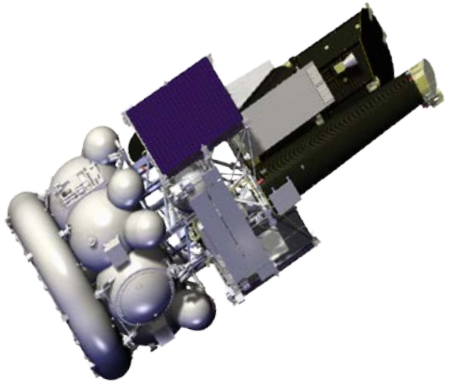
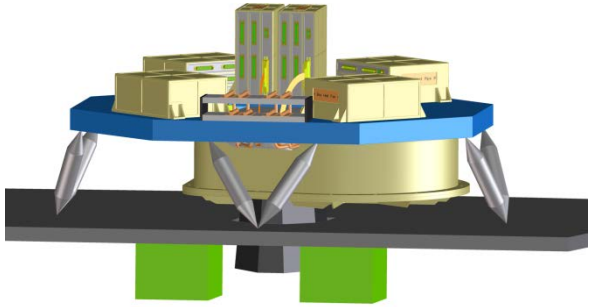


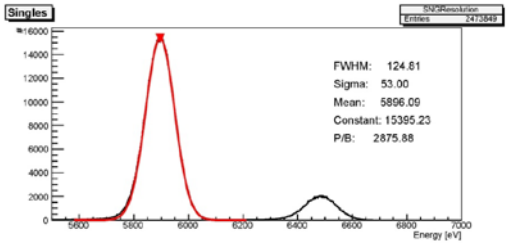
Interdisciplinary Cluster Workshop
" Detectors and Instrumentation"
30th May 2016, MPE

X-ray cameras

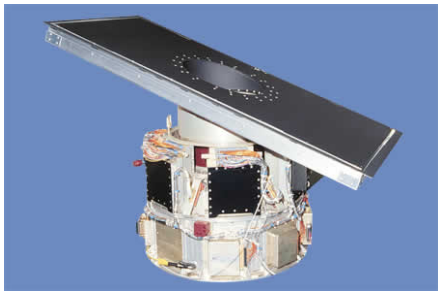
XMM-Newton to eROSITA up to Athena

Norbert Meidinger
Max Planck Institute for extraterrestrial physics (MPE)
Garching, Germany
E-mail: meidinger@mpe.mpg.de

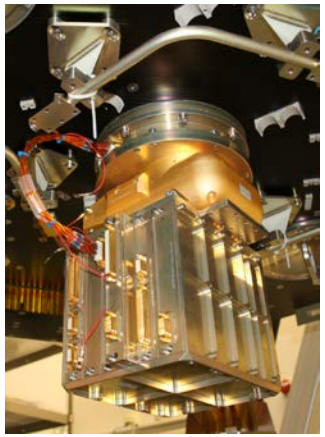




Overview

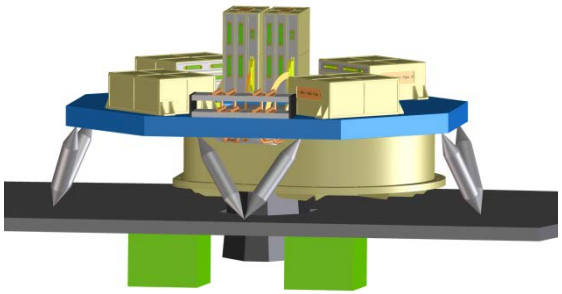


1. XMM-Newton EPIC PN camera



2. eROSITA cameras

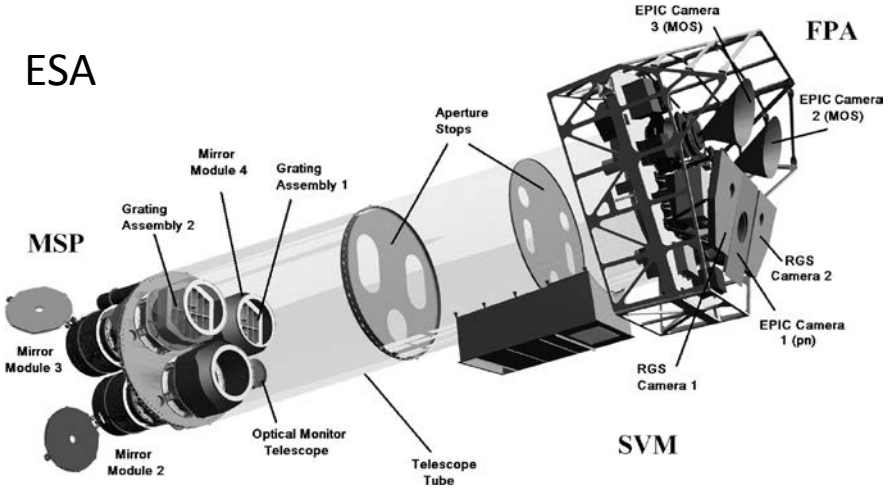
3. Athena WFI

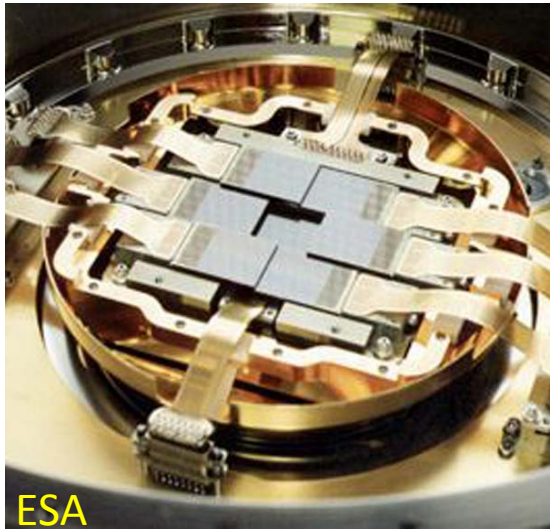


4. Summary & Outlook

1.XMM-Newton EPIC PN camera

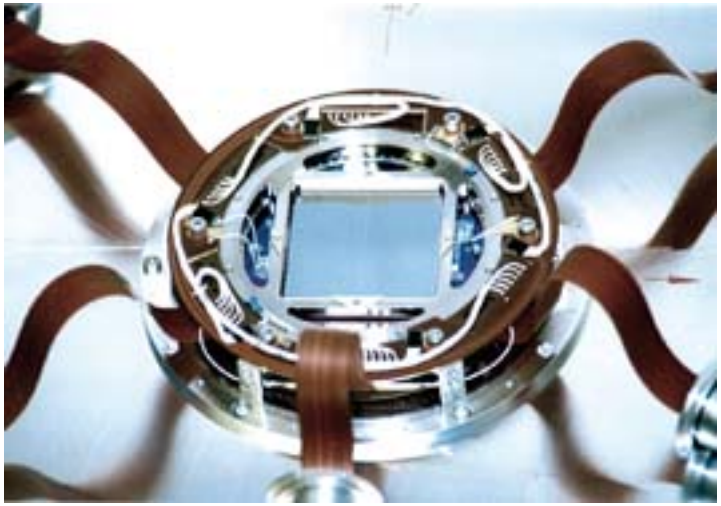
ESA





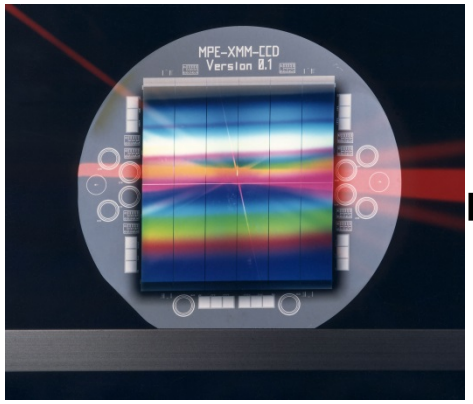
← MOS CCD camera

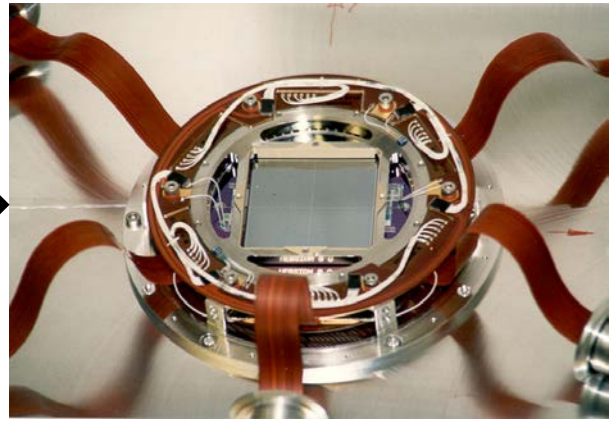
PNCCD camera →

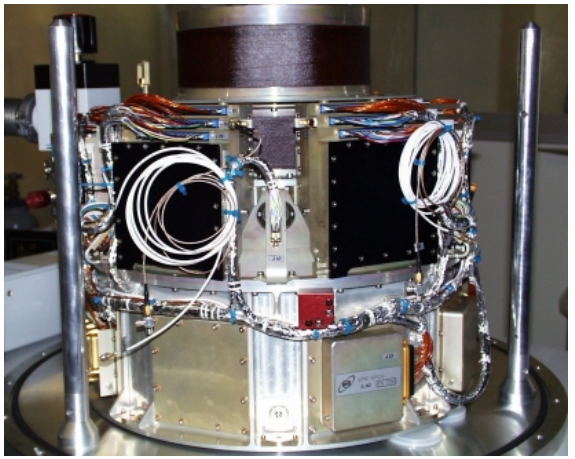


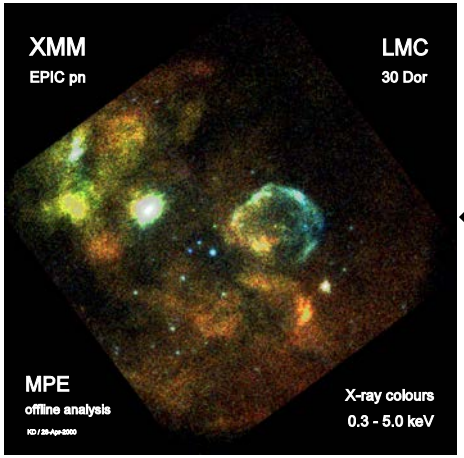
1.XMM-Newton EPIC PN camera

- Single X-ray photon counting detector
  with high energy, time & spatial resolution + high quantum efficiency



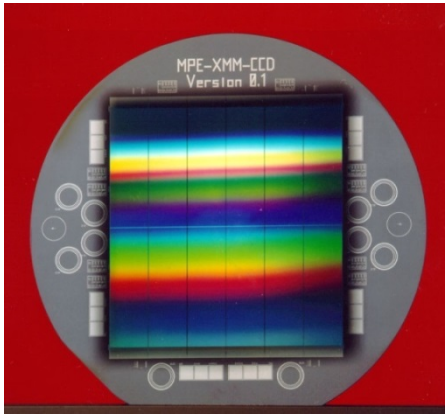






- Operation aboard XMM-Newton since January 2000

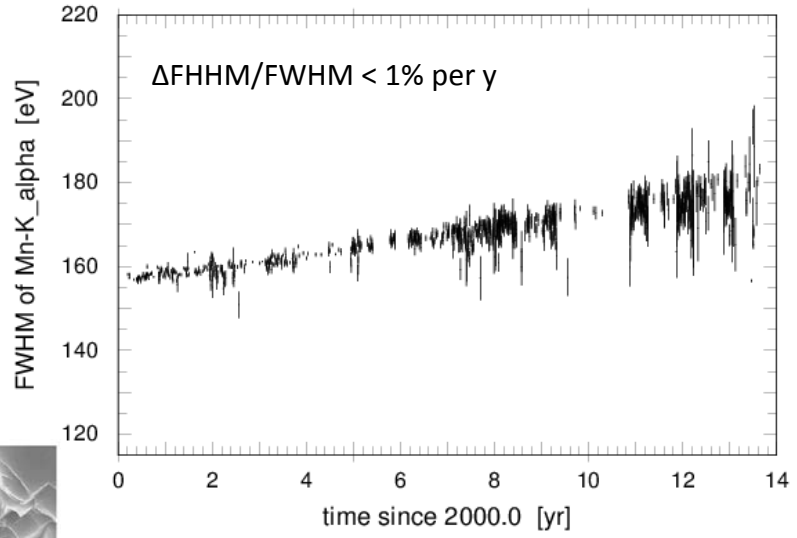
1.XMM-Newton EPIC PN camera

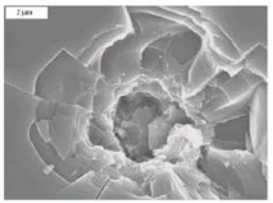


- **PNCCD: spectroscopy of X-rays**
  → developed for X-ray astronomy: ESA's XMM-Newton
- **Pixel size: 150µm x 150µm (4.1 arcsec)**
- **12 CCDs: each 64 x 200 pixels**
- **Δt = 73 ms**
- **E ≈ [0.3; 10] keV**
- **satellite launch: 1999**

- **Long term stability of EPIC PN camera:**
  - all 12 CCDs are still operating
  - operating parameters unchanged (e.g. T = -90°C)
  - QE unchanged
  - slight radiation damage as expected: CTI

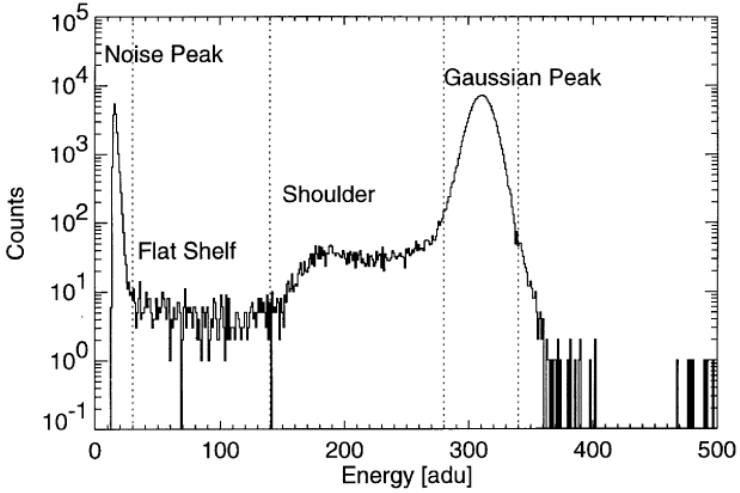
- **Micrometeoroid event (rev. 156) survived**
  → several bright+noisy pixels occurred

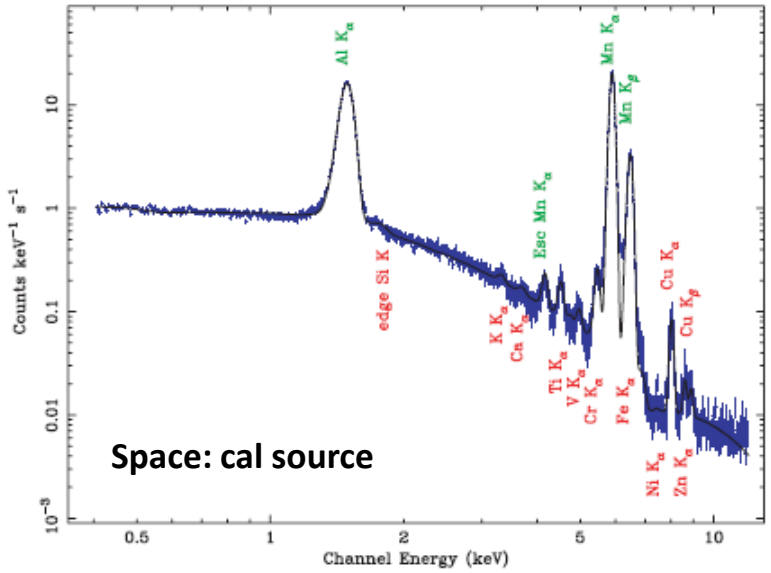




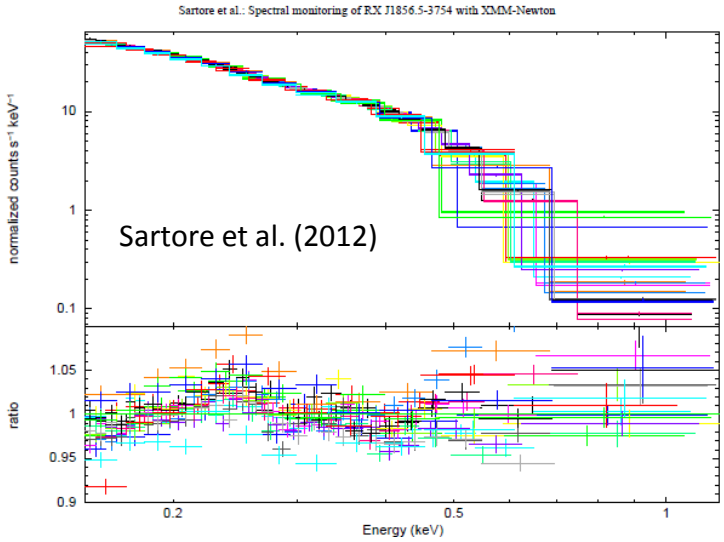
1.XMM-Newton EPIC PN camera

1400 eV line (BESSY)

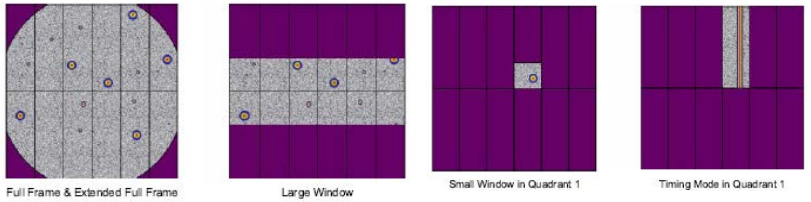




RX J1856 (BB spectrum)



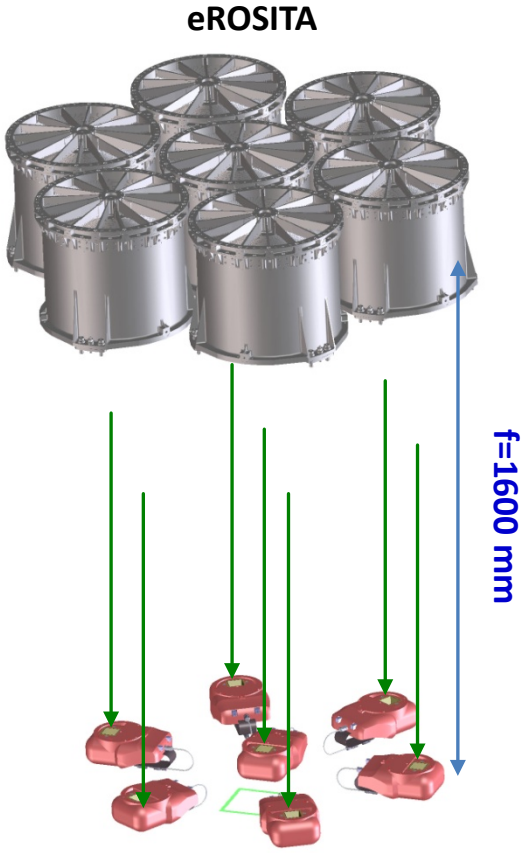
EPIC PN: 6 op. modes:
Fullframe, extended FF, large window, small window, timing, burst



2. eROSITA cameras

→ eROSITA (extended Roentgen survey with an imaging telescope array)

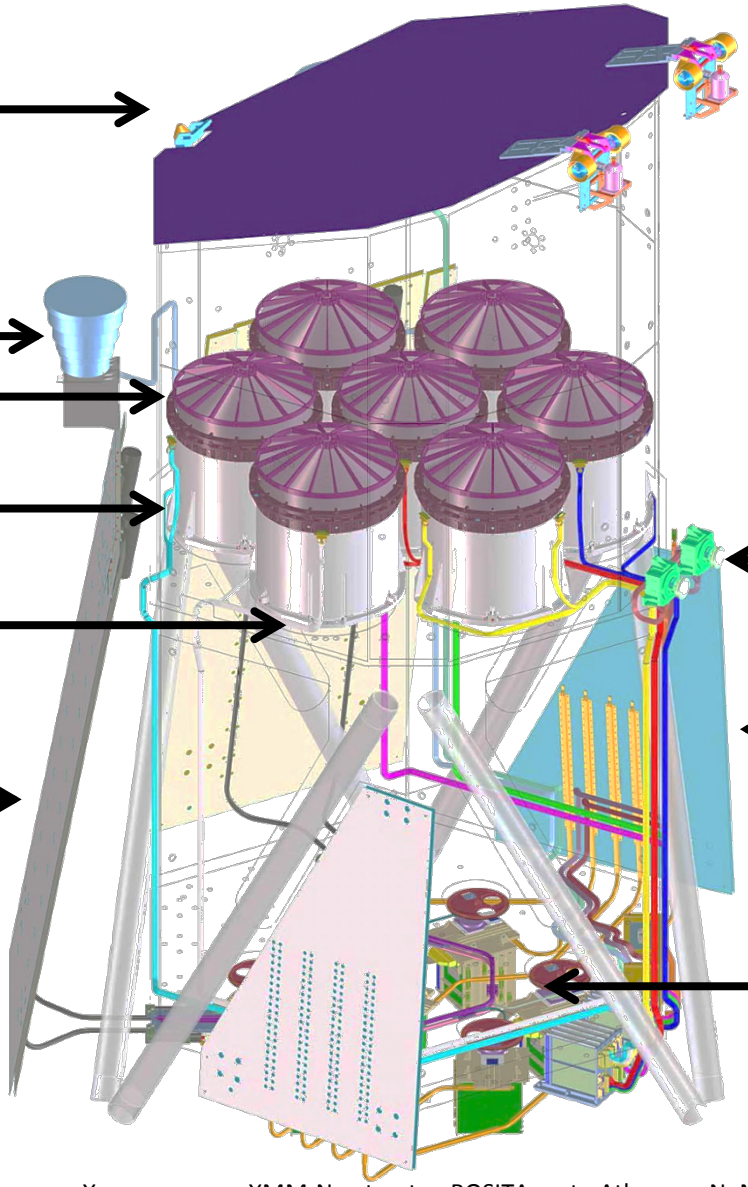
- **all-sky survey**: 4 y (/7.5y)
  - soft band: 30 x sensitivity of ROSAT
  - hard band (>2keV): first all-sky survey
- **cosmological model** (Dark Energy)
- eROSITA telescope: MPE responsibility
- Wolter-I mirror system: 54 Ni shells
- PSF: 15‘‘ resolution (HEW) on-axis
- FoV 1.0° diam.
- Russian SRG satellite → L2 orbit



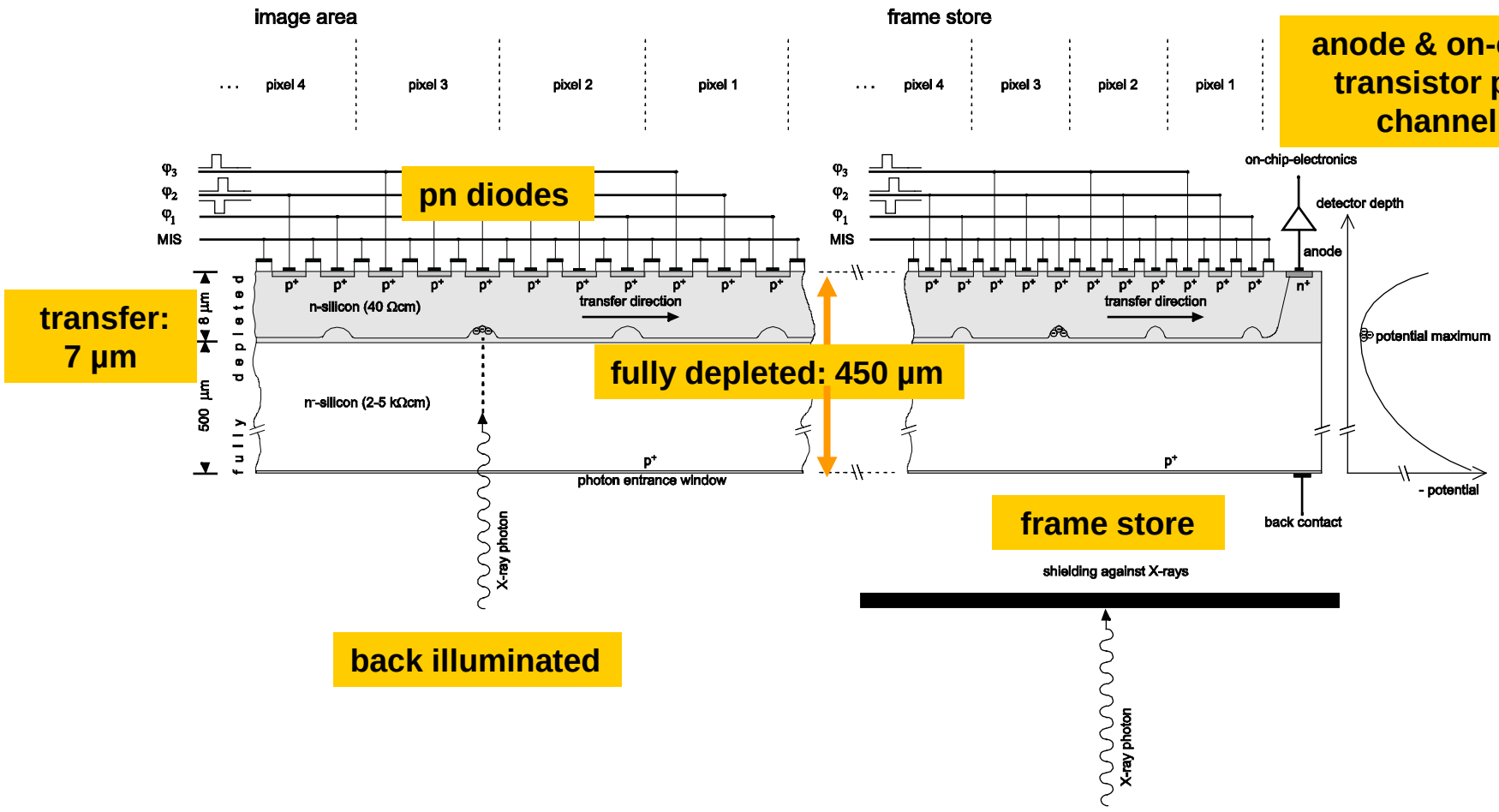
7 PNCCD focal plane **cameras**:

- E= **0.3 keV - 10 keV**
- Δt = **50 ms**

Scheme of Telescope

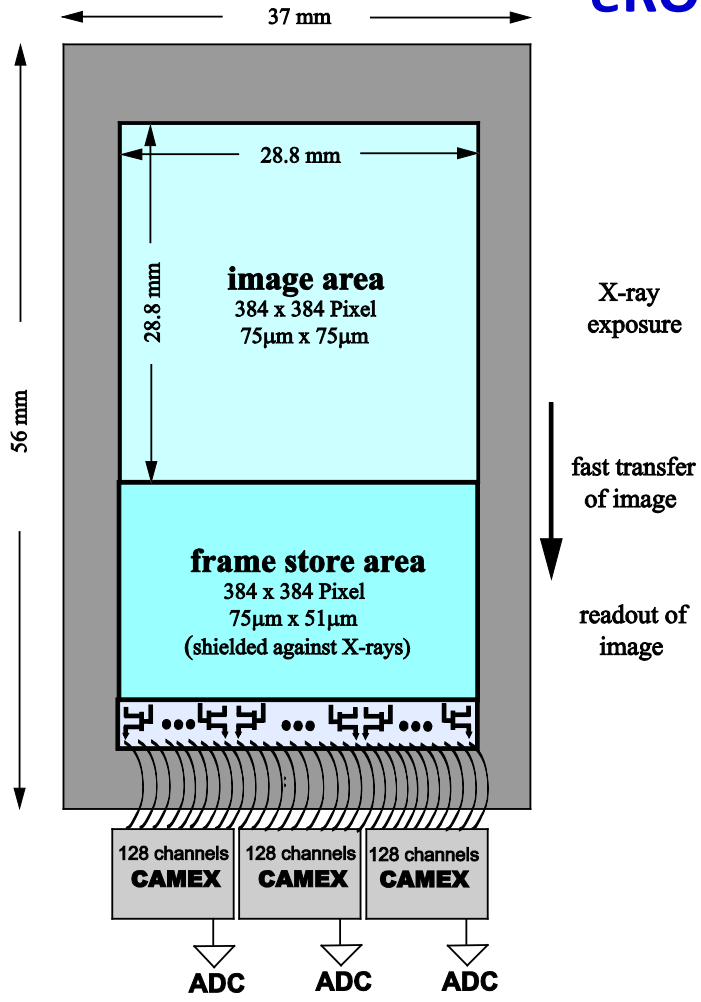


2. eROSITA cameras



2. eROSITA cameras

eROSITA PNCCD Detector

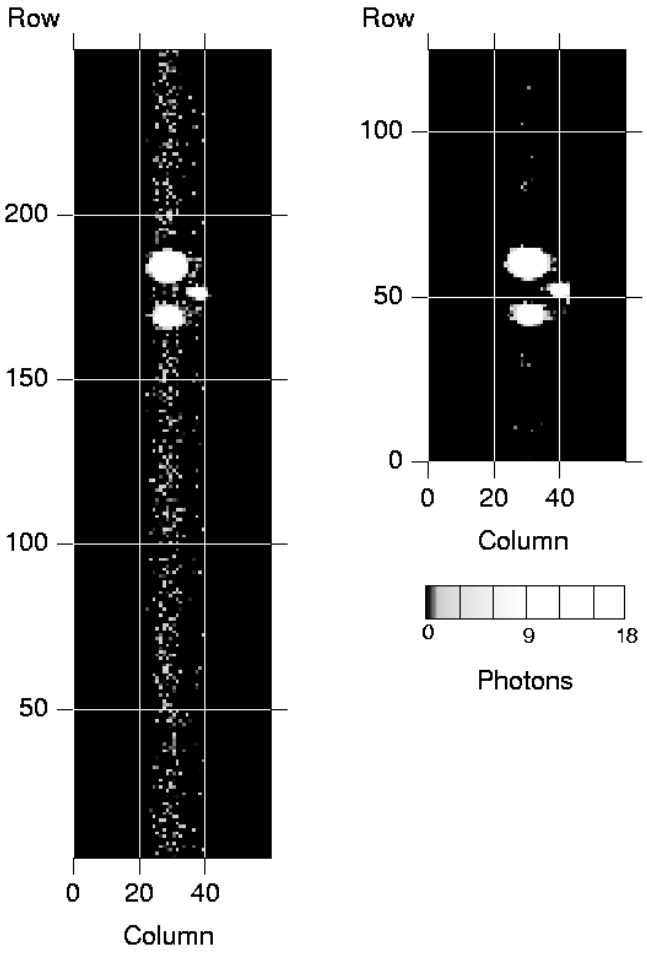


- based on XMM-Newton PNCCD
- back-illuminated frame-transfer CCD
- chip thickness (= 450 µm) fully sensitive
- image: **384 x 384** pixels of 75 x 75 µm^2 size
- column-parallel: 384 independent channels
- frame transfer: **0.12 ms**
- CAMEX: analog signal processor
- readout time: **9 ms**
- time resolution: 50 ms
- OOT events < 0.2%
- Read noise: **2.5 e$^-$** ENC
- excellent low energy response

2. eROSITA cameras

Elimination of
out-of-time events:

Experimentally
demonstrated:

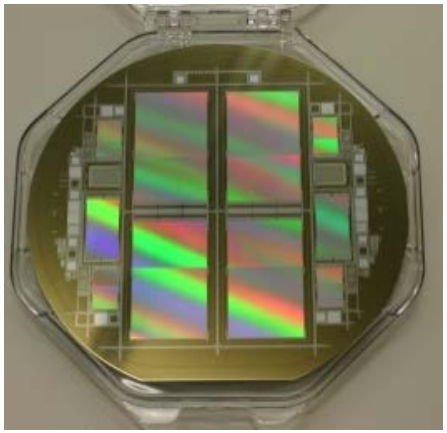


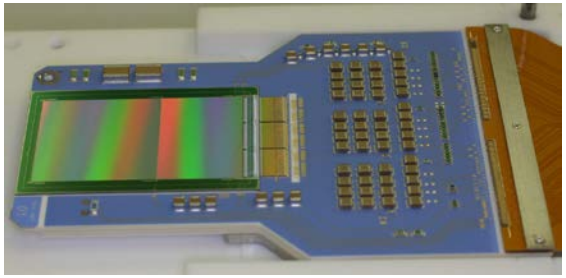
FF mode vs. FS mode

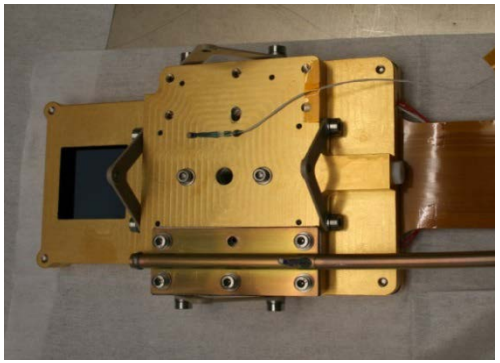
used for

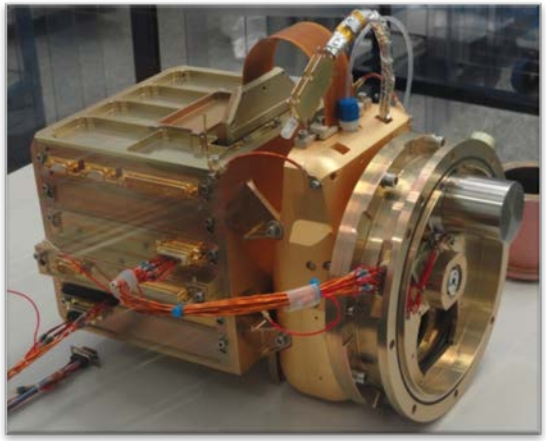
XMM PNCCD eROSITA

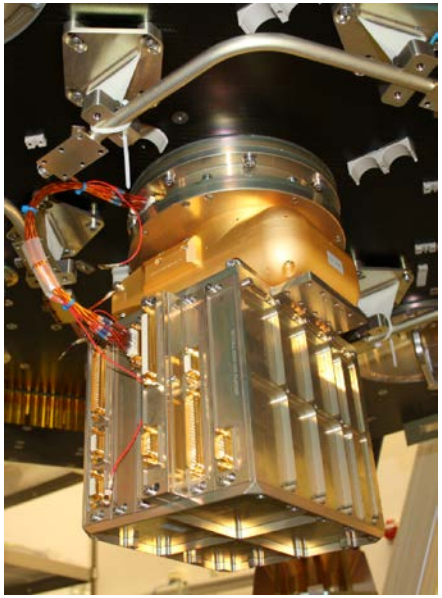
2. eROSITA cameras





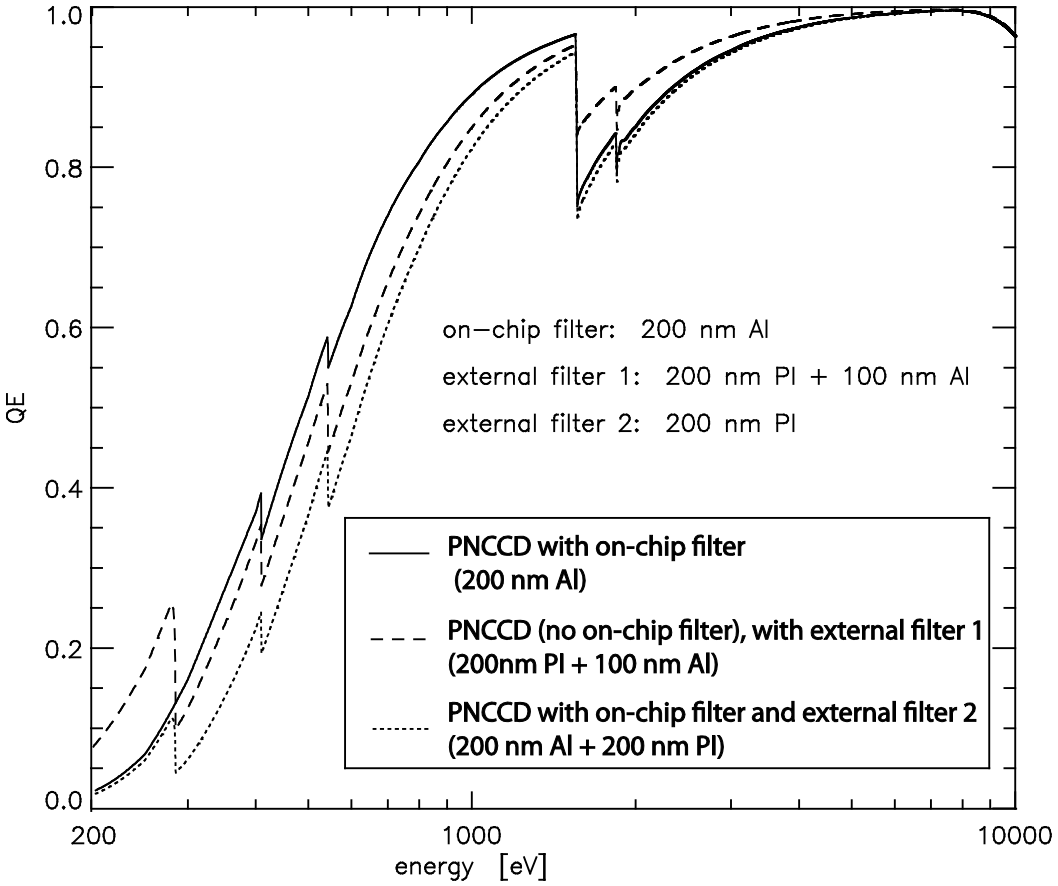






2. eROSITA cameras

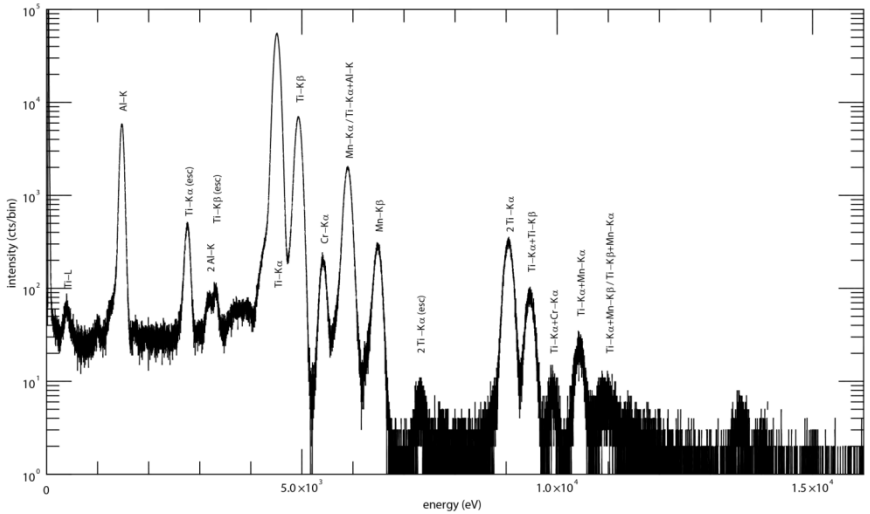
Quantum Efficiency with T(optical) < 10^{-5}



2. eROSITA cameras

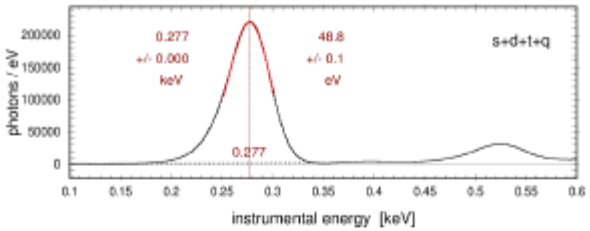
eROSITA FM1 camera calibration:

On-board calibration source spectrum

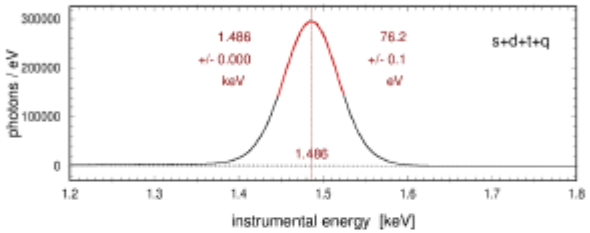


≈200 photons / frame

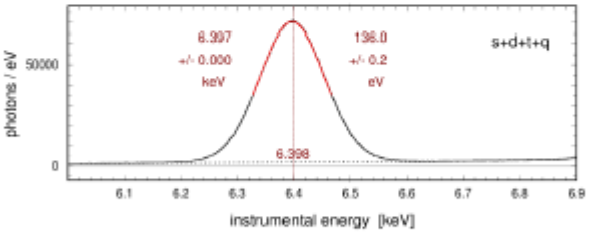
FWHM(277eV) = 48eV



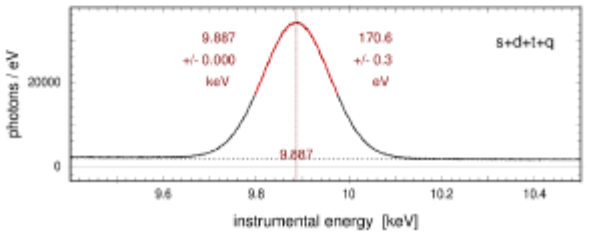
FWHM(1486eV) = 76eV



FWHM(6398eV) = 138eV



FWHM(9887eV) = 171eV



→ in spec

2. eROSITA cameras
Radiation damage

Simulation (SPENVIS, GEANT4): proton fluence to CCD after 7y @ L2

ϕ (5.6 MeV protons) = **2.5×10^8 cm^{-2}** (CL=95%)

Irradiation tests:

T = -100°C → ΔFWHM/FWHM ≤ 10%

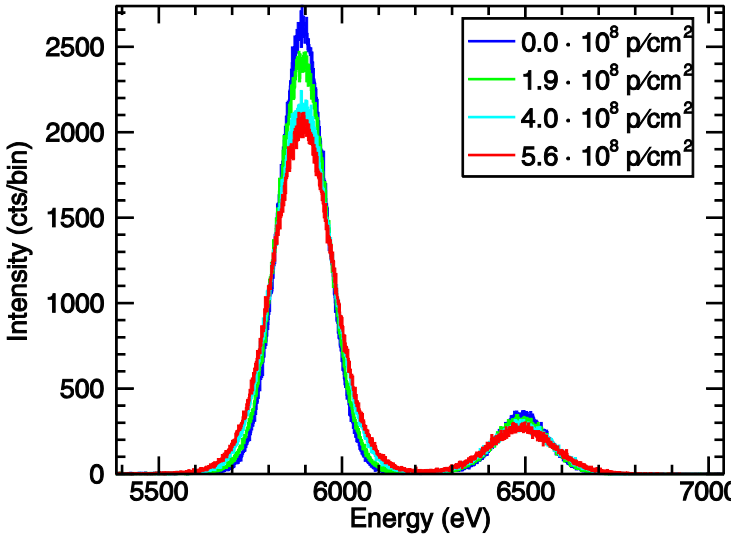
T = -90°C → ΔFWHM/FWHM ≤ 14%

T = -80°C → ΔFWHM/FWHM ≤ 25%

→ prerequisite for long-term stability

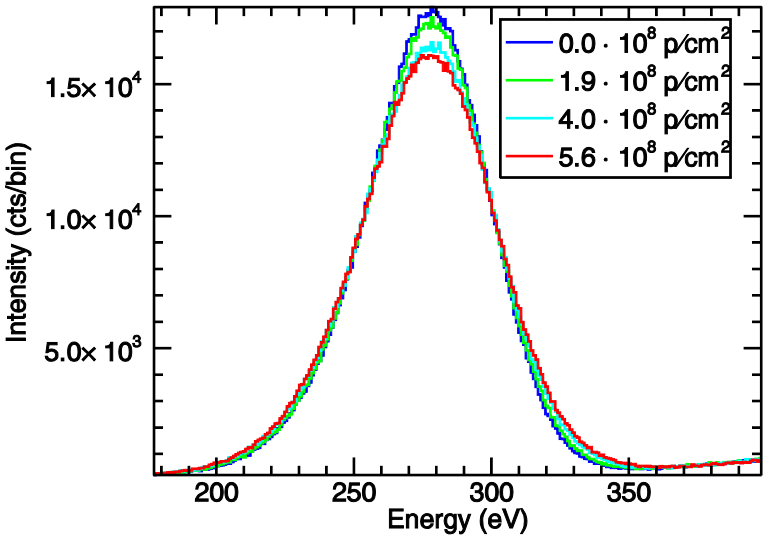
Fe55 spectrum **(5.894 eV, 6.489 eV)**

T=-90°C



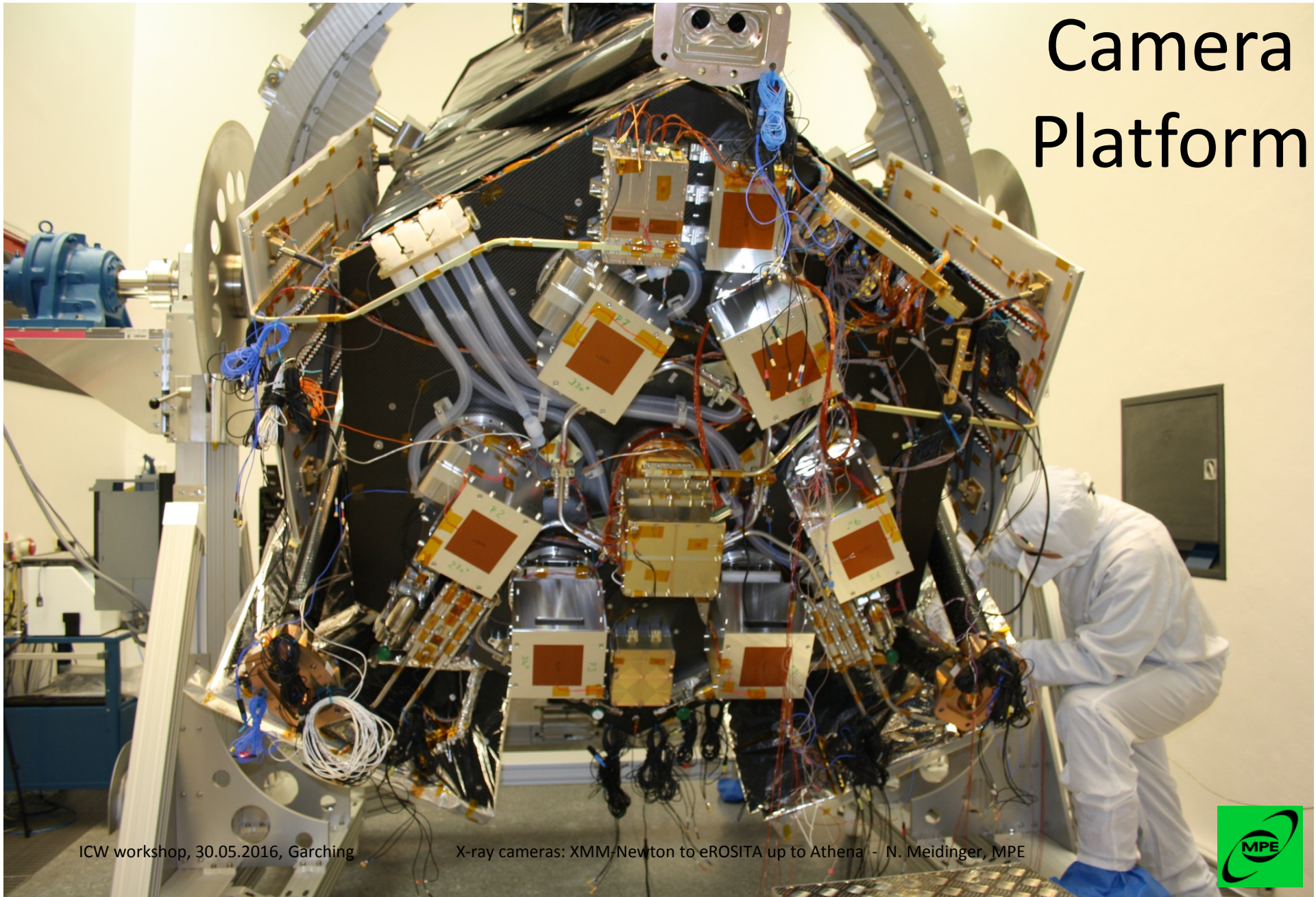
C-K spectrum **(277 eV)**

T=-90°C



2. eROSITA cameras

2. eROSITA cameras



3. Athena WFI

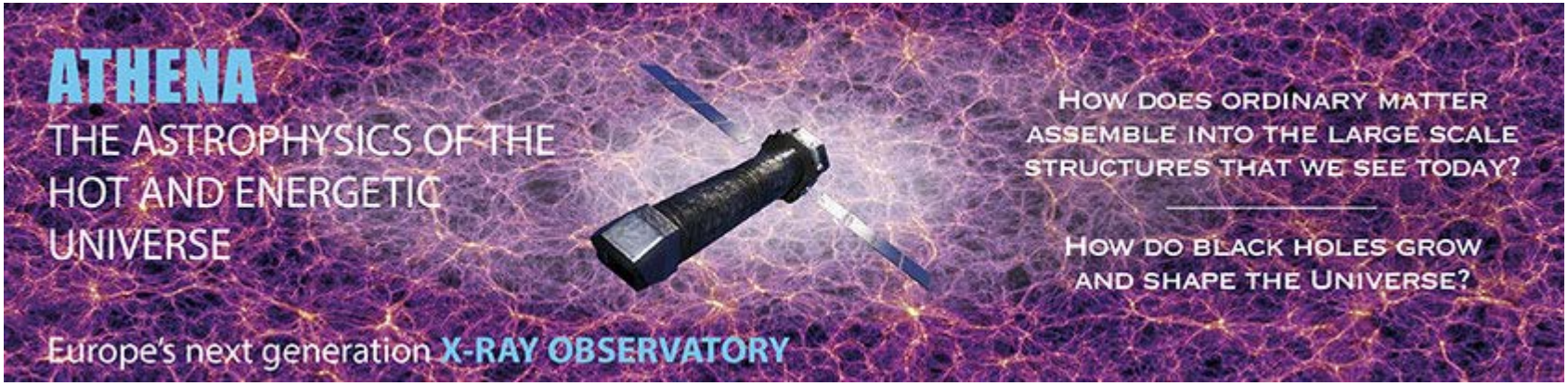
History: XEUS → IXO → ATHENA L1 proposals

ESA

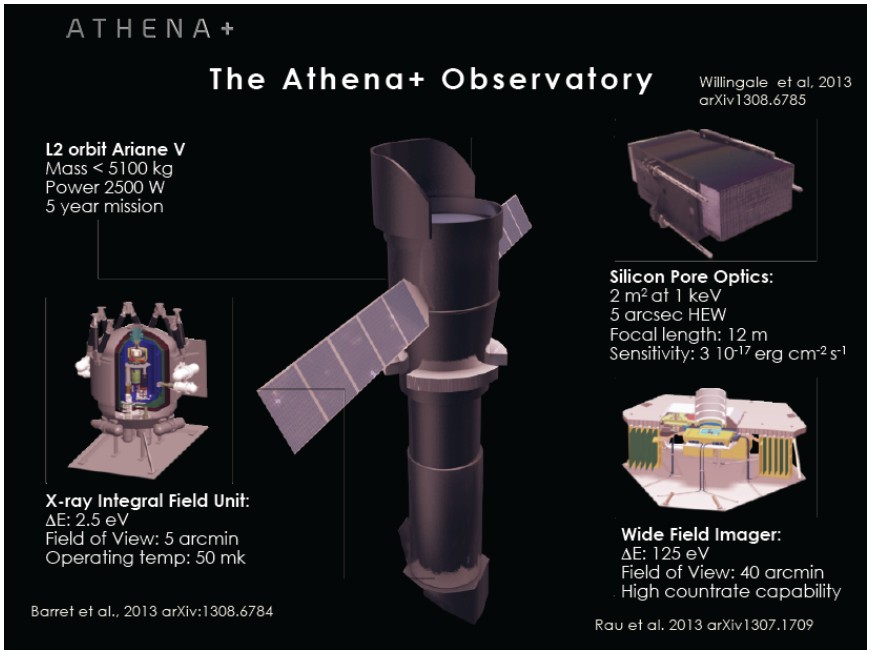
Missions in the Cosmic Vision 2015-2025 Programme

L1 mission	JUICE
L2 mission	ATHENA
M1 mission	Solar Orbiter
M2 mission	Euclid
M3 mission	PLATO
S1 mission	CHEOPS

selected on 27 June 2014



3. Athena WFI



X-IFU:

X-ray micro-Calorimeter

ΔE=2.5eV

T=50mK

FoV=5`

Mirror system:

SPO

f = 12 m

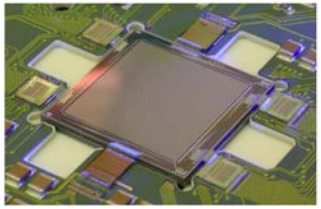
Aeff ≈2 m² at 1 keV

5`` HEW

Wide Field Imager:

- **unprecedented survey power** (40`x40` FoV)
- **high count-rate capability** (1 Crab)
- E=[0.2 keV – 15 keV] state-of-the-art energy resolution
- Sensor: **DEPFET APS**

(MIXS / BepiColombo)

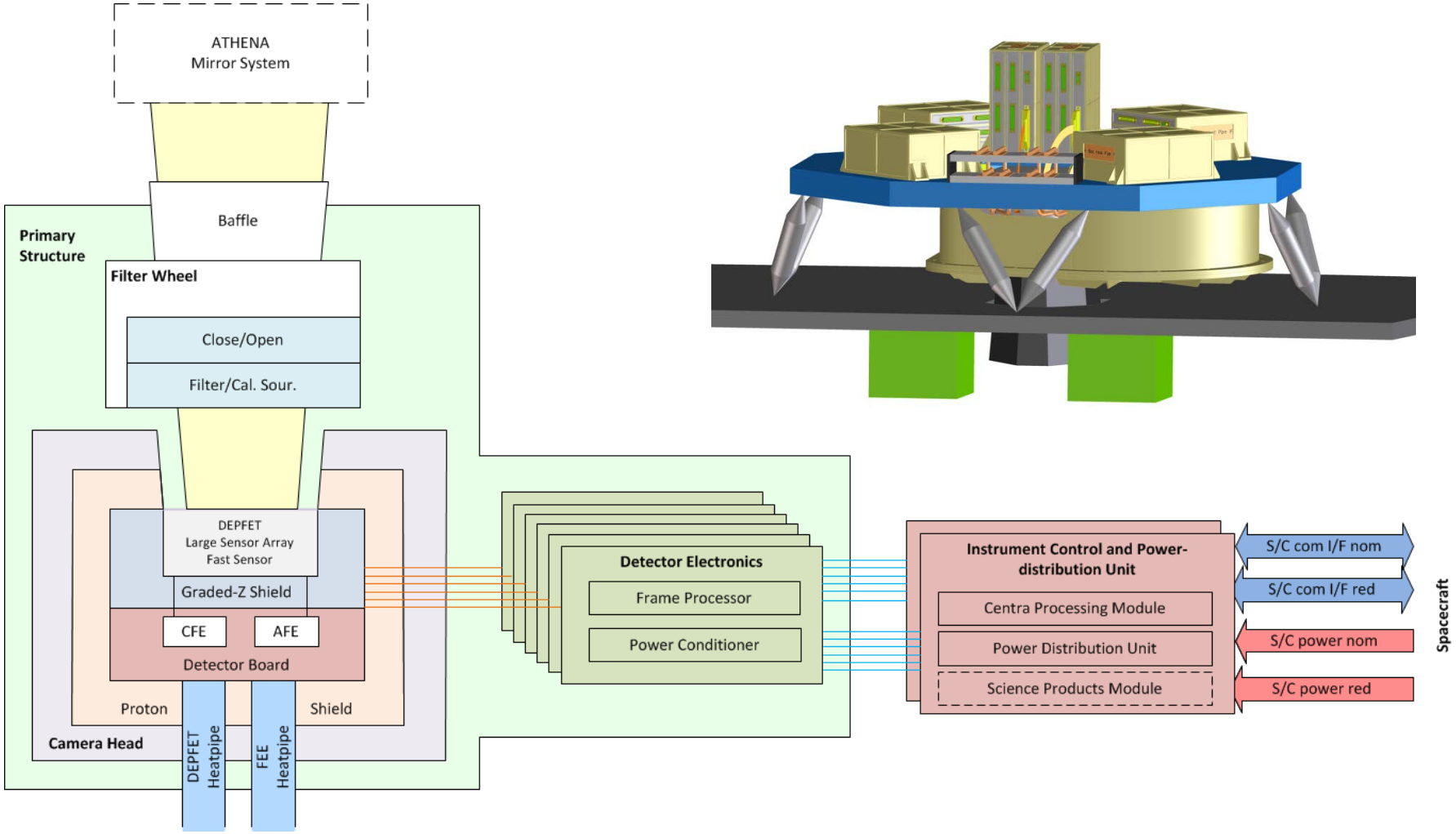


MPE/HLL/MPS

Athena **launch 2028** to **L2; 5y** life time

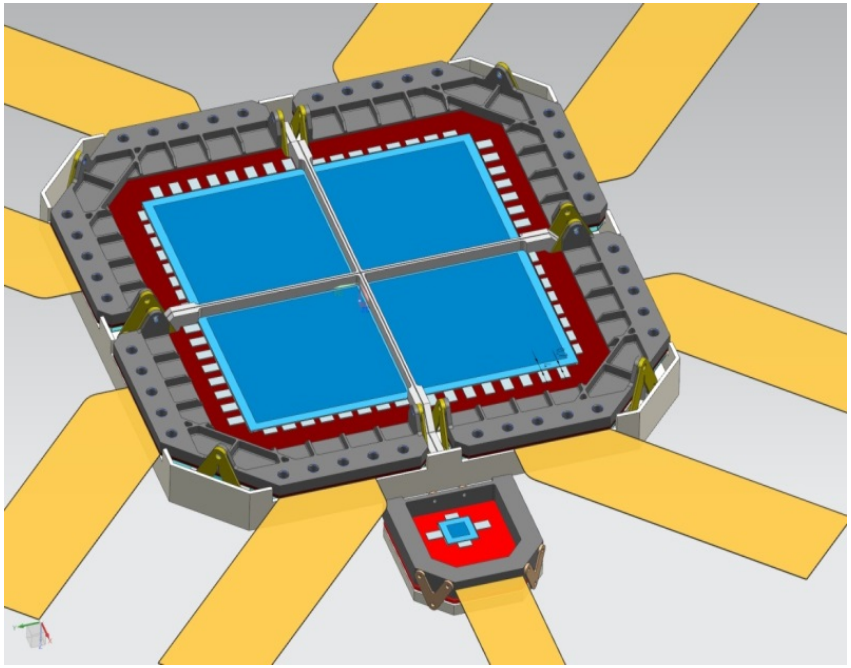
3. Athena WFI

WFI Functional Block Diagram + Conceptual design



3. Athena WFI

Focal plane layout



- Pixel: 130 µm x 130 µm (↔ 2.2``)
- Control ASIC (redesign): Switcher-A
- Readout ASIC (new): VERITAS-2

Pointing on **large** or **fast** WFI detector

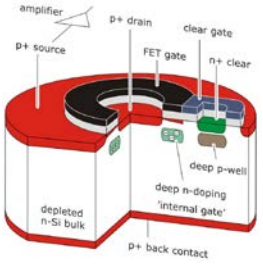
Large FoV DEPFET detector

- **40` x 40`** by **1024 x 1024 pixel**
  ↔ **Size ≈ 14 x 14 cm²**
- 4 independent + identical quadrants
- **<5ms/frame**

High count-rate capable detector

- FoV = 143`` x 143``
  ↔ **Size ≈ 8.3 x 8.3 mm²**
- **64 x 64** pixels → 2 halves
- **80µs/frame**
- defocussed

3. Athena WFI



Lechner et al. (2003)

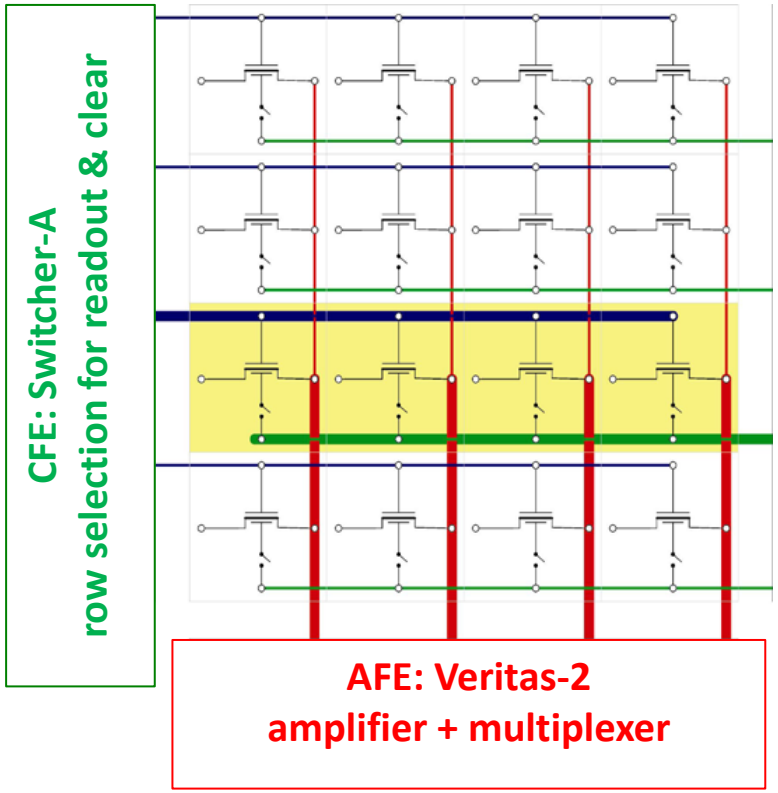
Operation: **Rolling shutter mode**

- ▷ one row active and read out
- ▷ all other rows store just signals

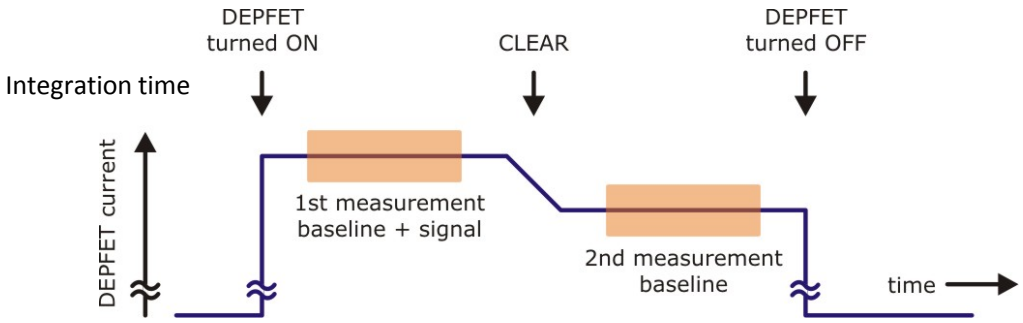
tradeoff:

fast readout

+ moderate heat dissipation

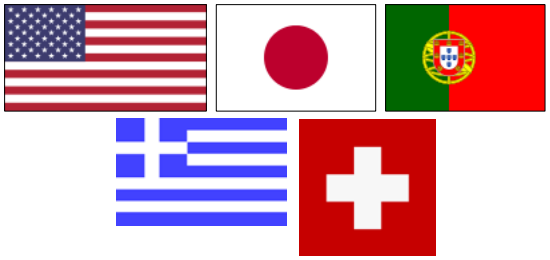


Readout sequence:



3. Athena WFI

Project organization



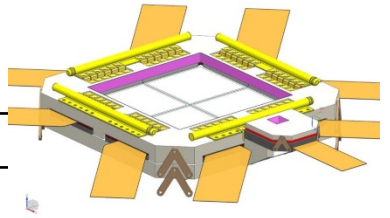
WFI consortium:
Austria, Denmark, France, Great Britain, Italy, Poland, and Germany
+ potential partners: **USA, Greece, Japan, Portugal, Switzerland**

WFI lead institute: **MPE**
PI: **Kirpal Nandra**
PM: Norbert Meidinger
SI: Markus Plattner
PS: Arne Rau

WFI consortium board
WFI science team

Schedule:
2015 - 2018: Conceptual design + TDA incl. BB
2019 - 2021: EM, STM, EFM
2022 - 2024: QM
2025 - 2026: FM
2026 - 2028: Integration + testing on S/C level

3. Athena WFI
Main WFI Requirements / Characteristics



Parameter	Value
Energy Range	0.2-15 keV
Field of View	40' x 40'
Angular Resolution **Pixel Size**	PSF=5`` (on-axis) 130 x 130 $\mu m^2$ (2.2``)
Large DEPFET detector	1024 x 1024 pixel (4 quadrants) =14cmx14cm
Fast DEPFET detector	64 x 64 pixel (split full frame mode)
Operating mode	Rolling shutter
Operating time	Nonstop possible
Quantum efficiency (incl. on-chip + ext. filter)	20% @ 277 eV 80% @ 1 keV 90% @ 10 keV
Energy Resolution	FWHM(1 keV) ≤ 80 eV (end of life) FWHM(7 keV) ≤ 170 eV (end of life)
Time Resolution full frame Fast detector Large detector	 80 µs <5 ms
Count Rate Capability	Fast DEPFET (defocused) **1 Crab**: >80% throughput, <1% pile-up
Particle Background (L2 orbit)	< 5 × 10^{-3} cts cm^{-2} s^{-1} keV^{-1} (60% of time)
Lifetime	5 y + opt. extension (launch 2028)

4. Summary & Outlook

MPE HEG instrument develop. for X-ray astronomy (list not complete)

- **XMM-Newton EPIC PN**: **>16 y** in space (fully operational)
- **eROSITA 7 flight cameras**:
  based on EPIC PN but substantial improvements
  delivery in 2016 – launch in 2017
- **Athena WFI**:
  DEPFETs instead of PNCCDs;
  phase A → launch: 2028
  challenges (detector, realtime proc., vis/UV filter, therm. system, background …)

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- MPS, MPS semiconductor lab., MPP
- DLR
- ESA, ESAC, ESOC
- Industrial partners
- All others contributing to the instruments