PN-CCD Detectors in Space

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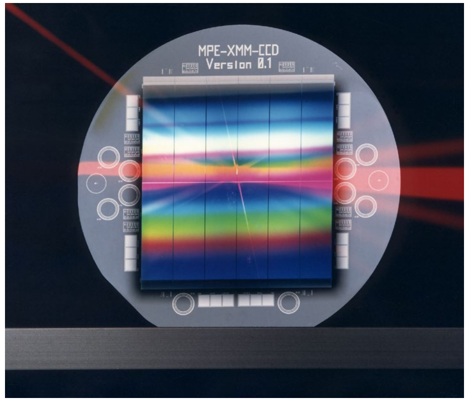
X-ray satellite missions with PN-CCD Detectors

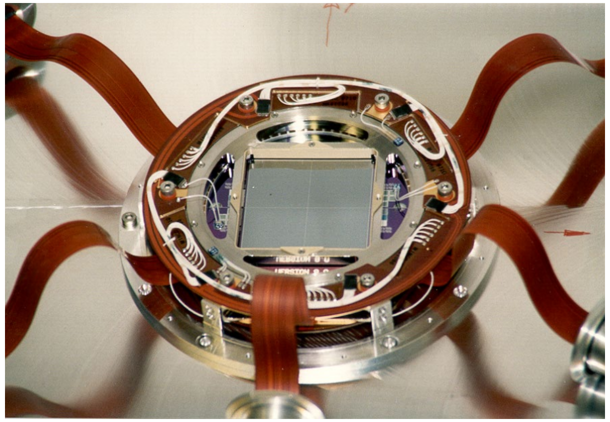
- **XMM-Newton:** ESA satellite **motivated PN-CCD** detector development**:** *launch Dec. 1999*
- **eROSITA: Optimization** of PN-CCD detector**:** *launch July 2019*
- **Einstein Probe:** *launch January 2024*
- **SVOM:** *launch June 2024*
- **eXTP:** *launch January 2030 (planned)*
- **SPICE:** PN-CCD detector development for **future X-ray missions**

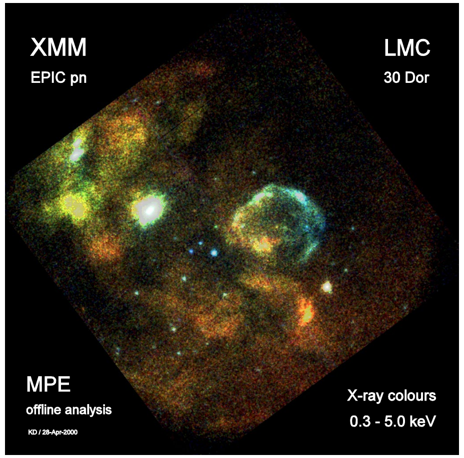
XMM-Newton

EPIC-PN camera of XMM-Newton

- PN-CCD: single X-ray photon counting detector with high energy, time and spatial resolution

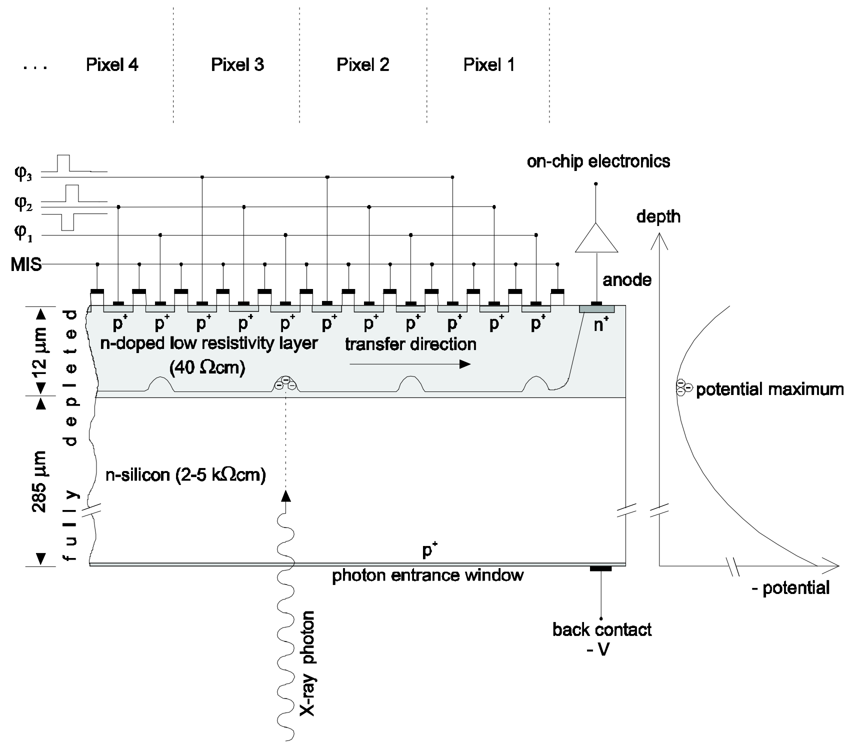


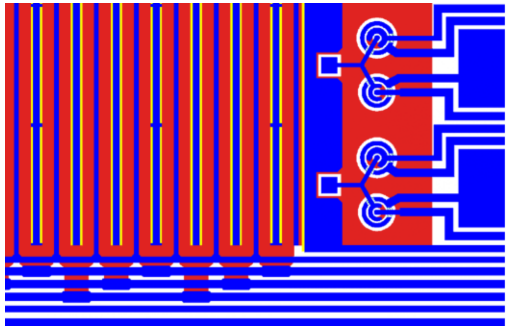


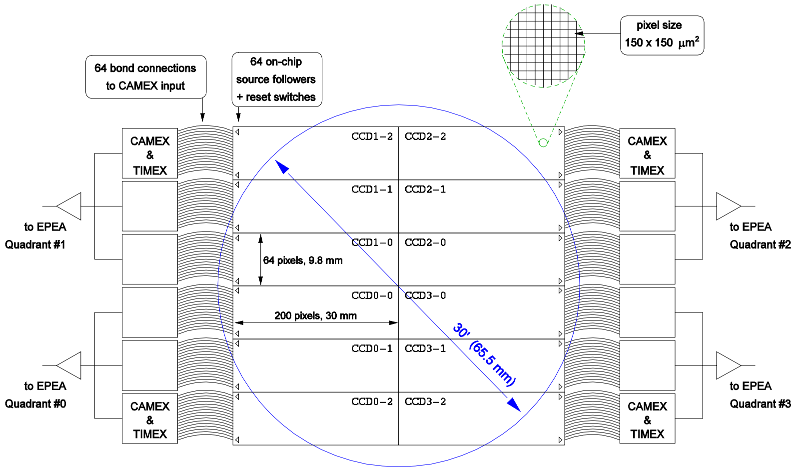


XMM-Newton

PN-CCD







- transfer gates: pn-junctions
- fully depleted = 300 µm
  → back-illuminated: high QE
  + radiation hard against soft protons
- parallel transfer & readout architecture
- 6 cm x 6 cm PN-CCD
  = 12 CCDs (64 channels x 200 rows)
- readout time: 4.6 ms / 3 cm² CCD unit

XMM-Newton

EPIC-PN camera operating modes

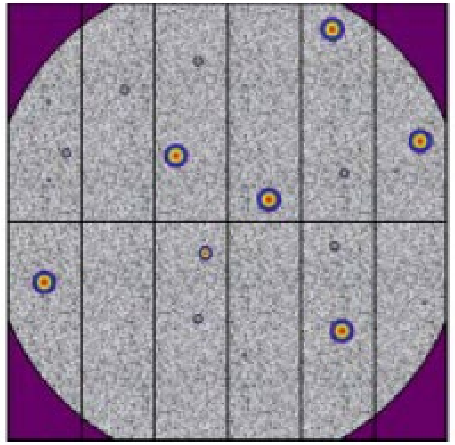
Strüder et al., A&A (2001)

mode	field of view (FOV) in pixel format in arc min.	time resolution in ms	out of time (OOT) events in %	life time with OOT events in %	brightest point source for XMM in counts s^{-1} in erg cm^{-2} s^{-1} *
FF	398×384 27.2×26.2	73.3	6.2	100	6 8.1×10^{-12}
eFF	398×384 27.2×26.2	199.2	2.3	100	for extended sources only
LW	198×384 13.5×26.2	47.7	0.15	94.9	9 1.2×10^{-11}
SW	63×64 4.3×4.4	5.7	1.1	71.0	100 1.4×10^{-10}
TI	199×64 13.6×4.4	0.03	100	100	4000 5.9×10^{-9}
BU	20×64 1.4×4.4	0.007	depends on PSF	3.0	60 000 8.1×10^{-8}

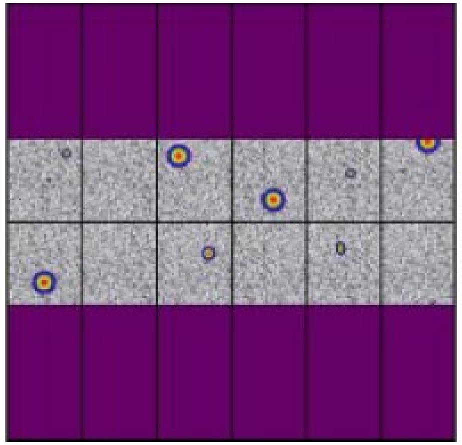
XMM-Newton

EPIC-PN camera operating modes

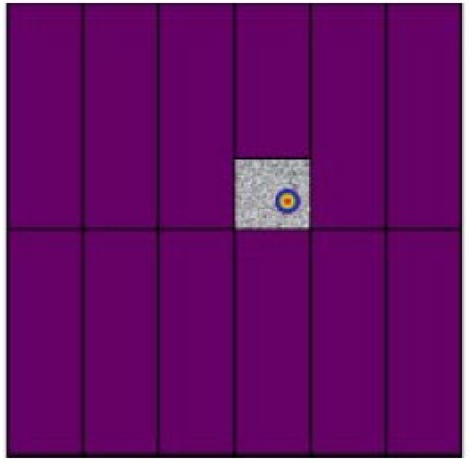
Strüder et al., A&A (2001)



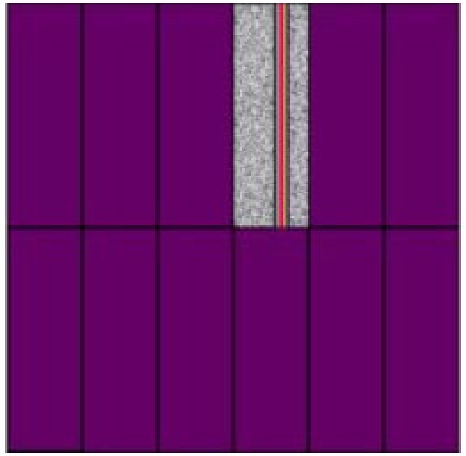
Full Frame & Extended Full Frame



Large Window



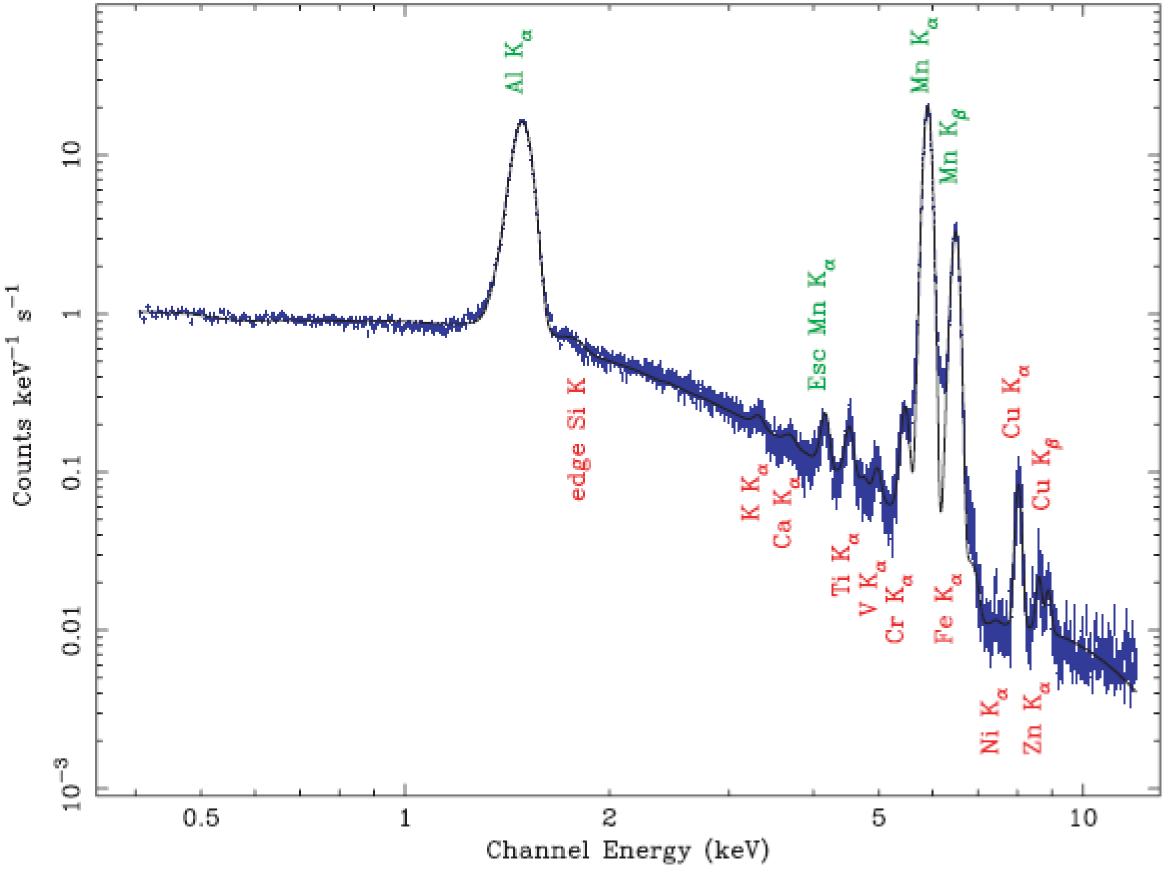
Small Window in Quadrant 1



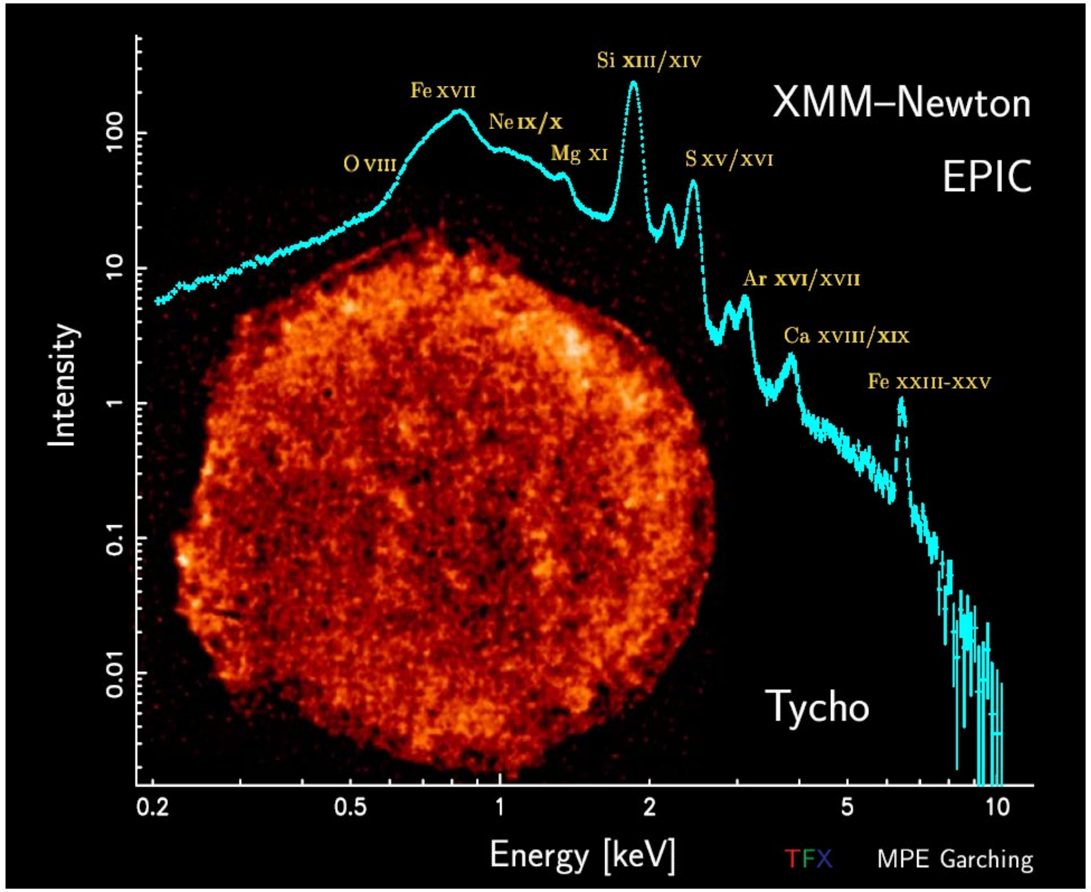
Timing Mode in Quadrant 1

XMM-Newton

EPIC-PN camera spectra + imaging



Calibration spectrum with the internal radioactive source



Strüder et al., NIM A 512 (2003)

XMM-Newton

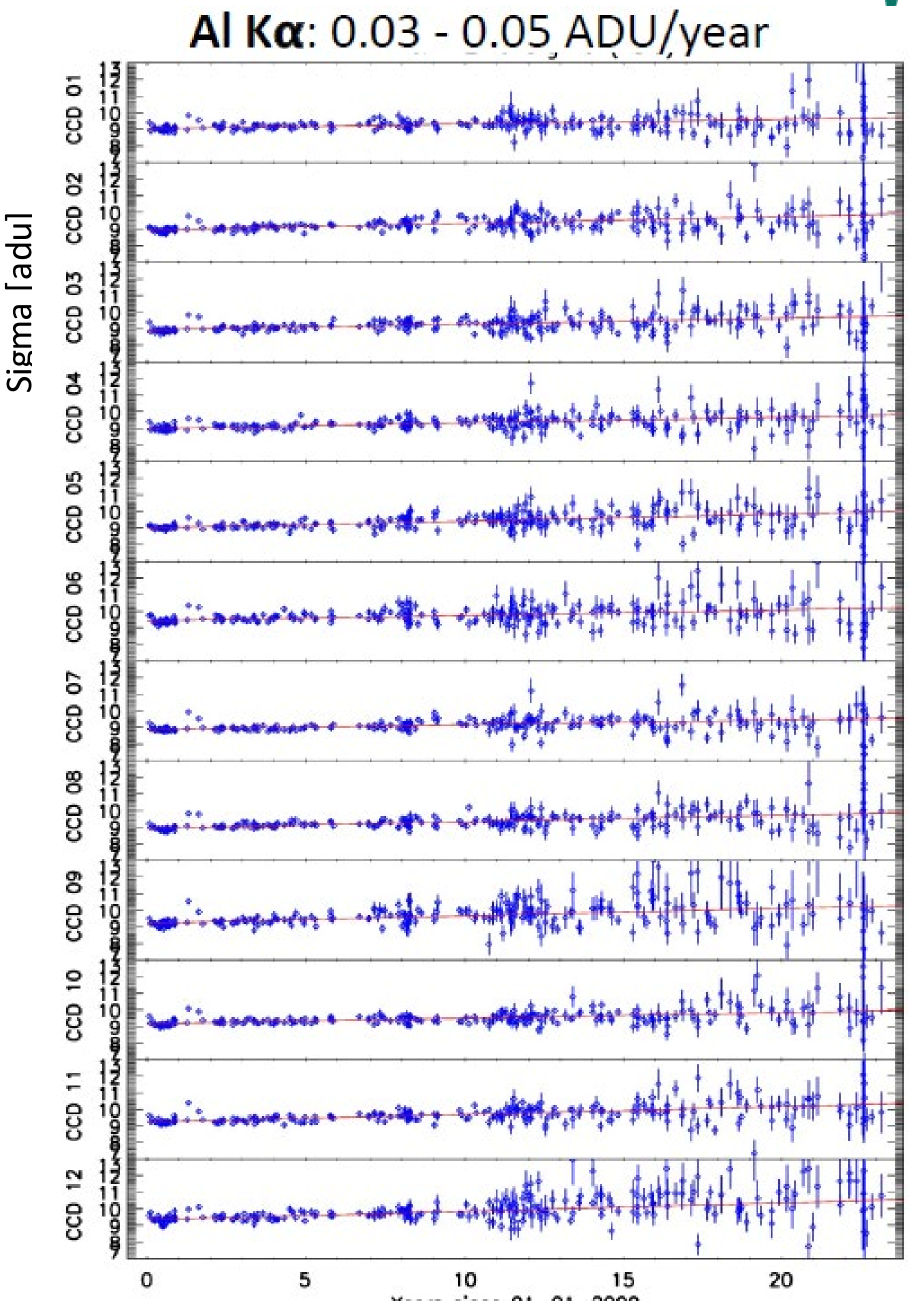
EPIC-PN

<u>Status of PN-CCD detector aboard XMM-Newton till today</u>:
- all 12 CCDs operational
- operating parameters unchanged

Energy resolution:

ΔFWHM/(FWHM · t) ~ 0.2% /y @1.5keV

Very minor degradation as expected



M. Smith | EPIC Cal Ops Meeting | 22 May 2023

XMM-Newton

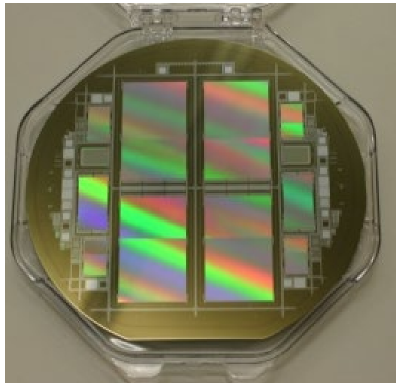
EPIC-PN camera summary

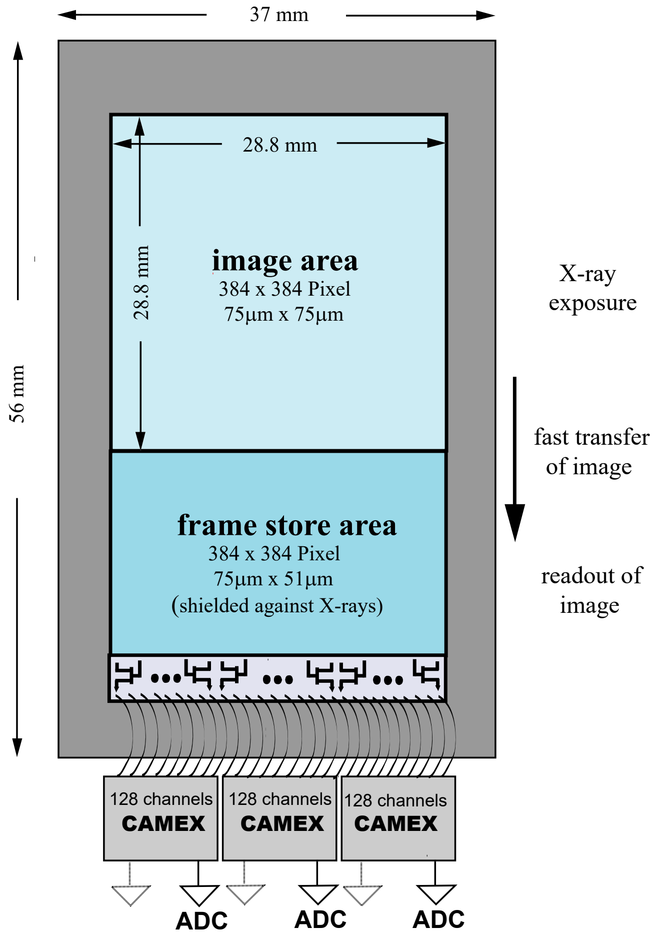
- EPIC-PN camera onboard XMM-Newton operates successfully since 1999 till today
- Performance still excellent + stable
- All instruments (EPIC-PN, EPIC-MOS1+2, RGS1+2) are fully functional
- XMM-Newton observation proposals over-subscribed by factor 7 (most EPIC-PN)
- Spacecraft fully healthy and fuel until 2034+

eROSITA PN-CCD Detector

- ▶ 3-phase, back-illuminated, 450 µm fully depleted
- ▶ frame store
- ▶ Excellent energy resolution in energy band [0.2 keV; 10 keV]
- ▶ Image area: 28.8 x 28.8 mm^2
- ▶ Pixel size: 75 x 75 μm^2 → 384 x 384 Pixel

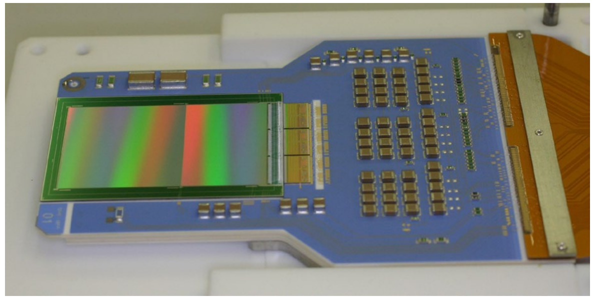
  ⇒ 384 parallel signal processing channels



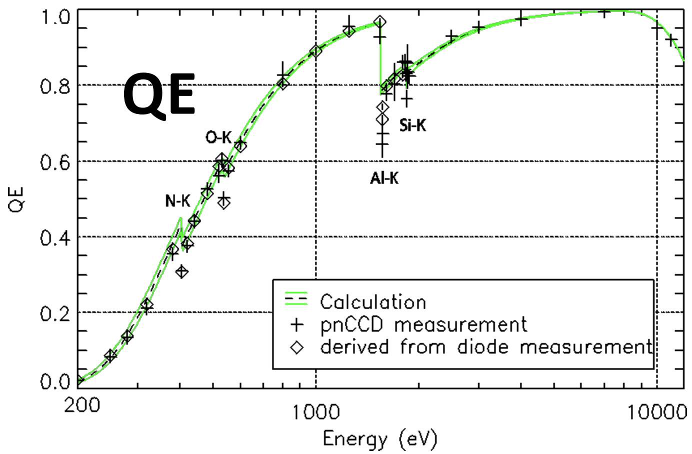


PN-CCD Detectors in Space

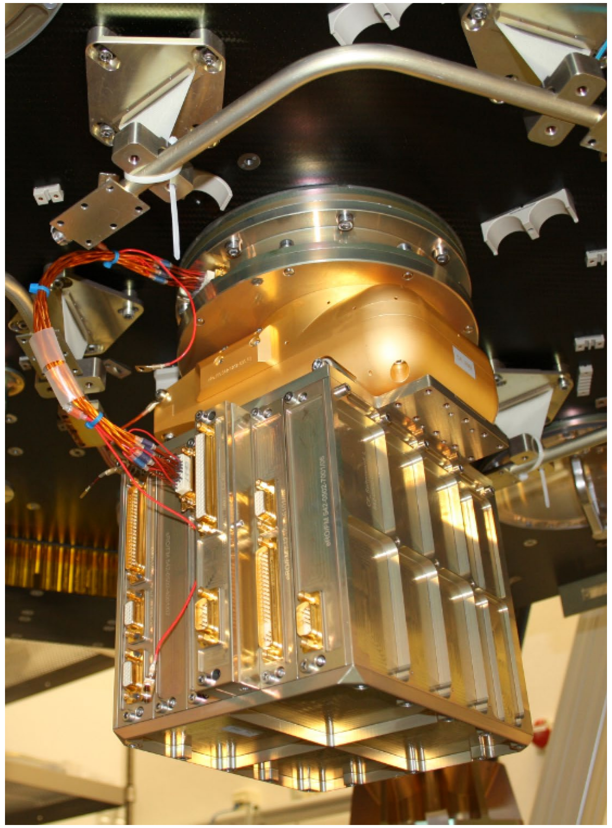
- ▶ **Image readout: 9.2 ms**
- ▶ **eROSITA: cycle time: 50 ms**
  - minimize heat dissipation ((40 ms CAMEX off)
    → T = -95°C (best wrt radiation damage)
  - on-board event processing

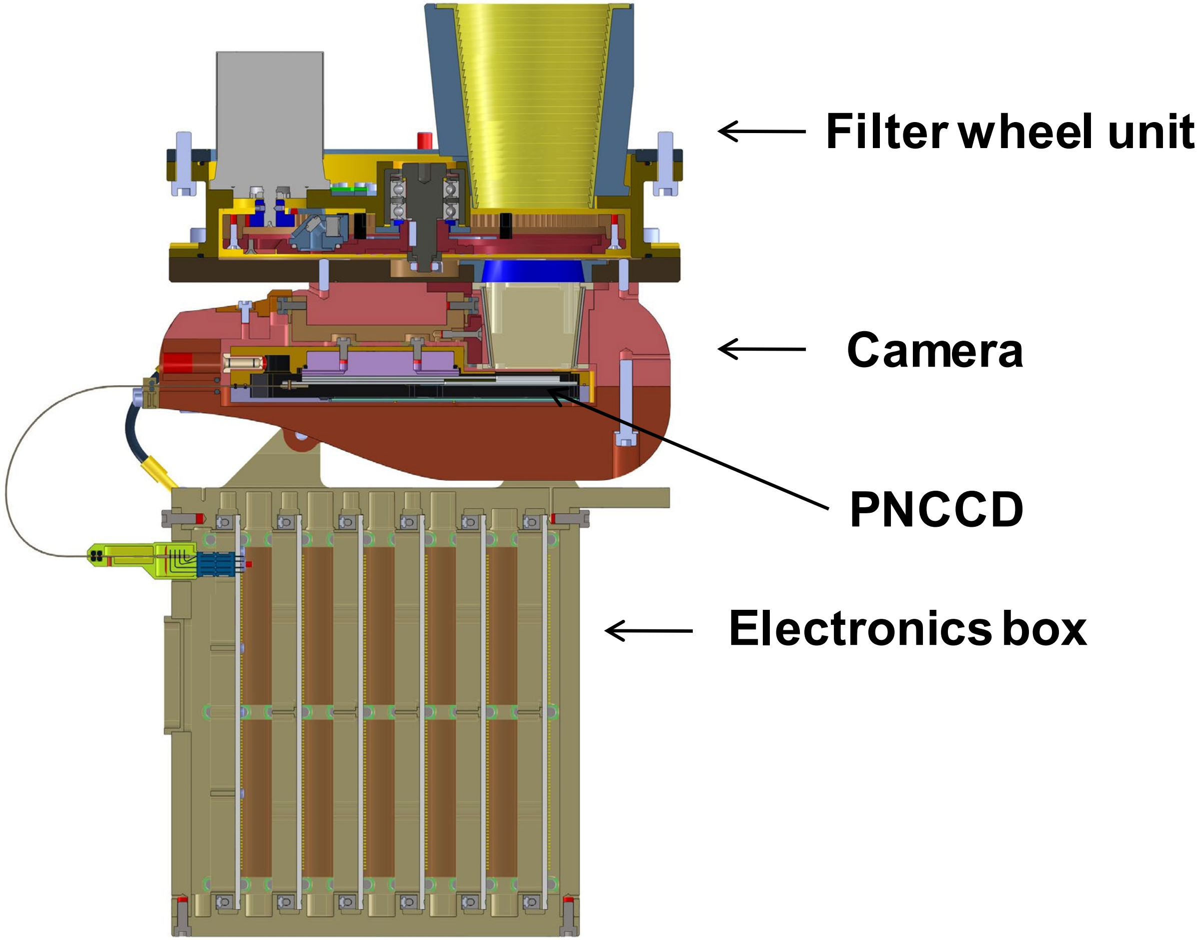


- ▶ **Space: light blocking filter**
  → option 1: external filter
  option 2: new: on-chip filter



eROSITA Camera (Assembly)

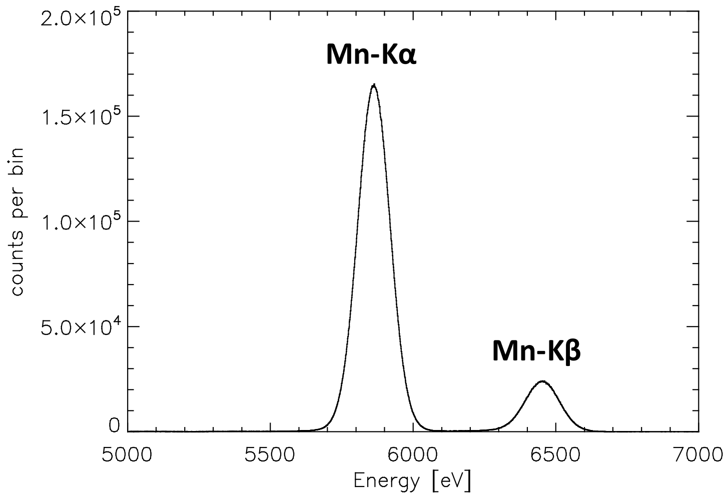


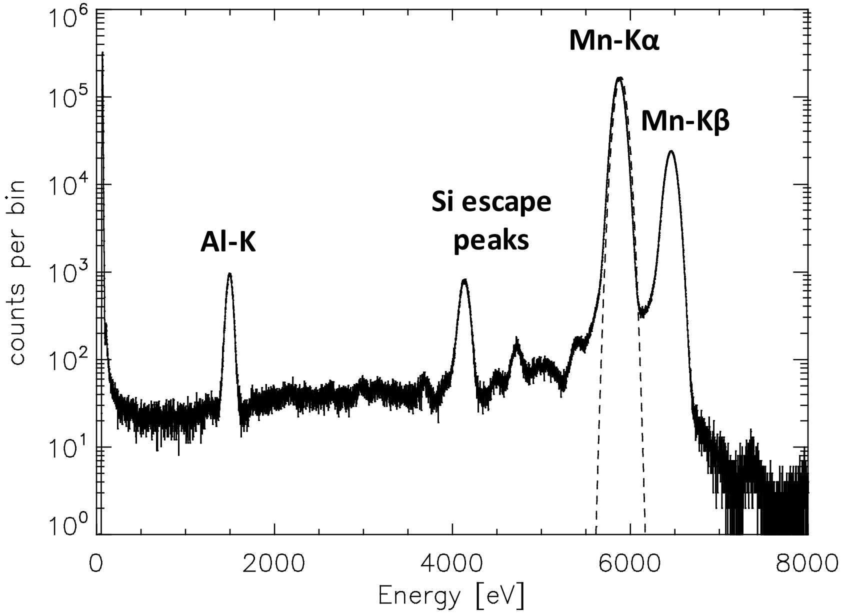


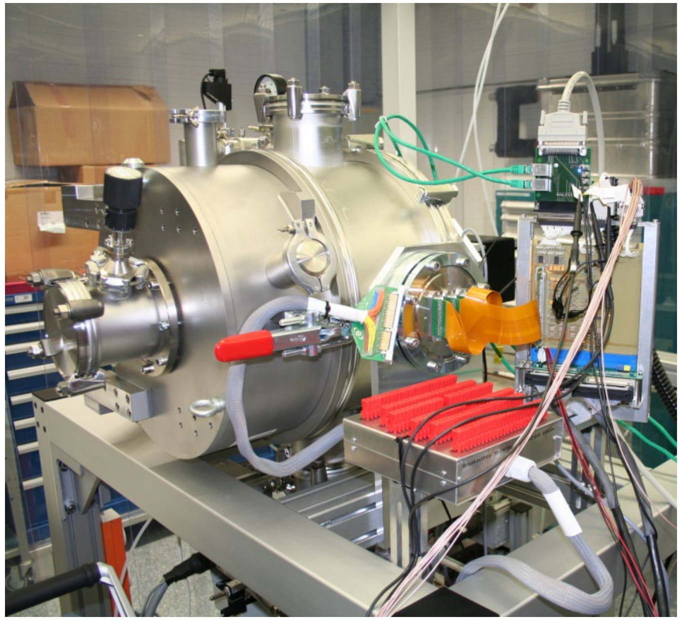
All PN-CCD Detector Modules tested (**GEPARD chamber**) at MPE with ^{55}Fe
→ performance test + voltage optimization

FWHM(5.9keV)≤ 140eV
Noise ≈ 2.5 el. ENC, # bad pixels ~ 0

Calibration + E2E test: PUMA + Panter test facilities (MPE)

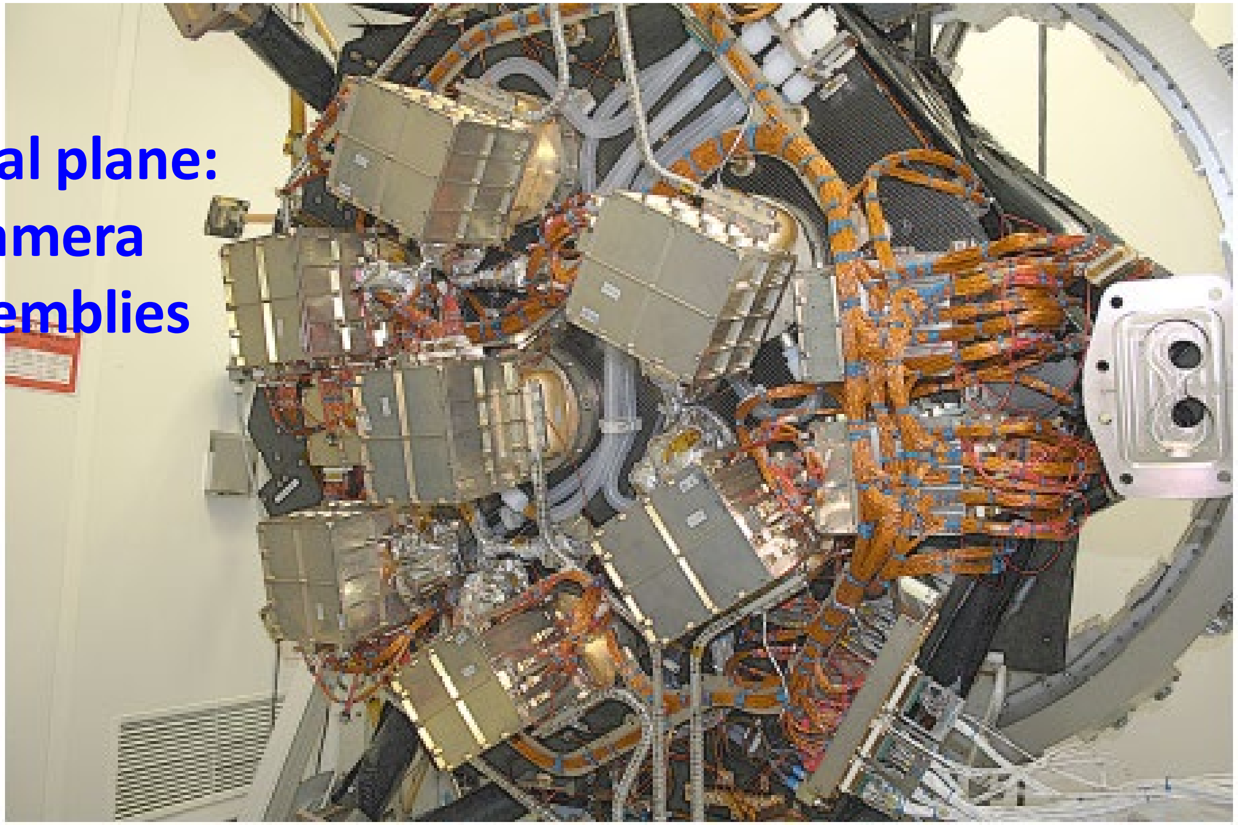






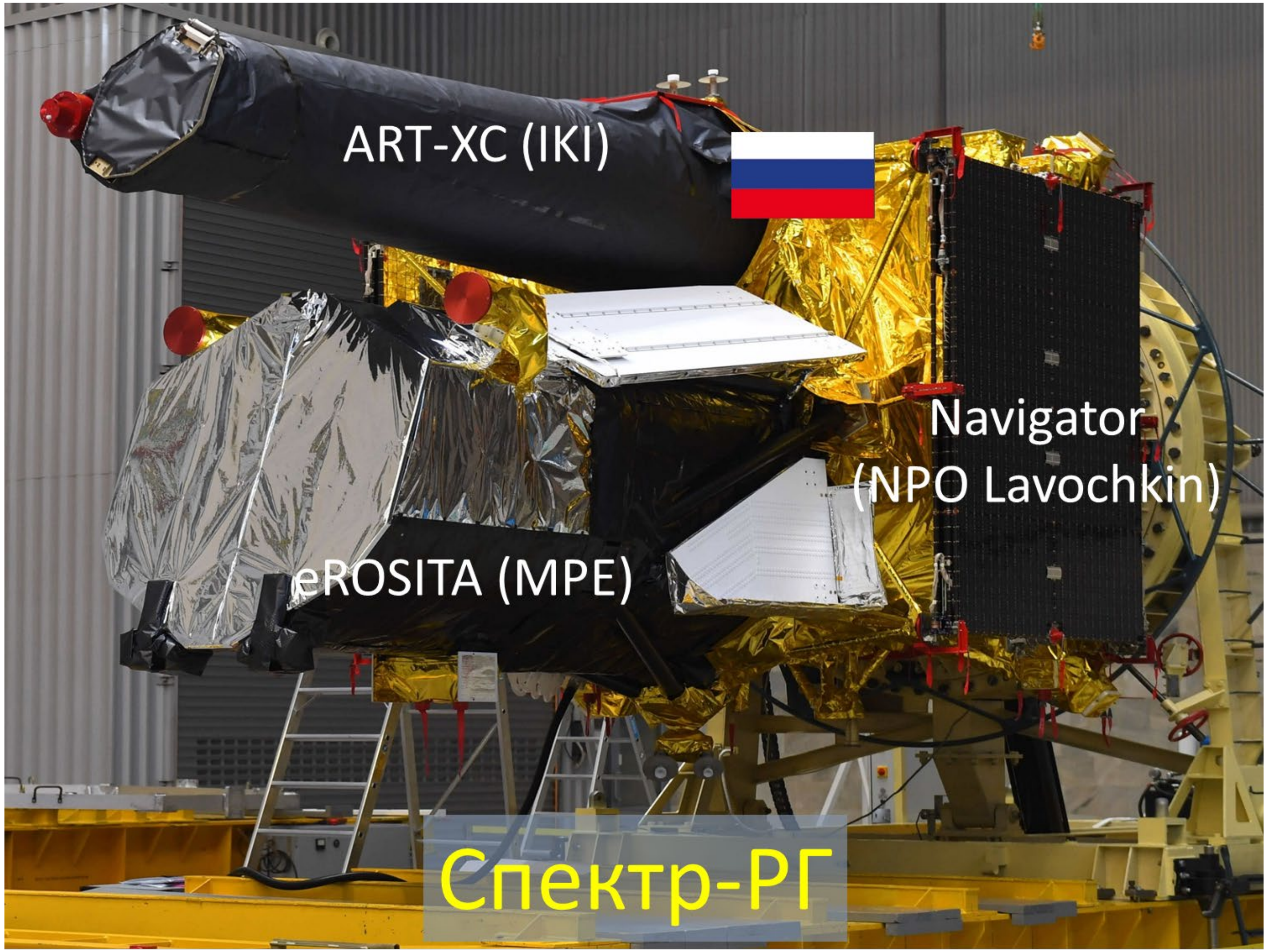
eROSITA telescope array assembled at MPE

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.)

PN-CCD Detectors in Space



PN-CCD Detectors in Space

Launch on 13 July 2019 (12:31 UTC)

in space: eROSITA fully functional - similar performance as measured on ground

eROSITA (extended ROentgen Survey with an Imaging Telescope Array)

eROSITA wide-field (1°) X-ray telescope developed under MPE's leadership:

- **7 Wolter-1 mirror modules** (54 nested mirror shells) +
- **7 cameras** with PN-CCD detectors incl. electronics + filter wheel

eROSITA onboard SRG → halo orbit around L2

Since Dec. 2019: SRG/eROSITA performed **all-sky survey**:

whole celestial sphere is mapped once every 6 months

Eight all-sky charts were planned until Dec. 2023.

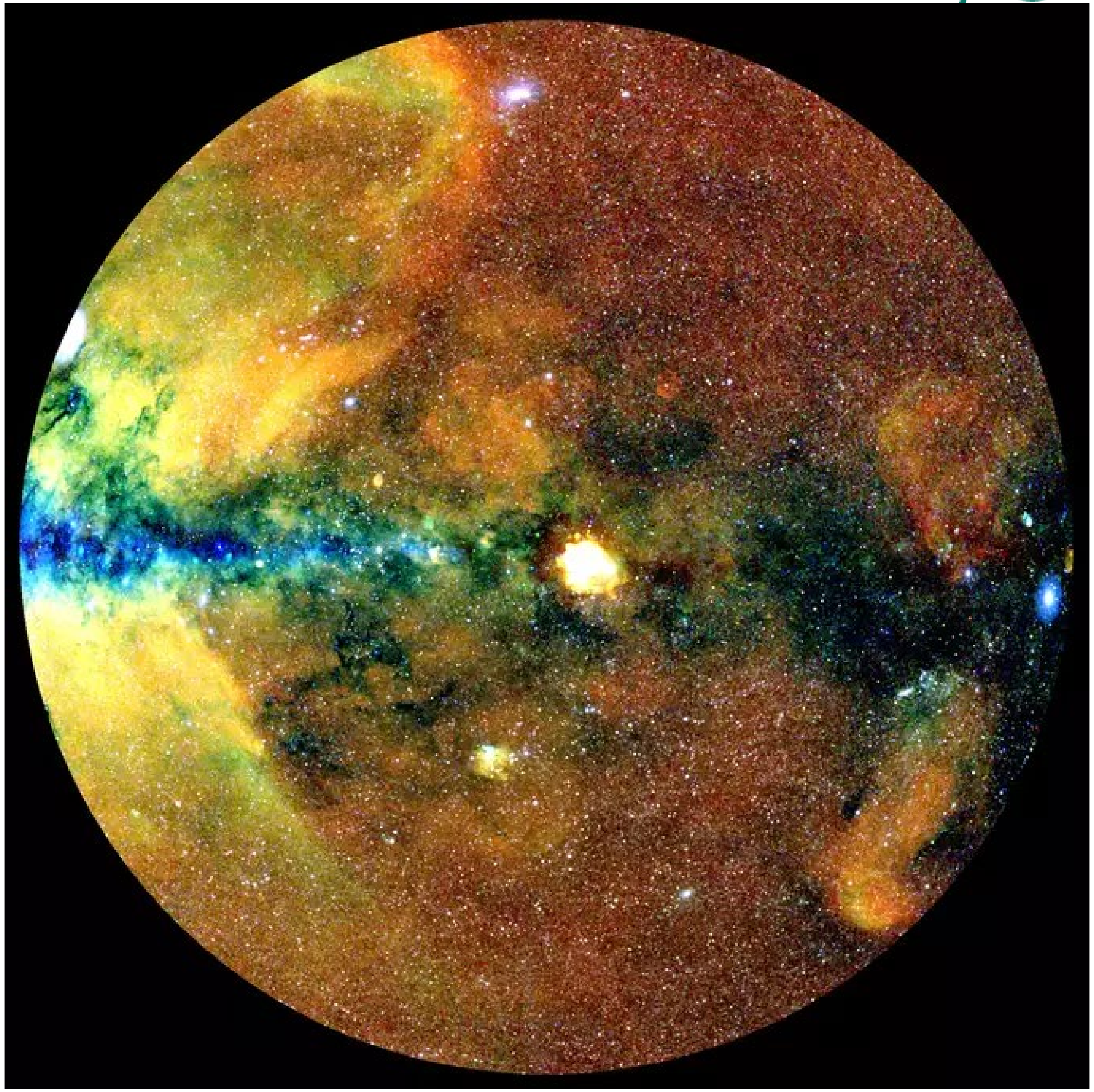
26 February 2022: eROSITA in **safe mode** for political reasons (cooperation with Russia suspended)

PN-CCD Detectors in Space

eROSITA data release by German eROSTIA consortium (**31 Jan. 2024)**:

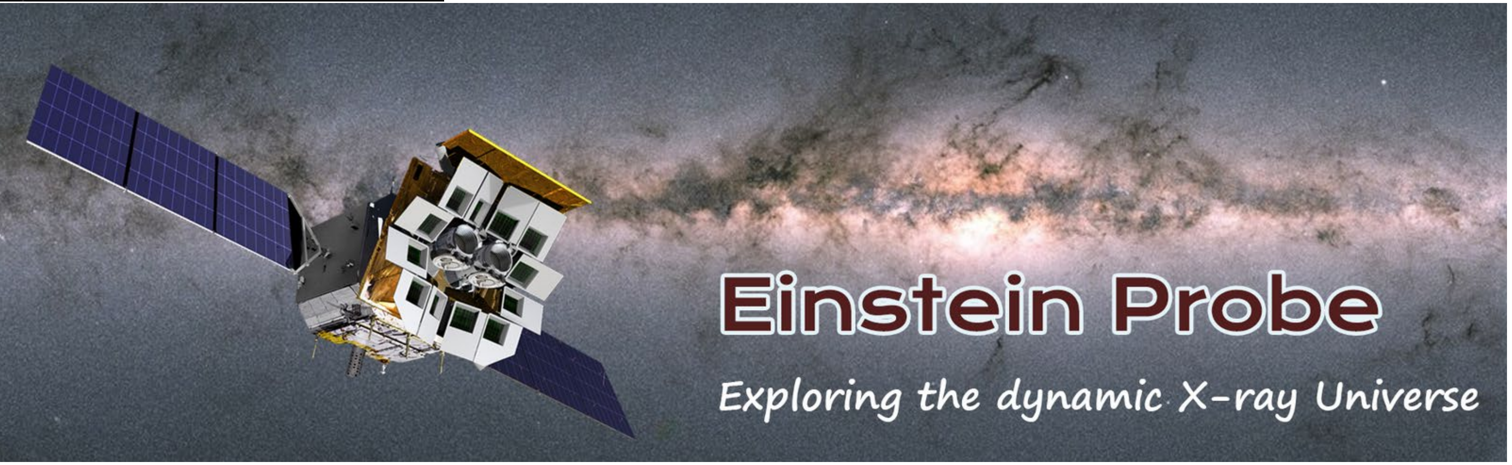
eRASS1 catalogue: 170 million X-ray photons

- observations 12 Dec. 2019 - 11 June 2020
- **>900 000 sources**, including **~710.000 AGNs**
  180 000 X-ray emitting stars in our **Milky Way**,
  12 000 clusters of galaxies, plus **binary stars, supernova remnants, pulsars**



Photons colour-coded according to energy
(red 0.3-0.6 keV, green 0.6-1 keV, blue 1-2.3 keV).

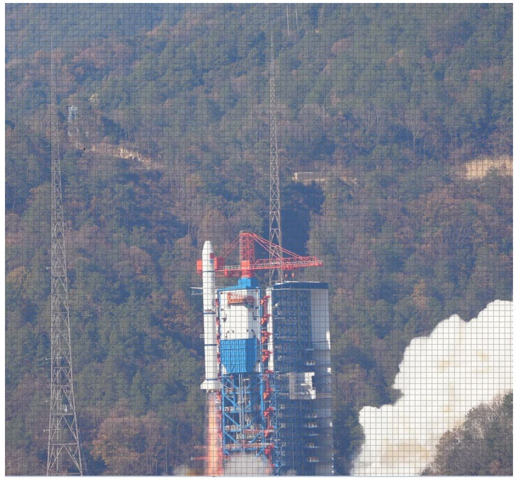
Einstein Probe



PN-CCD detectors of eROSITA type in operation on Chinese-European **X-ray mission Einstein Probe**

"A New Horizon in Detecting Cosmic X-ray Transients"

launched on January 9, 2024

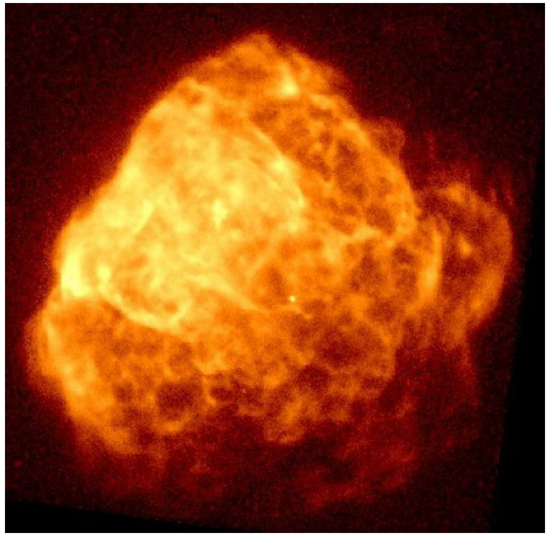


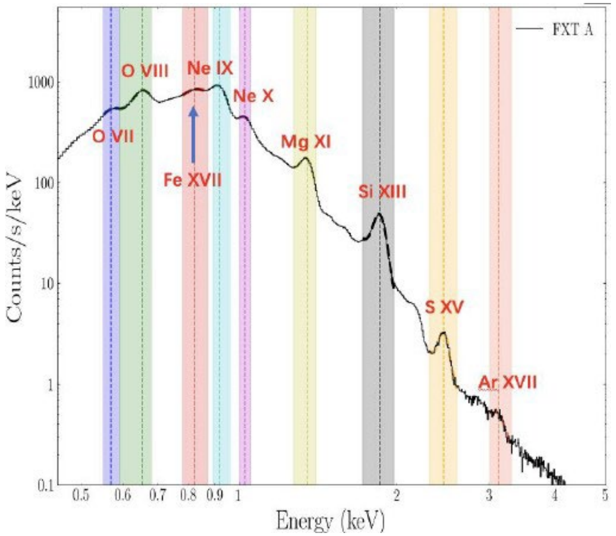
WXT: lobster-eye-based wide-field telescope:
12 MPO (3800 square degrees) + 48 CMOS detectors

FXT: 2 telescopes (eROSITA optics (FoV=1°) + PN-CCD detector)

Dedicated PN-CCD wafers for EP project by HLL (R. Richter et al.)

Einstein Probe

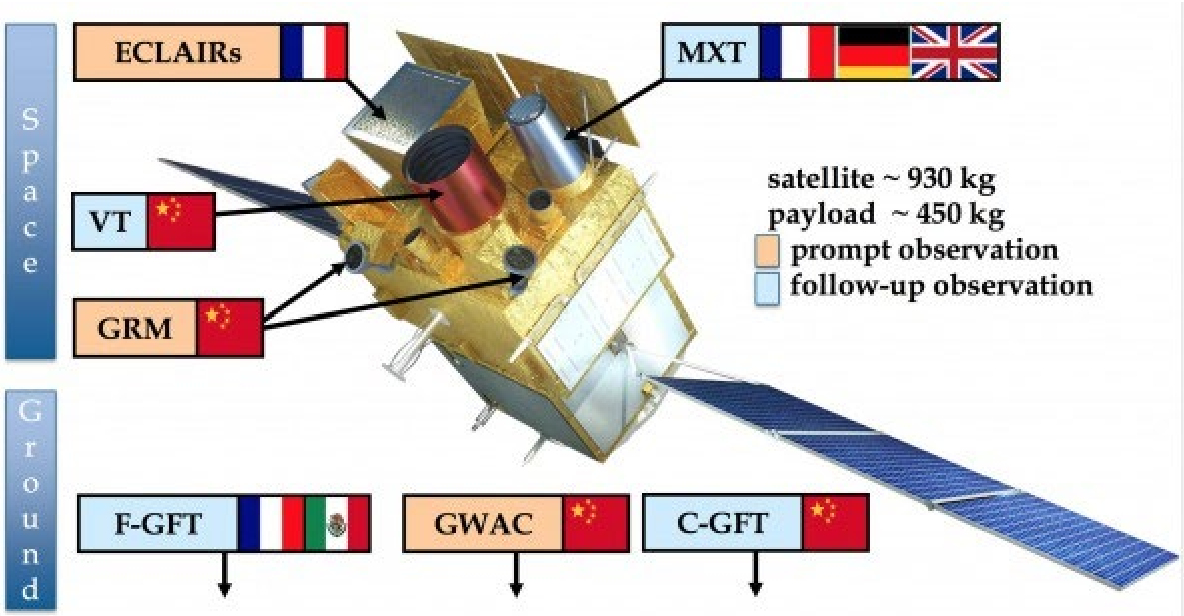




FXT „First Light“ observation: Puppis A SNR (Credit: Weimin Yuan)

Status end of 2024:

- >70 transient events detected
- thousands of candidates
- > 500 stellar flares
- > 100 alerts sent to international community, guiding follow-up observations from ground based and space instruments

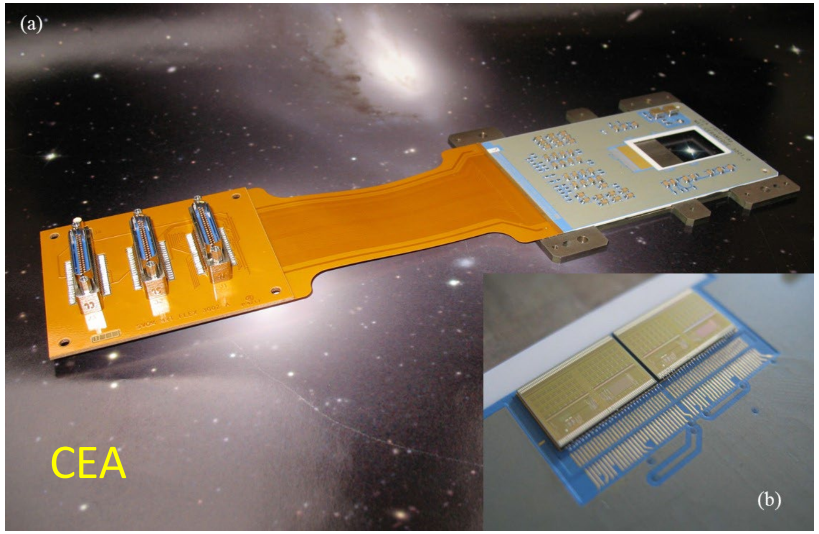


SVOM MXT

SVOM: Chinese-French mission dedicated to **gamma-ray bursts**

French MXT (Microchannel X-ray Telescope) instrument
prototype of eROSITA PN-CCD:
256x256 pixels (75x75µm^2)

- **MPE provided PN-CCDs, CAMEX readout ASICs, know-how for assembly and operation of detector.**

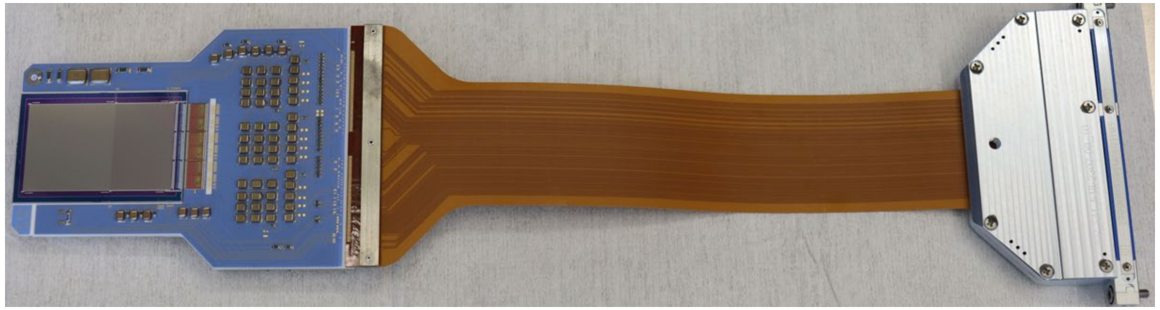


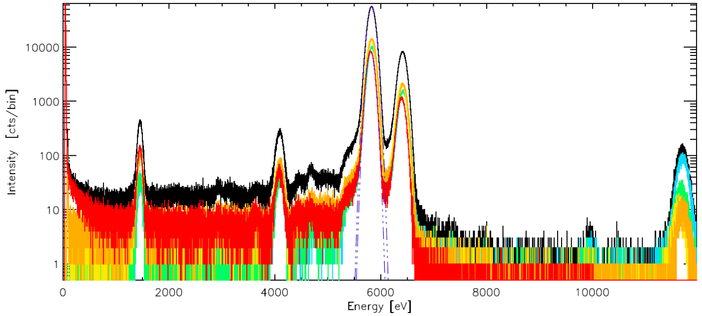
Launch on **22 June 2024**
from the Xichang
MXT successfully commissioned + in operation
SVOM has detected **113** gamma-ray bursts until
May 1st 2025

eXTP satellite mission

enhanced X-ray Timing and Polarimetry

- eXTP SFA planned to be equipped with **six 19-cell SDD detectors**
- Request in Dec. 2024 for PN-CCD detector of EP-FXT type: **imaging + spectroscopy**
- eXTP satellite launch: January 2030





SPICE (Small Pixel CCD Experiment)

Paul Nandra motivated CCD technology development for

Future X-ray missions with high-angular resolution X-ray mirrors (~arcsec)

Detector requirements :

- **smaller pixels**
- **larger pixel arrays**
- **high time resolution**
- **low heat dissipation** → sensor temperature (~ -80°C) on S/C

SPICE focal plane with **4 Mpixel**

Architecture: **4 quadrants** with **1024x1024 pixels** for IM

→ **4096** readout channels (**heat dissipation**!)

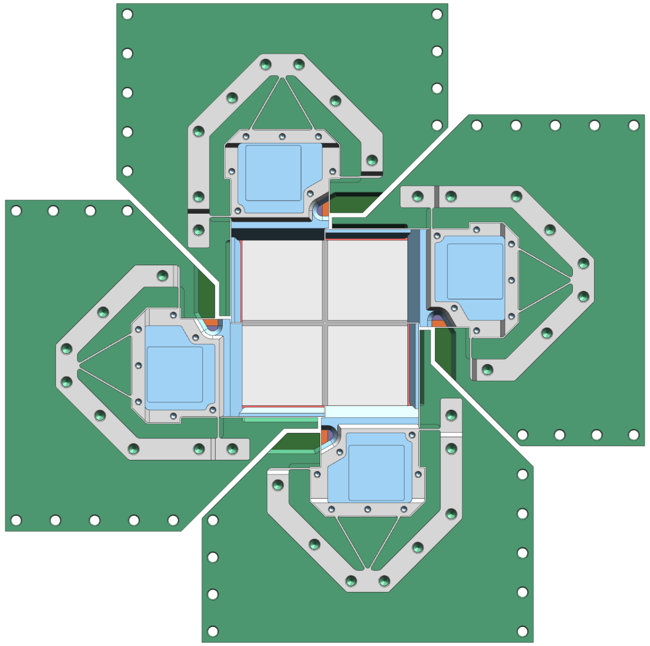
pixel size: **36 x 36µm²** → **signal charge** spread over up to **3x3 pixels**

centroiding → **subpixel resolution**

Time resolution **≥ 30ms**

higher time resolution by **window or timing mode**

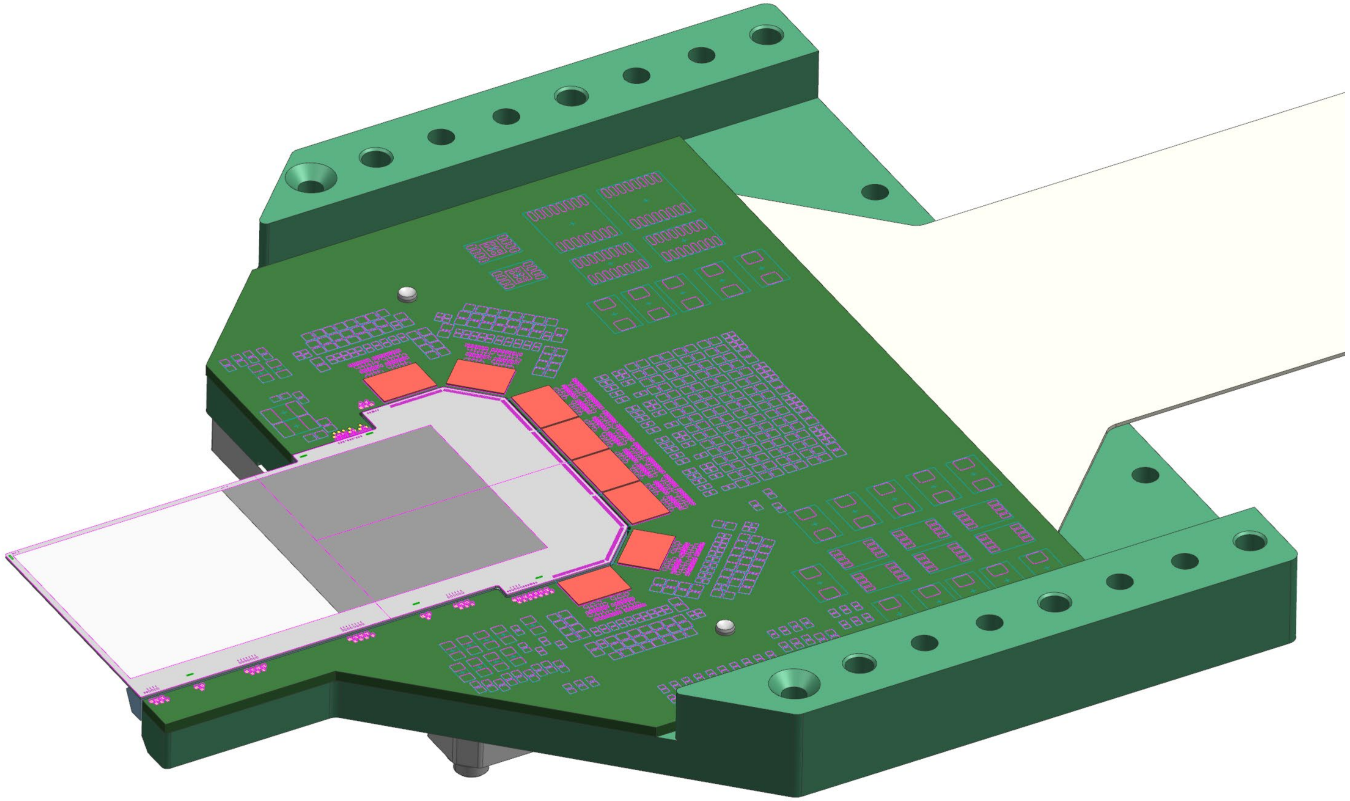
Readout ASIC: **CAMEX**

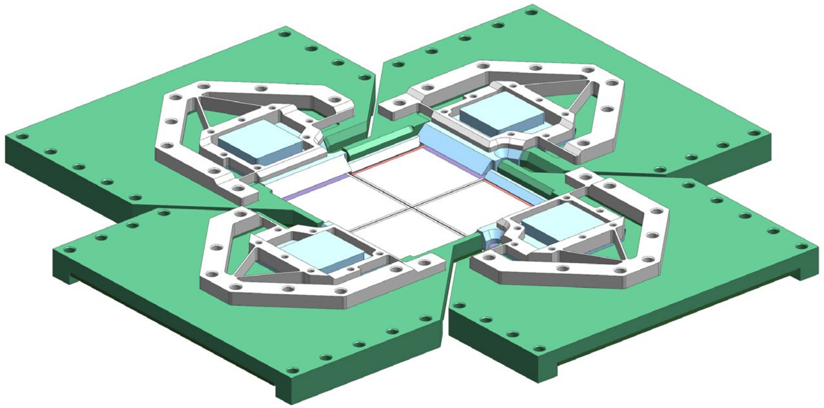


SPICE detector development in progress:

- **HLL: CCD sensor** layout & fabrication
- **MPE**: **Requirements (science)**
  Detector board incl. mech.-thermal design suitable for flight;
  Thermal vacuum chamber
  Lab electronics (→ flight electronics)
  Data analysis

SPICE PN-CCD Detector





FoV(4MPixel) ≈ 7.6 x 7.6 cm^2

→ Very innovative design developed for SPICE

Thank you