eROSITA On-ground Calibration and beyond..

Konrad Dennerl

MPE

eROSITA Calibration: Detector Gain and CTI

Energy Calibration:

extent of charge cloud & 75 μ m pixel size \rightarrow 4 pattern types





• pattern recognition

all events

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





pattern recognition

German eROSITA Consortium Meeting, Potsdam

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

example: Fe-K, measured with FM4



German eROSITA Consortium Meeting, Potsdam

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



CTI determination

German eROSITA Consortium Meeting, Potsdam

97	- Anton a start and a start of the start of	2.7	161		1.3	225	- soft to all and the soft of	1.9	289	- and the second se	2.1
98	- Variation of manual and a second and a second	2.2	162	اللاكمة المالية المراجع المواجع الم	2.2	226		1.4	290	- All and the second state of the state of the state of the second	1.3
99		2.4	163	^{- ئ} ىسىمەسىر كەندۇرىيە ئەرىرى ئەرىيە	2.4	227	مان المراجع ال	2.1	291	and the second provide the second	2.3
100	- Aplanana and in a private provide a provide a second	2.8	164	- and an interest of the state	1.4	228	- And and a state of the second of the secon	1.3	292	~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~	3.6
101	- Marine Strate and a free and the and the second states and the	2.1	165	- Warmon and the for and a second and the second	1.5	229	- and a state of the second and a	1.3	293	What have the and the second in the second	3.7
102	<u> </u>	1.9	166	- Song to the game of the second group of the to the second group of the second group	1.6	230		1.4	294	- Hart of any first of the ball of the second of the second of the	1.7
103		2.5	167	- Start frank af an start and a start of a start of a start a start and a	2.1	231	~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~	2.3	295	᠆ᠳᢂ᠅ᡭᡪᢤᢤᡬᡰᢖᠯᡊᢩᠧᡸ᠋ᡎᡄ᠅ᠼᡵᢣᢏᢍᢥᡊᢘᡭᢩᢞᢛᡘᢩᡷᡵᡊᡀᢣᢑᠯᠥᡀᢣᢑᡘ᠘ᠰᢣᠼᢩᡨ᠇ᡟᢩᡔ	2.2
104		2.4	168	-Mandalahar and a far far a	1.1	232	ىلىنى يەمەر ئالەرىمەر بەرىغۇر ئەرىغۇ ئەتھە يەتھە تەتھە يەر ئىن ئەتھە يەر ئىن ئەتھە بولىيە -	1.4	296	ۥ؞ۥڟۥؿٷڮڹڿ؞ڔٞؿٵۑڟٵڛٷۑۑۑڹٵڡڡٳ؈ۣڛؾٳؿ؆ؿۑڵۊٵۑ؇ڡؾۑڟؿ	1.6
105	يتجاوزون والمحاد للمعاقب والمتحديق والمحادث والمحاد والمحادث	1.7	169	- معرفة المعرفين والمراجع والمعالية المعالية المعالية والمعالية والمع	2.3	233	- Seal of the second state	2.2	297	- Start of the start of the back of the start of the star	2.2
106	- เ ¹⁴ ที่ที่สารรรมข้างหรือที่มีการเหลือหล่างจากจากสารการการกา	1.4	170		2.1	234		1.5	298		1.8
107	where and an and a second state of the second state of the second s	1.0	171	- and the second s	1.8	235	- senter in the stand with any farmer of the second stand and	2.1	299	- the adding for the second of the fact of the second of t	2.0
108	- and the state of	2.4	172		1.8	236	- where is the internet of the second of the	1.9	300	~~************************************	2.2
109	- a fight for the second se	1.3	173	- information of the state of the state of the state of the state	1.9	237	- And the formation of the second that and the state of the second to	2.1	301	معيد المراجع المعالية بالمراجع المعالية المعالم المراجع المعالي المحالية المح	1.9
110	- for the first property and a start of the	1.8	174		2.4	238	<u></u>	1.8	302		1.5
111		1.4	175		1.4	239	- And a fart of the set	2.9	303	- for a farter and particular for a farter of the farter o	1.5
112	<u></u>	1.5	176	٩٩٠٩ و٢٩٩٩ و٢٩٩٩ و٩٩٩ موموم ومواد المواد ومواد ومعادية معادية معادية معادية معادية معادية معادية معادية معادية معادية و٢٩٩٩ مواد وماد معادية معاد	1.8	240	- and the set of the s	2.1	304	٢٠٠٠، ٢٠٠٠، ٢٠٠٠، ٢٠٠٠، ٢٠٠٠، ٢٠٠٠، ٢٠٠٠، ٢٠٠٠، ٢٠٠٠، ٢٠٠٠، ٢٠٠٠، ٢٠٠٠، ٢٠٠٠، ٢٠٠٠، ٢٠٠٠، ٢٠٠٠، ٢٠٠٠، ٢٠٠٠، ٢٠ ٢٠٠٠، ٢٠٠٠، ٢٠٠٠، ٢٠٠٠، ٢٠٠٠، ٢٠٠٠، ٢٠٠٠، ٢٠٠٠، ٢٠٠٠، ٢٠٠٠، ٢٠٠٠، ٢٠٠٠، ٢٠٠٠، ٢٠٠٠، ٢٠٠٠، ٢٠٠٠، ٢٠٠٠، ٢٠٠٠، ٢٠٠	2.7
113	Manifester of the second second second second second	1.0	177	- iterianisina ana panananisa ang panjang ang panjang	2.4	241		2.1	305	- ماران از از از از المسلم والمراجع المسلم و المراجع المراجع و المراجع و المراجع و المراجع و المراجع و المراجع	1.9
114	- Constraint for a fair of the second of the	1.9	178		1.7	242	with the state of the	2.8	306	and the second second second second second second second second	1.8
115	ala ala ang ang ang ang ang ang ang ang ang an	1.2	179	ماذهن كالاولالية وموادهوه والمنافع والمتحد والمعادية والمحارف	1.4	243	- And the second and the second second second second second	1.9	307	- and the second second by the bar and the second second	1.9
116	+ the stand of the second soft of the stand	1.0	180		1.8	244		2.2	308	<u>~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~</u>	1.7
117		1.8	181	and a second	2.1	245	٢٠، دميد خود تعديد الله ويونية المارية المعدية ما المارية المراجع المارية المراجع المراجع المراجع المراجع المراج	2.0	309	- the state of the	2.0
118		1.9	182	<u>~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~</u>	1.2	246	- and a far and a start and a start a s	2.2	310	- where the second state of the second state o	2.0
119	- and a second	2.1	183	~~;+***;+******************************	1.5	247		2.4	311		2.1
120	- the appropriate and the second of the seco	2.7	184	- marily and a low and that a free and the art of the a	1.7	248	- manual phases and best and a fact and a fact and a second provide second	1.9	312	- the state of the	1.1
121	- was interesting to a station of the state	1.9	185	- the second sec	1.4	249	-initial production of the production of the second s	1.5	313		1.7
122	~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~	1.8	186	-Myrthalanaanaanaanaanaanaanaanaanaanaanaanaan	2.2	250	- aptress of a first start and go grand and the first start of the first start and a first start and a first st	2.2	314	٢٠٠٠٠ من من المراجعة ا	2.5
123	- A Share produce it with a second state of a state of a second	1.2	187	- Separate front and the second s	1.3	251	ינין אישר גער איר איר איר איר איר איר איר איר איר אי	2.5	315	- the state of the	1.1

CTI determination

1			65	- Annaldation and a second	2.0	129	- And the second state of	1.8	193	-upper and a second	1.6	257	- and the second second	1.5	321	- Printer and the second second	2.7
2	which the hard states of the	2.1	66		0.8	130	Address Contractor	2.8	194	-Non-Non-Incolation	1.2	258		2.1	322	- Alter Margaret Margaret	2.0
	- Partition of the second	9.1	67	430104.00.000000000000000000000000000000	1 1	131	All	99	195	-Alexandra -	91	259	Ministerilli annes	9.1	999	Walkelike and the second	1.8
4		94	69		1.6	199	And the state of t	1.6	198	- dollars in make with st. 2	14	280	Reference in Aug. A.	9.6	323	- Alleh and an and a second	1.0
5	and a provide a second	1.0	60	- All and a second s	17	100	the analytical structure of the	1.0	107	-Automobile Anno and	1.4	961		9.4	305	whether the second second	9.6
3	Advantation of the second	1.0	70	and a set of the set o	0.0	133	and the second s	1.0	107	- think and a	1.00	201		2. 4	323	applied and to	2.0
2	Chillen and a m	1.0	70	Consultation of the	2.5	134	and the set of the set	2.3	198	and the second second second	1.8	262	The street services and	0.8	320	Shine of the second sec	2.4
	And a full and a full	2.0	/1	- Andrewski an a	1.8	130	Andrew In the Contraction	1.3	199		2.4	263	All the second the second	2.3	327		1.5
8	A State of the second s	2.1	12	-d-o-like	2.5	136	A REAL PROPERTY AND A REAL PROPERTY.	2.9	200	and the second s	3.0	264	and the second standing	1.3	328	Construction of Construction	2.1
3		1.1	73	Contractor of the second s	2.5	137	A CALIFORNIA STATE OF THE OWNER	2.2	201	- Cherry Coloring State	1.8	265	- And and a second s	1.7	329	A LEAST AND A DESCRIPTION OF A DESCRIPTI	2.5
10	- Alter - Color - Colo	2.5	74	and the second s	1.6	138	- Million Contraction	1.7	202	- AND	2.1	266		1.9	330	and the second s	2.4
11	allowed and a state of the stat	2.6	75	And the second s	2.5	139	State of the state	3.7	203	and the second s	1.4	267	- Shell and the state of the st	1.9	331	and the state of t	2.9
12	- Contraction of the second	1.7	76	- names of a Decay Property	2.6	140	- Marine States	1.4	204	- State of the second s	2.1	268	-winder and a second second	1.9	332	- Alter and the second second second	1.5
13	- And the state of the local division of the	1.9	77	- Andrewski and a state of the	1.7	141	-States and and and a state of the states of	1.9	205		2.1	269	- and the state of	2.0	333	- WALKERSON AND A CONTRACTOR	1.6
14	- And the second second second second	1.7	78		2.0	142	- Alfahar Marine and Antonia Station of the	1.5	206	- And the state of	2.1	270	-Pulling and a stand of the sta	1.7	334	Construction of the local data	2.5
15	- Angladian (State State States	2.1	79	-without and a second second second	1.7	143	-aggeographic and a second sec	1.7	207	- Marking provident	1.4	271	- Phate and the second second	2.2	335	- Alternative State State State State State	1.9
16	- and a first processing of the first processing of th	2.3	80	And the state of t	2.9	144		1.5	208	-Wildersteinisterijigensee	1.5	272	- Water and the second s	2.0	336	- Contraction of the second	2.6
17	The second s	2.7	81	Billerdlenet Capage and	1.8	145	- Contraction of the Contraction	1.8	209	Collection of the Westmanning of	2.6	273	- William State St	1.8	337	ويهجعون معاليه ومقوقا وال	1.6
18	All and a second second second	2.2	82	- The Association of Stations	1.9	146	- And the second	2,9	210	- And the property of the second	2.0	274	ARTICLE CONTRACTOR OF THE OWNER	1.4	338	- Angel Delayer Sound St. St. Surrow, Mar.	2.0
19	- Contraction of the second second second	1.5	83	- and the state of the second states	1.7	147	With Tyre Clinking	1.7	211	-Mitrichandration and and and and and and and and and an	2.3	275	- Alight Strengther Strengther	1.3	339	-	1.8
20	Charleson of the section of the sect	1.9	84	- Harris Party - Harrison	1.4	148	- and the second	1.4	212	Contraction of the second second	1.9	276	- Breaked and the American	2.4	340	-Markele Colorest Contraction Contraction	1.9
21	-	1.7	85	- Spring the Constant Street Street	1.5	149	-herichenterterentidensat	1.9	213	-Medianelogianelogiane	2.0	277	WWWWWWWWWWW	1.7	341	Ashanasadan pananan	1.3
22	With the Street Street and	1.9	86	- Propherical Contractor State	1.6	150	Advantation of the	23	214	-diminipation of the second second	1.4	278	Astronomy and a second	2.7	342	-	2.1
23	The second second second	2.2	87	Alt Contractor	1.7	151	- Address and the owner way.	1.1	215	- Martin Martine Conto.	1.5	279	- Aller Handland And I contain	1.4	343	White the party of the second	2.3
24	Arrest and Arrest Annual Annua	1.6	88	- and a state of the state of t	18	152	- White the state of the second	12	216	- Carlo Carlos and Carlos and -	17	280	- Silitan Anton Manual	1.8	344	- Party Ballanda In	29
25	And the state of the second state	94	89	Alter Control of the second	28	163	Serie Lange	30	217	- Rolling to the second	18	281	- William Salar Barnel	1.6	346	Support and the support of the	23
26	-herry destination of the second seco	1.0	90	-FORMAR AND	23	154	- Constanting of the second	23	218		97	282	Contraction of the second	91	346	- 10 Million and all an annot	1.8
97	- Charleston de la company	1.0	61	Statements Astronom	26	166	"Charles Condensate Lines on an	20	910	the part of the part of the	20	283	windowine The thread on one of a	16	947	The second state of the se	9.1
98 98	-	1.0	89	- Contractor of the second	94	156	Shering and a second	2.0	220	-endedation to out on an	10	284	Adapted in the other	1.0	349		9.1
20	Added to be a set of the set	1.0	00	- Webshinetie from on a	0.7	100	all and means on the state	4.0	0.04	- Mikhawing and an a	1.0	0.05	Patient and an an	0.0	010	Antiberry and	4.0
29	Alter and a second second second	1.3	33	- Constraint and the standing of the stand	2.3	187	Construction and the second	1.0	221	Contract of the second second	1.2	263	and the second second second	2.0	349	Coloradore and a substantion of the	1.8
30	And Andrews have a second	3.1	99	- adapted - the -	2.0	150	Thill Contraint	2,3	222	and the second s	22	200	- All and a second seco	1.8	350	- Belle Brite all address -	3.8
31	- and a second s	1.8	30	and a market when the second s	2.7	129	which we are an	2.3	223	Children and a start of the sta	1.8	28/	and provide the second state	1.0	331		1.0
32	and the second s	1.8	30	and share of the state of the s	2,1	160	Contraction Algorithm	2,4	224	Addition and addressing the first	1.2	265	and a set of a	2.1	322	And a state of the	2.4
33	And a second	2.0	97	and the second s	2.7	161	- Andrew A. J.	1.3	225	And the second s	1.9	289		2.1	353	Construction of the second	2.1
34	and the second sec	1.9	98	- the second sec	2.2	162	Construction of the second sec	2,2	226	A REAL PROPERTY AND A REAL PROPERTY.	1.4	590	donate on the second second	1.3	354		2.6
35	-marin while the planet strength	1.7	88	A -	2.4	163	And the second s	2,4	227	and the second second second	2.1	291	Contraction of the second seco	2.3	355	Contraction of the second s	1.7
36	- Alasting and a second second	2.0	100	- Constant Contraction	2.8	164	- the state of the second seco	1.4	228	-spacestration	1.3	292	and the second s	3.6	356	- And the state of the second s	2.1
31	Contraction of the Association	1.5	101	Contraction of the Advanced	2.1	165	-	1.5	559	And the second s	1.3	293	Contraction of the second	3.7	357		1.6
38	Antonia for the second second	2,1	102	and the state of the set of the	1.9	166	- Allen and and a second second second	1.6	230	- Physical or Consider Streets	1.4	294	- Harder Contraction	1.7	358	- Street of the second second second	1.8
39	- The second sec	1.9	103	All and the second s	2.5	167	Sales and the second second	2.1	231	the standard standard standard	2.3	295	- All and the second	2.2	359	-	1.9
40		1.5	104	-teat (and a start of a synthetic starts	24	168	and the second sec	1.1	232	Carried and a second se	1.4	296	and the second s	1.6	360	and the second s	1.8
41	- Statistic Constraints	1.8	105	- And the state of	1.7	169	-terreterreterreterreterreterreterreter	2,3	233	A State of the second s	2.2	297	- and the second second second	2.2	361	-NARABARANANANANAN	1.6
42	Billion of the second s	2.7	106	-things in the second state of the second	1.4	170	Marriel and a state of the second designed of	2.1	234	م <u>وارماسين المريسالية المارية</u>	1.5	298	-Paradonal parate	1.8	362	- Stall Vingest Hay Astronom	1.3
43	State and the second second	1.3	107	and the second designed of the second se	1.0	171	-	1.8	235	- Profestion in a low fragment	2.1	299	- Service and the second se	2.0	363	and the second s	2.4
44	- Contractor States	2.3	108	- And the state of	2.4	172	with the second second	1.8	236	-minimum (statement	1.9	300	-wildtered and a set of the	2.2	364	Adapted and the second	2.2
45		0.7	109	- Colorest and a state of the second	1.3	173	مرم بر می برده با از این و استانین و ا	1.9	237	- Alter and the second second second	2.1	301	- and an and a state of the second	1.9	365	-Witherspectration	2.4
46		1.3	110	-	1.8	174	Charles and the product of the produ	2.4	238	-	1.8	302		1.5	366	- Address of the Address of the Address	1.7
47	- State of the second second	1.6	111	The State back States	1.4	1/5	which and the first states	1.4	239	The state of the s	2.9	303	The standard strands stranger	1.5	367	- Children and Children and Children	2.0
48	And and a second second	2.8	112	- All of the state	1.5	176	William a house of the	1.8	240	"President and a second	2.1	304	- Charles and a state of the st	2.7	368	-	1.8
49	Contraction of the second second	2.0	113	Married Constant of the State	1.0	177		24	241	-Holindaladaata.c	2.1	305	- Wennelssford Lang	1.9	369	Aller a finishing and the	2.6
50	Configuration of the second	3.0	114	Telever representation	1.9	178	- and the state of	1.7	242	- Andrew -	2.8	306	The second secon	1.8	370		1.4
51	State of the second second	2.6	115	-Witchtellensiesen	1.2	179	- and the second second	1.4	243	-Albertalkinener .	1.9	307	- Strategic Concernence	1.9	371	The Section of the section	1.7
59	Contraction of the second	9.6	116	Although and a start	1.0	180	- Sherifichana austra	1.8	944	-treatestantest.	99	308	-Shink a factor for the	17	379		1.6
53	And the second	4.6	117	-thedaes he is	10	100	Construction of the second sec	0.4	946	-allia and a star and a star	20	200	MARGIN IN LOS	9.0	979	Marilla Charles Salada Share	1.0
54	-decord	94	118	NAME AND ADDRESS OF A DESCRIPTION OF A D	1.0	189	at Hathamaaalaha a	19	246	- Andrew Contraction of the	23	310	- Alive Shall be a factor of	20	374	Contraction of the local days	91
ee.	And a state of the second second	10	440	Carlos and a second	10.6	100		1.0	0.47	Wilderstein all as	0.4	0.00	All and a second	10 d	101240 101240	All and the second second	
99 66		1.9	110	A colorite al colorite de la colorit	61 97	10.0	All and a second second second	1.9	246 246		4.00	011	Addated and a second as	4.4	818 876		4.0
90) 10 1		≝.⊜ N.4	120	Contraction of the local sector	≝.f ∎ Li	100	and and all and the second sec	15 E 11 A	248 13.40	- Part -	1.00 1.00	69 122 NA 1102		1.1	010	Constant of the second se	1.6
97 97		2.9) 0.4	121		1.9	189	a free free free free free	1.9	249		1.0	រូវ ដែ ពេល	and an and an an and an an and an	1.7	3//		1.8
98	and the set	2.1	122	and the second s	1.8	186	- According to the state of the	22	×20	and the second s	22	314		2.9	378		2.0
59	and the second se	1.5	123	- Arthough and a second second second	1.2	187		1.3	251	The station of the station of the state	52	315	- Warder State State Strategy	1.1	379		2.9
60		1.1	124		21	188	State and All States	24	252	where a fi	2.0	316	Contraction of the second second second	1.8	380	and the Real Property of the P	2.4
61	-	Q.9	125	and the second s	2.4	189	construction of the second sec	1.5	253	Construction of the local distance	2.1	317		1.2	381		2.2
62	- All and the second second	1.6	126	-marthdoodydoorhadar	1.8	190	And the second s	2.0	254	-modelinger/anger/anger/	1.8	318	- Children Contractorio	1.8	382		1.2
63		1.4	127	-and the second of the second s	1.2	191	- Margaritation (Charmange	23	255	Augustan and the second second	1.7	319	and the second state of th	1.2	383	- Warden and the second and second	4.1
6.4	Charles Anna Anna Anna Anna Anna Anna Anna Ann	0.0	6.9.0	The state of the set o	4 95	400-0	mb.Bhoursell 1941 and do a	4 25	0.000	Therefore and the second second	4 77	0.00	will profe the new second	0.0	80.00.4		

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



CTI determination

German eROSITA Consortium Meeting, Potsdam



7 CCDs (with 3.3 billion events) calibrated

CTI determination

German eROSITA Consortium Meeting, Potsdam

Energy interpolation of the CTI and gain

individually for each CCD column

gain





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

German eROSITA Consortium Meeting, Potsdam

CTI

On-ground Calibration and beyond

K. Dennerl, 2019 Mar 04

- pattern recognition •
- correction for gain variations between CCD channels ٠



reconstructed spectral distribution

German eROSITA Consortium Meeting, Potsdam

On-ground Calibration and beyond

15000

10000

5000

6.397

keV

+/- 0.000

132.5

+/- 1.5

eV

singles

6.8

doubles

6.8

triples

6.8

quadruples

6.8

s+d+t+q

6.9

6.9

6.9

6.9

6.9

6.8

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.

German eROSITA Consortium Meeting, Potsdam

eROSITA flight cameras: absolute energy reconstruction

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



German eROSITA Consortium Meeting, Potsdam

eROSITA flight cameras: absolute energy reconstruction

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



German eROSITA Consortium Meeting, Potsdam

eROSITA Calibration:

Detector

Energy Resolution

German eROSITA Consortium Meeting, Potsdam

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)



German eROSITA Consortium Meeting, Potsdam

Energy resolution of the eROSITA flight cameras

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



German eROSITA Consortium Meeting, Potsdam

On-ground Calibration and beyond

K. Dennerl, 2019 Mar 04



eROSITA Calibration: Detector Response



E_out ["keV"]



German eROSITA Consortium Meeting, Potsdam









German eROSITA Consortium Meeting, Potsdam





Deriving the spectral response from measured spectra



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**



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**

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**

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**

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







German eROSITA Consortium Meeting, Potsdam

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 (\rightarrow uncertainty about charge transfer loss)
- how "clean" the environment was $(\rightarrow \text{ efficiency of charge collection})$

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



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

German eROSITA Consortium Meeting, Potsdam

Effective resolution obtained with "sdtq" in pixel scans


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



dam On-ground Calibration and beyond

German eROSITA Consortium Meeting, Potsdam

Determination of the eROSITA PSF Off-axis PSF



1.5 keV



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



German eROSITA Consortium Meeting, Potsdam

Method: operate the CCD in "charge accumulation mode" Challenge: Suppression of MIPs in the case of extreme pile-up



PANTER Geometry (overview)



Determination of the eROSITA PSF PSF Focal Plane Mapping



1.5 keV

6.4 keV

German eROSITA Consortium Meeting, Potsdam





German eROSITA Consortium Meeting, Potsdam



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



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



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



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

 $\begin{array}{l} \mathsf{A} = 3095.3 \mbox{ mm}, \mbox{ B} = 3252.7 \mbox{ mm}, \mbox{ D} = 1622.2 \mbox{ mm}\\ \\ gamma = \ 46.4 \mbox{ arcmin}, \ delta = \ -9.9 \mbox{ arcmin}\\ \\ x = (\ 127.8 \mbox{ - } y_ccd \), \ y = (\ x_ccd \mbox{ - } 129.7 \) \end{array}$

mean positional 1o deviation: 2.1"

before geometry correction

FM2, AI-K

German eROSITA Consortium Meeting, Potsdam

after geometry correction

FM2, AI-K

eROSITA Calibration: Mirror Plate Scale



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 ..

German eROSITA Consortium Meeting, Potsdam

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
В	= 3252.9 mm							fixed
x ₀	126.5	126.2	127.8	126.4	126.6	127.8	126.9	free
У 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 !

German eROSITA Consortium Meeting, Potsdam

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



Ray-tracing simulation

(P. Friedrich, M. Freyberg)



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









German eROSITA Consortium Meeting, Potsdam

On-ground Calibration and beyond

K. Dennerl, 2019 Mar 04

eROSITA FoV

RGB image: C-K Ag-L Fe-K

distance of PSF centers:

226.5 px @ Al-K 225.7 px @ Ti-K 225.4 px @ Fe-K

 \rightarrow 12" difference

36.0 arcmin



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

German eROSITA Consortium Meeting, Potsdam

On-ground Calibration and beyond

K. Dennerl, 2019 Mar 04



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

German eROSITA Consortium Meeting, Potsdam



- 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)
- \rightarrow image distance given by focal length and image scale are conceptually different



 \rightarrow Problems may occur with escape peak and pile-up,

but there should be an overall improvement

German eROSITA Consortium Meeting, Potsdam





German eROSITA Consortium Meeting, Potsdam

On-ground Calibration and beyond

K. Dennerl, 2019 Mar 04

eROSITA Calibration: Mirror Vignetting

after geometry correction

FM2, AI-K

German eROSITA Consortium Meeting, Potsdam



after geometry correction

FM2, AI-K

extraction radius: 4 arcmin

 \rightarrow vignetting





FM2, AI-K

extraction radius: 4 arcmin

 \rightarrow vignetting

German eROSITA Consortium Meeting, Potsdam

PSF Focal Plane Mapping: Vignetting and HEW



German eROSITA Consortium Meeting, Potsdam

PSF Focal Plane Mapping: Vignetting and HEW



German eROSITA Consortium Meeting, Potsdam

On-ground Calibration and beyond

K. Dennerl, 2019 Mar 04

eROSITA Calibration:

RGB images of PSFs

mirror

German eROSITA Consortium Meeting, Potsdam

On-ground Calibration and beyond

K. Dennerl, 2019 Mar 04


On-ground Calibration and beyond





On-ground Calibration and beyond



On-ground Calibration and beyond



On-ground Calibration and beyond

eROSITA Calibration: mirror

mean PSF during survey

German eROSITA Consortium Meeting, Potsdam

On-ground Calibration and beyond

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

0.23 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

German eROSITA Consortium Meeting, Potsdam

On-ground Calibration and beyond

Superposition of PSFs → preview of the eROSITA Survey PSF



scan at -30 arcmin

Al-K, 1.49 keV

German eROSITA Consortium Meeting, Potsdam

On-ground Calibration

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

German eROSITA Consortium Meeting, Potsdam

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. Plucinsky¹, Andrew P. Beardmore², Adam Foster¹, Frank Haberl³, Eric D. Miller⁴, Andrew M. T. Pollock⁵, and Steve Sembay²







Chandra ACIS-S3 0.5 Energy (keV) Suzaku XIS 0.5 Energy (keV) Swift XRT 0.5 1 Energy (keV)

German eROSITA Consortium Meeting, Potsdam

On-ground Calibration and beyond

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





1E 0102

10.72

10.72

10.72

5 10

S

ar

General properties of the ARF and RMF

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



\rightarrow find appropriate RMF parametrization and try to optimize it..

German eROSITA Consortium Meeting, Potsdam

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







XMM / EPIC-pn RMF and ARF parameterization

р	0.10 0.15 0.21 0.28 0.35 0.44 0.53 0.56 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 ka 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21	V sn Ivalue	noothiness weight penalty
ecar		0.000	0.000 0.000
gamma	1462 1216 1211 1507 1676 1510 1.221 1.171 1.138 1.191 1.119 1.060 1.106 1	1.408	0.020 0.028
vtherm	0.659 0.655 0.672 0.692 0.737 0.828 0.964 1.041 1.107 1.004 0.991 1.014 1.000 1	0.346	0.100 0.035
sigma	0.855 0 0.859 0 0.851 0 0.839 0 0.850 0 0.824 0 0.842 0 0.866 0 0.879 0 0.900 0 0.949 0 0.971 0 0.990 1.000 1	0.039	2.000 0.078
sh esep	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 1.079	0.106	0.100 0.011
ch mom		0.227	0.200 0.045
sh_nonn		0.227	0.200 0.045
sh sia r		2.135	0.010 0.020
shif more		14 060	0.005 0.020
shif dana		0.000	0.100 0.000
ann_aope		0.000	0.100 0.000
esc_morm	1.000 1.000	0.000	0.000 0.000
egamma	1000 1000 1000 1000 1000 1000 1000 100	0.000	0.000 0.000
evtherm	1.000 1.000	0.000	0.000 0.000
esigma	1200 1200 1200 1200 1200 1200 1200 1200	0.000	0.000 0.000
esh_esep	1000 1000 1000 1000 1000 1000 1000 100	0.000	0.000 0.000
esh_morm		0.000	0.000 0.000
esh_sig_l	1.000 1.000	0.000	0.000 0.000
esh_sig_r		0.000	0.000 0.000
eshif_mm	1.000 1	0.000	0.000 0.000
pat_frc	1.010 1.010 1.000	0.018	0.100 0.002
	0.10 0.15 0.21 0.28 0.35 0.44 0.53 0.56 0.90 1.00 1.20 1.50 1.74 2.20 2.70 2.40 4.20 5.10 5.20 9.00 1.000 km		nonthingee
	UTU	v sn	INVESTIGATION OF A DESCRIPTION OF A DESC
t		v sn value	weight penalty
t ecor	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 0.0<	v sn value 0.000	weight penalty 1.000 0.000
t ecor gamma	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 0.0	v sn value 0.000 0.000	weight penalty 1.000 0.000 1.000 0.000
t ecor gamma vitherm	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 0.0	v sn value 0.000 0.000 0.000	weight penalty 1.000 0.000 1.000 0.000 1.000 0.000
t ecor gamma vtherm sigma	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 0.0	v sn 0.000 0.000 0.000 0.000 0.000	weight penalty 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000
t ecor gamma vtherm sigma sh_esep	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 0.0	v sn 0.000 0.000 0.000 0.000 0.000	weight penalty 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000
t ecor gamma vitherm sigma sh_esep sh morm	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 0.0	v sn 0.000 0.000 0.000 0.000 0.000 0.000 0.000	weight penalty 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000
t ecor gamma vtherm sigma sh_esep sh_morm sh_sig_1	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 0.0	v sn value 0.000 0.000 0.000 0.000 0.000 0.000 0.000	weight penalty 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000
t ecor gamma vtherm sigma sh_esep sh_morm sh_sig_l sh_sig_r	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 0.0 0.00 0.0	v sn value 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.005	weight penalty 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000
t ecor gamma vtherm sigma sh_esep sh_rnorm sh_sig_l sh_sig_r shlf_rnorm	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 0.0	v sn value 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.005 0.000	weight penalty 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.005 1.000 0.000
t ecor gamma vtherm sigma sh_esep sh_morm sh_sig_l sh_sig_r shlf_morm shlf_slope	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 210 0.0	v sn value 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000	weight penalty 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000
t ecor gamma sigma sh_esep sh_morm sh_sig_1 sh_sig_r shif_morm shif_slope esc_morm	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 0.0	v sin value 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000	weight penalty 1.000 0.000 1.000 0.000
t ecor gamma vitherm sigma sh_esep sh_morm sh_sig_1 sh_sig_r shif_morm shif_slope esc_morm eaamma	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 0.0	v sn value 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000	weight penalty 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000
t ecor gamma vitherm sigma sh_esep sh_morm sh_sig_1 sh_sig_r shif_morm shif_slope esc_morm egamma eytherm	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 0.0	v sn value 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000	weight penalty 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000
t ecor gamma vitherm sigma sh_esep sh_morm sh_sig_l sh_sig_r shif_morm shif_slope esc_morm egamma evitherm	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 0.0	v sn value 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000	weight penalty 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000 1.000 0.000
t ecor gamma vitherm sigma sh_esep sh_rnorm sh_sig_l shi_rnorm shif_slope esc_morm egamma evitherm esigma	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 0.0	v sn value 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000	weight penalty 1.000 0.000 1.000 0.000
t ecor gamma vitherm sigma sh_esep sh_morm shi_sig_l shi_morm shif_slope esc_morm egamma est_esep	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 0.0	v salue 0.0000 0.00000 0.00000 0.0000 0.0000 0.0000 0.0000000	weight penalty 1.000 0.000 1.000 0.000
t ecor gamma vitherm sigma sh_esep sh_morm sh_sig_1 shi_sig_r shif_morm shif_slope esc_morm egamma est_esep esc_morm esigma esh_esep	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 0.0	v salue 0.0000 0.00000 0.00000 0.0000 0.0000 0.0000 0.0000000 0.000	weight penalty 1.000 0.000 1.000 0.000
t ecor gamma vtherm sigma sh_esep sh_morm shi_sig_l shi_roorm egamma est_form esigma esh_esep esh_sig_l	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 1 0.0 0.0 0.00	V salue 0.0000 0.00000 0.0000 0.0000 0.0000 0.00000 0.00000 0.0000 0.00	weight penalty 1.000 0.000 1.000 0.000
t ecor gamma vtherm sigma sh_esep sh_morm shi_sig_l shi_roorm egamma est_sig_r esh_esep esh_sig_r esh_sig_r	1 2 3 4 5 6 7 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 0.0	v salue 0.0000 0.00000 0.0000 0.0000 0.0000 0.0000000 0.00000 0.00000000	weight penalty 1.000 0.000 1.000 0.000
t ecor gamma vtherm sigma sh_esep sh_morm shi_sig_l shi_roorm egamma est_gama est_esep esh_esep esh_esep esh_sig_l esh_sig_r eshsig_r	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 0.0	v salue 0.0000 0.00000 0.00000 0.0000000 0.00000 0.00000000	weight penalty 1.000 0.000 1.000 0.000
t ecor gamma vtherm sigma sh_esep sh_morm sh_sig_l shi_roorm egamma est_sope esc_morm esigma esh_esep esh_sig_l esh_sig_r esh_sig_r esh_sig_r esh_sig_r	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 16 19 20 20 20 20 20 20 20 20 21 21 3 14 15 16 17 16 19 20 21 0.00	v salue 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.00000 0.00000 0.0000 0.00	weight penalty 1.000 0.000 1.000 0.000

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 \rightarrow 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

German eROSITA Consortium Meeting, Potsdam

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



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:

"IACHEC model" with only 1 free parameter: the global normalization + gain fit (offset) **RXJ1856:**



average reduced χ^2 = 1.31

eROSITA On-ground Calibration and beyond...

Konrad Dennerl

MPE