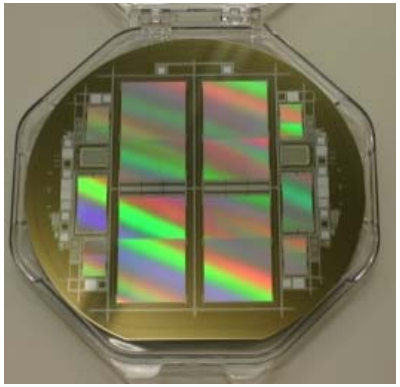
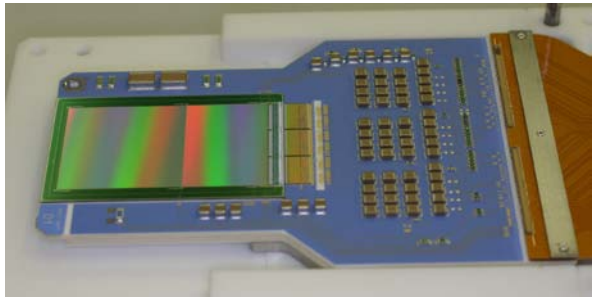


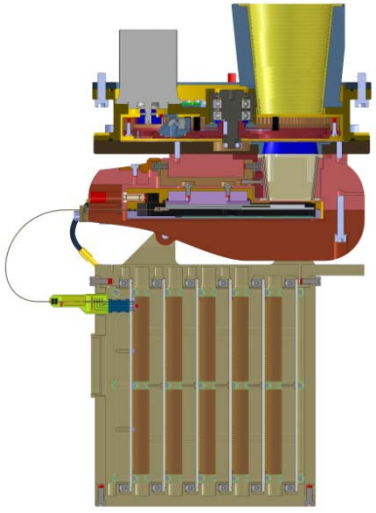


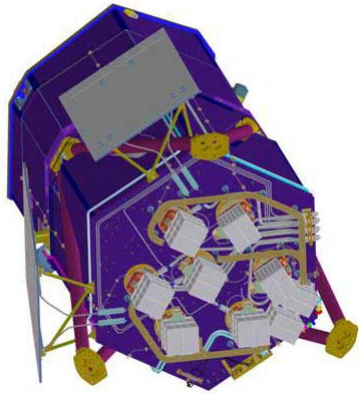
eROSITA CCD Detectors

Time-Resolved Spectroscopy and Imaging of X-Rays

R. Andritschke, J. Elbs, S. Granato, O. Hälker,
G. Hartner, S. Herrmann, N. Meidinger, D. Mießner,
D. Pietschner, J. Reiffers, T. Rommerskirchen,
G. Schmaler, L. Strüder, G. Weidenspointner

Max-Planck-Institut für extraterrestrische Physik
MPI Halbleiterlabor
17. October 2011

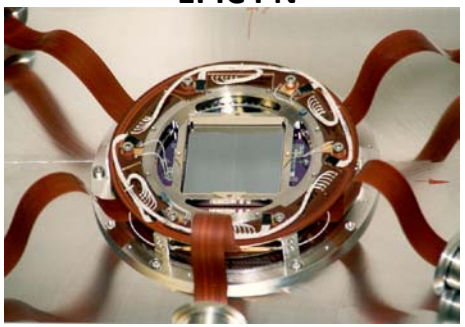




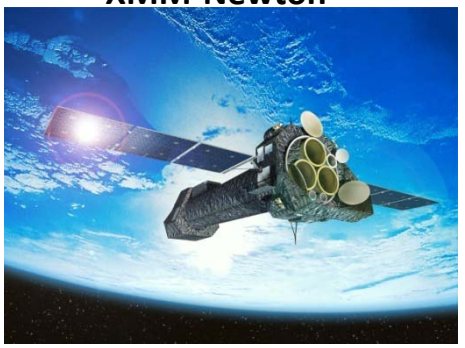
Introduction

PNCCD developed by 'MPI Halbleiterlabor'
→ ESA's XMM-Newton mission (1999 – today)

EPIC PN

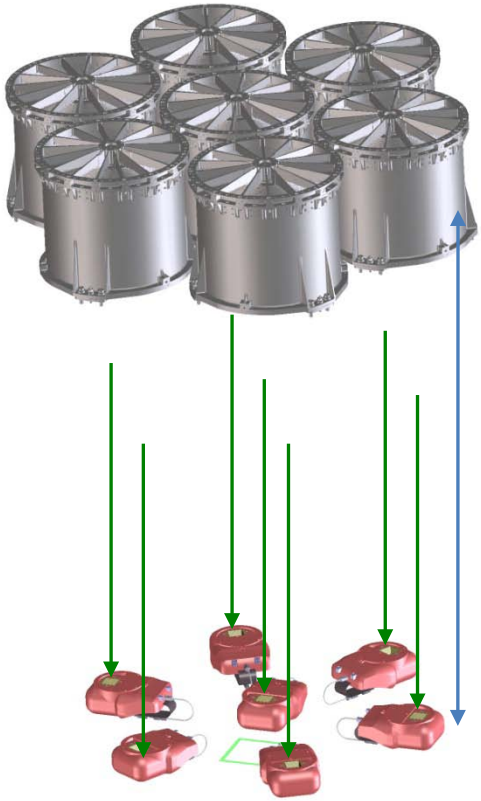


XMM-Newton



ground-based applications:
e.g. X-Ray Imaging Measurements at Free Electron Lasers
(FLASH (D), LCLS (USA), SPRING 8 (J), EuXFEL (D))

eROSITA



→ enhanced XMM-Newton PNCCD developed for space project:
eROSITA (extended Roentgen survey with an imaging telescope array)

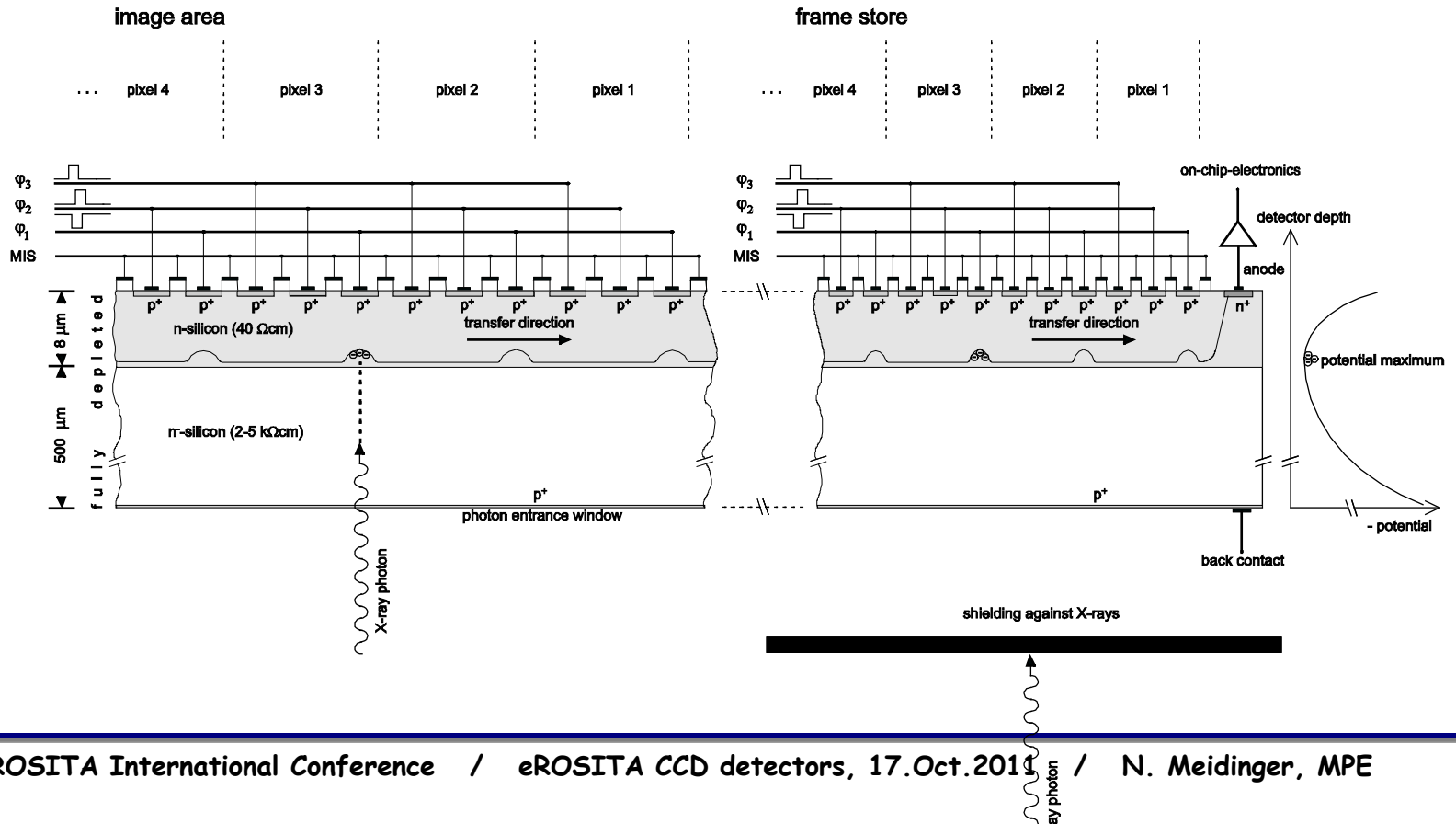
= **7** x telescope {X-ray mirror system + PNCCD camera}
→ FoV = 1.0°

E ~ [0.3 keV; 10 keV]

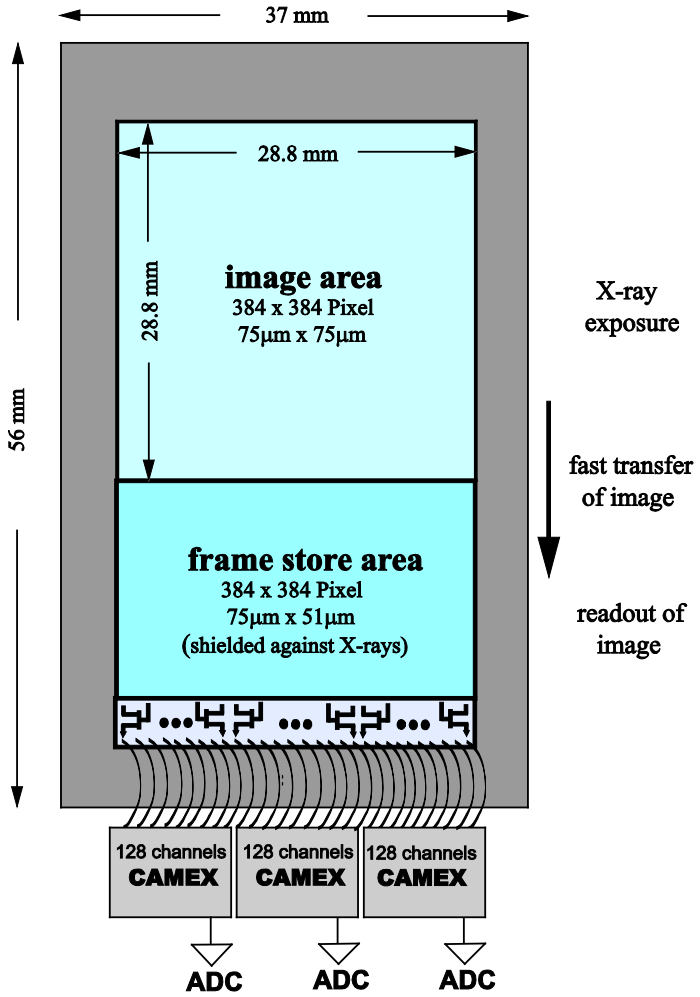
- **spectroscopy**: theoretical limit
- **imaging**: 147,456 pixel
- **time resolution**: 50 ms
- **quantum efficiency** QE_{eff}(CCD + optical filter))[800eV; 14keV] > 75%

PNCCD detector concept

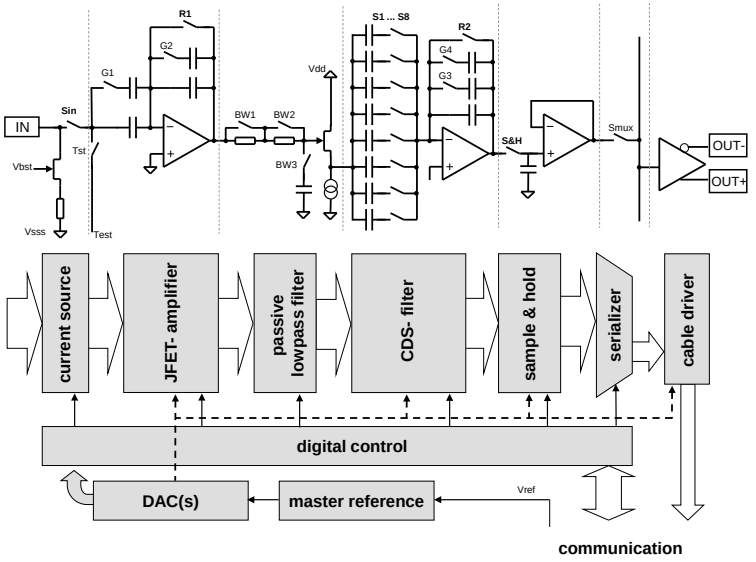
- pn-junctions for transfer registers → PNCCD
- back-illuminated → high + uniform QE @ low energies
- fully depleted → high QE @ high energies
- on-chip amplification + CAMEX ASIC → low noise
- parallel architecture → high speed readout
- frame store: minimization of OOT events



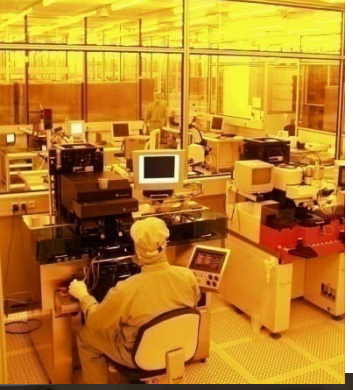
eROSITA PNCCD detector design

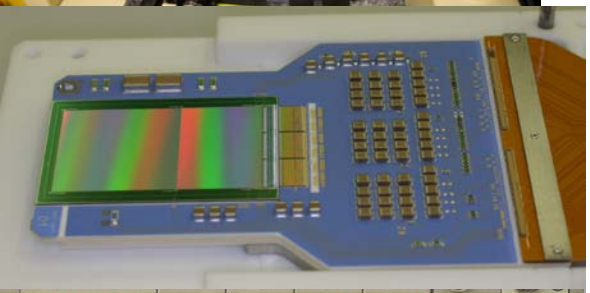


- back-illuminated frame-transfer-CCD
- chip thickness (= 450 µm) fully sensitive
- image: 384 · 384 pixels of 75 · 75 µm^2 size
- column-parallel: 384 independent channels
- CAMEX:
  - 128 analog signal processing channels
  - low-noise (<1 e$^-$ ENC), fast (> 5MHz), low-power (≤ 0.7W)
  - fabrication: JFET-CMOS technology at FHI Duisburg



eROSITA PNCCD detector development





☑ eROSITA **CCDs** developed + manufactured
in MPI Halbleiterlabor

☑ CCD chips tested with **cold-chuck probe station**
(full device operation including spectroscopy)
→ 7 best CCDs for eROSITA

☑ eROSITA **CAMEX** developed + manufactured + tested

☑ eROSITA **detector board**:
flight-prototype board: developed + manufactured + tested
- thick film technology on Al_2O_3 substrate
- 5 layers
- mechanical+cooling interface
- flex interface to electronics

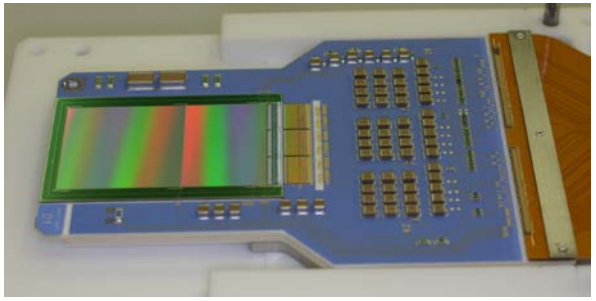
☑ development of **supply, control and DAQ electronics**
for detector system testing in lab

☑ ⇒ detailed testing of PNCCD detector

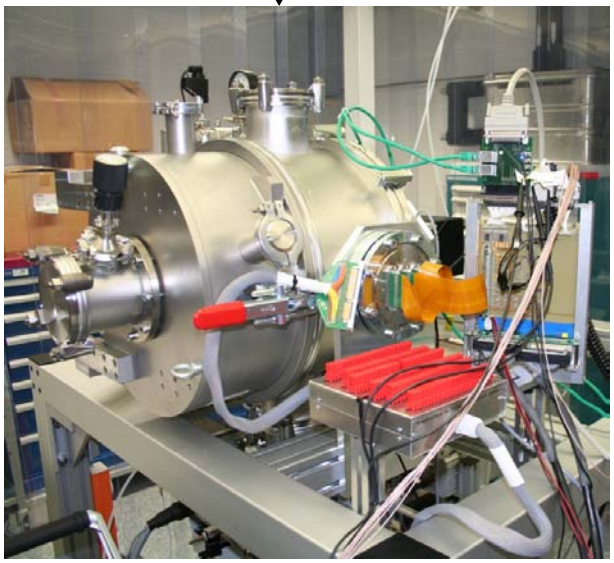
Detector performance

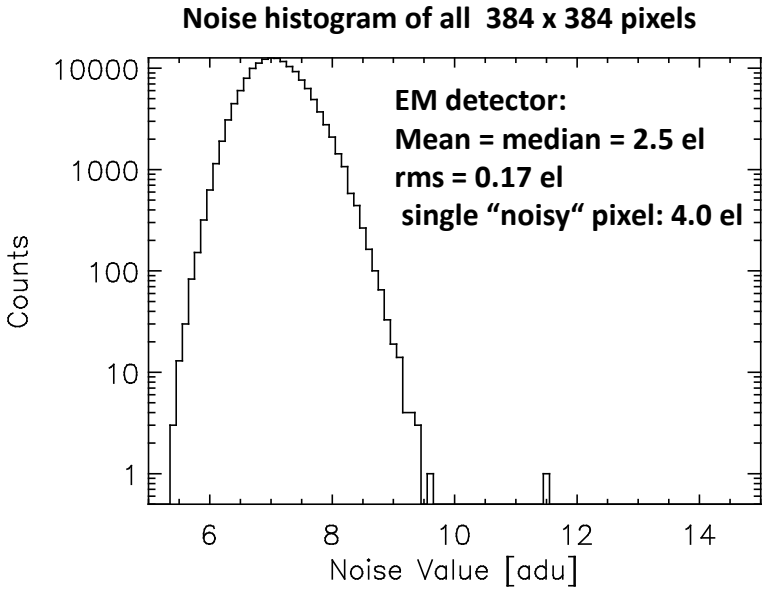
- Frame rate: 20 images / s
  → 2.9 Mpixel/s
- P(OOT events) ≈ 0.2%
- Readout time: 10 ms / image
- CAMEX in standby after readout
- Power consumption: 0.7 W / detector in FP
- Operating temperature ≈ -94°C (rad. dam.!)

→ Read noise: 2.5 electrons rms ENC
no bright pixel

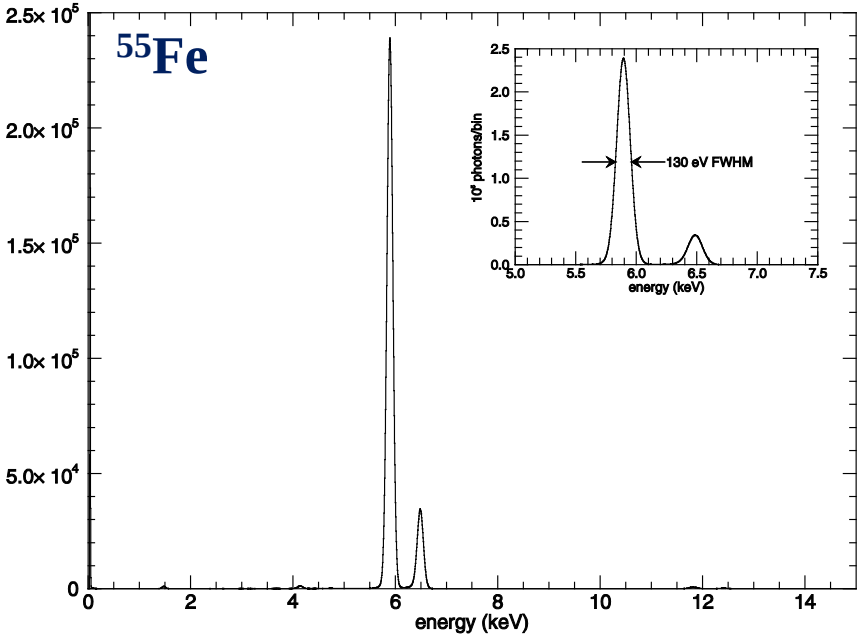


- eROSITA **EM** detector
  with front-end electronics
  tested at GEPARD / MPE (2010/2011)

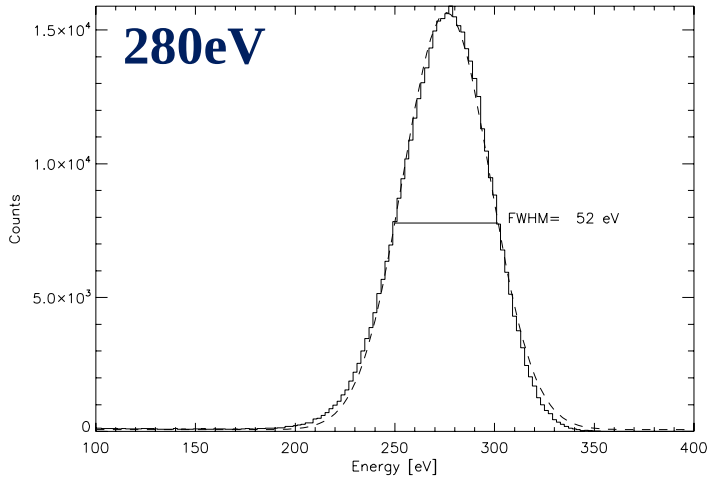




Spectroscopy



eROSITA EM detector + FEE
at GEPARD:
^{55}Fe spectrum
FWHM(5.9keV) = 130 eV
σ = 2.5 el. ENC
CTI < 10^{-5}



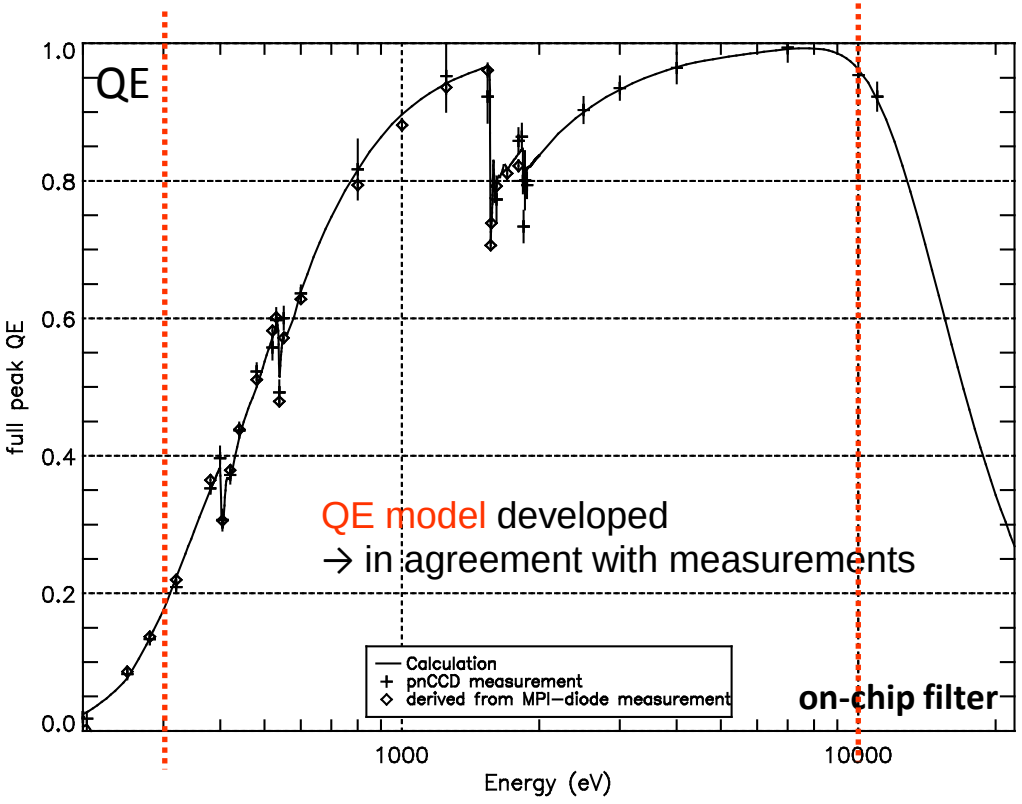
eROSITA CCD lab module
at BESSY synchrotron:
E= 280 eV spectrum
FWHM(280eV) = 52 eV

Quantum Efficiency Measurement

Full peak quantum efficiency of eROSITA CCD with on-chip light filter

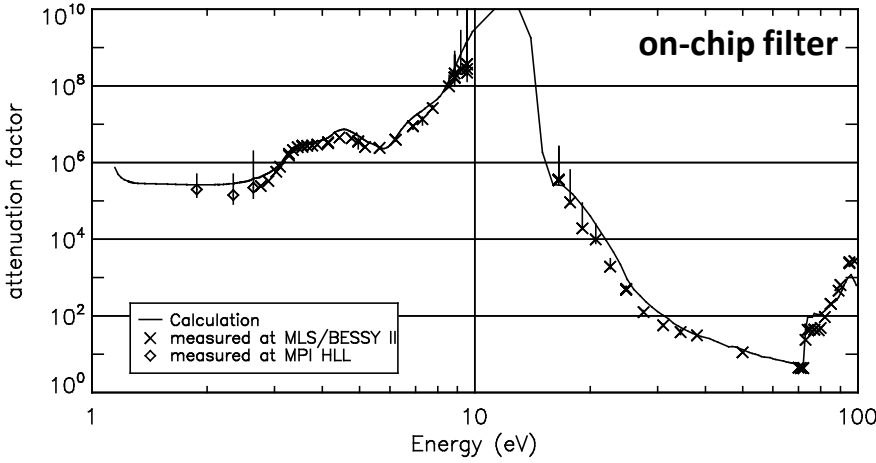
measured at BESSY synchrotron in collab. with PTB

trade-off:
high QE vs. suppression of visual light >10^5



eROSITA CCD photon entrance window:

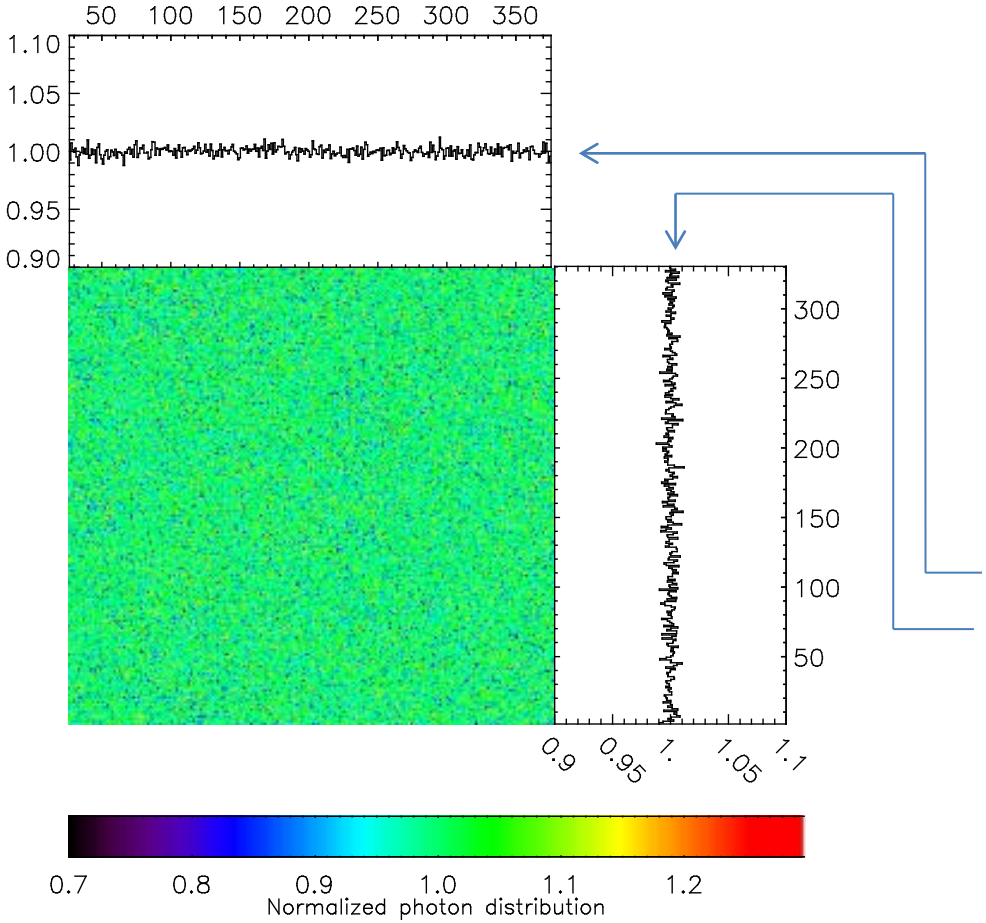
- I.batch with **on-chip light filter**
  T(optical) >10^{-5}
- II.batch **w/o** on-chip light filter
  → conventional external light filter



Uniformity of detector sensitivity

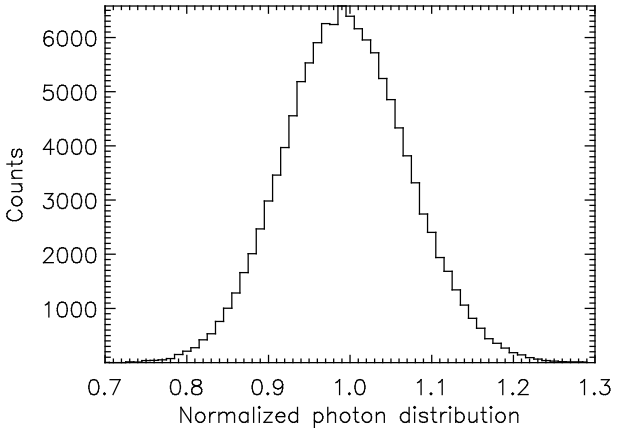
Normalized Al-K (1.5 keV) photon distribution over CCD area:

RÖSTI:



Histogram of measured # photons per pixel:

$\sigma_{\text{measured}} = \sigma_{\text{Poisson statistics}} = 7.5\%$



per channel: $\sigma_{meas.} = 0.41\%$ / $\sigma_{statistics} = 0.40\ \%$

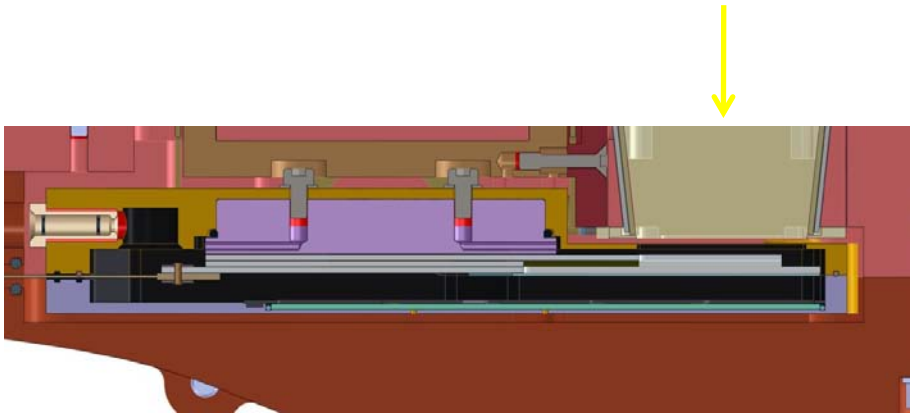
per row: $\sigma_{meas.} = 0.41\%$ / $\sigma_{statistics} = 0.41\ \%$

⇒ **Check verifies uniformity of detector sensitivity** (within the limits of statistics)

Instrument background

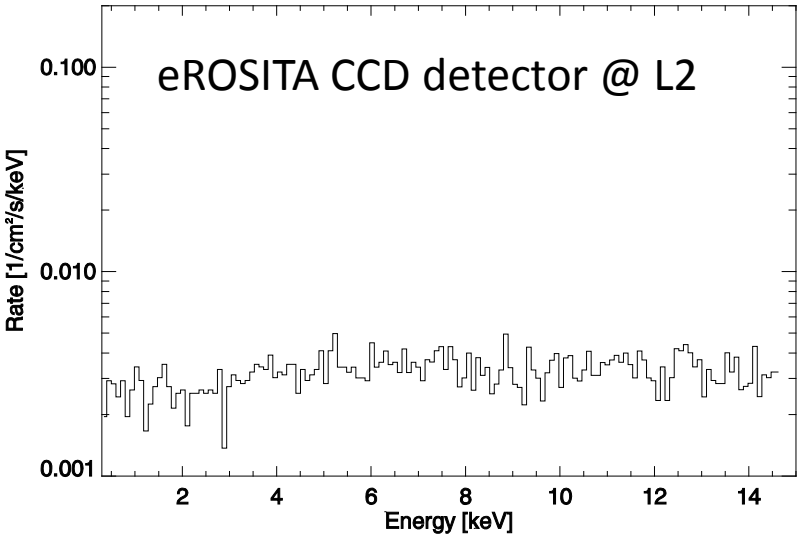
Minimization of instrumental background: graded-Z shield

Cu (proton shield) → Al → B_4C/Be



⇒ no fluorescence lines

Instrumental background simulation (SPENVIS + GEANT4 + CCD event analysis):

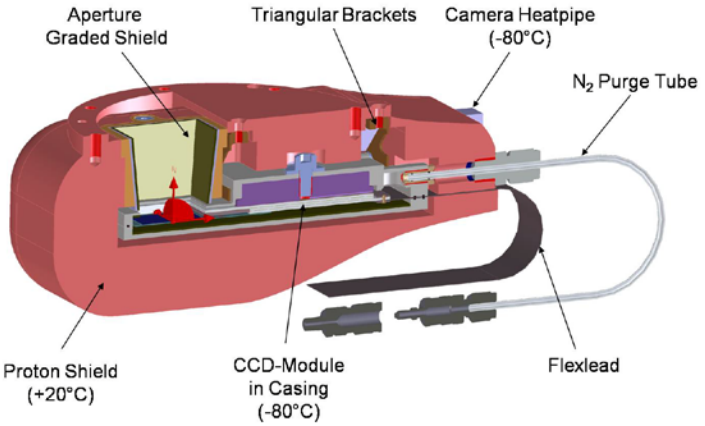


→ continuum

Radiation environment in space

L2 orbit, 7 years (2013 - 2020):

- primary **proton spectrum** (SPENVIS, JPL-91)
- proton interaction in **detector shielding** (Z-graded): 3 cm Cu + 1 mm Al + 1 mm B_4C (Monte Carlo simulations using GEANT4)
- Proton fluence + energy spectrum in **charge transfer depth**
  → lattice defects (A, E, V_2) relevant for CTI
- solar + cosmic protons: 1.0 E9 / cm^2 (CL=95%)
- proton energy spectrum: norm. to equiv. NIEL of 10MeV-protons in transfer depth
  solar + cosmic protons: **2.5 E8 / cm^2** (CL=95%)
- **Irradiation test of eROSITA CCDs with protons at TANDEM accelerator (Maier-Leibnitz-Lab.)**



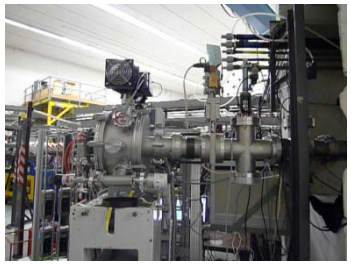
Radiation damage results

eROSITA,7 y
CL≈95%

	Φ (#p/cm²)	0	0.51E8	1.0E8	1.5E8	1.9E8	2.3E8	3.3E8	4.0E8	5.6E8
T=-80°C	Read noise	2.26e⁻	2.28e⁻	2.31e⁻	2.28e⁻	2.24e⁻	2.30e⁻	2.29e⁻	2.25e⁻	2.26e⁻
	FWHM(277eV)	52eV	52eV	54eV	55eV	54eV	55eV	55eV	57eV	58eV
	FWHM(5.9keV)	148eV	151eV	162eV	169eV	178eV	181eV	189eV	215eV	236eV
T=-90°C	FWHM(277eV)	52eV	52eV	53eV	54eV	53eV	54eV	55eV	56eV	57eV
	FWHM(5.9keV)	148eV	150eV	158eV	161eV	166eV	168eV	170eV	186eV	197eV
T=-100°C	FWHM(277eV)	51 eV	52eV	53eV	55eV	54eV	56eV	56eV	60eV	64eV
	FWHM(5.9keV)	146eV	150eV	153eV	155eV	155eV	158eV	158eV	166eV	171eV
T=-110°C	FWHM(277eV)	51eV	53eV	55eV	57eV	57eV	61eV	65eV	70eV	74eV
	FWHM(5.9keV)	144eV	148eV	152eV	156eV	155eV	158eV	158eV	162eV	164eV

T ≤ -80°C: No increase of read noise
T = -90°C: ΔFWHM/FWHM ≤ 14% @ 277eV, 5.9keV; CL=95%
T =-100°C: ΔFWHM/FWHM ≤ 10% @ 277eV, 5.9keV; CL=95%

Necessary: CTI degradation in space precisely measured + corrected !

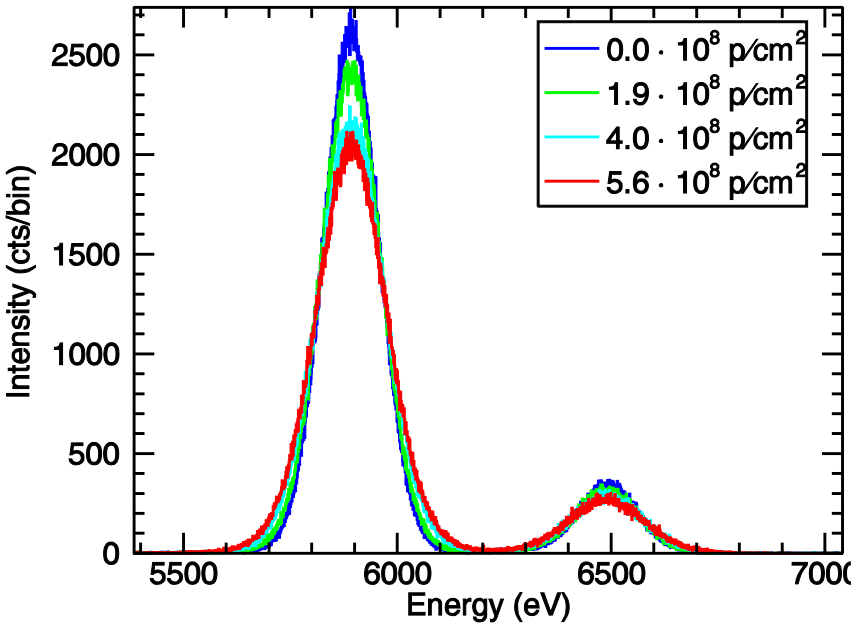


eROSITA pnCCD: radiation damage results

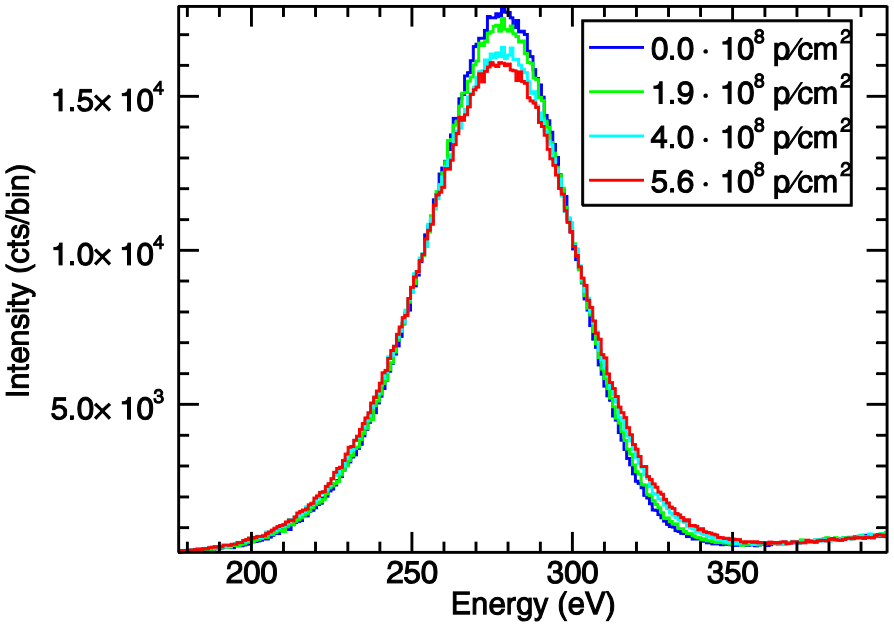
Spectra of irradiated CCD at T=-90°C

normalized to same number of counts

^{55}Fe spectrum **(5.894 eV, 6.489 eV)**

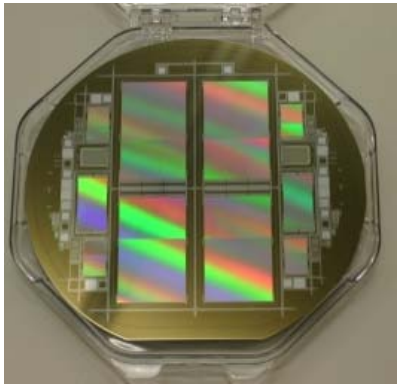


C-K spectra **(277 eV)**



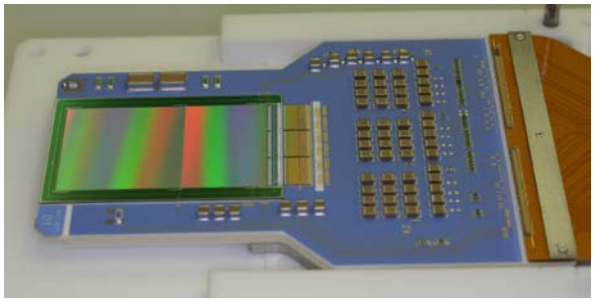
Necessary: CTI degradation in space precisely measured + corrected !

Summary and Outlook



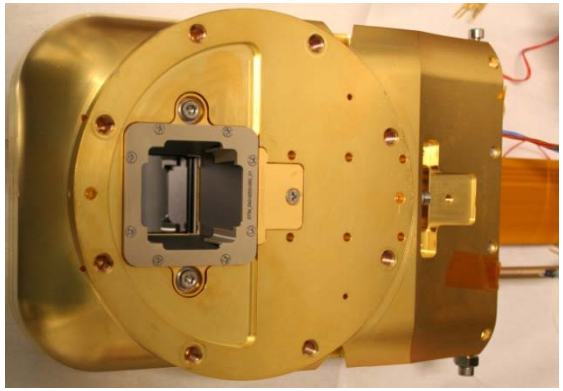
☑ eROSITA flight **CCDs**:
→ developed + manufactured

☑ eROSITA flight **CAMEX**:
→ developed + manufactured



☑ **Lab / EM CCD detector**:
→ detector performance tested and verified
read noise: 2.5 el. ENC
spectroscopy at E < 0.5keV
image smearing: P(OOT) = 0.2%
...

☑ Radiation hardness test: eROSITA after 7 y:
→ **ΔFWHM(end of mission)/FWHM ≤ 14% @ T = -90°C**



✘ Next steps:
→ Operation with complete **EM flight electronics**
→ **QM CCD detector** (environmental tests)
→ **7 FM CCD detector** (calibration)