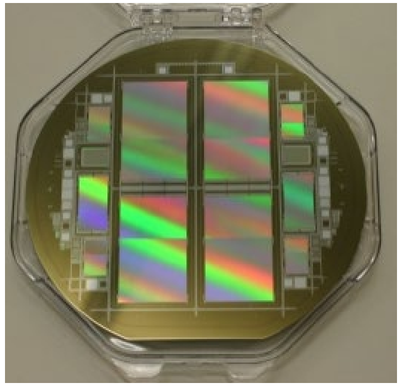
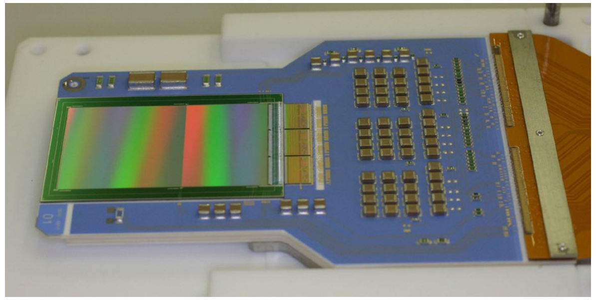
eROSITA - Science and Data Analysis School

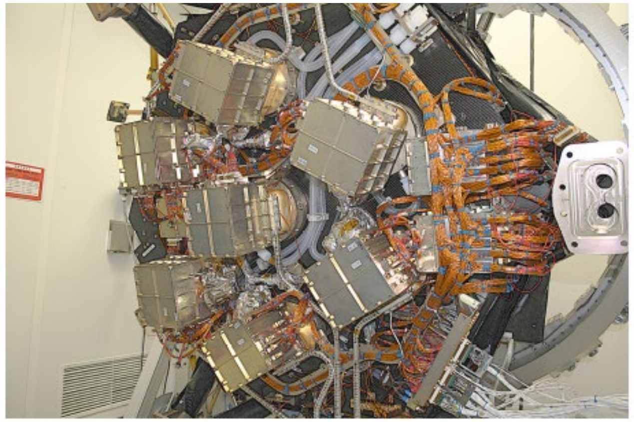
eROSITA cameras

Norbert Meidinger (Max-Planck-Institut für extraterrestrische Physik)

18 November 2024





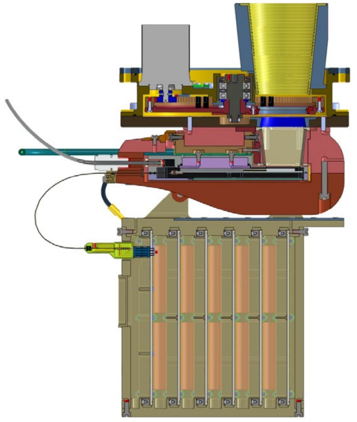


What is such a camera good for?

- Measurement of energy of single X-ray photons E(photon)
- Measurement of incidence time t (with accuracy Δt)
- Accurate source location by high spatial resolution
- Photon detection probability determined by quantum efficiency

What you should consider:

- Operation of the detector (voltages, timing, operating mode) $\rightarrow$ Electronics
- Telemetry rate limitation from satellite to ground $\rightarrow$ onboard data reduction
- Vibration-resistant (launch!)
- Low mass, low heat dissipation, cooling
- Shielding of visible light $\rightarrow$ optical blocking filter
- Re-calibration of signal gain + charge transfer efficiency $\rightarrow$ onboard calibration source
- ……..
- Operation in space: stable performance, life time



Overview

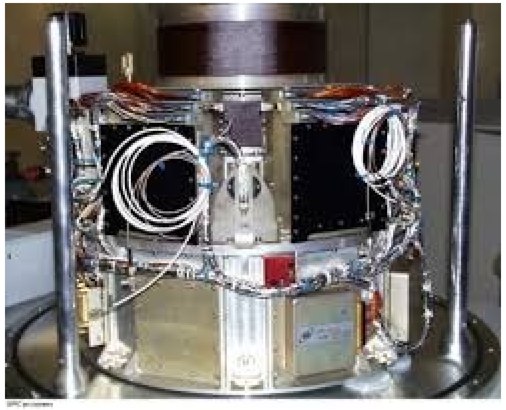
1. Detector Design
2. Detector Performance
3. eROSITA Camera
4. Launch and operation in space

1. Detector Design

Heritage:

PNCCD X-ray detector originally developed for XMM-Newton (ESA) since launch (1999) until today: excellent spectroscopy and imaging

PNCCD Detector



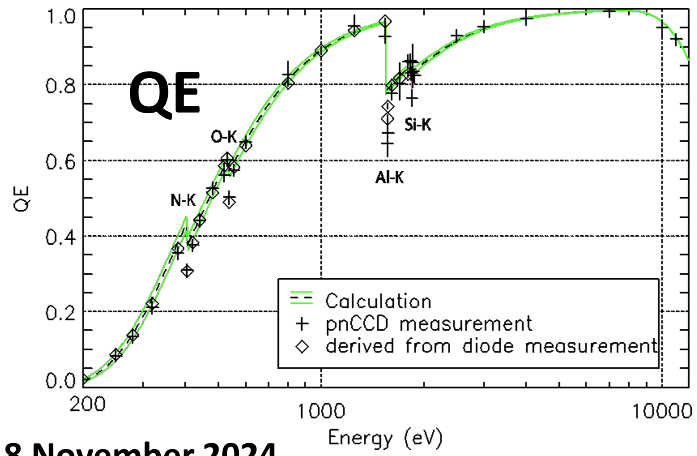
EPIC-PN

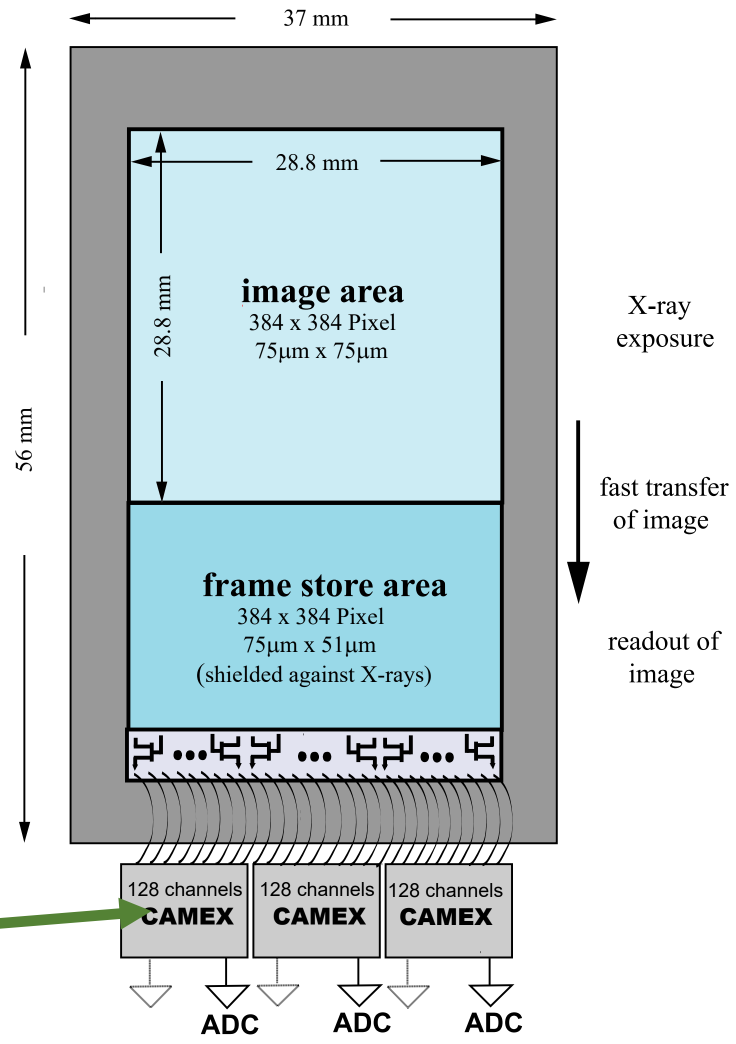
XMM-Newton

1. Detector Design

- ▶ 3-phase, back-illuminated, 450 µm fully depleted
- ▶ pn-junctions → transfer registers
  + photon entrance window
- ▶ Excell. energy resolution in energy band [0.2 keV; 10 keV]
  e.g. FWHM(5.9keV) ≈ 125 … 150 eV
- ▶ Image area: 28.8 x 28.8 mm^2
- ▶ Pixel size: 75 x 75 µm^2 → 384 x 384 Pixel
- ▶ CCD channel + anode + JFET + MOSFET + CAMEX channel

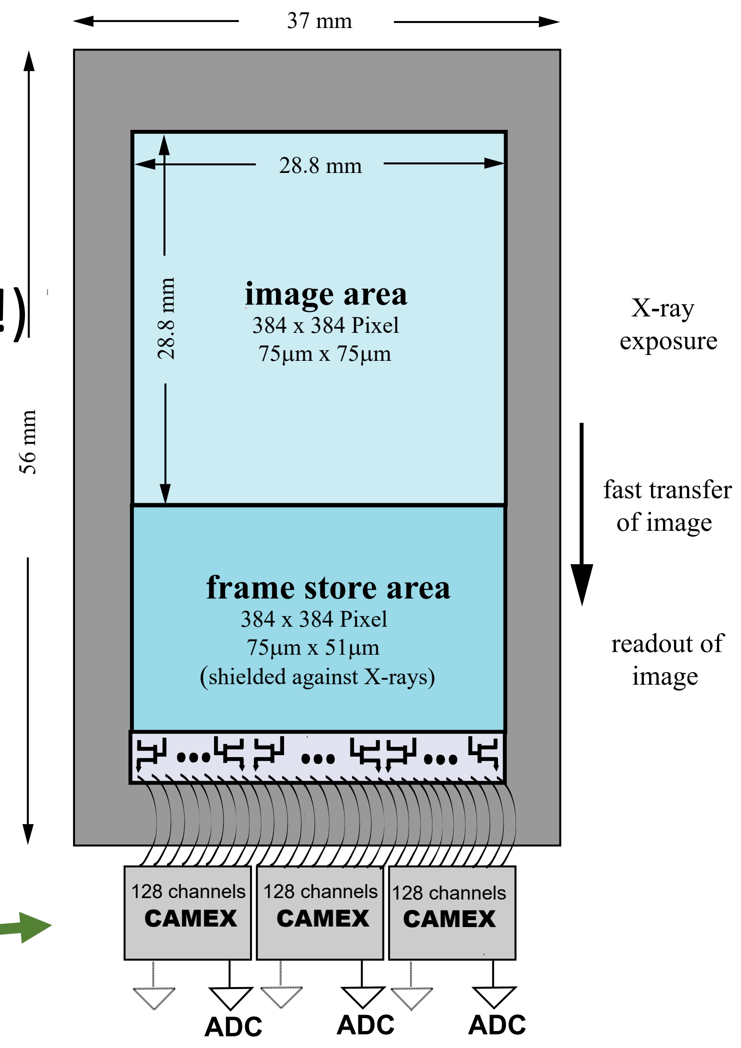
⇒ 384 parallel signal processing channels





1. Detector Design

- ▶ **Image area + frame store → frame transfer 115 µs**
- ▶ **Image readout: 9.2 ms**
- ▶ **eROSITA: cycle time: 50 ms (40 ms CAMEX off)**
  - on-board event processing (data reduction → telemetry!)
  - min. heat dissipation (≈ 80% standby) → 0.7 W
    → **T = -95°C** (best wrt radiation damage)
  - OOT events ≈ **0.2%** (cf. XMM-Newton PN-CCD **6.3%**)
- ▶ **Space: light blocking filter**
  → optical transmittance < 10^{-5}
  → option: deposition on CCD entrance window
- ▶ **Excellent low energy response**



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2. Detector Performance

All CCD Detector Modules tested in GEPARD chamber at MPE with ^{55}Fe

→ voltage optimization

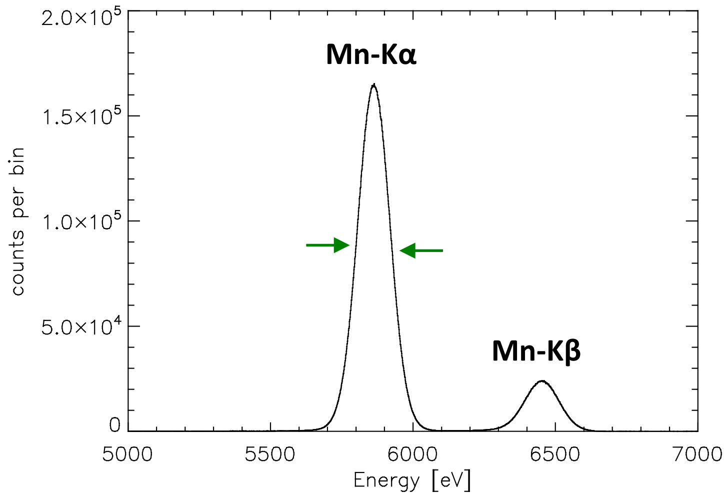
→ functional test + performance at 5.9 keV

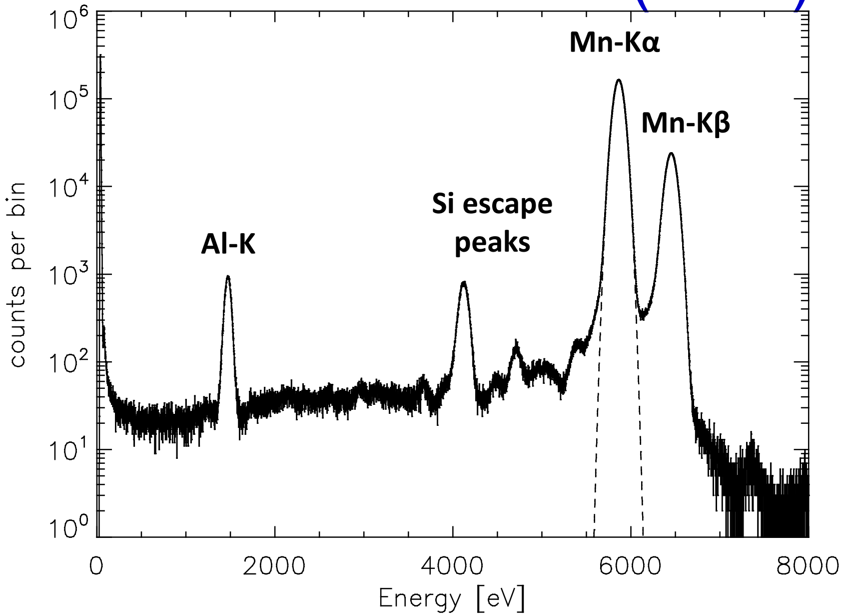
FWHM(5.9keV) = ~129 → ~140eV (lab → flight electronics!)

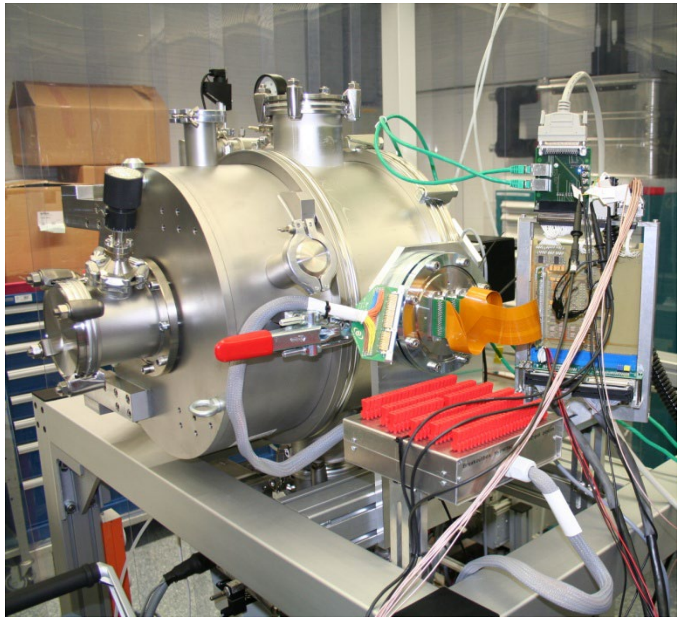
σ ≈ 2.5 el. ENC

CTI ~ 10^{-5}, gain (1.2adu/eV), # bad pixels …

Later: calibration at PUMA and Panter test facilities (MPE)







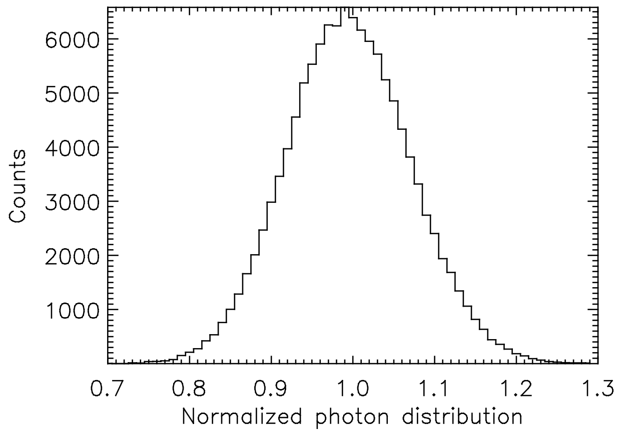
2. Detector Performance

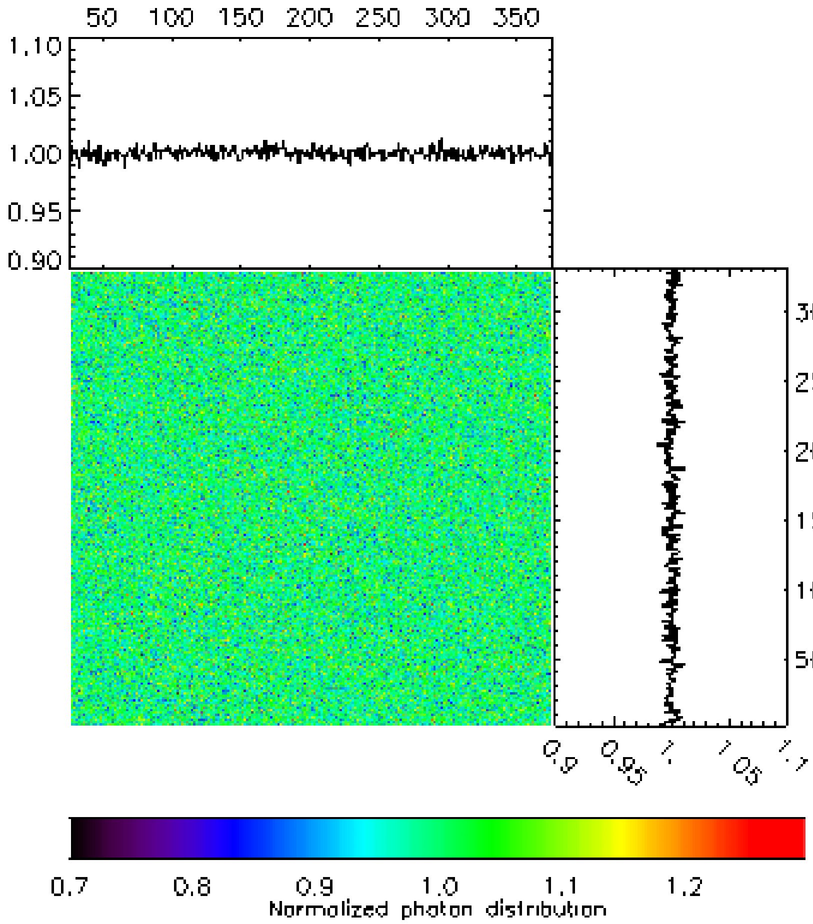
Normalized Al-K (1.5 keV) photon distribution over CCD area:

⇒ **Check verifies uniformity of detector sensitivity**

(within the limits of statistics)

Histogram of measured # photons per pixel:



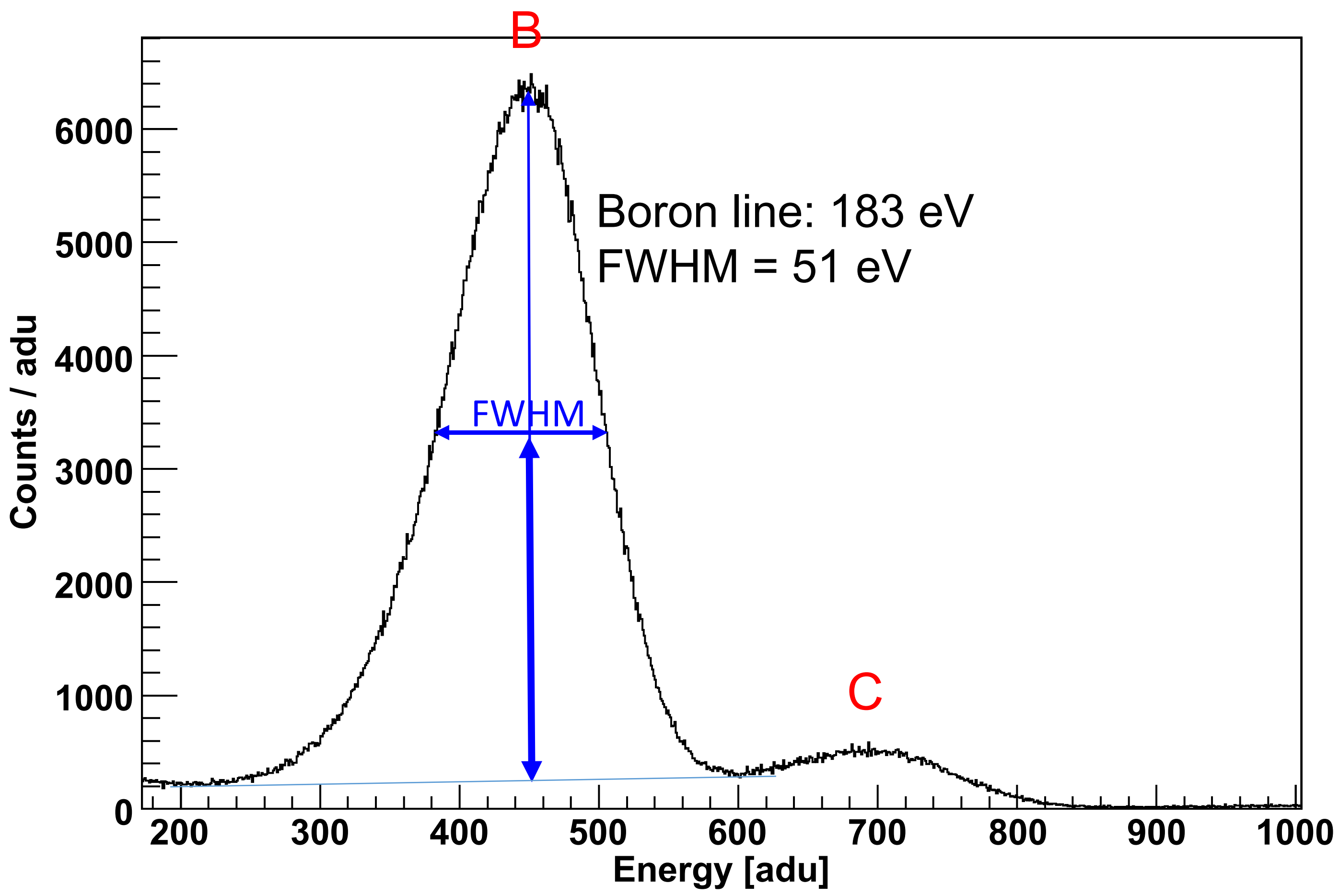


2. Detector Performance

Low-energy response:
(X-ray tube with continuum)

eROSITA PNCCD
with light filter
(w/o calibration)

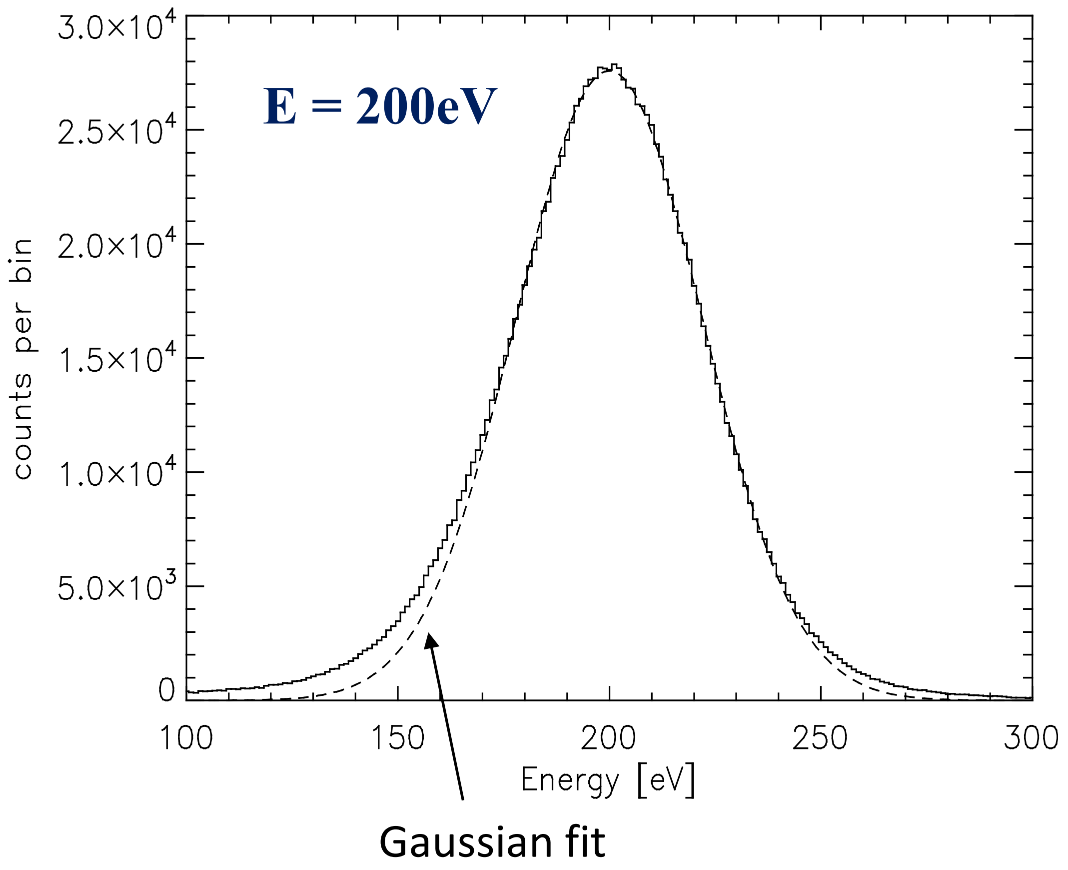
Note: 183 eV → 50 el.



2. Detector Performance

Low-energy response:

eROSITA CCD lab module
at **BESSY synchrotron**:
E= 200 eV spectrum
FWHM(200eV) = 52 eV



Overview

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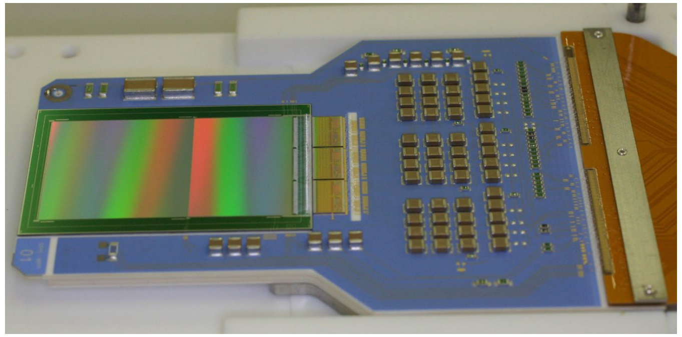
3. eROSITA Camera

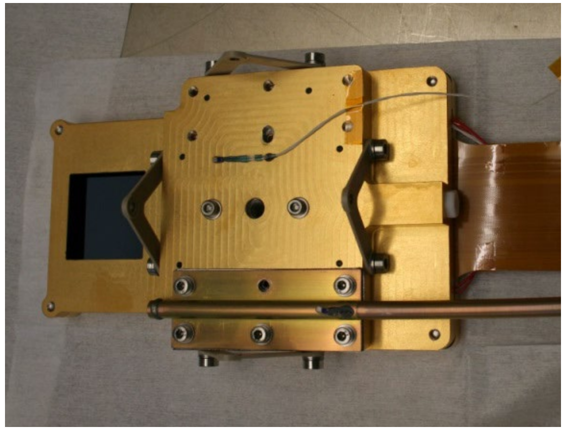


Detector housing:

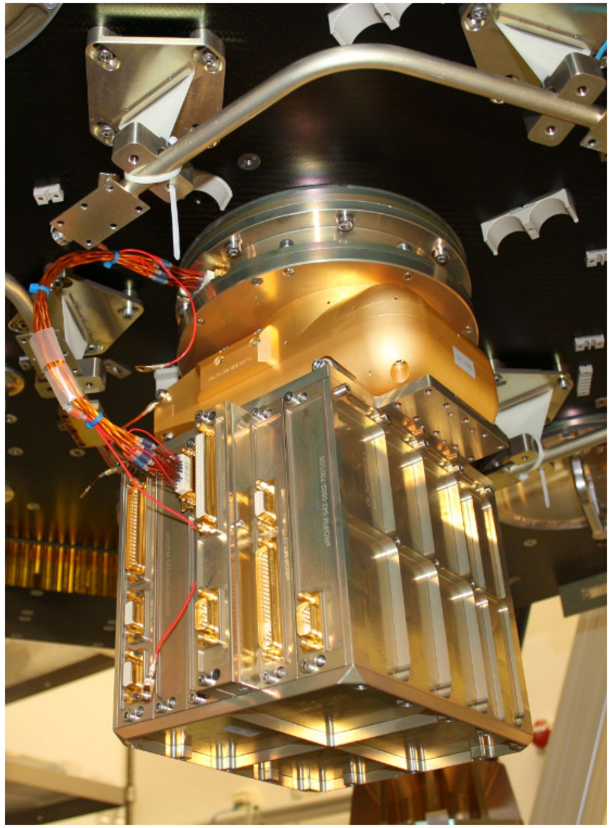
- Mech. + thermal I/F
- Graded Z-shield: Be/B_4C - Al – Cu

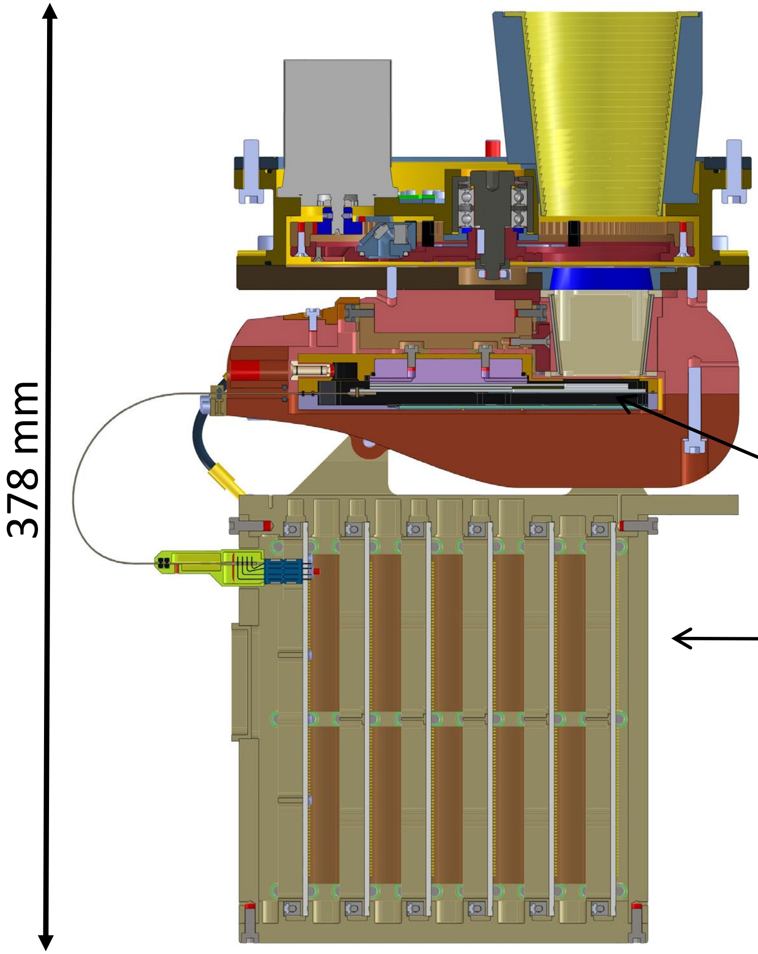
  (→ minimization of instrumental background)

- Proton shield



3. eROSITA Camera (Assembly)





Filter wheel unit

Camera

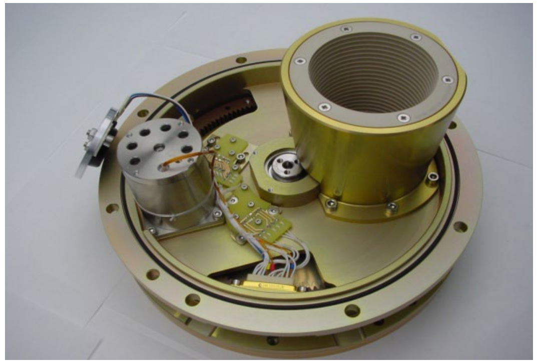
PNCCD

Electronics box

power converter + control units
Sequencer
14-bit ADCs
FPGA: event processing
filter wheel control

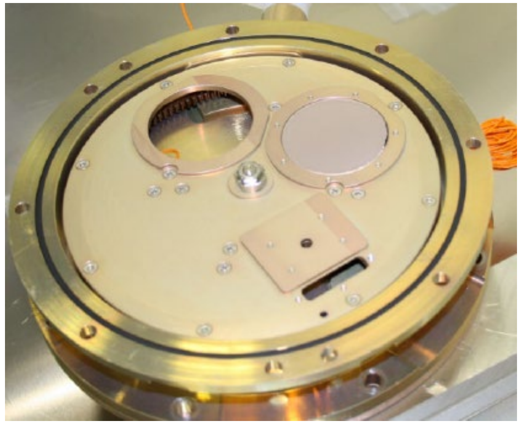
3. eROSITA Camera

Filter wheel

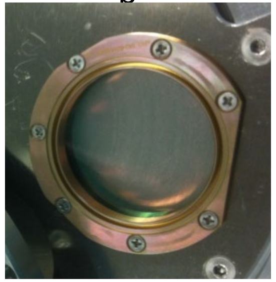

Filter wheel with aperture and motor

- **Open position**
  - venting of camera system
  - **optional:** CCDs with **on-chip filter** permit **observations**

- **Filter position**
  a) **EUV blocking** filter (100nm PI) for CCDs + **on-chip filter** (200nm Al)
  TM1, TM2, TM3, TM4, TM6 with **on-chip** OBF filter
  b) **optical blocking** filter (100nm Al+100nm PI) for CCDs w/o on-chip filter
  TM5, TM7 with OBF in **filter wheel**



- **Onboard calibration position**
  ^{55}Fe + Al-Ti target: Mn-K_α + Mn-K_β (5.9 keV, 6.5 keV) + Ti-K_α (4.5 keV) + + Ti-K_β (4.9 keV) + Al-K (1.5 keV)

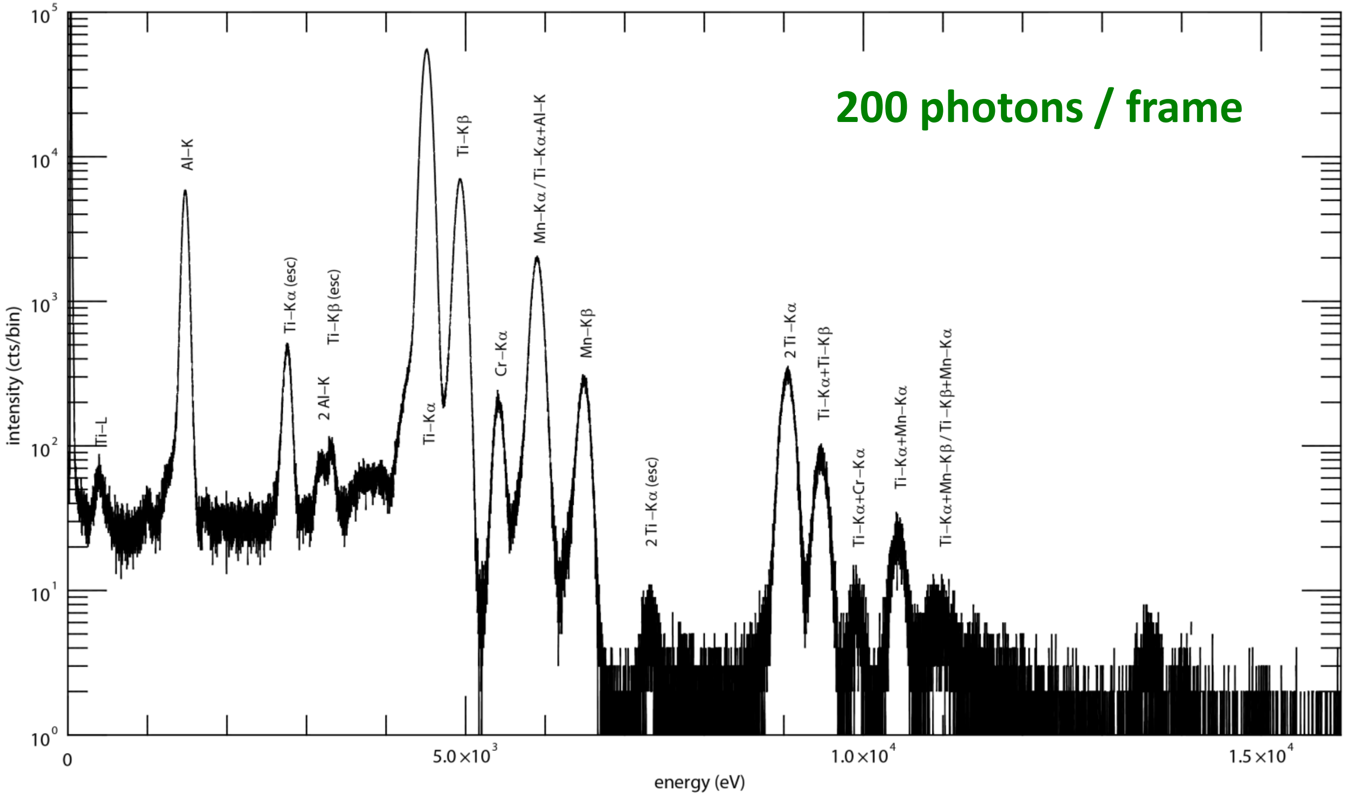

Filter mounted on support structure

- **Closed position**
  – on ground → **protection**
  – in space → **instrument background**

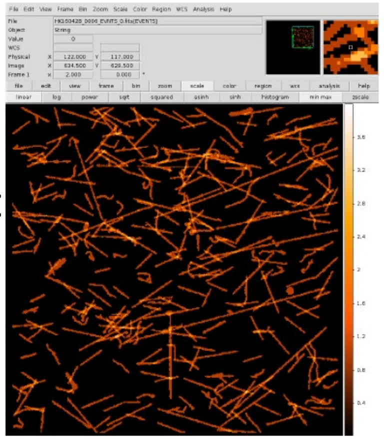
3. eROSITA Camera

On-board calibration source spectrum

characteristic lines + pile-up combinations



Ground measurement
selected mip tracks →
(>50 pixels in size)



3. eROSITA Camera
Tests with QM/FM camera/s

Vibration Test ☑

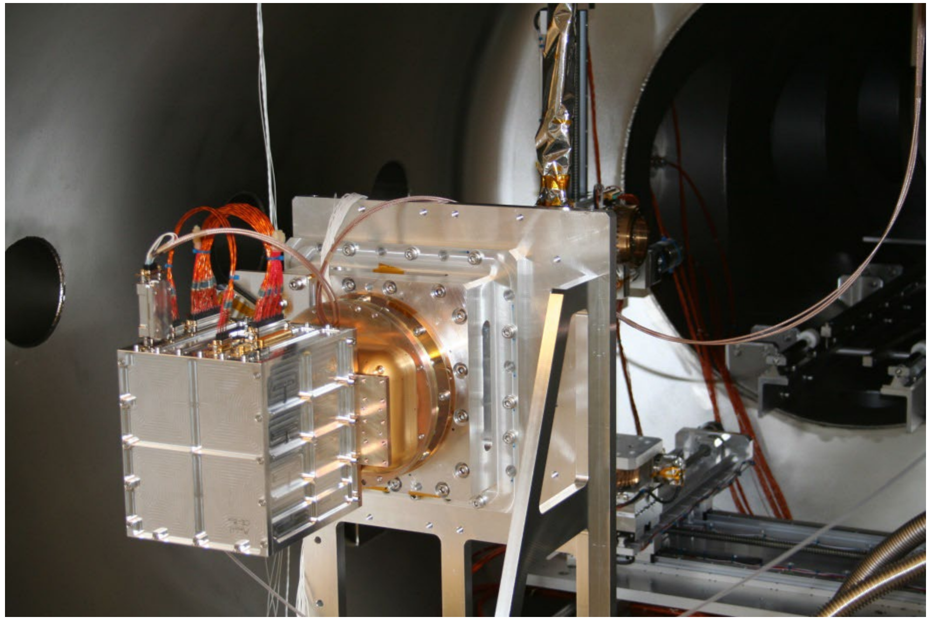
Thermal Cycling Tests of QM detector (T_{op}=-105°C) ☑

Thermal Cycling Tests of QM electronics (T_{op}= +25°C / -24°C) ☑

Performance Test of Camera Assembly in PUMA facility ☑

- flight-like configuration
- onboard calibration source + multi-target X-ray tube

EMC and ESD tests ☑



3. eROSITA Camera

eROSITA flight camera energy resolution and QE calibrated on ground

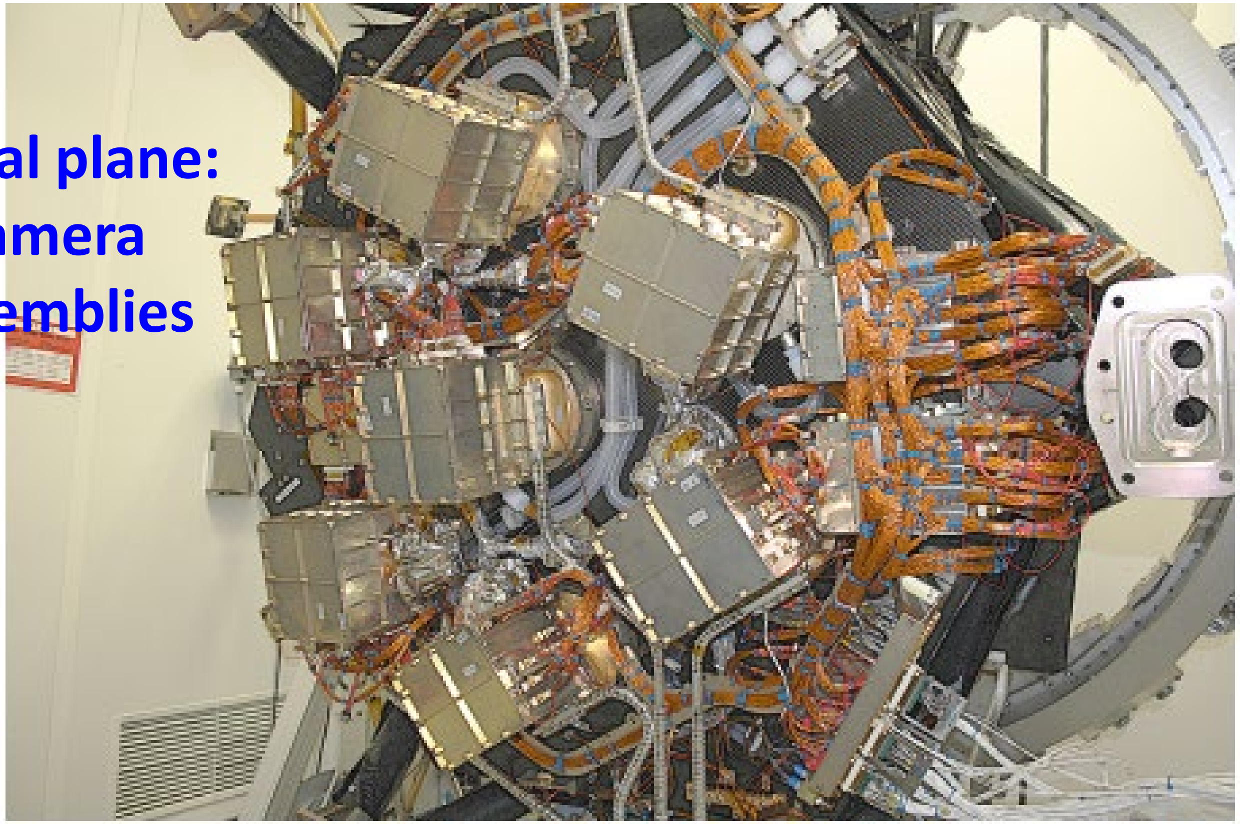
	TM1	TM2	TM3	TM4	TM5	TM6	TM7	QE12346	QE57
C-K at 0.277 keV	58 ± 0.3	58 ± 0.3	58 ± 0.4	58 ± 0.3	50 ± 0.2	58 ± 0.4	49 ± 0.2	12.4 ± 1.7%	31.3 ± 4.4%
O-K at 0.525 keV	64 ± 0.2	65 ± 0.3	66 ± 0.3	64 ± 0.2	57 ± 0.3	63 ± 0.2	56 ± 0.4	42.2 ± 1.6%	51.3 ± 2.1%
Cu-L at 0.93 keV	70 ± 0.3	74 ± 0.3	72 ± 0.3	70 ± 0.3	68 ± 0.3	70 ± 0.3	68 ± 0.3	80.0 ± 4.5%	83.2 ± 4.7%
Al-K at 1.49 keV	77 ± 0.3	82 ± 0.3	80 ± 0.3	77 ± 0.3	75 ± 0.3	77 ± 0.3	77 ± 0.2	94.0 ± 4.1%	94.8 ± 4.2%
Ti-Kα at 4.51 keV	118 ± 0.5	125 ± 0.6	122 ± 0.6	118 ± 0.6	116 ± 0.6	118 ± 0.6	117 ± 0.6	97.9 ± 2.2%	98.2 ± 2.2%
Fe-Kα at 6.40 keV	138 ± 0.6	145 ± 0.7	142 ± 0.7	138 ± 0.6	135 ± 0.7	138 ± 0.7	136 ± 0.7	98.9 ± 2%	99.1 ± 2%
Cu-Kα at 8.04 keV	158 ± 0.7	167 ± 0.7	163 ± 0.7	159 ± 0.7	155 ± 0.6	159 ± 0.6	156 ± 0.7	99.3 ± 2%	99.4 ± 2%
Ge-Kα at 9.89 keV	178 ± 1.0	181 ± 1.0	182 ± 1.1	173 ± 1.1	170 ± 1.0	174 ± 1.1	175 ± 1.0	96.9 ± 2%	96.9 ± 2%

! eROSITA camera performance better than that of XMM-Newton EPIC PN !

3. eROSITA Camera

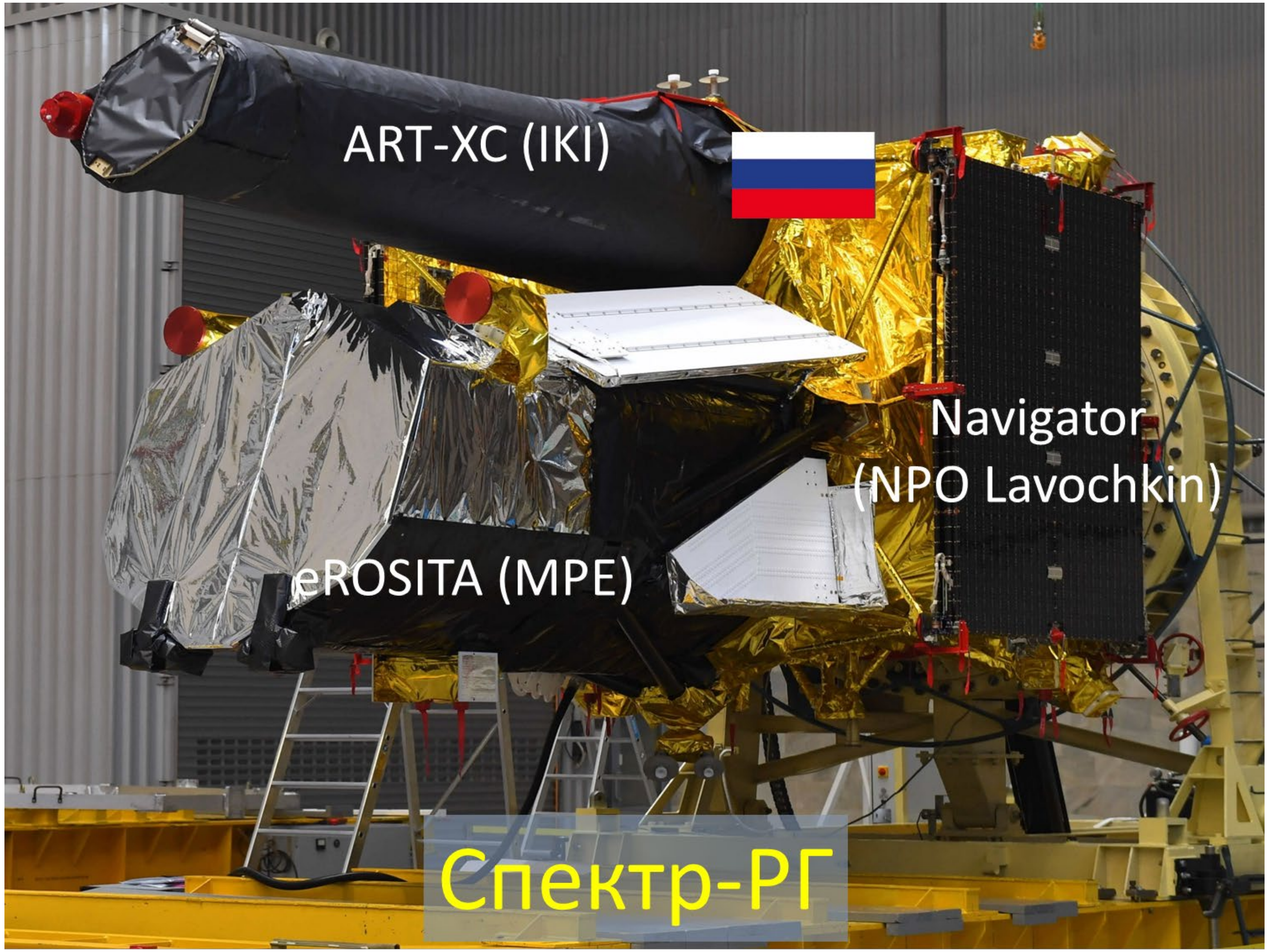
eROSITA telescope array assembled at MPE

Focal plane:
7 camera
assemblies



Size: 1.9 m Ø x 3.5 m
Mass: 808 kg
Power: 522 W (max.)
Data rate: 400 MB/day (average)
600 MB/day (max.)

3. eROSITA Camera



Camera array volume should have been **light-tight** by means of MLI foil cover -
but it was not
→ CA5+CA7 w/o on-chip filter affected)

Overview

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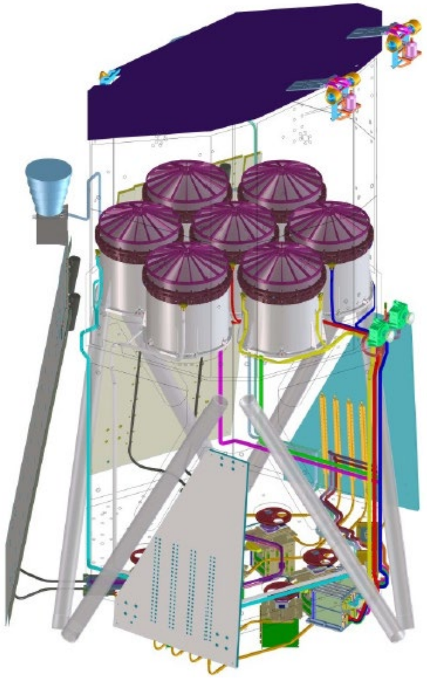
2. Detector Performance
3. eROSITA Camera
4. Launch and operation in space

4. Launch and operation in space

Launch on 13 July 2019 (12:31 UTC)

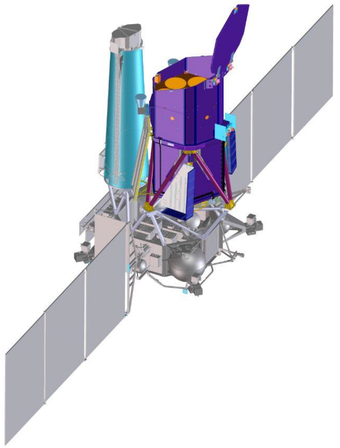
4. Launch and operation in space

eROSITA Camera Commissioning + Operation



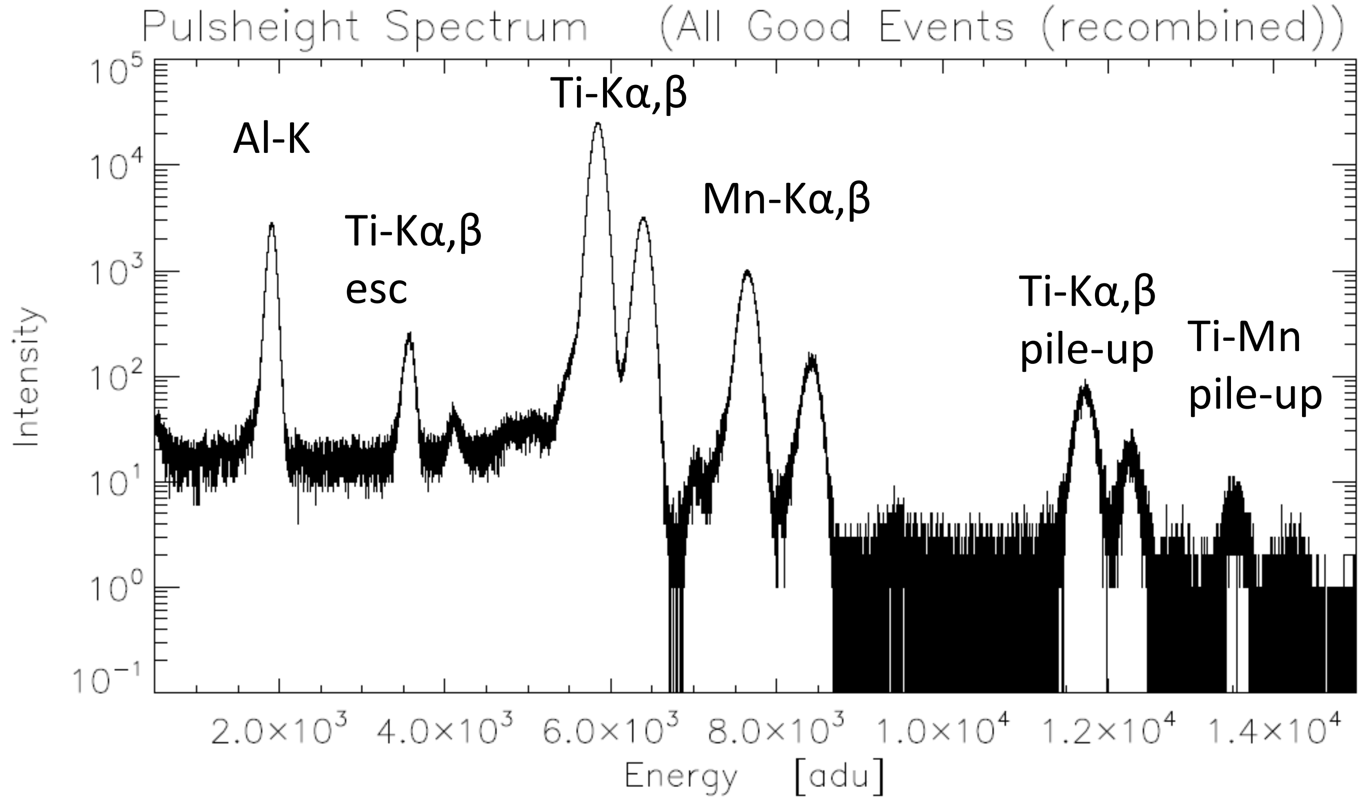
- 23 July 2019: Telescope cover opens. Outgassing period begins
- 29 July 2019: Start of CE commissioning
- 22 August 2019: Cool-down and start of camera commissioning (one by one)

  → **all 7 cameras fully functional**
  similar performance as measured on ground
  (but **light leak** in focal plane MLI cover affects perf. of 2 CCDs w/o on-chip OBF)
- 16-18 October 2019: First light (LMC) with all 7 TMs
- 18 October - 8 December 2019: Calibration and performance verification program
- **12 December 2019: Start of all-sky survey**
- 26 February 2022: eROSITA in safe mode



4. Launch and operation in space

TM6: cal-source spectrum measured in space



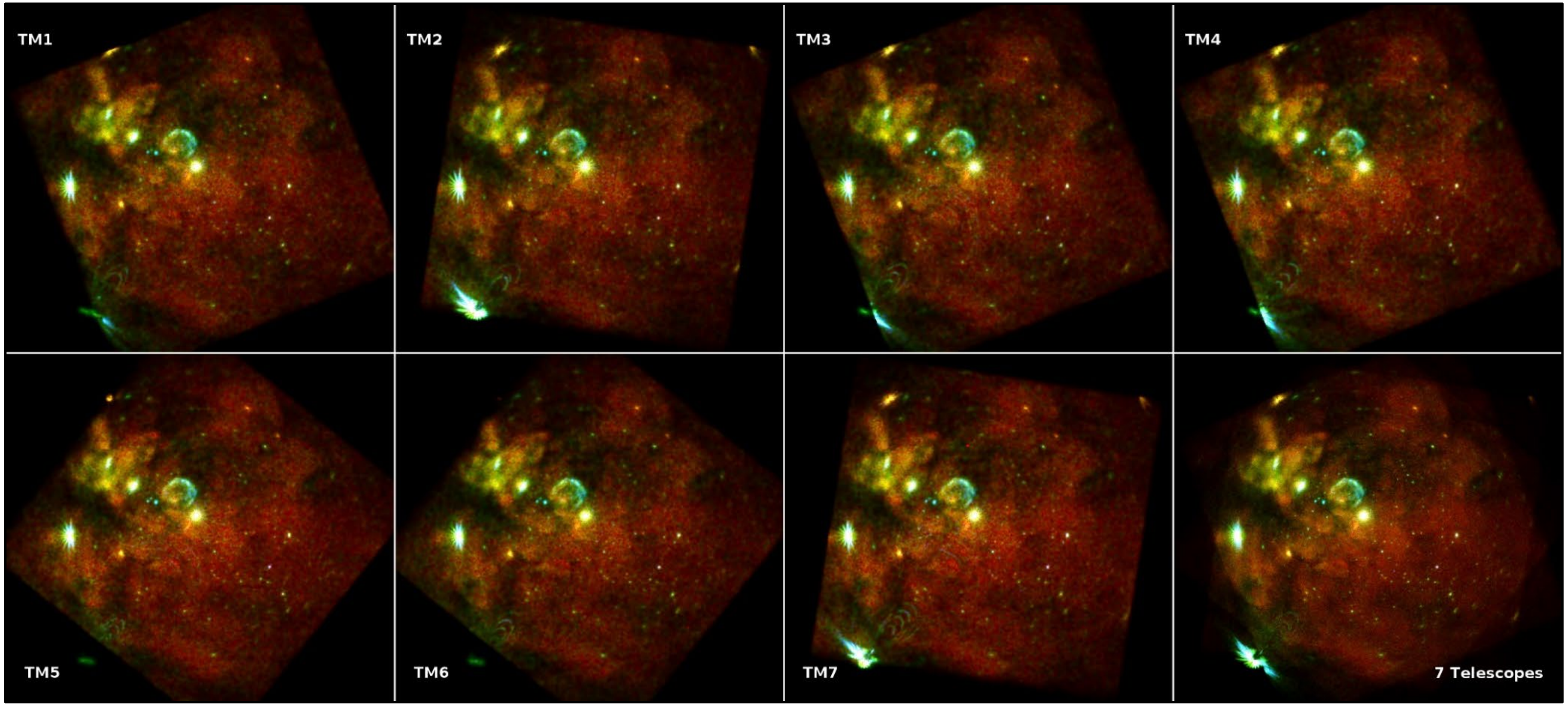
Commissioning phase /MPE

4. Launch and operation in space

SRG/eROSITA (0.2-4.5 keV)

First light. LMC region centered on the supernova SN1987A

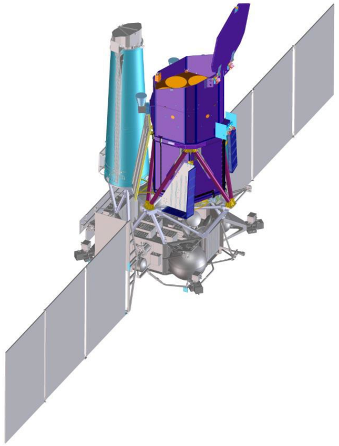
(Red, green, and blue: X-ray intensities 0.2–1.0, 1.0–2.0, and 2.0–4.5 keV)



LMC/SN1987A

MPE/IKI

Credit: F. Haberl, M. Freyberg, C. Maitra



4. Launch and operation in space

Issues

- Thermal system problem (1 of 2 VCHPs) → T ≈ -85° … -80°C instead of planned -95°C
- Light leak in focal plane volume: TM5 and TM7 affected (slightly worse energy resolution)
- SEU once per week caused by particle in FPGA XILINX Virtex-4

  (issue: not sufficient resources for complete Triple Module Redundancy implementation)

  → CE reset (not detector) necessary (optimization of f/w planned)

None of the issues was an obstacle to the success of eROSITA

4. Launch and operation in space

Energy resolution similar good as on ground

(single events – needed for CTE and gain correction)

Space:

Values changing
because of more accurate calibration
but also due to radiation damage

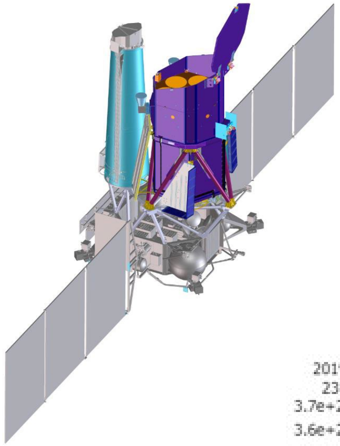
Spectral line energy	F					M6 VHM eV)	TM7 FWHM (eV)
Al-K: 1.49 keV	74.					± 0.7	90.2 ± 1.2
Ti-Kα: 4.51 keV	116.5 ± 0.4	120.3 ± 0.5	118.3 ± 0.5	115.9 ± 0.4	118.1 ± 0.6	115.2 ± 0.4	128.0 ± 0.6

Ground:

Al-K: 1.49 keV	73.5 ± 0.5	76.7 ± 0.5	75.2 ± 0.5	73.2 ± 0.5	72.1 ± 0.5	73.4 ± 0.5	73.0 ± 0.4
Ti-Kα: 4.51 keV	113.6 ± 1.2	117.5 ± 1.4	115.7 ± 1.4	113.7 ± 1.3	111.9 ± 1.4	113.6 ± 1.3	113.1 ± 1.3

→ **similar** on **ground** and in space apart from TM5 and TM7:

eROSITA had best prerequisites to achieve its scientific goals

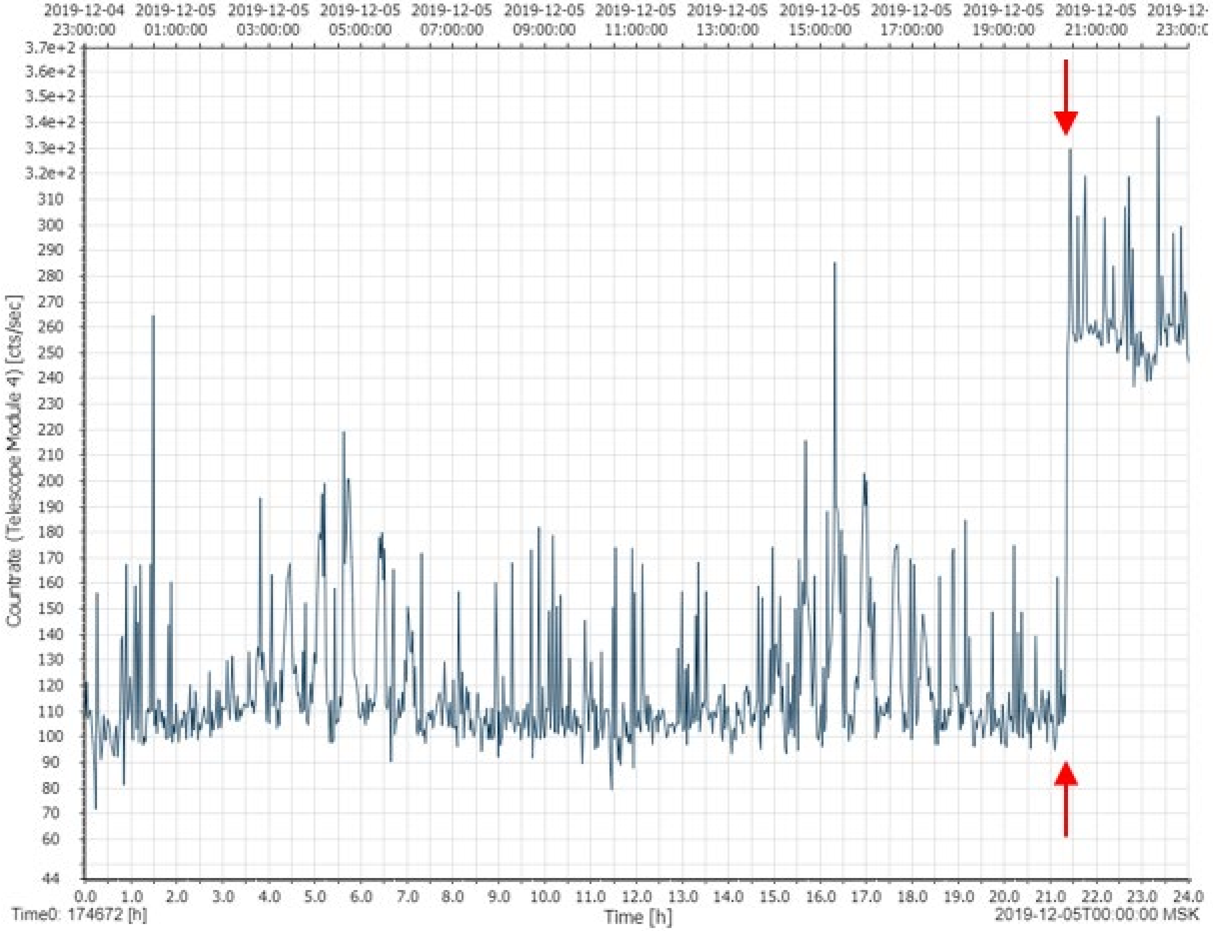


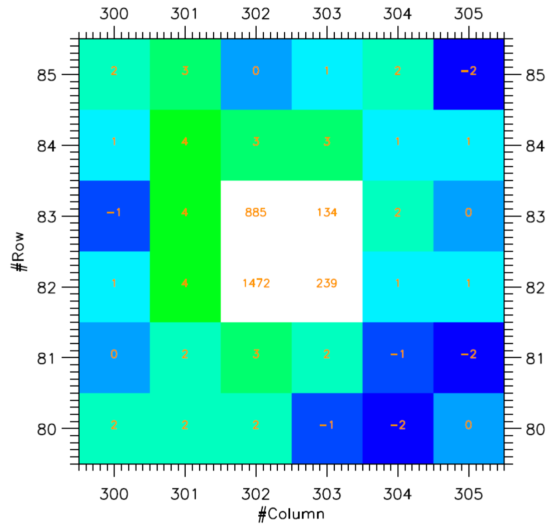
4. Launch and operation in space

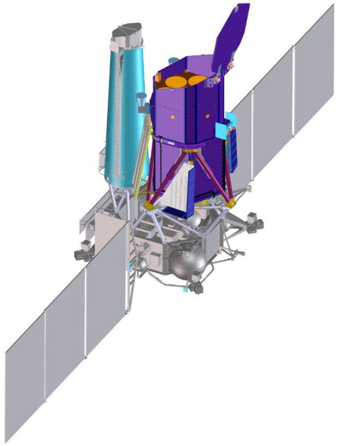
Micro-meteoroid impact

7 impacts observed since launch until 2022 (2 x TM2, 2 x TM4, 1 x TM5, 2 x TM7)

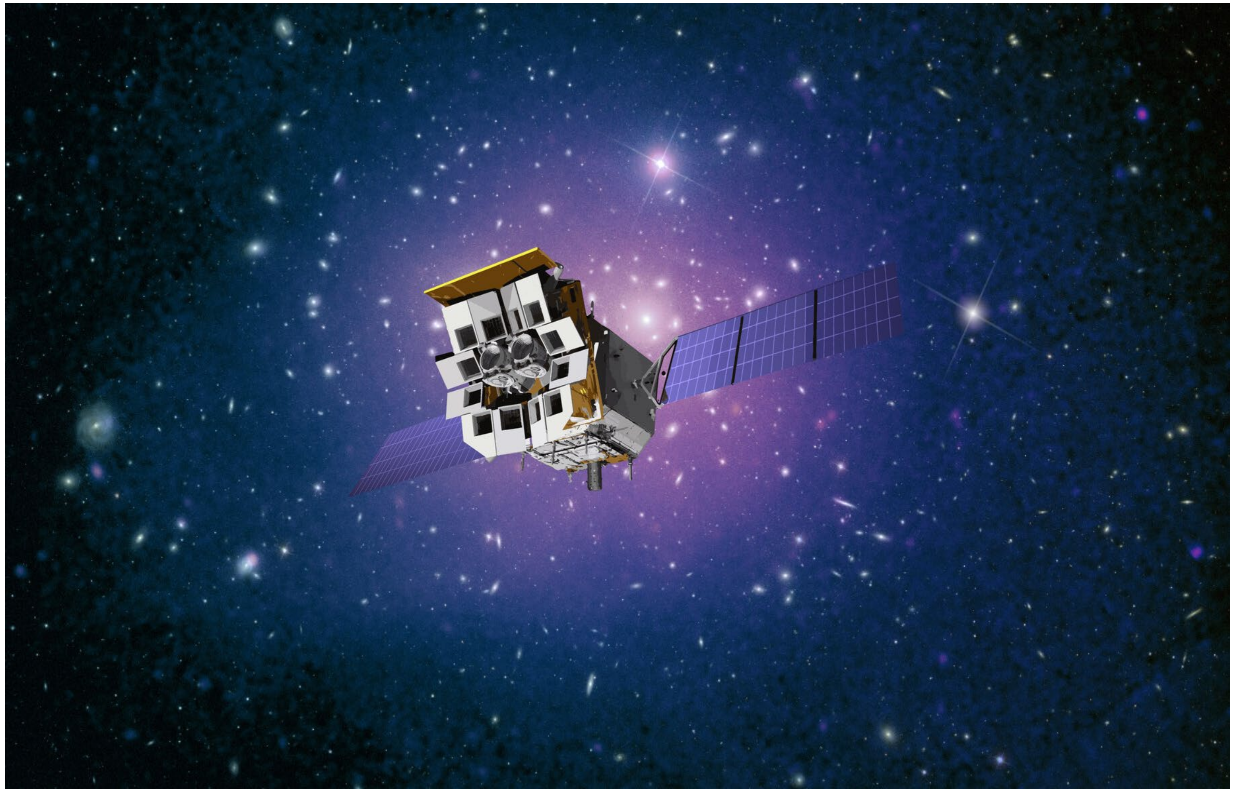
→ pixel defects







Addendum



Same PN-CCD detector type and X-ray optics as used for eROSITA
are in operation on the Chinese-European
X-ray mission Einstein Probe
"A New Horizon in Detecting Cosmic X-ray Transients"

- **launched on January 9, 2024**
- **FXT comprising 2 telescopes with eROSITA type PN-CCD detectors**

Thank you !