eXTP (enhanced X-ray Timing and Polarimetry mission): scientific objectives and sensors

Daniela Cirrincione on behalf of the eXTP Consortium

INFN-Trieste

HPXM2023 - High Precision X-ray Measurements
19-23 June 2023 – INFN-LNF

Abstact

The Enhanced X-ray Timing and Polarimetry (eXTP) mission is a collaboration between Chinese and European research institutes and is designed to study the state of matter under extreme conditions of gravity, density and magnetic field. The primary objectives are to determine the equation of state of matter at densities higher than nuclear, measure QED effects in very high magnetic fields and study accretion discs in the strong gravity regime. To do this, the mission will study neutron stars in binary and isolated systems, magnetars and black holes.

The observations will be carried out thanks to the satellite's instrumentation, which will allow spectroscopy, timing and polarimetry of X-ray sources in the 0.5-30 keV energy range to be analysed simultaneously. The instrumentation includes the Spectroscopic Focusing Array (SFA), the Large Area Detector (LAD), the Polarimetry Focusing Array (PFA) and the Wide Field Monitor (WFM).

The Trieste section of INFN and TIFPA, in particular, are involved in this mission through the design and testing of Silicon Drift Detectors (SDD) for LAD and WFM, large area sensors for collimator X-ray spectroscopy and imaging respectively.

In order to achieve the scientific objectives of the mission, the sensors must meet very stringent specifications. Design techniques and verification measures were devised to assess their characteristics in order to carry out a careful selection process before integration.

Main features of eXTP

eXTP - enhanced X-ray Timing and Polarimetry mission

- Very large collecting area
- Good spectral resolution
- Unprecedented polarimetry capabilities

- Explore the properties of matter and propagation of light in the most extreme condition of density of matter, gravity and magnetic fields

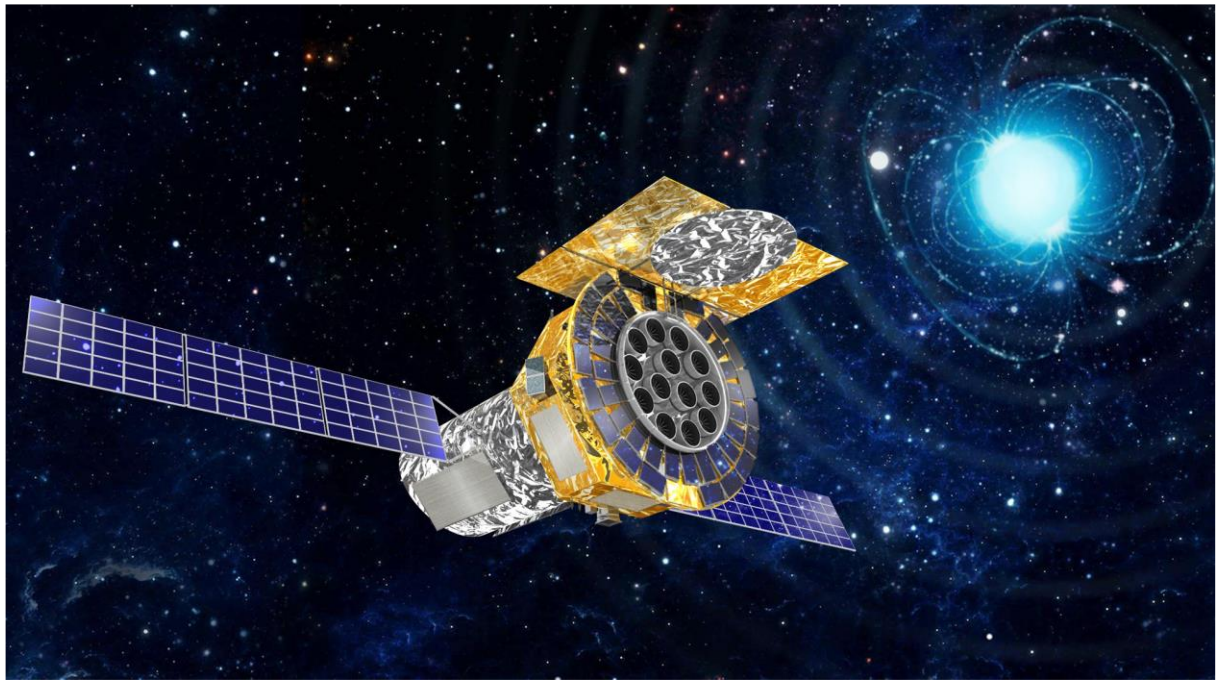
eXTP international consortium

eXTP PI Institute:
IHEP/CAS, Beijing

- CAS — 中国科学院 CHINESE ACADEMY OF SCIENCES
- CNSA
- IHEP Beijing — Institute of High Energy Physics, Chinese Academy of Sciences
- Tsinghua University — 清華大學 Tsinghua University
- Tongji University — 同濟大學 TONGJI UNIVERSITY
- CAST Beijing — 中国空间技术研究院 China Academy of Space Technology / 中国航天
- IAMC Shanghai — microsat

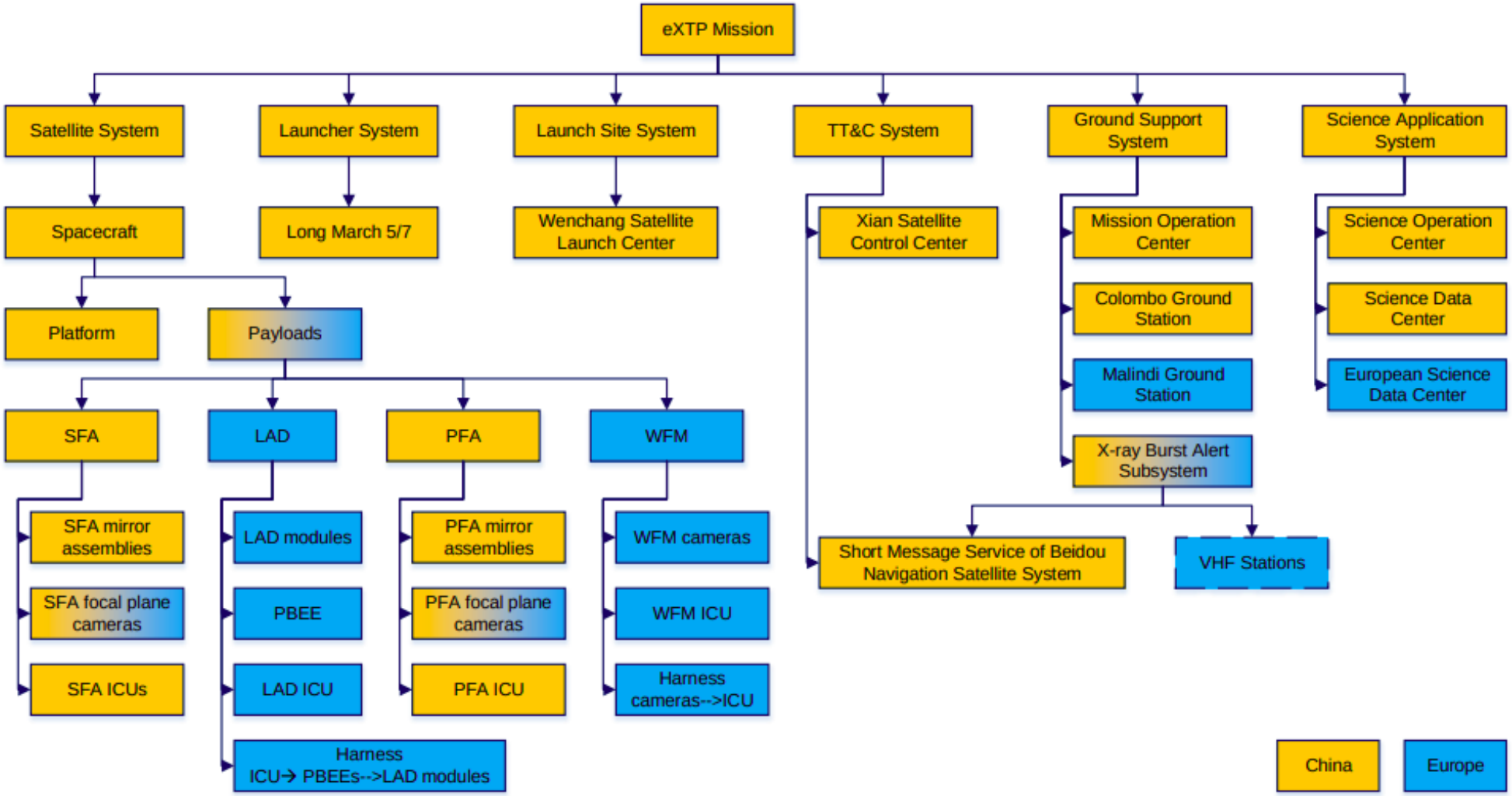
- Italy — INAF, INFN, Fondazione Bruno Kessler
- Spain — CSIC, IEEC
- Germany — Eberhard Karls Universität Tübingen, MPE, FAU
- France — cea
- Switzerland — Université de Genève
- Czech Republic — Astronomical Institute of the Czech Academy of Sciences
- Poland — CBK, CAMK PAN
- Denmark — DTU
- The Netherlands — NOVA, SRON
- Austria — universität wien
- Turkey — Sabancı Üniversitesi, TÜBİTAK

Mission



- Launch is planned for 2027
- Ended of phase-B
- To be launched in a low-earth orbit at an altitude of ≤570 km
- The inclination of the orbit is ≤2.5 deg (to minimize background)
- Baseline Launcher is the Chinese Long March-5 (CZ-5) vehicle
- Nominal science operations will last for 5 years, with a design goal for 8 years

eXTP mission system-level product tree



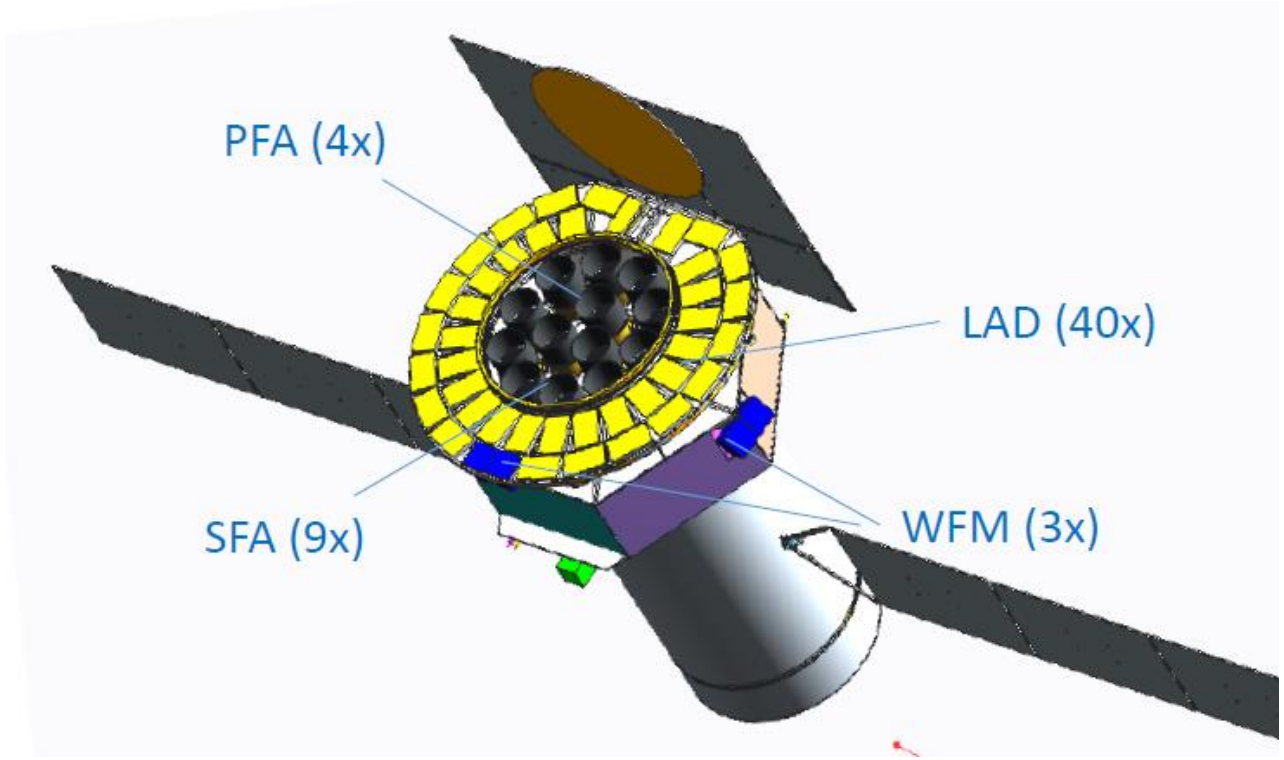
Scientific objectives

1. the physical nature of cold **ultra-dense matter**
2. the behaviour of matter and light in the space-time shaped by **strong-field gravity**
3. the astrophysics and physics of the **strongest magnetic fields** in nature

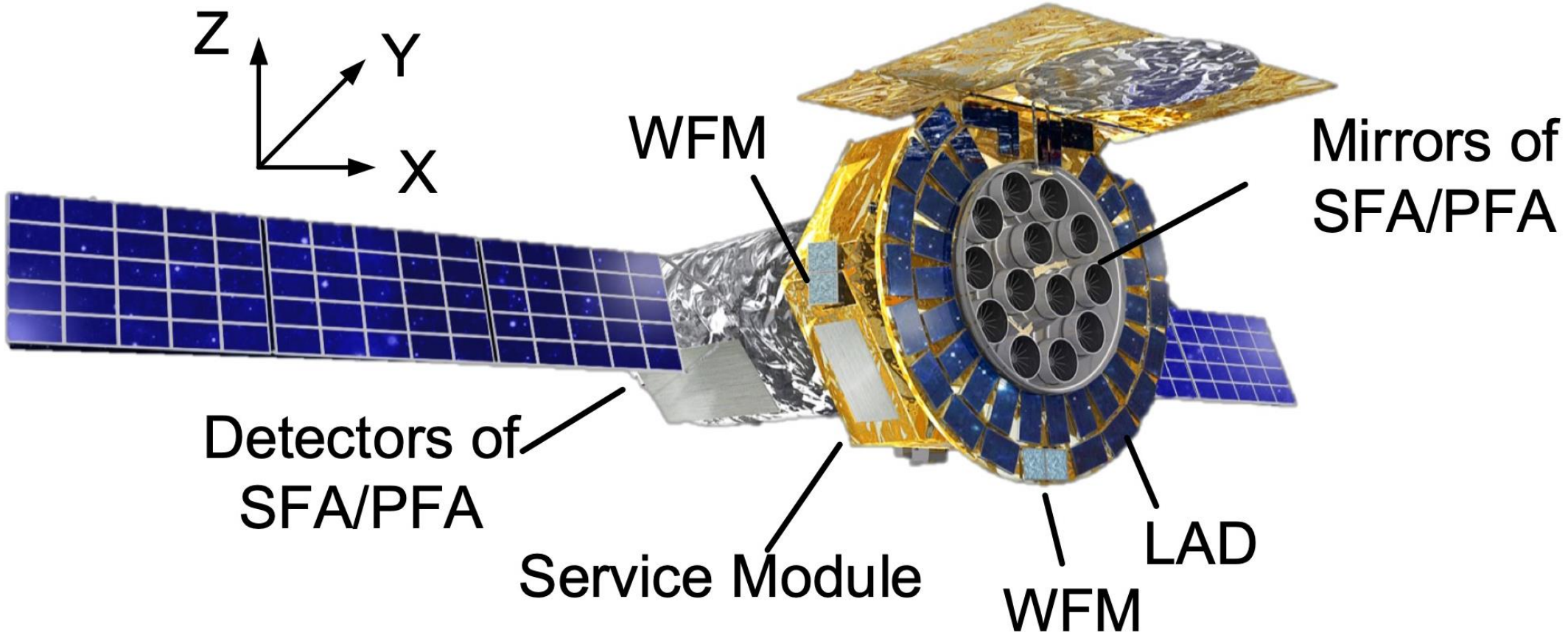
- Powerful X-ray observatory: **monitor X-ray sky**
- Multi-wavelength and **multi-messenger** studies for gravitational waves and neutrinos sources

Payload and instruments

- Spectroscopic Focusing Array (SFA) – a multiple short focal-length modules for large telescope area
- Large Area Detector (LAD)
- Polarimetry Focusing Array (PFA) – a polarimeter with imaging capability
- Wide Field Monitor (WFM)



Payload and instruments



The instrument configuration and key specifications

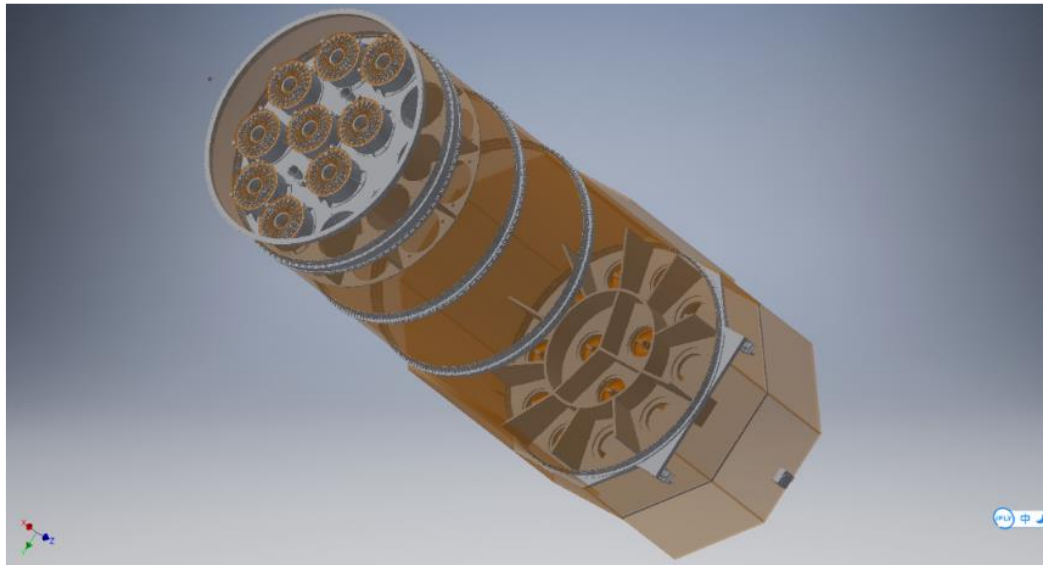
Table 1.1: The instrument configuration and key specifications

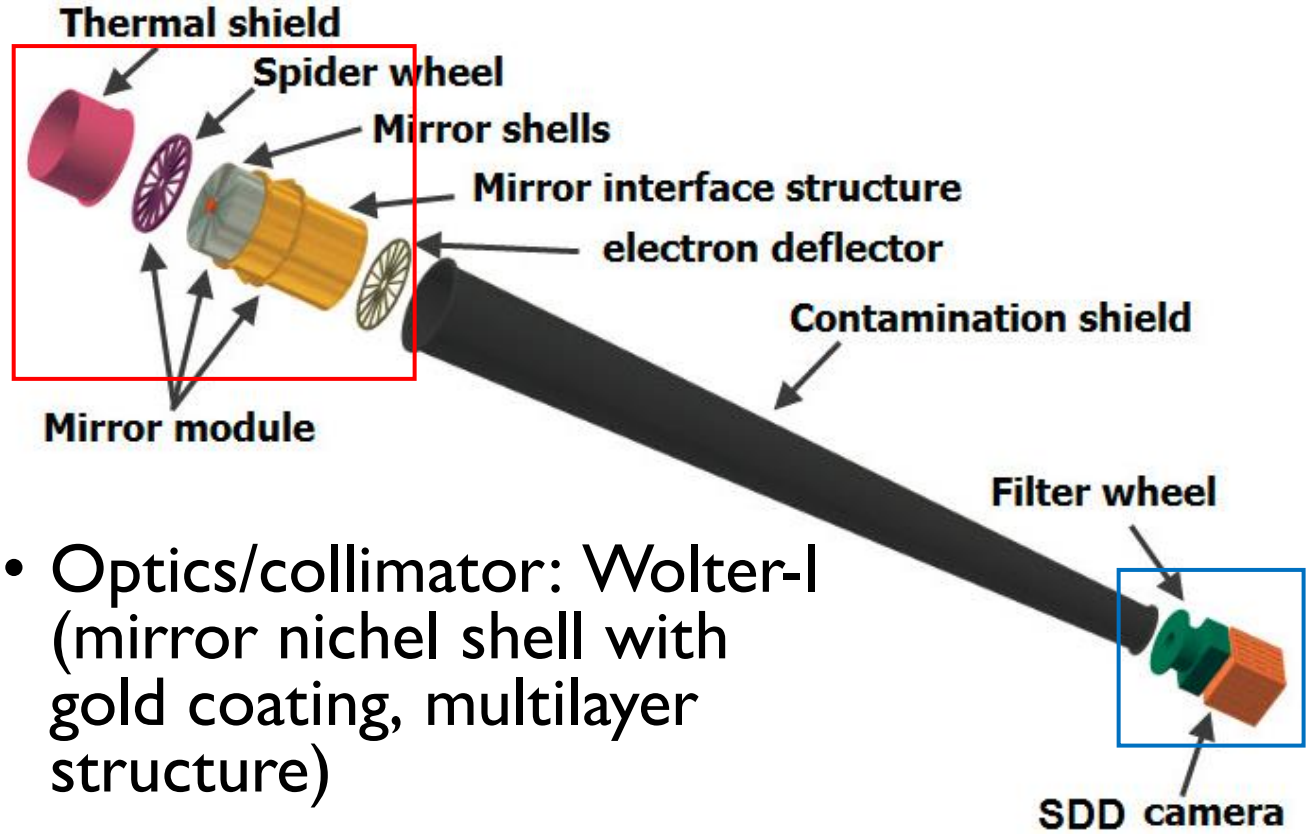
Instrument	SFA	LAD	PFA	WFM
Configuration	9 telescopes	40 modules	4 telescopes	6 cameras
Optics or Collimator	Wolter-I, Nickel F = 5.25 m	capillary-plate collimators	Wolter-I, Nickel F = 5.25 m	Coded mask
Detector	19-pixel Silicon Drift Det. (SDD)	SDD	Gas Pixel Detector (GPD)	SDD
Energy range	0.5 – 10 keV	2-30 keV	2-8 keV	2-50 keV
Effective area or FoV	≥0.6 m^2@1-2 keV 0.4 m^2 @ 6 keV	3.0 m^2 at 8 keV	500 cm^2 @ 2 keV 300 cm^2 @ 3 keV	FoV ≥ 3.1 sr
Energy res. (FWHM)	180 eV @ 6 keV	260 eV @ 6 keV	25% @ 6 keV	≤500 eV@6 keV
Time res.	10 μs	10 μs	10 μs	10 μs
Remarks	unprecedented effective area in the soft X-ray energy range	high throughput; effective area is a factor of 5-10 larger than any previous mission	~ 5 times the area of IXPE, X-ray polar. Pathfinder by NASA; Min. Detectable Polarization ~3% in 2-8 keV range	peak sensitivity: 1 Crab in 1s and 5 mCrab in 50 ks (5σ source); Point source localization ≤ 1′

Soft response Large area Polarization Monitoring

SFA - Spectroscopic Focusing Array

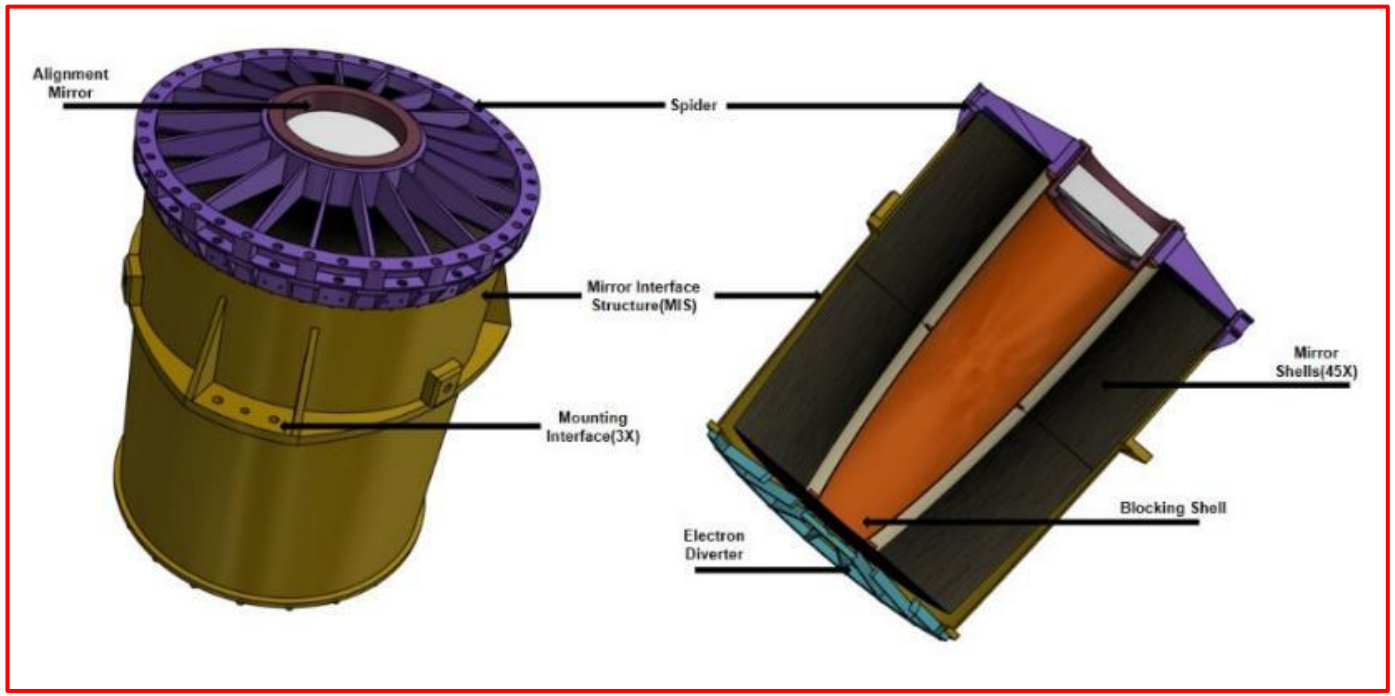
- 9 optics (X-ray telescope)
- Optics: Mirror + SDD at focal plane
- Sensor: 19-cells SDD (x9)
- Spectral and timing observation

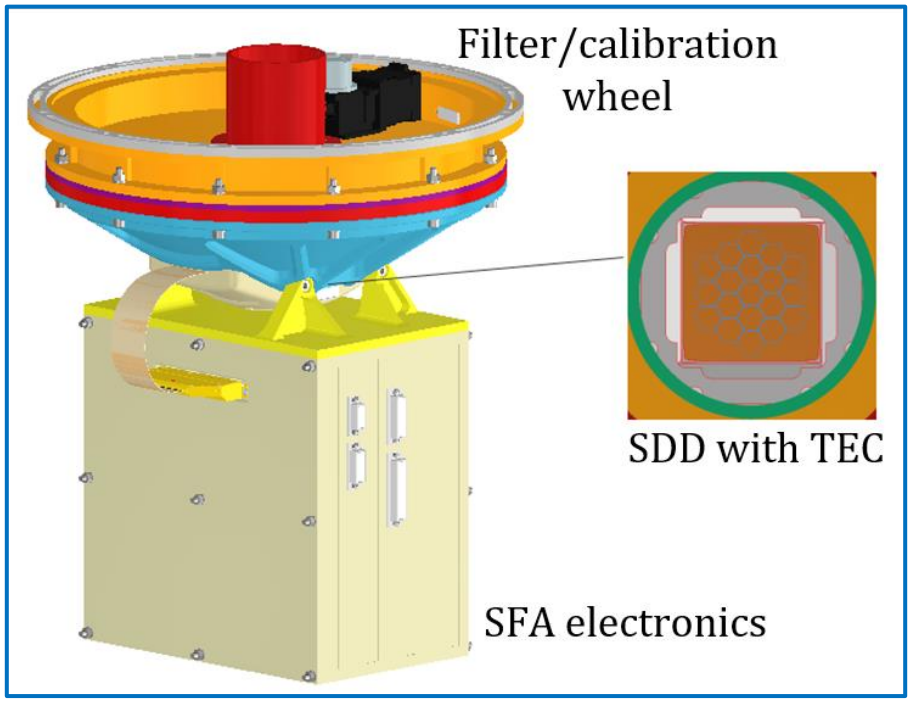




- Optics/collimator: Wolter-I (mirror nichel shell with gold coating, multilayer structure)
- Energy range: 0.5-10 keV

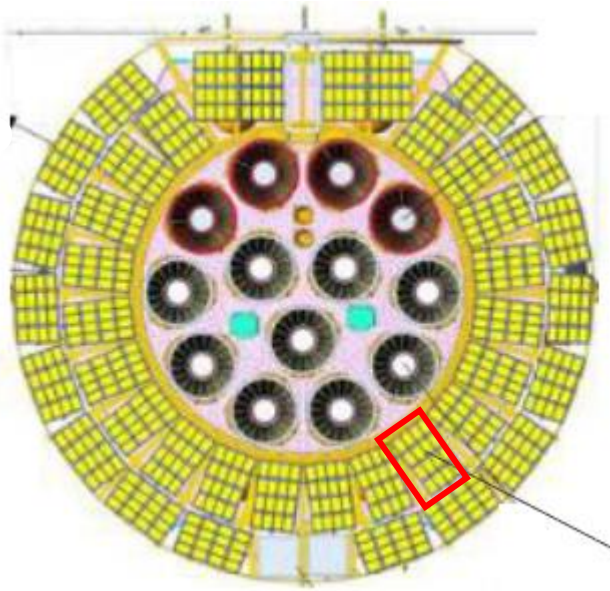
SFA - Spectroscopic Focusing Array



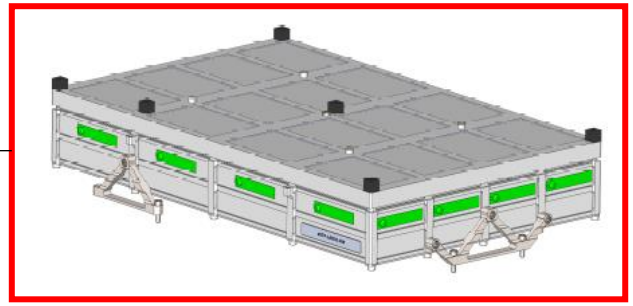


Mirror assembly and SFA focal plane camera [composed by 19 cells SDD, electronics box, wheel mechanism, and thermal electric cooler (TEC)]

LAD - Large Area Detector

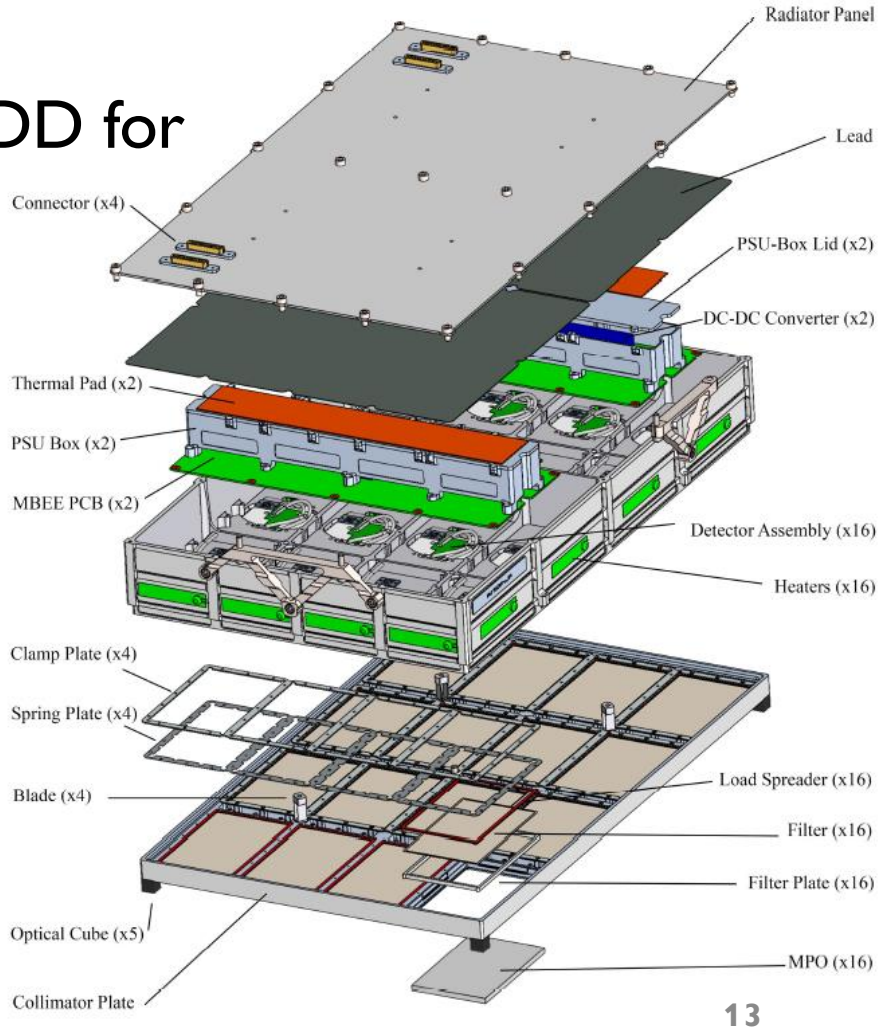


- 40 modules (effective area larger than 3 m^2
- Sensor: 16 large area SDD for each module
- Large collecting area



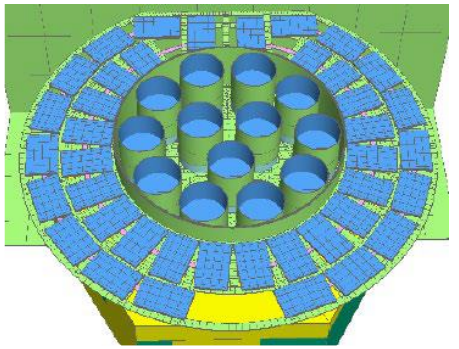
- Optics/collimator:

  capillary plate collimators
- Energy range: 2-30 keV
- Measure the energy and time of arrival of the incident photons

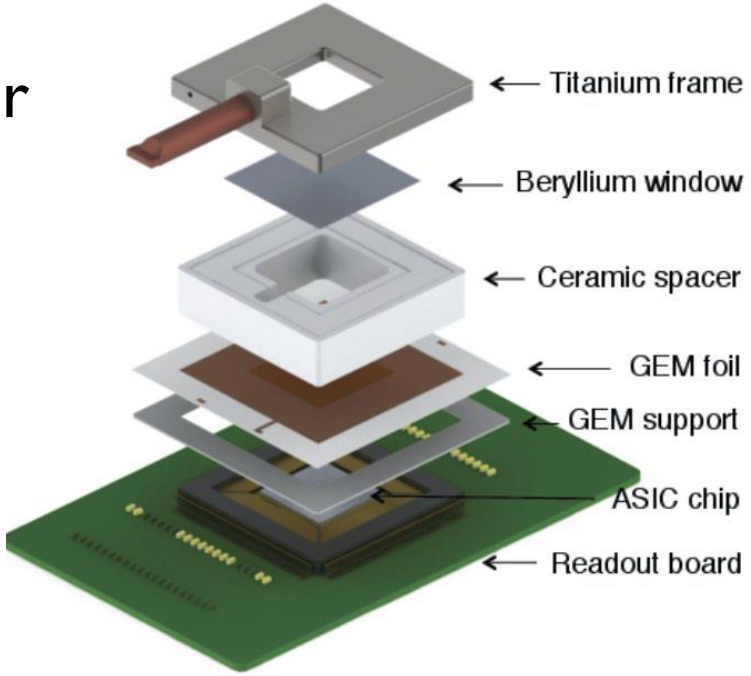


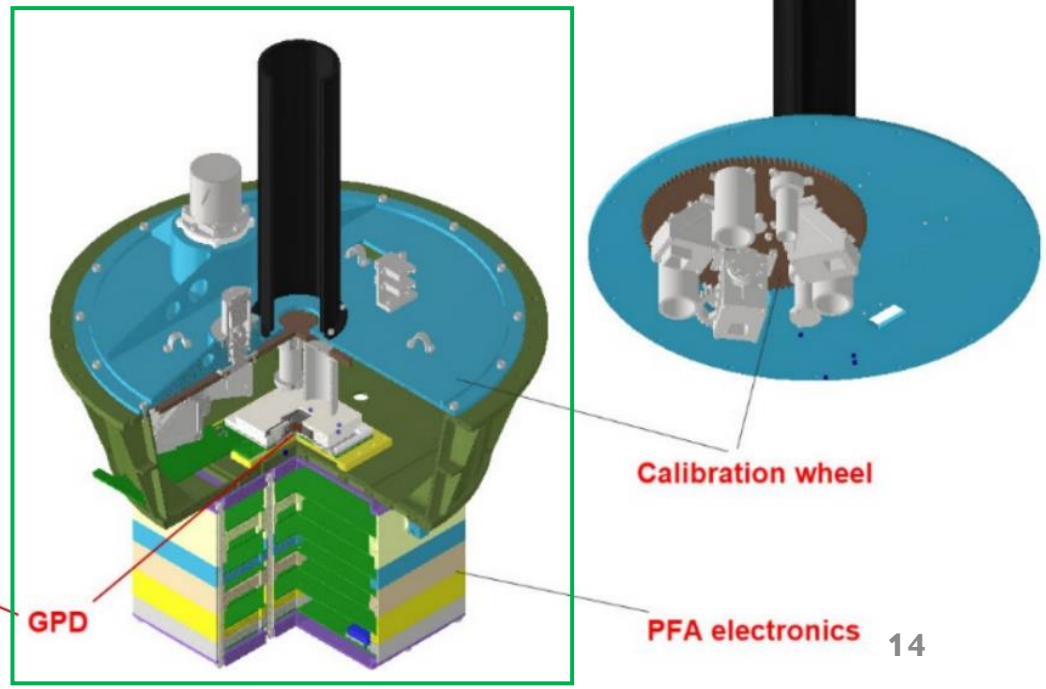
PFA - Polarimetry Focusing Array

- 4 telescopes (same optical design of SFA)
- X-ray imaging polarimetry
- Optics/collimator: Wolter-I (mirror nichel shell, multilayer structure)



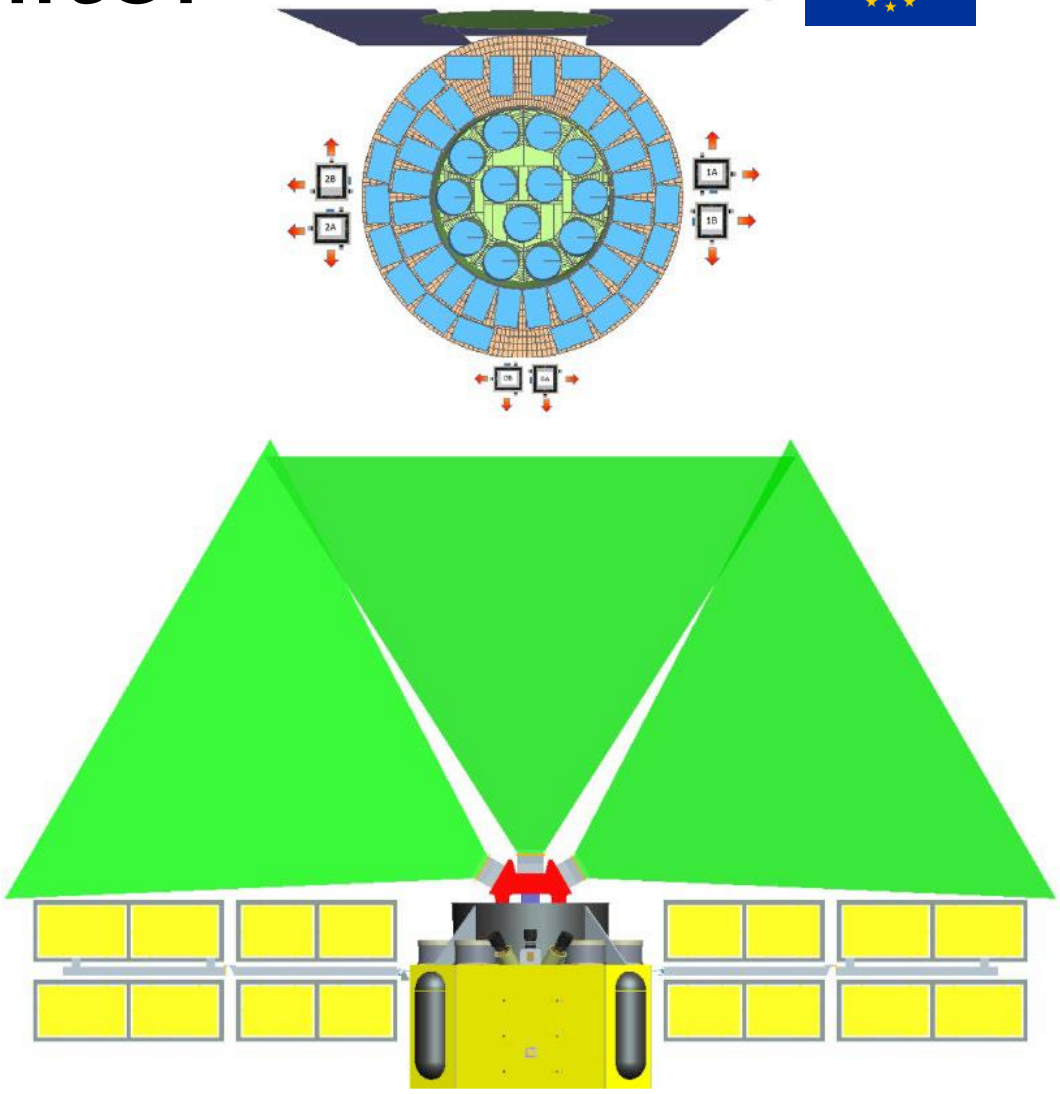
- Sensor: Gas Pixel Detector (GPD)
- Energy range: 2-8 keV
- Focal plane camera



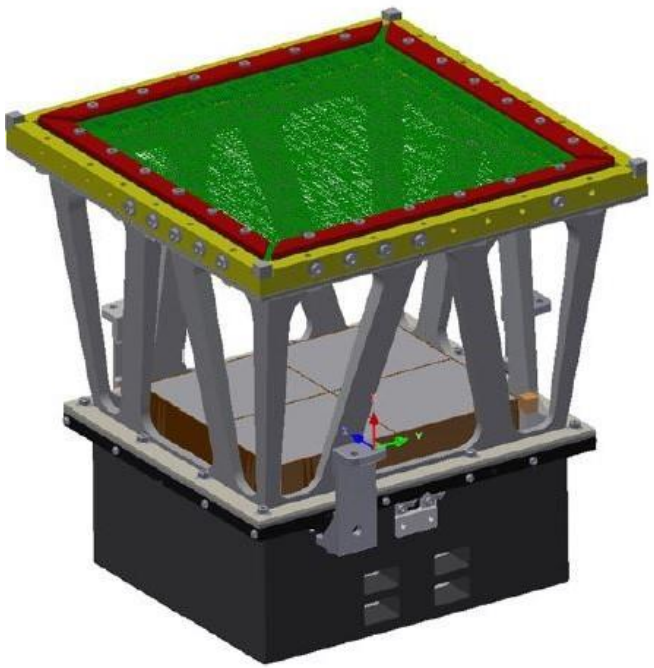


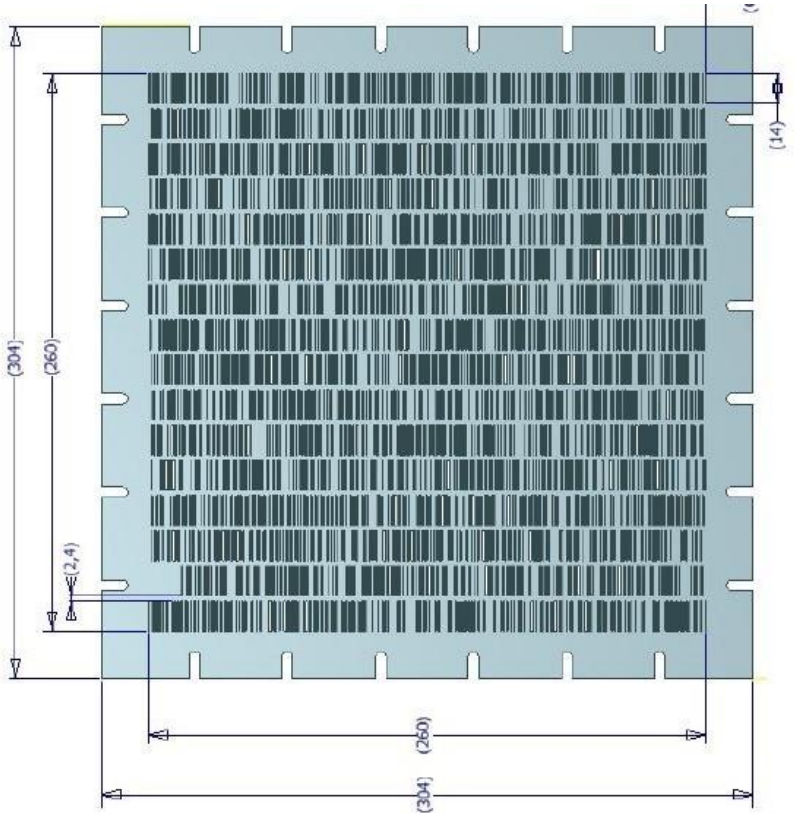
WFM - Wide Field Monitor

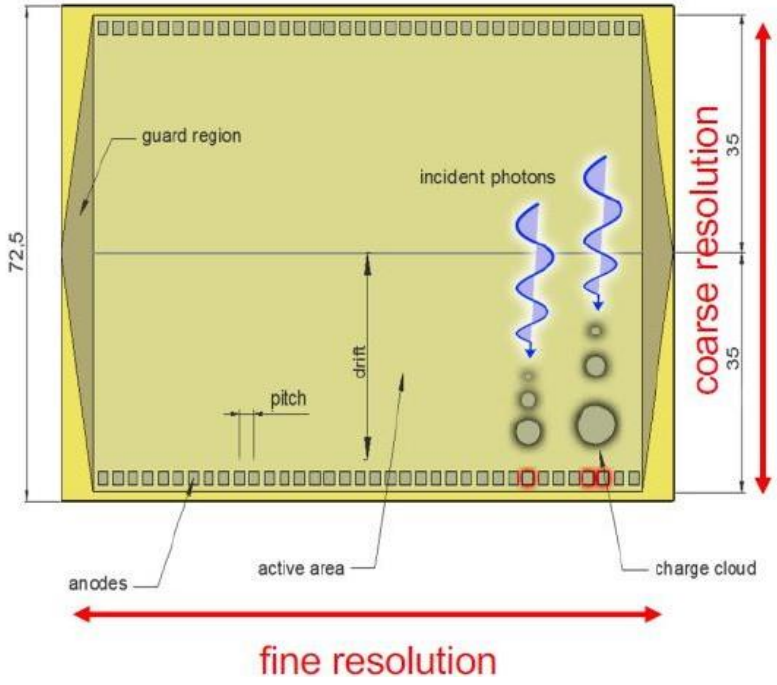
- 3 unit (6 cameras)
- Sensors: 4 SDD for each camera -> 24 SDD (position-sensitive)
- Optics/collimator: coded mask
- Energy range: 2-50 keV
- Covering about 33% of the sky
- Field of view and imaging
- Objective: monitoring X-ray sky (trigger and localization of transient event)



WFM - Wide Field Monitor







The ReDSoX Collaboration experience

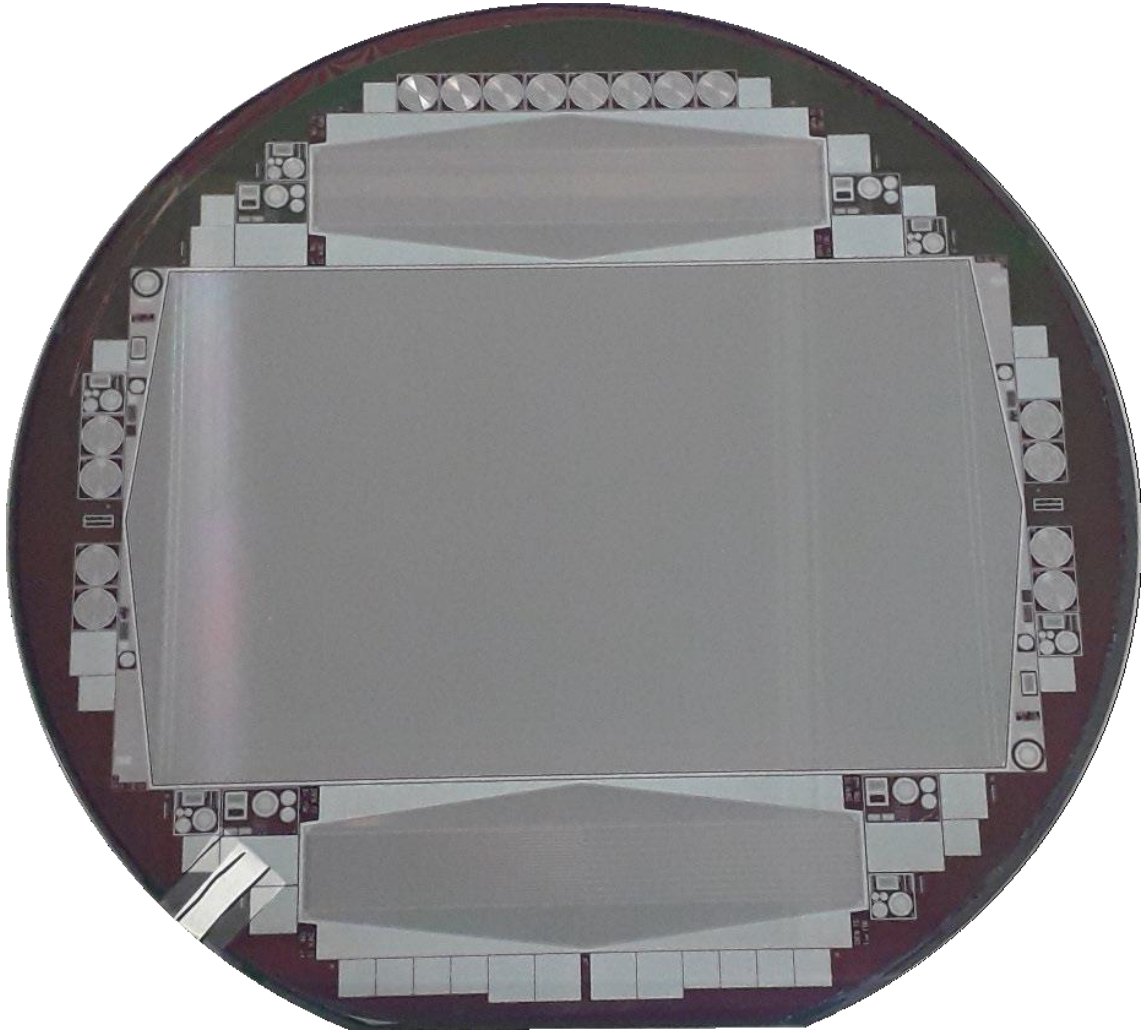
In the last decade, development of innovative detection systems based on Silicon Drift Detectors (SDD) and integrated readout electronics (ASICs) for X-ray Astronomy (and other applications...)

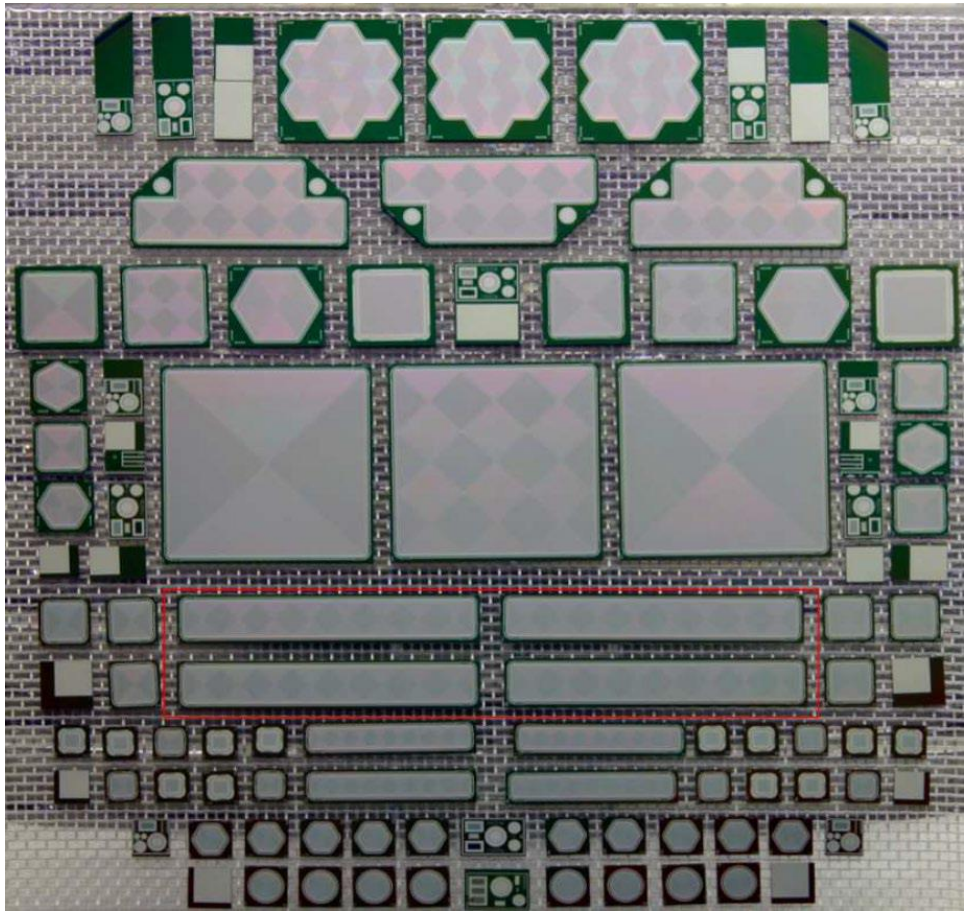
39. Application Specific Integrated Circuits in large format hyperspectral imaging radiation detectors for space-borne instrumentation
Filippo Mele (Politecnico di Milan...
20/06/2023, 11:50

67. Silicon Drift Detector technologies for high-throughput spectral-timing X-ray space astronomy
Francesco Ceraudo (INAF/IAPS)
20/06/2023, 12:30

81. Comparison of characteristics and performance between the new detection system based on Silicon Drift Detectors of XAFS beamline of Elettra and SESAME
Daniela Cirrincione (Istituto Nazionale di...
22/06/2023, 10:30

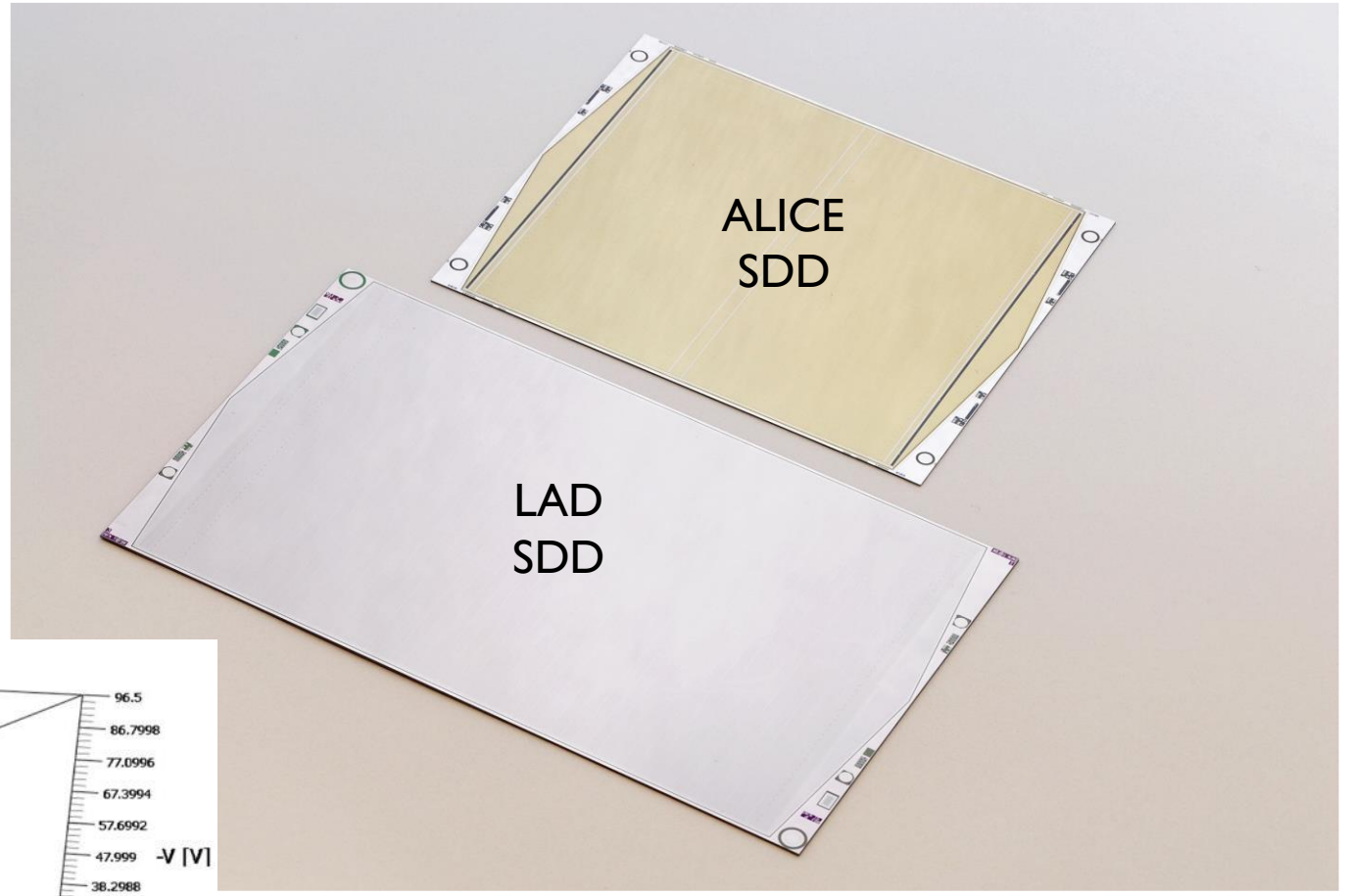
ReDSoX Silicon Drift Detectors

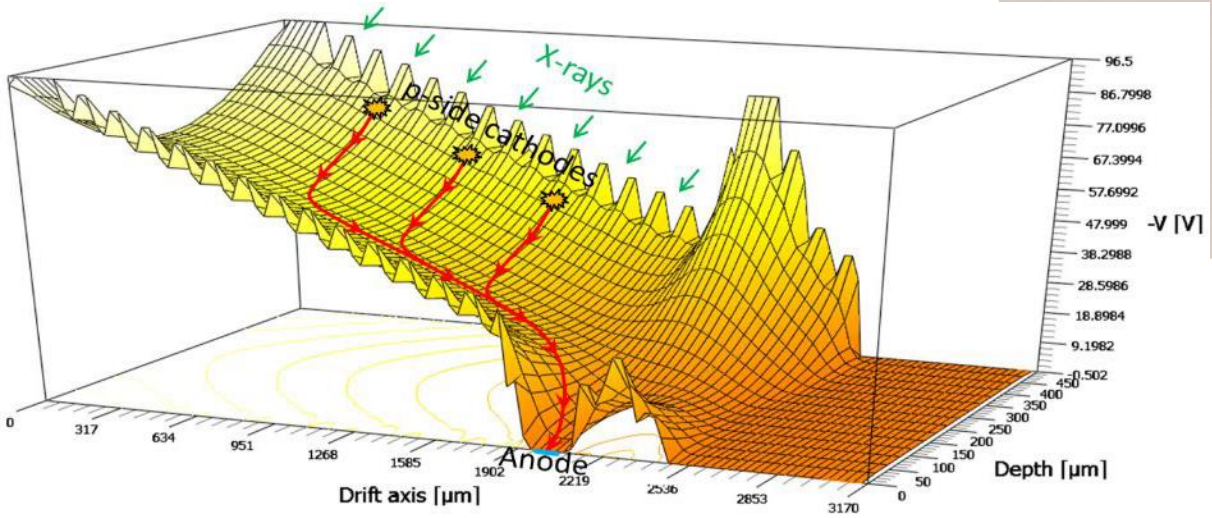




Heritage for Silicon Drift Detector for LAD and WFM

- SDD production for ALICE
- Updates for large-area, low-power, space qualified devices for X-ray missions in space
- LOFT phase-A mission study for ESA

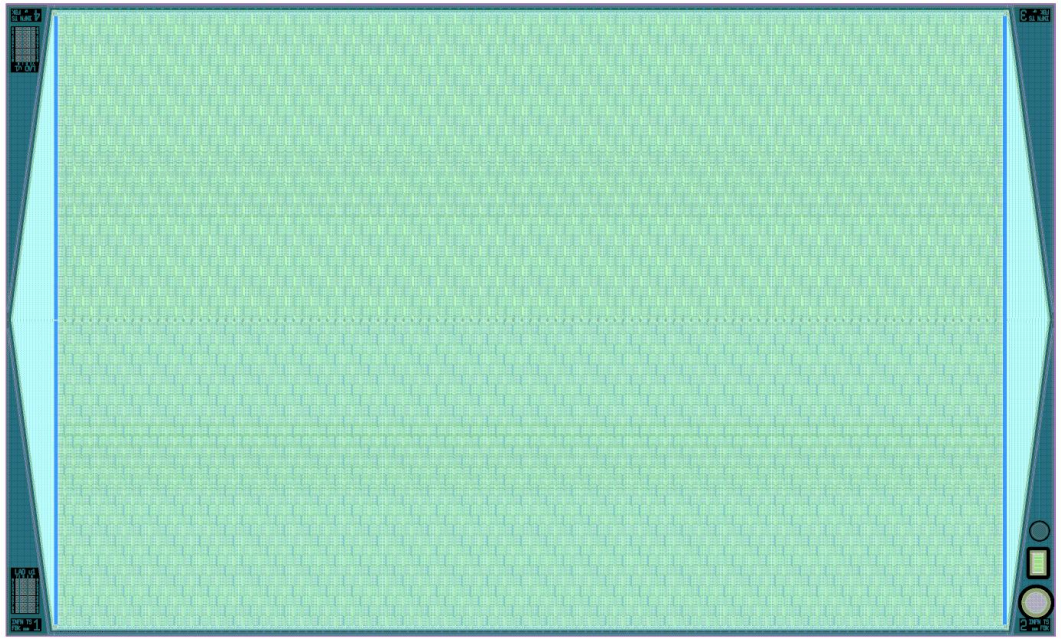




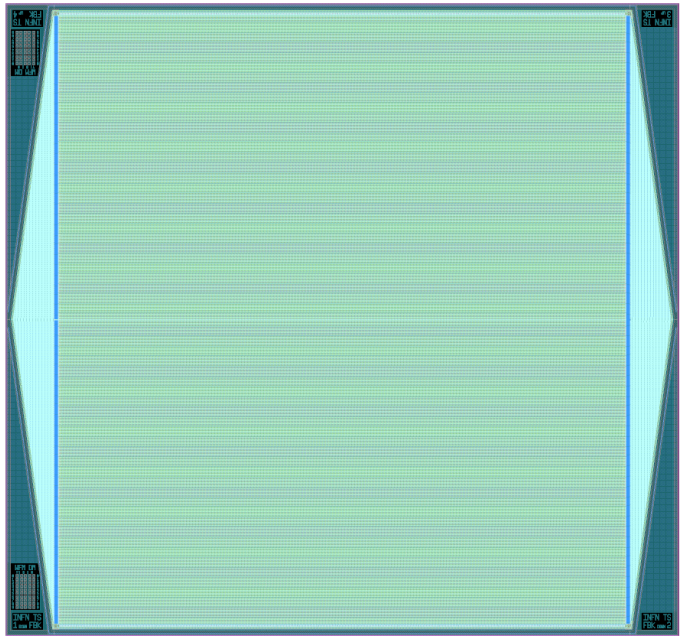
Alice SDD: active area 7.53 x 7.00 cm^2
LAD SDD: active area 10.86 x 7.00 cm^2

Our main contribution: SDD of LAD and WFM

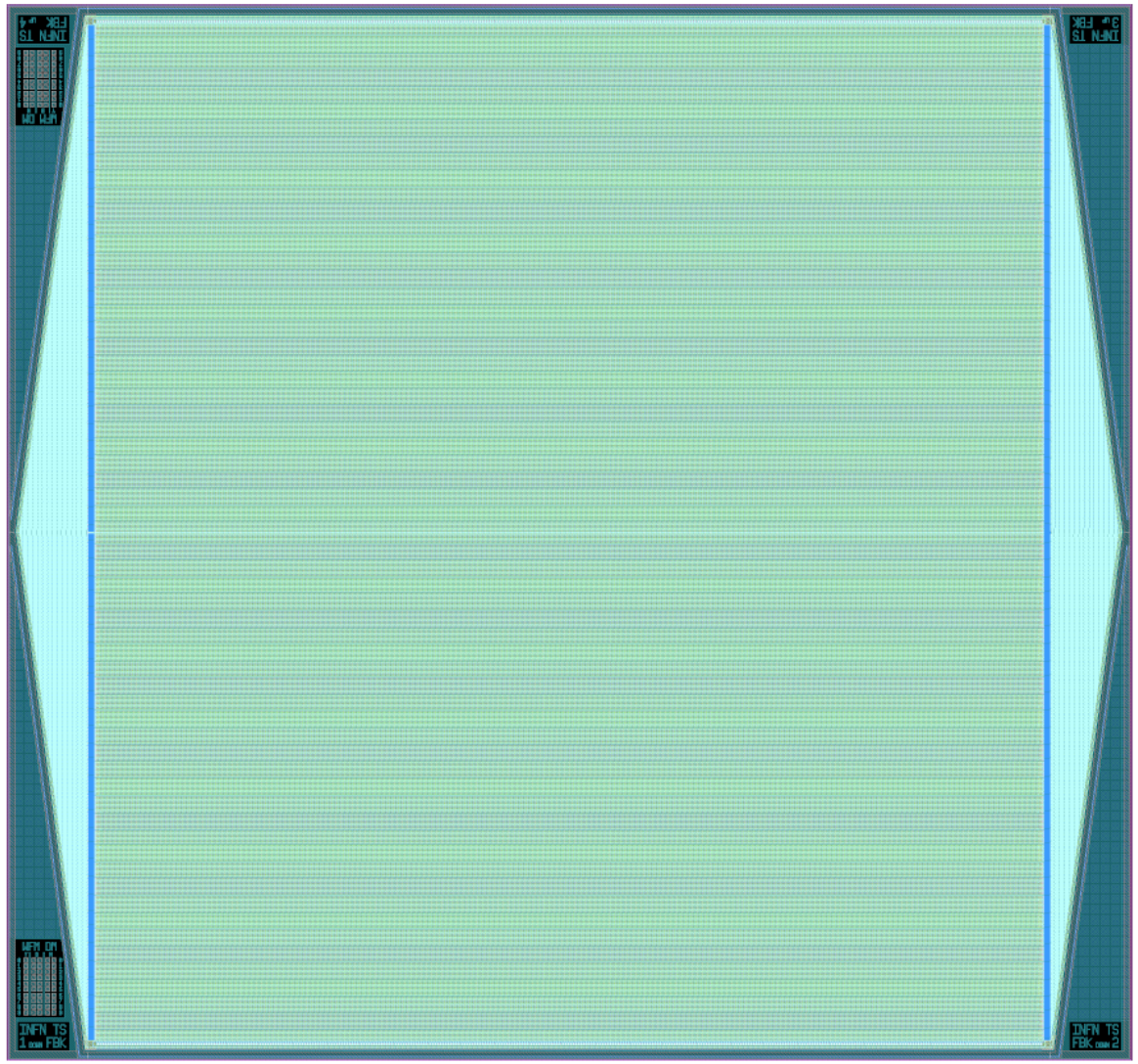
LAD sensor



WFM sensor

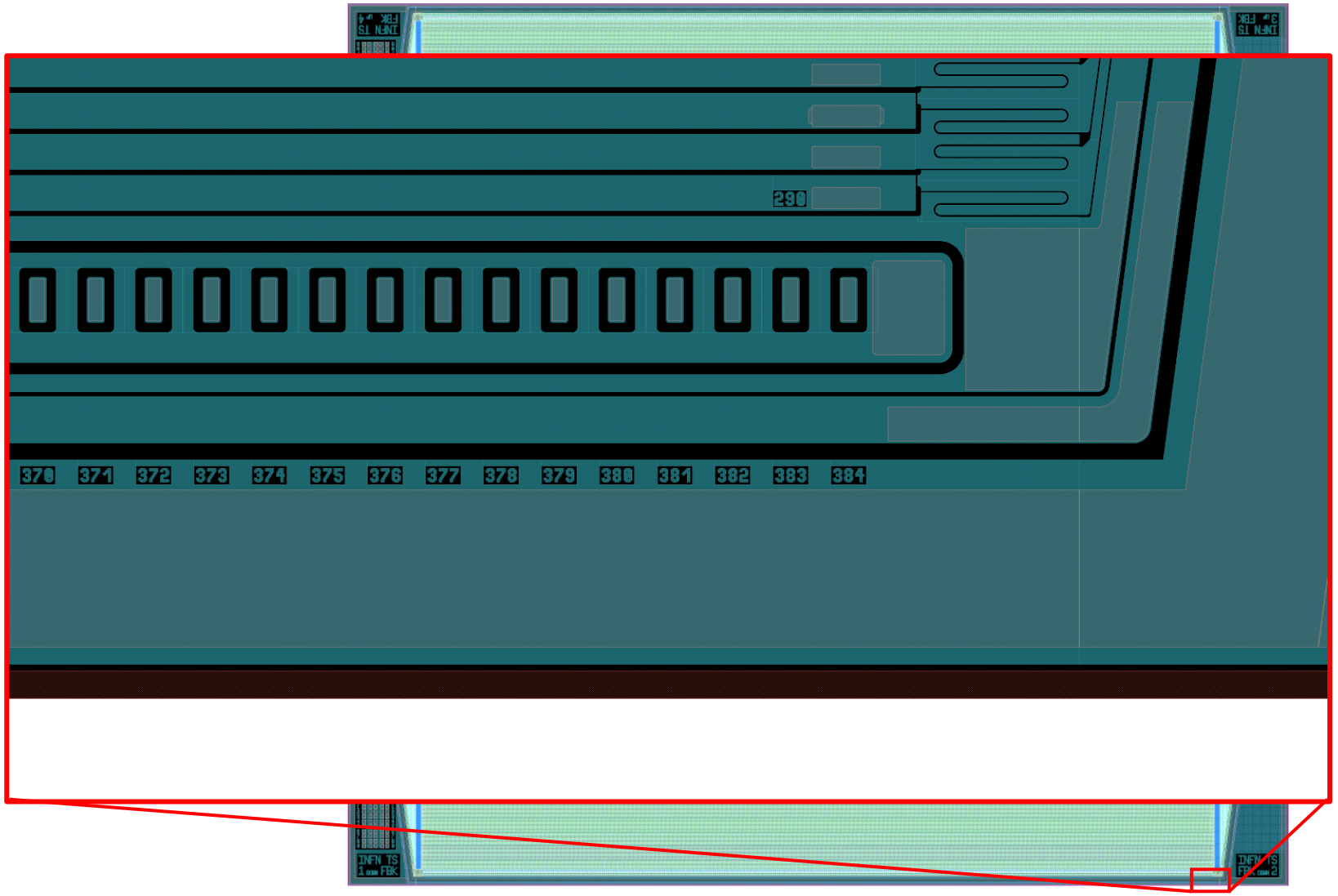


WFM sensor



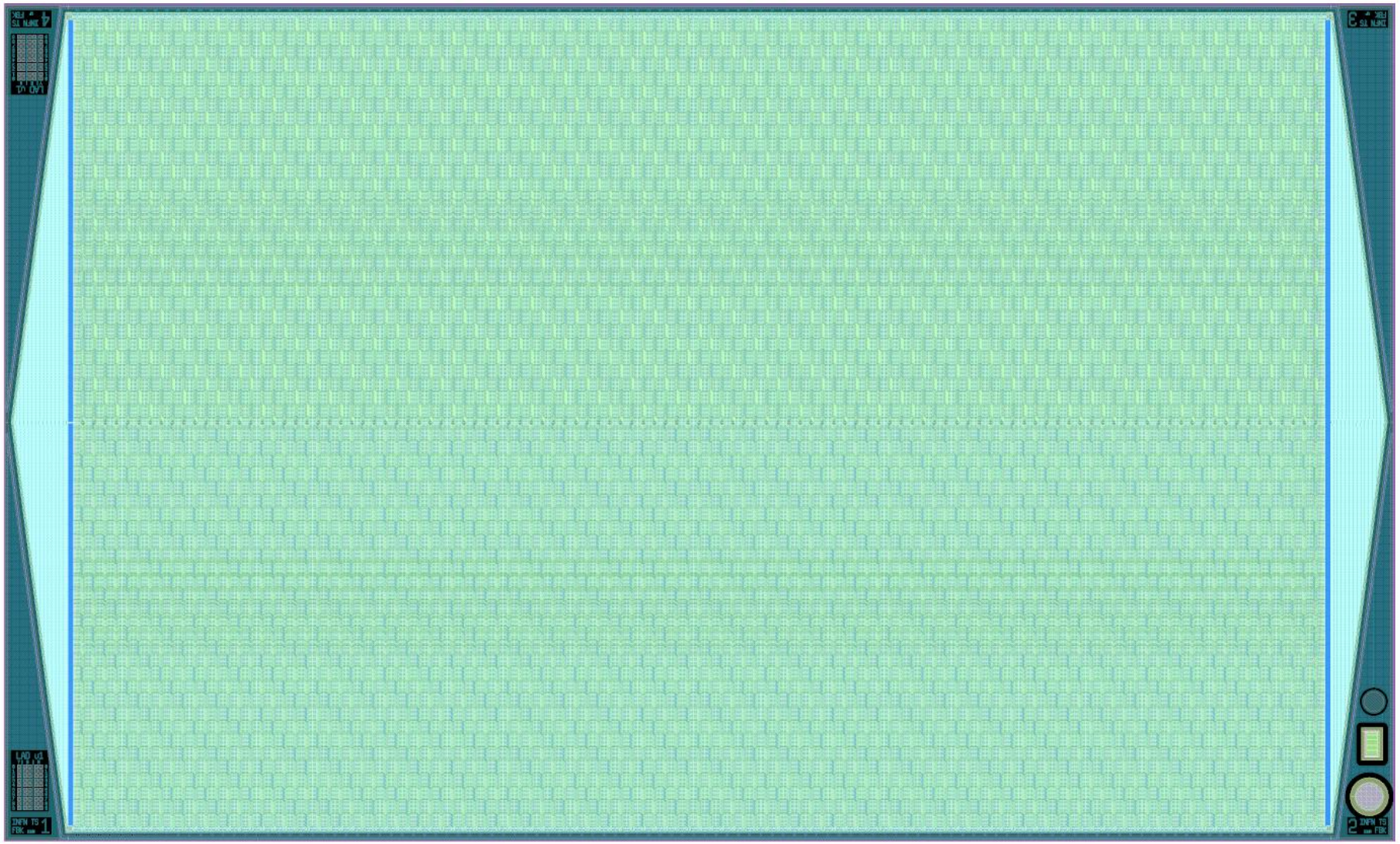
- Dimensions: 72,4 x 77,1 mm^2
- Thick: 450 µm
- Anodes: 384
- Pitch between anodes: 169 µm
- Standard design of cathodes

WFM sensor



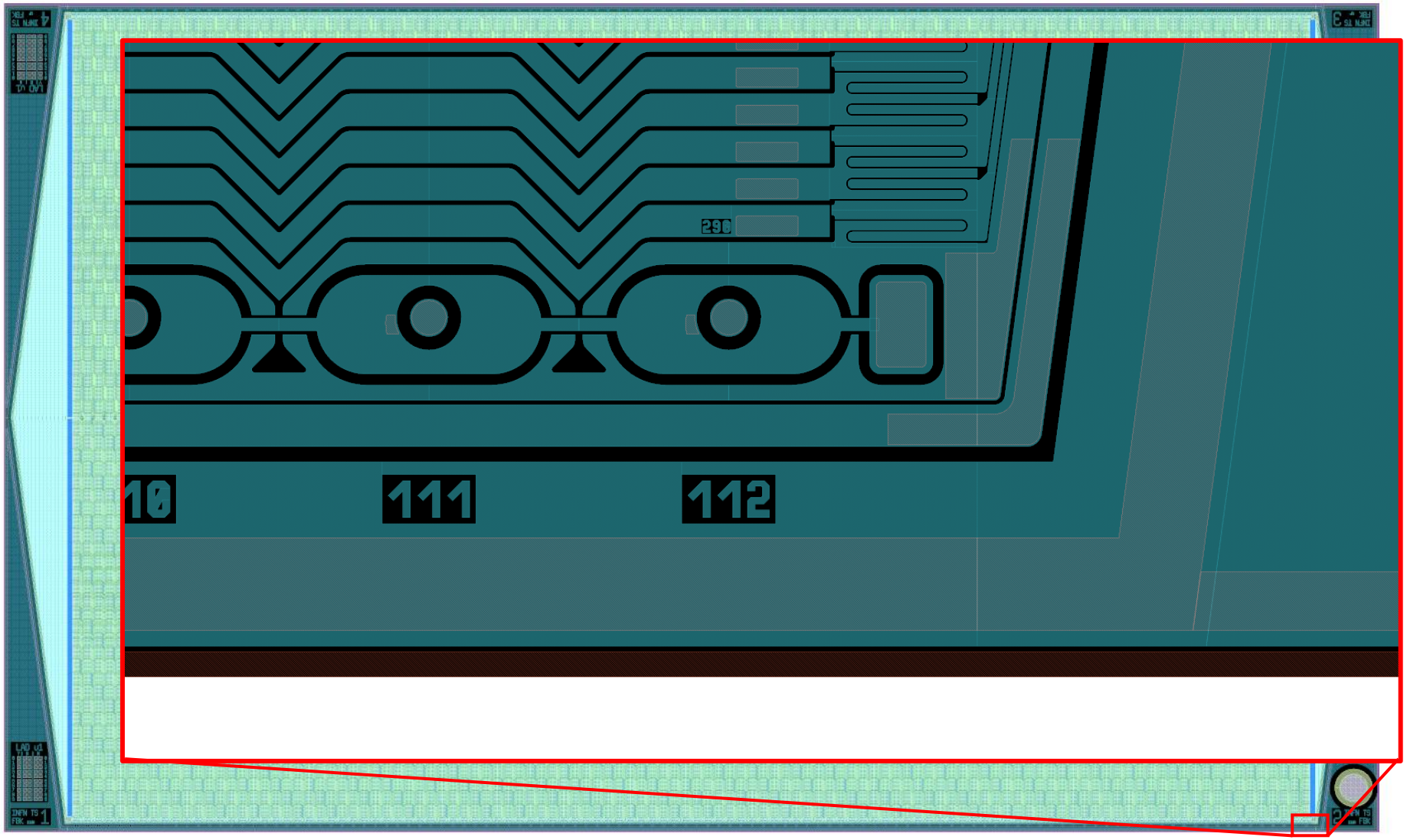
- Dimensions: 72,4 x 77,1 mm^2
- Thick: 450 µm
- Anodes: 384
- Pitch between anodes: 169 µm
- Standard design of cathodes

LAD sensor



- Dimensions: 72,4 x 120 mm^2
- Thick: 450 µm
- Anodes: 224 (112 on each side)
- Pitch between anodes: 970 µm
- Dimension anodes: 110 µm
- New design of cathodes to focus the signal charge

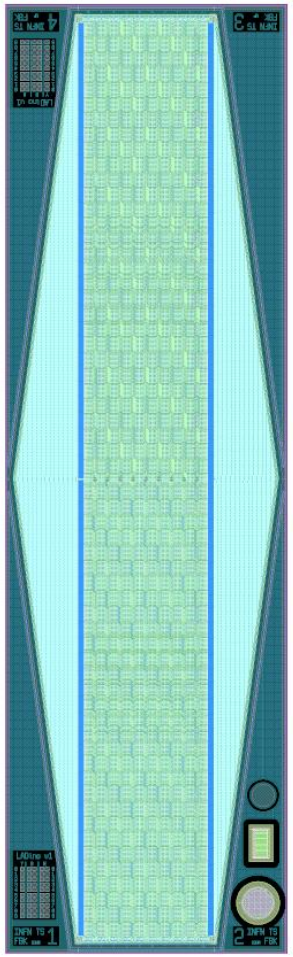
LAD sensor



- Dimensions: 72,4 x 120 mm^2
- Thick: 450 µm
- Anodes: 224 (112 on each side)
- Pitch between anodes: 970 µm
- Dimension anodes: 110 µm
- New design of cathodes to focus the signal charge

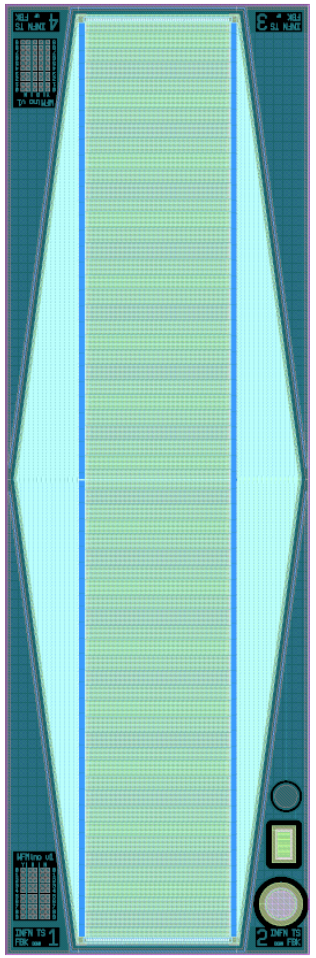
Prototype sensors: *-ino* version

LADino

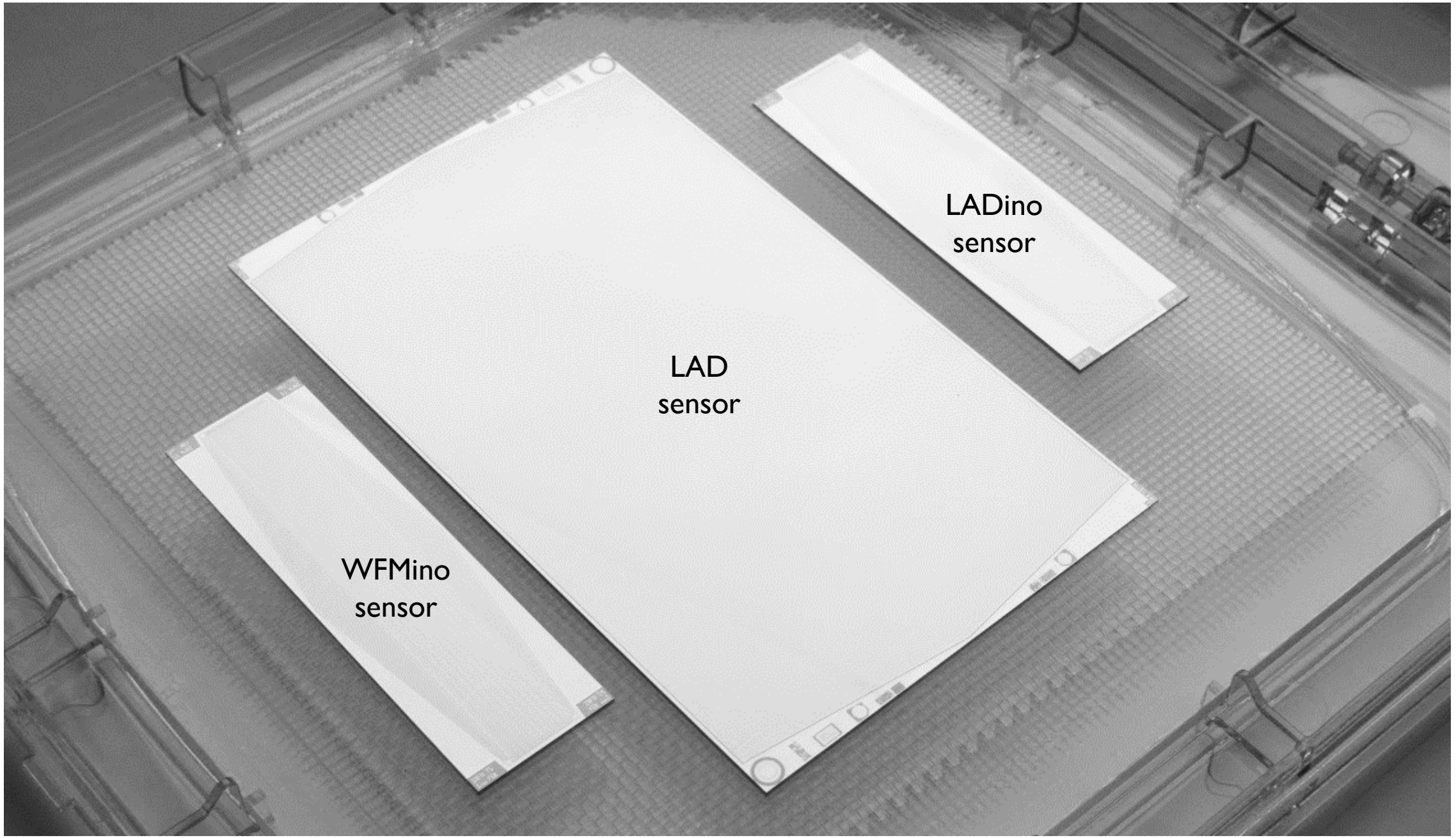


- Dimensions: 72,4 x 21,3 mm^2
- Thick: 450 µm
- Anodes: 10
- Pitch between anodes: 970 µm

WFMino

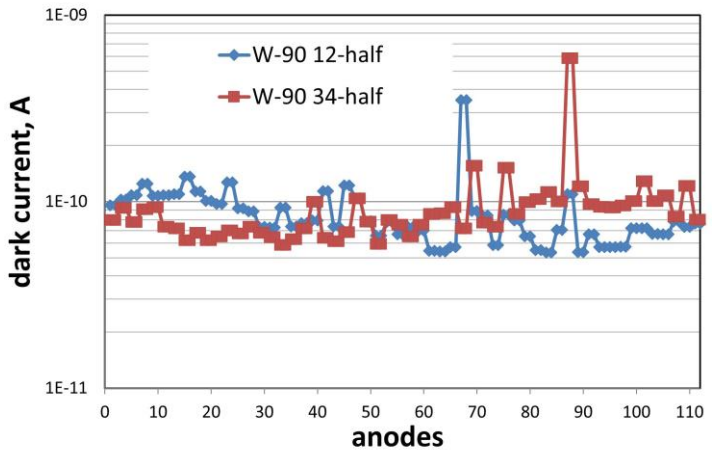


- Dimensions: 72,4 x 30,0 mm^2
- Thick: 450 µm
- Anodes: 64
- Pitch between anodes: 169 µm

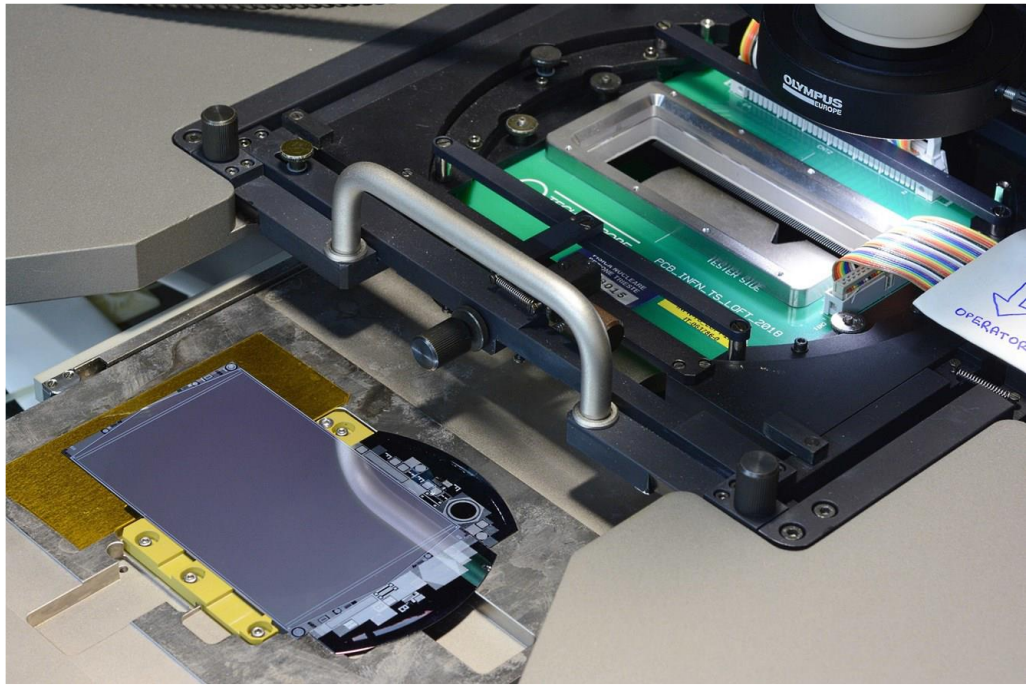

LADino
sensor
LAD
sensor
WFMino
sensor

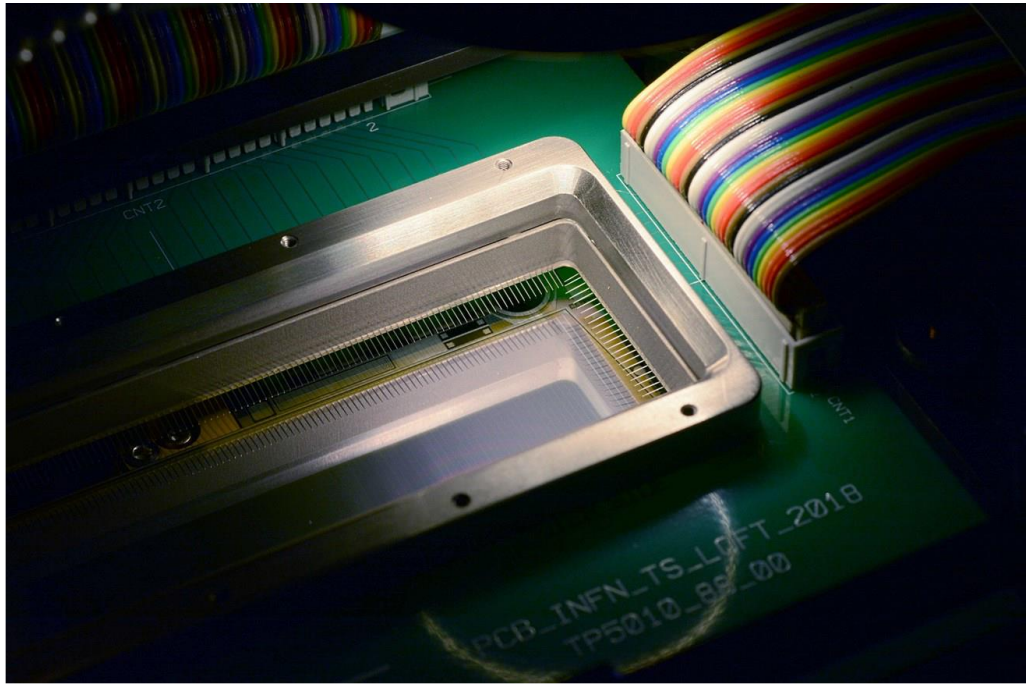
Optimization, testing and sensor selection

- Optimization: effective area, anode pitch, layout
- Preliminary tests by the manufacturer on wafers
- Extensive sensor characterization tests
- Flight qualification tests
- Spectroscopic performance tests



The automatic characterization tests of the LAD sensor anodes carried out with the Karl-Suss PM8-DSP double-sided probe-station and the use of a probe card equipped with 144 pins on the top and 32 on the bottom, and an example of the results with the dark current values of the anodes.





Recent eXTP references

- Zhang, Shuang-Nan, et al. "Enhanced X-ray Timing and Polarimetry mission: eXTP: an update on its scientific cases, mission profile and development status." Space Telescopes and Instrumentation 2022: Ultraviolet to Gamma Ray. Vol. 12181. SPIE, 2022.
- Feroci, Marco, et al. "The large area detector onboard the eXTP mission." Space Telescopes and Instrumentation 2022: Ultraviolet to Gamma Ray. Vol. 12181. SPIE, 2022.
- Hernanz, Margarita, et al. "The wide field monitor onboard the Chinese-European x-ray mission eXTP." Space Telescopes and Instrumentation 2022: Ultraviolet to Gamma Ray. Vol. 12181. SPIE, 2022.
- Rachevski, A., et al. "eXTP Large Area Detector: Qualification procedure of the mass production." Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 1046 (2023): 167750.

eXTP (enhanced X-ray Timing and Polarimetry mission): scientific objectives and sensors

THANKS FOR YOUR ATTENTION

Daniela Cirrincione on behalf of the eXTP Consortium
INFN-Trieste

HPXM2023 - High Precision X-ray Measurements
19-23 June 2023 – INFN-LNF