X-Ray Detectors Development at LNLS / Sirius

LNLS Brazilian Synchrotron Light Laboratory + sirius

CNPEM Brazilian Center for Research in Energy and Materials

MINISTRY OF SCIENCE TECHNOLOGY AND INNOVATION

BRAZILIAN GOVERNMENT BRASIL UNITING AND REBUILDING

January 15, 2025.

X-Ray Detectors Development at LNLS / Sirius

OUTLINE

- Introduction
- PIMEGA Project: X-ray Hybrid Detectors
- MOBIPIX Project: A Mobile X-ray Hybrid Detector

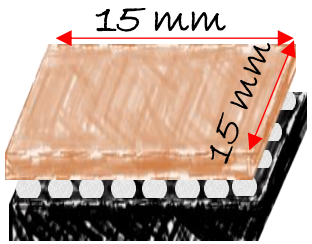
Ongoing Development at LNLS / Sirius

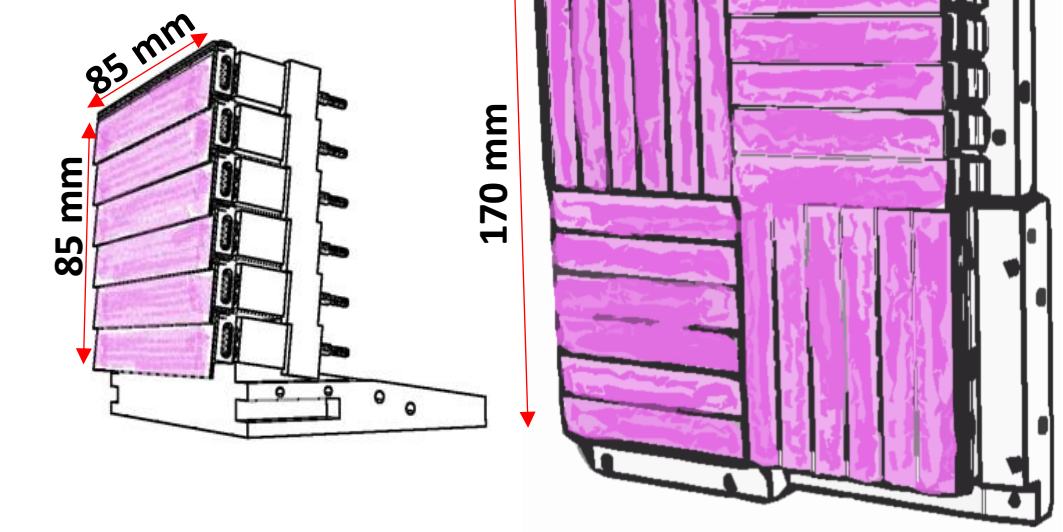
- TUPI Project: Timepix-based Ultra-fast Photon Imaging Detector

X-Ray Detectors Development at LNLS / Sirius

- PIMEGA Project: X-ray Hybrid Detectors

Creating large area detectors with Medipix



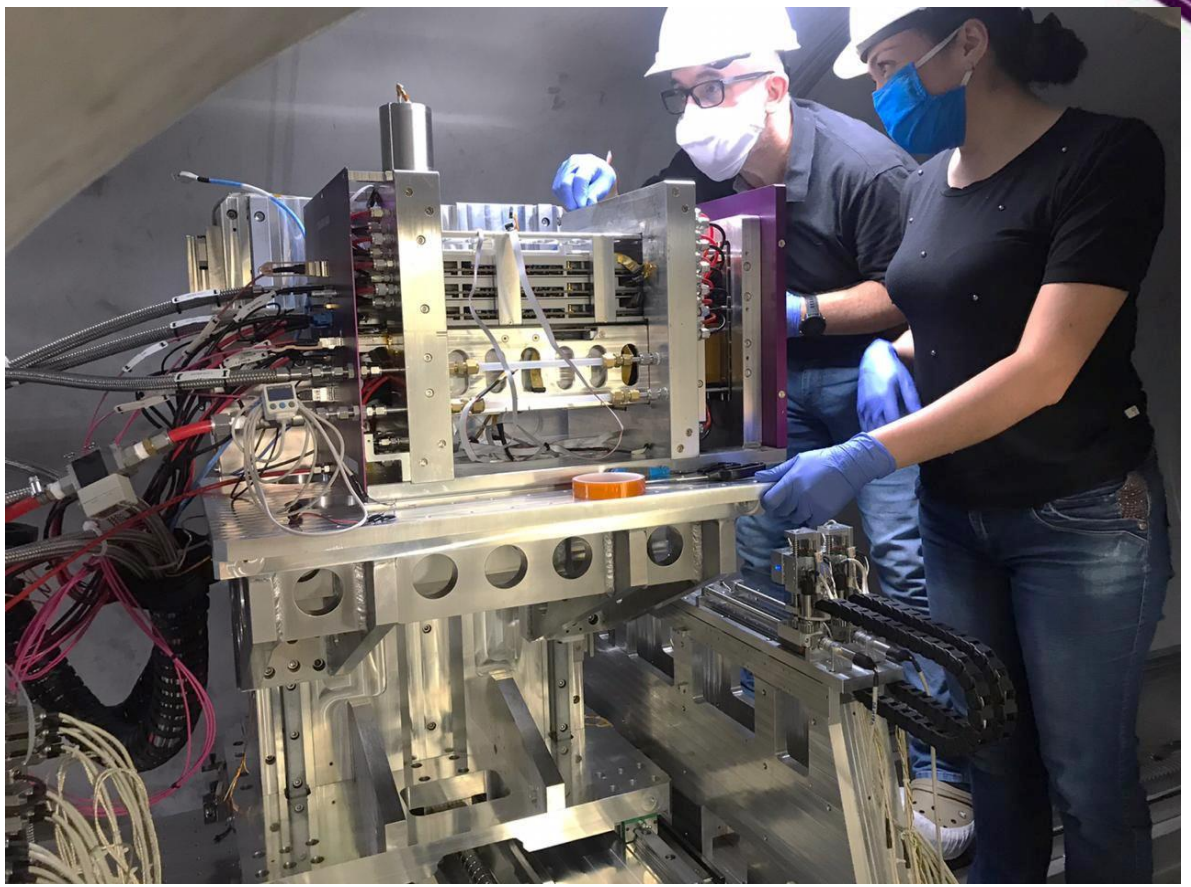


EMA DETECTOR PIMEGA 540D

- 9.4 megapixels 55 x 55 um²
- Up to 2000 frames/s.
- 90 TB/hour

X-Ray Detectors Development at LNLS / Sirius

- PIMEGA Project: X-ray Hybrid Detectors



Assembling first PIMEGA Detector at Sirius (inner the vaccum túnel of the CARTERÊ beamline)

Jean Marie Polli

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LNLS - Brazilian Synchrotron Light Laboratory

On behalf Detectors Group

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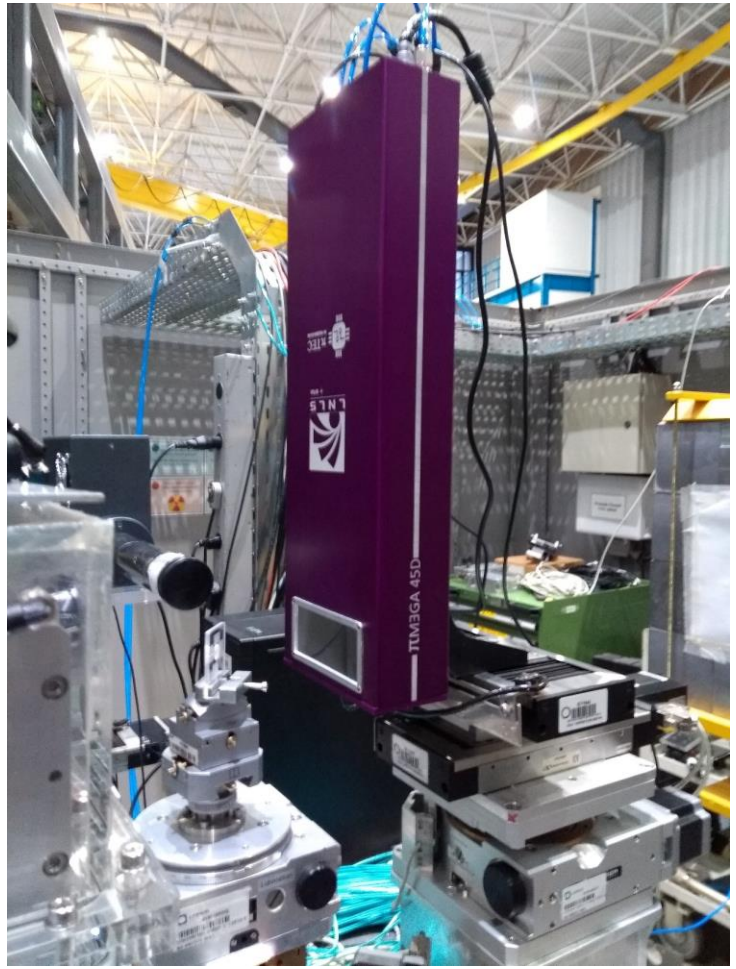
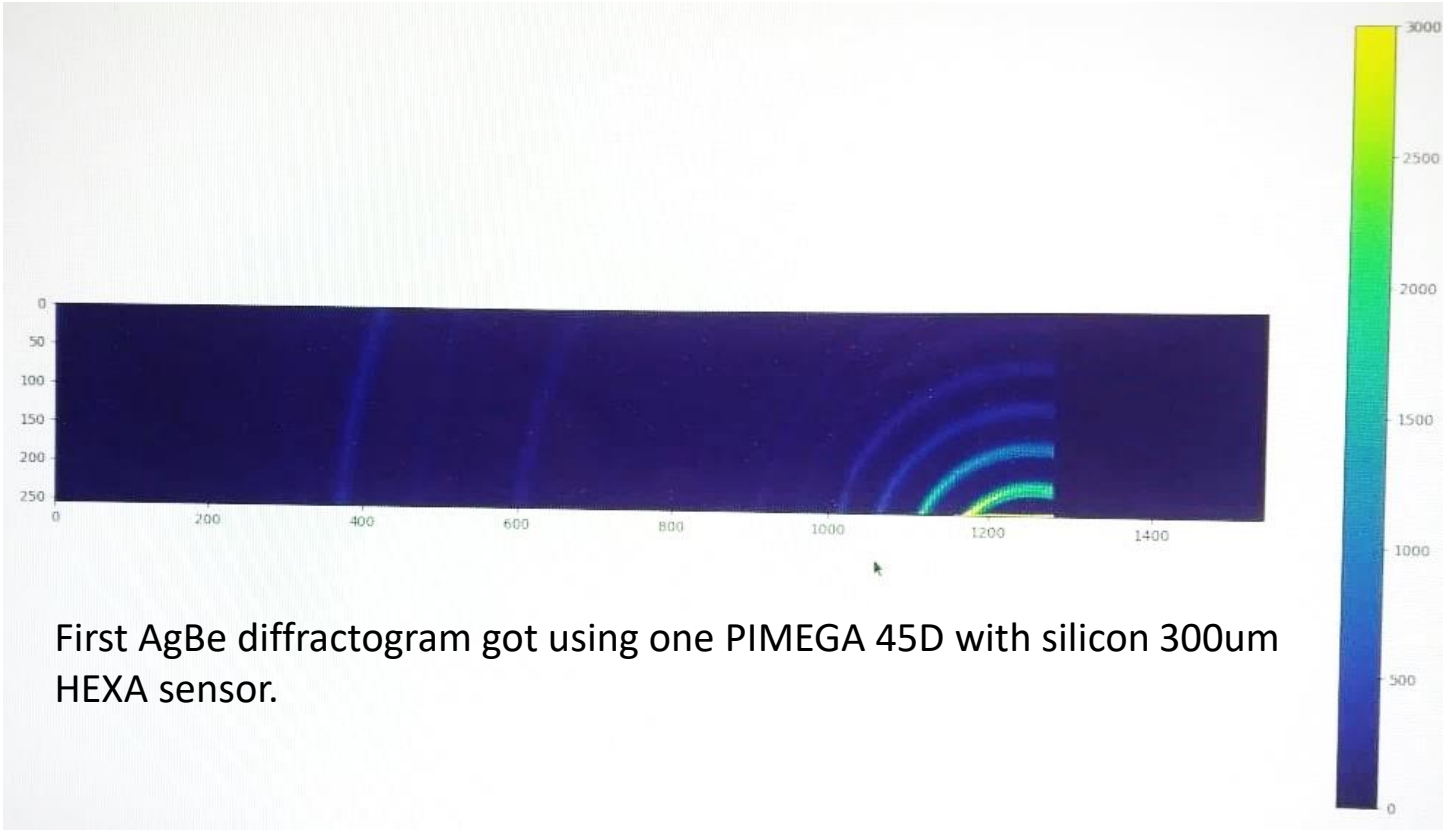
- PIMEGA Project: X-ray Hybrid Detectors

Two PIMEGA 45D Si prototypes



Silicon Pimega 45D installed in UVX Beamline for tests (2019).



First AgBe diffractogram got using one PIMEGA 45D with silicon 300um HEXA sensor.

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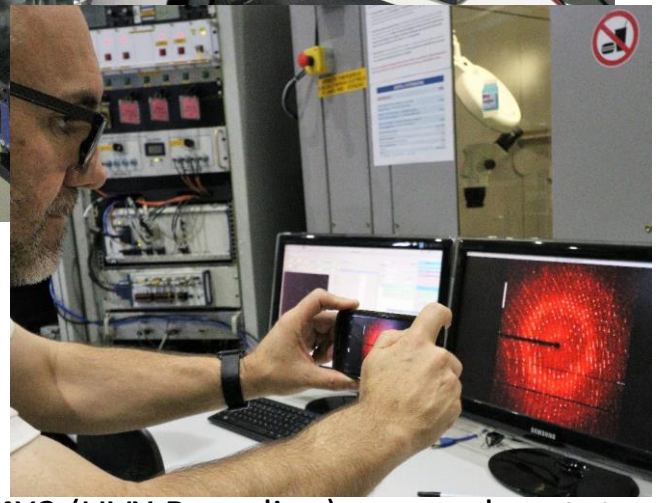
- PIMEGA Project: X-ray Hybrid Detectors

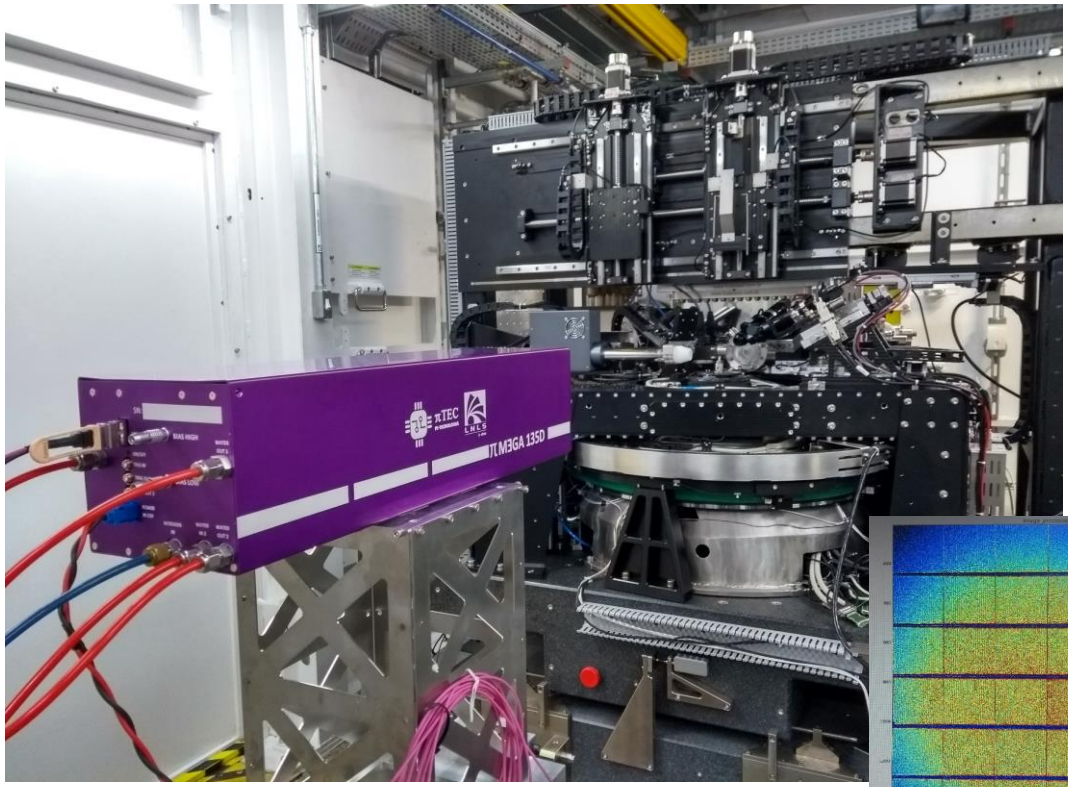
Five PIMEGA 135D (Mogno / Carnaúba beamlines)

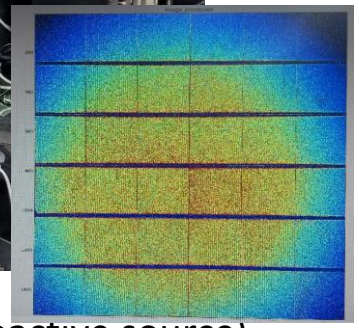


and a lisozyme cristallography test.

Testing PIMEGA 135D in the MX2 (UVX Beamline) secound prototype 2019

PIMEGA 135D Si 675um testing Carnaúba beamline





Pimega 135D-675 under tests (image of ^{55}Fe radioactive source). 2022

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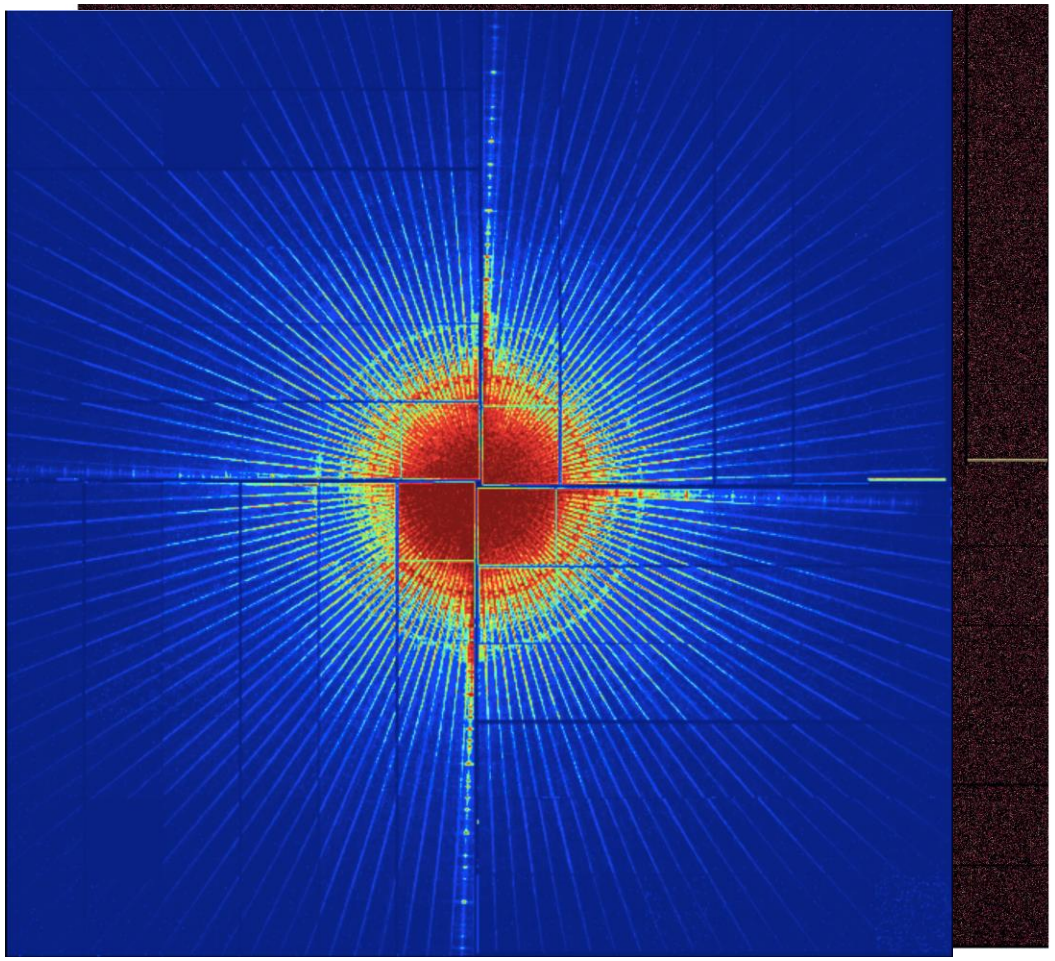
- PIMEGA Project: X-ray Hybrid Detectors

Four PIMEGA 540D detectors

Pimega 540D Si mounted in the vacuum chamber tunnel of CATERETÊ beamline.

Cateretê (**C**oherent **A**nd **T**im**E** **RE**solved scat**TE**ring) at
Experiment goal: alignment purposes Setup: Distance: 12000 mm; Diffraction Pattern
Credits: Aline Passos, Eduardo Miqueles, Florian Meneau, Jean Polli, Carla Polo



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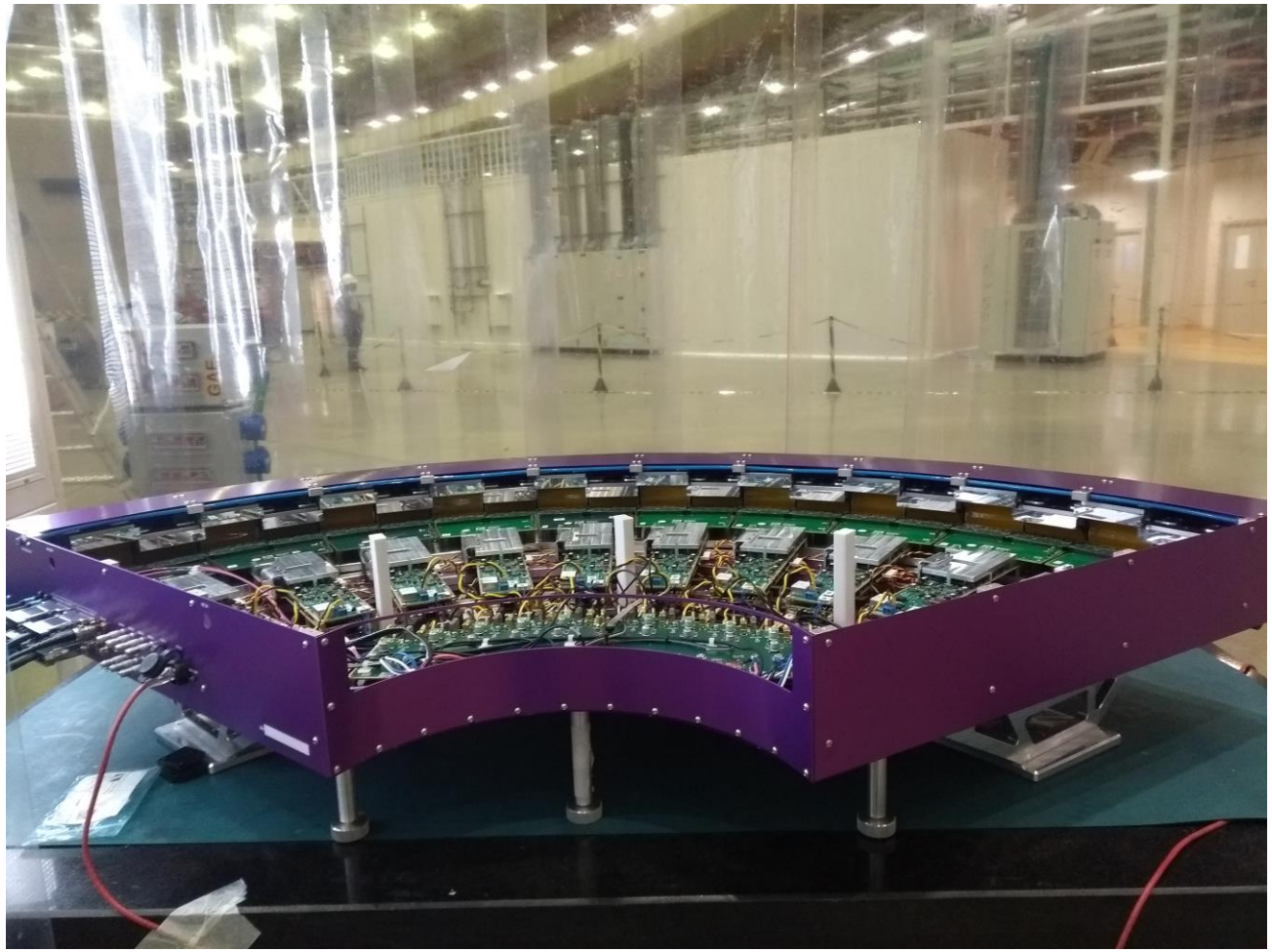
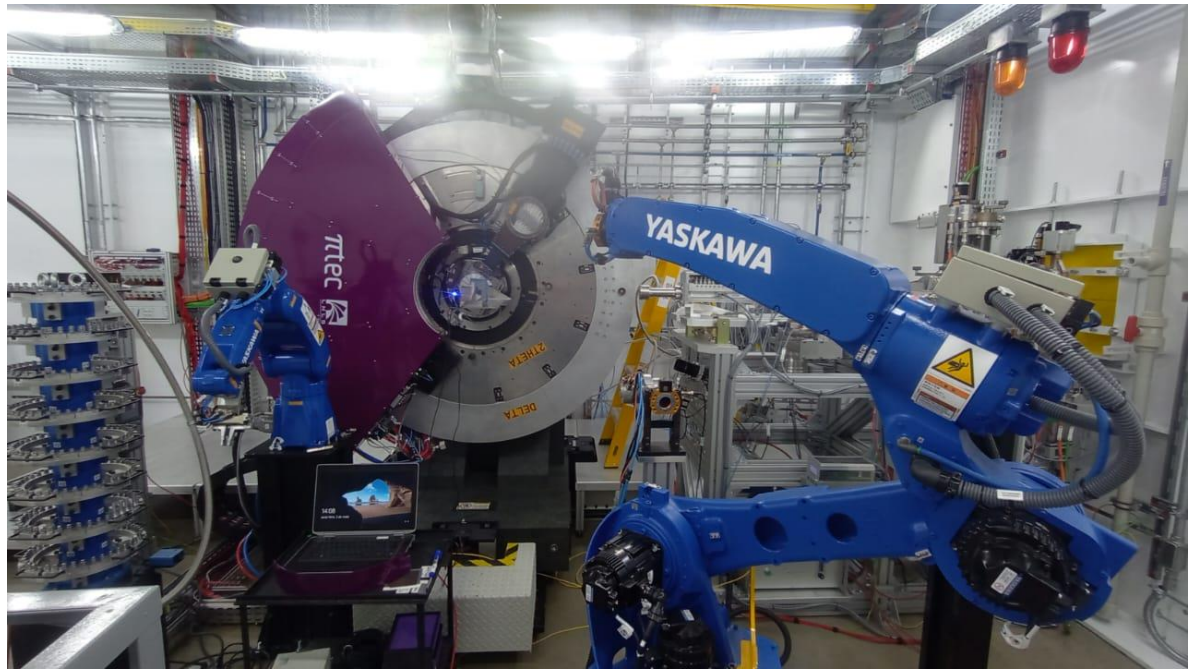
- PIMEGA Project: X-ray Hybrid Detectors

PIMEGA 450D PAINEIRA and EMA beamlines



Assembling PIMEGA 450DD #1 detector for PAINEIRA beamline



PIMEGA 450D#1 mounted in the PAINEIRA Beamline Diffractometer

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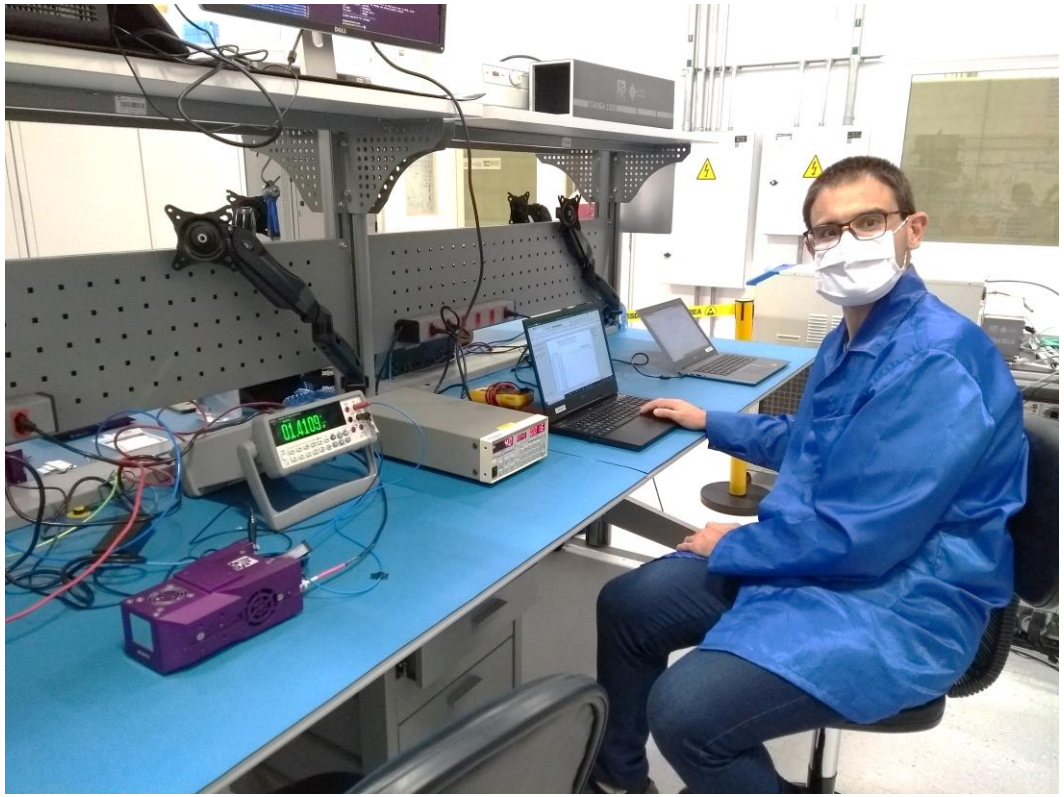
- MOBIPIX Project: A Mobile X-ray Hybrid Detector



Detectors Eletronic LAB: MOBIPIX 15D under test

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On behalf Detectors Group

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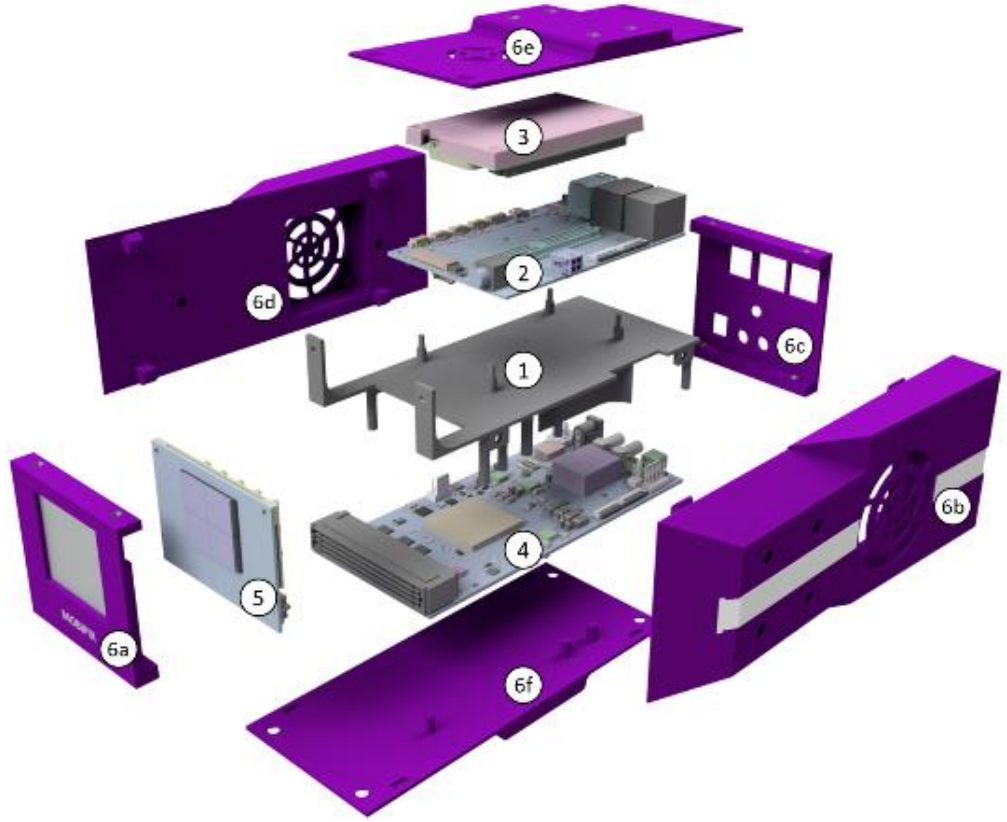
- MOBIPIX Project: A Mobile X-ray Hybrid Detector



1 — Heat spreader
2 — Carrier board
3 — Jetson TX1
4 — Mobipix board
5 — Medipix board
6a — Chassis head
6b — Chassis right
6c — Chassis back
6d — Chassis left
6e — Chassis top
6f — Chassis bottom

MOBIPIX 15D - A Mobile High-Performance X-Ray Detector with Embedded Image Processing; William R. de Araújo *et al.*

The sensors arrangment of 4 image chips

Detector with area of approximately (28 x 28 mm²)
Four X-Ray image ASICs MEDIPIX 3RX in a 2x2 configuration (512 x 512 pixels)
With Si or CdTe sensors
Pixel size 55 x 55 µm2
Pixels Number 262 kpixels

Michael Campbell, **SINGLE X-RAY PHOTON COUNTING SYSTEMS: EXISTING SYSTEMS, SYSTEMS UNDER DEVELOPMENT AND FUTURE TRENDS**. CERN. https://portal.slac.stanford.edu/sites/conf_public/nxd2012/presentations/MCampbellXray.pdf

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- PIMEGA and MOBIPIX Design Summary

Five models of X-ray cameras using Medipix3RX ASICs [1]. 17 units operational

Partnership: www.pitec.co

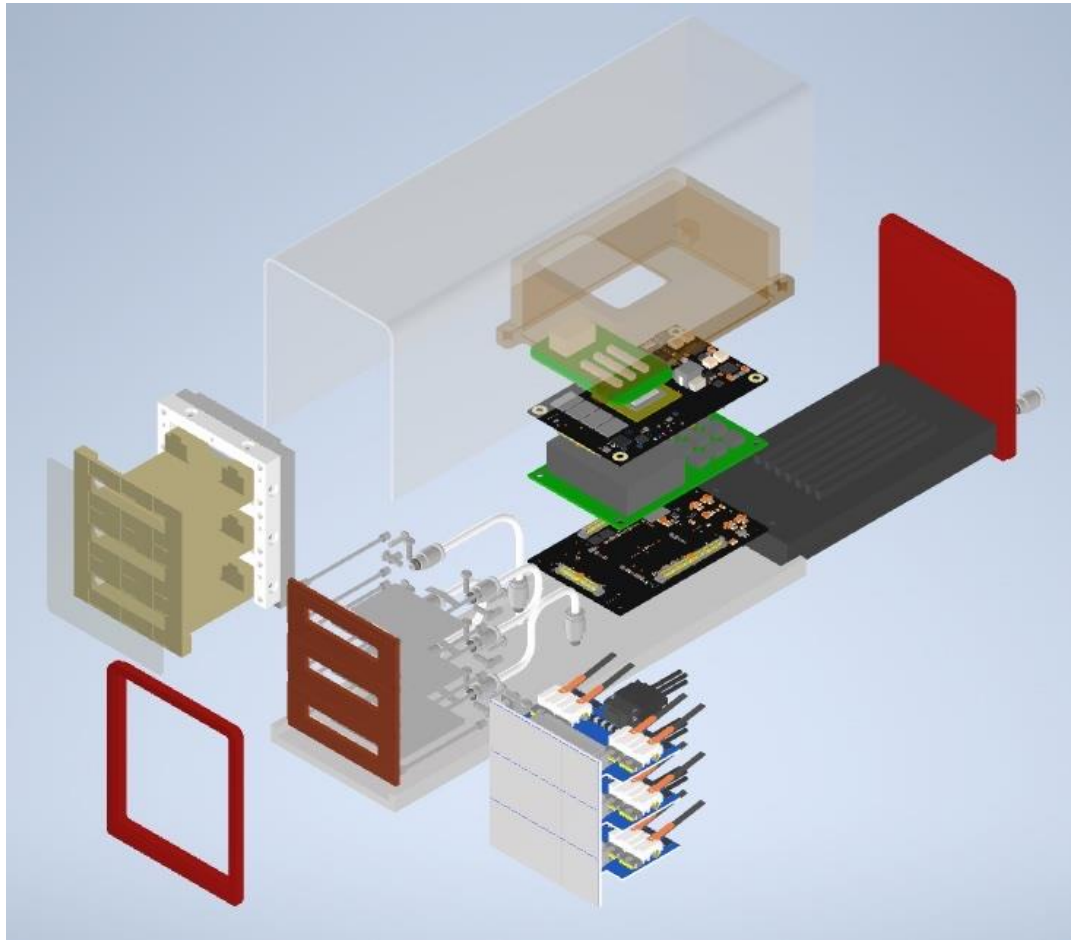
	MOBIPIX 15D	PIMEGA 45D	PIMEGA 135D	PIMEGA 450D	PIMEGA 540D
Sensors (µm type)	300 Si / 1000 CdTe	300 Si	300 Si / 675 Si / 1000 CdTe	300 Si / 675 Si	300 Si / 675 Si
Pixels (number / arrangement)	262,144 / 512 x 512	786,432 / 512 x 1536	2,359,296 / 1536 x 1536	7,864,320 / 512x15360	9,437,284 / 3072 x 3072
Pixel size (µm²)	55 x 55	55 x 55	55 x 55	55 x 55	55 x 55
Detection area (mm²)	≈28 x 28	≈28 x 85	≈ 85 x 85	≈14.2 x 1710	≈170 x 170
Active area (%)	≈99.7	≈99.6	≈100 (minimal gaps)	≈100	≈99 (minimal gaps)
Incident Flux (counts/px/s)	3 x 10^5	3 x 10^5	3 x 10^5	3 x 10^5	3 x 10^5
Max Dynamics range	24 bits	24 bits	24 bits	24 bits	24 bits
Frame rate @ 12 bits (fps)	2000	600	2000	1000	2000
Throughput @ 12bits (Gb/s)	6.3	5.7	56.6	87.9	226.5
Vacuum (10^{-3} mbar)	No	No	Yes	No	Yes

[1] Medipix3 Collaboration https://medipix.web.cern.ch/medipix3

Ongoing Development at LNLS / Sirius

- **TUPI** Project: **T**imepix-based **U**ltra-fast **P**hoton **I**maging

Hardware Block Diagram



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LNLS - Brazilian Synchrotron Light Laboratory

On behalf Detectors, SWC, GIE and MEP groups

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- **TUPI** Project: **T**imepix-based **U**ltra-fast **P**hoton **I**maging

Target

To prototype a Hybrid Pixel Detector Using Timepix4 ASICs, for X-Ray Imaging at Orion (level 4 biosafety lab).

medipix collaboration

			Timepix4 (2019)
Technology			65nm – 10 metal
Pixel Size			55 x 55 µm
Pixel arrangement			4-side buttable 512 x 448
Sensitive area			6.94 cm^2
Readout Modes	Data driven (Tracking)	Mode	TOT and TOA
		Event Packet	64-bit
		Max rate	**$3.58x10^6$ hits/mm^2/s**
		Max Pix rate	**10.8 KHz/pixel**
	Frame based (Imaging)	Mode	CRW: PC (8 or 16-bit)
		Frame	Full Frame (without pixel addr)
		Max count rate	~5 x 10^9 hits/mm^2/s
TOT energy resolution			**< 1Kev**
TOA binning resolution			**195ps**
TOA dynamic range			**1.6384 ms** (16-bits @ 40MHz)
Readout bandwidth			**≤163.84 Gbps** (16x @10.24 Gbps)
Target global minimum threshold			<500 e^-

Produced by TSMC (Taiwan Semiconductor Manufacturing Company)

Energy expected ranges between approximately 10 and 45 keV.

Vacuum compatible of ~ 10^{-3} mBar.

44 kHz @ 16bits

[Medipix4 Collaboration https://medipix.web.cern.ch/medipix4](https://medipix.web.cern.ch/medipix4)

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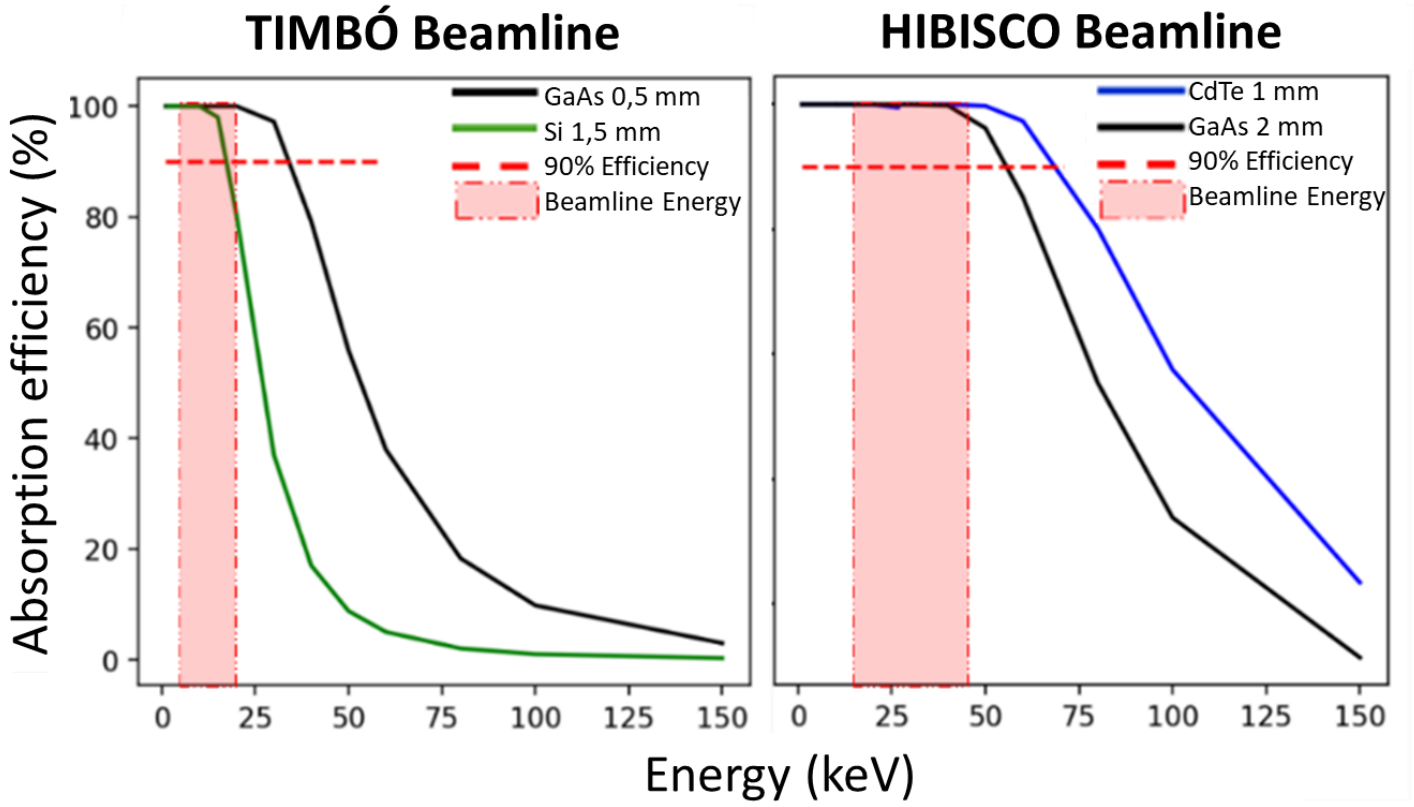
- **TUPI** Project: **T**imepix-based **U**ltra-fast **P**hoton **I**maging

Possible Sensors Materials that can be used



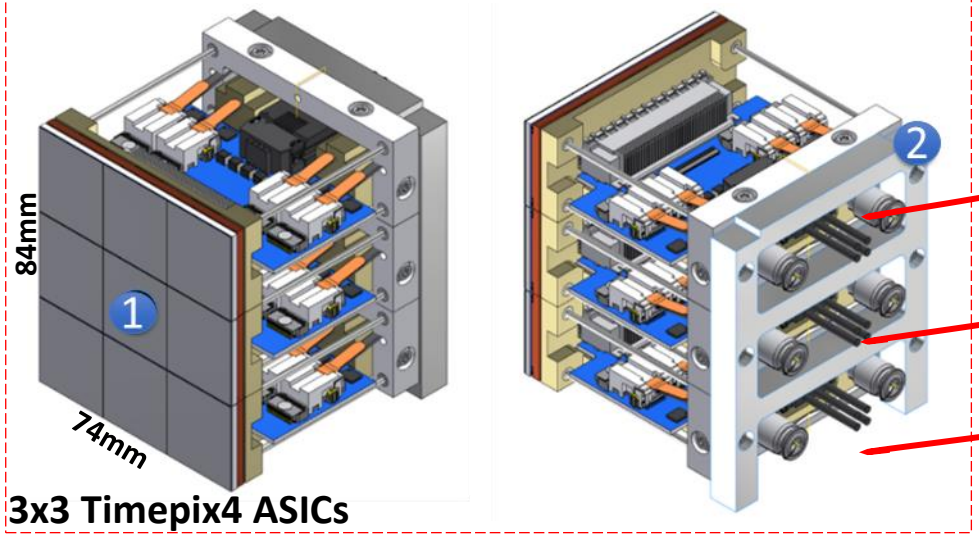
Absorption efficiency curves as a function of incident photon energy. The materials and thicknesses have been conceptualized for two beamlines at the Orion laboratory.

Ongoing Development at LNLS / Sirius

- **TUPI** Project: **T**imepix-based **U**ltra-fast **P**hoton **I**maging

Hardware Block Diagram Concepts

Figura 1 – Detector Head Concept for TUPI prototype



Optical Fiber Links

48 channels

48 channels

48 channels

Figura 2 – Beamline Local Server

Commercial PCIe FPGA boards (Bitware XUPP3R or AV-870P or CERN FELIX boards)

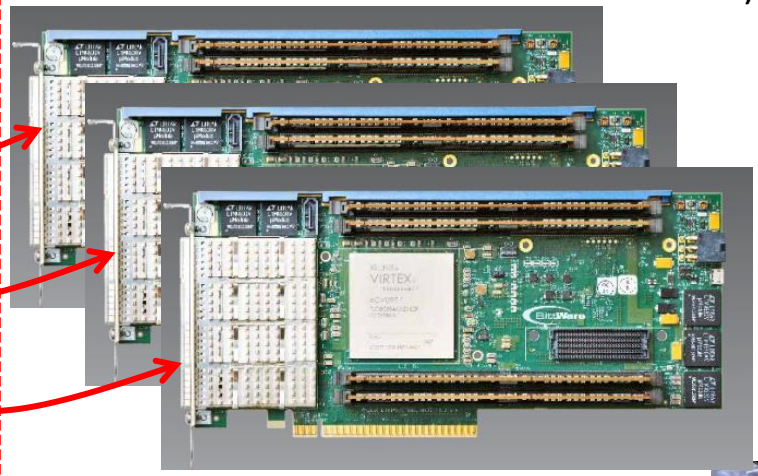


Figura 3 - Datacenter

The proposed TUPI detector concepts emphasize modularity, utilizing a minimum hybrid configuration of three 3x1 Timepix4 ASICs. This design allows for the assembly multiple unit arrays, enabling to reach large active detection areas.

The system is composed of two main parts:

1. **The detection head** (1, 2 in Figure 1) can be arranged in various geometries using 'n' 3x1 hybrid modules. This configuration requires minimal hardware for the control and transmission of generated images through optical channels (Firefly standard), along with cooling managed by electronic control of Peltier devices.
2. **The backend stage** utilizes commercial FPGA boards, which can be hosted on a local or remote server for the collection, organization, and transmission of image data to a datacenter for processing.

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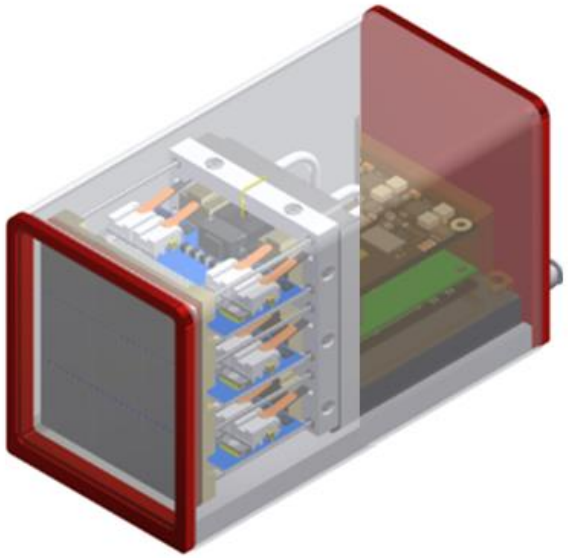

Pixel array of 1536x1344 pixels of 55 x55 μm^2

More than 2 megapixels

Active area of 84 x 74 mm^2

Achieving acquisition rates up to 11 kHz in continuous reading mode

Photon counting mode with a 16-bit dynamic range

Can handle photon count rate up to 5 x 10^9 photons/mm^2/s

TUPI Project Timeline:

Conceptual Design Review: 2024/10 **Finished**;
Preliminary Design Review: 2025/06 **Modeling Simulations end Proofs of concepts under going**...
Final Design Review: 2025/12;
First Prototype: 2026/08.

Long-term Expectations for Detectors

The ideal detector

Should have:

- 10^9 pixels — Well, nowadays it is possible but conflicts with last desire.
- 1um spatial resolution — Microelectronics needs to be smaller. (dozens o microns is enought)
- 1eV energy resolution — New sensors materials and microelectronics improvements.
- 1 fs time resolution — Dead time response needs improvements in sensors and analog circuits (Timepix4 = 100ps)
- count rates up to 10^9 / pixel — Dynamic range needs improvements in sensors and analog circuits (Timepix4 can go up to 10^7)
- Efficient from 100eV out to 100keV — New sensors materials to cover larger energy ranges.
- ~~And it should be free!~~ — Impossible!

Shamelessly stolen from Peter Siddons

Cornell University
Physics Department & CHESS

Detector Capabilities XDL-2011

Source: X-ray Detectors: State-of-the-art & Future Possibilities. Sol M. Gruner. Physics Dept. & Cornell High Energy Synchrotron Source (CHESS)

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Thank you

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Disclaimer Note

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Companies

http://www.lauquen.com.br/en/home

https://www.matool.com.br/

https://www.cadservice.com.br/?lang=en

https://www.japan-fc.co.jp/en/

https://advafab.com/

https://www.xilinx.com/products/boards-and-kits.html

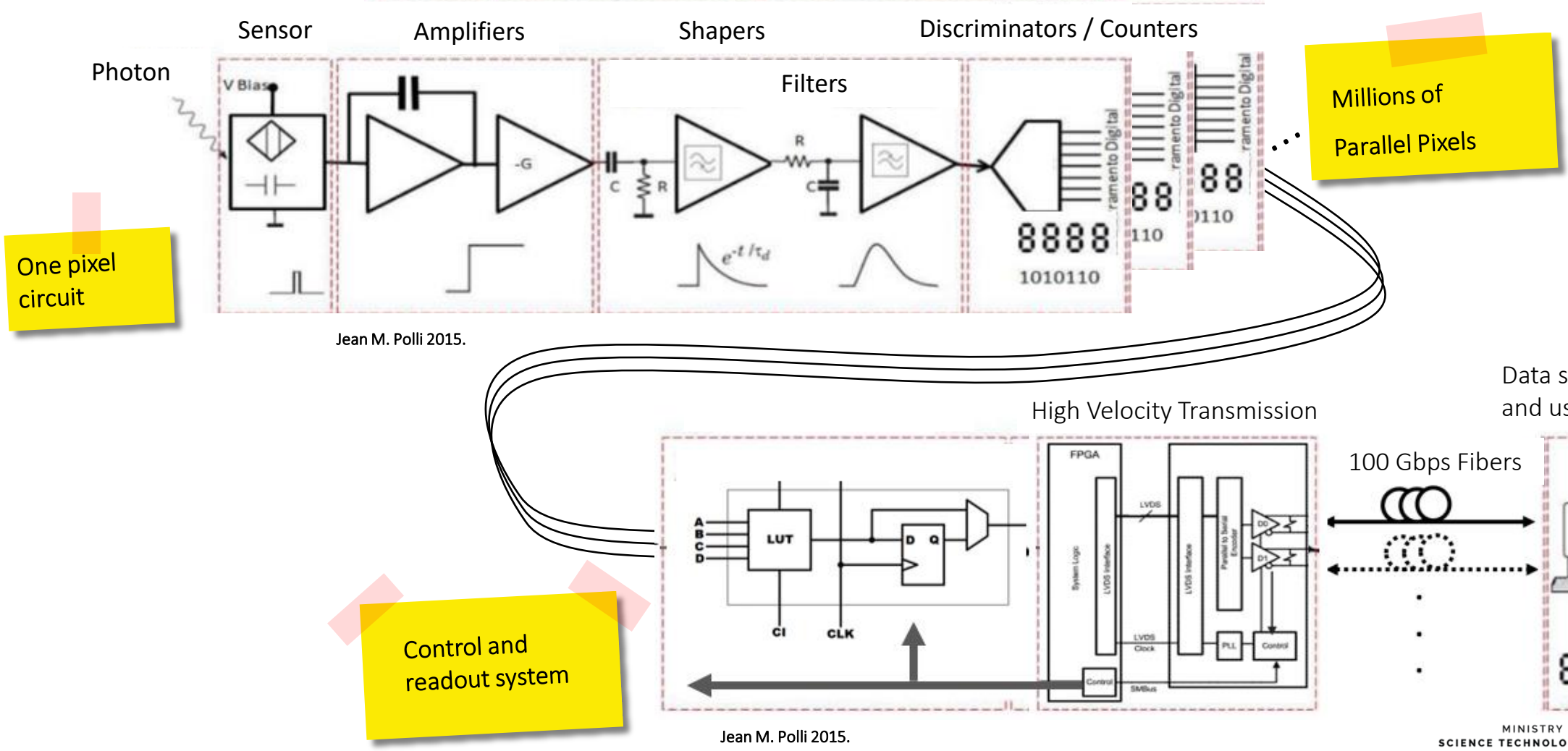
https://www.supermicro.com/en/

https://www.nvidia.com/en-us/

X-Ray Detectors Development at LNLS / Sirius

- PIMEGA Project: X-ray Hybrid Detectors

Hardware Block Diagram



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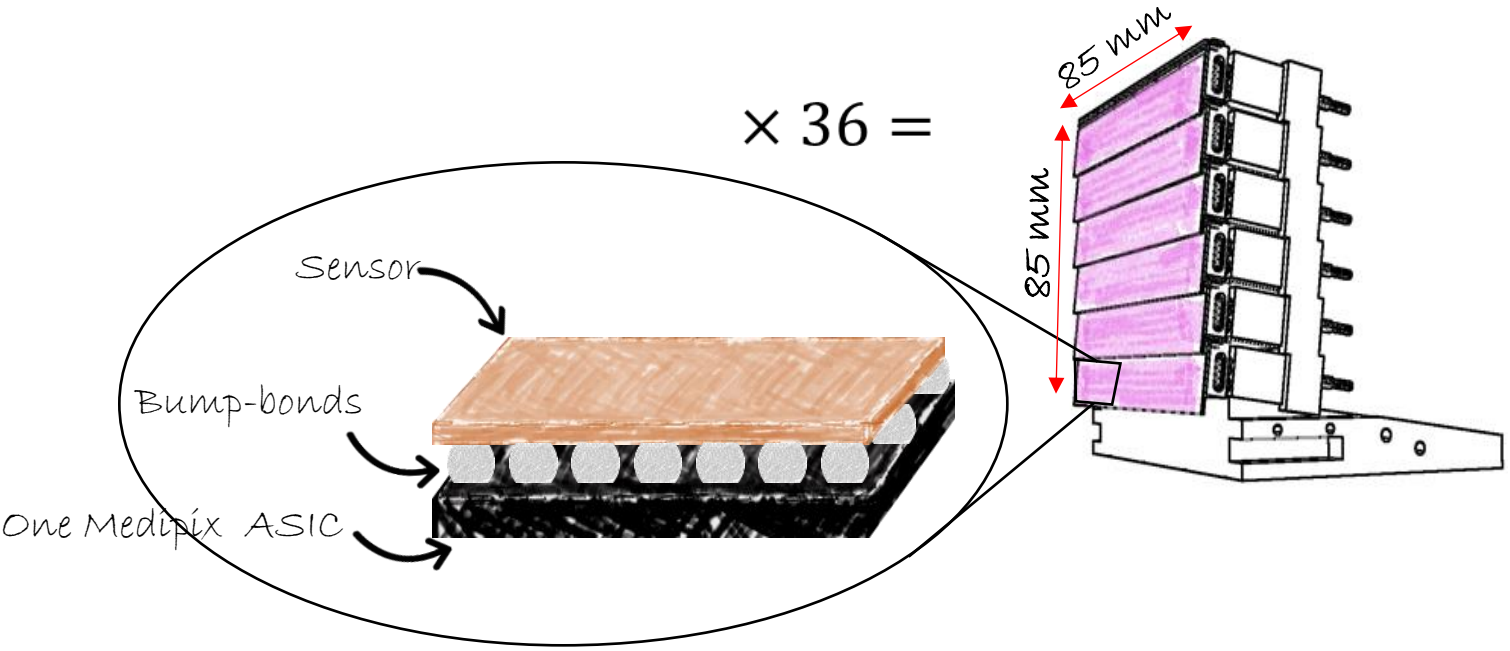
- PIMEGA Project: X-ray Hybrid Detectors

Creating large area detectors with Medipix



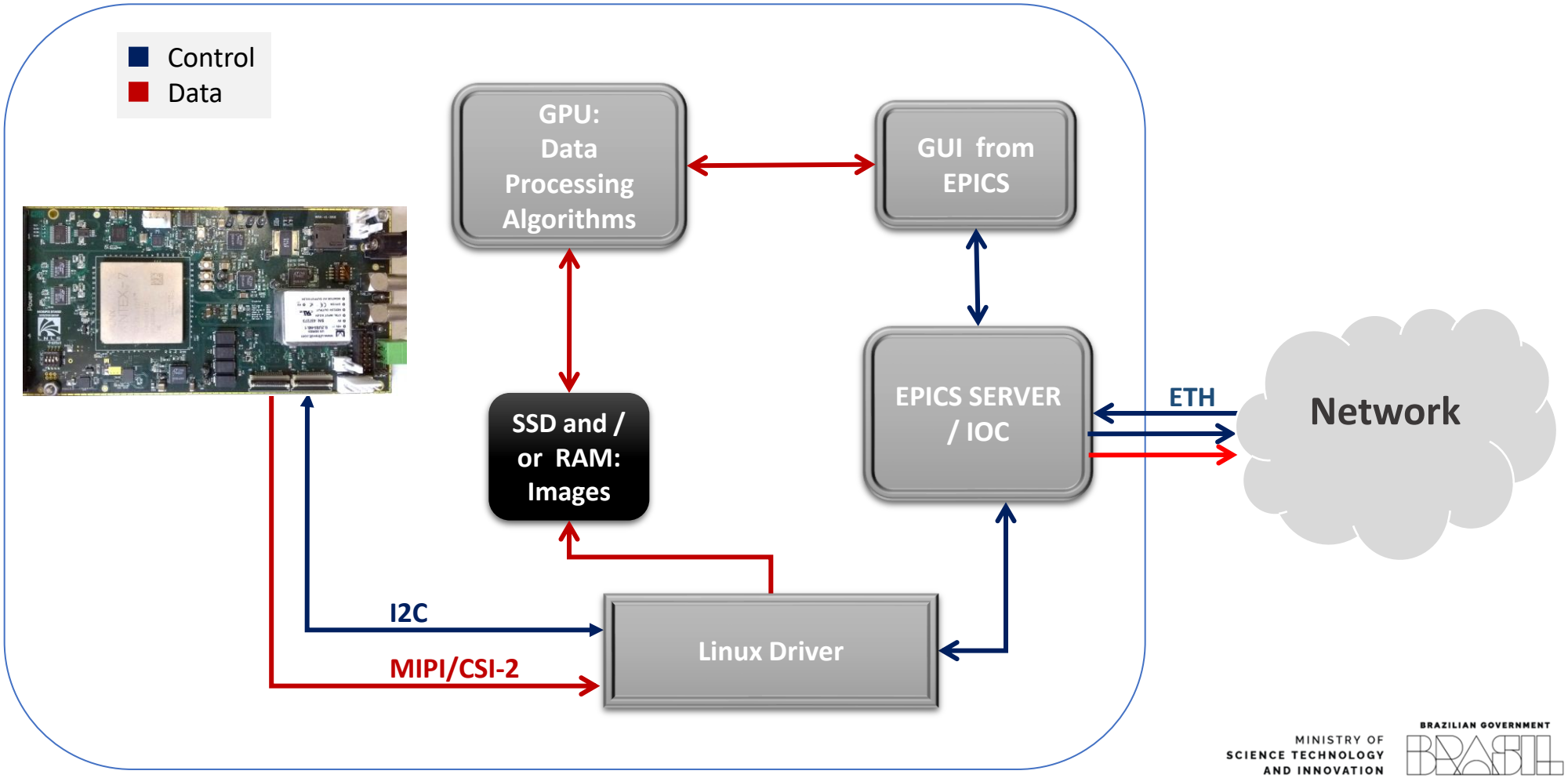
135D Module

- 2.359.296 pixels 55 um²
- Up to 2000 frames/s.
- May be assembled side by side to reach larger areas

X-Ray Detectors Development at LNLS / Sirius

- MOBIPIX Project: A Mobile X-ray Hybrid Detector

Software Diagram

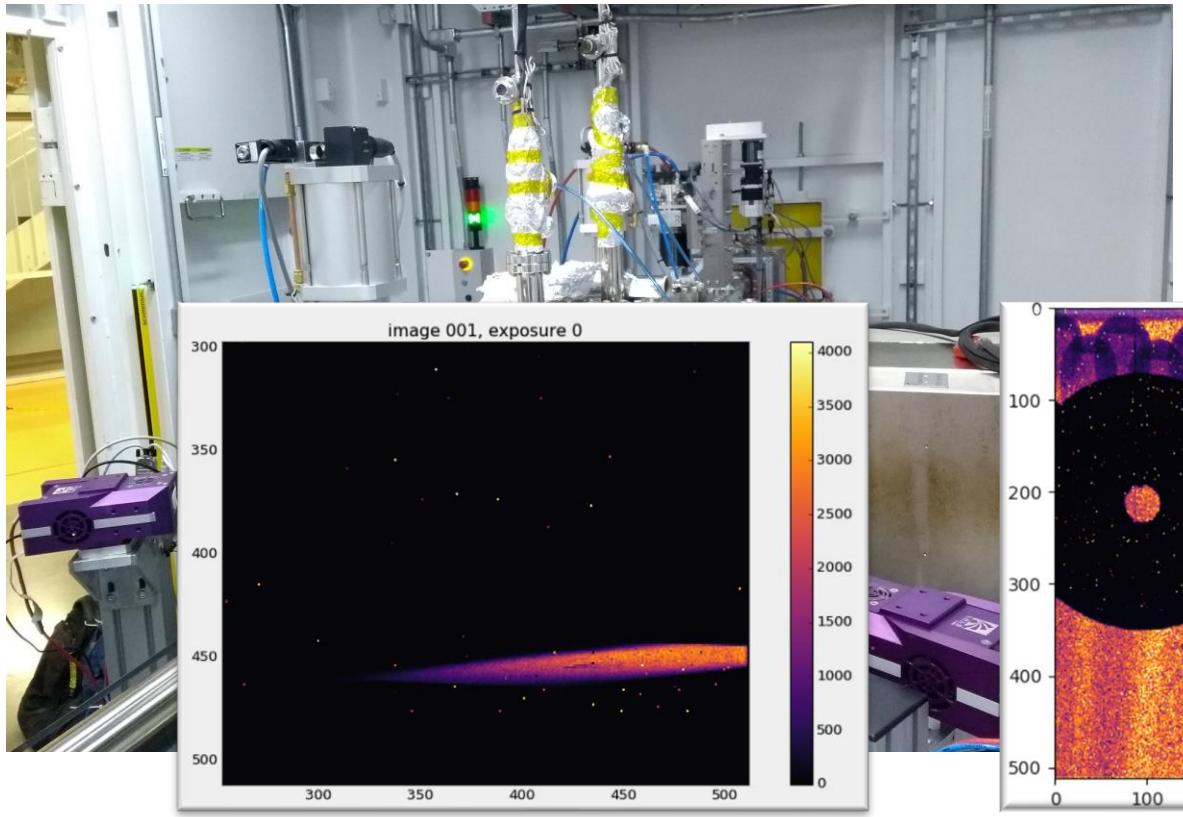


X-Ray Detectors Development at LNLS / Sirius

- MOBIPIX Project: A Mobile X-ray Hybrid Detector

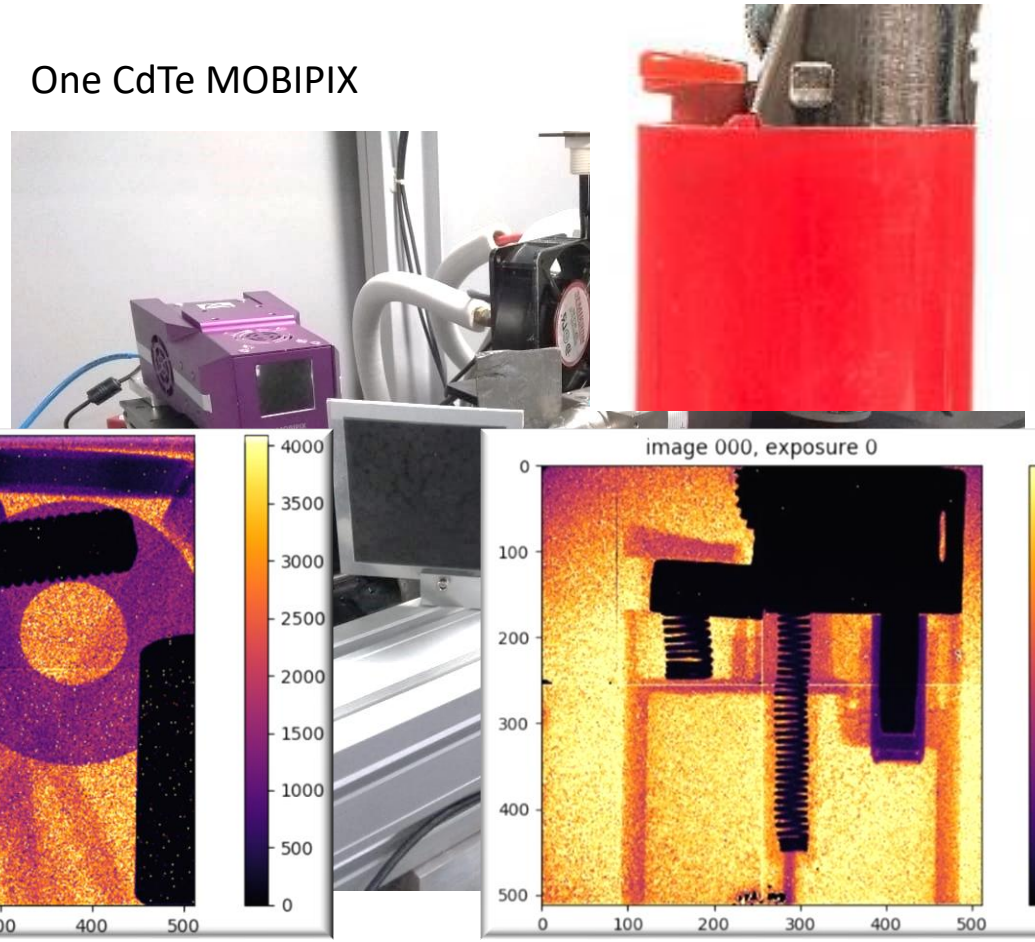
MOBIPIX 15D detector

Seven silicon MOBIPIX



Example of raw image diffracted by a silicon crystal to check the beam coherence in the CARNAÚBA beamline.

One CdTe MOBIPIX



Cdte Raw image of a matchbox with screws and washers under polychromatic x-rays.

Cdte Raw image of a lighter under polychromatic x-rays.

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