HardPix: A Modular Timepix3-Based Radiation Monitor for Advanced Radiation Environment Characterization

WRMISS 3.8.2026

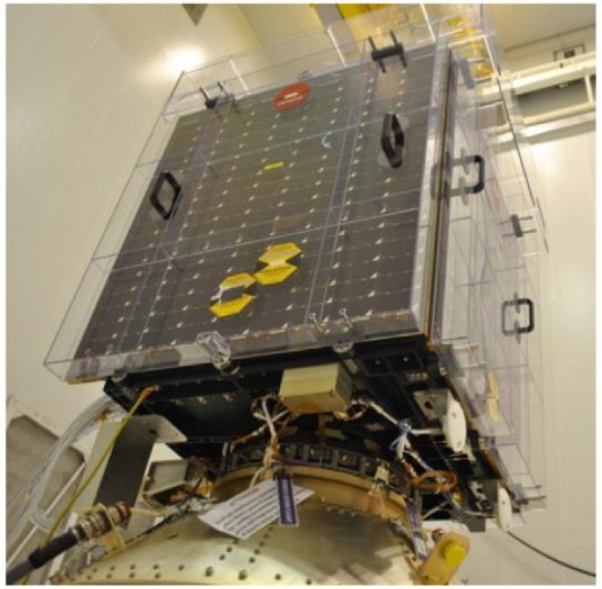
Milan Malich & Team

Institute of Experimental and Applied Physics

Czech Technical University in Prague



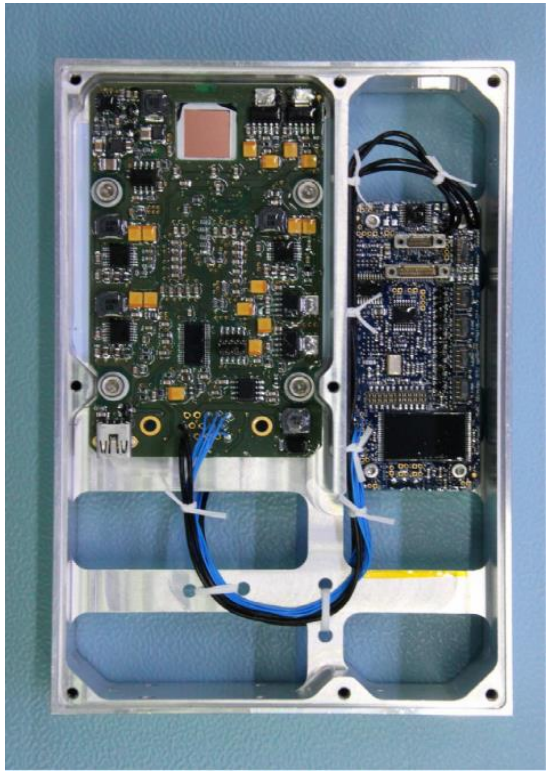
History



ESA Proba-V (2013 – now)

<u>Features</u>

- Timepix 1
- 4W
- RS422



RisePix (2012-2019) - Cooperation Tohoku University, JAXA

<u>Features</u>

- 2xTimepix 1
- 4W
- Modified USB protocol



MIRAM (2018-2020) - Cooperation ESA, Advacam

<u>Features</u>

- Timepix3 + 4x Diodes
- 3.5W
- CAN Bus

Requirements

- **Up to 2 pixel detectors** (telescope) - will cover most scientific applications
- **Modularity** - easy upgrade (it is not necessary to redesign the entire device), adaptation to specific mission requirements:
  - SWIMMR1,SWIMMR2, HEKI – Interface: RS422 , Power: 5V
  - ERSA – Interface: RS422, Power: 28V
  - Cassini – Interaface: UART, Power: 5V
- **On-board data processing** – Output Data products is spectra (Electron, Proton, Other)
  - Simple (fast) data-processing for High-Fluxes
  - Complex data processing (AI) for Low-Fluxes, Special mission requirement
- **Low-Power** – Limited power budget
- **Small size** – Limited space and weight
- **Interfaces** - Support many industrial standart (CAN, RS422, Ethernet)
- **Robustness** – Fault tolerance (Redundancy, ECC, Safety controller)



HardPix

- Instrument to Harsh(Hard) enviroment: Space, Beam campaign, Balloon experiments
- 2x Pixel detectors Timepix 3 (Telescope)
- Consists of three boards (Detector, Mainboard, Communication modules)
- Based on COTS components. Many component is radiation tested (some component is possible update to certified Space version)
- SoC – Xilinx ZYNQ (Dual Core A9) – FreeRTOS/Linux
- Low-power: 1.2W-5W
- Temperature range: –40 to +85 Celsius
- OnBoard processing (particle identification): separating Electron, Proton, and other. Energy spectrum for every particle type on the Orbit)
- Latch-Up Current Limiter
- Main memory DDR3 ECC (128MB)
- Dual Data Memory Flash ECC (16MB
- Dual Data Memory MRAM
- Optional: SD card with ECC – (16GB - 64GB)
- Mass: 180g
- Dimension: 86 x 41 x 21,5mm

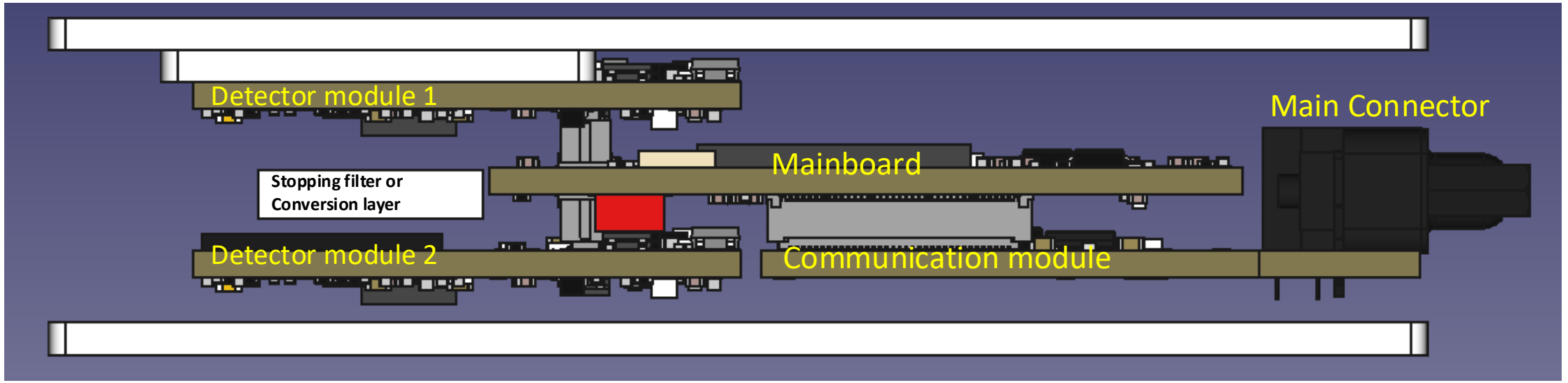


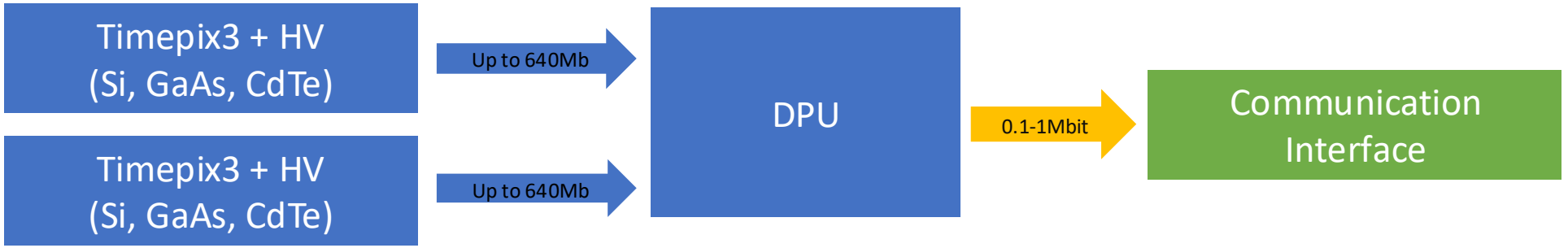
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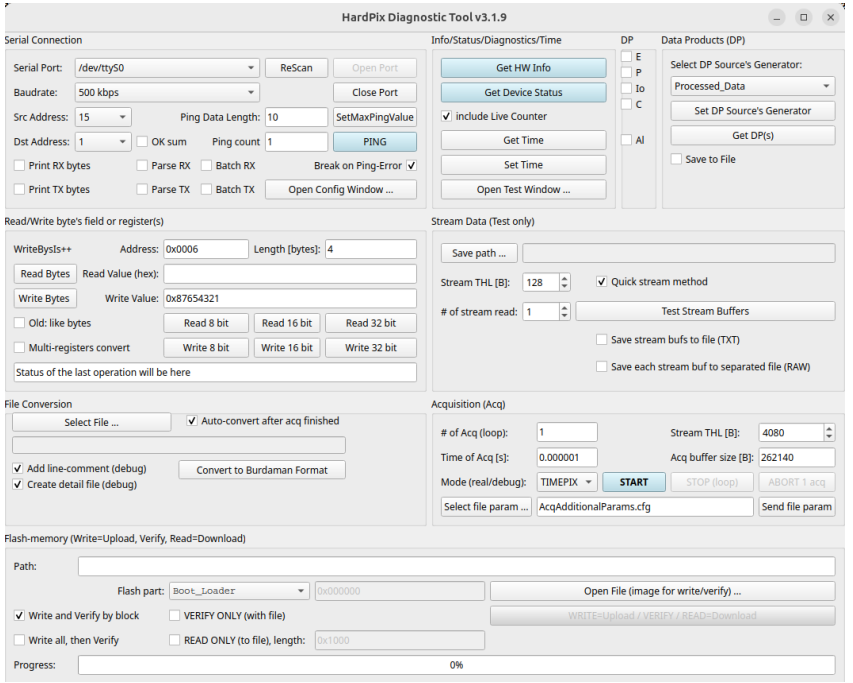
Hardpix - Structure



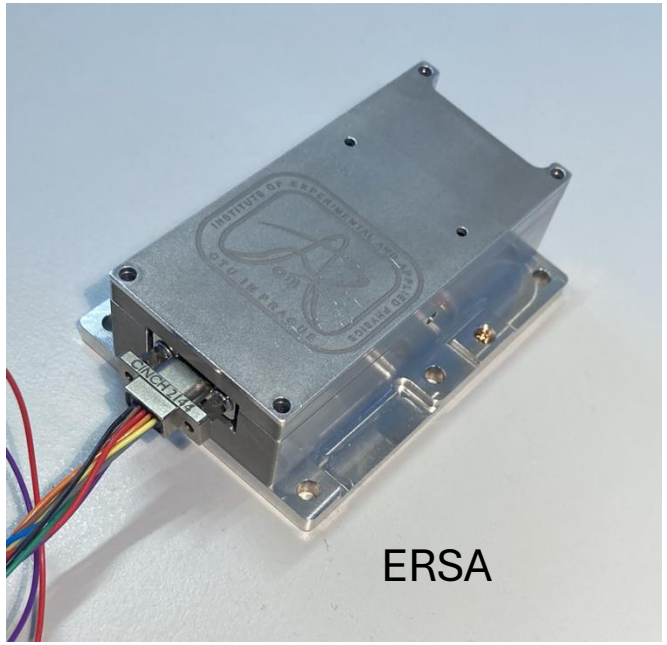


Space Versions

Name	Interface	Note	Level
Hardpix-SWIMMR1/2	RS422, +5V	1xTimepix3	TRL9
Hardpix-ERSA	RS422, +25V	1xTimepix3	TRL7
Hardpix-CASSINI	UART, +5V	2xTimepix3	TRL7
Hardpix-Ethernet	Ethernet PoE	2xTimepix3	TRL5



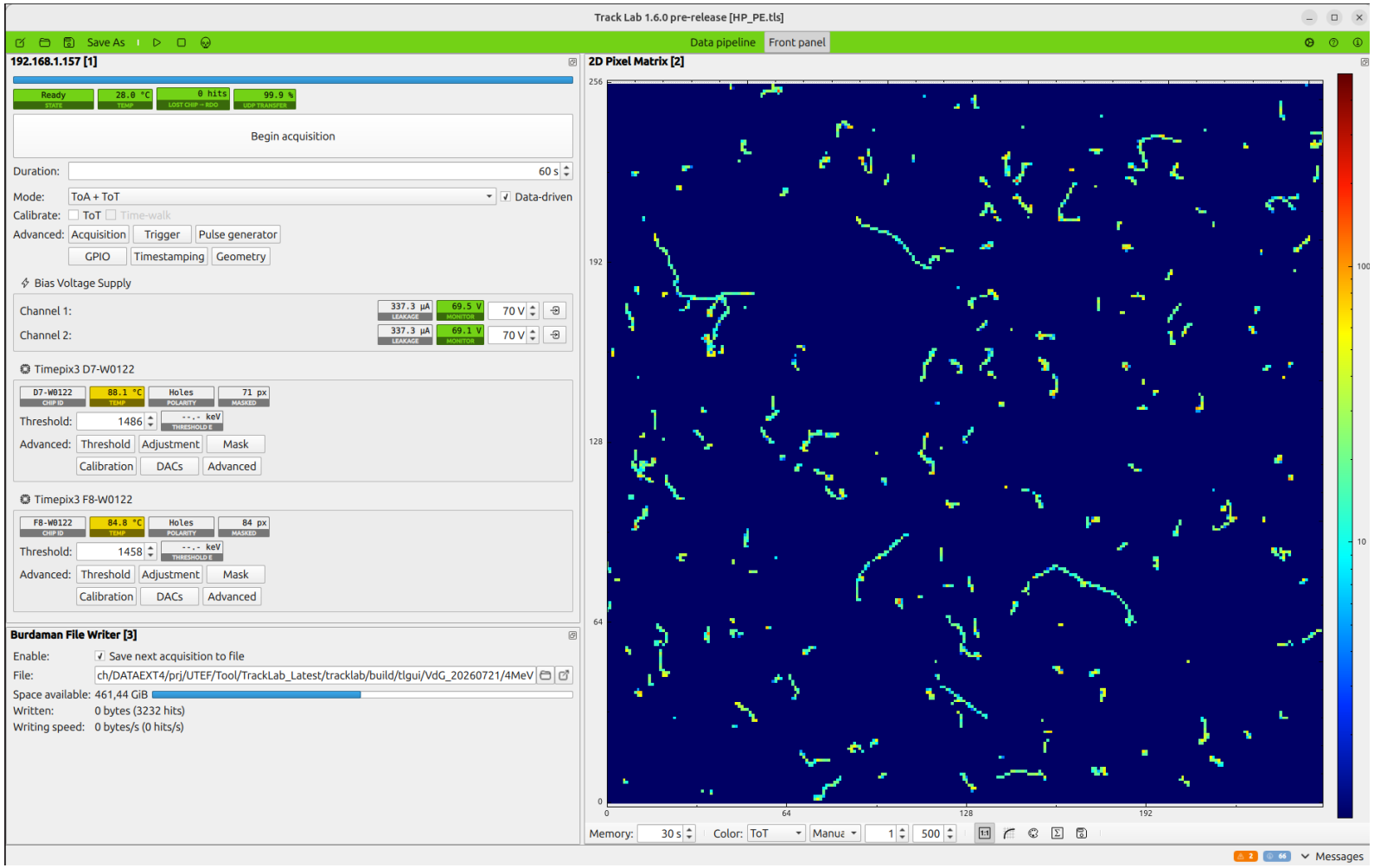




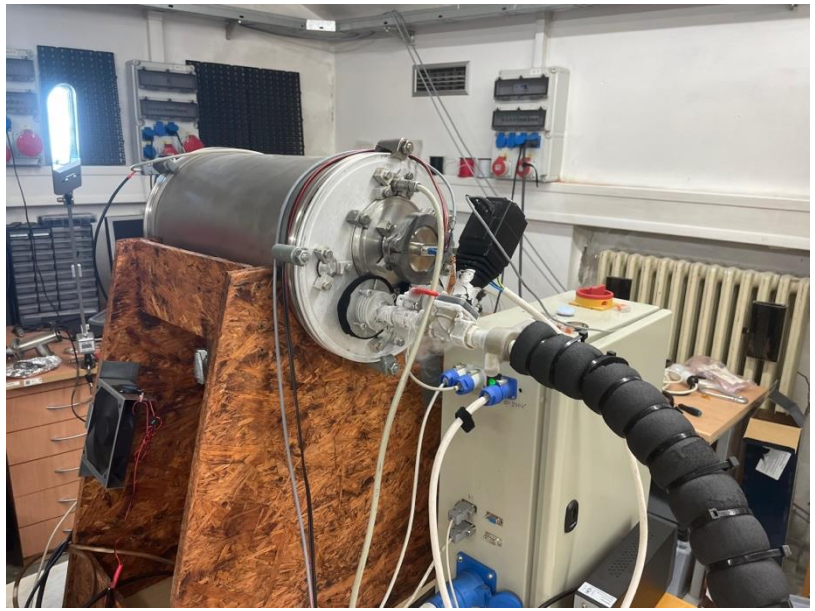


Ethernet (100Mbit)



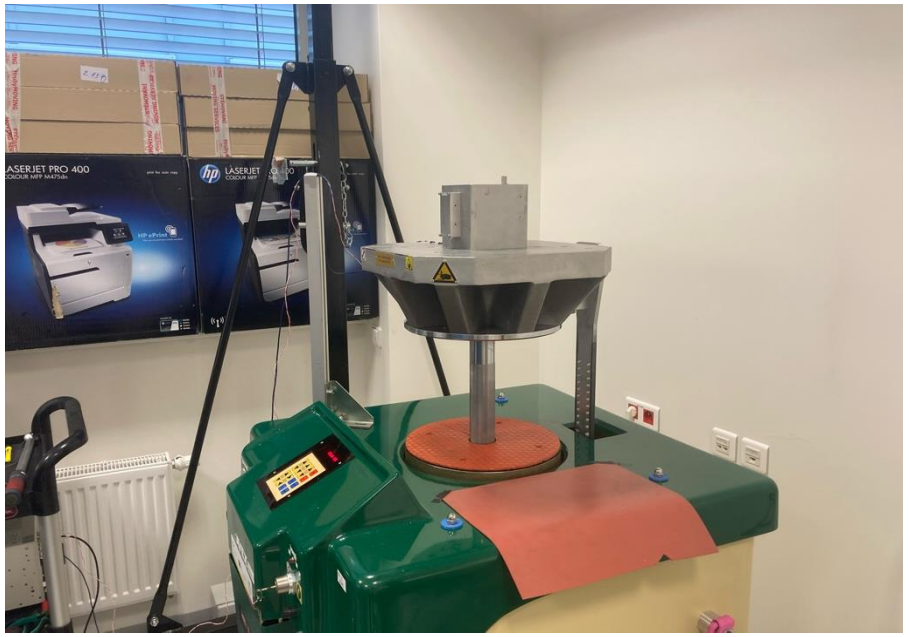


Qualification



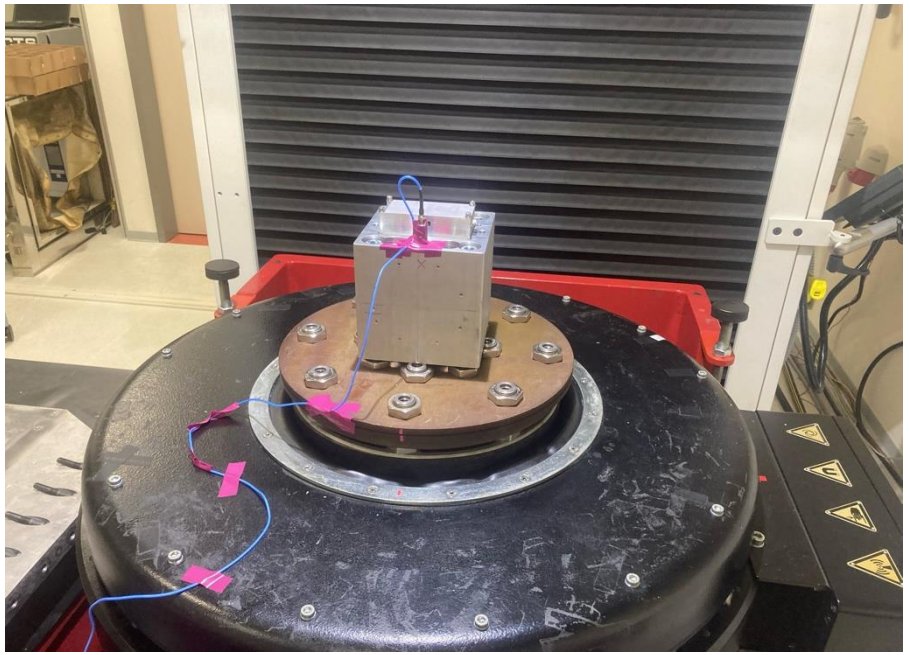
TVAC (-40 to 70˚C)

Shock test

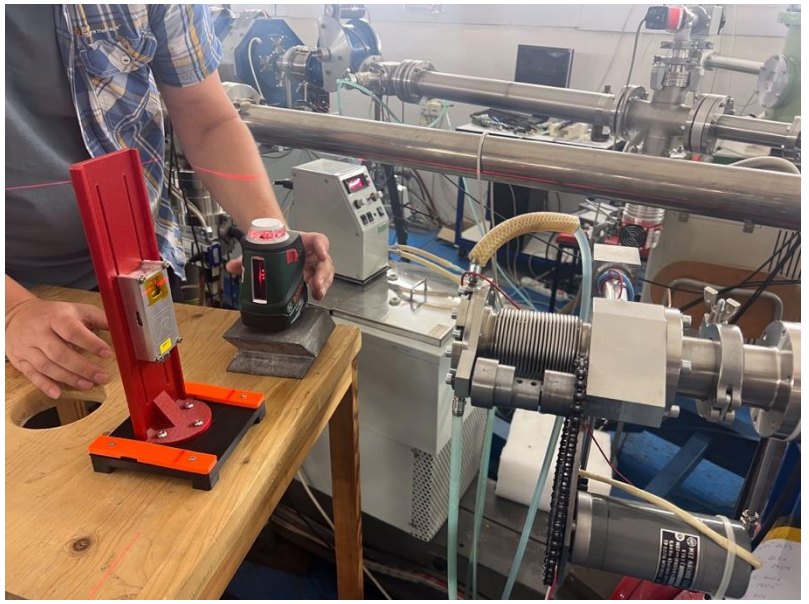


EMC



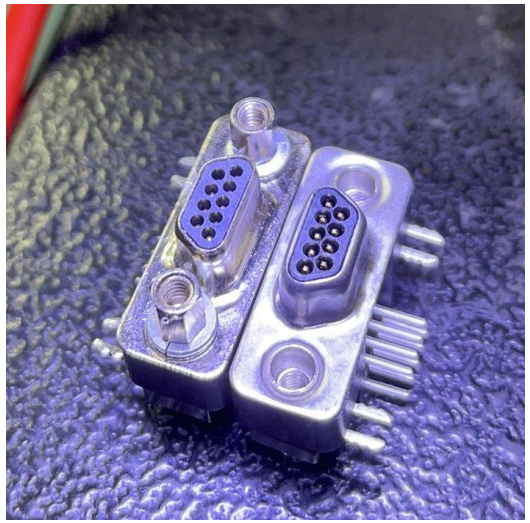


Vibration test



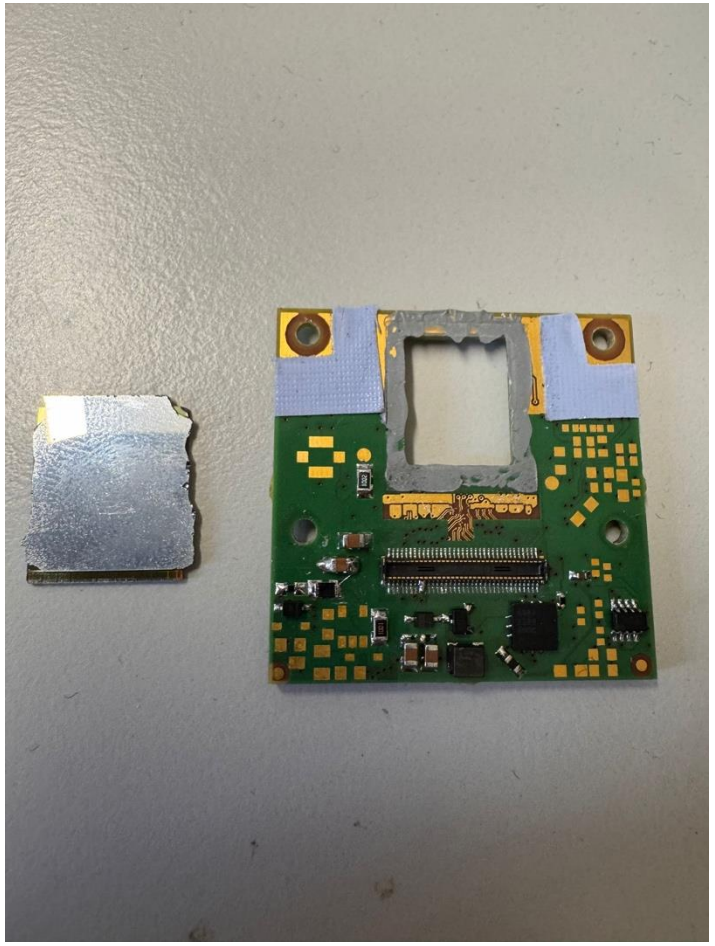
Functional

Problems



Micro-D connectors are not 100 percent compatible

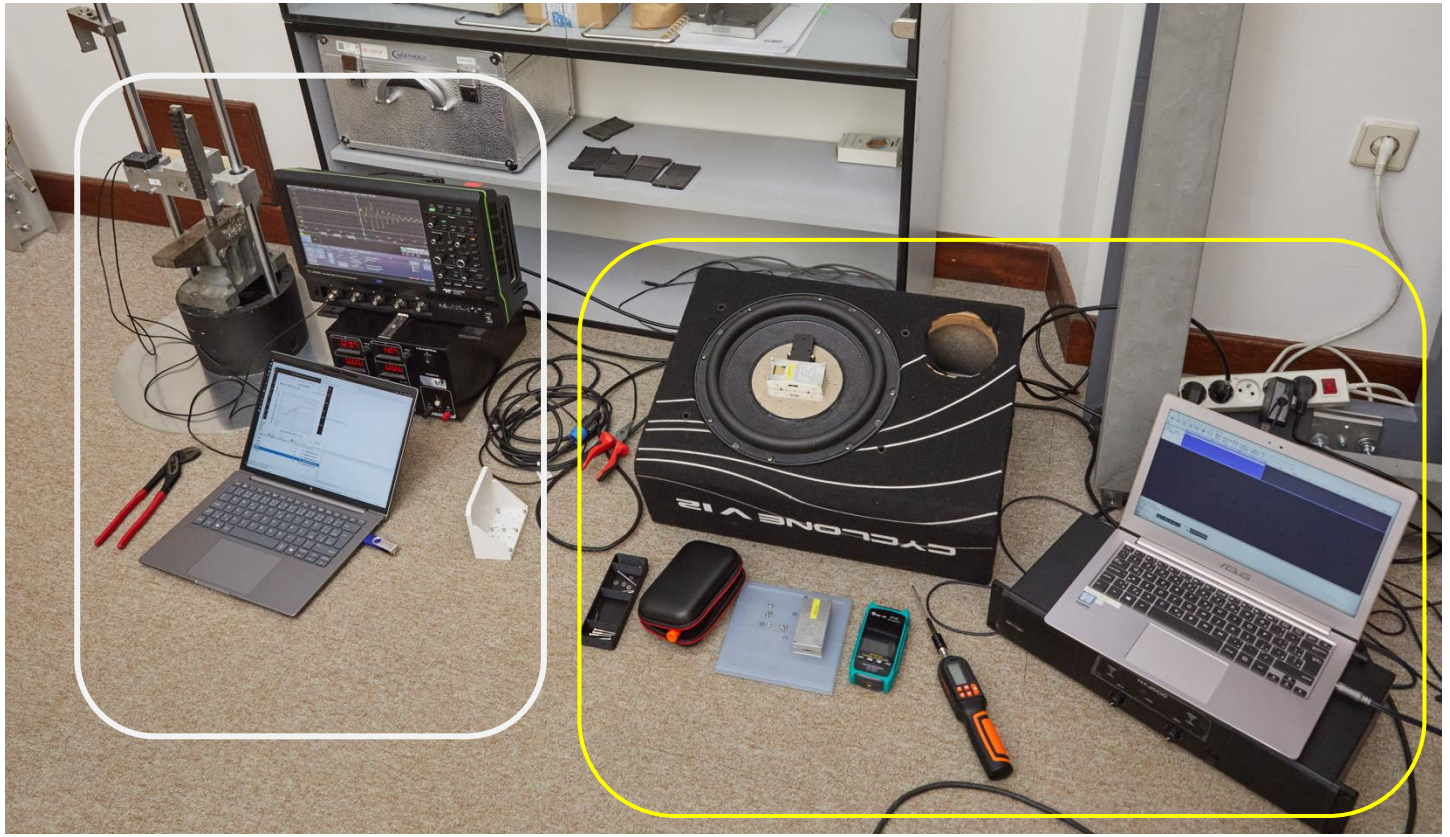
	Vibration	Shock
First try	1xSensor Failed	-



	Vibration	Shock
Second try	Pass	2xSensor Failed



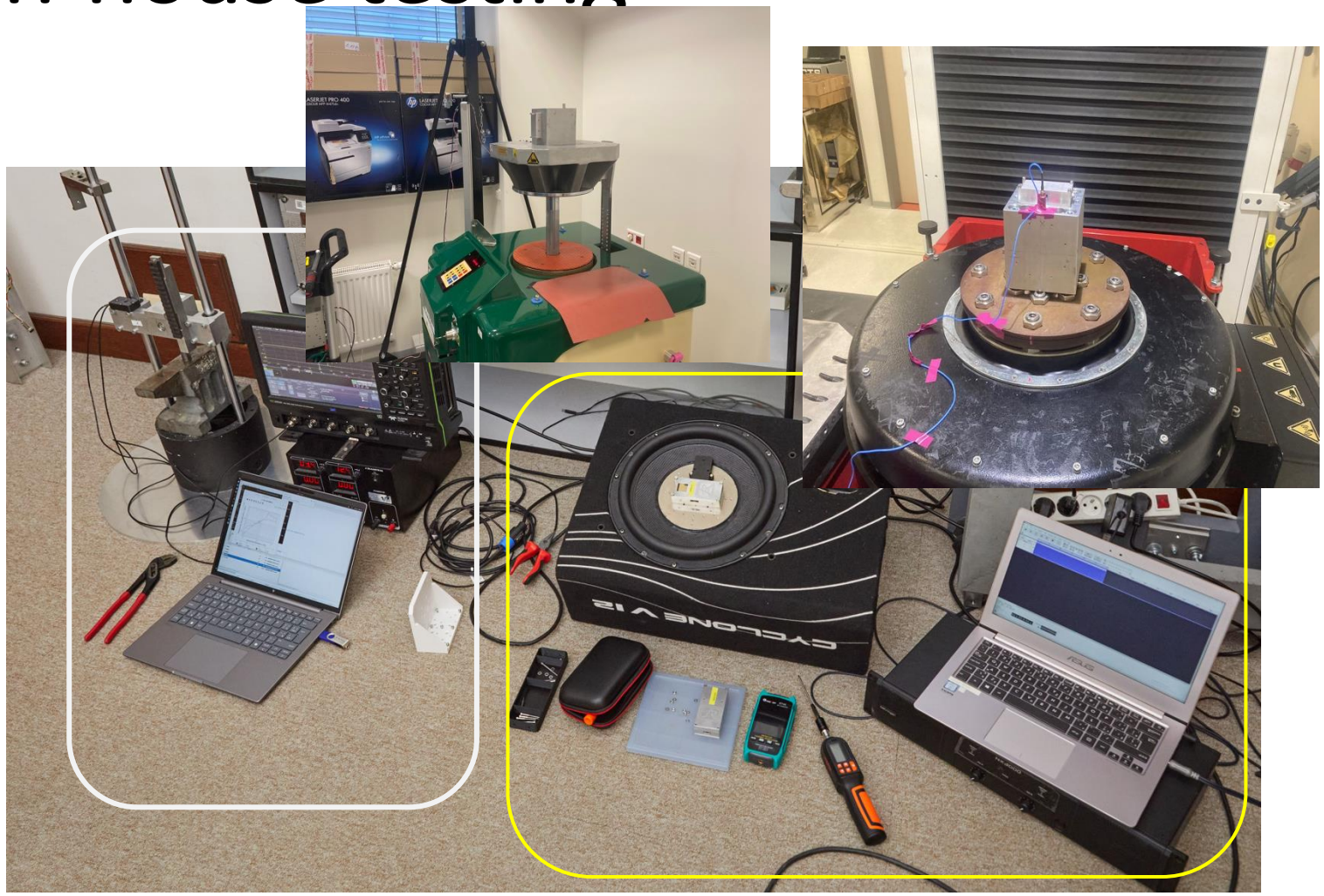
In-house testing



Shock machine
(Vozembouch)

Vibration table

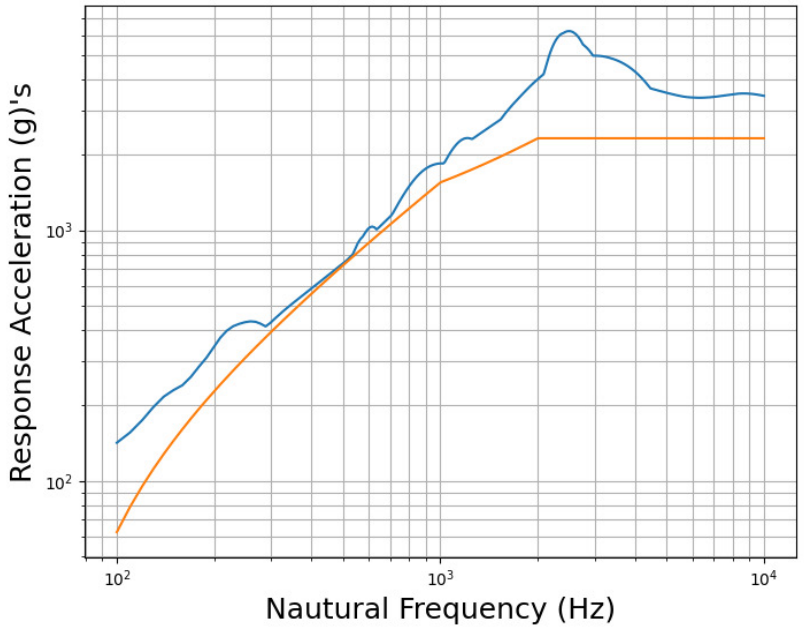
In-house testing

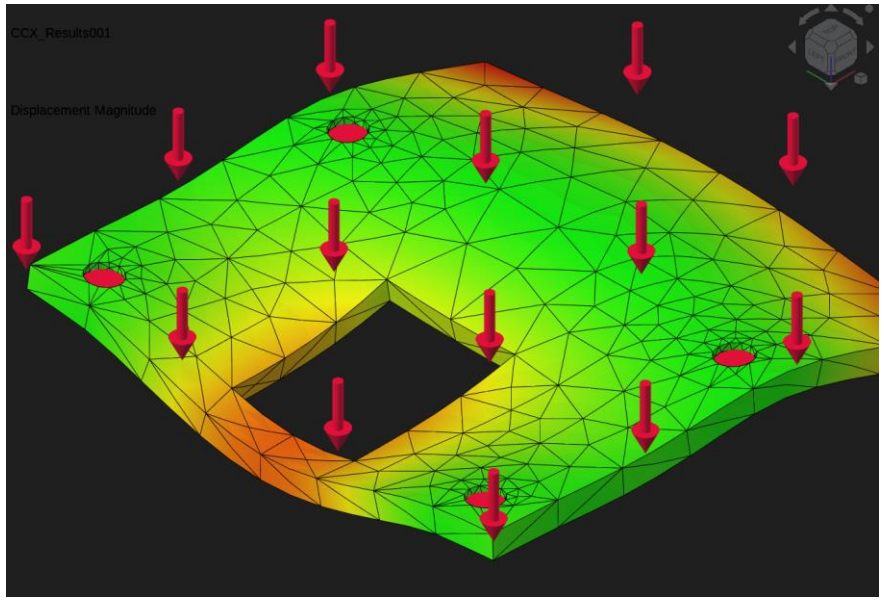


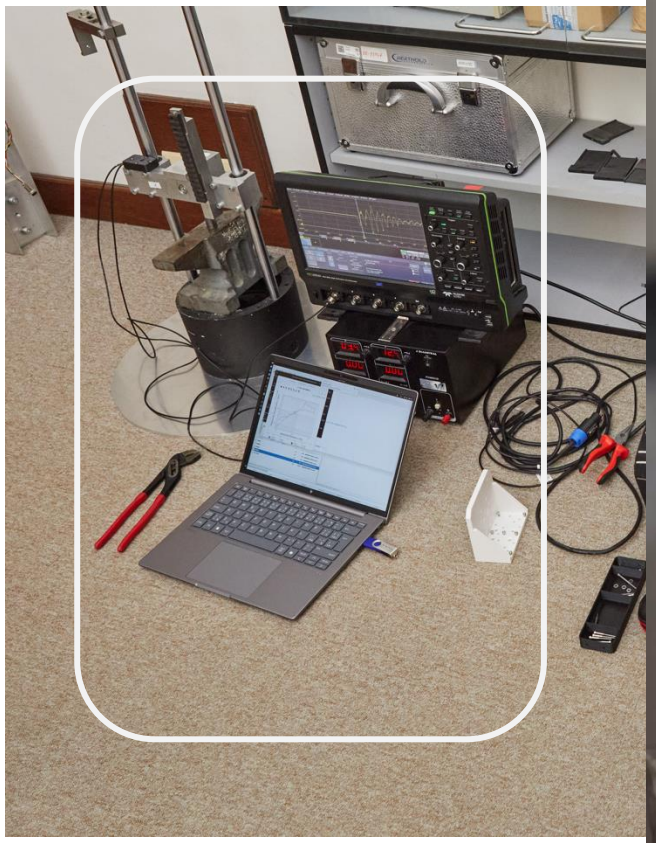
Shock machine
(Vozembouch)

Vibration table

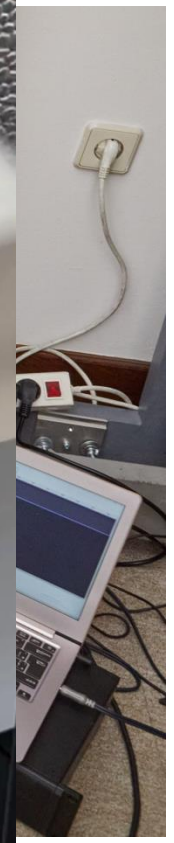
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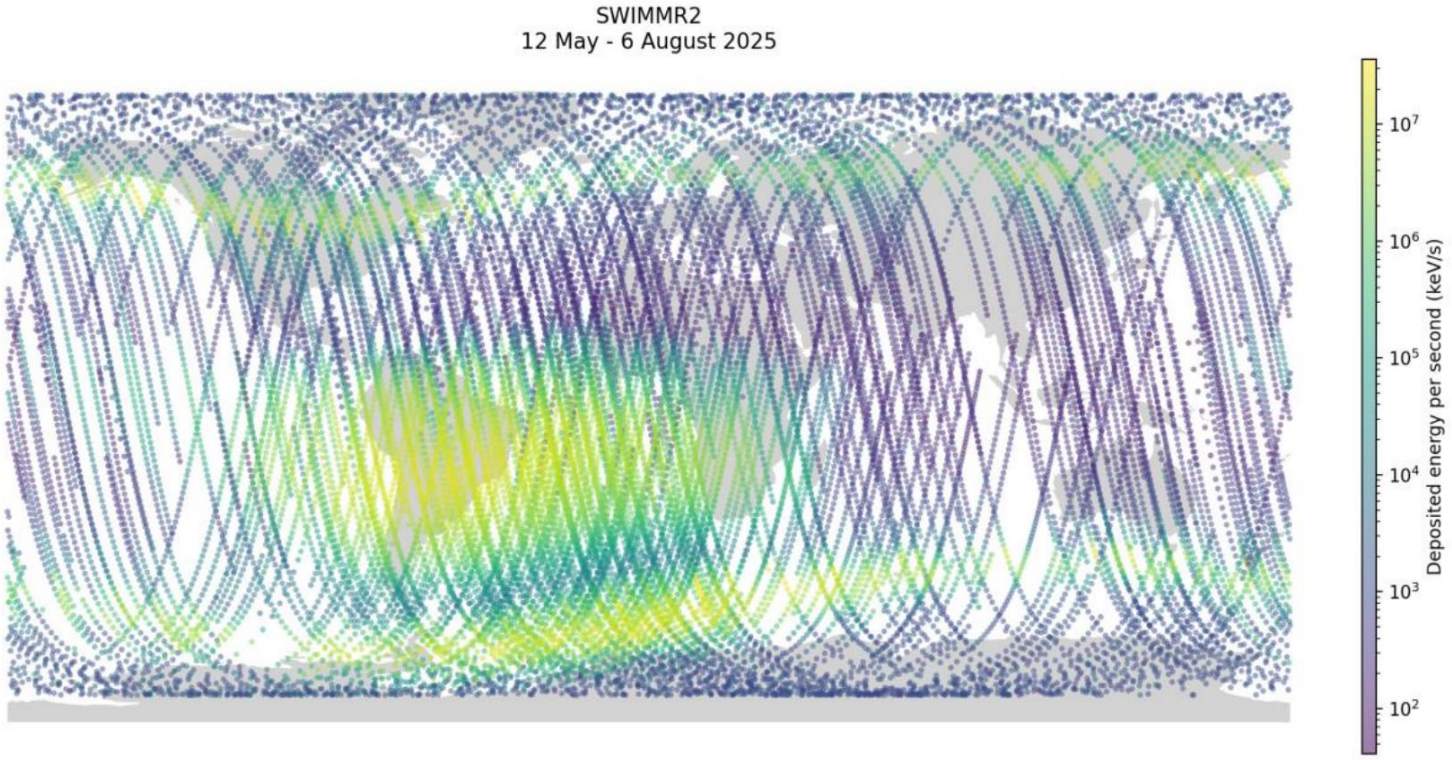


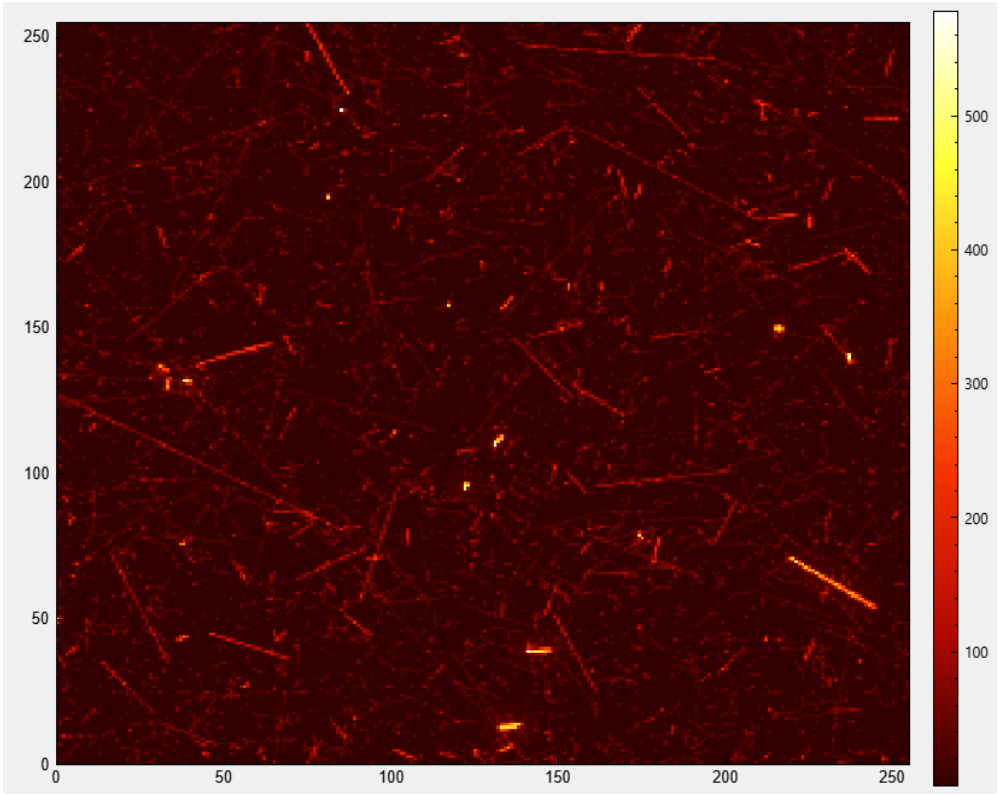


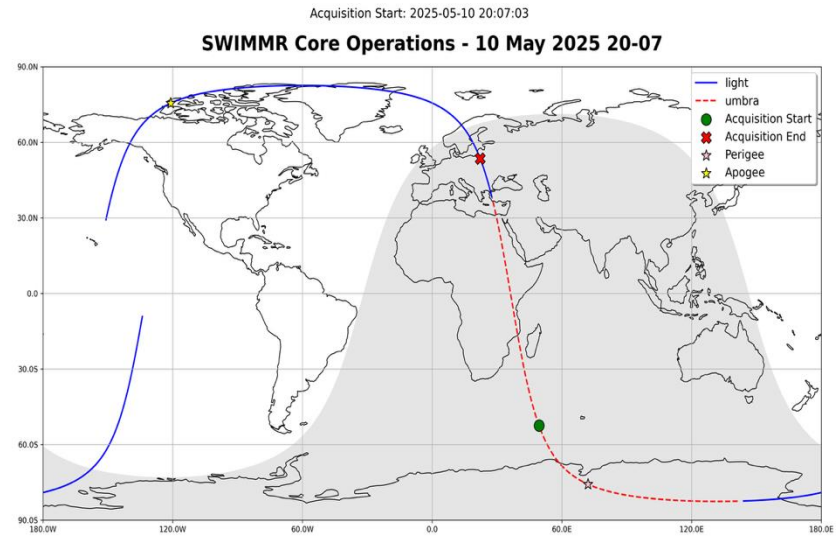


Shock machine
(Vozembouch)

Space mission: SWIMMR 2

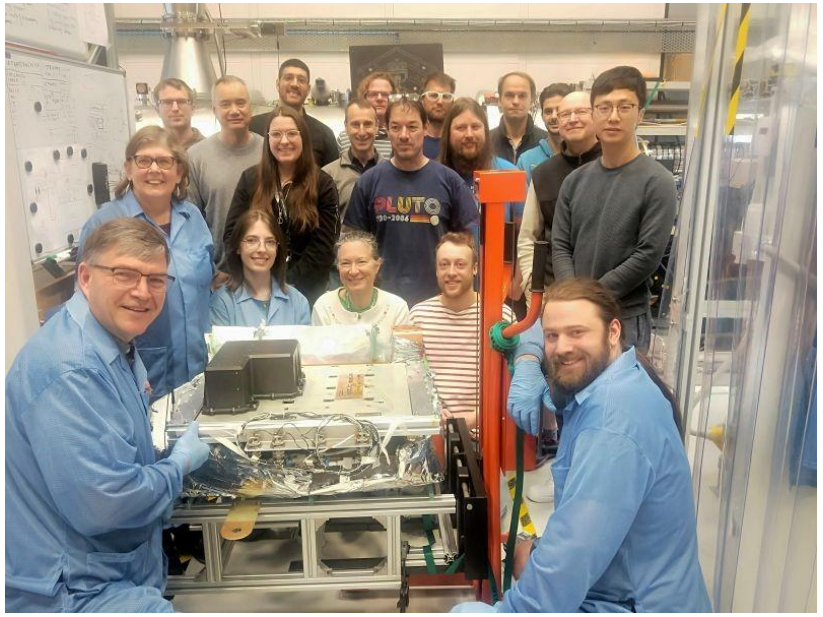


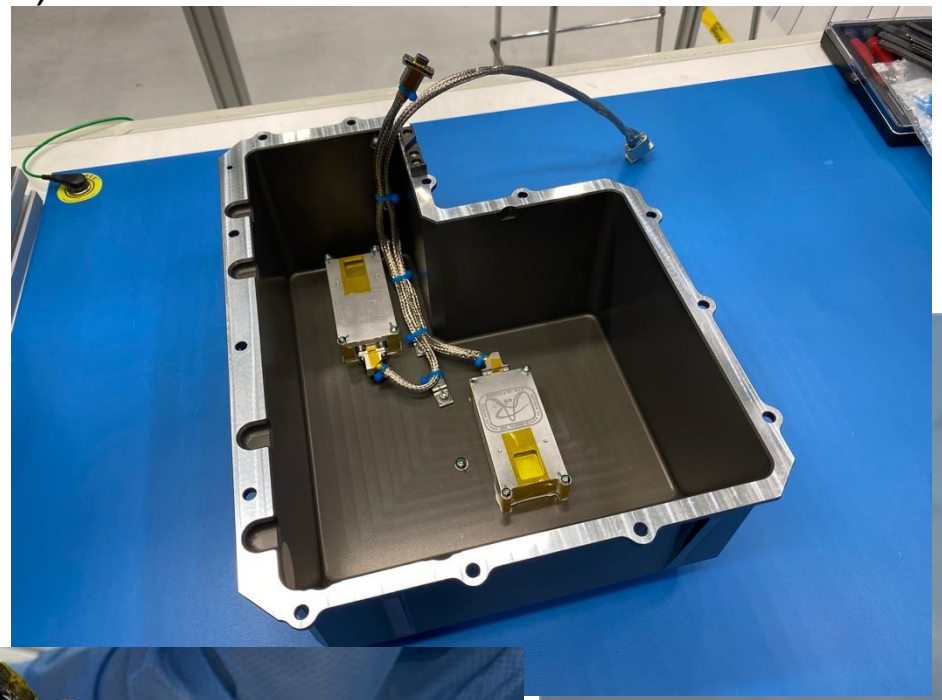


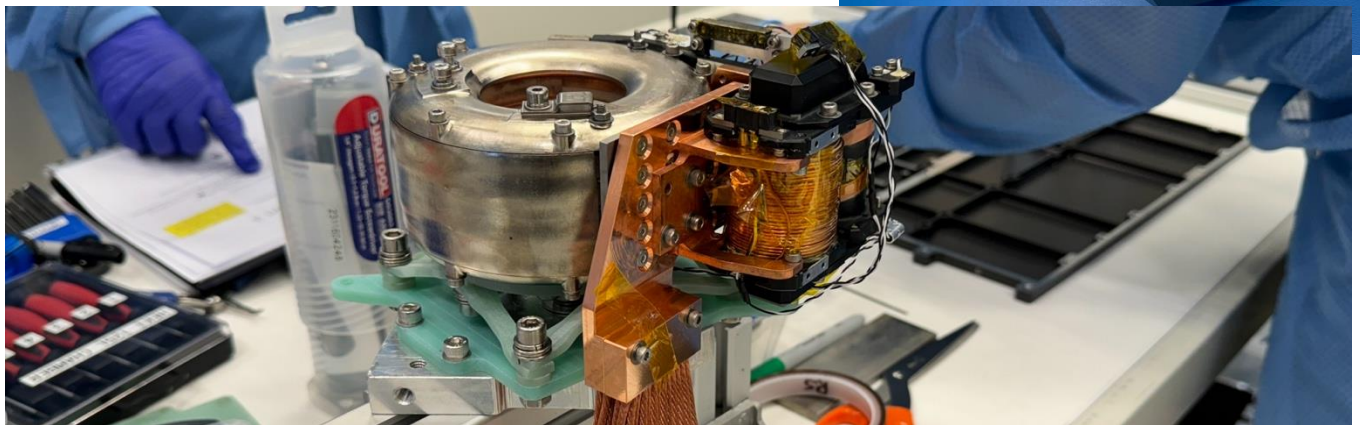


HEKI (ISS open-space)

Paihau-Robinson Institute (NZ) experiment Heki with their superconducting magnet and 2x HardPix's launched to ISS on Sep 15 (2025).





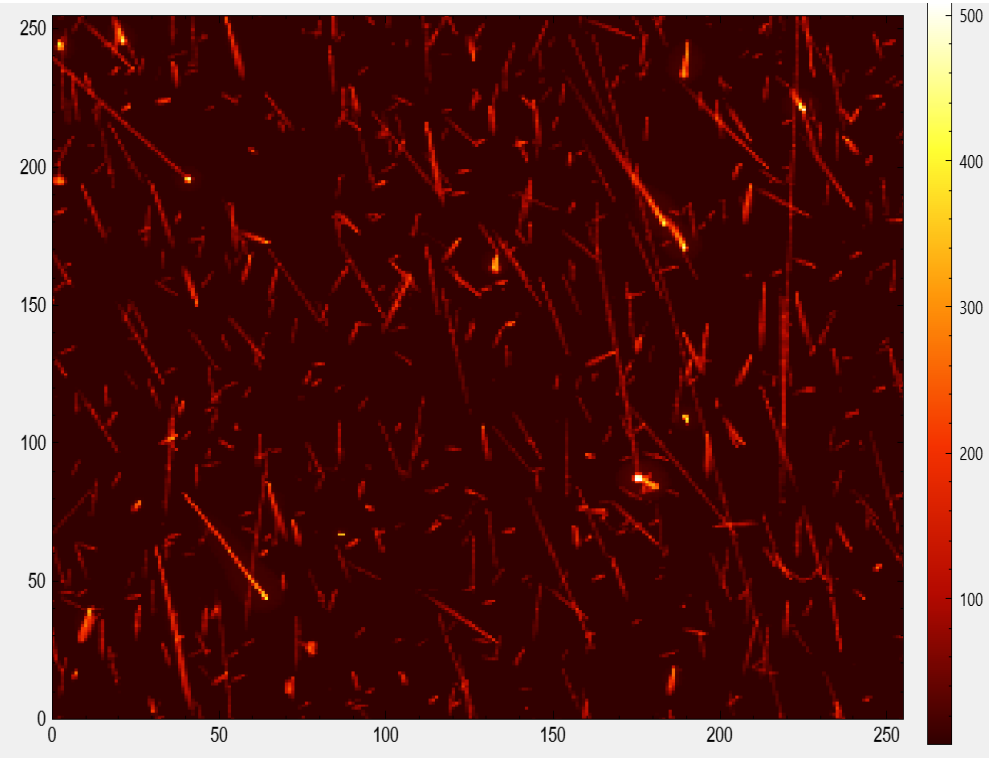


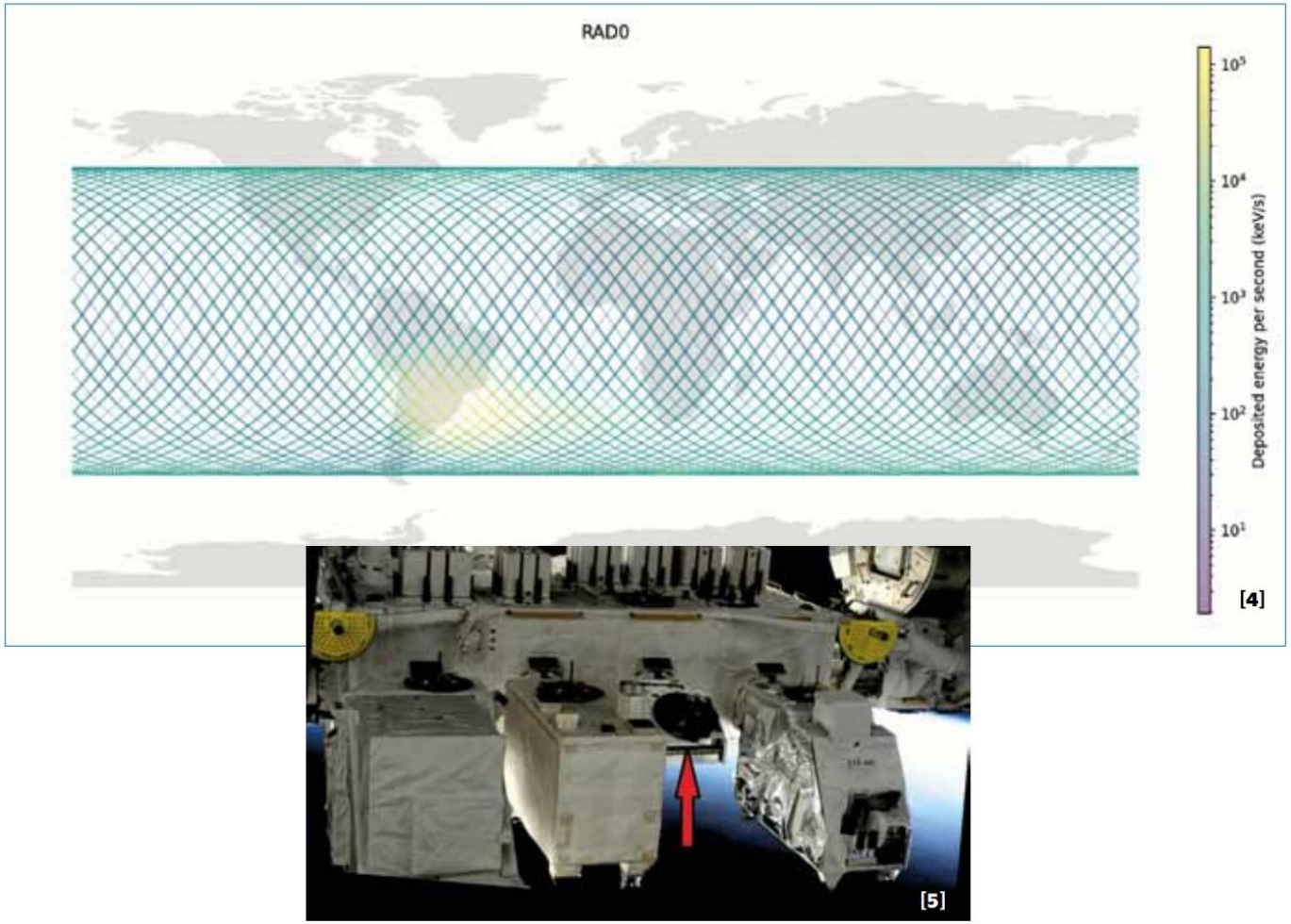


HEKI (ISS open-space)

NG-23 Cygnus XL docked with ISS on Sep 19 (2025).

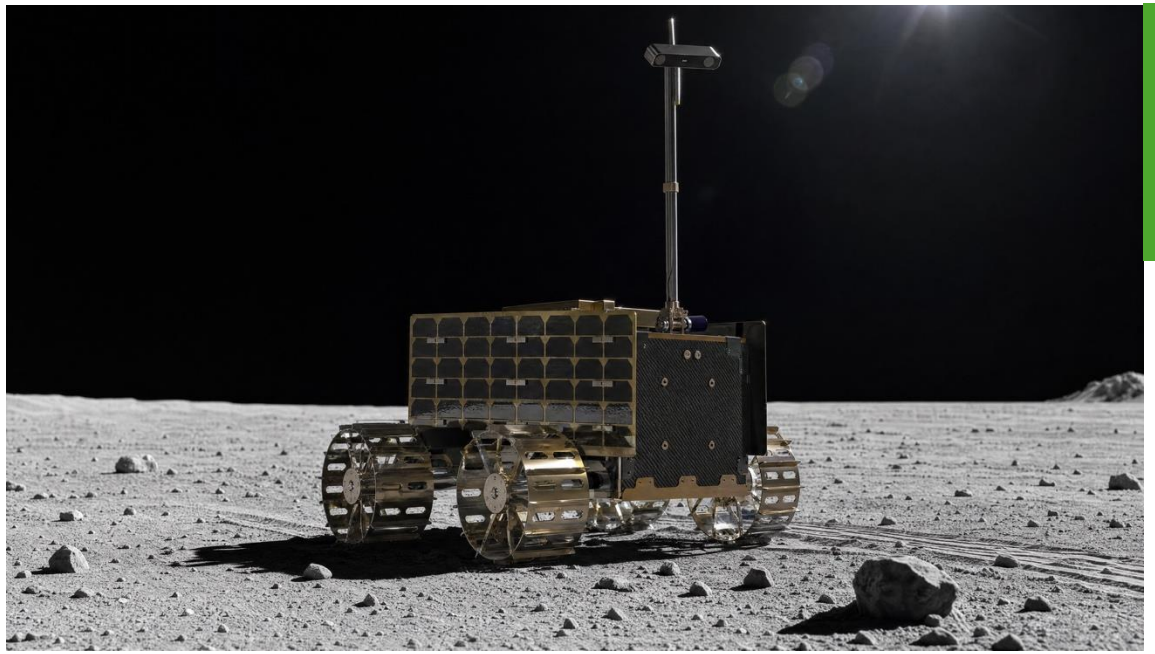
Heki installed on NREP on Sep 27 (2025).





MAGPIE mission

Mission for **A**dvanced **G**eophysics and **P**olar **I**ce **E**xploration

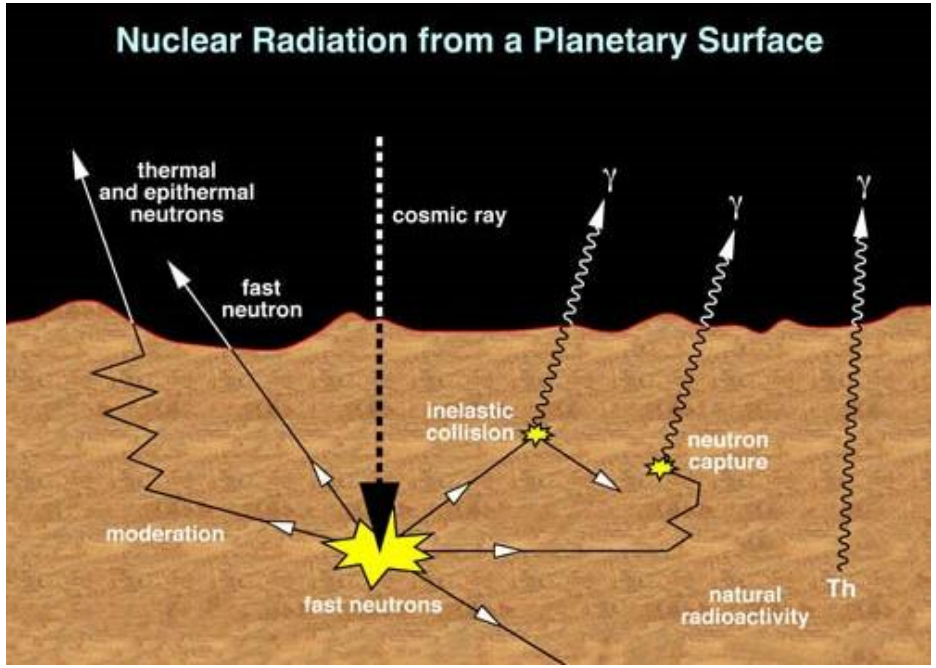


HP - Telescope Lander (Radiation Monitor)

HP - Telescope Rover Bottom (PE)

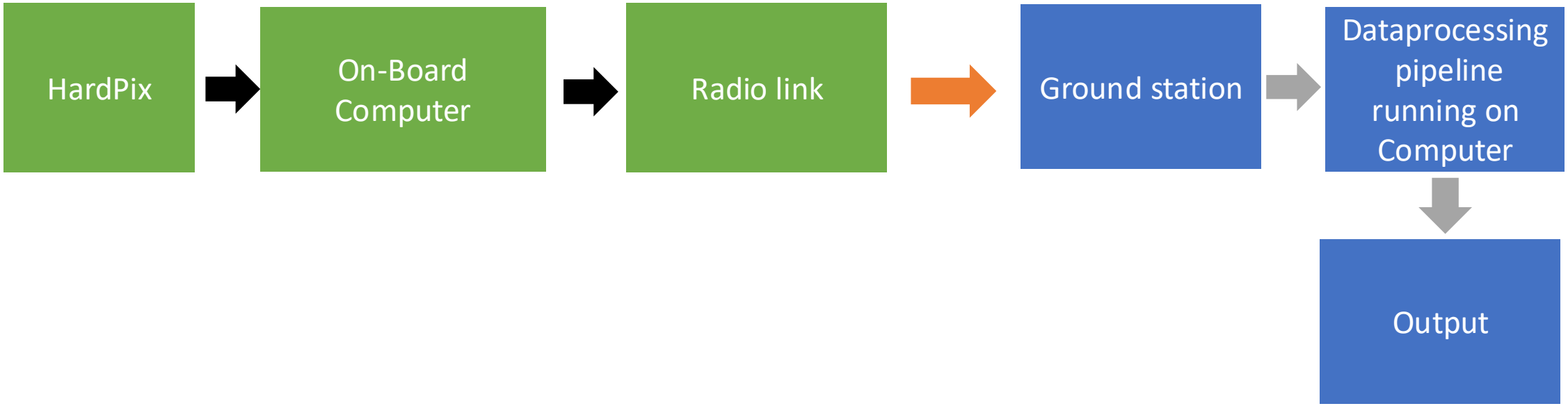
HP - Telescope Rover Bottom (Gd+LiF)

The need to process data, classify particles, search for coincidences and filter events



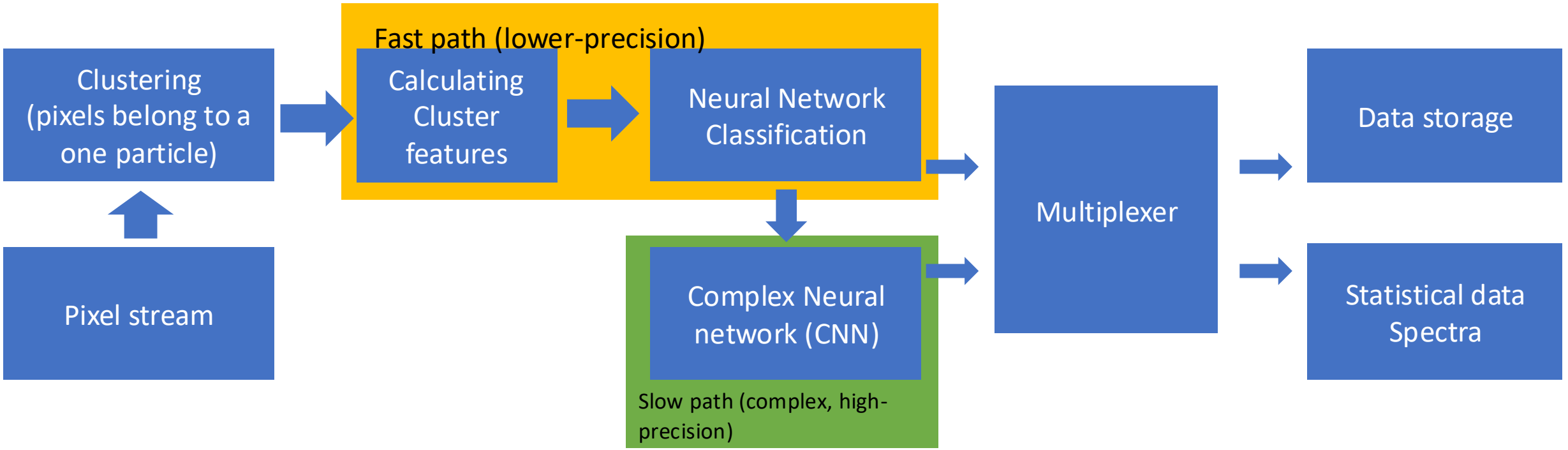
Dataprocesssing

Motivation: The HardPix has been tested in RAW mode on several missions, during which the data is sent to the ground only partially processed. It is transmitted to the ground via a radio link (bottleneck).



Dataprocesssing

Strategy: select only interesting data (particles) and save completely to storage and process the rest data into statistical data (LET spectra). Select a method for hardware with limited resources (dual-core 300MHz, 128MB RAM in the HardPix).



CNN - Cluster recognition

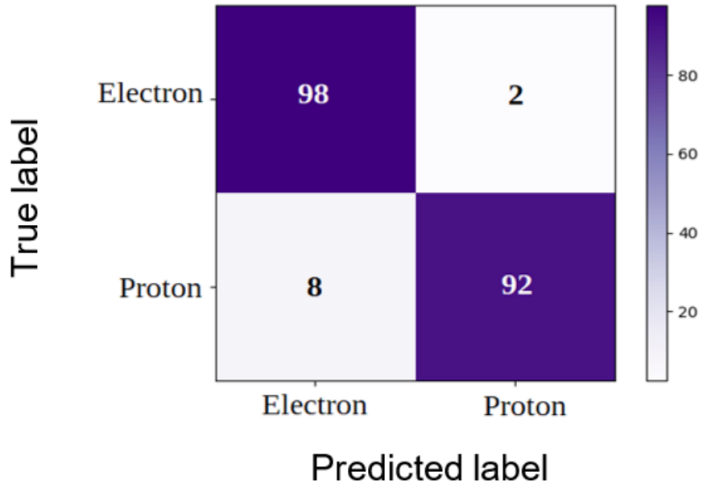
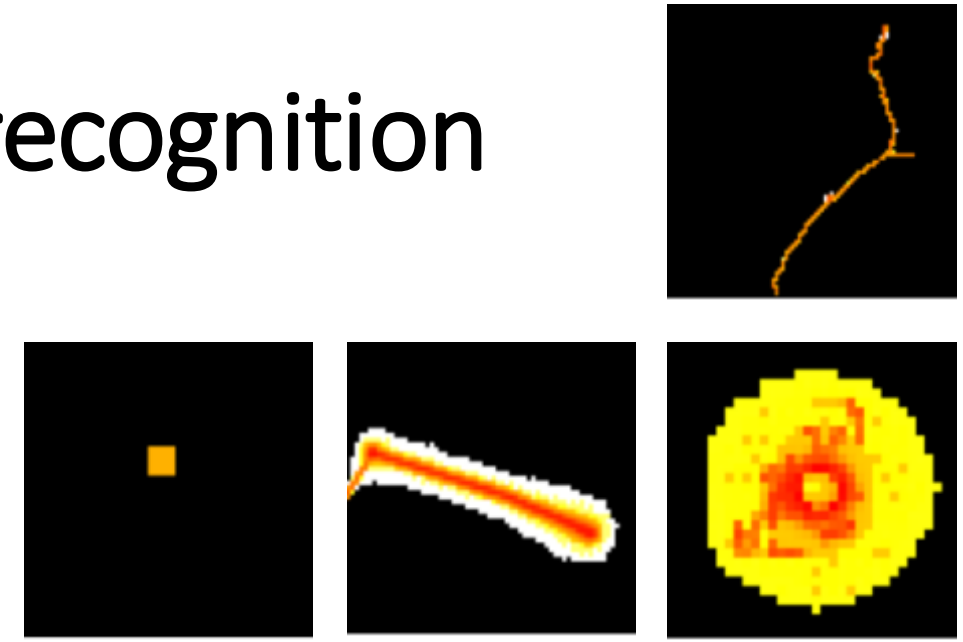


Fig. 5. Normalized confusion matrix for the type recognition. The numbers are in percent.

1000 clusters/s

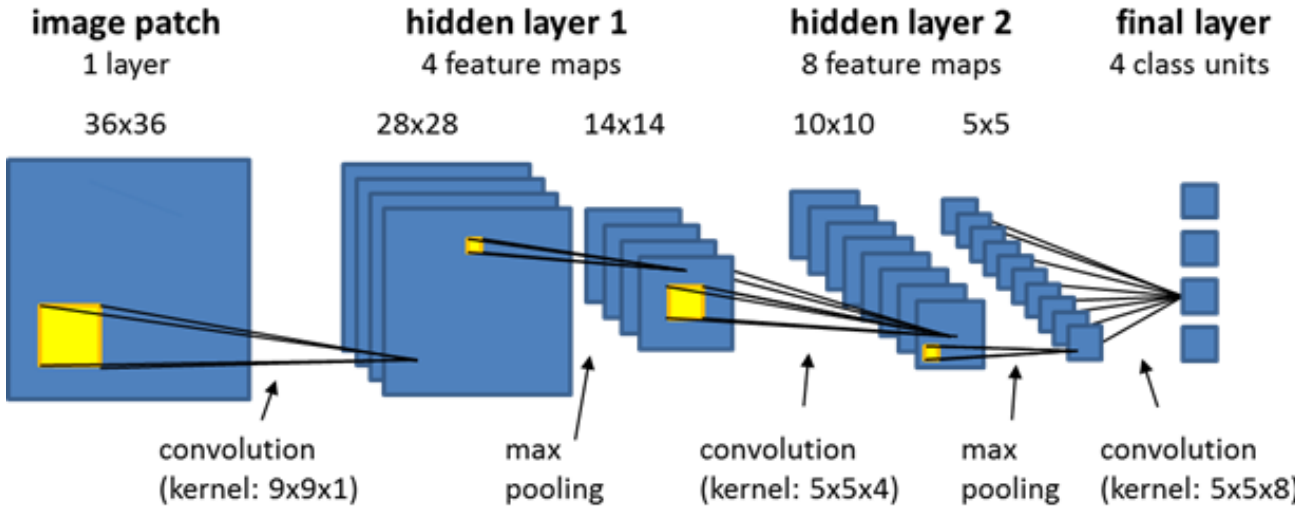


Pixel Matrix [36,36]

Cluster [36x36]

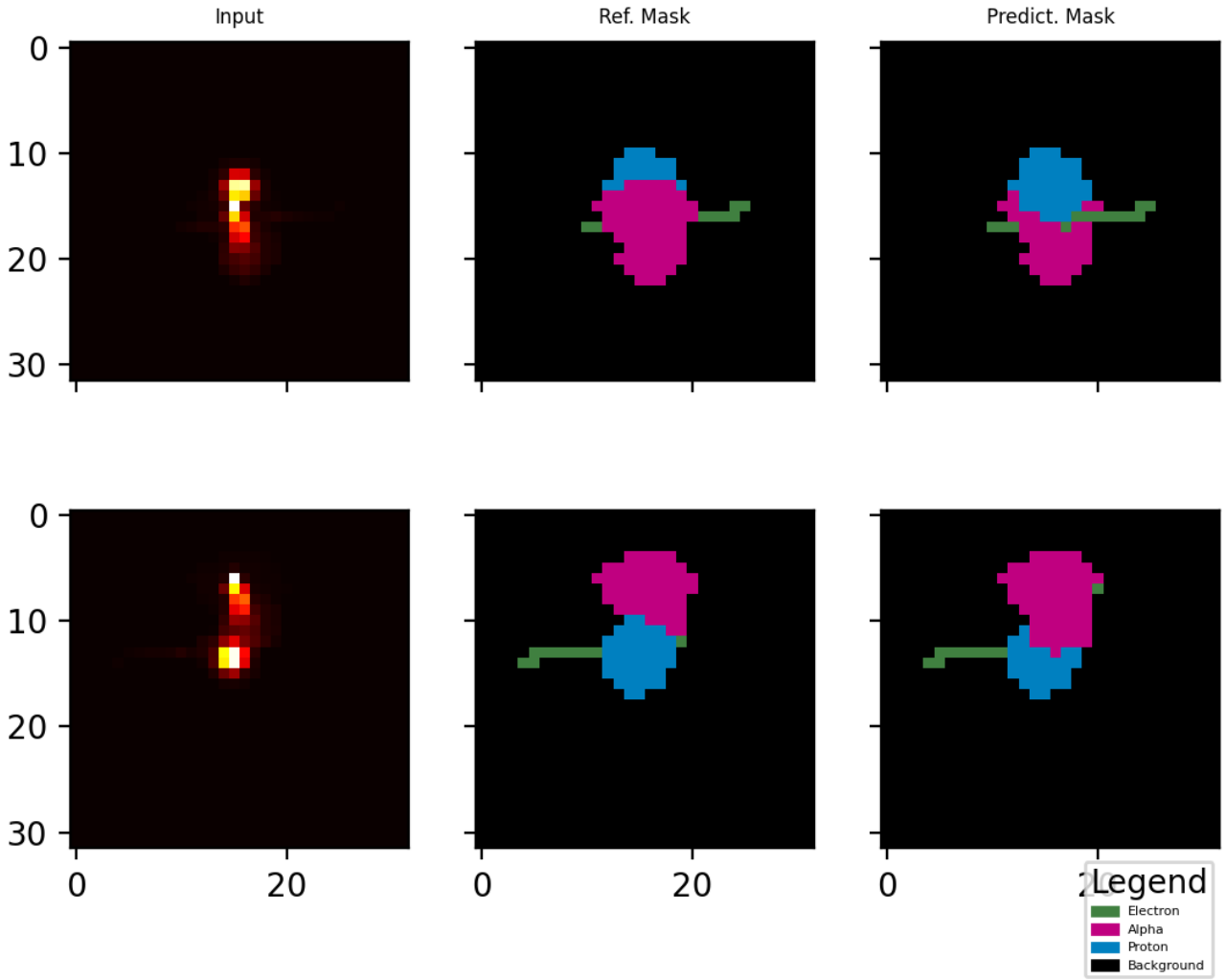
CNN Classification

Probability vector
[Proton, Electron, Other]

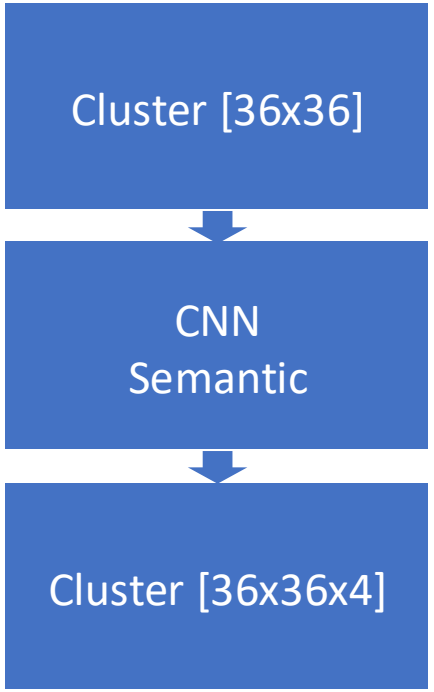


M. Ruffenach et al., IEEE Trans. Nucl. Sci., vol. 68, no. 8, pp. 1746–1753, 2021, doi: 10.1109/TNS.2021.3071583

CNN - Semantic segmentation



A way to separate strange particles (not clearly classifiable) that are caused by several types of particles overlapping. Computationally very intensive



Each pixel has a probability vector [Background, Proton, Alpha, Electron]

Precalculated Cluster with NN - Result

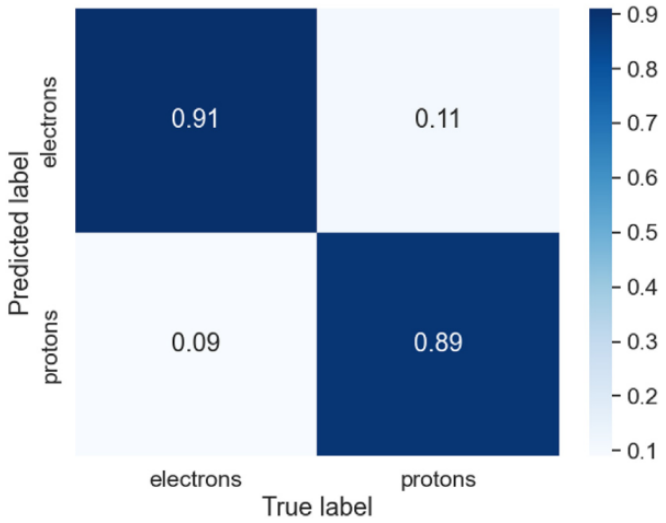


Fig. 4. Confusion matrix for the neural network between truly and falsely identified protons and electrons.

20000 clusters/s

Cluster

↓

Calculating Cluster features (roundness, ratio of total energy vs number of pixels)

↓

Neural Network Classification

Probability vector
[Proton, Alpha, Electron]

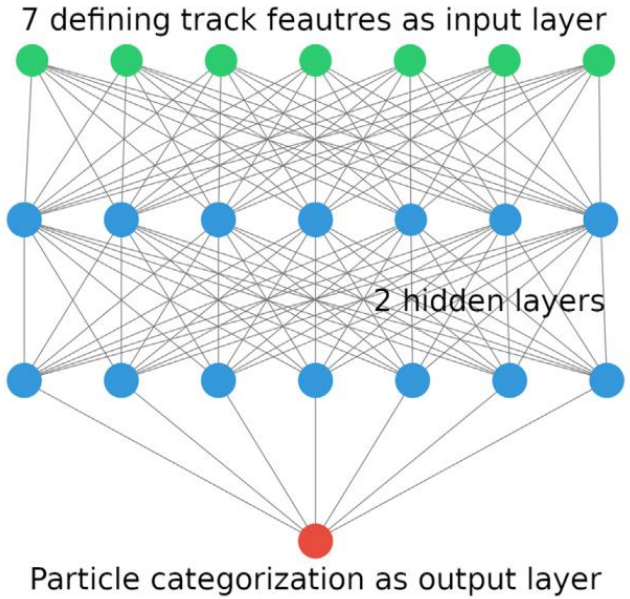


Fig. 3. Scheme of the neural network with one input layer with seven features, two hidden layers and one output layer.

S. Gohl, B. Bergmann, M. Kaplan, and F. Němec, "Measurement of electron fluxes in a Low Earth Orbit with SATRAM and comparison to EPT data," Adv. Space Res., vol. 72, pp. 2362–2376, 2023, doi: 10.1016/j.asr.2023.05.033.

Summary

- COTS can be used on LEO orbit and allows a good power-to-performance ratio
- We have verified that the platform works in space
- Ongoing missions: MAGPIE, CevroSat2, Cassini

Next step:

- Complete the classification of particles
- Implement the conversion of the LET spectrum from deposited to kinetic energy
- Opening up the platform to other partners for their own applications

Thank You


INSTITUTE OF EXPERIMENTAL AND APPLIED PHYSICS
CTU IN PRAGUE

Question?


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