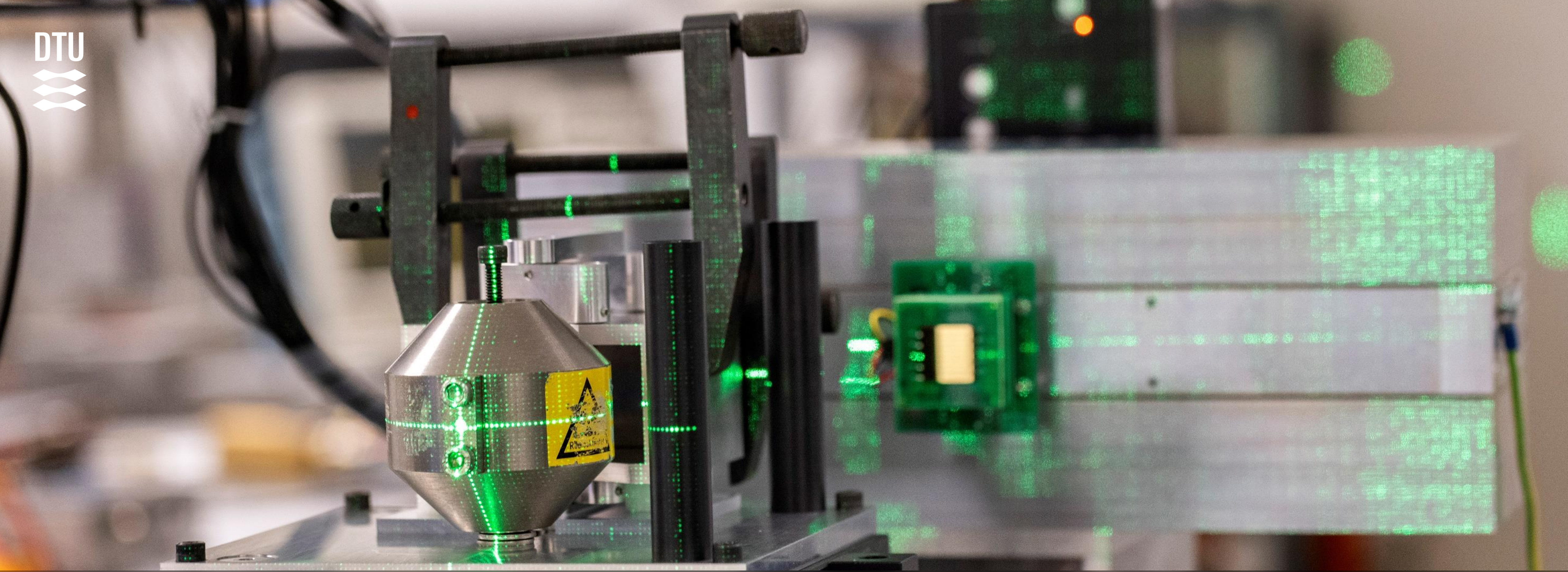
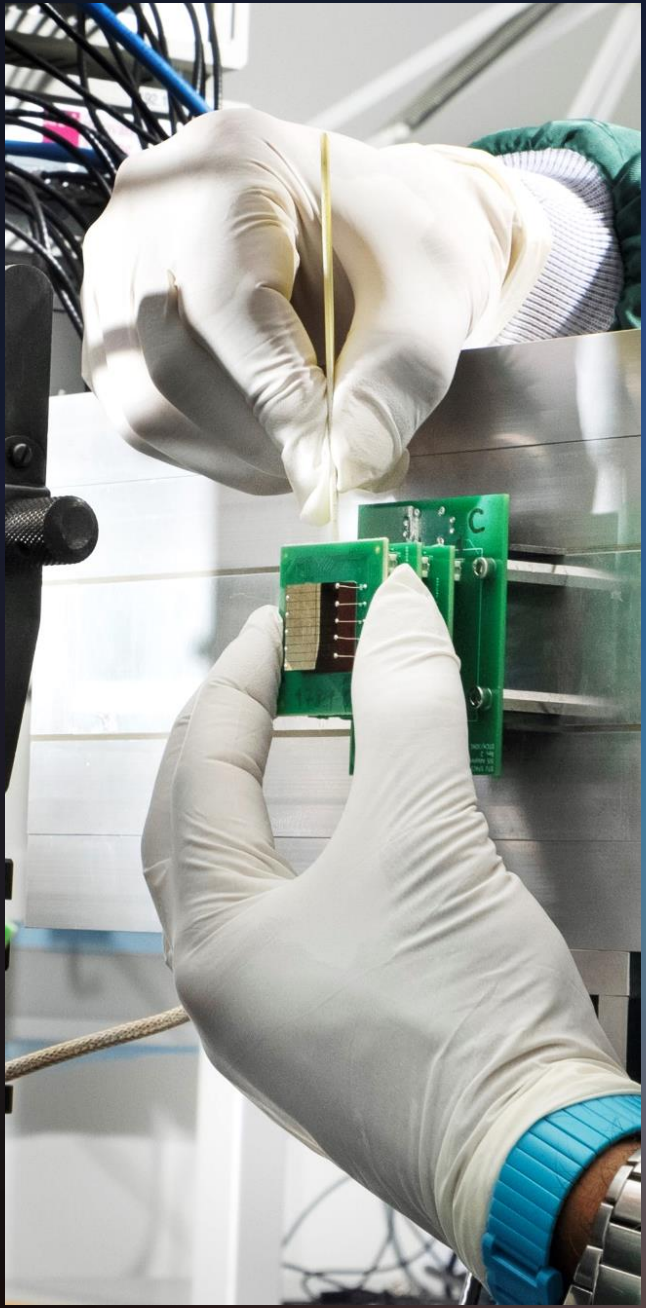


Next-generation radiation detector technologies:
i-RASE Intelligent Radiation Sensor Readout Systems

Selina R. H. Owe

DIBS - Danish Instruments for Big Science and Quantum Technologies 2024

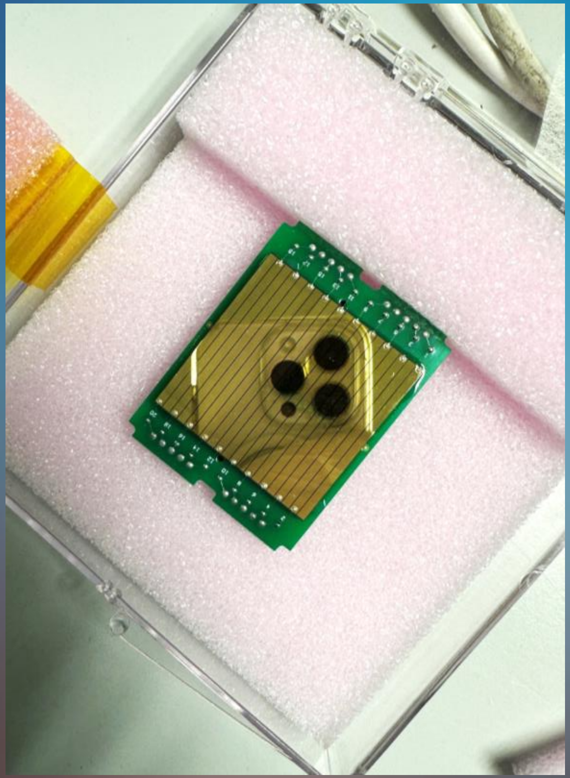


DTU Space Detector Laboratory

Detector technology development

Detector material research

Advanced detector modelling



DTU Space Detector Laboratory

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ADMINISTRATIVE OFFICER
MALILU@DTU.DK

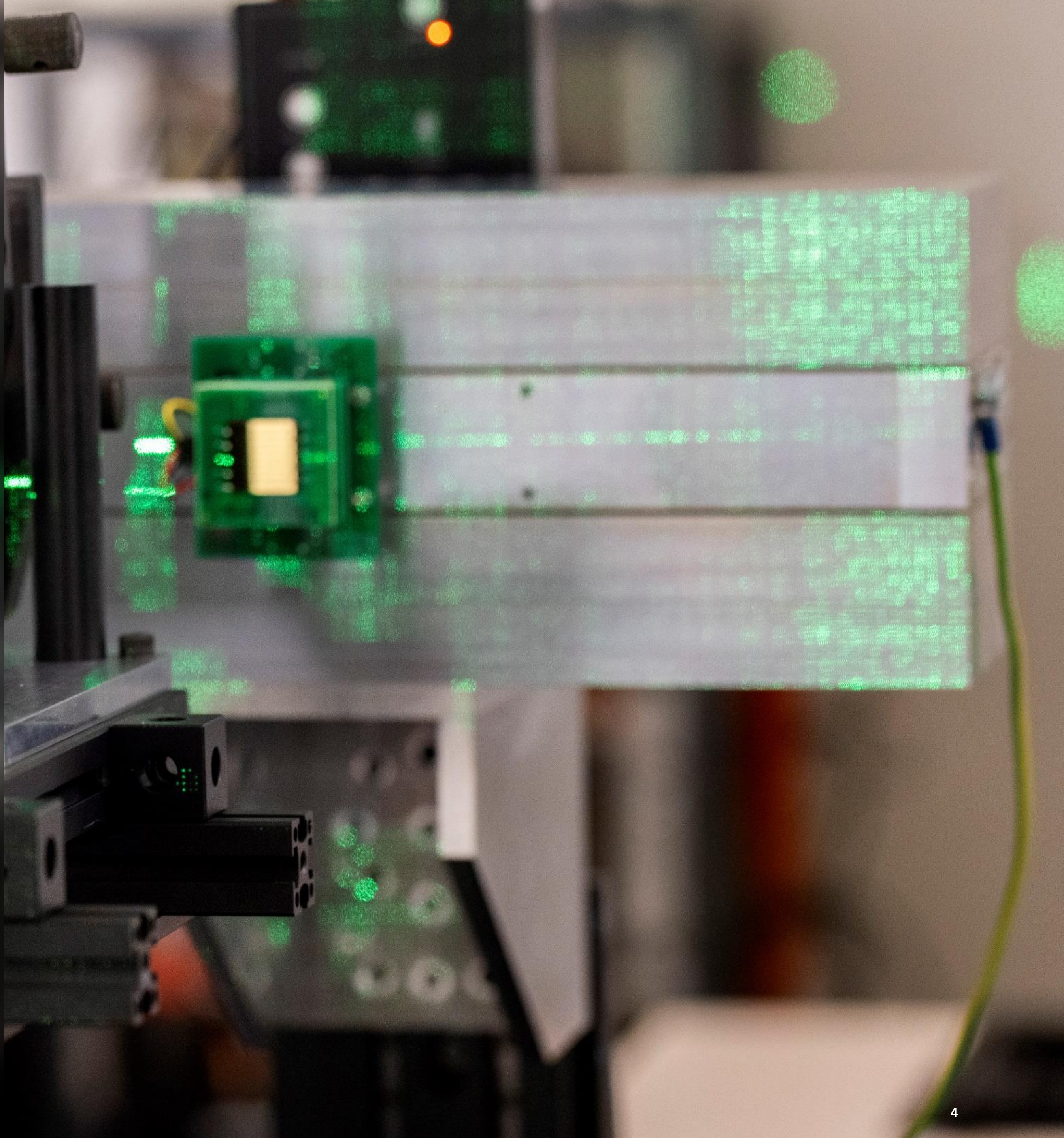
And we will hire +2 PhD +2 postdoc

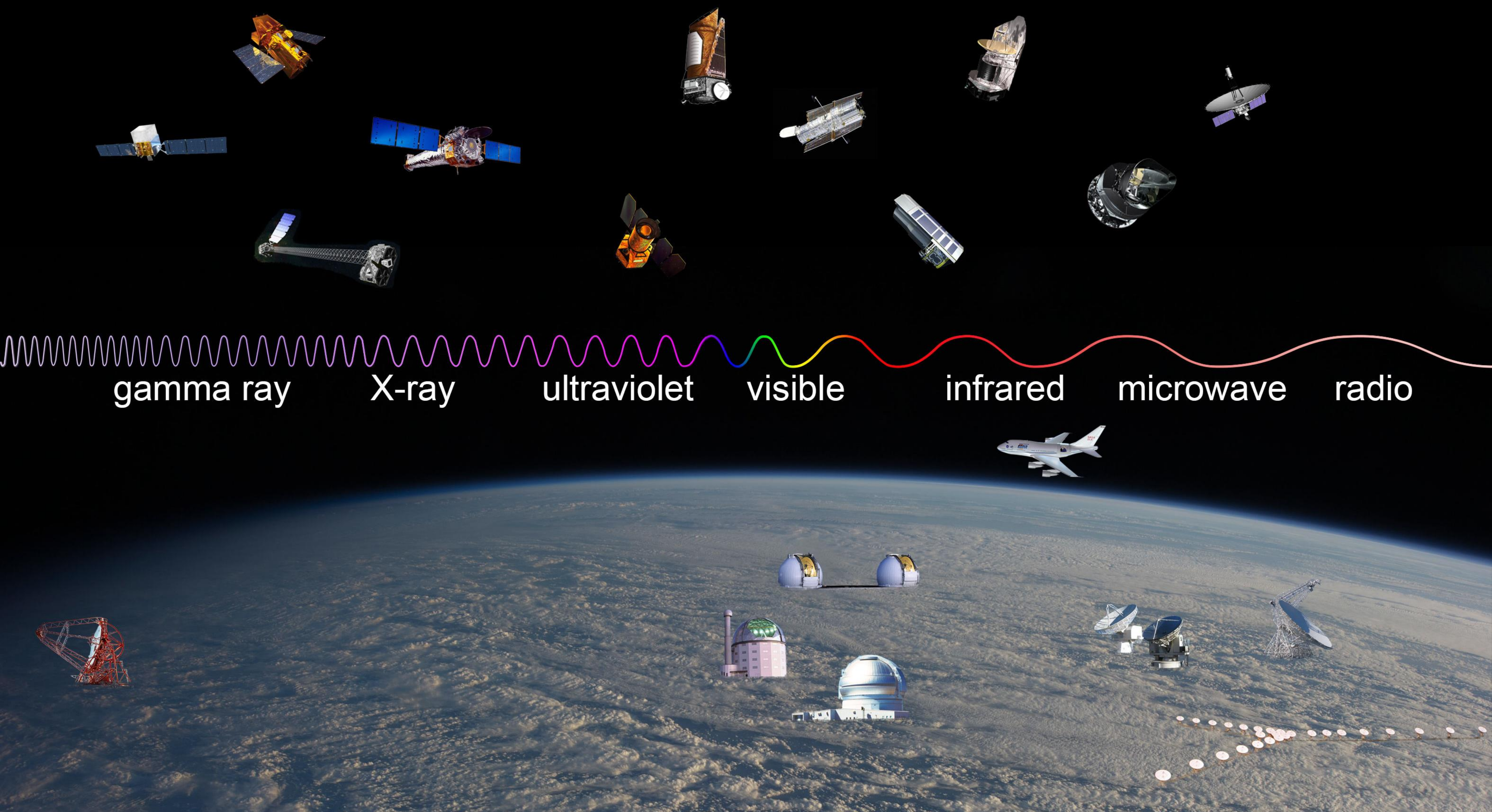
Ongoing MSc student projects

Introduction and motivation

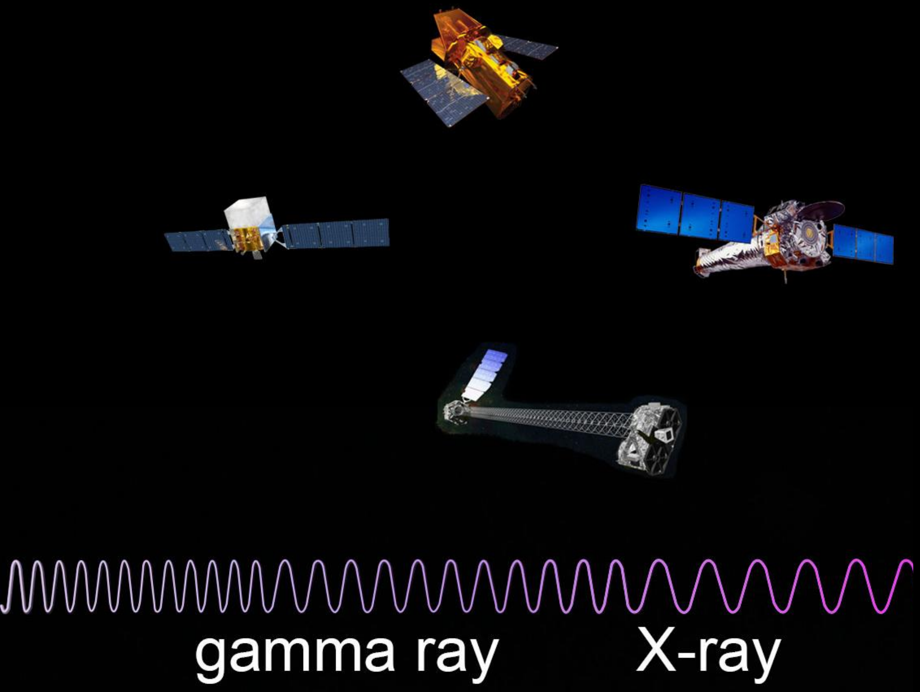
The 3D CZT drift strip detector

i-RASE





Credit: Observatory images from NASA, ESA (Herschel and Planck), Lavochkin Association (Specktr-R), HESS Collaboration (HESS), Salt Foundation (SALT), Rick Peterson/WMKO (Keck), Germini Observatory/AURA (Gemini), CARMA team (CARMA), and NRAO/AUI (Greenbank and VLA); background image from NASA)



TeV- GeV

High energy gamma

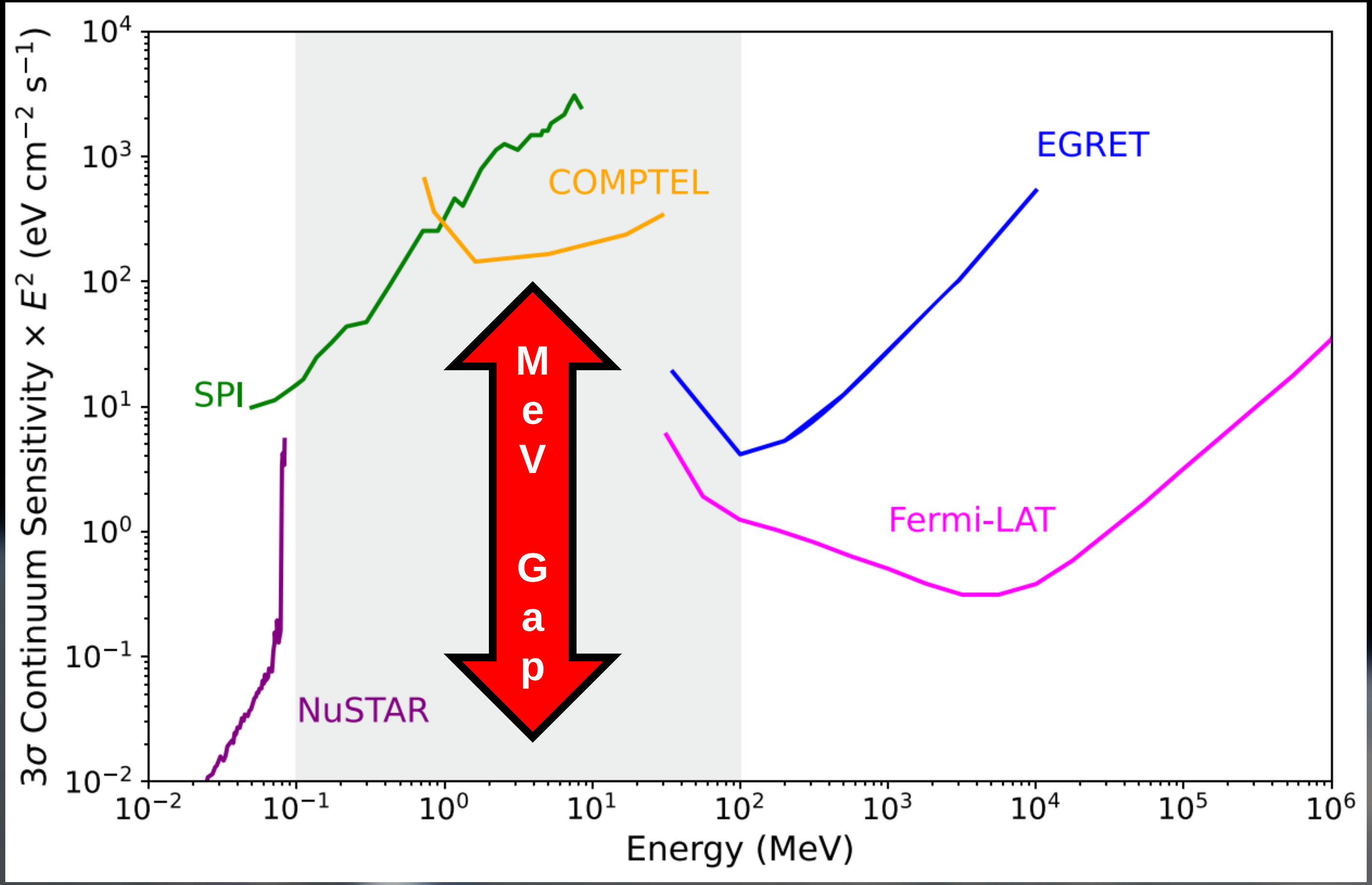
MeV

Low-medium energy gamma

keV

High energy x-ray

Image: Michela Negro et al. 2022

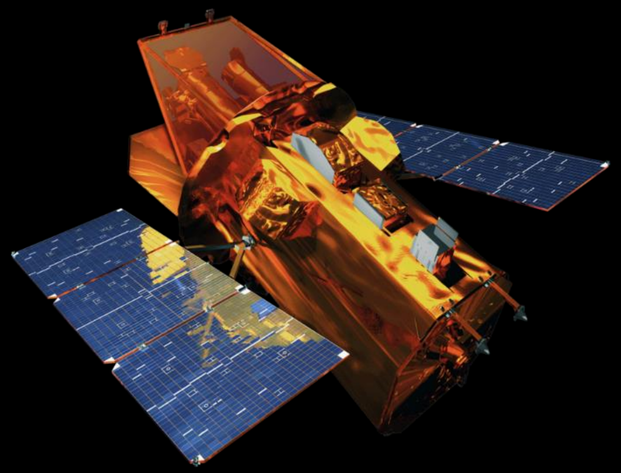


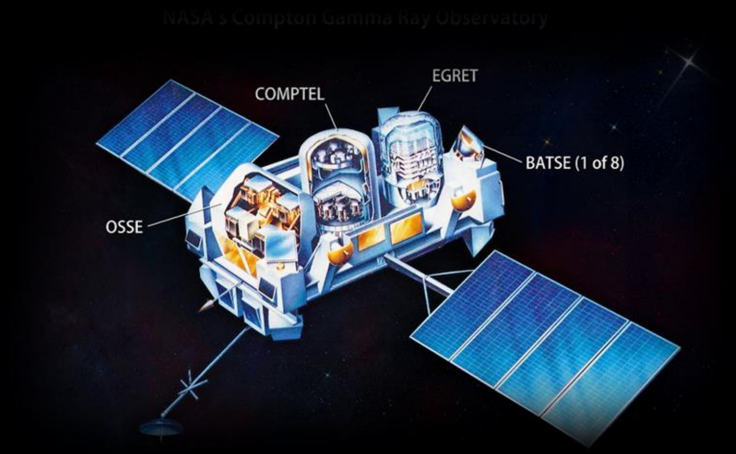
High energy x-ray

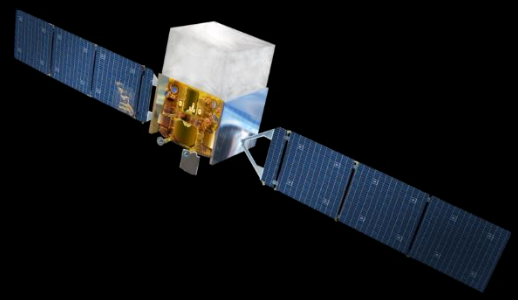
Low-medium energy gamma

High energy gamma

Sources in the X- and gamma-ray domain







Burst Alert Telescope (BAT) on Swift (2004-present)

Energy range: 15-150 keV

1632 detected sources.

COMPTEL on CGRO (1991-2000)

Energy range: 0.75 – 30 MeV

A few tens of steady sources.

Large Area Telescope on Fermi (2008 – present)

Energy range: 20 MeV - 300 GeV

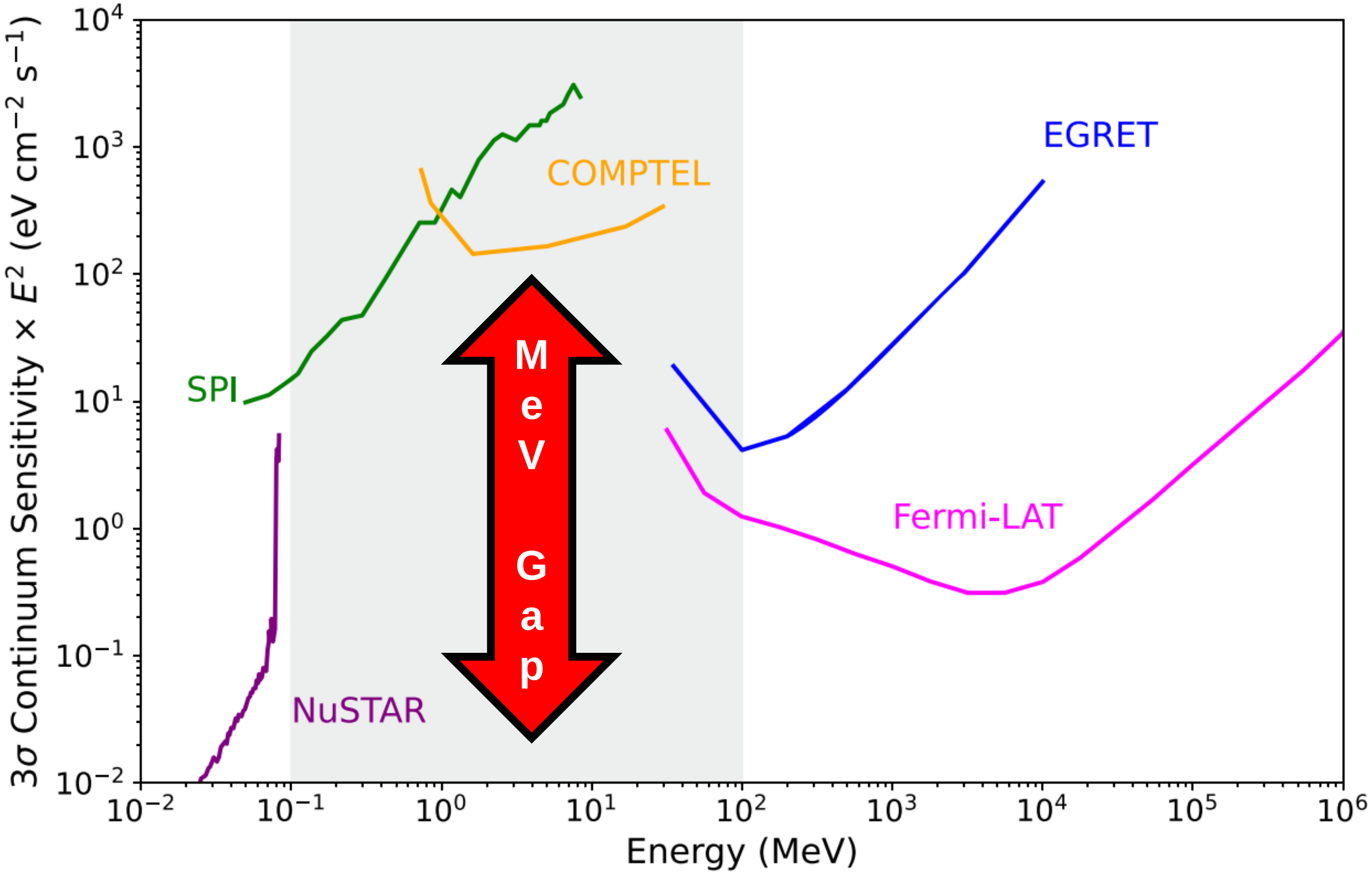
Over 5000 detected sources (blazars, pulsars, supernova remnants, high-mass binaries, gamma-ray bursts (GRBs) etc.).

The MeV gap

Difficulties of observing this domain is due to

- Three energy-loss processes
- Low interaction cross-sections
- Inherent difficulty of imaging
- High instrumental and atmospheric background

Image: Michela Negro et al. 2022



To improve sensitivity, new state-of-the-art detector technology is required

A successor to the COMPTEL instrument on the Compton Gamma Ray Observatory, CGRO

The Gamma Cube, Lebrun et al. 2014

GRIPS - Gamma Ray Imaging Polarimetry and Spectroscopy, Greiner et al. 2012

e-ASTROGRAM, Tatischeff et al. 2016

DUAL, von Ballmos et al. 2012

ASTROMEV, de Angelis et al. 2021

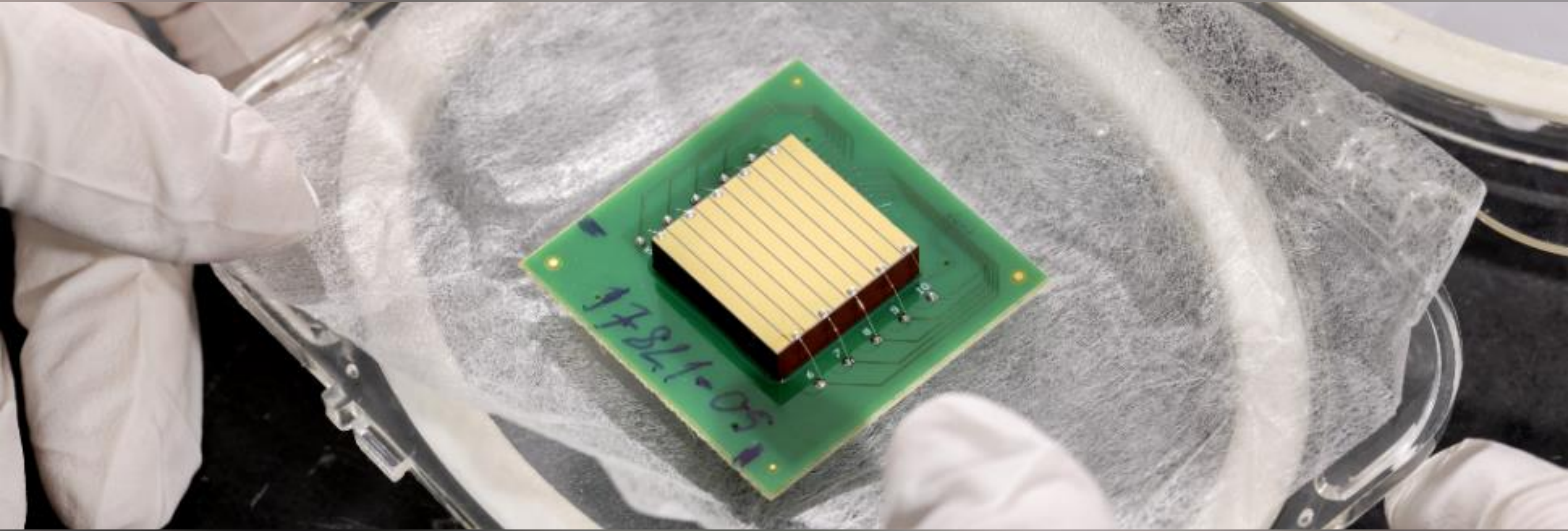
AMEGO, Kierans et al. 2020

MEGA, Andritschke et al. 2006

Focus on maturing the 3D CZT Drift Strip Detector Technology from a prototype towards a space ready module.

Image: ESO/S. Brunier

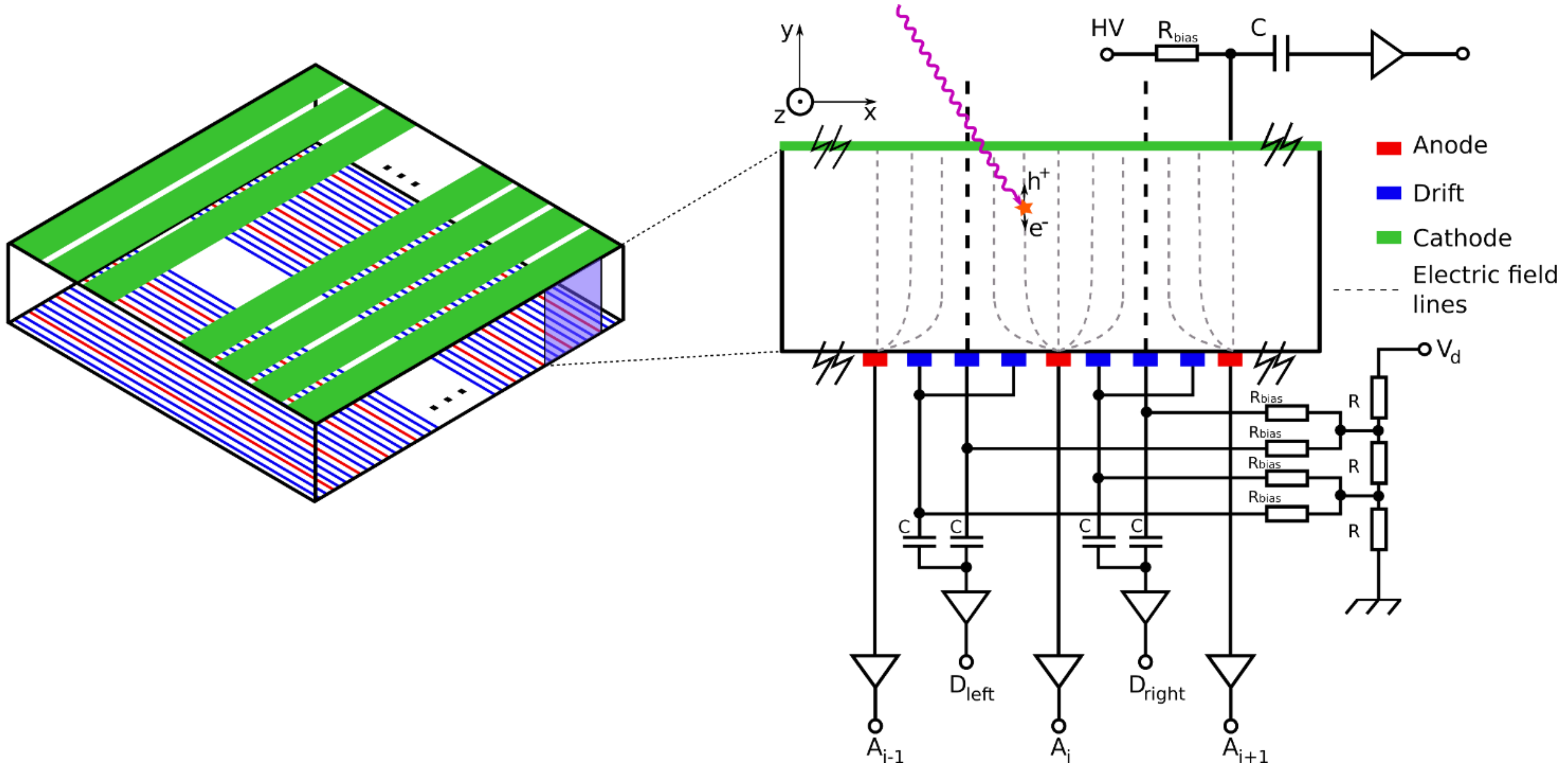
The 3D CZT Drift Strip Detector



Semiconductor detector (CdZnTe)	Electron only device	Room temperature operation	Energy resolution ~1% @661.6 keV	3D position capability (0.4 mm in 3D @661.6 keV)

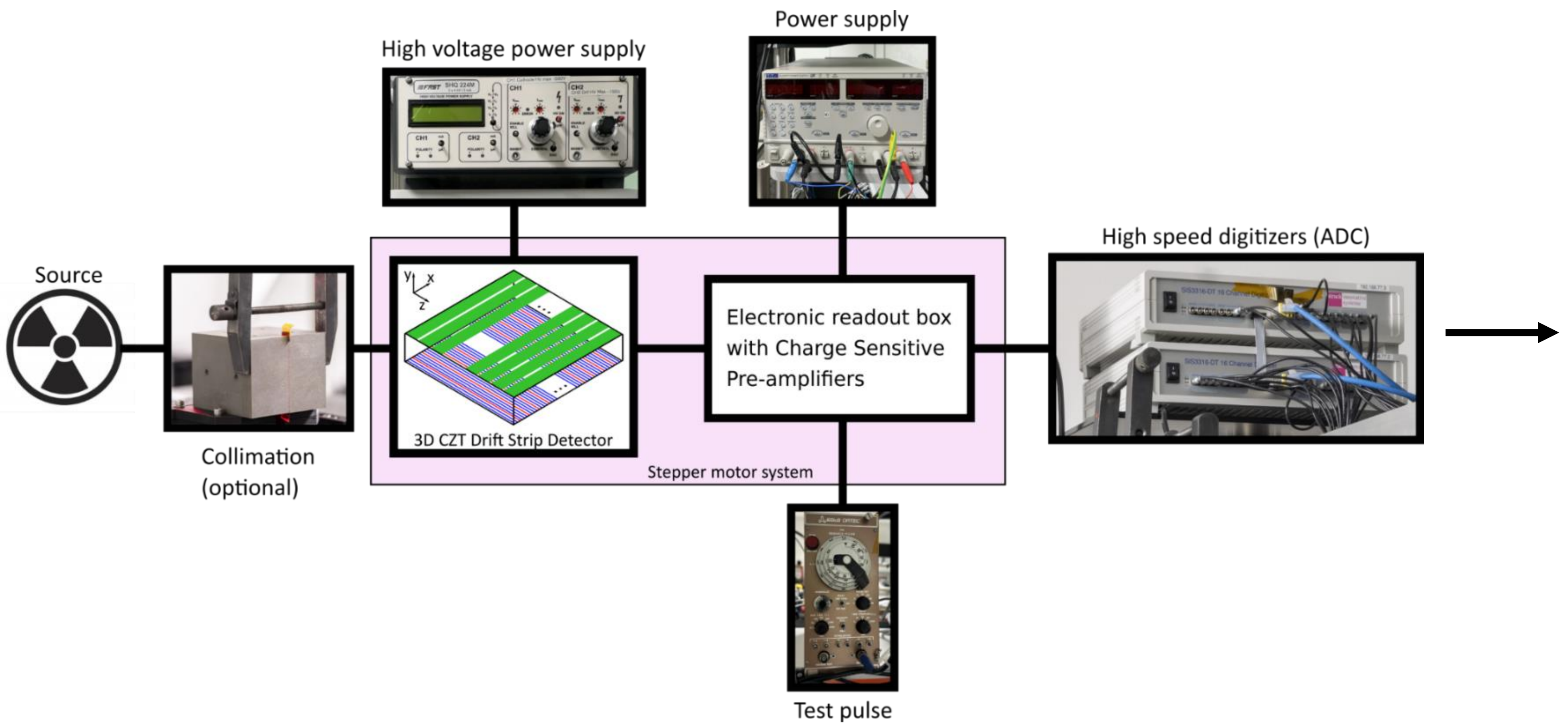
Current state-of-the-art:
The 3D CZT drift strip detector

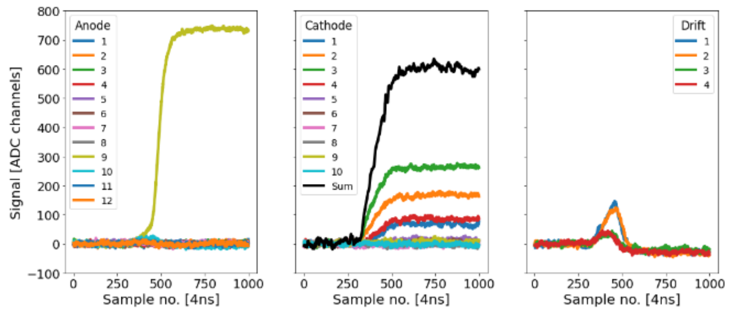
Electrode configuration



Current state-of-the-art:
The 3D CZT drift strip detector

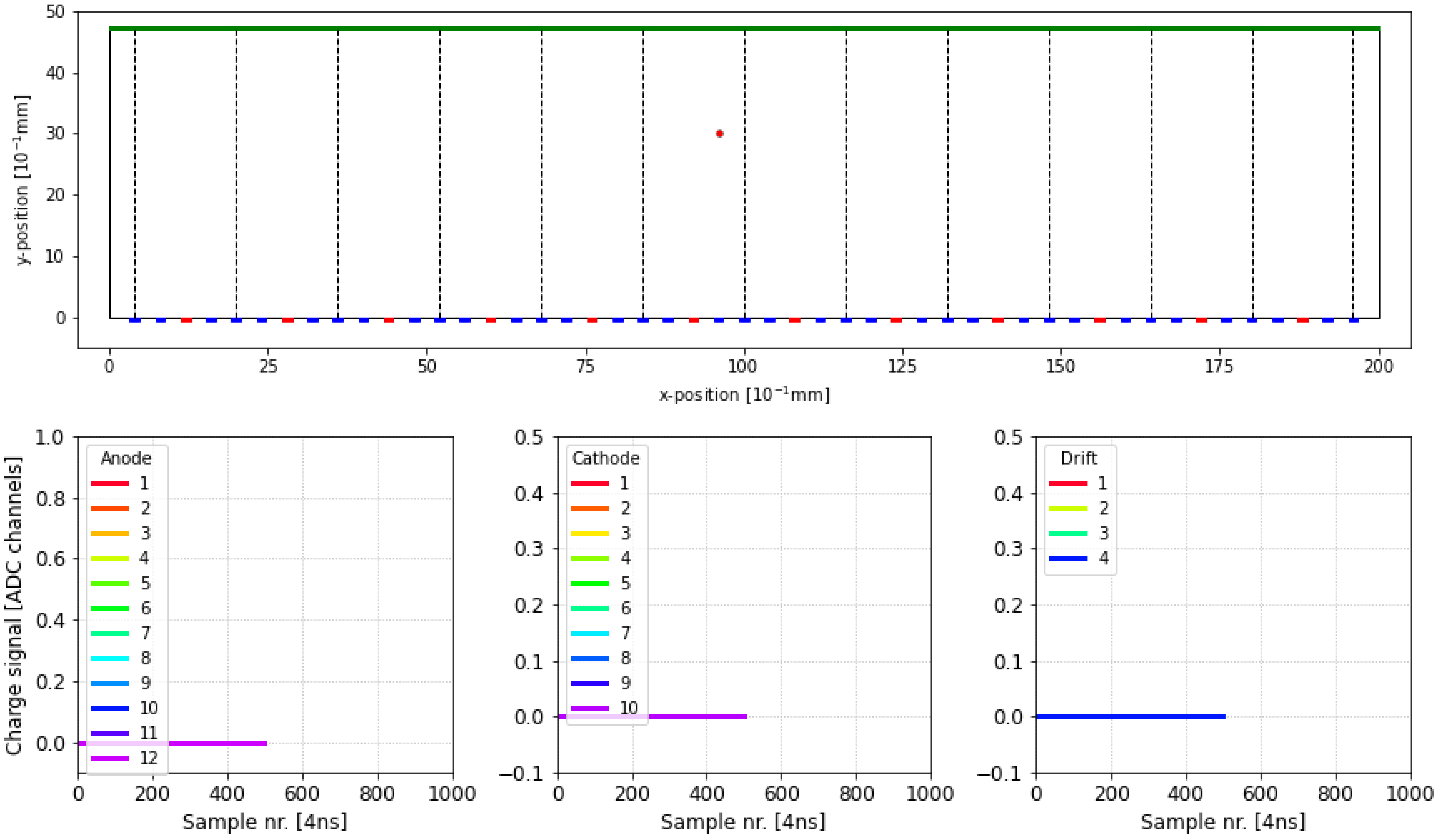
Detector lab





Data to be analysed

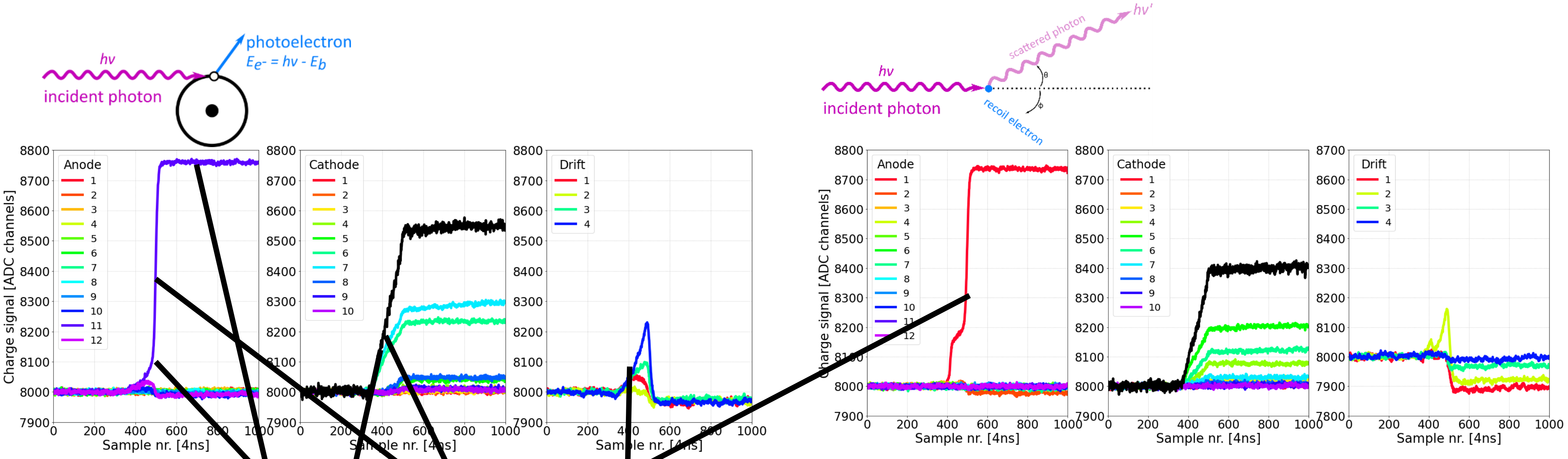
Offline data analysis



y-position [10^{-1}mm]
x-position [10^{-1}mm]
Charge signal [ADC channels]
Anode
1
2
3
4
5
6
7
8
9
10
11
12
Sample nr. [4ns]
Cathode
1
2
3
4
5
6
7
8
9
10
Sample nr. [4ns]
Drift
1
2
3
4
Sample nr. [4ns]

Current state-of-the-art:
The 3D CZT drift strip detector

Electrode configuration and signal analysis



Summed cathode signal provide information of
Electron drift time

Activated anode, cathode and drift strip numbers provide information of
3D interaction position

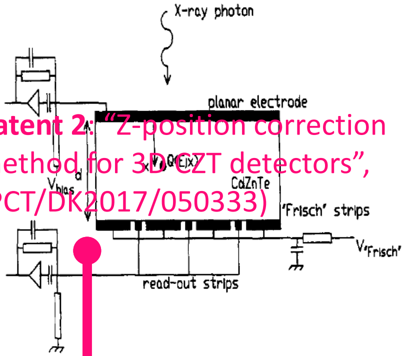
Anode, cathode and drift pulse shapes reveal
event (interaction) type

Anode pulse height provide information of
Deposited energy

Timeline

Concept development of the CZT drift strip detector

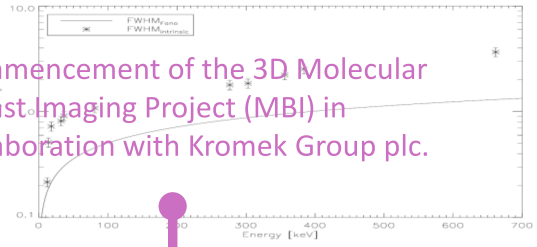
(Van Pamelen and Budtz-Jørgensen, 1998)



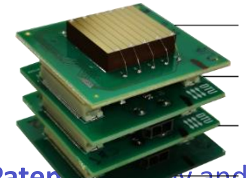
Patent 2: "Z-position correction method for 3D CZT detectors", (PCT/DK2017/050333)

High-energy resolution demonstration of pixelated drift strip detectors

(Kuvvetli, 2004)



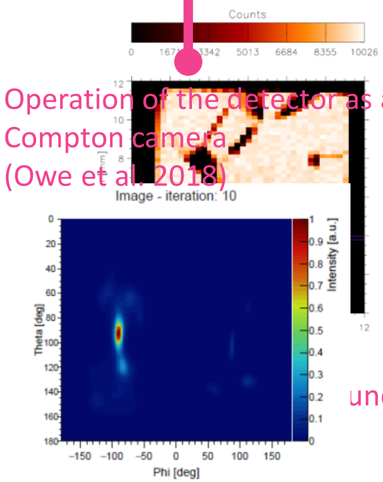
Commencement of the 3D Molecular Breast Imaging Project (MBI) in collaboration with Kromek Group plc.



Paten… ray and Gamma-Ray Radiation Detector", IPC No.: G01T 1/24, patent No.: WO2015078902, June 4, 2015.

"Evaluation of CZT Drift Strip Detectors for Use in 3-D Molecular Breast Imaging" (Owe et al. 2023)

2018 2018 2019 2021 2023 2023

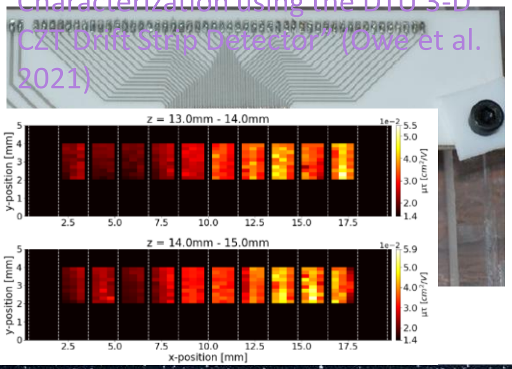


Operation of the detector as a Compton camera (Owe et al. 2018)

…undaries using the DSM

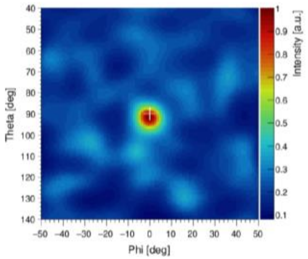
"Carrier Lifetime and Mobility Characterization using the DTU 3-D CZT Drift Strip Detector" (Owe et al. 2021)

ESA R&D project



"Feasibility of Using 3D CZT Drift Strip Detectors for Small Compton Camera Space Missions" (Owe et al. 2024)

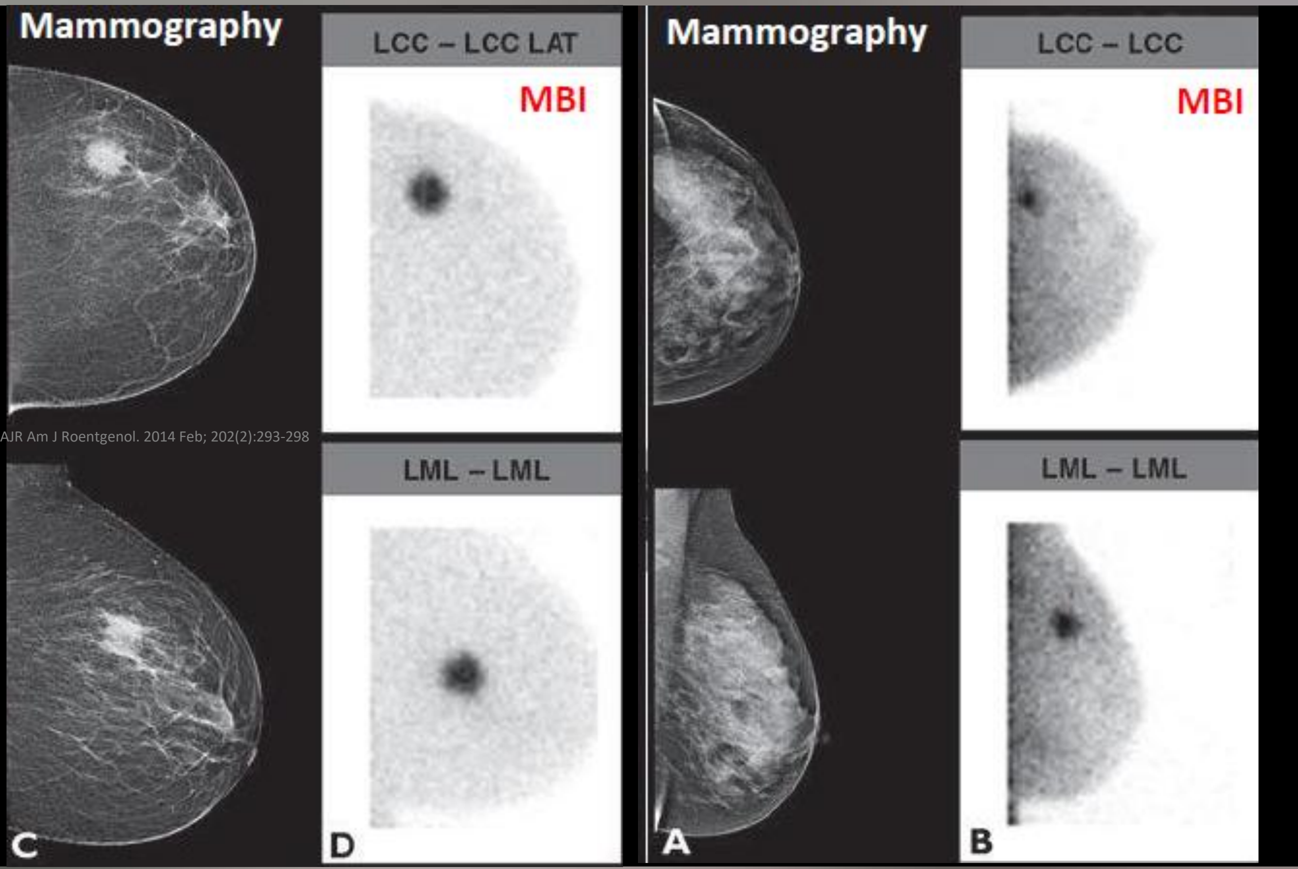
New Position Algorithm for … CZT Drift Detector



Application examples

The 3D CZT Drift Strip Detector

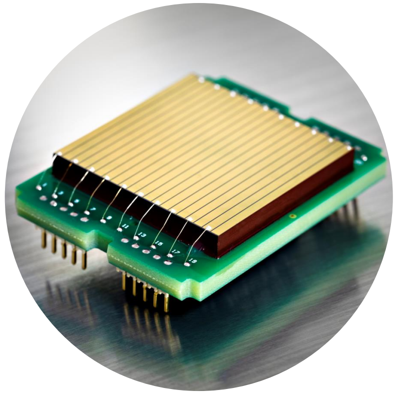
Astrophysical telescopes in keV-MeV range:
- Focusing optics
- Compton camera
- Coded mask



AJR Am J Roentgenol. 2014 Feb; 202(2):293-298

X- and gamma-ray telescopes	Medical imaging	Homeland security	Industrial applications	Laboratory applications

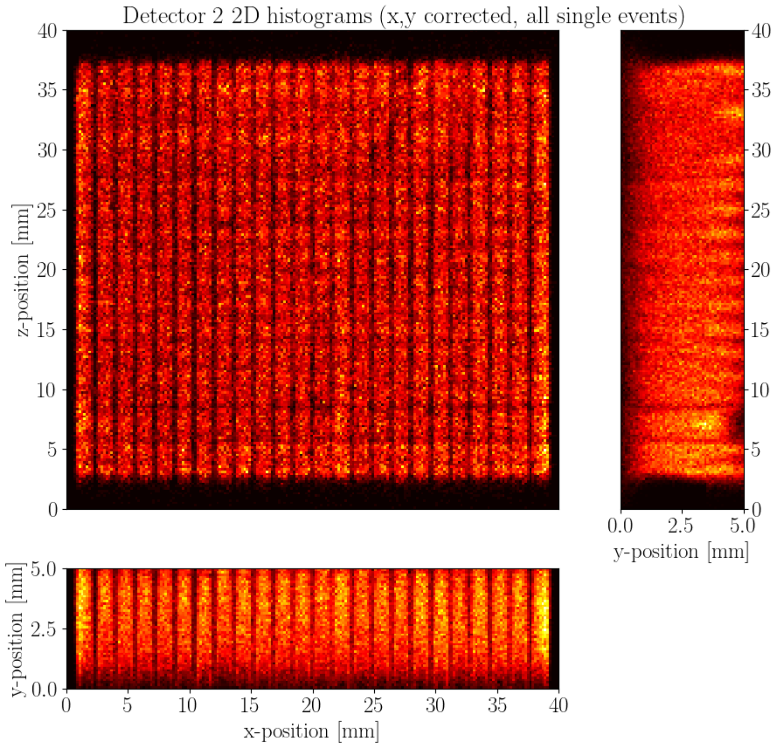
$4x4x0.5\ cm^3$ preliminary performance results

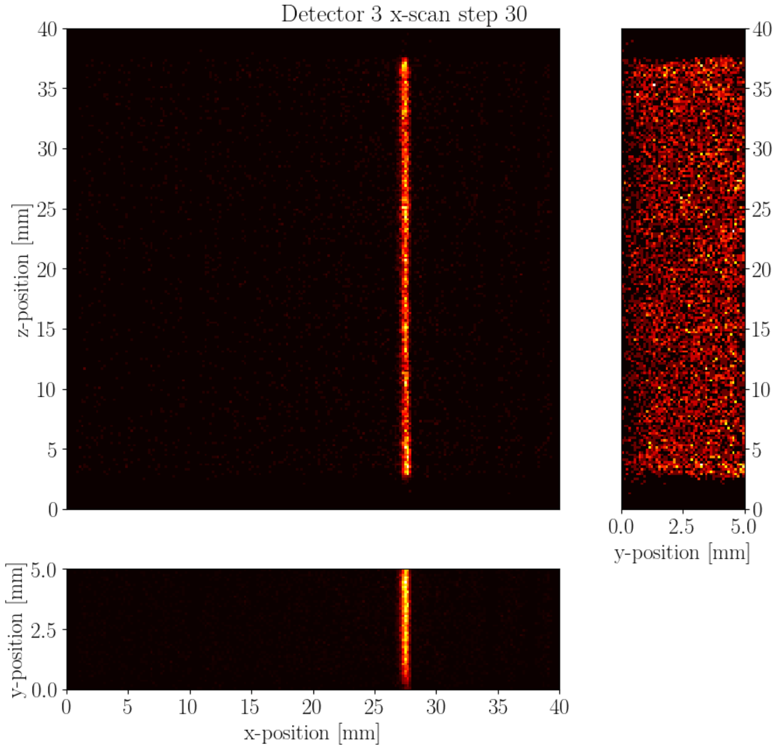


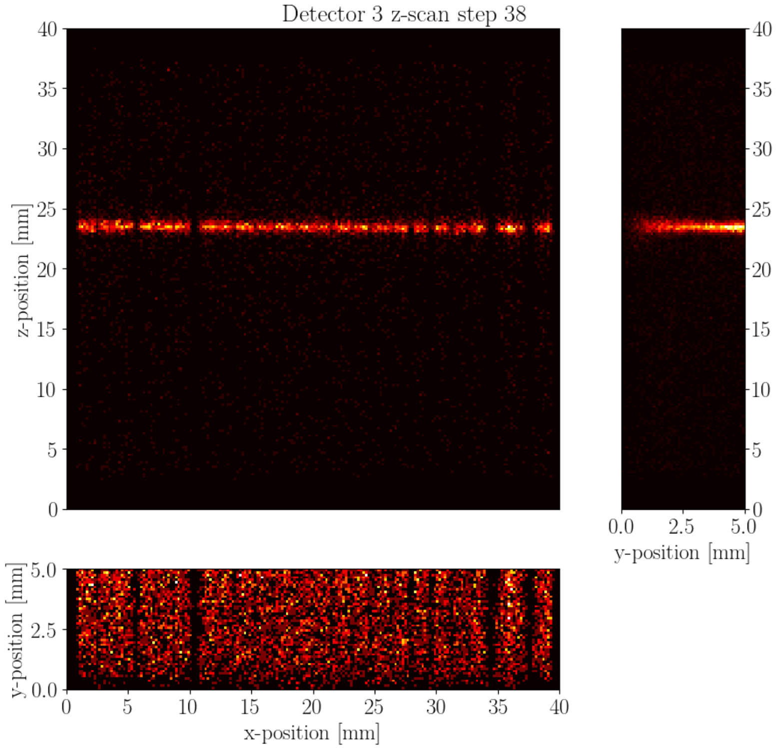
Spectral resolution:
~1.4% @ 661.6 keV
~1.2% @ 1460 keV

Spatial resolution @ 661.6 keV:
~0.5 mm in x and z direction

Some faulty electrodes, but in general good performance.



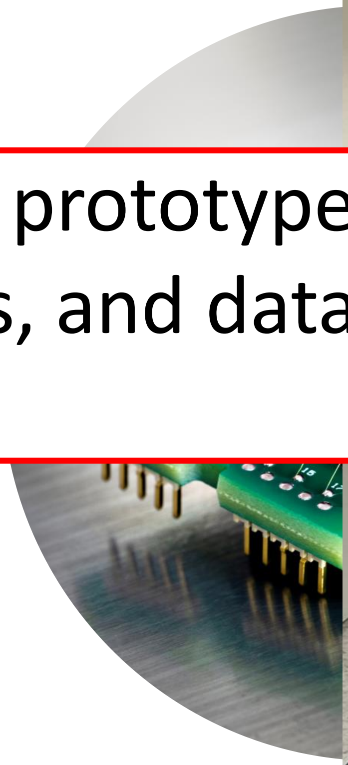




Benjamin Nobre Hauptmann, 2024

In summary:
Detector technology tested and verified in a laboratory environment

Sub-mm spatial resolution in 3D



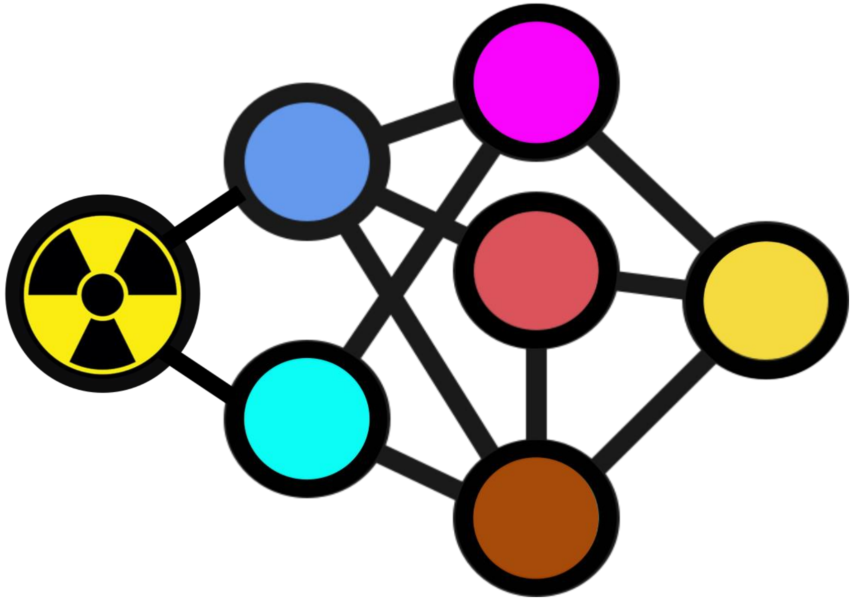
But… the current prototype setup, electronics, and data sizes are large….

Event type characterization

Applicable for medical imaging

Horizon-EU EIC Pathfinder Open

Funded by the European Union



i-RASE - Intelligent Radiation Sensor Readout Systems

Horizon-EU EIC PATHFINDER OPEN

Funded by
the European Union

i-RASE - Intelligent Radiation Sensor Readout Systems

Real-time radiation measurement via physics-inspired neural networks

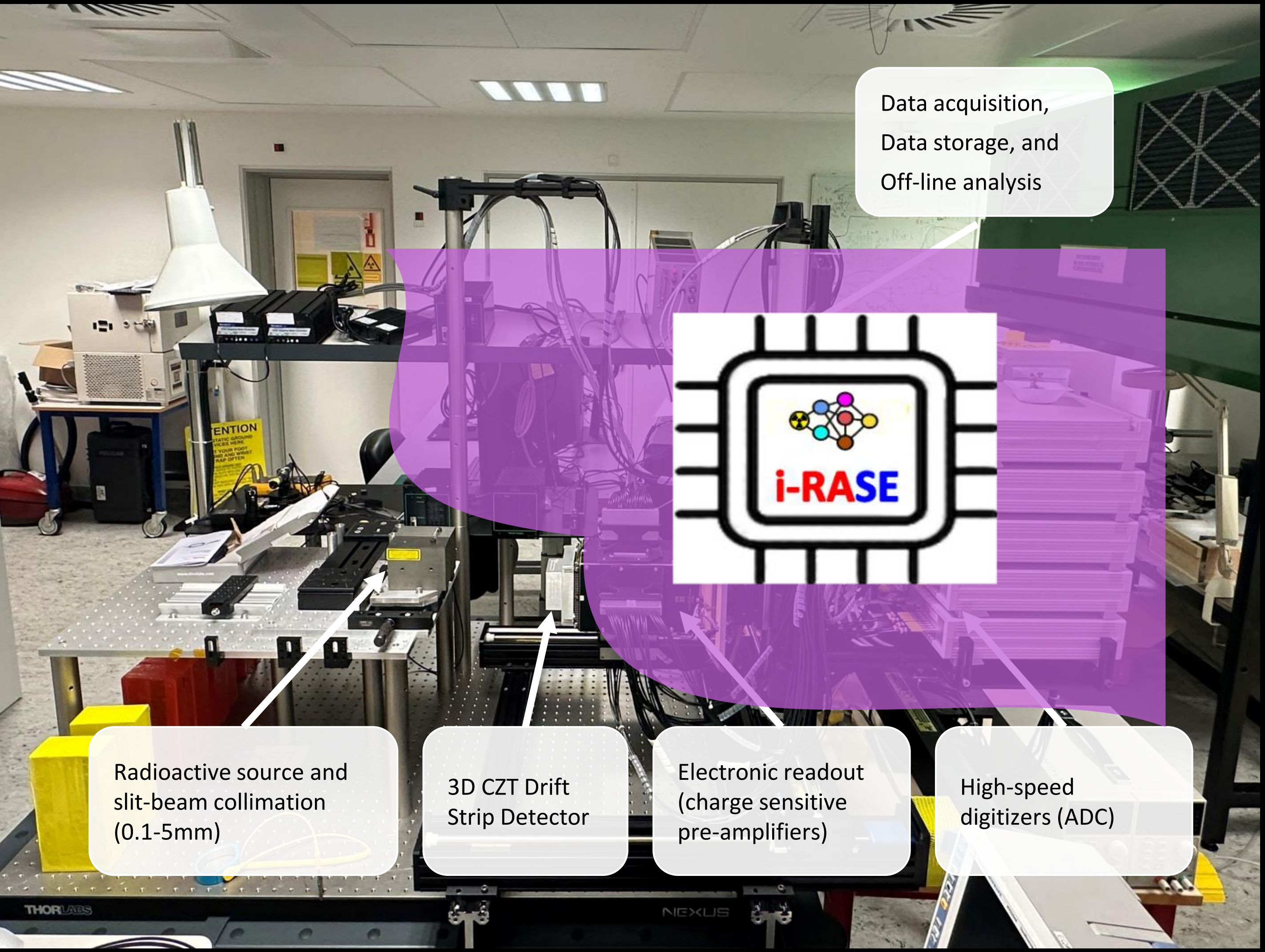
EBERHARD KARLS UNIVERSITÄT TÜBINGEN
Institut für Astronomie und Astrophysik

DTU Space & Compute

POLITECNICO MILANO 1863

ideas Integrated Detector Electronics AS

kromek



Goals of i-RASE

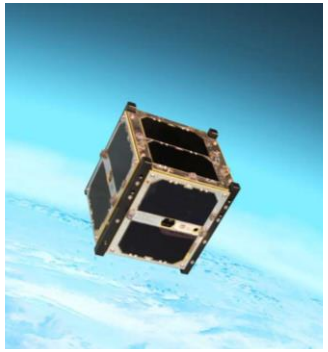
- **Design, build, test, and implement the 1st on-the-fly photon-by-photon radiation**
- **A physics-inspired artificial neural networks (ANN) for comprehensive sensor signal processing**
- **Real-time measurement of radiation interactions.**
- **Intelligent output of radiation data with unprecedented accuracy and speed.**

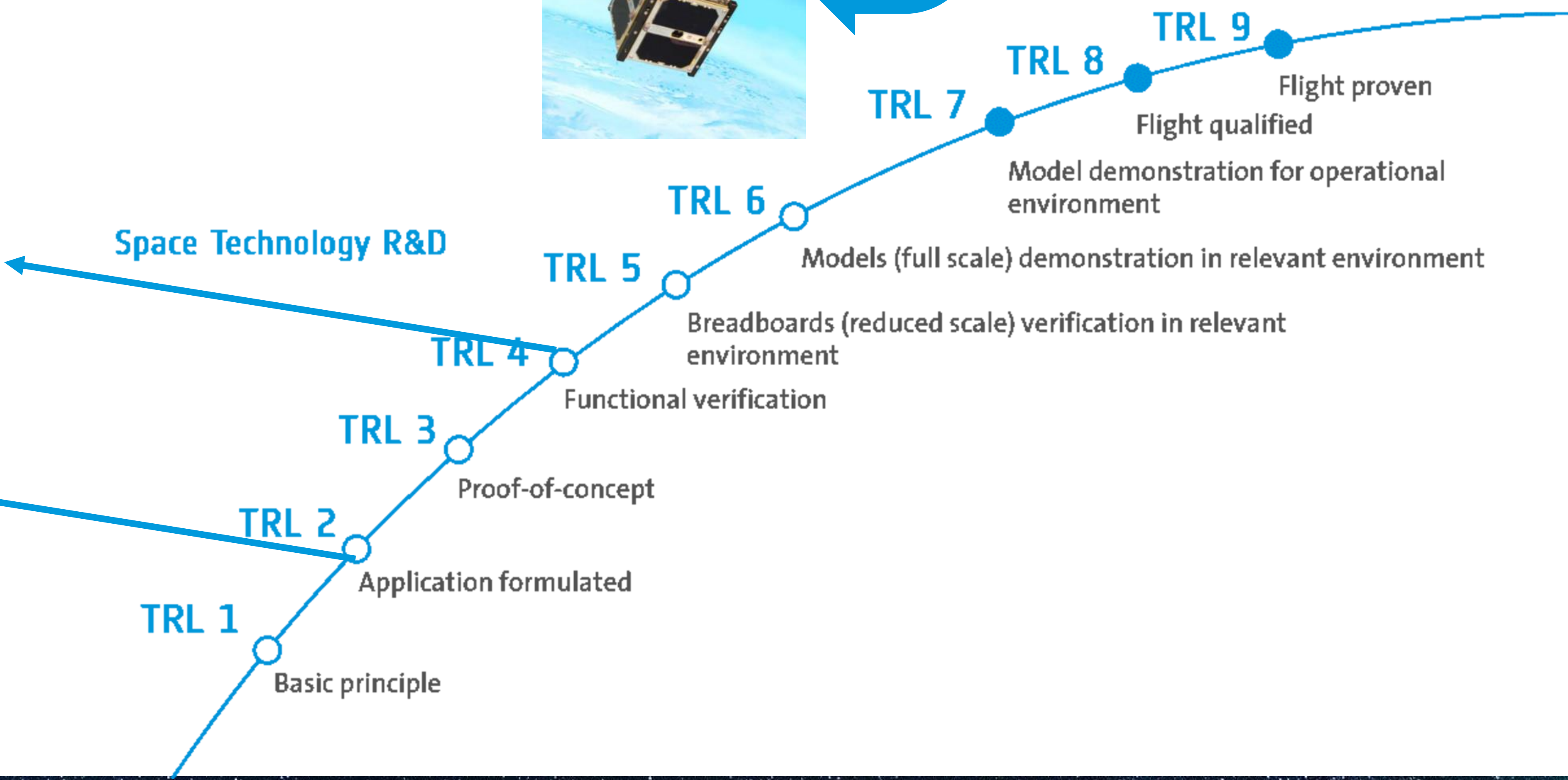
Estimated example:

Offline analysis: 80 GB data
i-RASE: 5 MB

Outlook
TRL – Technology Readiness Level

“End”-goal:
Assess the technology in a relevant environment → **Space**
3D CZT Drift Strip Detector + i-RASE





3D CZT Drift Strip Detector

Electronic readout concept
(i-RASE)

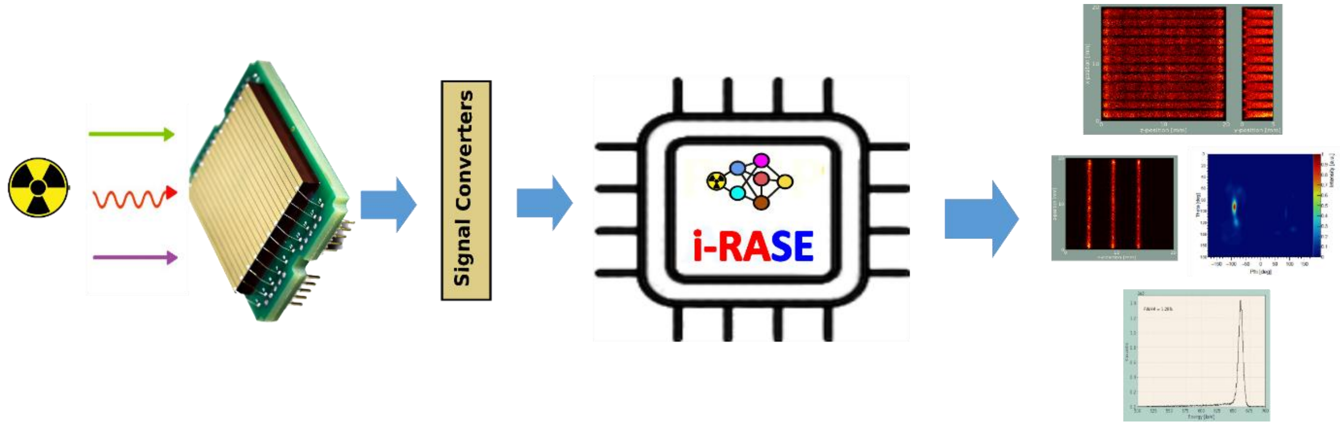
DTU

Horizon-EU EIC PATHFINDER OPEN

Funded by
the European Union

i-RASE - Intelligent Radiation Sensor Readout Systems

Real-time radiation measurement via physics-inspired neural networks



i-RASE is the next-gen AI-powered sensor readout technology using Artificial Neural Networks (ANNs) for radiation detectors signal processing

HE EIC - i-RASE – 101130550, KO: March 01, 2024, Duration: 48 months

Thank you ☺

Selina R. H. Owe, Postdoc, DTU Space

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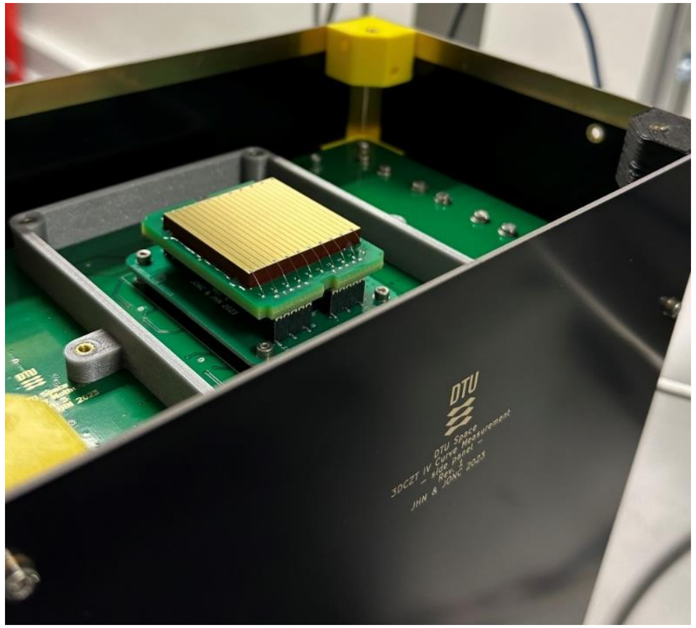

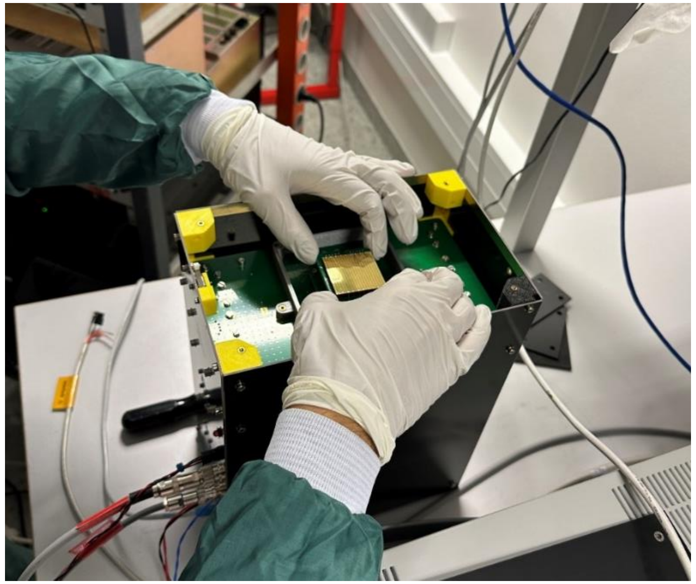

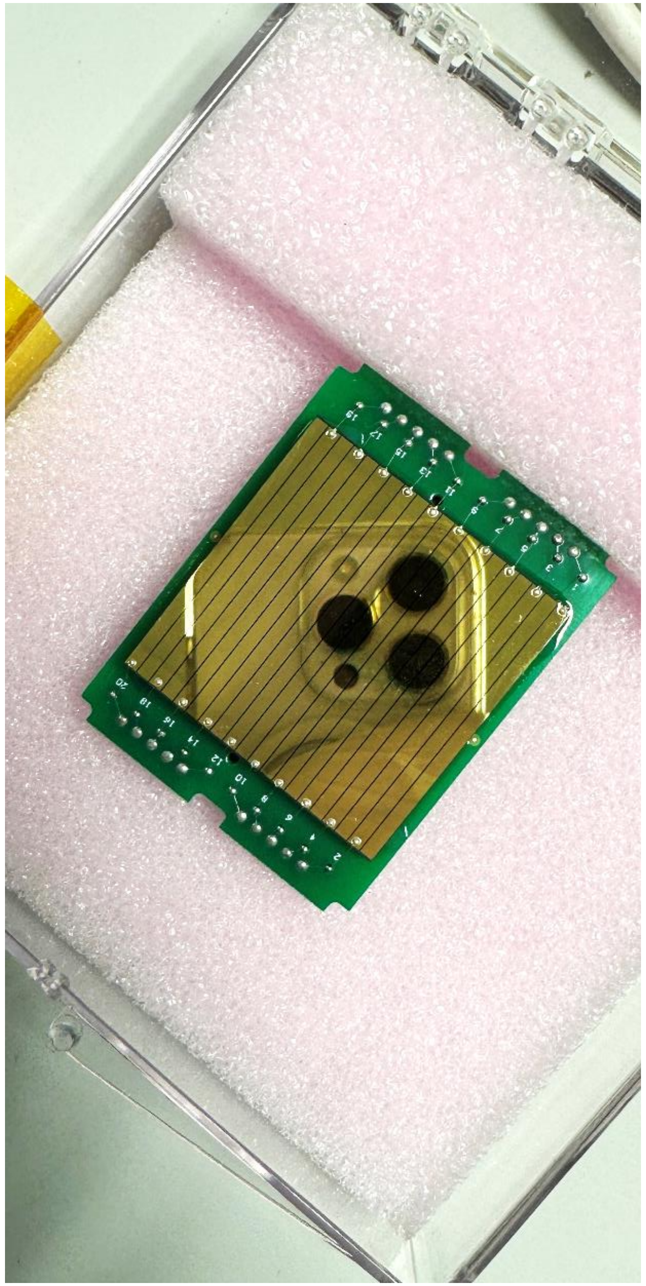

The 3D CZT drift strip detector

Space applications, e.g.

- Compton camera telescope
- MeV telescopes

Medical applications, e.g.

- Molecular Breast Imaging
- Sub-mm PET

Safety, e.g.

- Monitoring nuclear material and waste packages