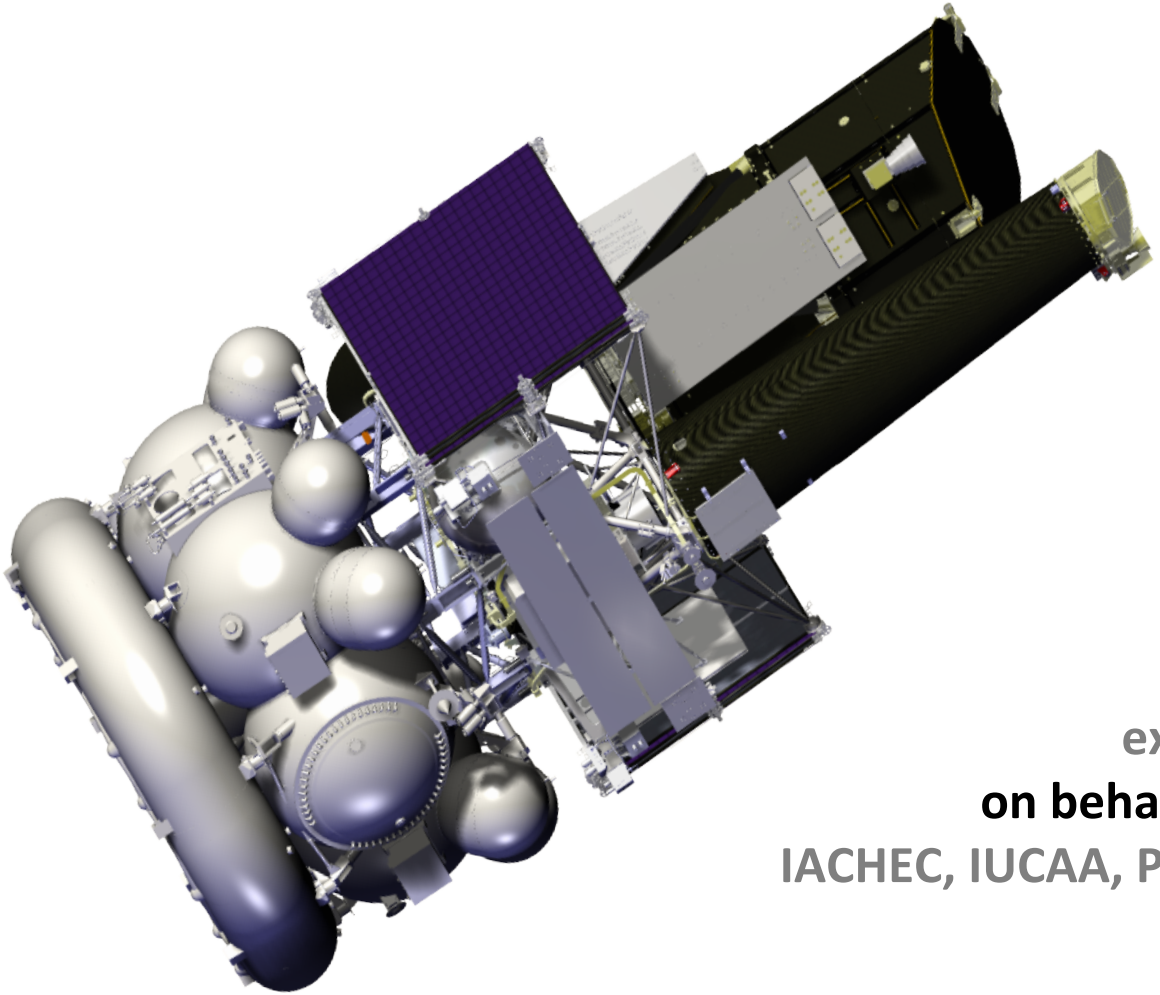
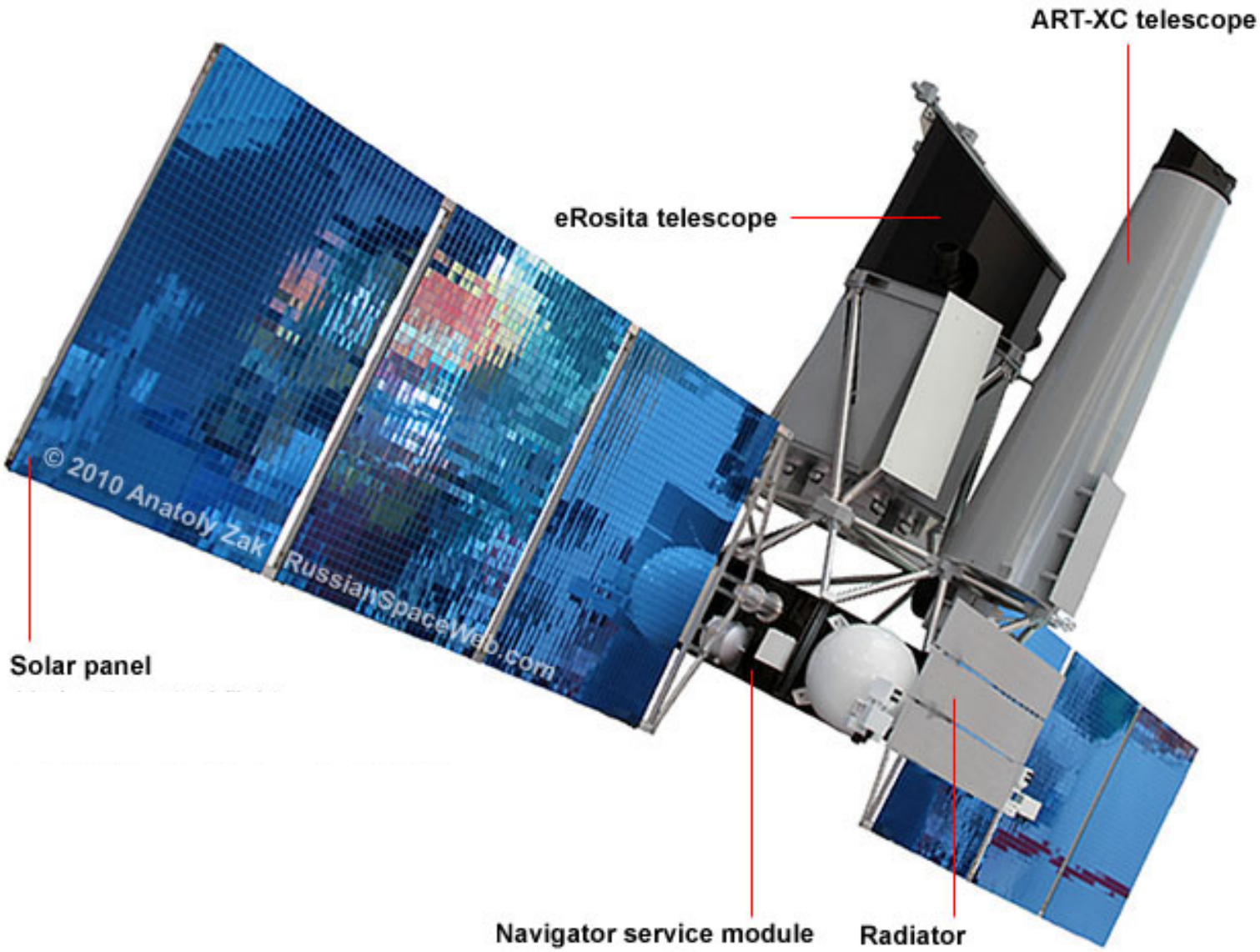
The eROSITA X-ray Telescope: Calibrating the Mirrors and Detectors „eROSITA calibration status“

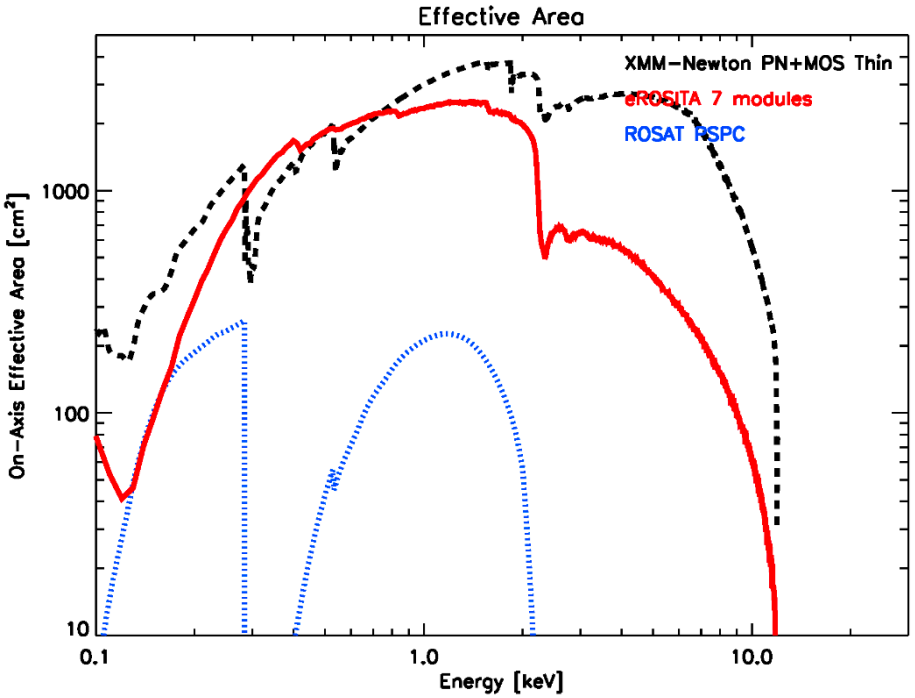


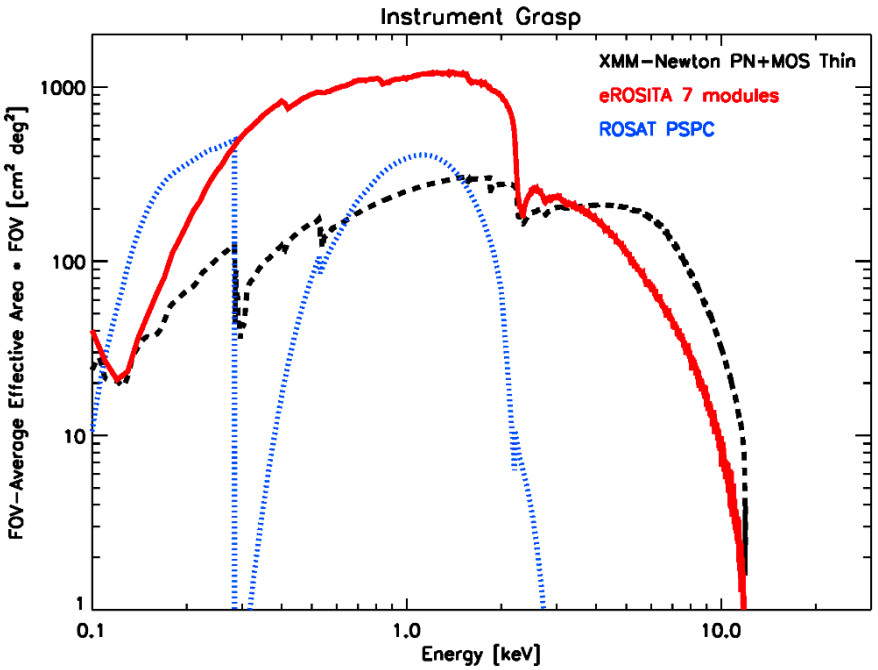
Vadim Burwitz
Max-Planck Institut für extraterrestrische Physik
on behalf of the eROSITA Team
IACHEC, IUCAA, Pune, India 29-Feb-2016

Spektr-Rentgen-Gamma (SRG)



eROSITA – Effective Area and Grasp

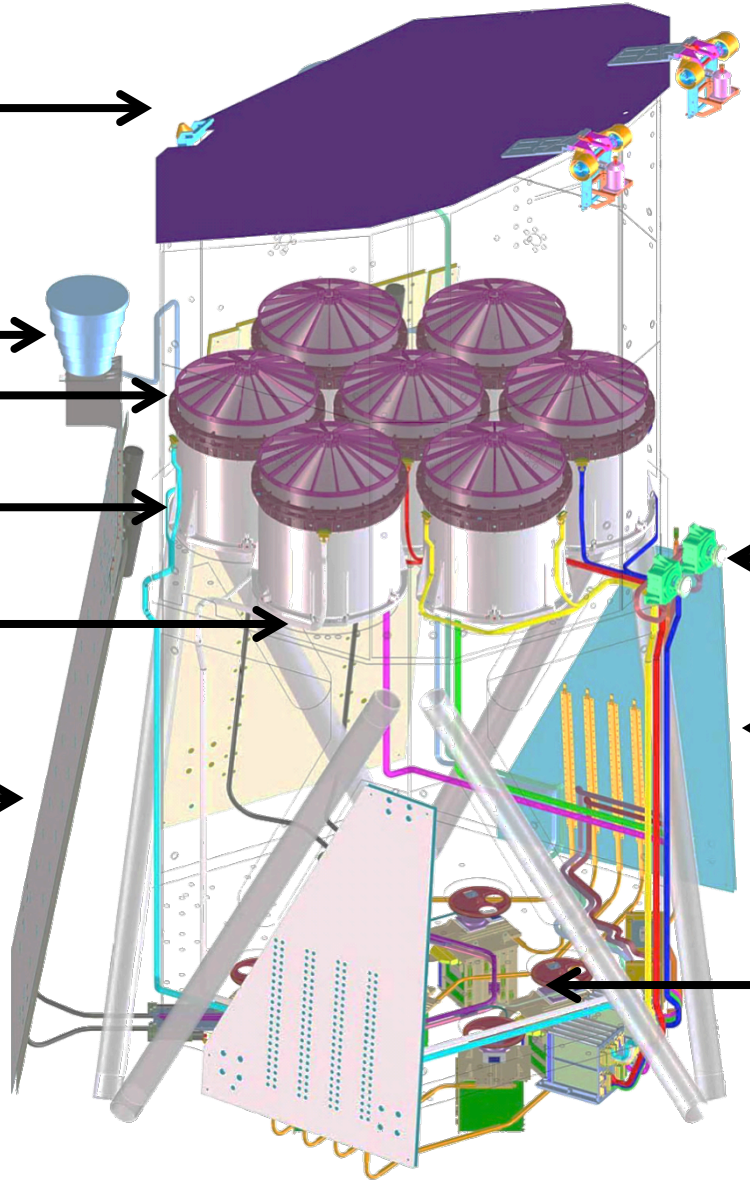




- Effective area at 1keV comparable with XMM/Newton
- Factor ~7-8 larger surveying speed
- 4 years dedicated to all sky survey (with estimated 70-80% efficiency)

Energy range 0.3keV to 10 keV
Energy resolution 50ev@0.3keV, 137ev@6.4 keV

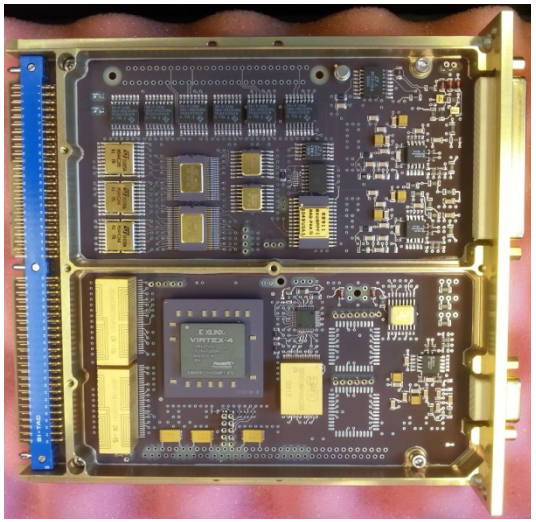
eROSITA - Schematic View



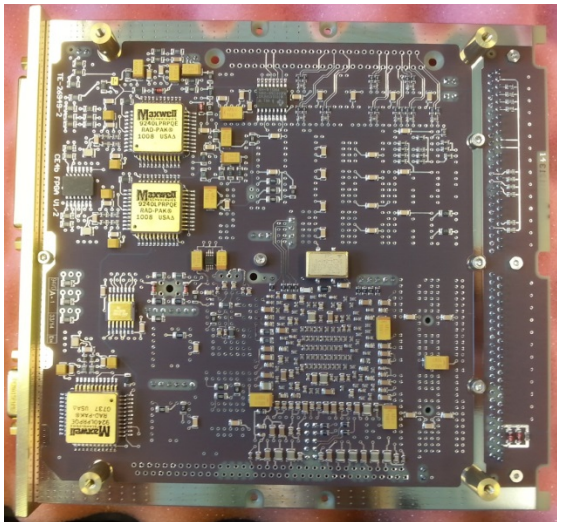
FM Hardware Status

	February 2016
Mirror Modules (8)	FM Calibration ongoing
X-ray Baffles (8)	ready
Electron Deflectors (8)	ready
Filterwheels (8)	ready
Camera Mechanics (8)	ready
Electronics Boxes (10 FM)	ready
Electronics Heatpipes (9)	ready
Harness	ready, outgas. just prior integ.
MLI	ready
Heatpipe System Camera	ready
Telescope Structure	ready
Radiators (4)	ready
CCD-Modules (11)	ready
Electronics	CE FM Tests ongoing

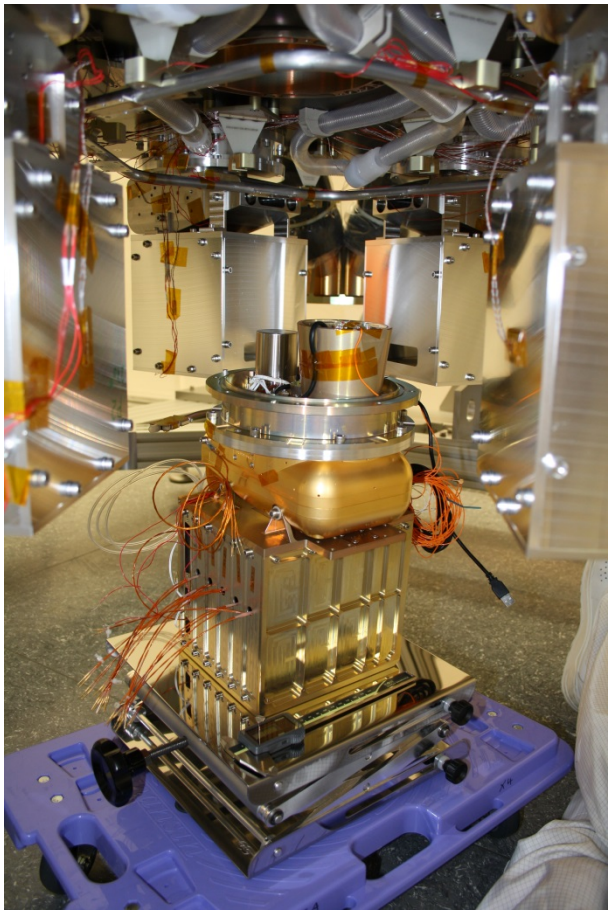
Electronics Manufacturing



frontside



backside



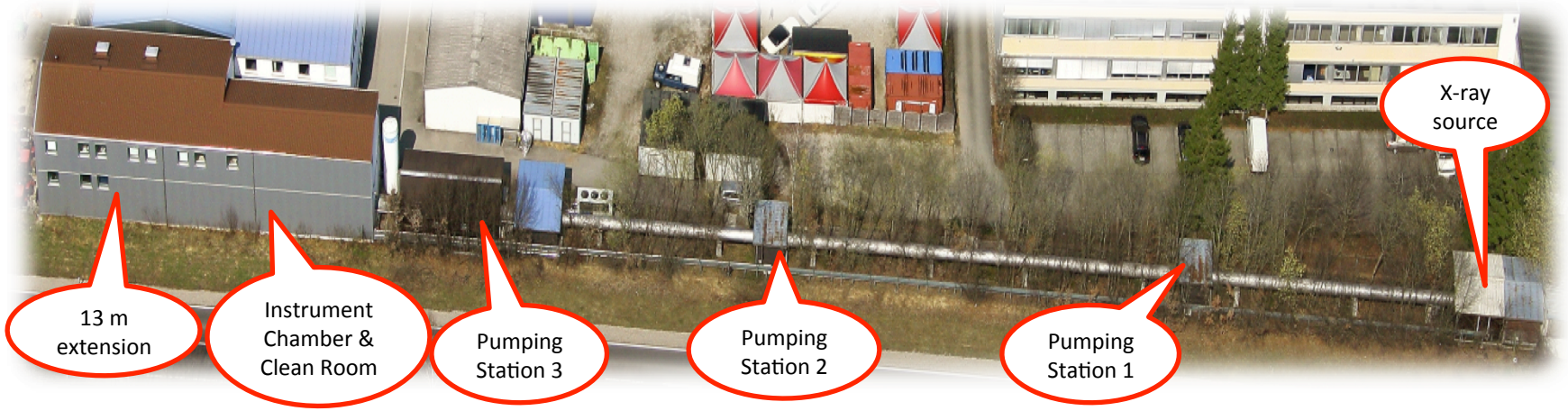
83 Circuit Boards (FM + FS + QM)
~35.000 components

Qualification Tests & Calibration

Vibration	MPE Shaker, IABG
Acoustic Noise	IABG
EMC	MPE, IABG
Thermal Vacuum	MPE: TVK2,4,5, PUMA, PANTER, IABG
Calibration	**MPE: GEPARD, PUMA, PANTER**

The MPE PANTER X-ray Test Facility

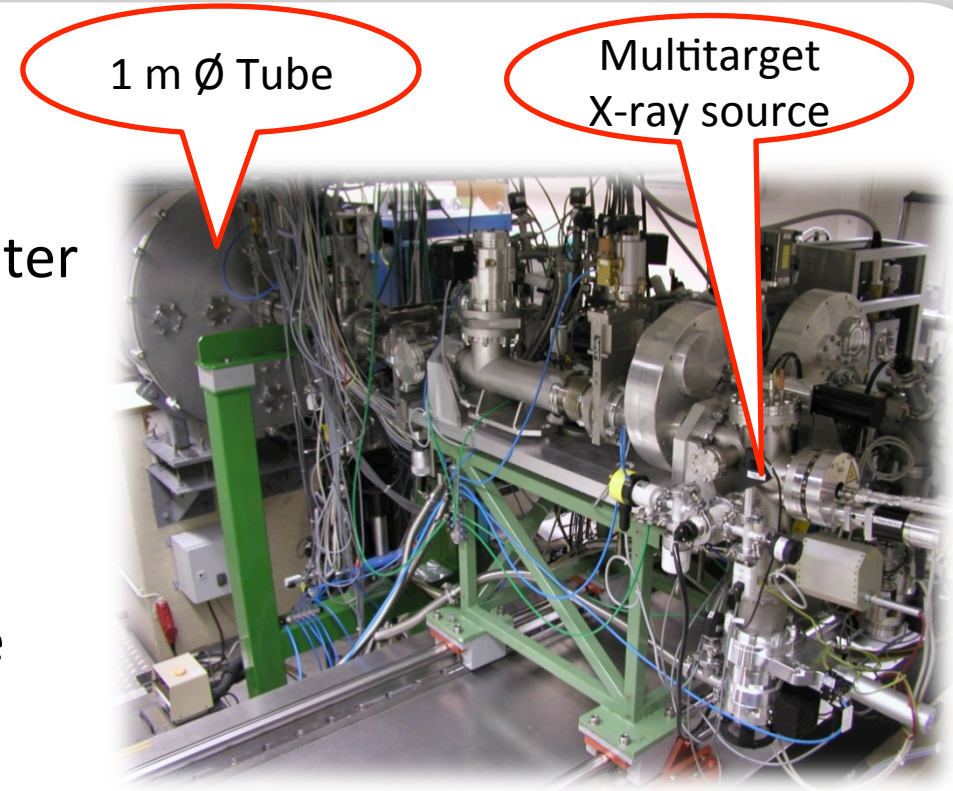
- Located in Neuried, south west of Munich
- 120 m X-ray beamline, 1 m diameter
- 12 m instrument chamber, 3.5 m diameter
- Large cleanroom for handling X-ray optics
- Movable 10 m extension with 0.25 m diameter and 3 m instrument chamber, 1.2 m diameter



PANTER X-ray sources

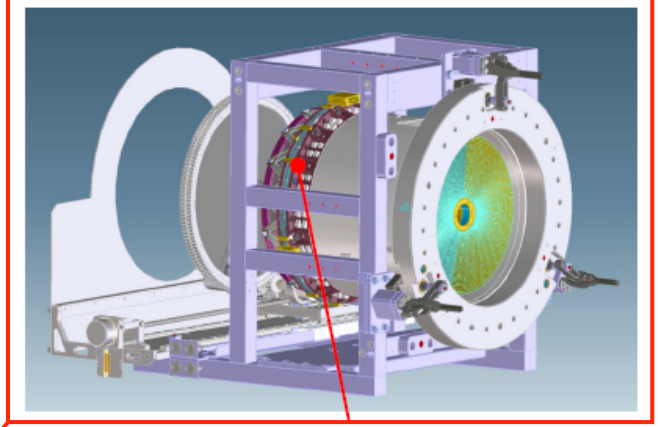
Homogeneous Beam →
up to 1m diameter
Source size → 1mm → 1“

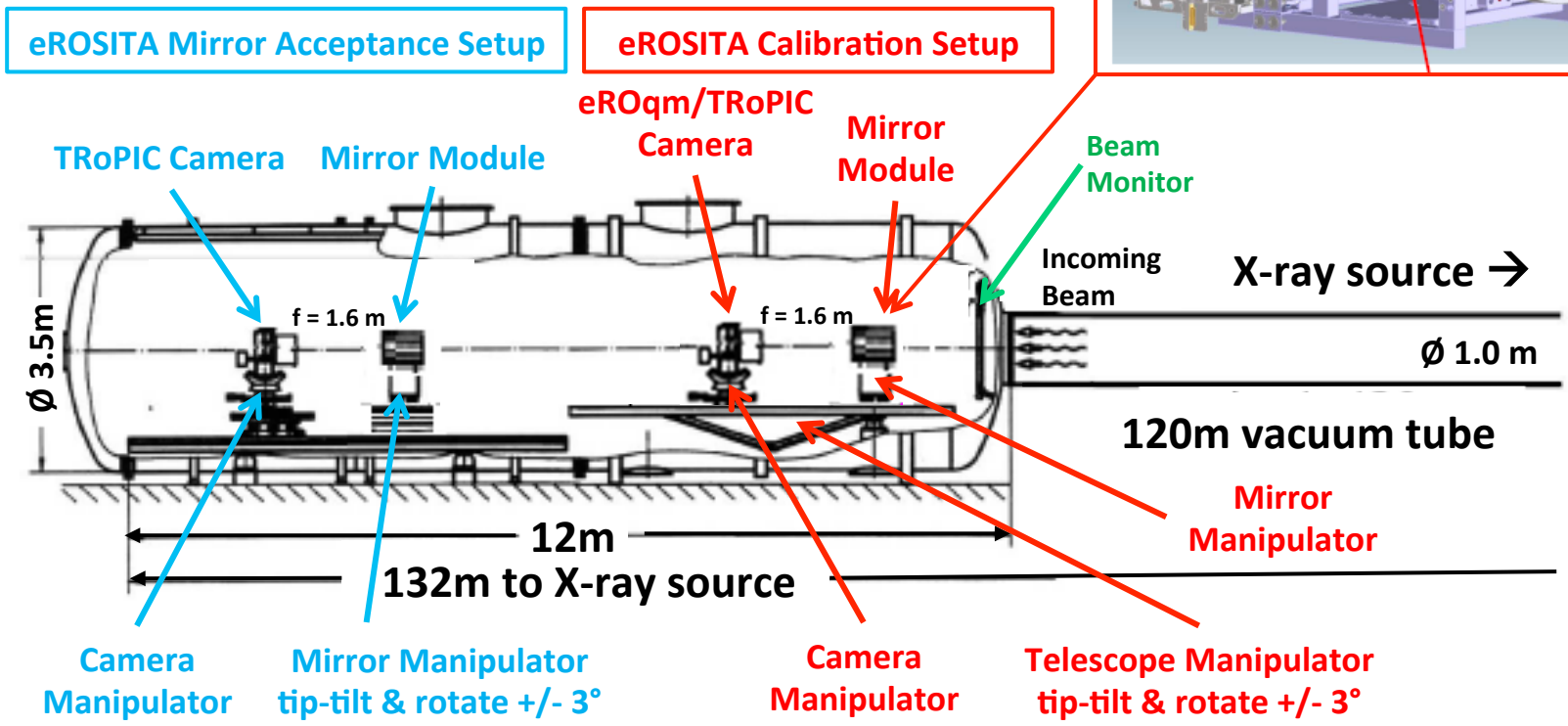
- Open multi target -
  electron impact source
  → up to 0.18 - 10 keV
- Seifert closed X-ray source
  → up to 40keV
- X-ray Monochromators
  - Double Crystal
  - Reflection Grating



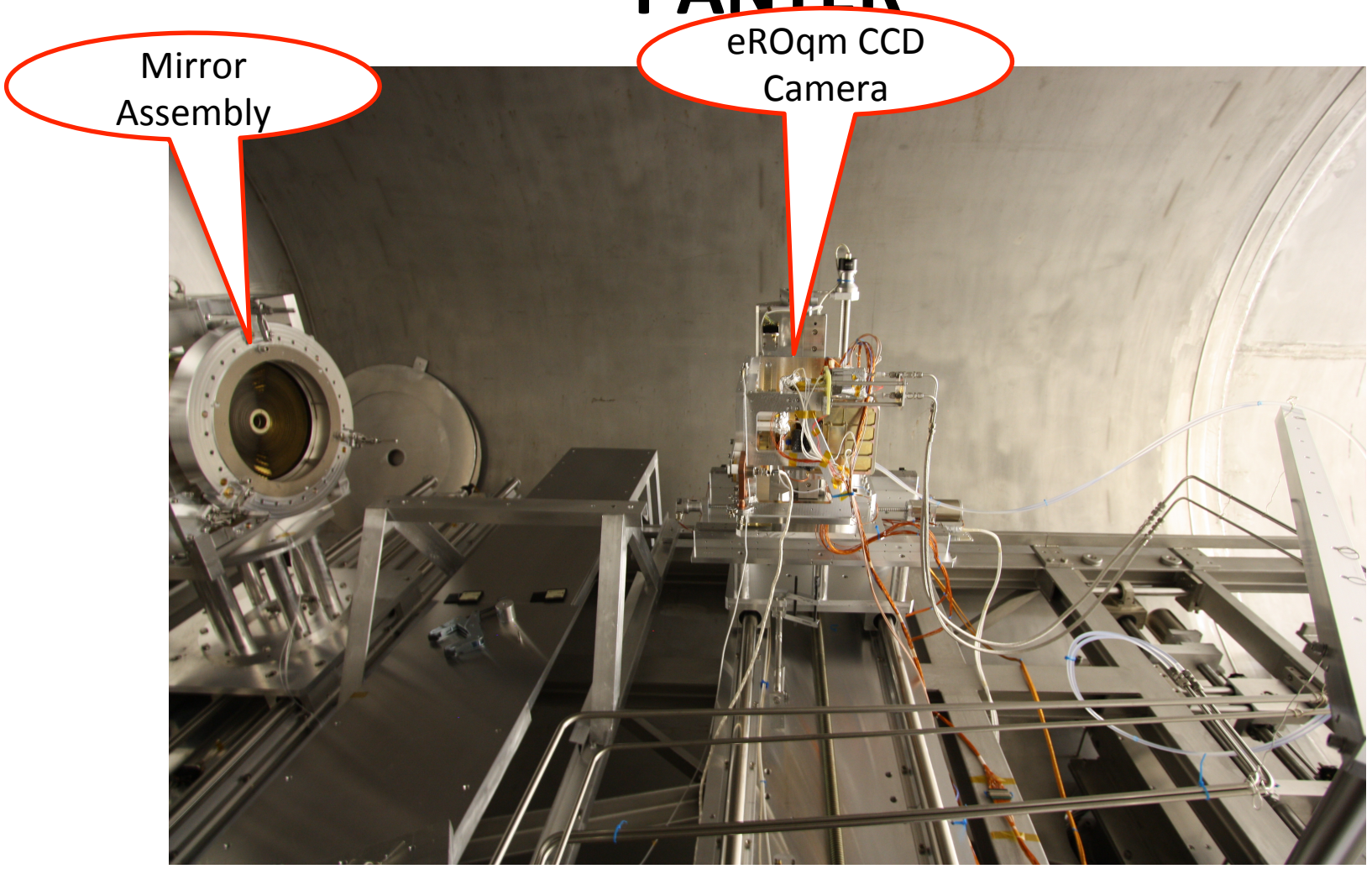
View of the X-ray sources at PANTER

eROSITA Mirror Tests at the PANTER test Facility





Calibrating the eROSITA X-ray Optics at PANTER



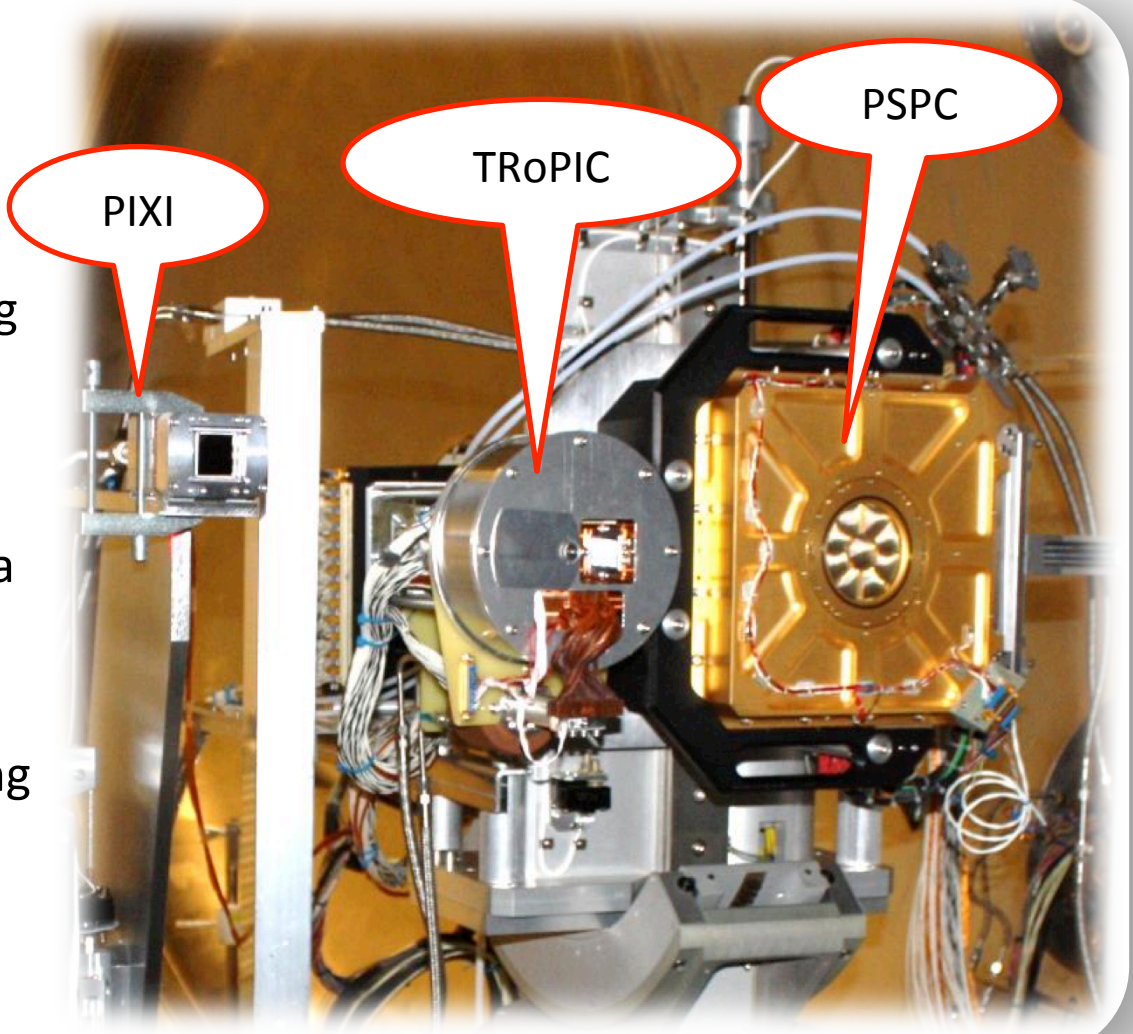
The PANTER Detectors

PSPC : Position Sensitive Proportional Counter
f.o.v. 80 mm diameter

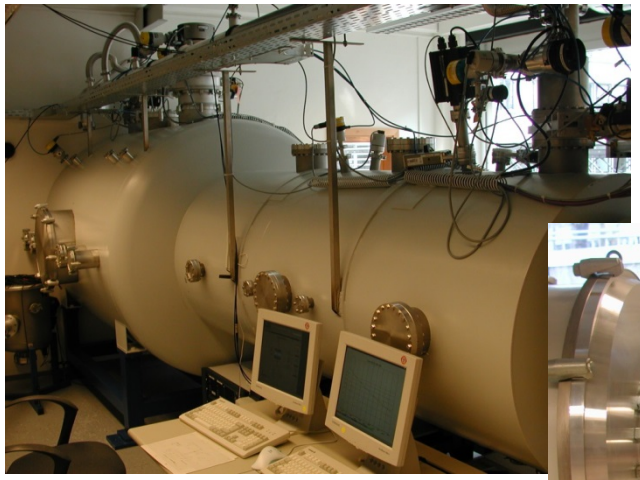
TRoPIC : Single photon counting CCD camera
75µm x 75 µm pixels
f.o.v. 19 mm x 19 mm

PIXI : Integrating CCD Camera
20 µm x 20 µm pixels
f.o.v. 26 mm x 26 mm

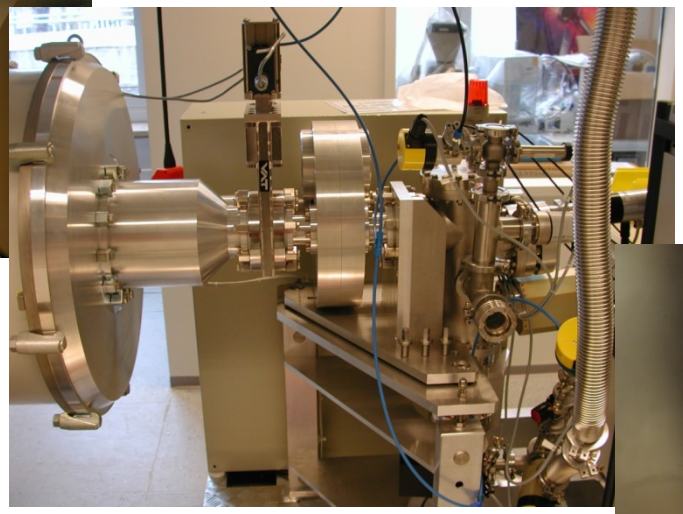
eROqm : Single photon counting CCD camera
75µm x 75 µm pixels
f.o.v. 27 mm x 27 mm



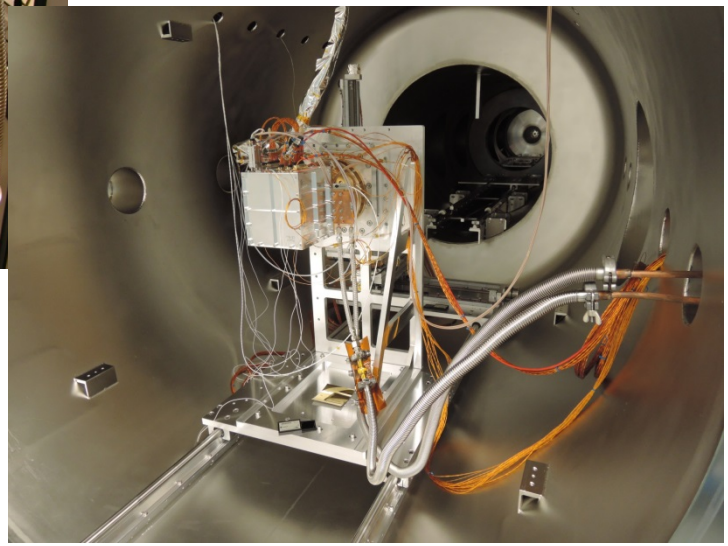
PUMA Facility



Vacuum: p = 2×10^{-7} mbar
StirlingCooler: T < -120°C
2nd cooler for electronics



Multitarget X-ray Source
Double Filterwheel
charact. lines 0.3keV – 10keV

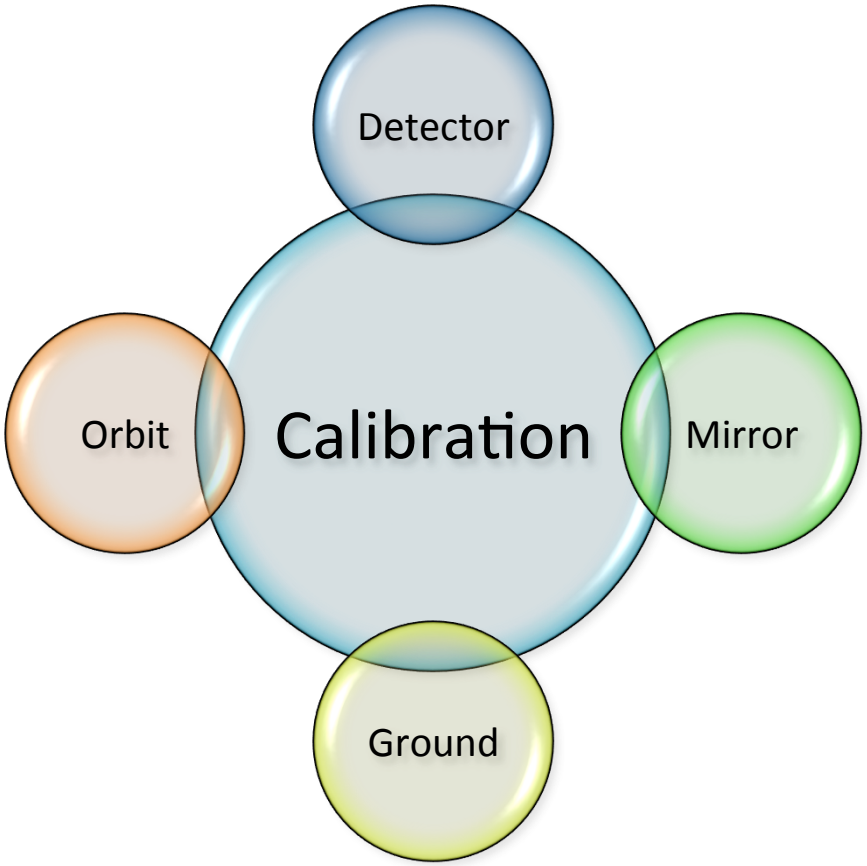


eROSITA QM camera for testing in PUMa

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

device	*process*	*signal*	*characteristic properties*	
telescope	reflection (scattering)	*photon [eV]*	effective area (E,φ) point spread function (E,φ) field of view (FOV) boresight	collecting area, reflectivity, vignetting mirror quality focal length, detector geometry, plate scale alignment
filter	absorption		transmission (E) contamination (E,t)	filter thickness, spatial homogeneity temporal behaviour
CCD	charge release	*charge [e^-]*	charge splitting low energy threshold	**patterns** (singles, doubles, triples, quadruples, invalid..)
			contaminating effects	**pile-up** (single pixel, pattern) **photon background** (fluorescence, optical loading) **particle induced background** (soft protons, MIPs) **detector induced background** (noise, bright pixels)
			quantum efficiency (QE) energy resolution (ΔE)	
	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]*	energy offsets (offset map) common mode correction signal extraction MIP suppression	**restrictions likely due to limitations in on-board computing power and telemetry** (low energy threshold, MIPS..)

General concept of the eROSITA calibration



FM Mirror Calibration

Sequence of Activities:

1. Focus search
2. Deep in-focus (HEW)
3. Focal plane mapping
4. Effective Area
5. Focal length (mechanical gage)

- FM1 done
- FM2 done
- FM3 nearly done
- FM4 starting this week

- Calibration needs ~ 2 weeks / mirror

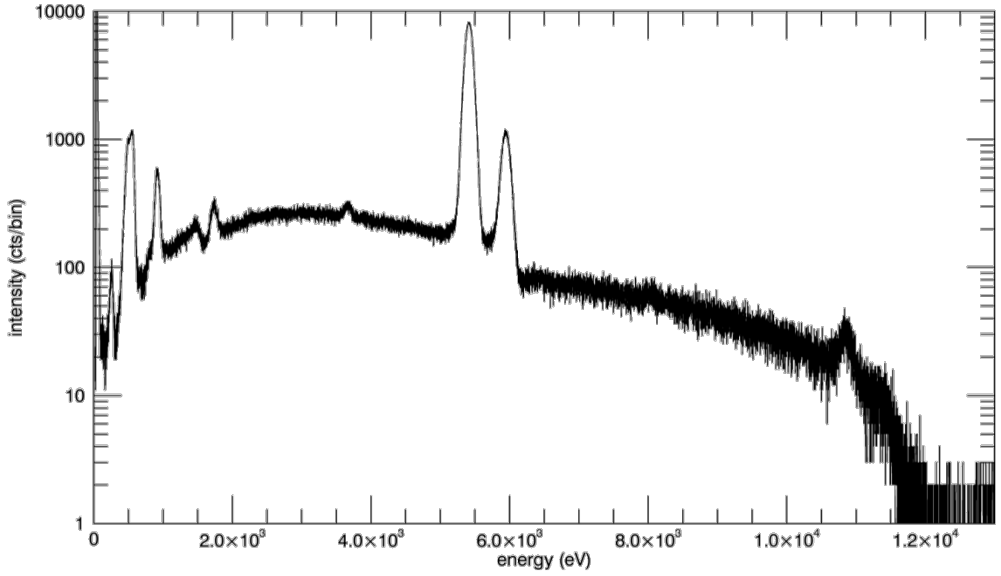
The Cameras

- 7 framestore pn CCDs developed at MPE
- 50 ms frame time
- Sensitive in the 0.2-10 keV
- 5 CCDs with on chip Al-filter 2 without
- Filterwheel with Al, PI filters and
  Fe55 calibration source
- Energy Resolution 50eV@0.3keV 157eV@6.4keV

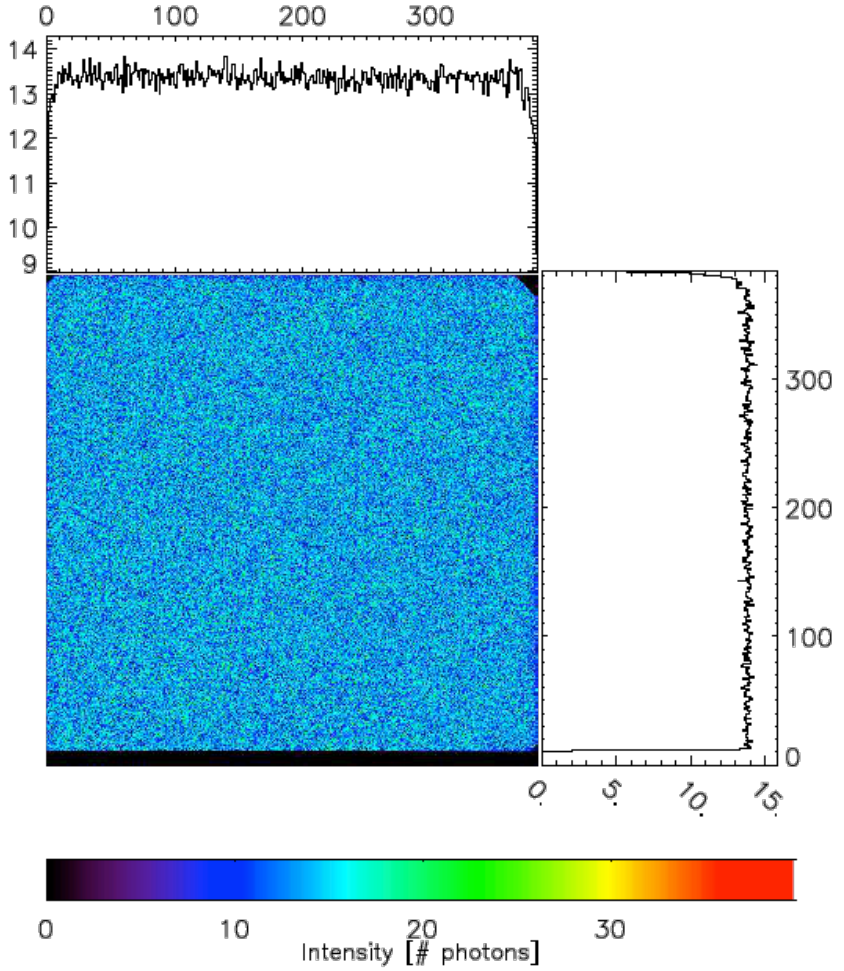
CCD Detector specifications

High Spectral Resolution

Cr-Kα 136eV FWHM
Cu-L 70eV FWHM



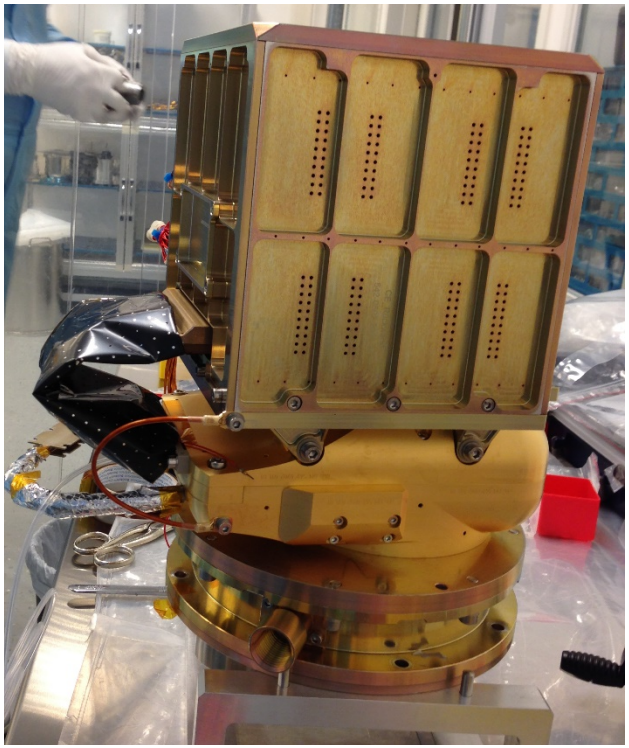
Very Uniform CCD



FM Camera Test & Calibration

Sequence of Activities:

1. Electronics Test („carousel“)
2. E-Box assembly, outgassing
3. Test with CCD-Module #9 (GEPARD facility)
4. Camera Assembly (CE, CA, FR) → PUMA facility
5. TV Test
6. EMC Test (conducted)
7. Calibration (9 different X-ray energies)
8. Vibration (1 axis)

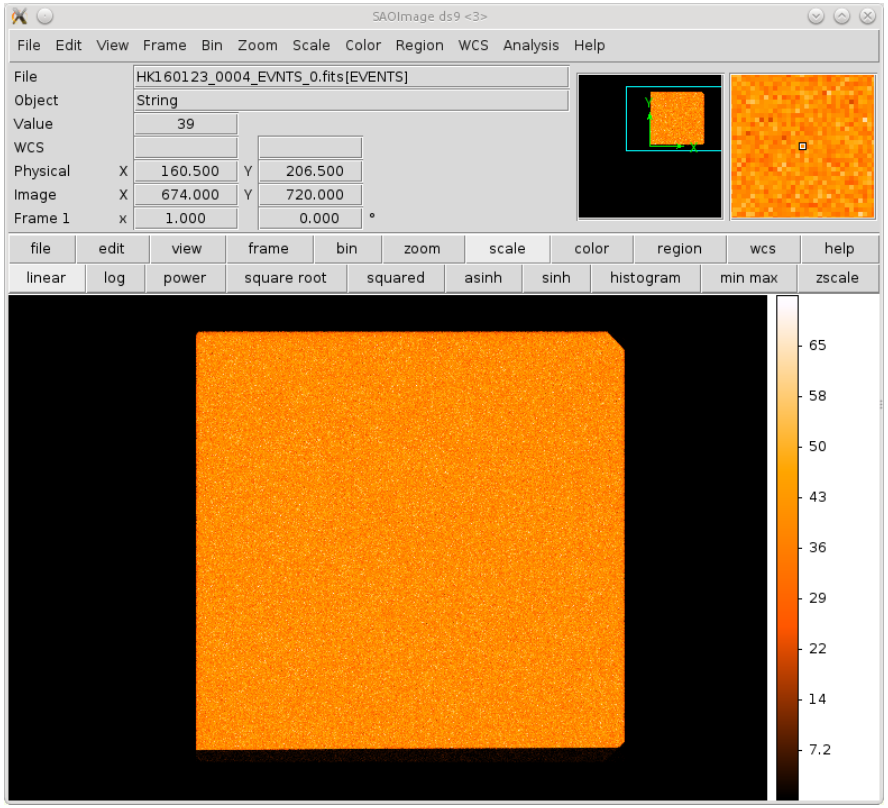


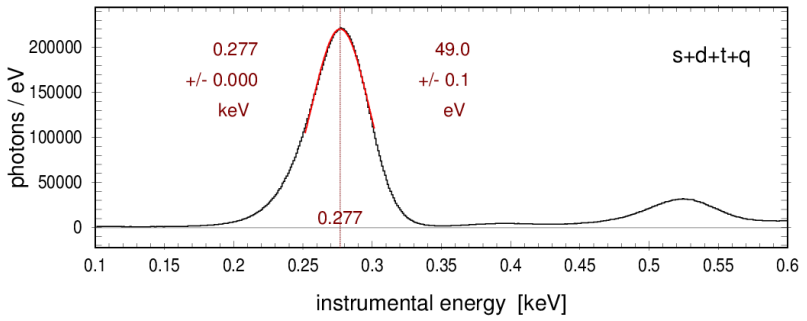
- All PUMA tests need 2 weeks

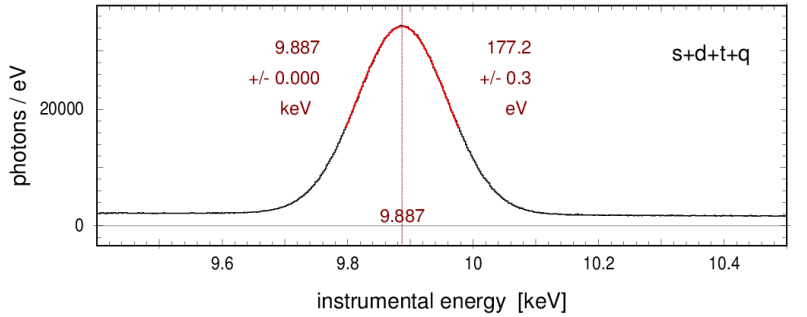
- FM1 done additional activities: Vib (qual.), EMC (rad.)
- FM2 done
- FM3 in progress (at 7.)
- FM4 in progress (at 2.)
- FM5 in preparation

FM Camera Calibration

- Spectral resolution at all 9 measured energies well within specification
- Extremely good uniformity
- Only weak dependence on temperature of CCD and electronics (unlike XMM-EPIC!)

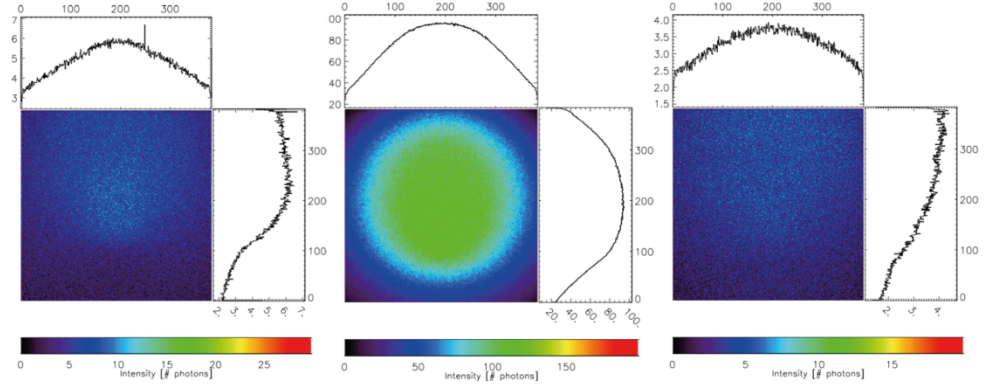


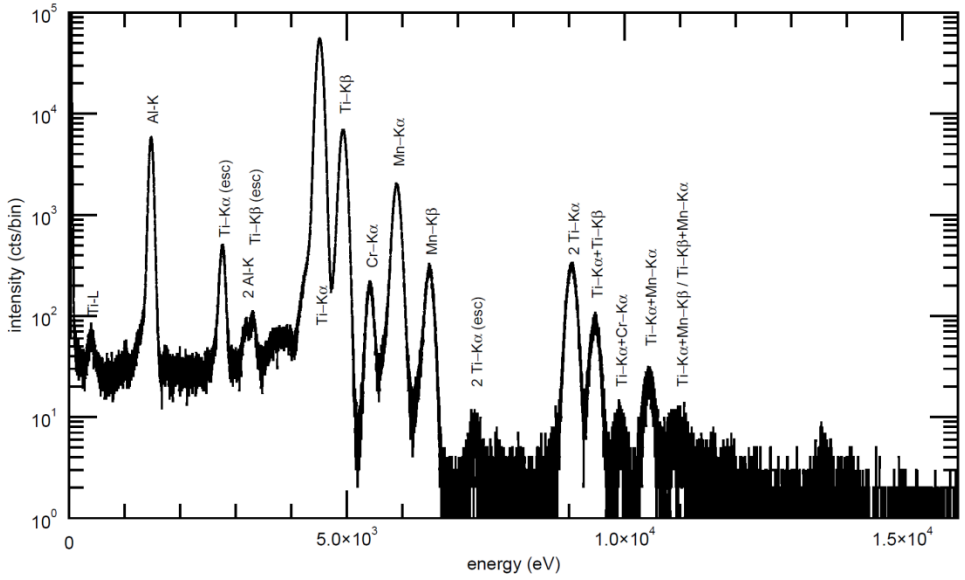




Onboard Fe 55 Calibration Source

Al Kα Ti Kα Mn Kα





Summary of detector calibration measurements

data set name	transition	energy	thresholds	exposure	cal signal	quality	events	frames	ev/fr
HK150825 0028	B–K	0.18 keV	100 adu, 3σ	7534 s	18.7 fs/px				
HK150825 0029	B–K	0.18 keV	100 adu, 3σ	6911 s	17.1 fs/px				
HK15082829_B-K	(O–K)	0.18 keV	100 adu, 3σ	14444 s	5.6 fs/px	-	22 086 110	288 881	76.5
HK150824 0067	C–K	0.28 keV	105 adu, 3σ	2385 s	2.4 fs/px				
HK150825 0011	C–K	0.28 keV	105 adu, 3σ	11322 s	10.1 fs/px				
HK15082425_C-K	C–K	0.28 keV	105 adu, 3σ	13707 s	12.5 fs/px	ok	28 930 175	274 133	105.5
HK150826 0028	N–K	0.39 keV	105 adu, 3σ	7177 s	1.6 fs/px				
HK150826 0029	N–K	0.39 keV	105 adu, 3σ	9295 s	2.0 fs/px				
HK150826 0030	N–K	0.39 keV	105 adu, 3σ	8210 s	1.6 fs/px				
HK15082626_N-K	N–K	0.39 keV	105 adu, 3σ	24682 s	5.3 fs/px	ok	10 368 639	493 634	21.0
HK150827 0023	Ti–L	0.45 keV	105 adu, 3σ	7340 s	4.8 fs/px				
HK150827 0026	Ti–L	0.45 keV	105 adu, 3σ	5486 s	2.4 fs/px				
HK150827 0028	Ti–L	0.45 keV	105 adu, 3σ	4414 s	2.9 fs/px				
HK150827 0029	Ti–L	0.45 keV	105 adu, 3σ	1498 s	1.0 fs/px				
HK15082727_TiL	Ti–L	0.45 keV	105 adu, 3σ	18737 s	11.0 fs/px	ok	26 346 870	374 738	70.3
HK150828 0009	O–K	0.53 keV	105 adu, 3σ	7233 s	17.2 fs/px				
HK150828 0010	O–K	0.53 keV	105 adu, 3σ	2294 s	5.4 fs/px				
HK15082828_O-K	O–K	0.53 keV	105 adu, 3σ	9527 s	22.6 fs/px	ok	21 990 187	190 540	115.4
HK150825 0036	Cu–L	0.93 keV	105 adu, 3σ	6212 s	7.8 fs/px				
HK150825 0037	Cu–L	0.93 keV	105 adu, 3σ	3141 s	4.0 fs/px				
HK15082525_CuL	Cu–L	0.93 keV	105 adu, 3σ	9353 s	11.8 fs/px	ok	21 217 145	187 051	113.4
HK150826 0020	Mg–K	1.25 keV	105 adu, 3σ	4740 s	7.1 fs/px				
HK150826 0021	Mg–K	1.25 keV	105 adu, 3σ	4379 s	6.5 fs/px				
HK15082626_MgK	Mg–K	1.25 keV	105 adu, 3σ	9119 s	13.7 fs/px	ok	21 571 766	182 370	118.3
HK150824 0065	Al–K	1.49 keV	105 adu, 3σ	1202 s	1.8 fs/px				
HK150824 0073	Al–K	1.49 keV	105 adu, 3σ	5468 s	9.1 fs/px				
HK150824 0074	Al–K	1.49 keV	105 adu, 3σ	5384 s	9.0 fs/px				
HK15082424_AlK	Al–K	1.49 keV	105 adu, 3σ	12056 s	10.0 fs/px	ok	27 513 100	241 117	114.1
HK150827 0005	Ti–K	4.51 keV	105 adu, 3σ	7187 s	5.2 fs/px				
HK150827 0006	Ti–K	4.51 keV	105 adu, 3σ	3848 s	2.8 fs/px				
HK15082727_TiK	Ti–K	4.51 keV	105 adu, 3σ	11035 s	8.0 fs/px	ok	24 573 841	220 702	111.3
HK150828 0016	Cr–K	5.41 keV	105 adu, 3σ	7473 s	5.4 fs/px				
HK150828 0017	Cr–K	5.41 keV	105 adu, 3σ	7715 s	5.4 fs/px				
HK150828 0018	Cr–K	5.41 keV	105 adu, 3σ	6436 s	4.7 fs/px				
HK15082828_CrK	Cr–K	5.41 keV	105 adu, 3σ	21624 s	15.3 fs/px	ok	47 416 959	432 476	109.6
HK150827 0012	Fe–K	6.40 keV	105 adu, 3σ	10005 s	7.1 fs/px				
HK150827 0013	Fe–K	6.40 keV	105 adu, 3σ	4347 s	3.1 fs/px				
HK15082727_FeK	Fe–K	6.40 keV	105 adu, 3σ	14352 s	10.1 fs/px	ok	31 362 050	287 037	109.3
HK150825 0021	Cu–K	8.04 keV	105 adu, 3σ	7122 s	4.8 fs/px				
HK150825 0022	Cu–K	8.04 keV	105 adu, 3σ	8337 s	5.6 fs/px				
HK15082525_CuK	Cu–K	8.04 keV	105 adu, 3σ	15459 s	10.4 fs/px	ok	34 390 219	309 177	111.2
HK150826 0009	Ge–K	9.89 keV	105 adu, 3σ	7053 s	3.0 fs/px				
HK150826 0010	Ge–K	9.89 keV	105 adu, 3σ	5518 s	2.3 fs/px				
HK15082626_GeK	Ge–K	9.89 keV	105 adu, 3σ	12570 s	5.3 fs/px	ok	26 008 923	251 403	103.5

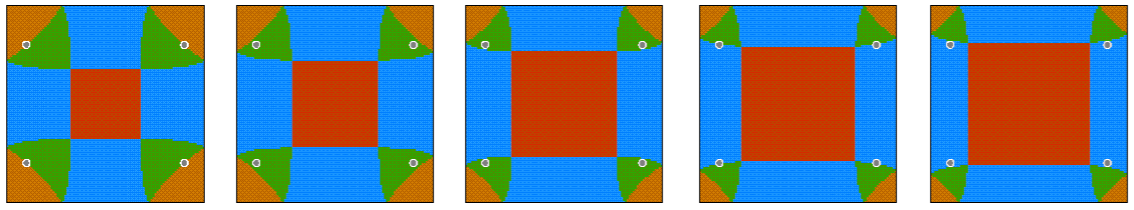
Table 2. Overview of the measurements for the eROqm calibration at PANTER. A total of 343 775 984 events was recorded. fs/px: number of first singles per pixel, ev/fr: number of events per frame

Summary of detector calibration measurements

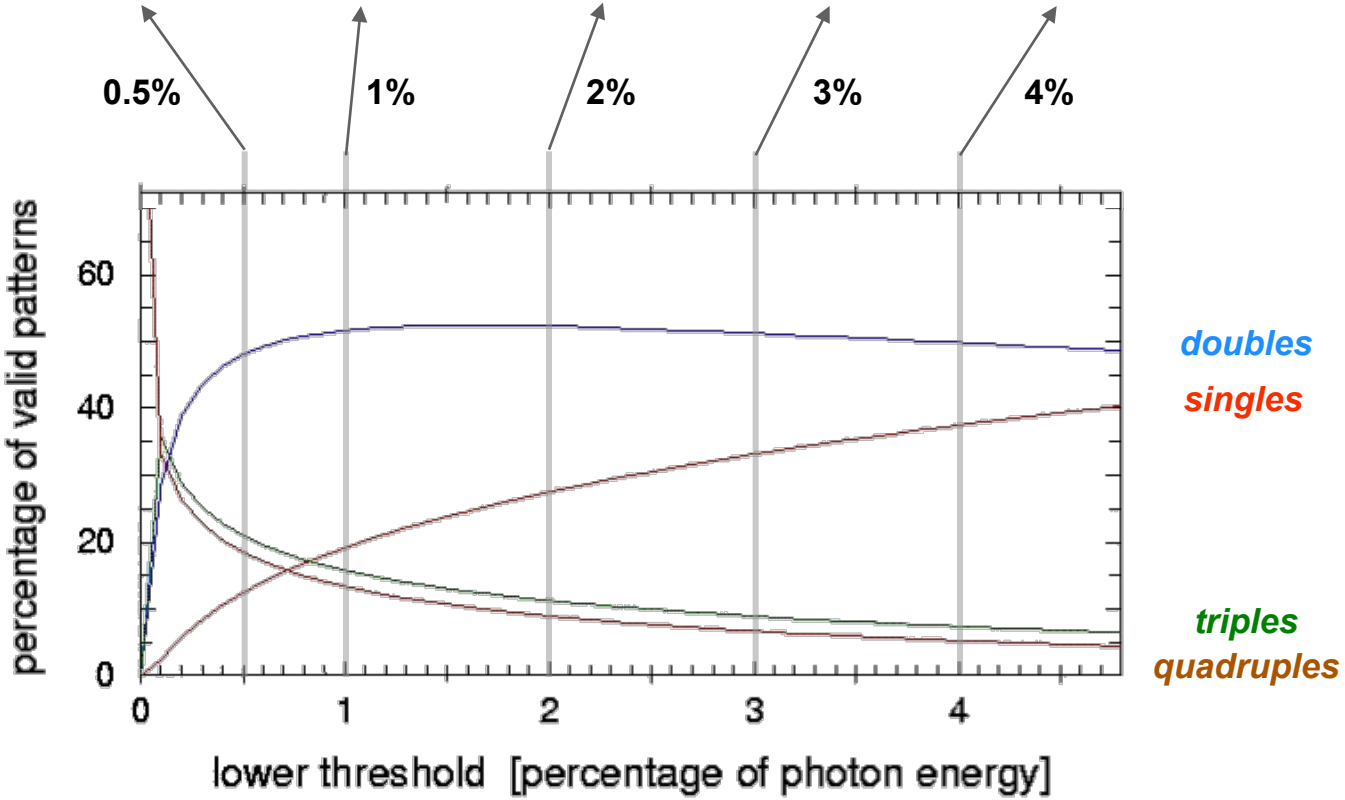
- At least 8 energies from C-K to Ge-K have to be measured
- ~30 million events per energy with
  - no pile-up
  - enough first singles (~10/pixel)
  - low continuum
- In total about one week of measurements per camera is needed at PUMA

Predicted subpixel regions

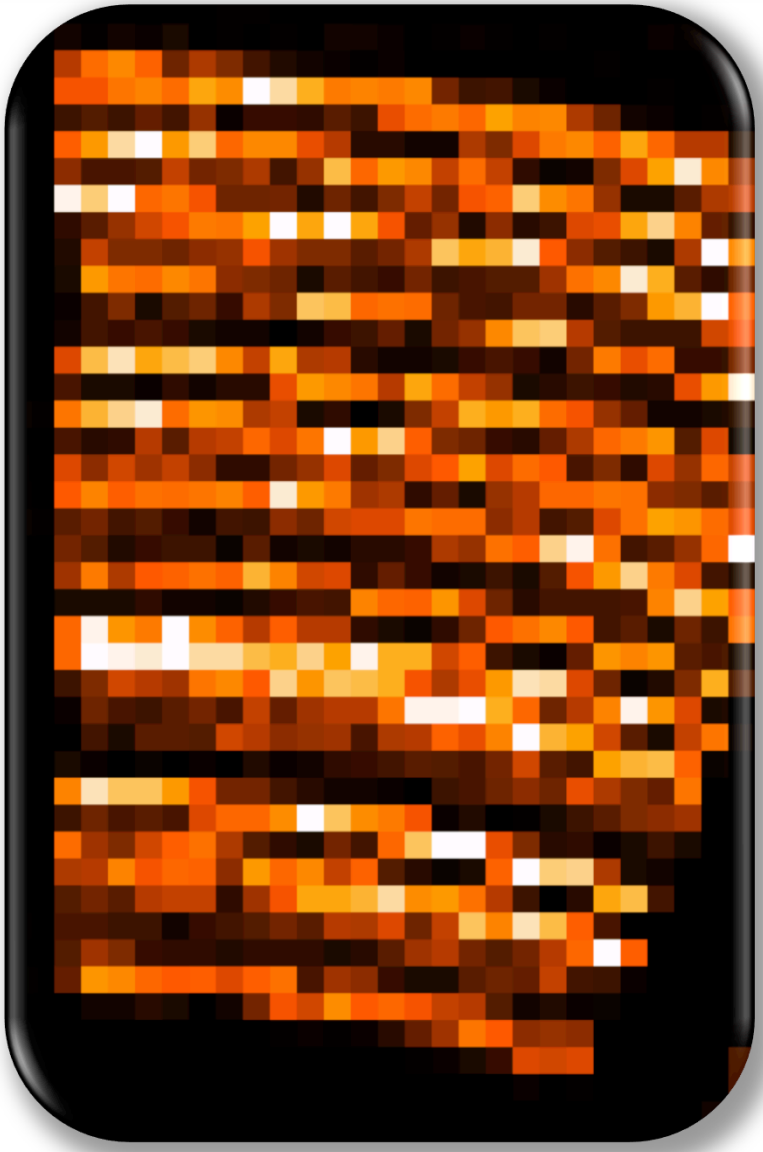
singles
doubles
triples
quadruples

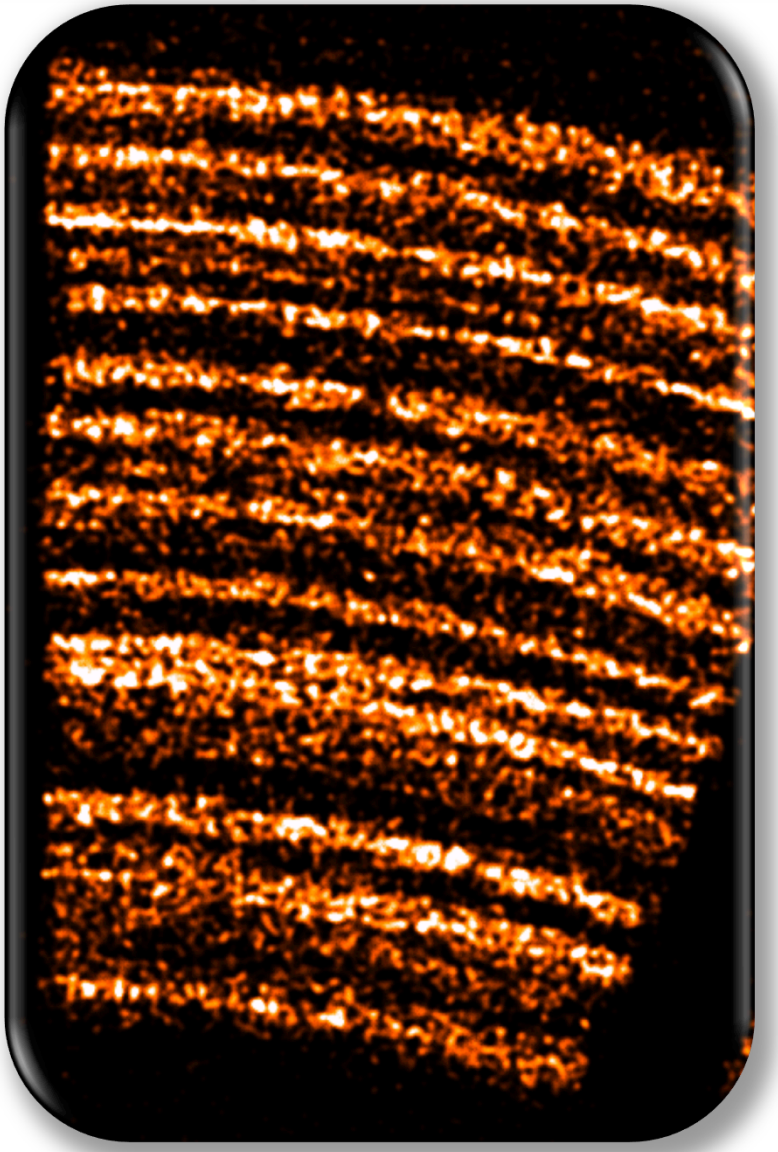


only one parameter: low energy threshold [%]



Comparison of X-ray CCD images without and with subpixel resolution





Mirror Module Calibration: Overview

PSF – on-axis → verification of performance
– off-axis mapping → Input for SASS and simulations
(shapelet reconstruction of PSF)

Effective Area (on- /off-axis) → Input for SASS and for more realistic simulations, for prediction of sensitivity, number of detectable objects
(difficult / time consuming in orbit)

Focal length → Essential input for positioning of the cameras in focus, tolerance <0.2 mm

eROSITA Mirror Module FMs

Performance Summary from Acceptance Tests

	Specification		Acceptance Test							
	Orbit	Derived for PANTER	FM 1	FM 2	FM 3	FM 4	FM 5	FM 6	FM 7	FM 8
			Dec 2012 / Jan 2013	Mar 2013	May 2013	Sep 2013 / Oct 2013	Sep 2013	Dec 2013	Dec 2013	Jun 2013
HEW Al-K (1.49 keV)	< 15''	< 15''	16.1''±0.2''	16.8''±0.3''	15.7''±0.3''	16.0''±0.3''	16.2''±0.2''	16.3''±0.3''	15.6''±0.3''	17.1''±0.3''
HEW Cu-K (8.04 keV)	< 20''	< 20''	15.2''±0.1''	15.4''±0.3''	16.7''±0.4''	16.4''±0.3''	16.2''±0.3''	16.2''±0.3''	16.6''±0.3''	18.4''±0.4''
W90 C-K (0.28 keV)	< 90''	< 90''	~89.8''	~106.5''	~107.9''	~106.7''	~119.6''	~127.3''	~107.9''	~123.6''
Eff. Area[1] Al-K	> 350 cm^2	> 363.6 cm^2	391.9 cm^2 ± 16.1 cm^2	391.1 cm^2 ± 20.6 cm^2	392.6 cm^2 ± 15.5 cm^2	369.4 cm^2 ± 24.8 cm^2	387.9 cm^2 ± 19.2 cm^2	378.4 cm^2 ± 19.2 cm^2	391.6 cm^2 ± 24.8 cm^2	389.6 cm^2 ± 20.5 cm^2
Eff. Area[1] Cu-K	> 20 cm^2	> 21.0 cm^2	24.8 cm^2 ± 0.8 cm^2	24.8 cm^2 ± 1.1 cm^2	25.1 cm^2 ± 1.2 cm^2	23.8 cm^2 ± 0.9 cm^2	24.1 cm^2 ± 0.6 cm^2	25.1 cm^2 ± 1.1 cm^2	25.0 cm^2 ± 0.9 cm^2	24.2 cm^2 ± 1.0 cm^2
Micro-roughness	< 0.5 nm	Scattering Cu-K < 15.7%	Scattering Cu-K 10.8%	Scattering Cu-K 11.2%	Scattering Cu-K 10.7%	Scattering Cu-K 12.0%	Scattering Cu-K 13.3%	Scattering Cu-K 11.3%	Scattering Cu-K 11.7%	Scattering Cu-K 11.4%
Focal length	1600±10 mm	1600±10 mm (with lens equation)	1600.94 ±0.5 mm	1600.90 ±0.5 mm	1600.77 ±0.5 mm	1600.93 ±0.5 mm	1601.14 ±0.5 mm	1601.80 ±0.5 mm	1600.93 ±0.5 mm	1601.21 ±0.5 mm
Optical axis alignment	< 30''	< 30''	0''±21''	30''±14''	110''±14''	47''±14''	72''±14''	61''±14''	38''±14''	105''±14''

[1] 3-σ errors

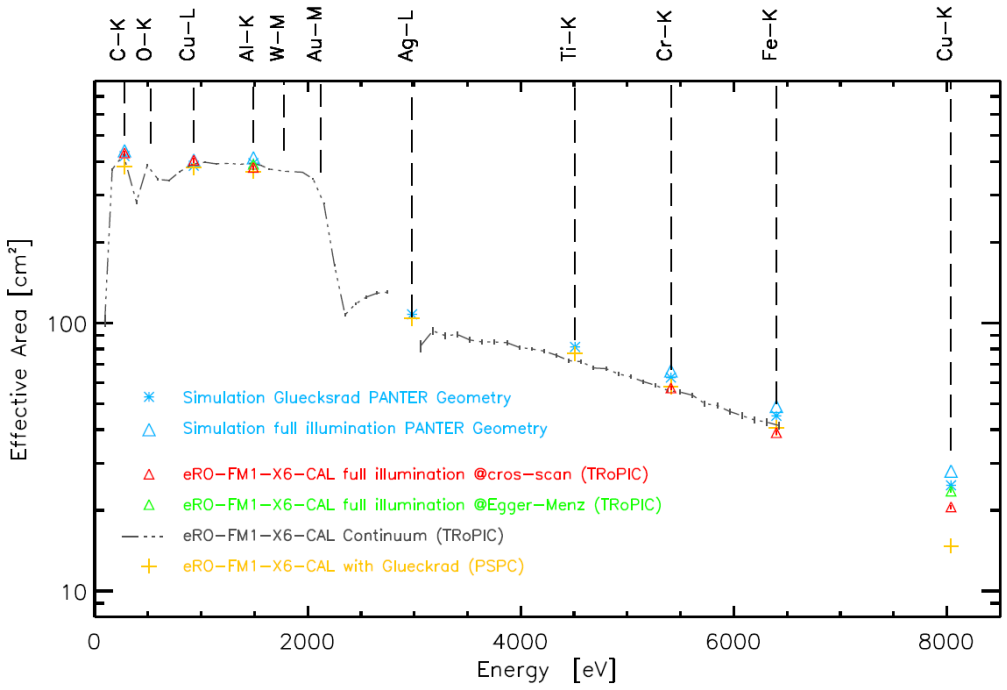
eROSITA Mirror Calibration

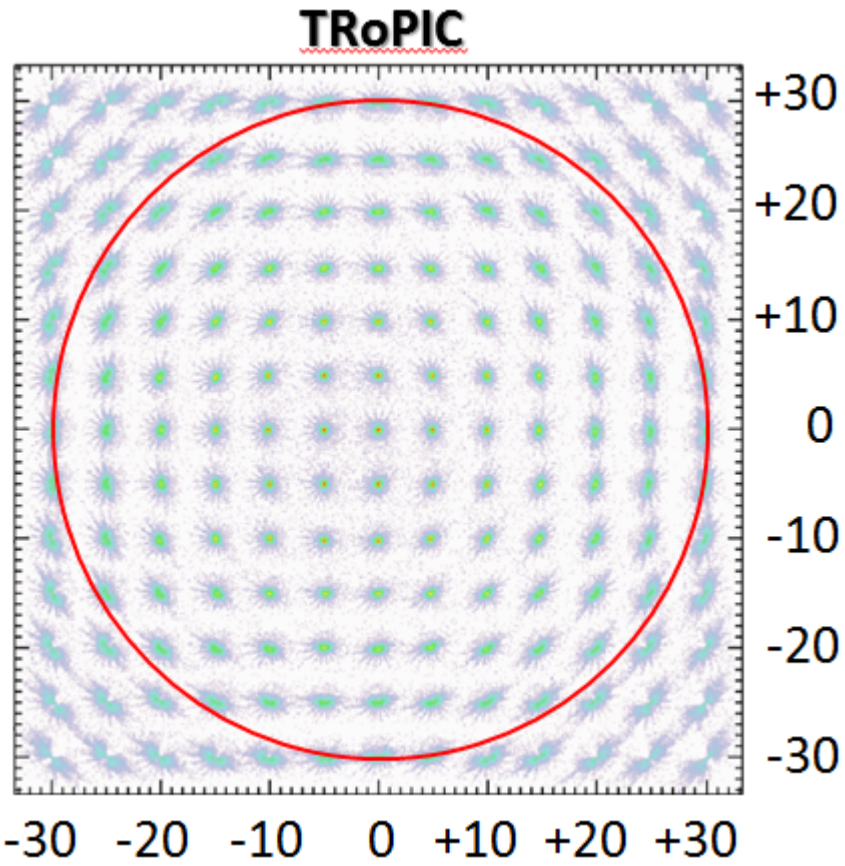
Mirror Assembly	FM 1	FM 2	FM 3	FM 4	FM 5	FM 6	FM 7	FM 8 (FS)
Acceptance Test								
X-Ray Baffle Mounting								
X-Ray Test								
Vibration								
X-Ray Test								
TV								
X-Ray Test								
Telescope Module Test								
Calibration								

Each of the 8 Mirror Modules
7 FMs and 1 spare)
will have gone through the following procedure:

- an X-ray acceptance test
  - HEW and effective area
- Integration of the baffle unit
- X-ray test after baffle integration
  - HEW and effective area
- Environmental tests (thermal cycling and vibration)
- Final calibration tests to measure the:
  - PSF on-axis / off-axis in the energy range 0.28 – 8.04 keV
  - effective area in the energy range 0.28 – 8.04 keV
  - contribution of scattering
  - Focal length measurement in X-rays and physically

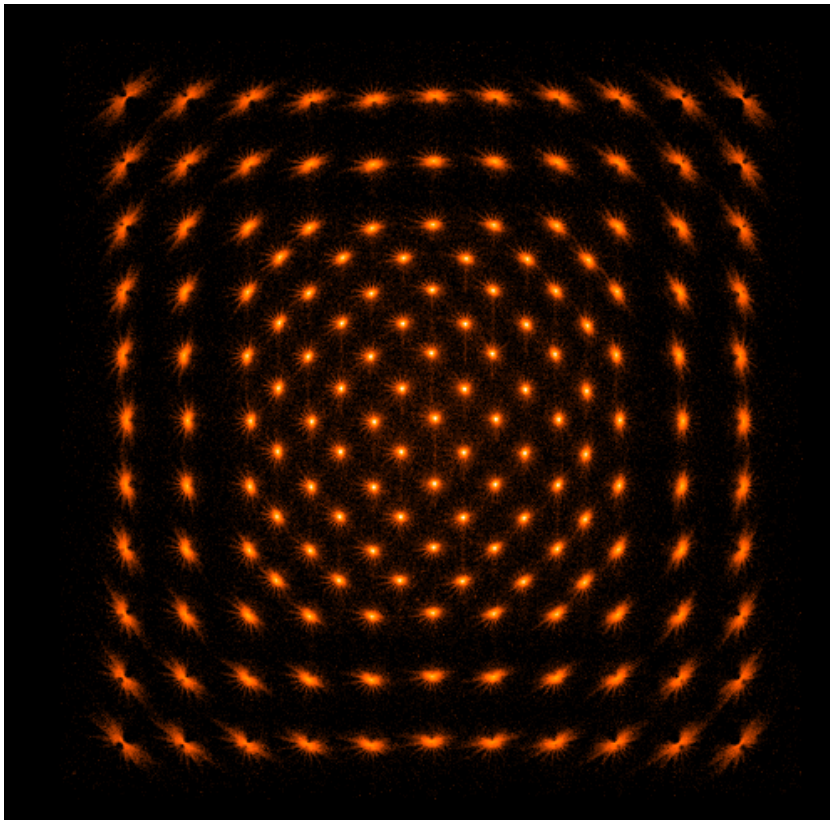
Effective Area PSF Measurements





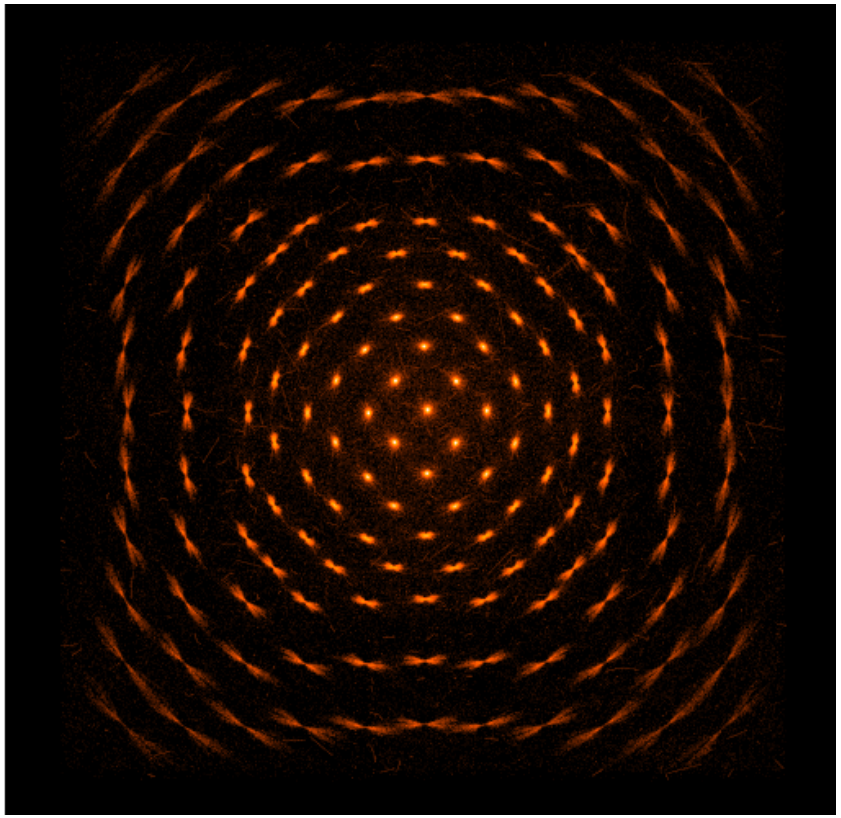
focal plane scanned In
5 arcmin steps in Al-K

Focal Plane Mapping



Al Kα

HEW = 16,3 arcsec



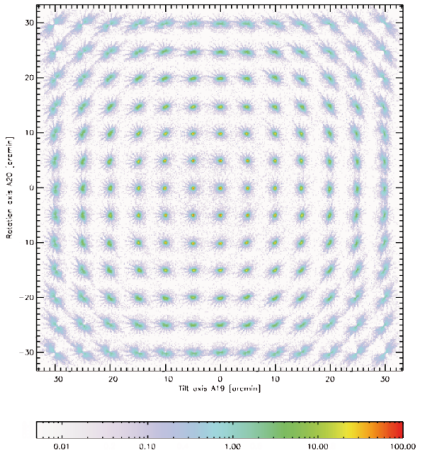
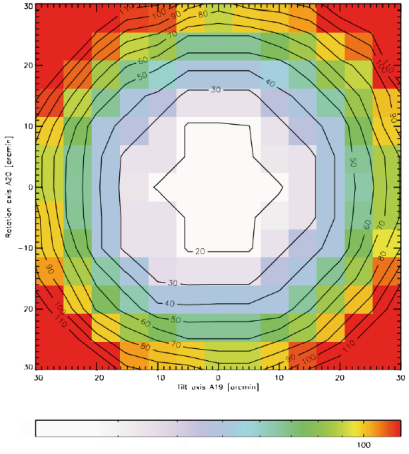
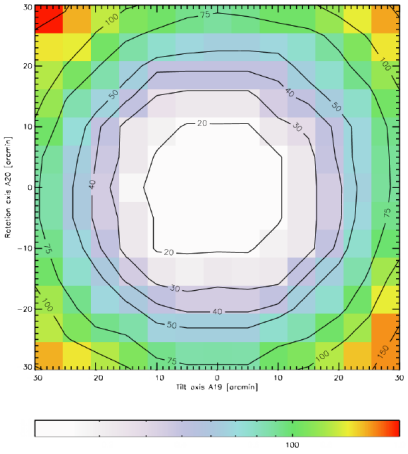
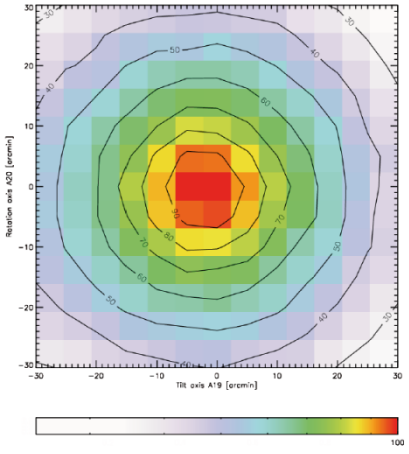
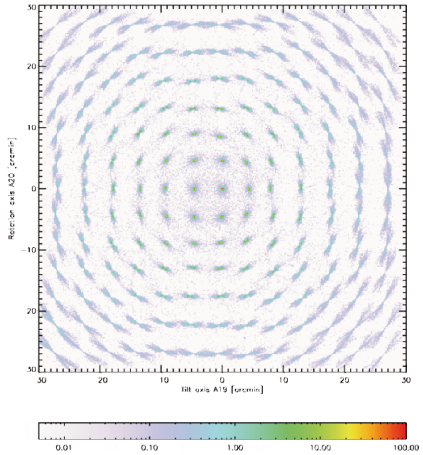
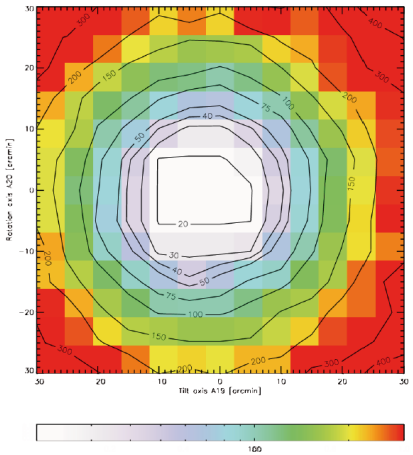
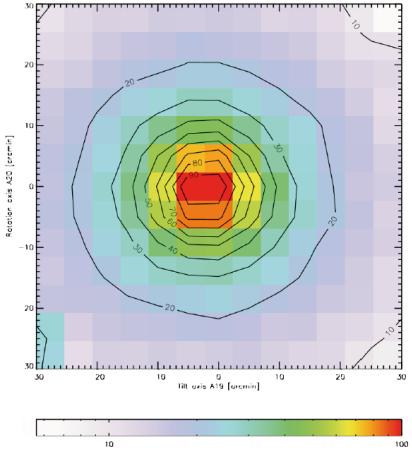
Cu Kα

HEW = 14,7 arcsec

Calibration: Survey PSF

(on-axis and off-axis)

from Benedikt Menz (MPE, PANTER)

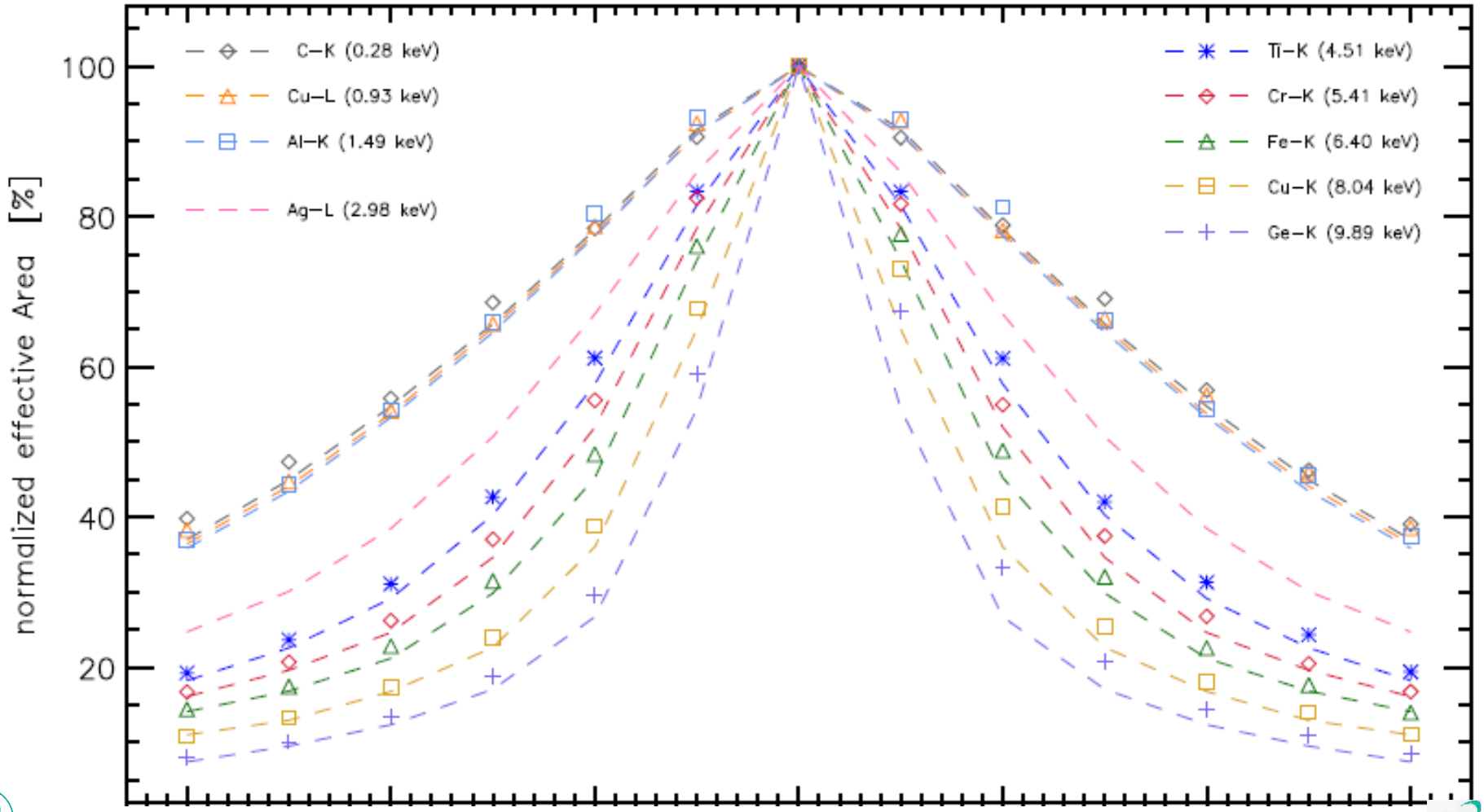
	PSF map	HEW map in-focus	HEW map 0.4 mm intra-focal	Flux map (vignetting)
1.49 keV				
6.40 keV				

Calibration: Effective Area

off-axis

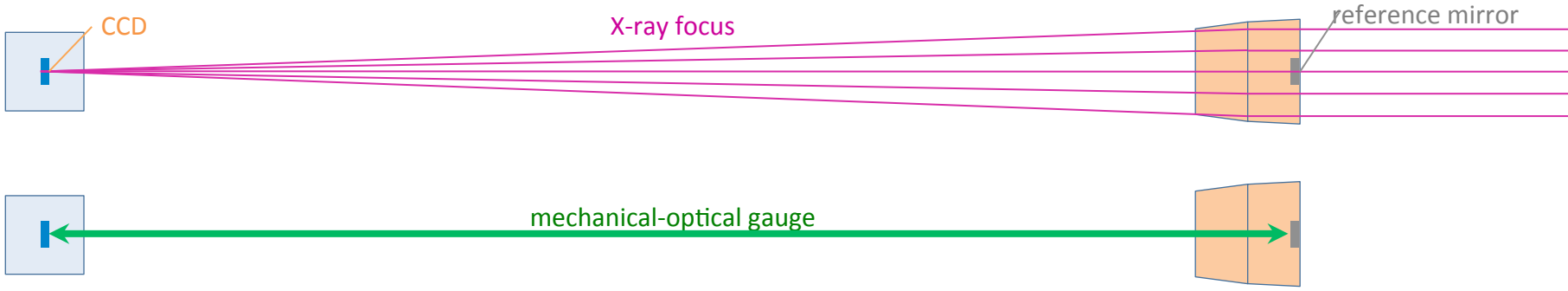
Vignetting curves for different energies

from Gisela Hartner (MPE, PANTER)

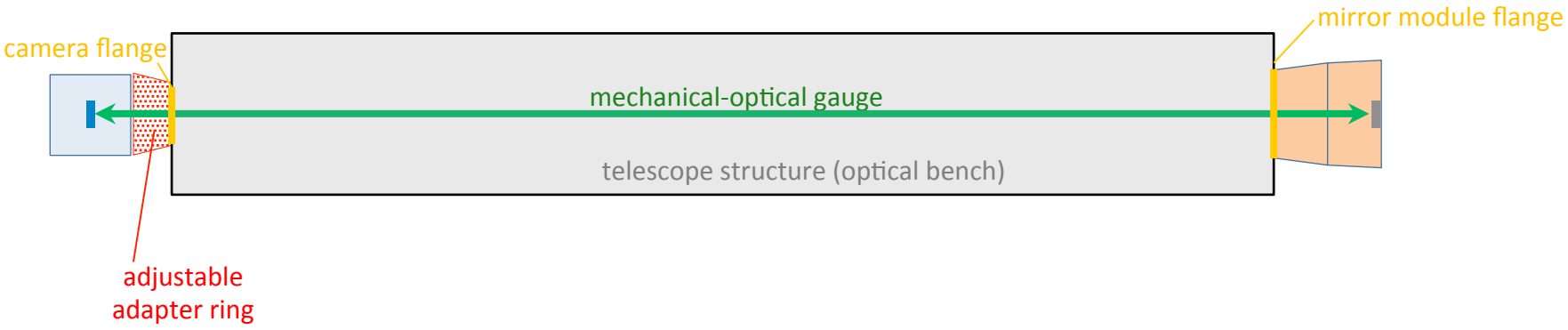


Focal Length

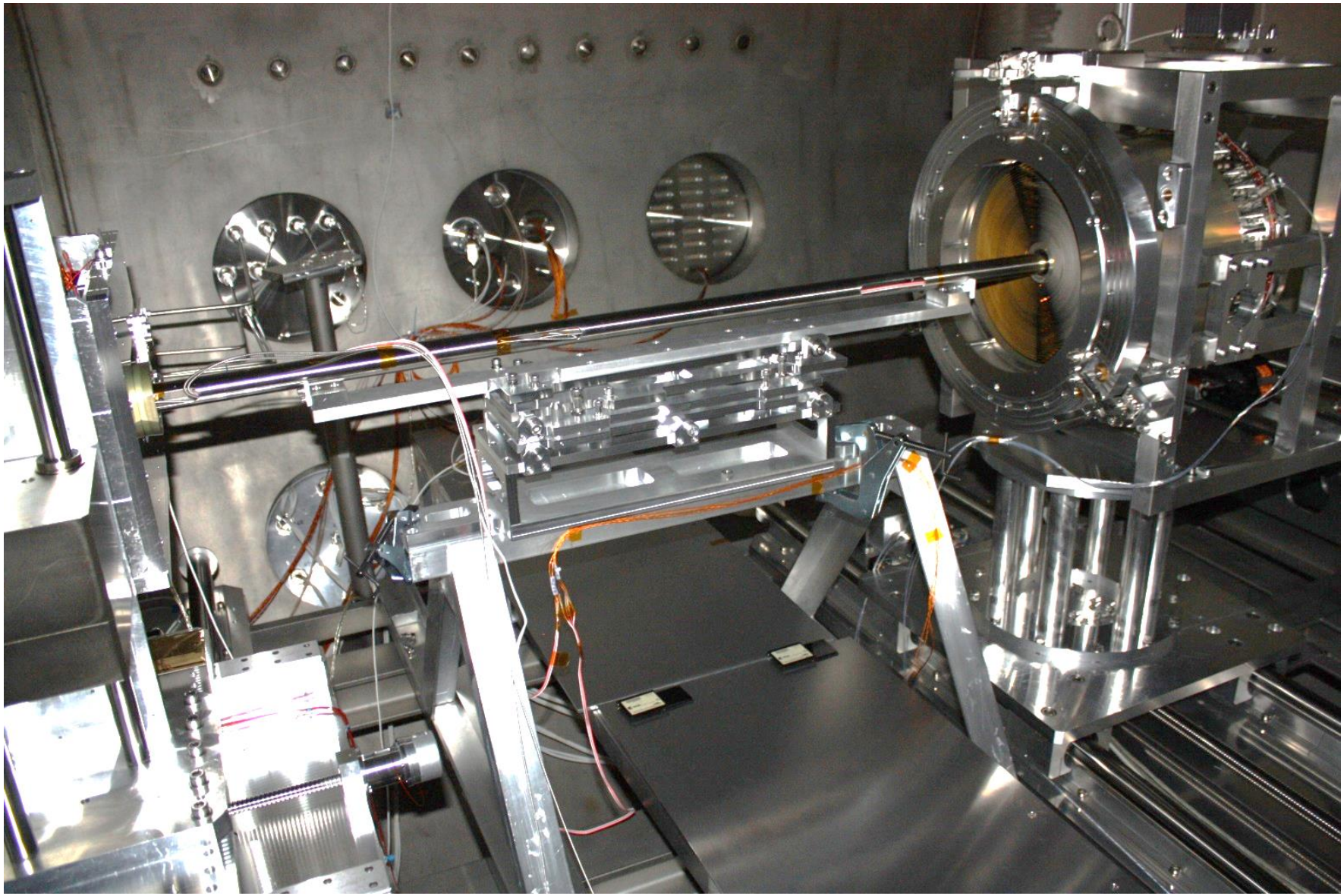
(1) X-Ray Calibration



(2) Mounting into Telescope Structure



Focal Length Gauge (Vacuum Proof)



eROSITA Summary

- Mirrors are currently at PANTER for calibration
  → FM1, FM2,FM3 Calibration complete ready for integration
- FM Cameras will be calibrated upon completion their respective electronics boxes
  → FM1, FM2 Calibration complete ready for integration
- Upon completion their calibration the mirrors and cameras will be integrated in the telescope structure.
- Once assembled a last environmental test at IABG will be performed
- Followed by an end-to-end test at PANTER before delivery to Russia
- Launch is planned for Sept. 26, 2017