

AHEAD 2020

eROSITA - Science and Data Analysis School

2024 November 18 - 22, MPE

eROSITA Calibration

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device
telescope
filter
CCD
on-board data processor

device	process
telescope	reflection (scattering)
filter	absorption
	charge release
CCD	charge transfer
	charge readout
on-board data processor	signal processing

device	process	signal	
telescope	reflection (scattering)	photon [eV]	
filter	absorption		
	charge release	charge [e ⁻]	
CCD	charge transfer		
	charge readout	pulse height amplitude [adu]	
on-board data processor	signal processing	event [bit]	

device	process	signal	characteristic properties	
telescope	reflection (scattering)	photon [eV]	effective area (Ε,θ,φ) point spread function (Ε,θ,φ) field of view (FOV) boresight	collecting area, reflectivity, vignetting mirror quality, encircled energy fraction focal length, detector geometry, plate scale alignment
filter	absorption			
CCD	charge release charge transfer	charge [e ⁻]		
	charge readout	pulse height amplitude [adu]		
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Imaging Analysis of X-ray data

While the imaging analysis of X-ray data is generally similar to imaging analysis in other energies/wavelengths, it has some specific properties which must be considered:

- strong dependence of the image quality on the off-axis angle
- generally low photon statistics

Telescope Calibration: Point Spread Function (PSF)



This one-million-second image ("Chandra Deep Field-South") is an extremely deep X-ray exposure. The darker area at center is caused by a sharper PSF.



XMM-Newton image of the V1118 Ori field

Telescope Calibration: eROSITA Point Spread Function (PSF)



eROSITA first light image of the LMC

MPE X-ray test facility PANTER



PANTER Geometry (overview)



PANTER Geometry (overview)



PANTER Geometry (overview)









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



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



$$\begin{split} u_{i} &= c_{i} + x_{0} + (x - x_{0}) \cos \gamma - (y - y_{0}) \sin \gamma \\ v_{i} &= d_{i} + y_{0} + (x - x_{0}) \sin \gamma + (y - y_{0}) \cos \gamma \\ u_{i}' &= u_{0} + (u_{i} - u_{0}) \cos \delta - (v_{i} - v_{0}) \sin \delta \end{split}$$

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



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"



Result of geometrical fit with 7 parameters:

A, B, D, γ, δ, x₀, y₀

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"



before geometry correction

FM2, AI-K



after geometry correction

FM2, AI-K



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after
geometry
correction
```

FM2, AI-K

extraction radius: 4 arcmin

 \rightarrow vignetting





after geometry correction

extraction radius: 4 arcmin

 \rightarrow vignetting

PSF Focal Plane Mapping: Vignetting



PSF Focal Plane Mapping: Vignetting and HEW



PSF Focal Plane Mapping: Vignetting and HEW



PSF Focal Plane Mapping: Vignetting and HEW











Effective Area, Vignetting



Vignetting derived from PSF focal plane mapping at PANTER

device	process	signal	characteristic properties	
telescope	reflection (scattering)	photon [eV]	effective area (Ε,θ,φ) point spread function (Ε,θ,φ) field of view (FOV) boresight	collecting area, reflectivity, vignetting mirror quality, encircled energy fraction focal length, detector geometry, plate scale alignment
filter	absorption		transmission (E,x,y) contamination (E,x,y,t)	
CCD	charge release charge transfer	charge [e ⁻]		
	charge readout	pulse height amplitude [adu]		
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Filter Calibration


From photons to bits: the fate of X-rays grabbed by eROSITA

device	process	signal	characteristic properties	
telescope	reflection (scattering)	photon [eV]	effective area (Ε,θ,φ) point spread function (Ε,θ,φ) field of view (FOV) boresight	collecting area, reflectivity, vignetting mirror quality, encircled energy fraction focal length, detector geometry, plate scale alignment
filter	absorption		transmission (E,x,y) contamination (E,x,y,t)	
CCD	charge release charge transfer	charge [e ⁻]	charge splitting	patterns (singles, doubles, triples, quadruples, invalid)
	charge readout	pulse height amplitude [adu]		
on-board data processor	signal processing	event [bit]		

Charge splitting \rightarrow Pixel patterns



From photons to bits: the fate of X-rays grabbed by eROSITA

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filter	absorption		transmission (E,x,y) contamination (E,x,y,t)	
CCD	charge release charge transfer	charge [e ⁻]	charge splitting low energy threshold	patterns (singles, doubles, triples, quadruples, invalid)
	charge readout	pulse height amplitude [adu]		
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Charge splitting and the low energy threshold



low energy threshold



→ observed pattern depends on the low energy threshold

low energy threshold



charge lost \rightarrow degradation of the energy resolution

Impact of the low energy threshold on the *spectral resolution*



→ the spectral resolution of X-ray CCDs depends on the low energy threshold

The effect of charge splitting can be utilized for improving the spatial resolution

PSF Focal Plane Mapping: HEW



Determination of the eROSITA PSF

On-axis PSF





single pixel events



Kimmel et al., SPIE 6276, 2006



double events



Kimmel et al., SPIE 6276, 2006



triple events



Kimmel et al., SPIE 6276, 2006



quadruple events



Kimmel et al., SPIE 6276, 2006



Pattern resolved subpixel anatomy of an X-ray CCD image



Pattern resolved subpixel anatomy of an X-ray CCD image



Pattern resolved subpixel anatomy of an X-ray CCD image



Determination of the eROSITA PSF

On-axis PSF



Determination of the eROSITA PSF

On-axis PSF



1 px = 9.6" x 9.6" = 75 μm x 75 μm

Impact of the low energy threshold on the *spatial resolution*



→ the spatial resolution of X-ray CCDs depends on the low energy threshold

12x12 pixel scans at Al-K, without subpixel resolution



12x12 pixel scans at Al-K, with subpixel resolution



From photons to bits: the fate of X-rays grabbed by eROSITA

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filter	absorption		transmission (E,x,y) contamination (E,x,y,t)	
CCD	charge release charge transfer	charge [e ⁻]	charge splitting low energy threshold contaminating effects	patterns (singles, doubles, triples, quadruples, invalid) pile-up (single pixel, pattern) photon background (fluorescence, optical loading) particle induced background (soft protons, MIPs) detector induced background (noise, bright pixels)
	charge readout	pulse height amplitude [adu]		
on-board data processor	signal processing	event [bit]		

Contaminating effects: pile-up



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Contaminating effects: pile-up of X-ray photons



Contaminating effects: pile-up of X-ray and optical photons



Contaminating effects: optical photon background

SRG/eROSITA-TM5

Optical light leak

10 min time bins



begin: Sa, 2019-08-31T19:37:15.00, eROday: 43098 (+0.66) end: Su, 2019-09-01T18:49:05.00, eROday: 43104 (+0.45) elapsed time: 83.5 ks, net exposure time: 77.5 ks (92.8%) linear intensity scale from 0 to 4 events/10 min

Contaminating effects: particle induced background



tracks of minimum ionizing particles (Freyberg et al. 2020)



average eROSITA spectrum in closed filter position (Freyberg et al. 2020)

Contaminating effects: detector noise





Contaminating effects: electronic artefacts





From photons to bits: the fate of X-rays grabbed by eROSITA

device	process	signal	characteristic properties	
telescope	reflection (scattering)	photon [eV]	effective area (Ε,θ,φ) point spread function (Ε,θ,φ) field of view (FOV) boresight	collecting area, reflectivity, vignetting mirror quality, encircled energy fraction focal length, detector geometry, plate scale alignment
filter	absorption		transmission (E,x,y) contamination (E,x,y,t)	
CCD	charge release charge transfer	charge [e ⁻]	charge splitting low energy threshold contaminating effects quantum efficiency (QE)	patterns (singles, doubles, triples, quadruples, invalid) pile-up (single pixel, pattern) photon background (fluorescence, optical loading) particle induced background (soft protons, MIPs) detector induced background (noise, bright pixels)
	charge readout	pulse height amplitude [adu]		
on-board data processor	signal processing	event [bit]		

Detector Calibration: Quantum Efficiency (QE)



http://xmm.esac.esa.int/external/xmm_user_support/documentation/uhb_2.2/node31.html

Telescope Calibration: effective area * filter transmission * QE



Effective areas of the three filter combinations for one eROSITA camera, composed of the expected effective area of one mirror assembly (averaged over the FoV), the filter transmissions, and the CCD quantum efficiency. All values are preliminary.

From photons to bits: the fate of X-rays grabbed by eROSITA

device	process	signal	characteristic properties	
telescope	reflection (scattering)	photon [eV]	effective area (Ε,θ,φ) point spread function (Ε,θ,φ) field of view (FOV) boresight	collecting area, reflectivity, vignetting mirror quality, encircled energy fraction focal length, detector geometry, plate scale alignment
filter	absorption		transmission (E,x,y) contamination (E,x,y,t)	
CCD	charge release charge transfer	charge [e ⁻]	charge splitting low energy threshold contaminating effects quantum efficiency (QE) energy resolution (ΔE)	patterns (singles, doubles, triples, quadruples, invalid) pile-up (single pixel, pattern) photon background (fluorescence, optical loading) particle induced background (soft protons, MIPs) detector induced background (noise, bright pixels)
	charge readout	pulse height amplitude [adu]		
on-board data processor	signal processing	event [bit]		

CCD calibration: energy resolution



CCD calibration: energy resolution








between 533 and 538 eV and between 1825 and 1848 eV a pronounced change in the spectral response is observed



RMFs used for XMM-Newton and Chandra



RMFs used for XMM-Newton and Chandra





Spectral resolution of XMM-Newton/MOS1



Modification of the incident spectrum by the instrument







From photons to bits: the fate of X-rays grabbed by eROSITA

device	process	signal	characteristic properties							
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filter	absorption		transmission (E,x,y) contamination (E,x,y,t)							
CCD	charge release	charge [e ⁻]	charge splitting low energy threshold contaminating effects quantum efficiency (QE) energy resolution (ΔE)	patterns (singles, doubles, triples, quadruples, invalid)pile-up (single pixel, pattern)photon background (fluorescence, optical loading)particle induced background (soft protons, MIPs)detector induced background (noise, bright pixels)trap saturation due to photons and particles						
	transfer		pattern migration	charge transfer noise threshold induced charge loss reemission, charge diffusion, charge splitting						
	charge readout	pulse height amplitude [adu]								
on-board data processor	signal processing	event [bit]								























Bivariate Analysis Analysis File Edit ROI: None 🖂 Use Markers Include = 61782 Color Table Image Scaling 529438 data points; centroid= [515.86, 315.30] Y-edit ~~ ^ Center Zoom+ F Auto Zoon-Range v. vv Save Titles 200 1000 800 □ 1-1 4 000 CPCY=-2.7955; 473.95 << < Center Zoom+ Range > >> X-edit Zoon-🗏 Auto Vertical generic1 -Rotation (degrees) [0.00 Horizontal y_position -Replot Dismiss

Amplitude of AI Ka line in units of DN, as a function of row number (FI device I3 at -120 C)

Townsley et al., Nuclear Instruments and Methods in Physics Research A 486 (2002) 751–784

Determination of the Charge Transfer Inefficiency (CTI)

25 macro pixels, 20-29 singles per macro pixel



low photon statistics

high photon statistics



noisy pixel





















column number (RAWX)

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CTI determination

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111	Addition of the second	0.4	70	All and a second second	4.7	1496	milianisti du a	1.0	200	and a second sec	4.4	679	- the configuration of the second	1.6	224	with the second	4.0
12	milema ha na	6.1	10		1.7	14-2	construction of the second sec	1.6	207	attable and an one	1.44	6/1	A cash of a second state (6.6	223	and the second s	1.8
10	and the state of t	2.3	80	- And a state of the state of t	2.9	144		1.5	208	- Sold and a straight of the sold of the s	1.5	272	and a few of the few o	2.0	336	and the second s	2.6
17	A sharehouse the state	2.7	81	COMPACT NOT ON THE OWNER	1.8	145	and a second and the second se	1.8	209	and the second sec	2.6	273	An discontinue of the state of	1.8	337	advantage of the second	1.6
18	- Service Contraction of the service	2.2	82	- and a second s	1.9	146	- and the second s	2.9	210	- water for the second state of the second	2.0	274	and the property of the second s	1.4	338		2.0
19	and the property of the particular of the partic	1.5	83	- and the second s	1.7	147	With the state of	1.7	211	-application of the production	2.3	275	- Alight Conservation (Conservation	1.3	339	- The Contraction of the Contract	1.8
20	Cardina of the second s	1.9	84	- And the second second second	1.4	148	- And the second se	1.4	212	and the second state of the second states of the second states of the second states of the second states of the	1.9	276	- Britage to Philipson Party Sectors (1)	2.4	340		1.9
21	-	1.7	85	-Syder Mary Colored Street Street	1.5	149	-herkelenterferreykineger	1.9	213	-Westmeleybookstates	2.0	277	where the second second	1.7	341	Ashanasal and a particular	1.3
22	With the Constant of Constant	1.9	86	- And the state of the second second	1.6	150	-Repairing a second second second	23	214	-distantisticki Goudenet.	1.4	278	-Valengiaterary	2.7	342	-	2.1
23	And the second second second	99	87	- Alexandra - Alexandra	17	161	-Related and the forest of the	11	916	-Administration does to	1.6	279	- Milling Constant	14	343	White Contractory	23
94	- Contract of Cont	16	88	- administration of the second	1.9	169	- and the state and the	19	916	- Salitanaturia dan	17	280	- Schementer Stranger	1.9	944	- Contraction of the second second	98
95	-1053 Gradelin market	9.4	00	- Address of the second	9.0	166	Sandhard and a second	3.0	917	California Barro	10	901	- Shinter Schendowed	1.0	945	entre all and a log of the state	e.0
20	town is about the second second	2.4	03	- Contraction of the second se	2.0	122	and the second strategy and the	2.0	61/	and a start of the second second	1.0	201	and the first state of the second state of the	1.0	242	and Barris and a	2.2
20	- exchanges from the first of the	1.0	30		2.3	124	The second s	2.3	218	And the second s	2./	282	And and the second second second second	2.1	340	and an a state of the state of	1.8
27		1.8	91	Same and the second	2.6	155	And the second se	3.0	219		2.0	283		1.6	347	And the second s	2.1
28	- And a state of the second state of the secon	1.8	92	a state of the second s	2.4	156	Sand And Park Property	2,5	220	- Standing of the standard standards	1.9	284	And a state of the	1.6	348		2.1
29	And the second states and	1.3	93	- Service Section Sect	2.3	157	and the second second	1.6	221	- Water and a state of the stat	1.3	285	- State of the Sta	2.8	349	- State and a second state of the second state	1.9
30	- Contractor of the second second	3.1	- 94	- The second second second second	2.9	158	where the set of the set	2,3	222	And the second s	2,3	206	- Andrew Contractory	1.5	350	and the second s	3.5
31	- And	1.9	95	- Indexed Station Department	2.7	159	THE REAL PROPERTY.	2.5	223	- And the part of	1.7	287		1.5	351	- Paladon and a strength	1.6
32	- Standard Add Standard Standard	1.8	96	State and Alexanded Andrews	2.1	160	Sherry March Street	2.4	224	-	1.5	288	- Alternation of the second	2.1	352	-	2.4
33	The second s	20	97	- Marine State Conference and Conference	27	161	Webookedleedees	13	225	-tellplacking and and a	19	289	- Provide the Science of the Science	21	353	WWWWWWWWWW	21
34	All the second s	19	98	- Bellett believe A. Assembles	22	162	Construction of the second	22	226	- Charles (Play as	14	290	-Astrochitettinen	13	354	The second secon	26
90	Westildungen bernen i	17	90	California Later Contra	94	163	Bananita demonstrations	94	997	AND IN THE OWNER	10.1	001	dealth and the states	0.0	969	Addisonal to select the second	17
80	the state of the s	1.1	- କଳ	And the second standards	a.a	100		a.a	200		4.0		Contraction of the state	8.9	999	Andread and a second se	8.8
30	The second secon	2.0	100	Construction of the second second	2.8	109	the state of the s	1.8	225	and the raid had filled in	1.2	592	company of an address of the	9.0	330	- Property and a	2.1
Эł		1.9	191	And the state of t	2.1	103	and an a state of the	1.0	223	and a set of a set of	1.4	230	- the state of the	ə.r	991	- Andread In the second second	1.0
38	The second secon	2.1	102	succession of the second	1.9	166	a constraint with the state	1.6	230		1.4	294	and the second second	1.7	328	Alternative and the second states	1.8
39	- The State of the	1.9	103	All and a support of the support of	2.5	167	And the state of t	2.1	231	Contraction of the second s	2.3	295	A REAL PROPERTY OF THE OWNER OWN	2,2	359	and the second s	1.9
40	and the second se	1.5	104	And South at a long or second of stages	24	168	-	1.1	232	Carried Control of Con	1.4	296	Sandren of the state	1.6	360	addition of the second se	1.8
41	- Statistic Contraction of the second	1.8	105	- Anticher State State State	1.7	169	-tentendemournes	2.3	233	A CONTRACTOR OF A CONTRACT OF	2.2	297	- and the second second second	2.2	361	-NARABARANANANANAN	1.6
42	Bandan telephone allowers of	2.7	106	-theory and the second second	1.4	170	Hand and a stand of the	2.1	234	- Alasharan and a starter	1.5	298	-they down do you prove a	1.8	362	- State of the sta	1.3
43	Same and the second state	1.3	107	and the second descent of the	1.0	171		1.8	235	- mailed and and a state of the	2.1	299	-territoria da la constanta da	2.0	363	-the property of surface	2.4
44	State of the second	2.3	108	- Allowed March States	2.4	172	and and an and and	1.8	236	- The state of the second second	1.9	300	-wildtowed to provide the	2.2	364	All particular to concerned.	2.2
45	-manufacture	07	109	- Contractor - Contractor	13	173	-	19	237	- aller and	91	301	- Andrewski Marana	19	365	-Middlefelighterspectare	24
46		1 3	110	definition in the second	18	174	Automation Change and	94	9.58	The second secon	1.8	303	with the state of	1 5	366	and the second s	17
47	Contractor Science	1.6	111	Charles and the second second	14	1/5		14	2039	The state of the s	52 M	SIE	A Real Property Lines	1 24	367	Childentral and the	52.03
30	Anotana and	1.6	44.9	Contraction of the second	8307/ 61.02	10.64	a del condect of the	1.0	949	A REAL PROPERTY AND A REAL		999	appropriate and the state of th	10.09 10.09	9691	and the second s	4.0
10	Construction of the State of the State	2.0	116	Server of the state of the	1.0	11.6	and the states of the states	1.6	240		8.1	900	- dalida - and - and - and - and - and -	6.1	900	Alless based on a	1.0
9Q	And the state of t	2.0	113	and the second s	1.0	111		2.6	261	a dia sa	2.1	305	A COMPANY OF THE OWNER.	1.0	90â	Construction of the second sec	2.0
60	- Contraction of the local diversion of the l	3.0	114	Allow the second second	1.0	178	and a state of the state	1.7	242	data and a second second	5.8	306	allow and a start of the start	1.8	370	-Statistical statistics of the	1.4
\$1		2.6	115	- Sheep and a standard and	1.2	179	And the state of the second se	1.4	243	- Minimum Providence Providence	1.9	301		1.9	371		1.7
52	And the second s	2.6	116	and the second s	1.0	180	- And the second se	1.8	244	- the state of the	22	308	- and the second s	1.7	372	- Alter States and a state of the	1.5
53	and the second state of the second	1.5	117	- Sheet and the state of the st	1.8	181	-and the second	2.1	245	Contraction of the second s	2.0	309	-MARTING CONTRACTOR	2.0	373	-Merilin Strategie (Meriline)	1.4
54	-Although - Manufactures	2.4	118	NORMAL PROPERTY AND INC.	1.9	182	- All the second second second	1.2	246	- Marine Contraction of the Cont	22	310	- Aller and the second second	2.0	374	- Charleston of the State of th	2.1
55	-	1.8	119	- and the state of	2.1	183	-	1.5	247	And a support of the support	2.4	311	- Million (Starford Street, Starford Street, Street, Street, Street, Street, Street, Street, Street, Street, St	2.1	375	- the second and a fact on the second s	2.3
56	The state of the s	2.5	120	And and and and a factor	2.7	184	Webster States and Streams	1.7	248	- Andrew State of the second second	1.9	312	Anderson and the second	1.1	376	-darit grant gand and	1.8
5/		2.4	121	Conference in the second se	1.9	185	Anter States	1.4	249	- and the second	1.5	3134		1.7	311	Chinese State State State State	1.9
58	Constant of the sector of	2.1	122	- Charles and a state of the second s	1.8	186	-helinetedorouthet.co.	2.2	250	- Harrison and the	22	314	-	2.5	378	Anternational data	2.0
-99 60	and the second s	1.6	199	- The second sec	1.9	187	Sakin Cale and a second	1.0	954	White Contraction of the local sector	9.6	12 1 12	- Relificant and a list in the party of	1 1	0.20	Contraction of the second second	3.0
en en		8 o 169	1000		1.6	197		1-10	691 689	the date of the local	20	19 19 19 19		1.1	967 Q		10.4 10.4
_	American Stranger			The second se		the second se		10.0 × 1787	and the second sec	Variation of the second se	and other	N3 153		H - 100	100 00 100		100 a 100 a
64		1.1	124-	- All Alaselines as -	81 94	100	collider to Alaberta and	1.6	959	The second secon	9.1	10.472	data standard and the	4.0	204	- alite building of the state of the	9.9
61		1.1	124		2.4	189	citility picture and an and an and an	1.5	253		2.1	317		1.2	381		2.2
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60 61 62 63		1.1 0.9 1.6 1.4	124 125 126 127		2.4 1.8 1.2	189 190 191		1.5 2.0 2.3	253 254 255	and the state of t	2.1 1.8 1.7	317 318 319	-Millelineshiriyingagagi -Dillineshiriyingagagi -Dillineshiriyingagagi -Dillineshiriyingagagagi	1.2 1.8 1.2	381 382 383		2.2 1.2 4.1

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



7 CCDs (with 3.3 billion events) calibrated

CTI determination
From photons to bits: the fate of X-rays grabbed by eROSITA

device	process	signal	characteristic properties					
telescope	reflection (scattering)	photon [eV]	effective area (Ε,θ,φ) point spread function (Ε,θ,φ) field of view (FOV) boresight	collecting area, reflectivity, vignetting mirror quality, encircled energy fraction focal length, detector geometry, plate scale alignment				
filter	absorption		transmission (E,x,y) contamination (E,x,y,t)					
CCD	charge release	charge [e ⁻]	charge splitting low energy threshold contaminating effects quantum efficiency (QE) energy resolution (ΔE)	patterns (singles, doubles, triples, quadruples, invalid) pile-up (single pixel, pattern) photon background (fluorescence, optical loading) particle induced background (soft protons, MIPs) detector induced background (noise, bright pixels)				
	charge transfer		charge transfer loss (CTI) pattern migration	trap saturation due to photons and particles charge transfer noise threshold induced charge loss reemission, charge diffusion, charge splitting				
	charge readout	pulse height amplitude [adu]	readout noise amplification ('gain')	non-linear gain, also dependence of the "apparent" gain on threshold(!) dependence on energy, temperature, time,				
on-board data processor	signal processing	event [bit]						

Detector Calibration: Gain



Energy interpolation of gain and CTI

individually for each CCD column

CTI



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 AI-K Ti-K Fe-K Cu-K Ge-K



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)



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

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



reconstructed spectral distribution

From photons to bits: the fate of X-rays grabbed by eROSITA

device	process	signal	characteristic properties					
telescope	reflection (scattering)	photon [eV]	effective area (Ε,θ,φ) point spread function (Ε,θ,φ) field of view (FOV) boresight	collecting area, reflectivity, vignetting mirror quality, encircled energy fraction focal length, detector geometry, plate scale alignment				
filter	absorption		transmission (E,x,y) contamination (E,x,y,t)					
CCD	charge release charge transfer	charge [e ⁻]	charge splitting low energy threshold contaminating effects quantum efficiency (QE) energy resolution (ΔE) charge transfer loss (CTI) pattern migration	patterns (singles, doubles, triples, quadruples, invalid) pile-up (single pixel, pattern) photon background (fluorescence, optical loading) particle induced background (soft protons, MIPs) detector induced background (noise, bright pixels) trap saturation due to photons and particles charge transfer noise threshold induced charge loss reemission, charge diffusion, charge splitting				
	charge readout	pulse height amplitude [adu]	readout noise amplification ('gain')	non-linear gain, also dependence of the "apparent" gain on threshold(!) dependence on energy, temperature, time,				
on-board data processor	signal processing	event [bit]	energy offsets (offset map) common mode correction signal extraction MIP suppression	(would require separate presentation)				

Baikonur, Kazakhstan, 2019 July 13



From photons to bits: the fate of X-rays grabbed by eROSITA

device	process	signal	characteristic properties			
telescope	reflection (scattering)	photon [eV]	effective area (Ε,θ,φ) point spread function (Ε,θ,φ) field of view (FOV) boresight	collecting area, reflectivity, vignetting mirror quality, encircled energy fraction focal length, detector geometry, plate scale alignment		
filter	absorption		transmission (E,x,y) contamination (E,x,y,t)			
CCD	charge release charge transfer	charge [e ⁻]	charge splitting low energy threshold contaminating effects quantum efficiency (QE) energy resolution (ΔE) charge transfer loss (CTI)	patterns (singles, doubles, triples, quadruples, invalid) pile-up (single pixel, pattern) photon background (fluorescence, optical loading) particle induced background (soft protons, MIPs) detector induced background (noise, bright pixels) trap saturation due to photons and particles charge transfer noise threshold induced charge loss		
	charge readout	pulse height amplitude	readout noise	reemission, charge diffusion, charge splitting non-linear gain, also dependence of the "apparent" gain on threshold(!)		
		[adu]	amplification (gain)	dependence on energy, temperature, time,		
on-board data processor	signal processing	event [bit]	energy offsets (offset map) common mode correction signal extraction MIP suppression	(would require separate presentation)		

Energy calibration with the internal ⁵⁵Fe source







Energy Calibration: internal calibration source



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Gain comparison: before / after launch



Gain comparison: before / after launch



CTI comparison: before / after launch



CTI comparison: before / after launch



Challenges for the energy calibration: 1) CCD temperatures (Sep 2019 – Feb 2022)



CCD temperatures during the first ⁵⁵Fe measurements after launch



Effect of CCD temperature on energy @ 1.5 keV



Effect of CCD temperature on energy @ 4.5 keV



Challenges for the energy calibration: 2) CTI increase due to radiation damage



Challenges for the energy calibration: 2) CTI increase due to radiation damage



CCD column specific CTI evolution

1

TM1, Al-K



CCD column specific CTI evolution





5

Temporal evolution of the energy resolution (FWHM)



eROSITA calibration observations of 1E 0102.2-7219











AHEAD 2020

eROSITA - Science and Data Analysis School

2024 November 18 - 22, MPE

eROSITA Calibration

Konrad Dennerl MPE