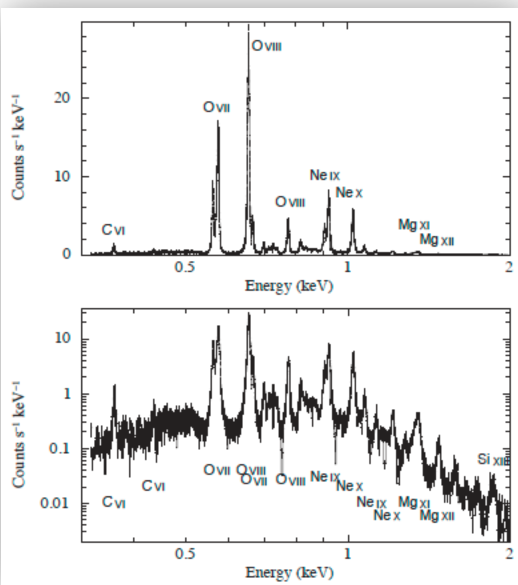
Plucinsky et al., A&A 597, A35 (2017)

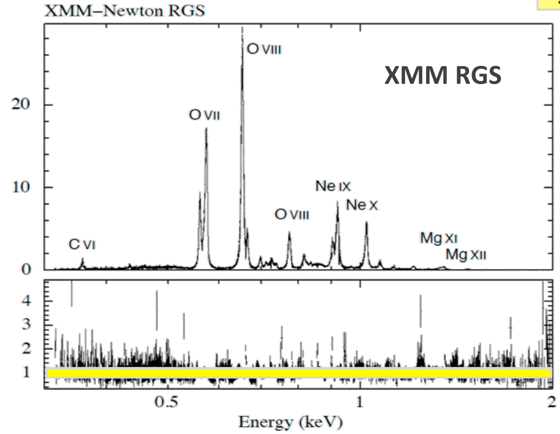
SNR 1E 0102.2-7219 as an X-ray calibration standard in the 0.5–1.0 keV bandpass and its application to the CCD instruments aboard *Chandra*, *Suzaku*, *Swift* and *XMM-Newton*

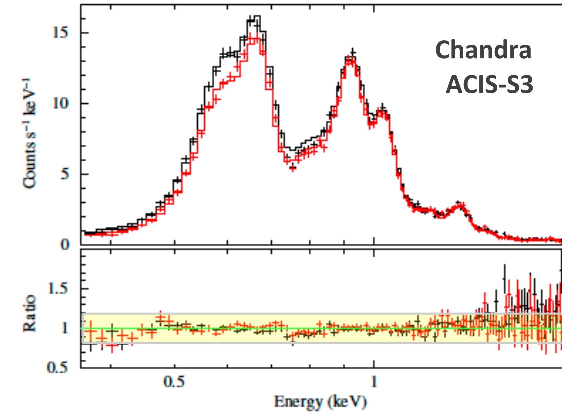
Paul P. Plucinsky[1], Andrew P. Beardmore[2], Adam Foster[1], Frank Haberl[3], Eric D. Miller[4], Andrew M. T. Pollock[5], and Steve Sembay[2]

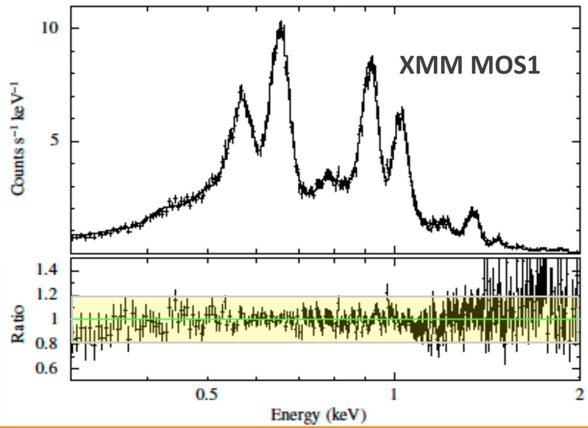
± 20%

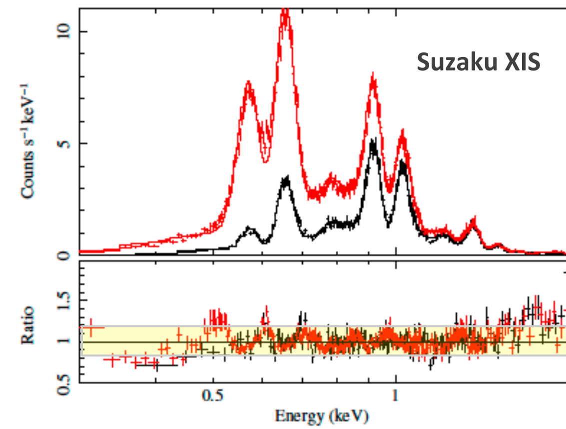


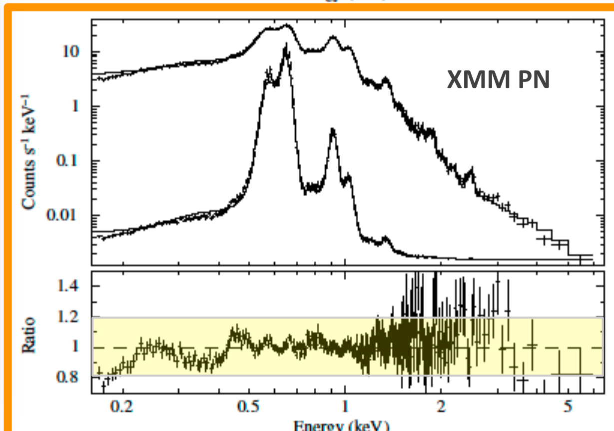


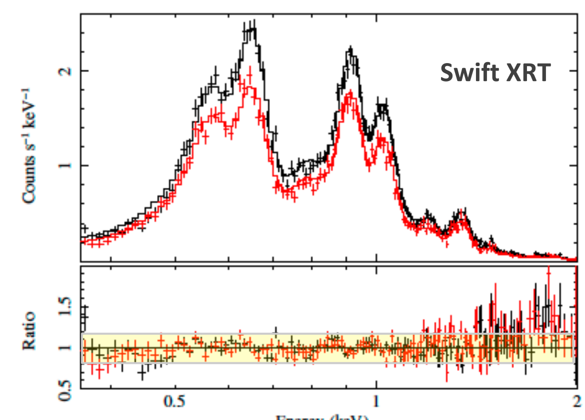








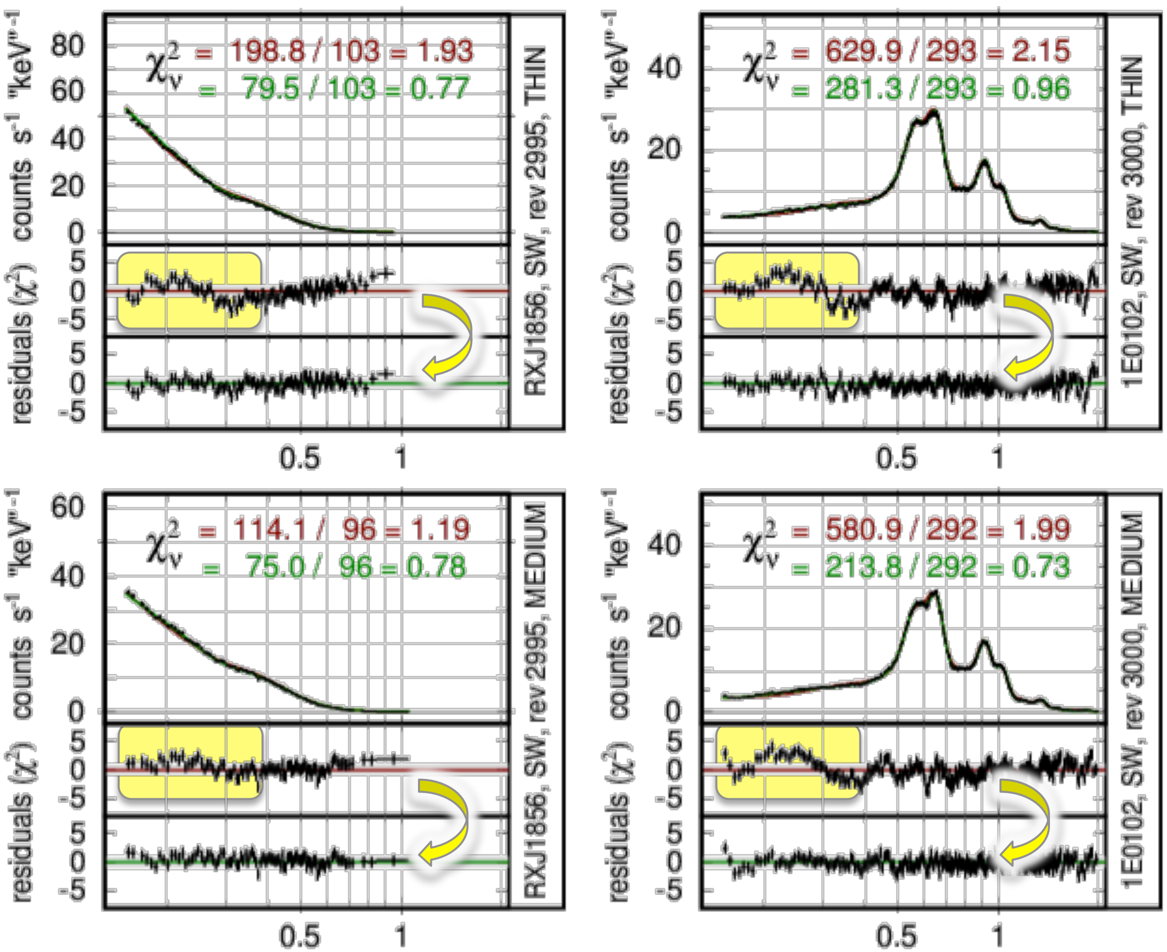




Warning: ARF adjustments alone may be dangerous !

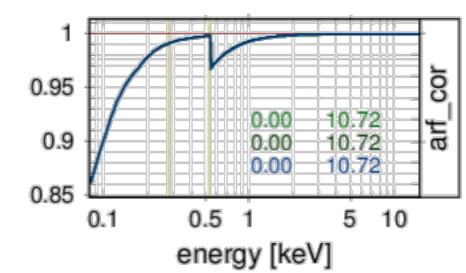
Example: XMM/EPIC-pn, simultaneous fit to RXJ 1856 and 1E0102 in three filters each, using the same model spectrum for each source, with no normalization between the filters

RXJ 1856 1E 0102



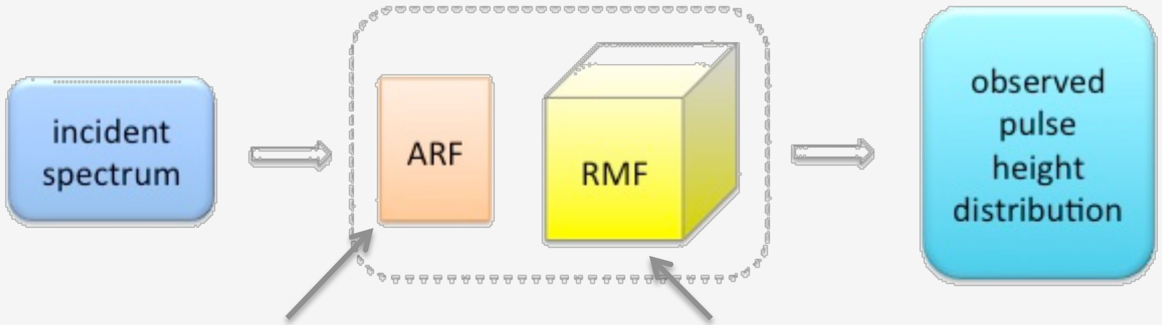
The apparent excess in residuals below 0.4 keV could be „repaired“ by **increasing the ARF** at low energies ..

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



General properties of the ARF and RMF

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



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

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

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

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

Improving the XMM-Newton / EPIC-pn RMF and ARF by „fitting“ them to known astrophysical spectra

Very ambitious project, with the prospect of high impact, if successful

Work started in 2014, motivated by the experience gained in modeling the eROSITA PSF

Synergy between XMM-Newton and eROSITA !

Major milestones already reached:

- ✓ parametrization of an existing RMF
- ✓ proof of concept
- ✓ separation of RMF and ARF effects
- ✓ parallelization
- ✓ temporal evolution

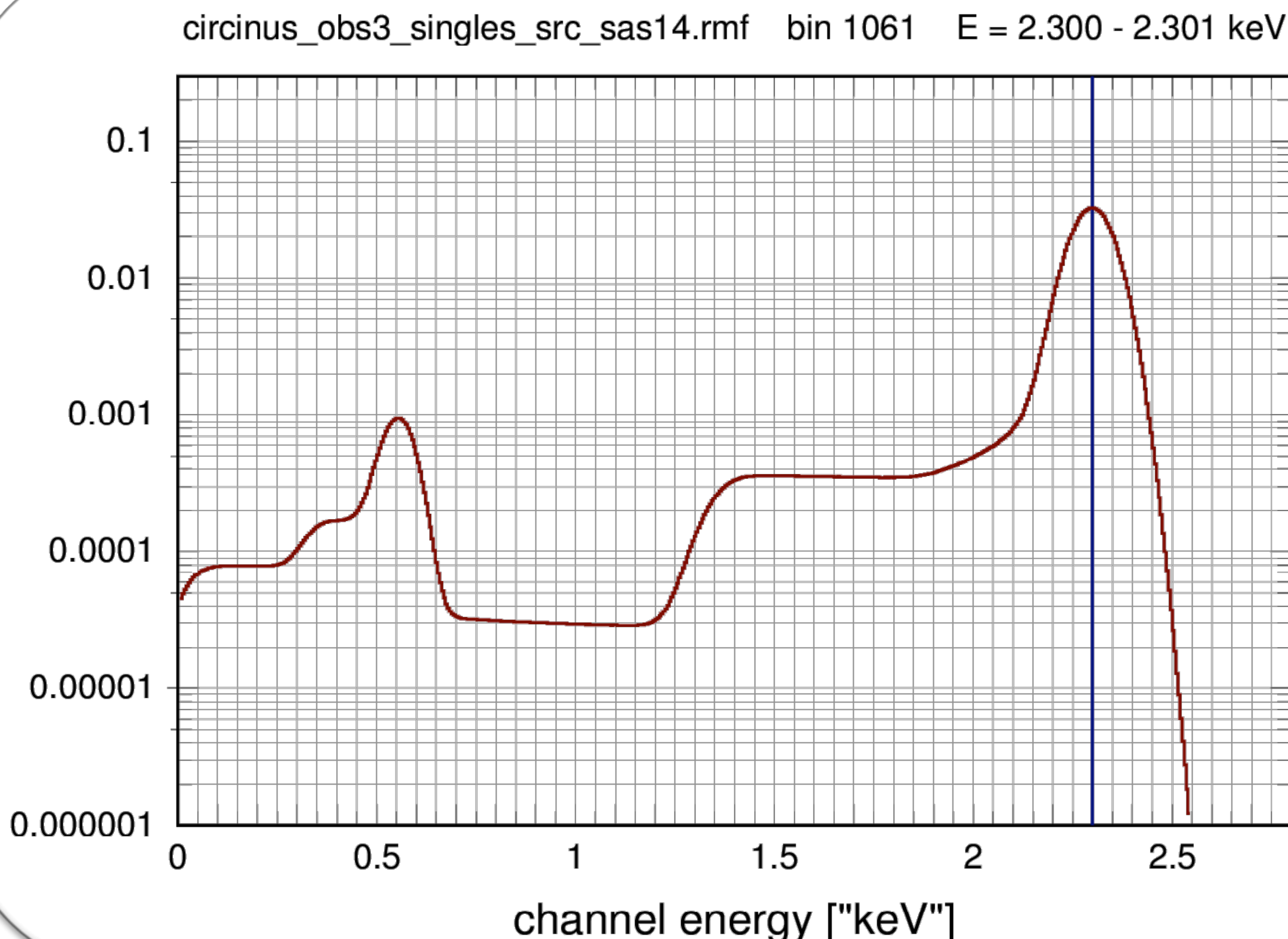
Currently **~14 000** lines of code,

~100 programs/modules/subroutines

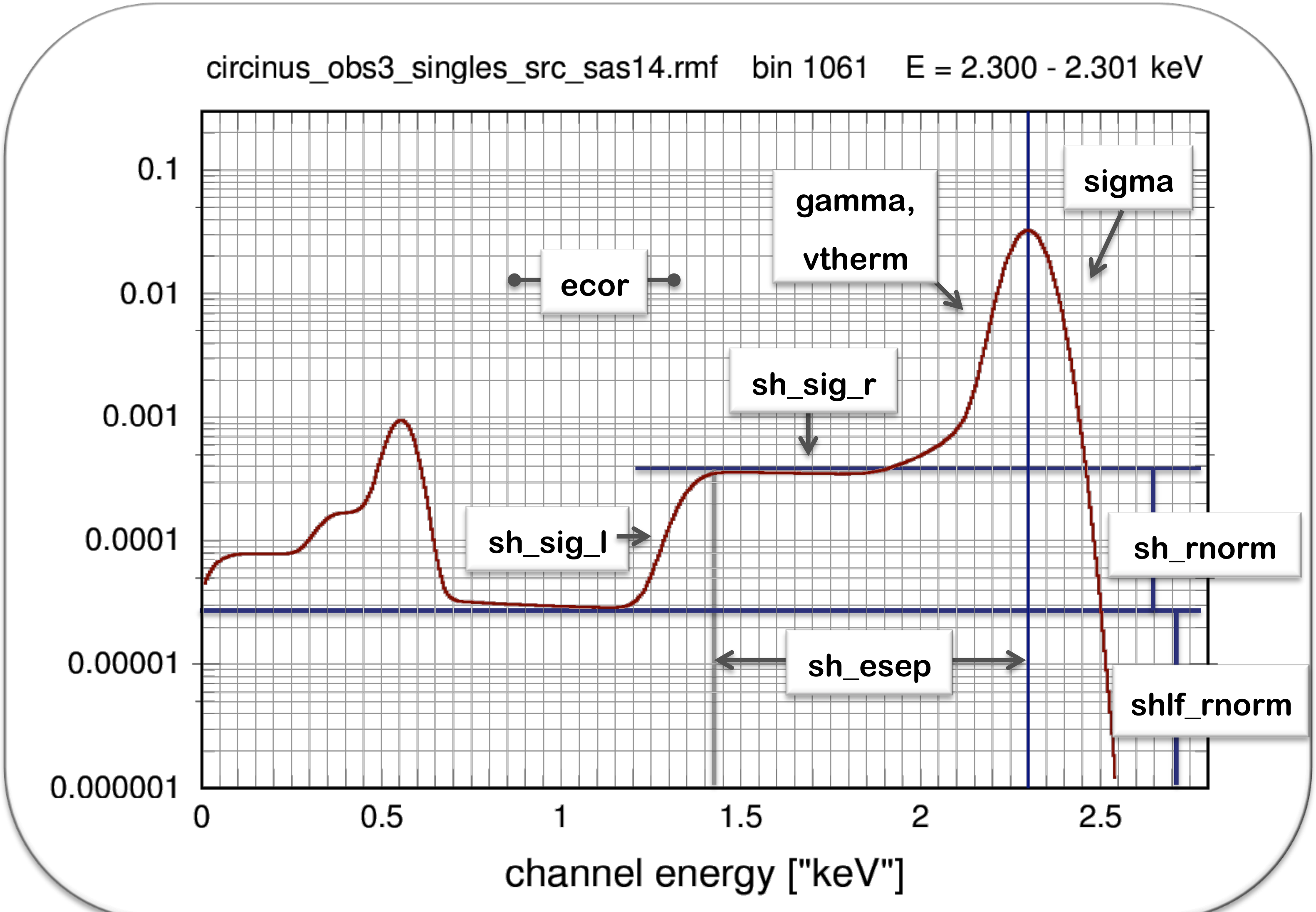
852 RMF + ARF shaping parameters plus many control parameters

various possibilities for monitoring, checks, and documentation

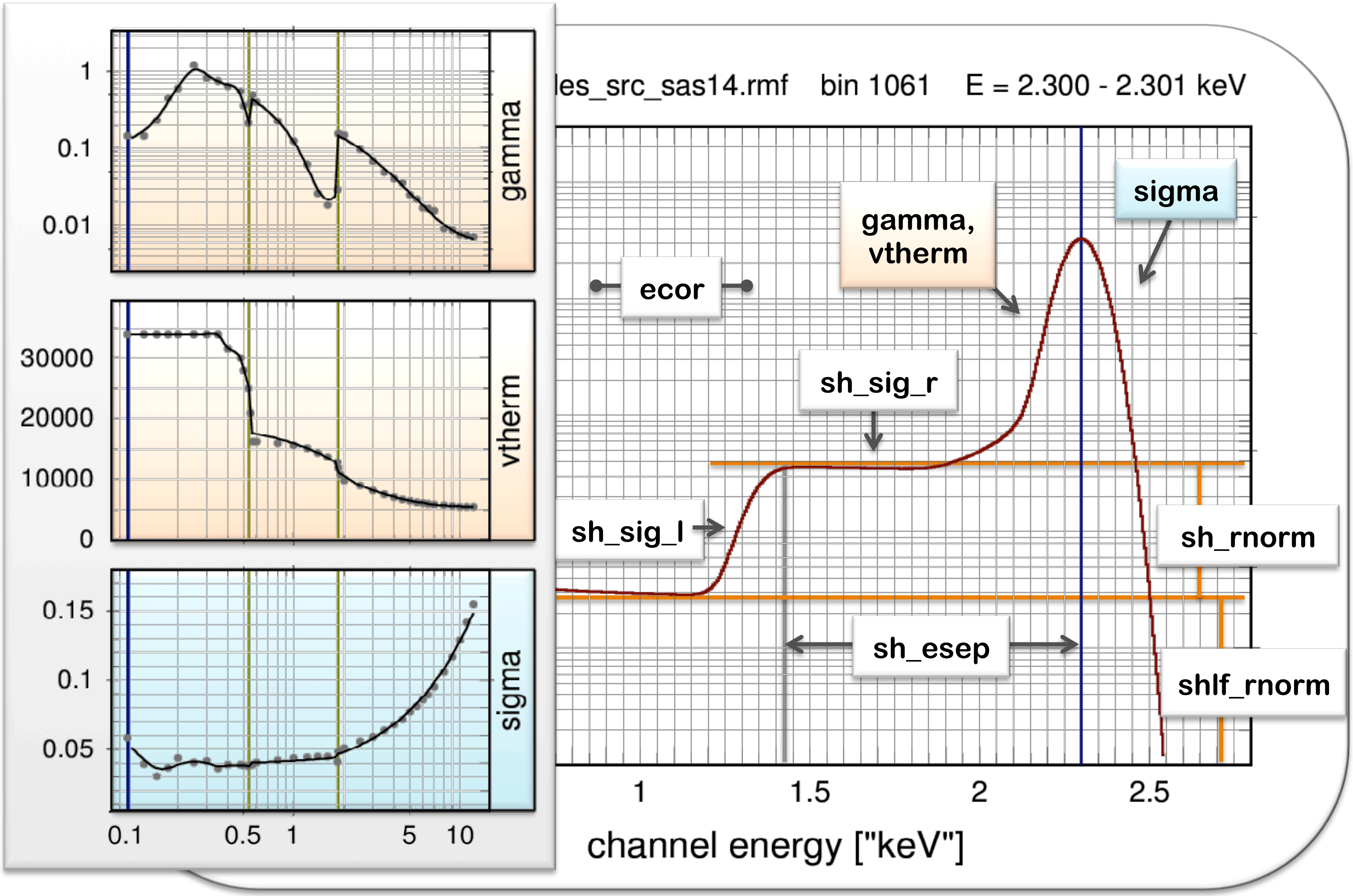
Model Parameters for the EPIC pn RMF



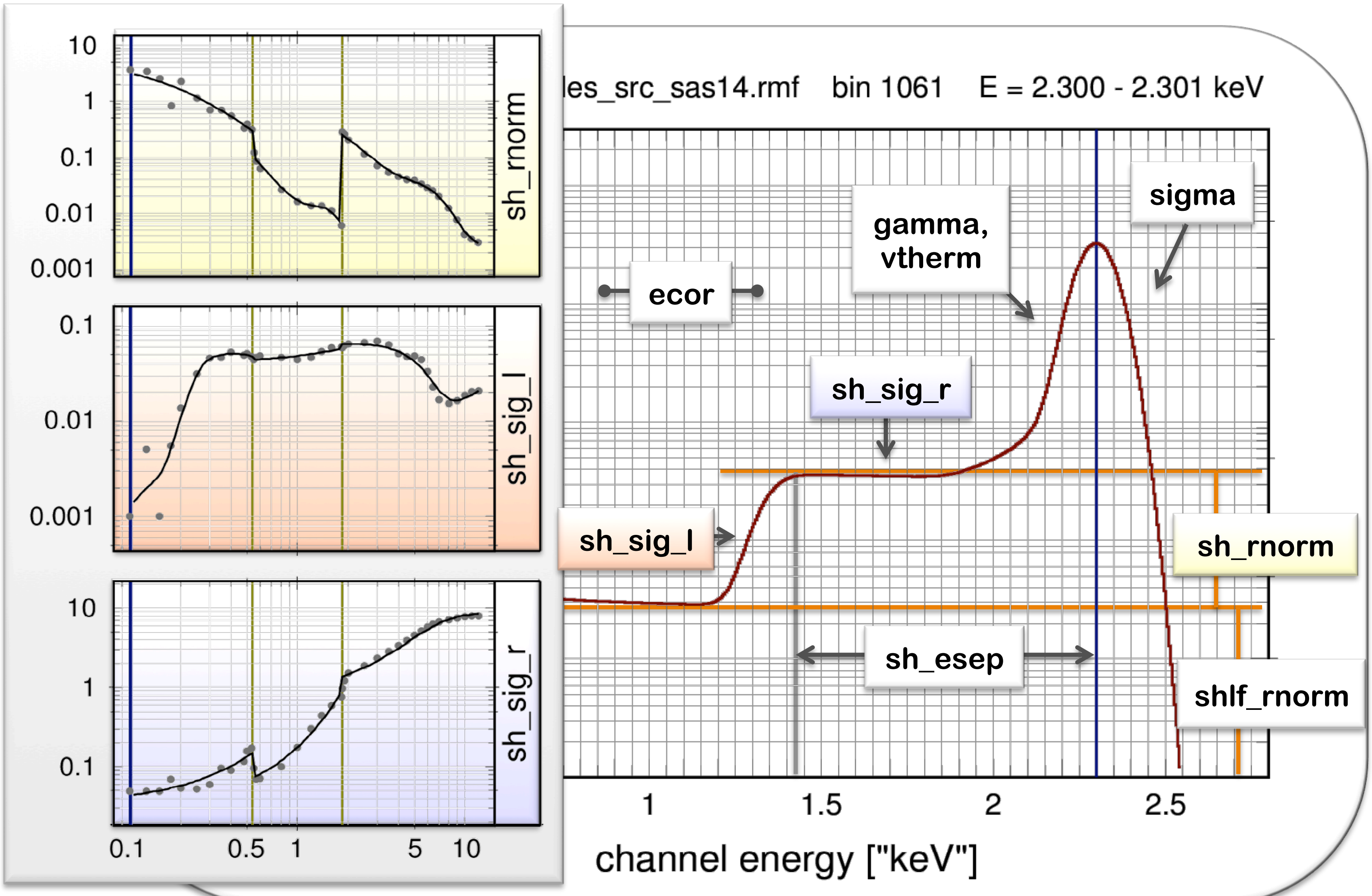
Model Parameters for the EPIC pn RMF



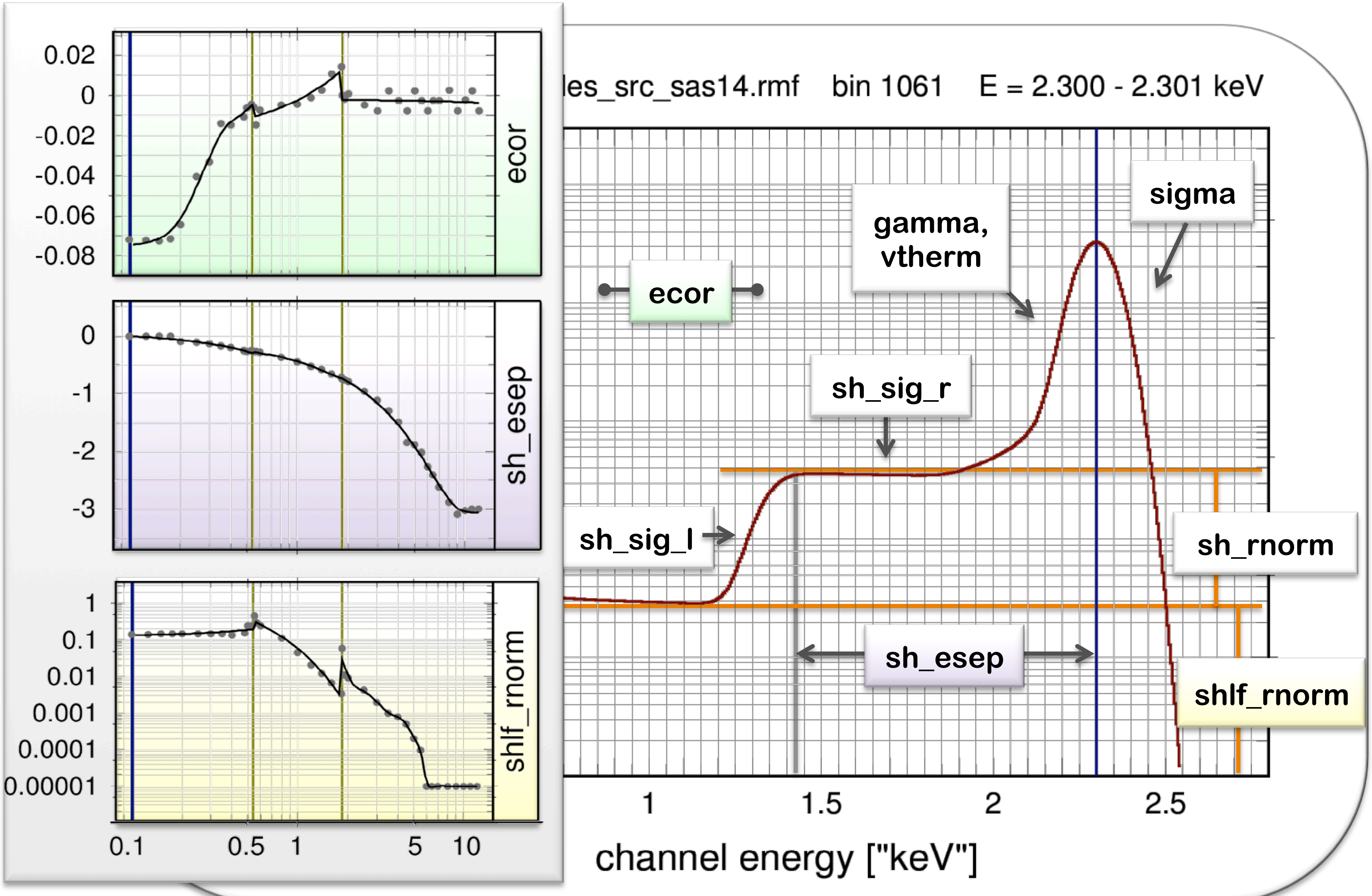
Modeling the EPIC pn RMF at individual energies



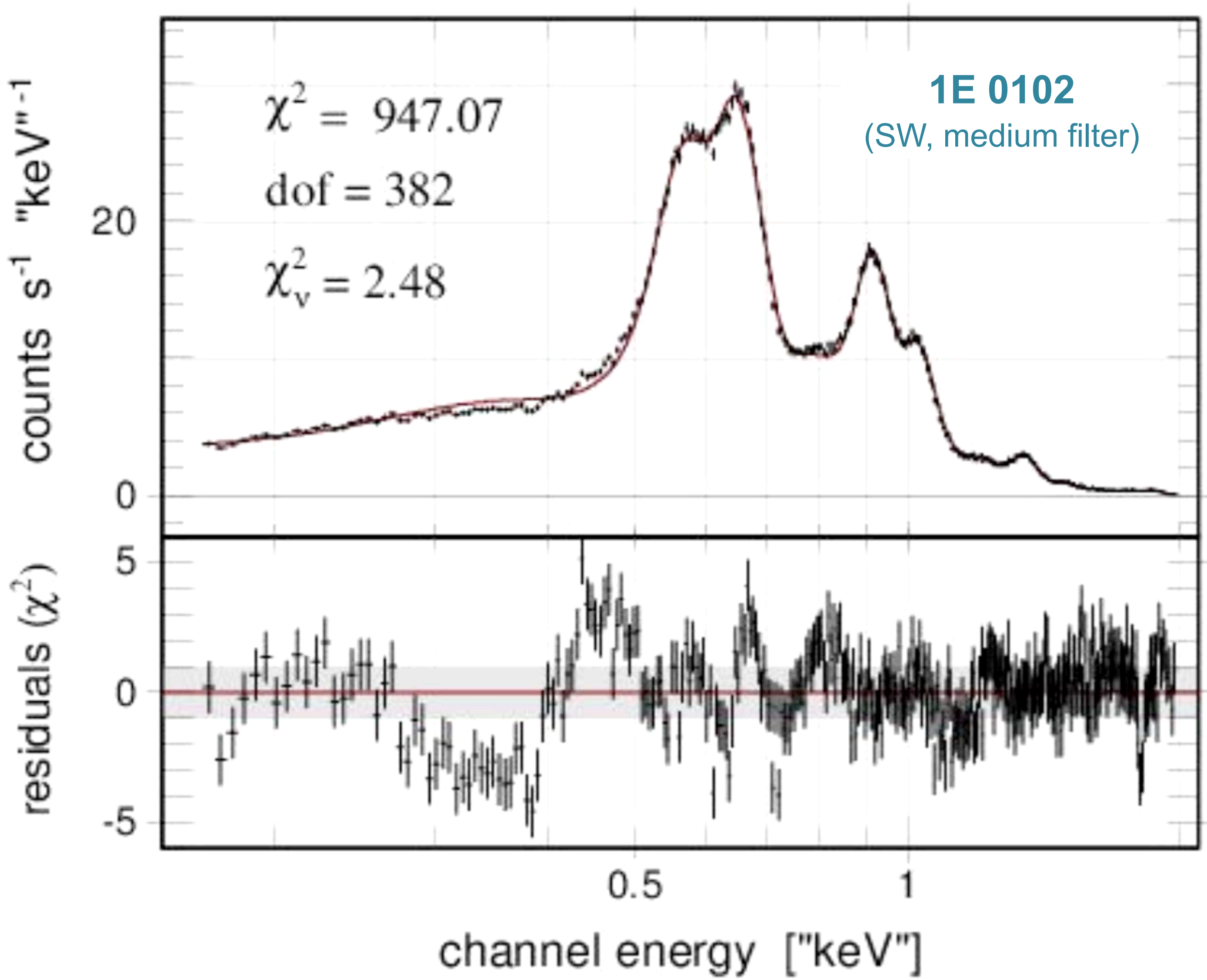
Modeling the EPIC pn RMF at individual energies

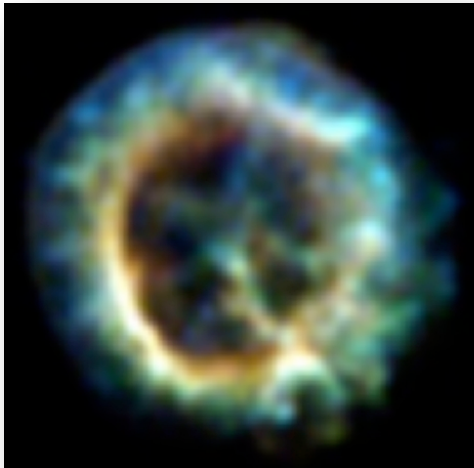


Modeling the EPIC pn RMF at individual energies



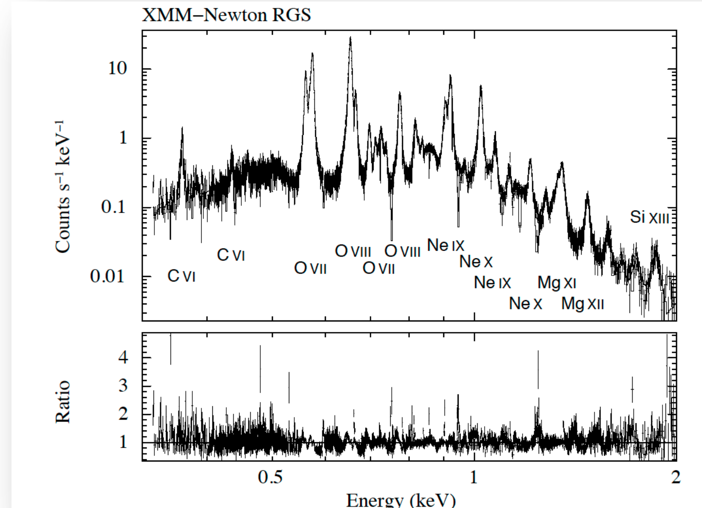
Improving the EPIC pn RMF



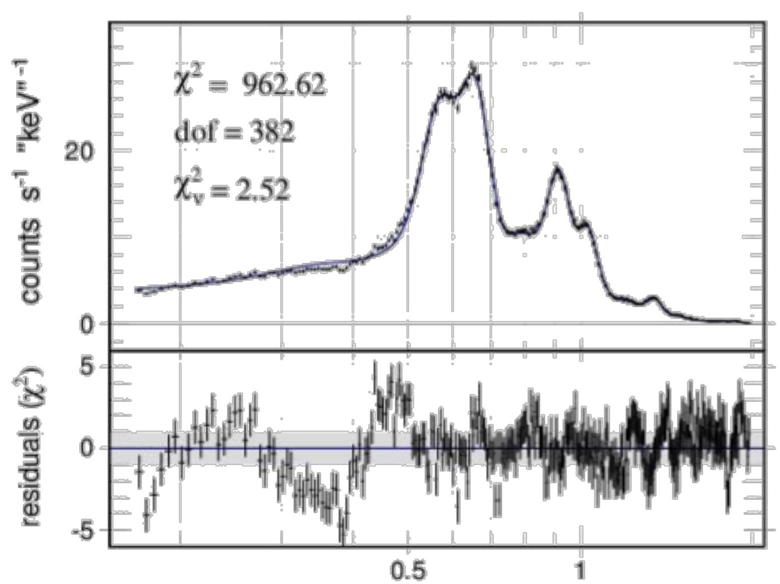


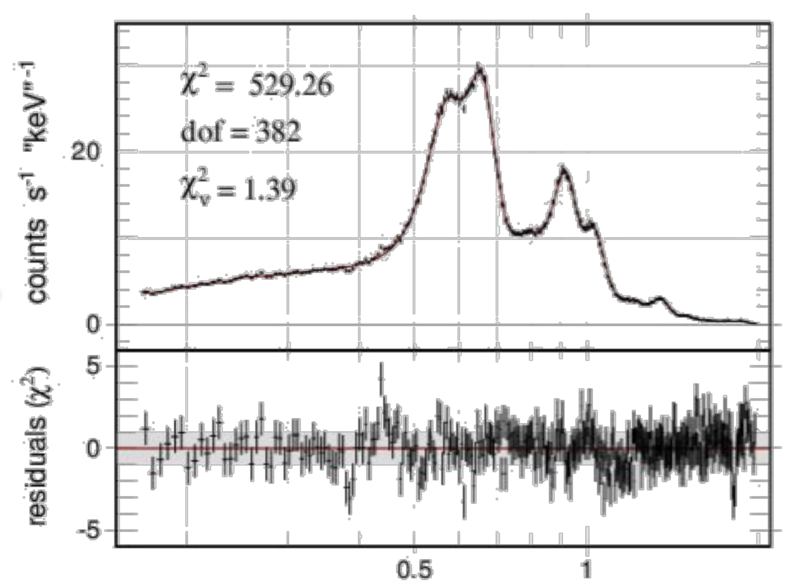
Improving the EPIC pn RMF

SNR 1E 0102



proof of concept





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

p	0.10	0.15	0.21	0.28	0.35	0.44	0.53	0.66	0.80	1.00	1.20	1.50	1.74	2.20	2.70	3.40	4.20	5.10	6.20	8.00	10.00 keV	smoothness		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	value	weight	penalty
ecor	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000
gamma	1.162	1.216	1.211	1.507	1.676	1.510	1.321	1.171	1.138	1.191	1.119	1.060	1.106	1.106	1.106	1.106	1.106	1.106	1.106	1.106	1.106	1.408	0.020	0.028
vtherm	0.658	0.659	0.656	0.672	0.692	0.737	0.826	0.964	1.041	1.107	1.004	0.991	1.014	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.346	0.100	0.035
sigma	0.858	0.859	0.851	0.839	0.850	0.824	0.842	0.866	0.879	0.900	0.949	0.971	0.990	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.039	2.000	0.078
sh_esep	1.113	1.117	1.240	1.217	1.206	1.200	1.195	1.206	1.183	1.159	1.117	1.099	1.079	1.079	1.079	1.079	1.079	1.079	1.079	1.079	1.079	0.106	0.100	0.011
sh_rnorm	0.519	0.536	0.503	0.521	0.516	0.525	0.614	0.678	0.756	0.823	0.884	0.941	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.227	0.200	0.045
sh_sig_l	0.262	0.265	0.533	0.584	0.630	0.624	0.467	0.610	0.505	0.887	0.847	0.898	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	2.133	0.010	0.021
sh_sig_r	1.333	1.214	1.115	1.197	1.150	1.266	0.914	0.856	0.667	0.821	0.925	1.076	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	2.015	0.010	0.020
shlf_rnorm	0.211	0.219	0.355	0.658	0.496	0.693	0.662	0.344	0.826	1.605	0.915	0.624	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	14.069	0.005	0.070
shlf_slope	-0.082	-0.082	-0.082	-0.082	-0.082	-0.082	[illegible]	[illegible]	[illegible]	[illegible]	-0.082	-0.082	-0.082	-0.082	-0.082	-0.082	-0.082	-0.082	-0.082	-0.082	-0.082	0.000	0.100	0.000
esc_rnorm	1.000	1.000	1.000	1.000	1.000	1.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000
egamma	1.000	1.000	1.000	1.000	1.000	1.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000
evtherm	1.000	1.000	1.000	1.000	1.000	1.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000
esigma	1.200	1.200	1.200	1.200	1.200	1.200	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.200	1.200	1.200	1.200	1.200	0.000	0.000	0.000
esh_esep	1.000	1.000	1.000	1.000	1.000	1.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000
esh_rnorm	1.000	1.000	1.000	1.000	1.000	1.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000
esh_sig_l	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000
esh_sig_r	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	[illegible]	[illegible]	[illegible]	[illegible]	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000
eshlf_rnrm	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.000	0.000
pat_frc	1.010	1.010	1.000	1.002	1.007	1.001	0.995	0.990	0.989	0.972	0.988	1.019	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.018	0.100	0.002

840 parameters with their state (free/fixed/tied/coupled) marked and their derived importance for the RMF and ARF indicated

t	0.10	0.15	0.21	0.28	0.35	0.44	0.53	0.66	0.80	1.00	1.20	1.50	1.74	2.20	2.70	3.40	4.20	5.10	6.20	8.00	10.00 keV	smoothness		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	value	weight	penalty
ecor	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
gamma	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.000	1.000	0.000
vtherm	0.026	0.026	0.026	0.028	0.028	0.028	0.028	0.028	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.000	1.000	0.000
sigma	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.000	1.000	0.000
sh_esep	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	-0.015	0.000	1.000	0.000
sh_rnorm	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	-0.022	0.000	1.000	0.000
sh_sig_l	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.000	1.000	0.000
sh_sig_r	-0.070	-0.070	-0.070	-0.070	-0.096	-0.096	-0.096	-0.096	-0.096	-0.096	-0.096	-0.096	-0.096	-0.096	-0.096	-0.096	-0.096	-0.096	-0.096	-0.096	-0.096	0.005	1.000	0.005
shlf_rnorm	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	0.000	1.000	0.000
shlf_slope	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.340	0.000	1.000	0.000
esc_rnorm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
egamma	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
evtherm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
esigma	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
esh_esep	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
esh_rnorm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
esh_sig_l	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
esh_sig_r	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
eshlf_rnrm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000	1.000	0.000
pat_frc	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.39E-3	0.000	0.000	0.000
																						total penalty:		0.316

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

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

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

→ 27 ARF parameters

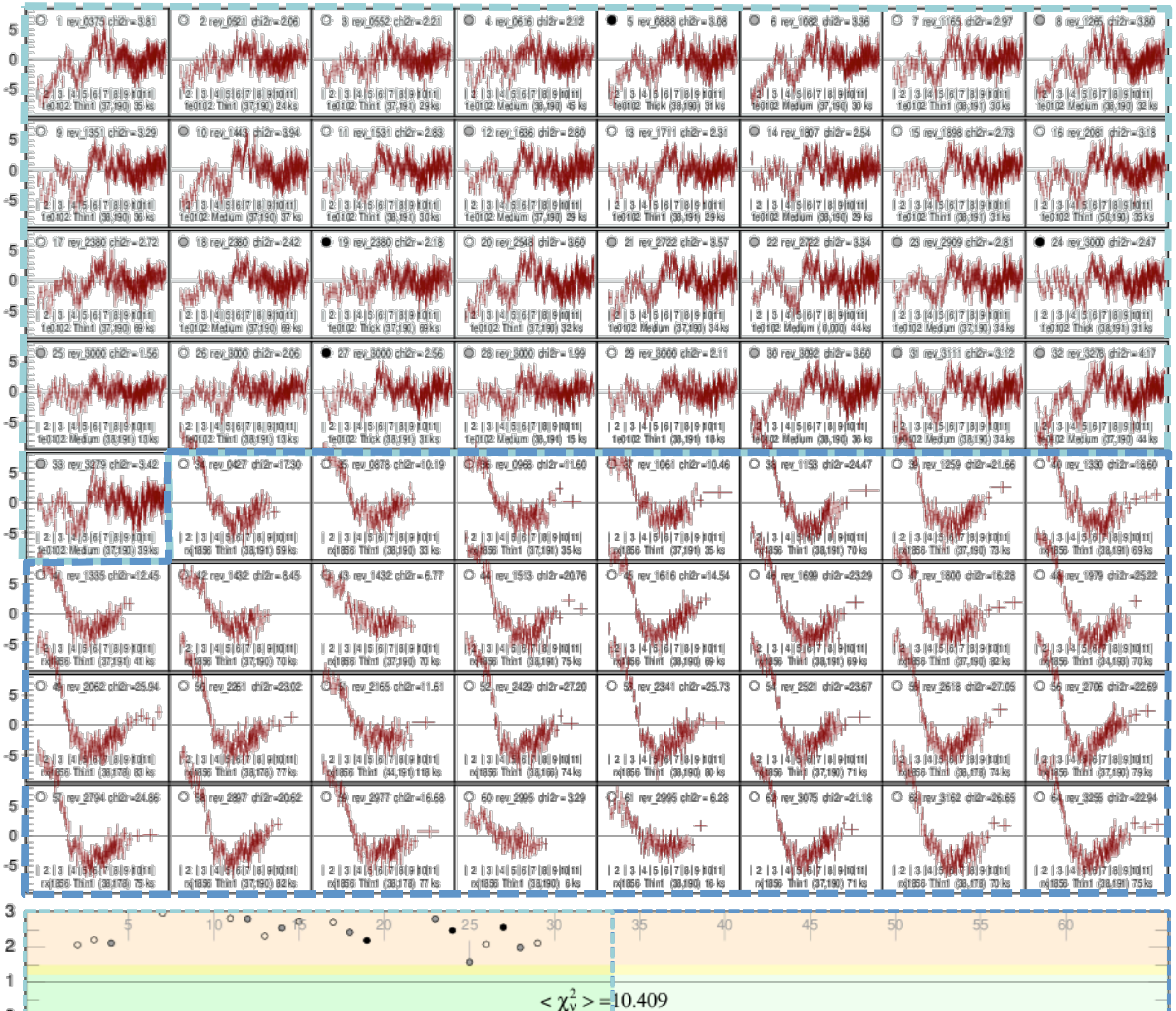
➔ 426 parameters

temporal dependence of each parameter

➔ **852 parameters**

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

Application to 64 XMM / EPIC pn spectra of 1E0102 (SNR) and RXJ1856 (isolated neutron star) taken from 2001 to 2017 in SW mode: residuals obtained with RMF and ARF from XMMSAS



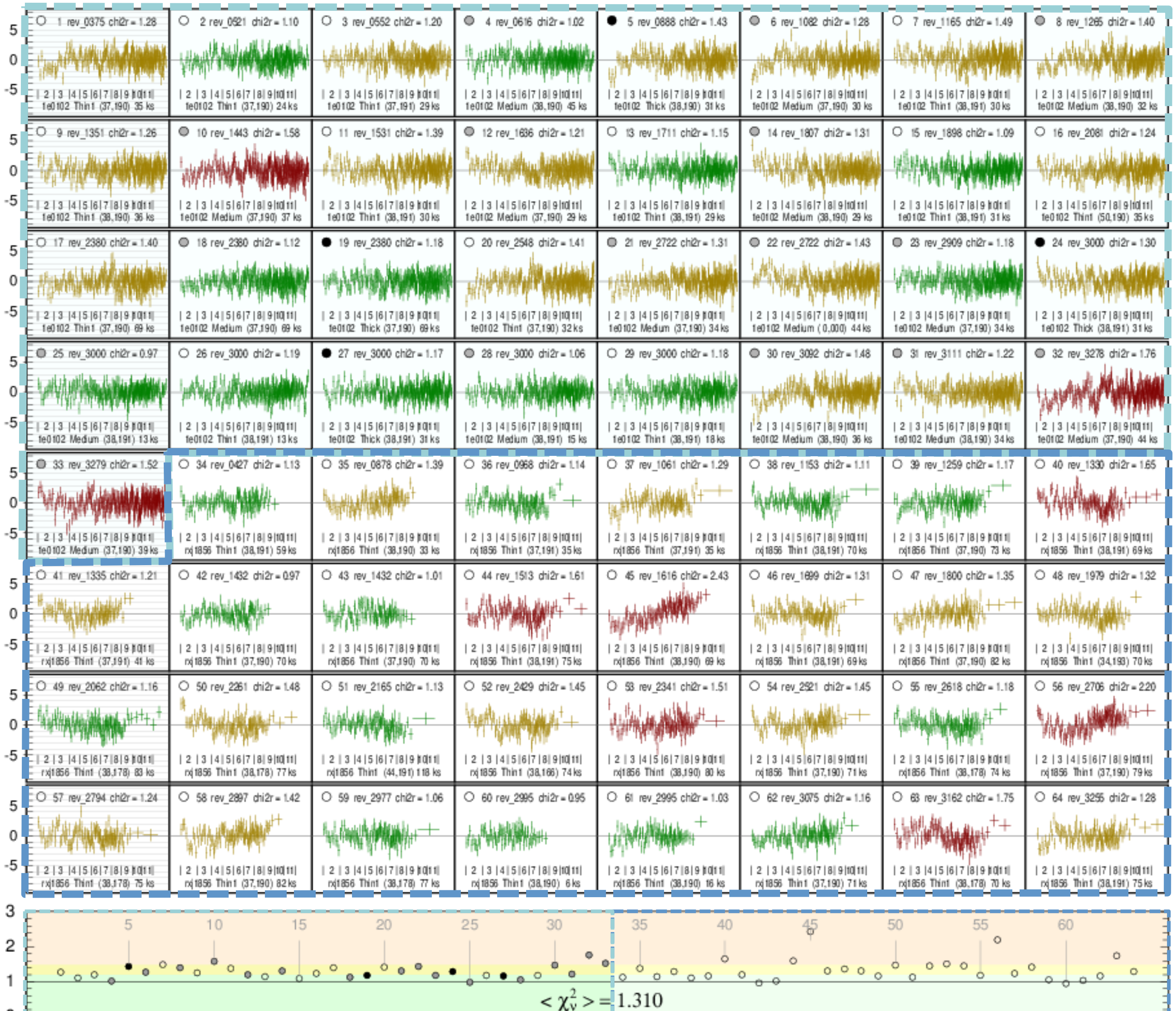
Spectral models used:

1E0102:
„IACHEC model“
with only 1 free parameter:
the global normalization
+ gain fit (offset)

RXJ1856:
TBabs * bbodyrad
with all parameters from Chandra
fixed (no free parameter!)
nH == 7.25 e-19 cm-2
kT == 62.4 eV
norm == 1.58 e5
+ gain fit (offset)

average reduced χ^2 = 10.4

Application to 64 XMM / EPIC pn spectra of 1E0102 (SNR) and RXJ1856 (isolated neutron star) taken from 2001 to 2017 in SW mode: residuals obtained with current parametrizations



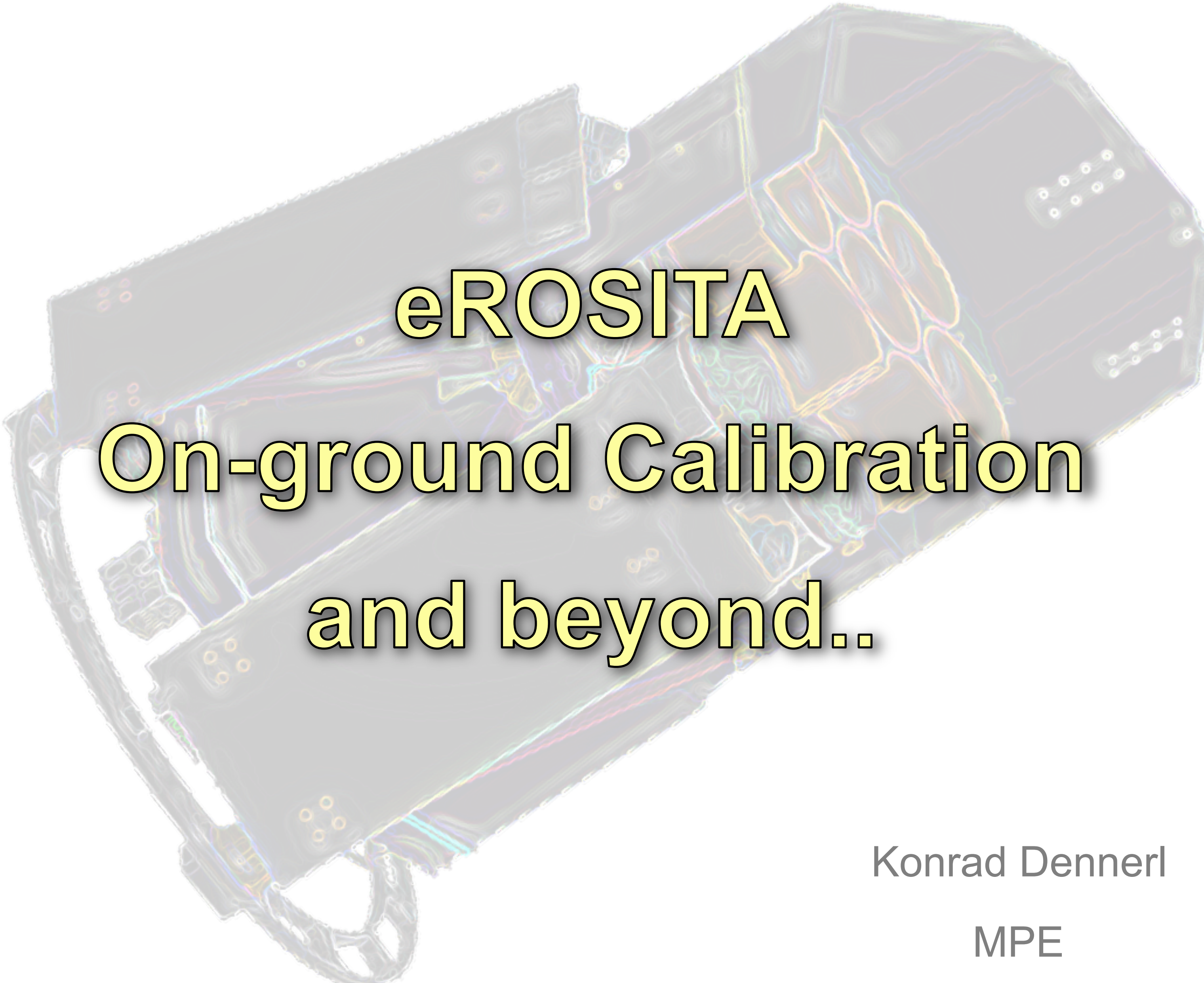
Spectral models used:

1E0102:
„IACHEC model“
with only 1 free parameter:
the global normalization
+ gain fit (offset)

RXJ1856:
TBabs * bbodyrad
with all parameters from Chandra
fixed (no free parameter!)
nH == 7.25 e-19 cm-2
kT == 62.4 eV
norm == 1.58 e5
+ gain fit (offset)

average reduced χ^2 = 1.31

eROSITA
On-ground Calibration
and beyond..



Konrad Dennerl

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