eROSITA Working Group

Calibration

eROSITA WG Calibration

- original WG member list from May 2011 (with 22 members)
- now starting with a fresh (open) list:

eROSITA Calibration Group Membership

Chair: Konrad Dennerl (kod@mpe.mpg.de)

erocalib members (Feb 5, 2019)			
Name	**First name**	**Institute**	**email**
Brunner	Hermann	MPE	hbrunner@mpe.mpg.de
Burwitz	Vadim	MPE	burwitz@mpe.mpg.de
Dennerl	Konrad	MPE	kod@mpe.mpg.de
Freyberg	Michael	MPE	mjf@mpe.mpg.de
Friedrich	Peter	MPE	pfriedrich@mpe.mpg.de
Meidinger	Norbert	MPE	nom@mpe.mpg.de
Haberl	Frank	MPE	fwh@mpe.mpg.de
Hartner	Gisela	MPE	gih@mpe.mpg.de
Kreykenbohm	Ingo	ECAP	Ingo.Kreykenbohm@sternwarte.uni-erlangen.de
Wilms	Joern	ECAP	Joern.Wilms@sternwarte.uni-erlangen.de

eROSITA WG Calibration

original idea:

work on the calibration

in practice:

- **hardware**: concerns about flight hardware
- **software**: easy tasks can be scripted, sophisticated tasks are really sophisticated and time consuming

mirror calibration (PANTER):
detector calibration (PUMA):
} hardware operated by very few trained people

ground calibration

eROSITA WG Calibration

?

in-orbit calibration

In-orbit calibration subjects

- Commissioning
- Background (graded shield, calibration and monitoring, "Closed", etc.)
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M. Freyberg 2018

eROSITA WG Calibration

Very little attendance: **in total just 3 people!**

(Michael Freyberg, Peter Friedrich, Konrad Dennerl)

Wednesday, 6/3

	Splinters Session II: WG meetings [Neues Palais]
9:00 - 10:30:	CWG5 ; ISM/SNR ; eSASS Q+A
10:30 - 11:00:	*Coffee Break*
11:00 - 12:30:	CWG6 ; TDA+AGN+CO
12:30 - 14:30:	*Lunch Break --> WG Chairs Meeting [Room 1.09.2.12]*
14:30 - 16:00:	CWG7 ; AGN ; TDA ; CAL
16:00 - 16:30:	*Coffee Break*
16:30 - 18:00:	CWG8-AGN Followup ; TDA ; Background

slides from the eROSITA consortium meeting in Hamburg, 2017

What we have calibrated on ground

detector: gain, CTI, RMF, sensitivity (incl. filter)

mirror: effective area, PSF (full focal plane)

may change in space:

different radiation environment

contamination

‚infinite' source distance

possible changes in mirror shapes

What could not be calibrated on ground

precise alignment of the 7 telescopes („boresight“)

„absolute“ timing

what we will not know before launch

radiation environment

→ detector noise → low energy threshold

→ energy range and energy resolution (RMF)

What we should check

e.g., that filters are ok, CCDs are in focus

What should be monitored

contamination, bad pixels

gain, CTI, energy resolution

What is meant by „calibration“ ?

- **Calibration:** derive quantities which have a direct impact on the scientific quality (i.e., derive CCF products to be used by eSASS, high quality data required)
- **Check:** determine whether the calibration is quantitatively acceptable
- **Monitoring:** search for changes in the performance, update calibration parameters (e.g., offset map, contamination, bad pixels, gain, detector noise)
- **Characterization:** get a better understanding of the instrument (e.g., MIP properties, soft proton properties, optical voids in the on-chip filter, optical loading, XUV sensitivity)
- **Recalibration:** repeat the calibration (high quality data required)
- **Cross-“Calibration“:** ideally this should be a verification, but what if it reveals inconsistencies ?

Requirements for in-orbit calibration

General consideration:

An in-orbit calibration/verification measurement makes only sense if its accuracy is high enough to improve/verify the ground calibration

Measurements producing inconclusive results should be avoided

→ a feasibility assessment should be made before each in-orbit calibration observation

→ this can and should be done already now(!)

Examples:

- what will be the maximum photon flux for an on-axis point source which is not affected by pile-up ?
- to which accuracy can a point source be localized ?

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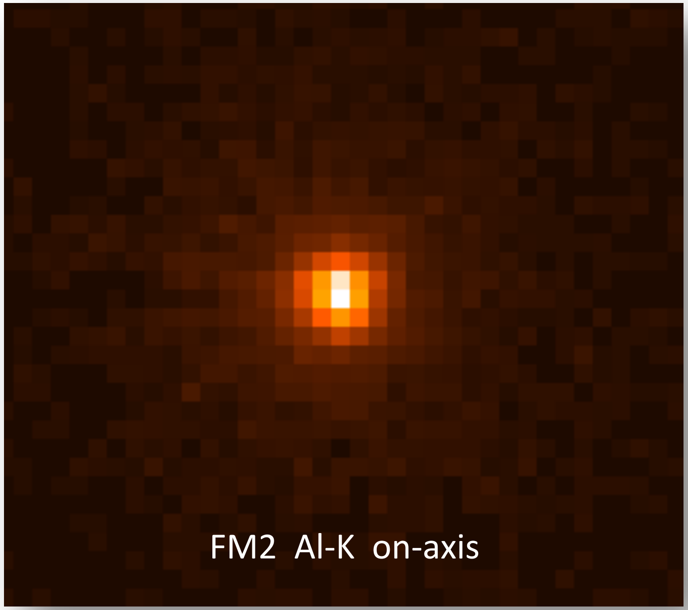
Localization of Point Sources

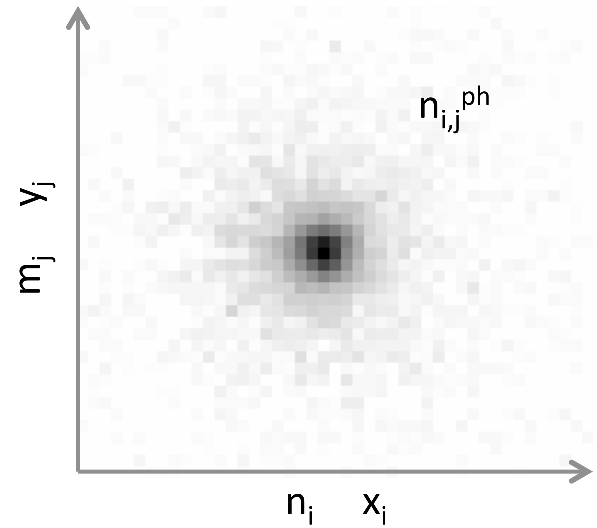
To which (relative) accuracy can a point source be localized ?



Result depends on
- PSF
- number of source photons
- number of background photons
- pixel size
- pointing stability

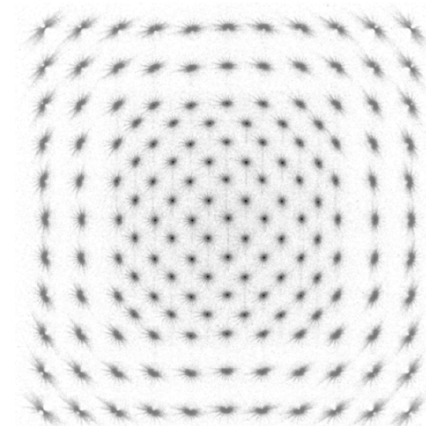
analytical approximation possible
for the center of gravity method..

Localization of Point Sources



Idealized case:

- PSF
- number of source photons
- ~~number of background photons~~
- pixel size
- ~~pointing stability~~



$$\langle x \rangle = \frac{1}{N} \sum_{i=1}^{k} n_i\, x_i \qquad \langle y \rangle = \frac{1}{N} \sum_{j=1}^{\ell} m_j\, y_j$$

$$n_i = \sum_{j=1}^{\ell} n_{i,j}^{\mathrm{ph}} \qquad m_j = \sum_{i=1}^{k} n_{i,j}^{\mathrm{ph}} \qquad N = \sum_{i=1}^{k} n_i = \sum_{j=1}^{\ell} m_j$$

$$\Delta \langle x \rangle \simeq \frac{1}{N} \sqrt{\sum_{i=1}^{k} \left(\left(\frac{[n]x_i - [nx]}{[n]} \right)^2 n_i + 0.217\, n_i^2 \right)}$$

$$\Delta \langle y \rangle \simeq \frac{1}{N} \sqrt{\sum_{j=1}^{\ell} \left(\left(\frac{[m]y_j - [my]}{[m]} \right)^2 m_j + 0.217\, m_j^2 \right)}$$

[unit: pixels]

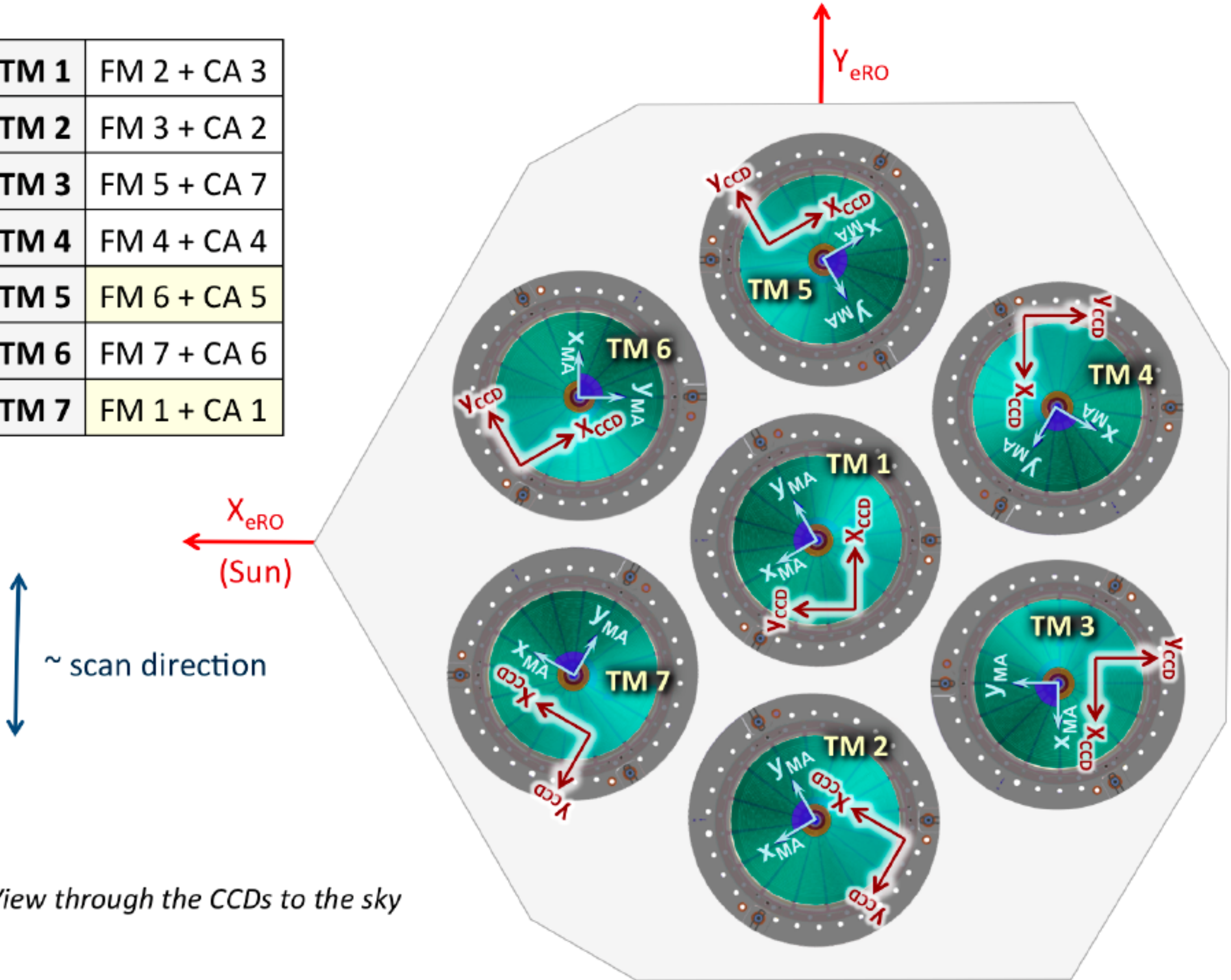
transition	$\langle n_{\mathrm{ph}} \rangle$	1σ error [pixel]			1σ error [arcsec]		
line	PSF	min	mean	max	min	mean	max
C–K	10 615	0.33	**0.49**	0.89	3.2	**4.7**	8.5
Cu–L	27 621	0.22	**0.30**	0.37	2.1	**2.8**	3.6
Al–K	11 593	0.27	**0.35**	0.42	2.6	**3.3**	4.0
Ag–L	9 882	0.32	**0.42**	0.66	3.0	**4.0**	6.3
Ti–K	3 364	0.38	**0.81**	1.69	3.6	**7.8**	16.1
Fe–K	4 760	0.38	**0.76**	1.76	3.6	**7.3**	16.8
Cu–K	3 561	0.39	**0.92**	2.45	3.7	**8.7**	23.3

$$\Delta\,(xy) = \sqrt{(\Delta x)^2 + (\Delta y)^2}$$

→ the 1σ error is at least 2 arcsec*

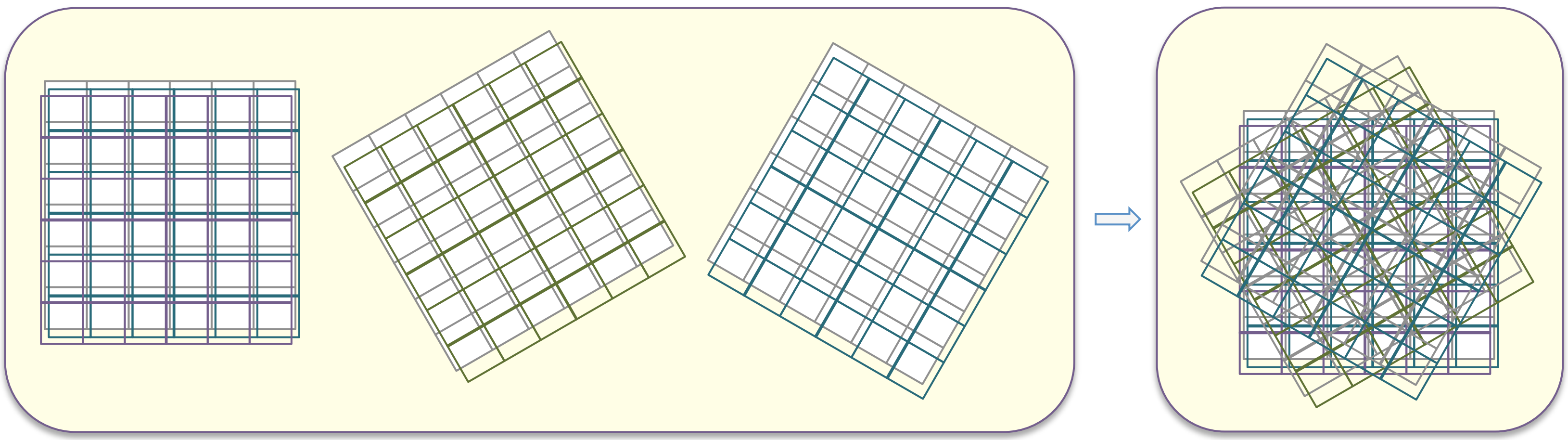
* in pointed observations with one single camera, not utilizing subpixel resolution

TM 1	FM 2 + CA 3
TM 2	FM 3 + CA 2
TM 3	FM 5 + CA 7
TM 4	FM 4 + CA 4
TM 5	FM 6 + CA 5
TM 6	FM 7 + CA 6
TM 7	FM 1 + CA 1



Localization of Point Sources

However, the fact that the same point source will be observed with pixel grids of different orientations and (probably) also different offsets will help in improving the localization accuracy:



TM 1, 3, 4 TM 2, 7 TM 5, 6

.. but this does not help in the determination of the boresight and plate scale, which has to be done individually for each telescope.

perhaps the survey scans may help..

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Decay of the internal calibration source

ordered in **August 2015** with an activity of **750 Mbeq**

assumption at that time: eROSITA launch in 2017

half life time: 2.737 years → activity in **August 2019**: **270 Mbeq (36%)**

Due to limitations of the on-board processor, the time needed for calibration exposures will be longer than the net exposure time until ~2026 (eRO-MPE-TN-55-37, 2017)

→ It is unlikely that the decreasing activity will have a major impact on the required (elapsed) times for calclosed exposures **until ~2026**

Rule of thumb estimates:

1 hour of elapsed time of calclosed exposure requires **2.3 MB of telemetry per camera**

minimum elapsed time for monitoring: **2 hours** (sufficient for gain determination at Ti-K)

minimum elapsed time for calibration: **1 day** (sufficient for CTI determination at Ti-K)

- immediately after the commissioning phase: 1 calibration exposure of 1 day each per camera
- during CalPV: ~4 monitoring exposures of 2 hours each
- after the CalPV phase: 1 calibration exposure of 1 day each per camera

- during the survey phase: 1 calibration exposure of 1 day each per camera every ~6 months (but better not exactly at 6 months intervals, to avoid deep exposure drops in the survey)

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