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CZECH TECHNICAL UNIVERSITY IN PRAGUE

Results from Radiation Spectrometer HardPix Onboard the ISS and ION Satellites

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Czech Technical University in Prague

Timepix-based radiation monitors

- It is highly desirable to have a radiation monitor onboard any space mission but they used to be big and heavy for modern age of cubesats.



Standard Radiation Environment Monitor (SREM)

Mass : 2.64 kg

Volume: 2.5 liters

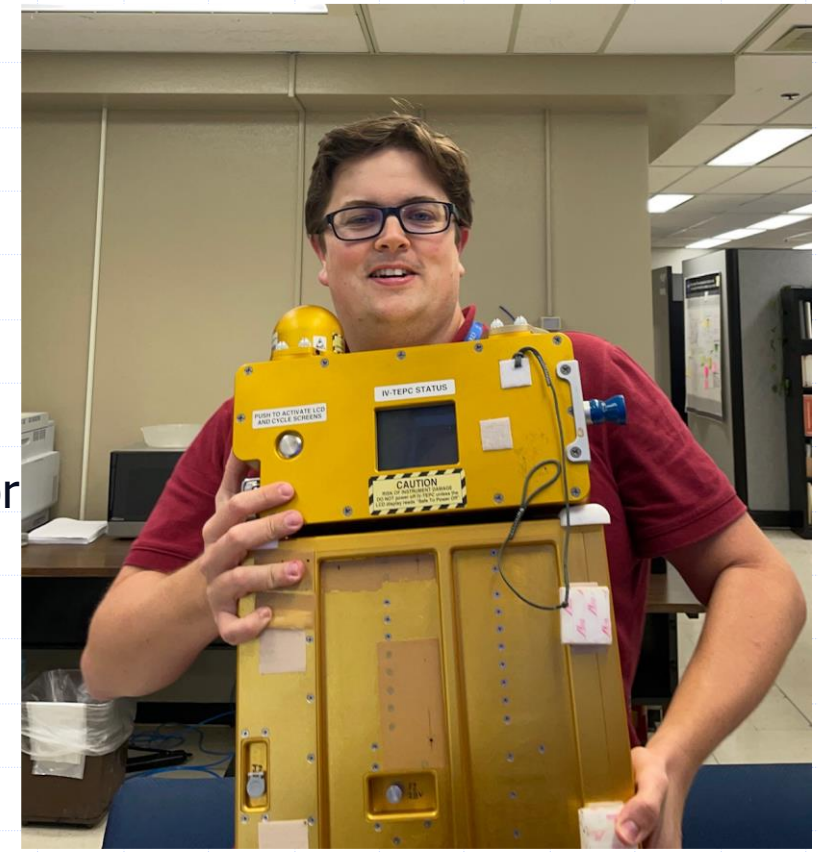


Next Generation Radiation Monitor (NGRM)

Mass : 1.17 kg

Volume: 1.3 liters

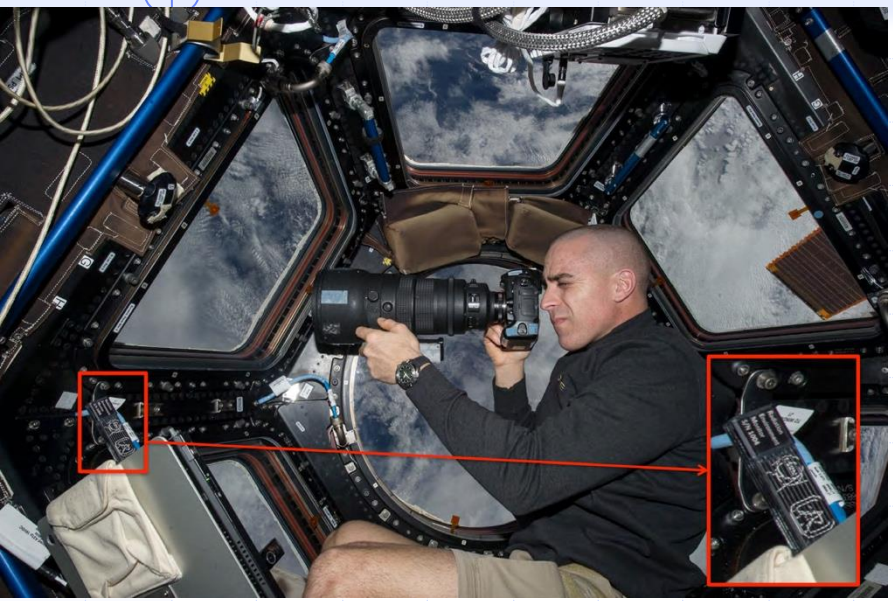
- Timepix-based radiation monitors are miniature, light and successful in space

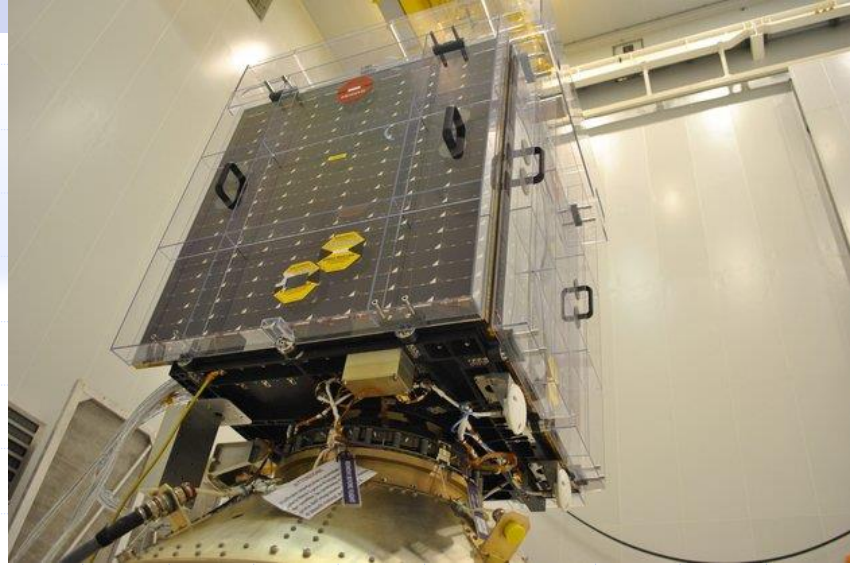




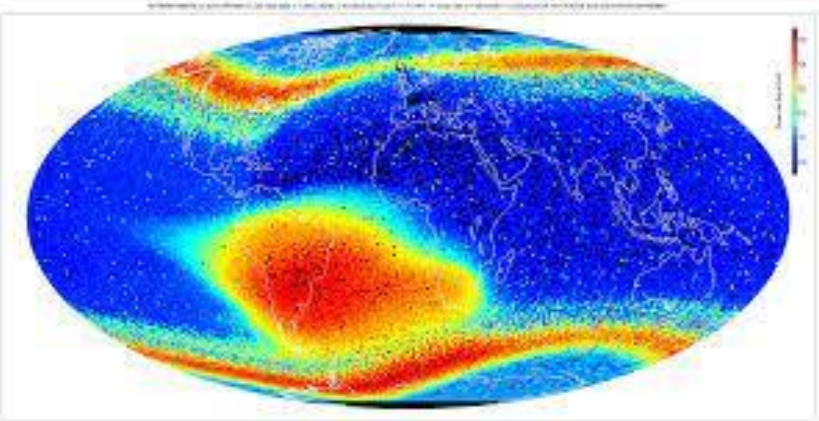
Courtesy of Stuart George NASA

IEAP CTU Space heritage



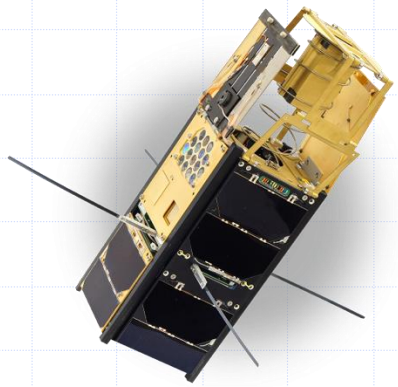


- 5 Timepix-Lite detectors deployed onboard ISS in 2012 in collaboration with NASA and the University of Houston. Online monitoring of radiation environment inside the station.

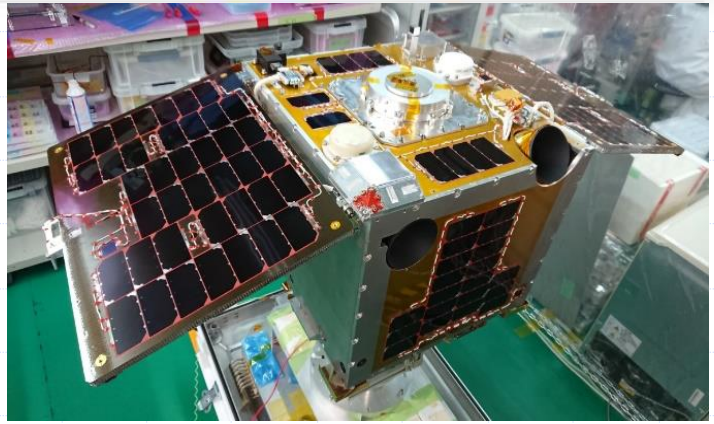


  - SATRAM onboard ESA satellite Proba-V, launched to LEO in 2013. The first deployment of Timepix in open space. (Stefan Gohl's talk)





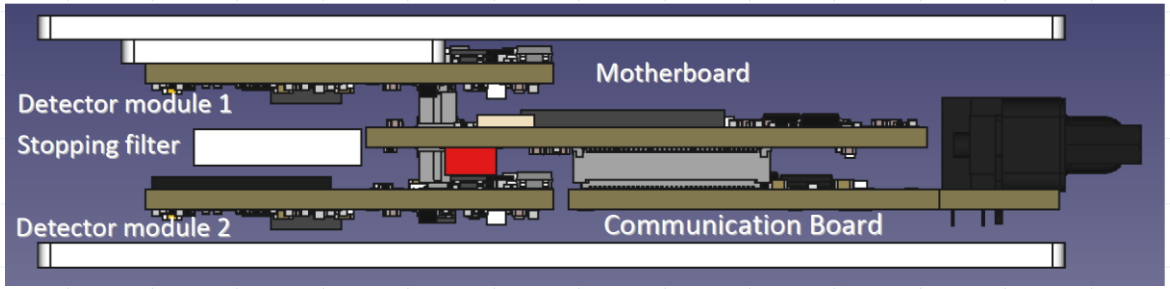




HardPix Radiation Spectrometer

- Based on Timepix success, we developed a universal radiation monitor for space applications called HardPix
- Modular design with 1 or 2 Timepix3 layers and interchangeable interface
- On-board processing (Xilinx ZYNQ Dual Core A9) – energy spectroscopy, particle identification, dosimetry



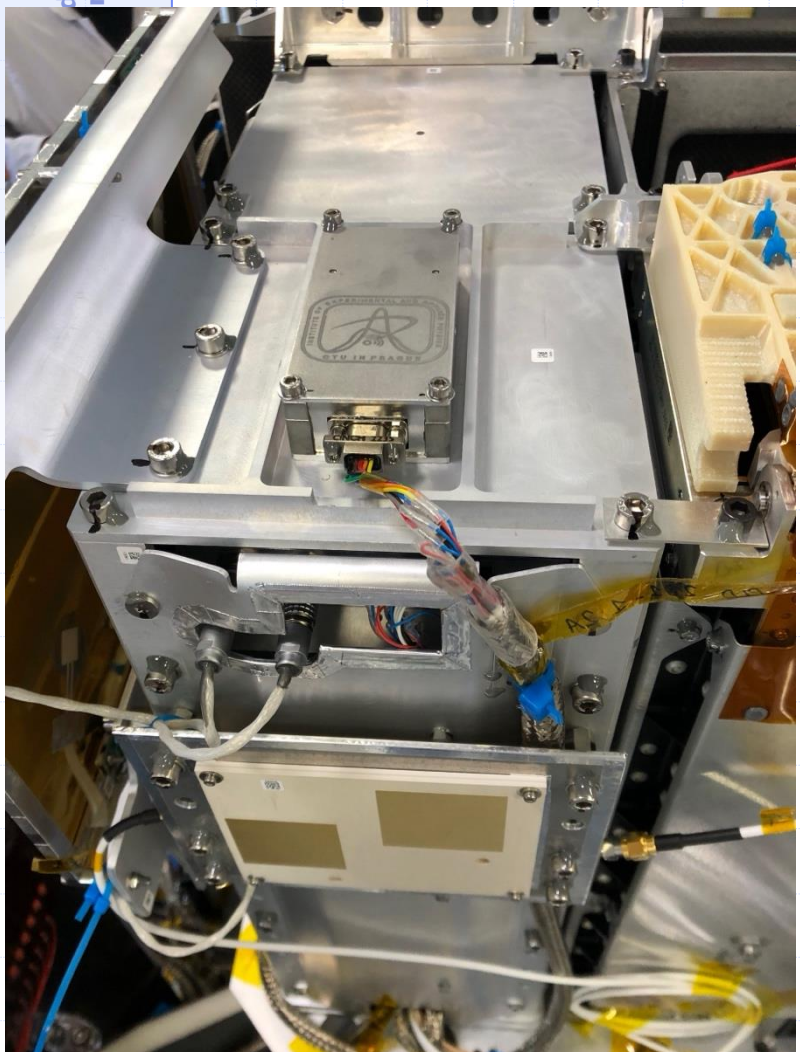


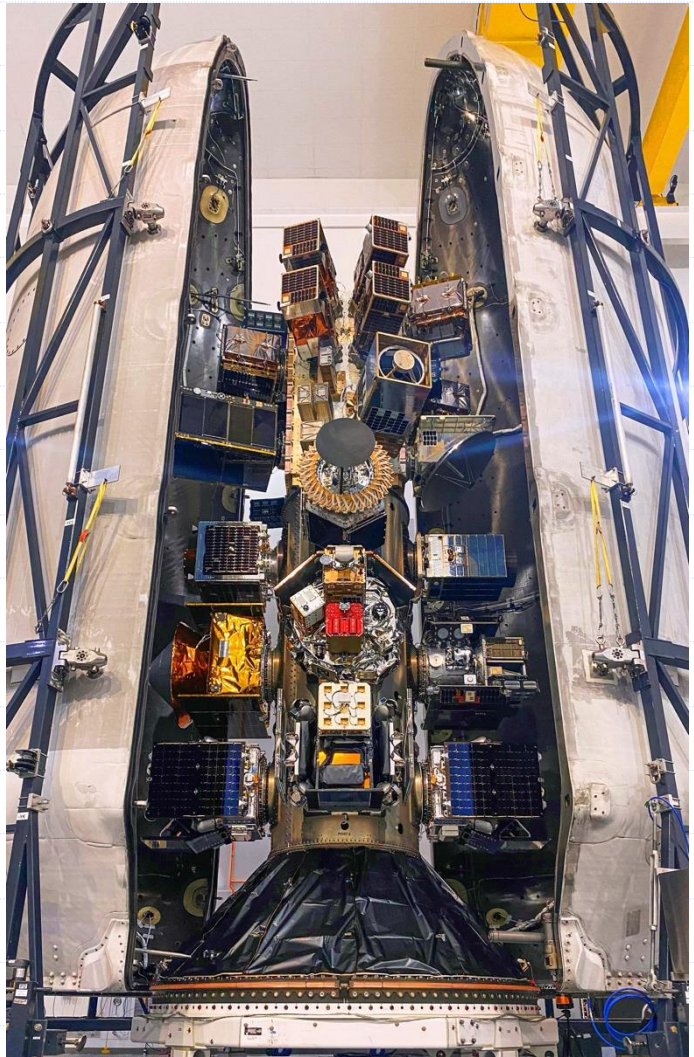
- Dimensions 81 x 40 x 22 mm (<0.1 U)
- Mass 150 g
- Power ~4 W

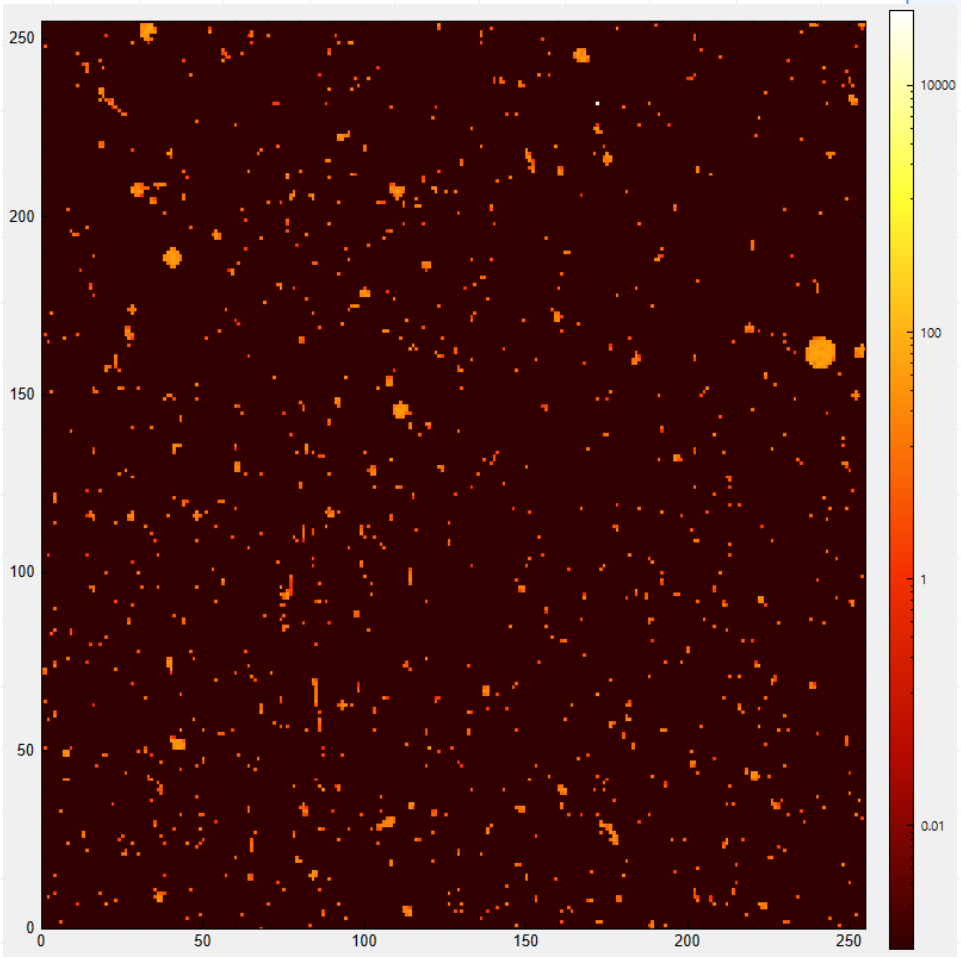
- Constant development – see Milan Malich's talk on Thursday for engineering details

HardPix space heritage - SWIMMR1 launched in 2023

HardPix prototype launched to space in June 2023 onboard D-Orbit ION satellite as part of UKRI STFC SWIMMR (Space Weather Instrumentation, Measurement, Modelling and Risk) programme.



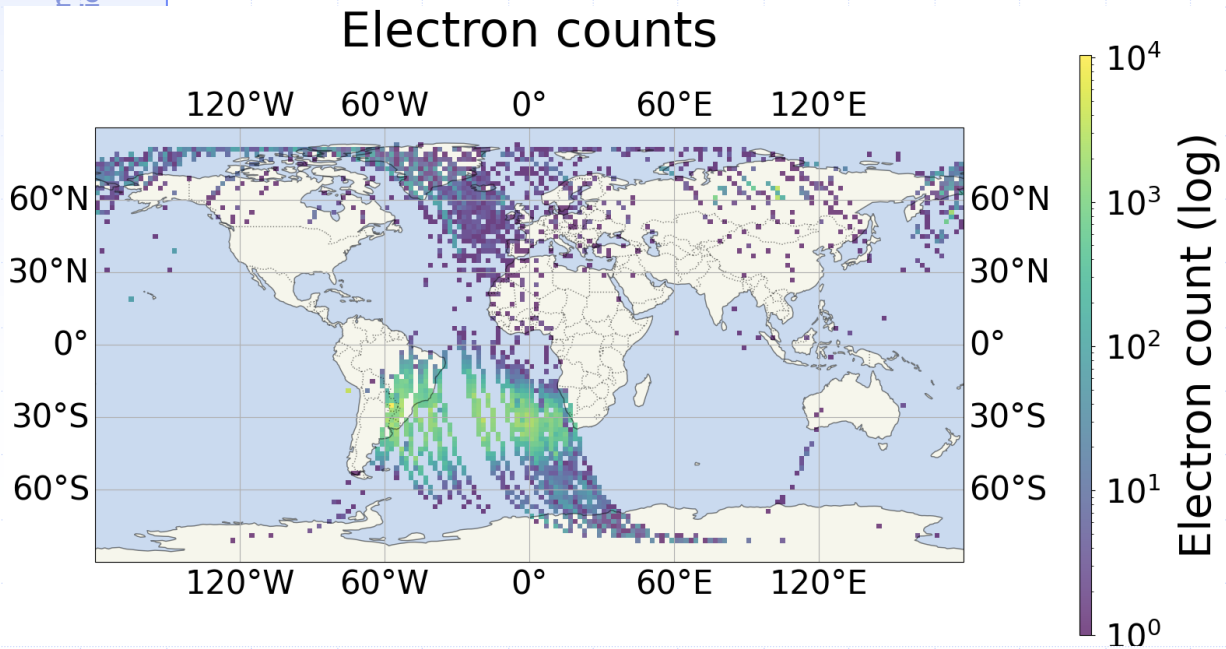


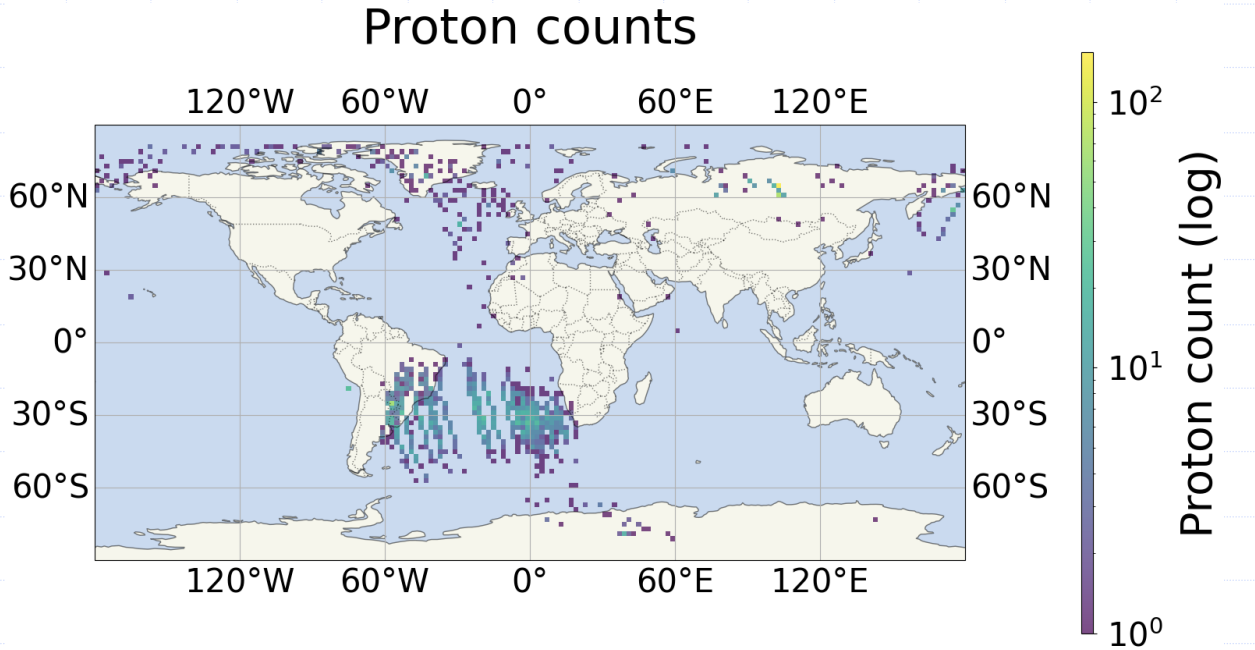


Credit: SpaceX, D-Orbit

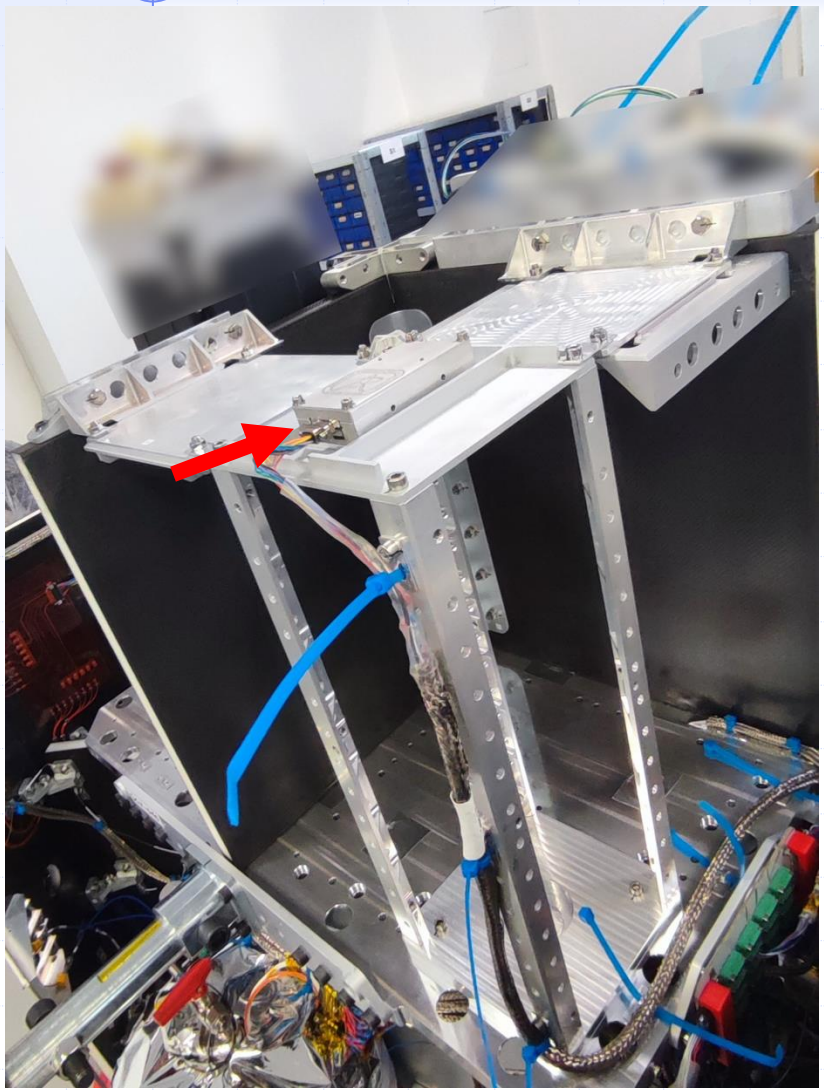
SWIMMR1 data

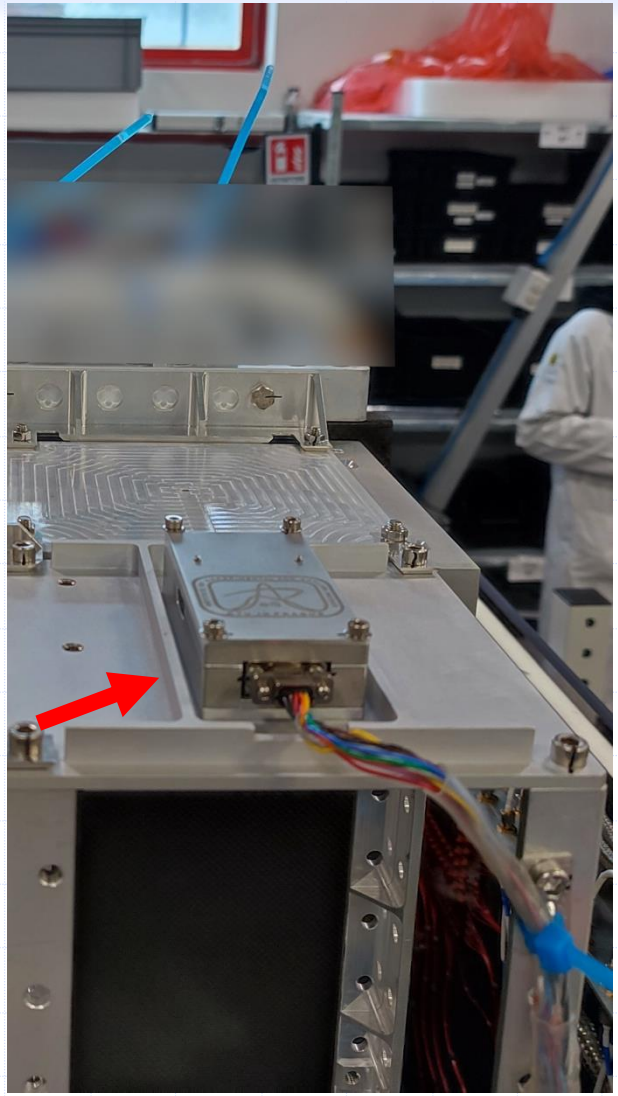
No time for testing before launch – plenty of errors and noise – very little useful data

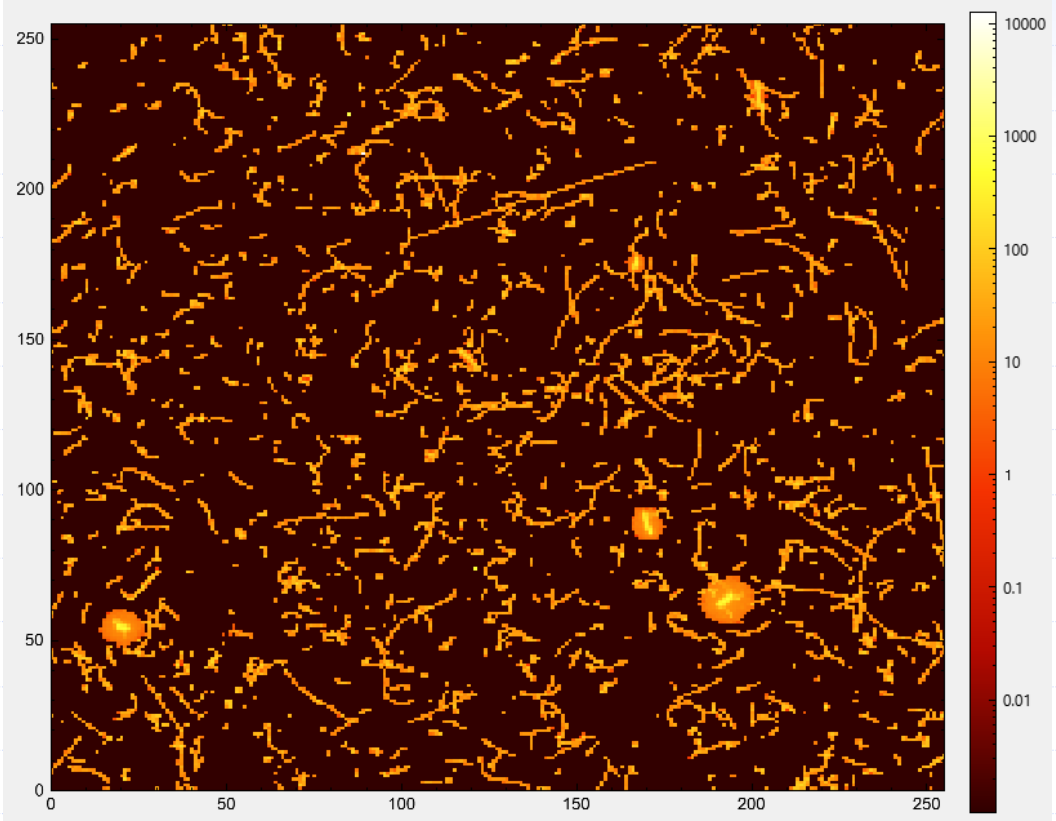




SWIMMR2 launched 1/2025 – apogee 1200 km





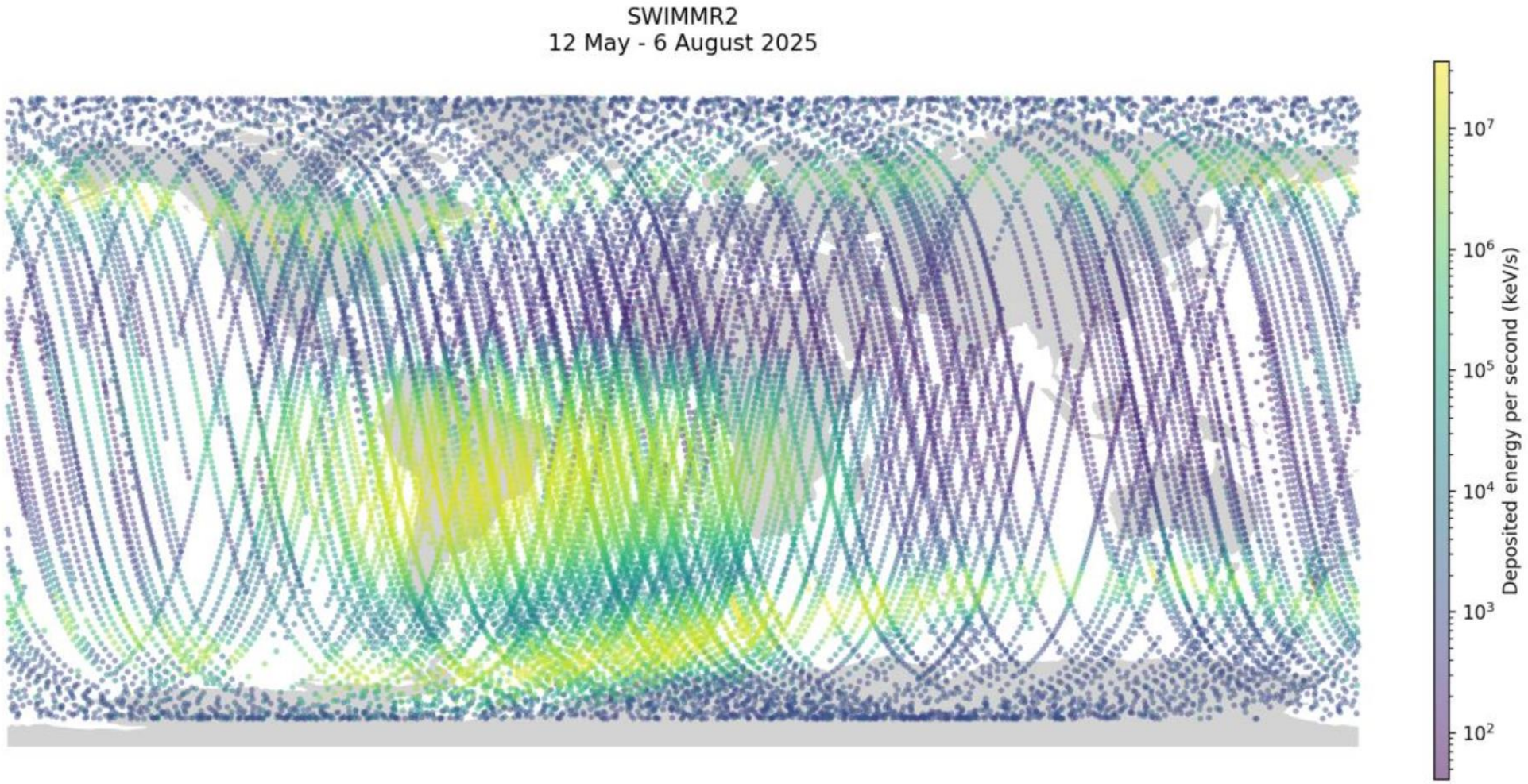


SWIMMR2 data 05-08/2025

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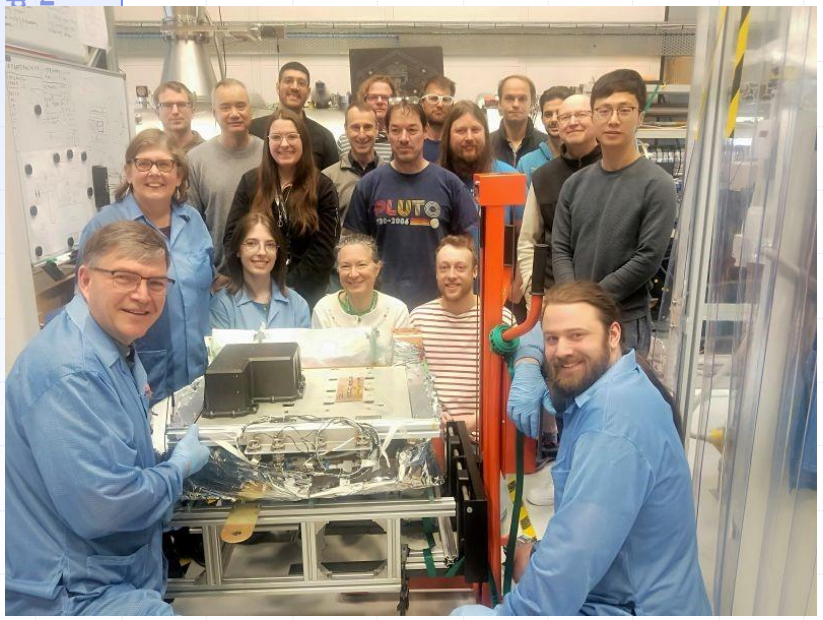
Updated FW working great, data limited by ION transfer rate (~5 MB/day) – data taken during apogee.

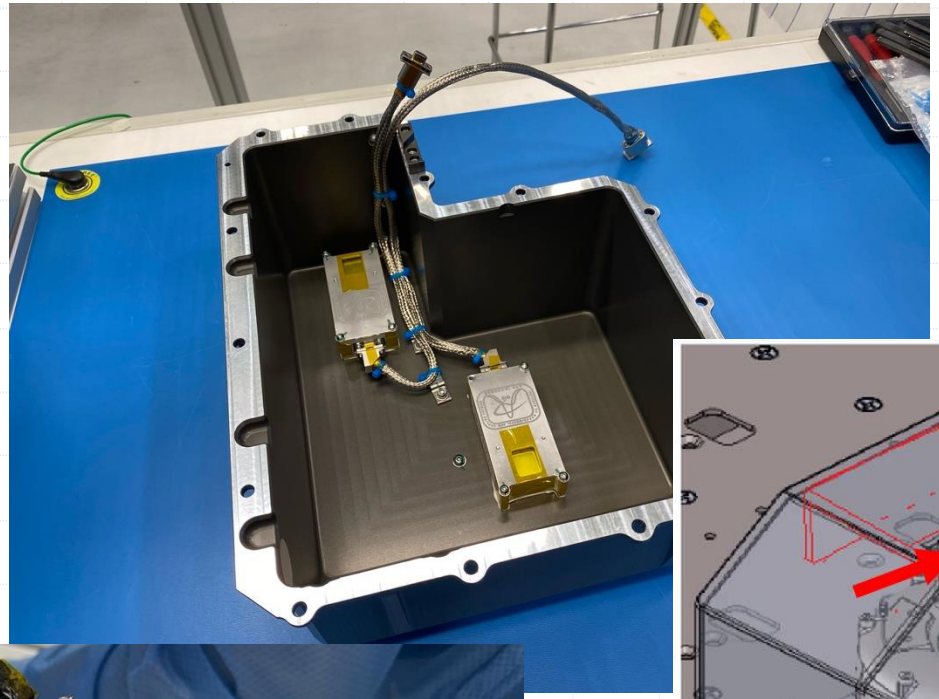
HardPix acquiring data again since January 2026

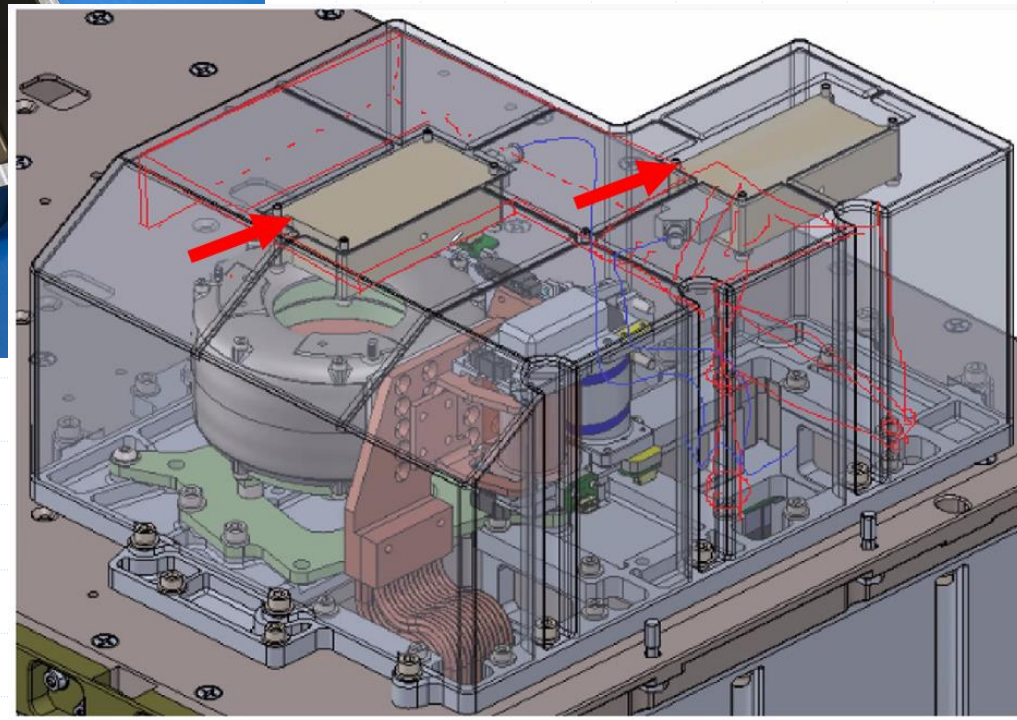


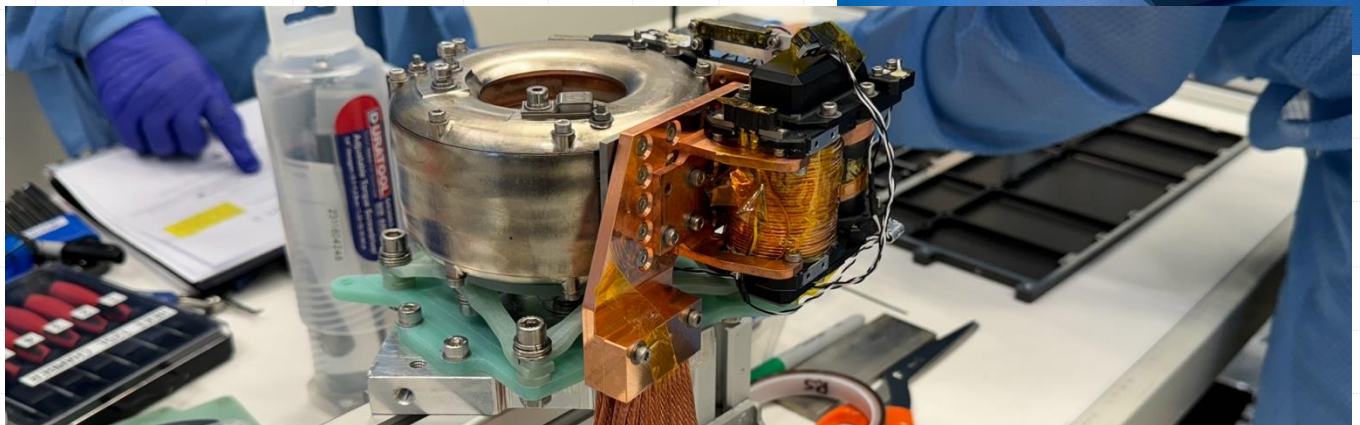
Heki – 2x HardPix on ISS

Paihau-Robinson Institute (NZ) experiment Heki with their superconducting magnet and our 2 HardPixes launched to ISS on Sep 15, 2025









Heki – 2x HardPix on ISS

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

Heki installed on NREP on Sep 27.

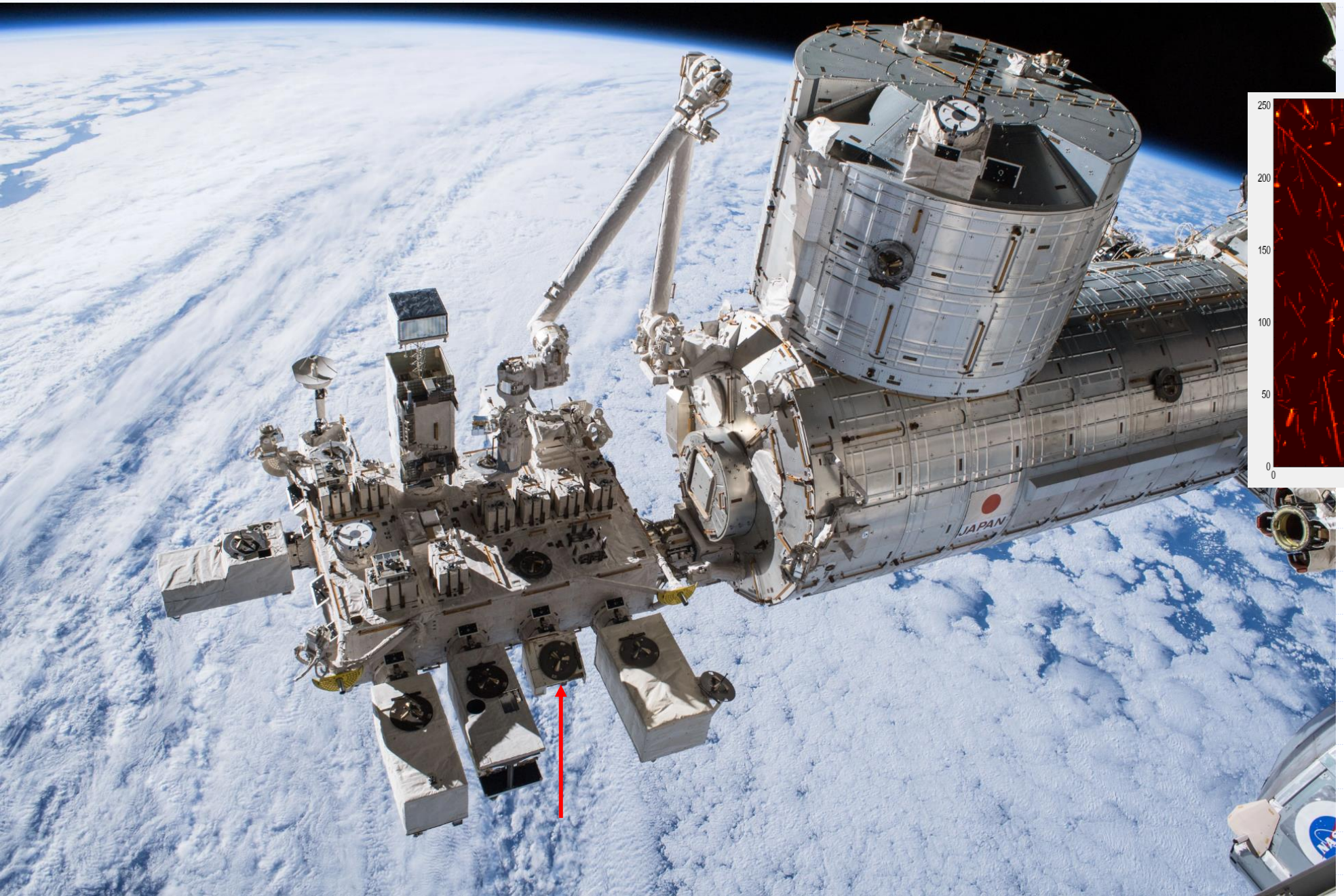


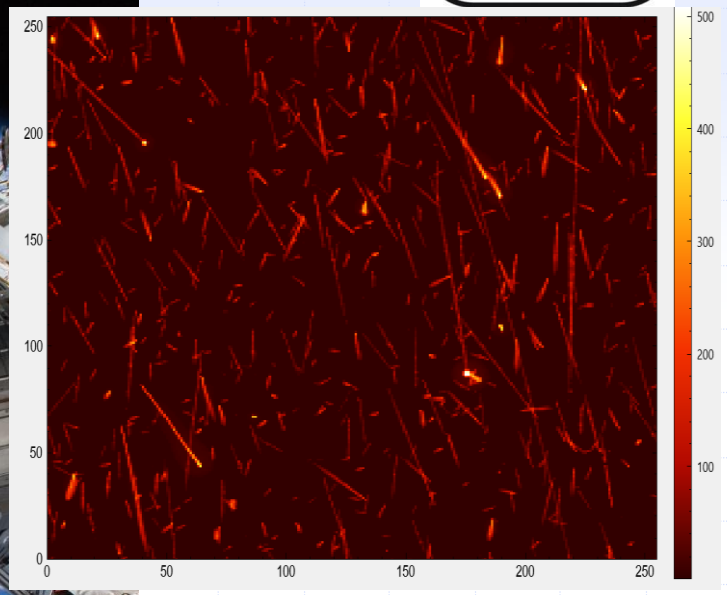






Heki installed outside ISS and powered on (Sep 29), taking data since early Oct. 2025

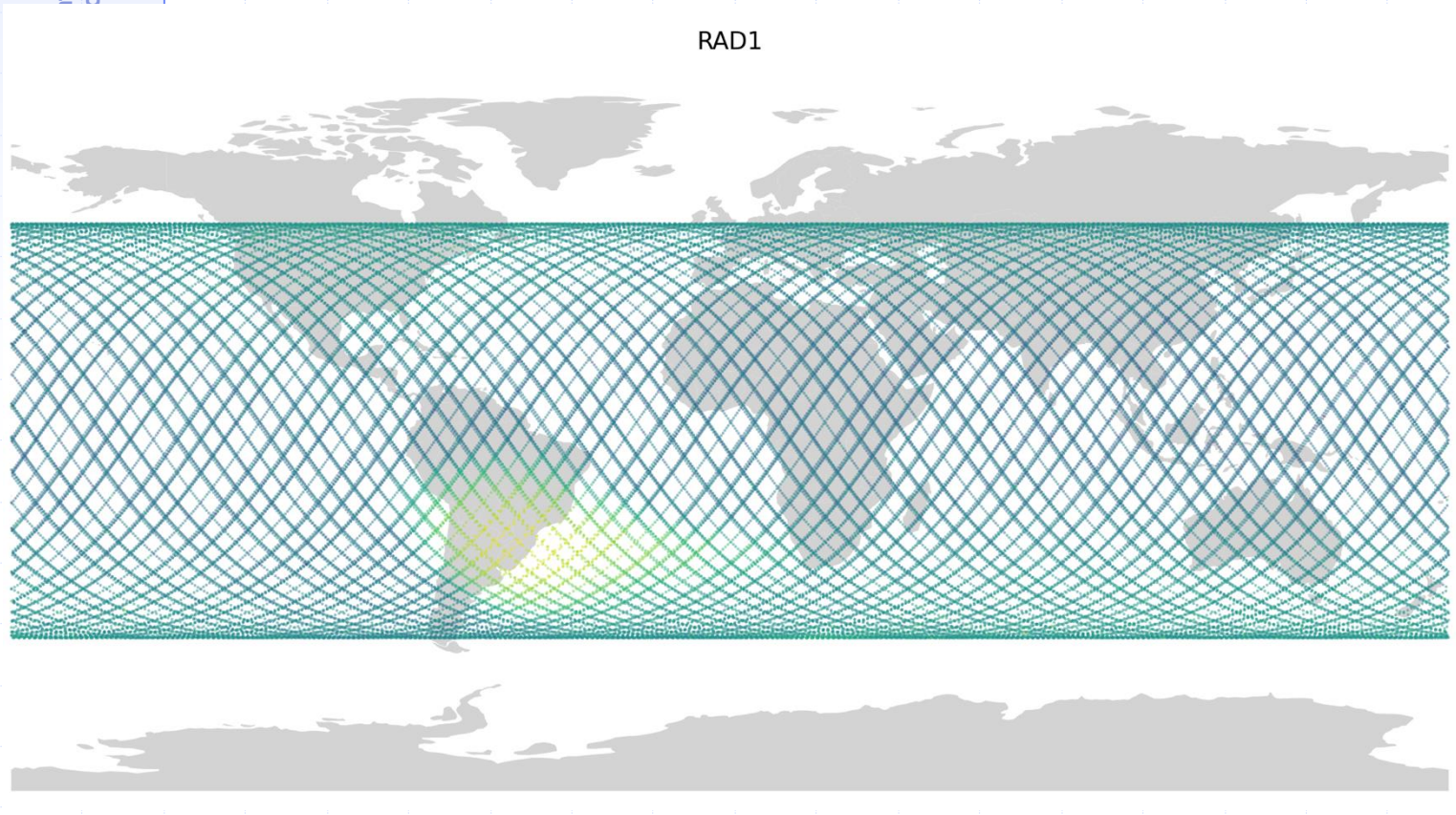


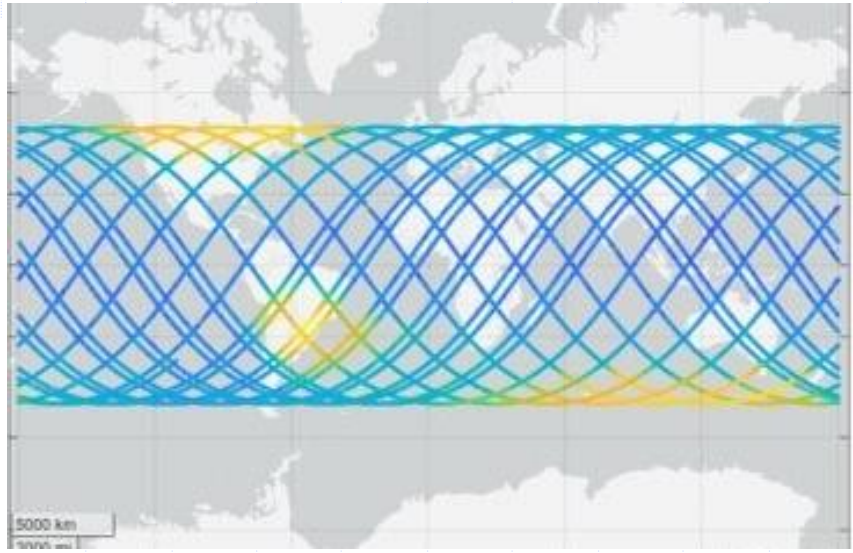


Heki data

Heki measured from 10/2025 to 03/2026 – mission was a success

Over 18 Million particles recorded by each HardPix





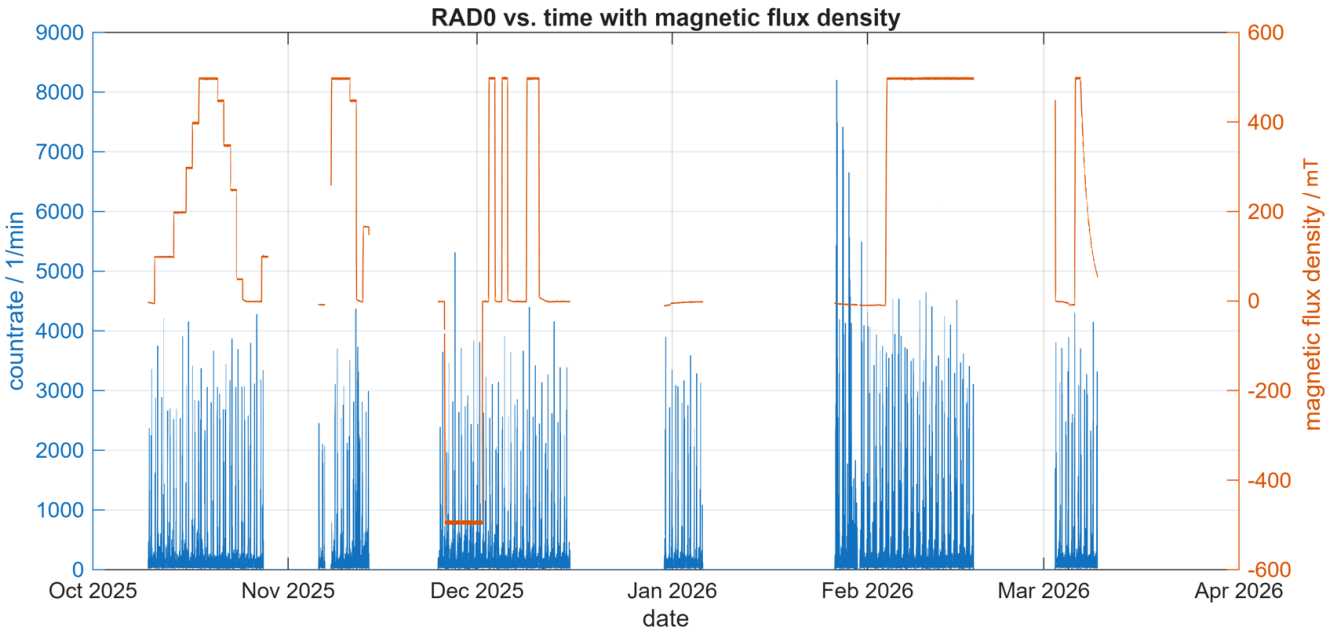
11-12 November 2025 Solar Flare

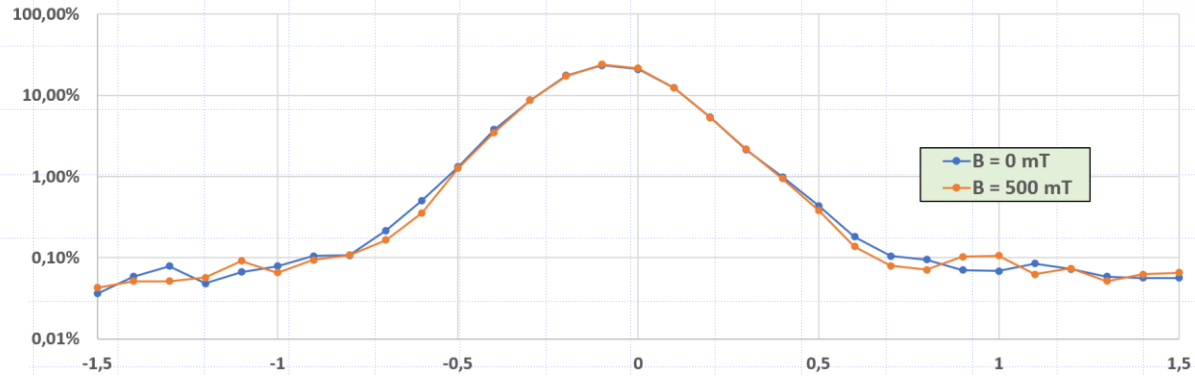
Heki data

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HardPixes outside but ISS fracture control requirements stray magnetic field requirement led to thick shielding of the Heki experiment.

ISS attitude meant Heki was exposed to sunlight and HardPixes were close to operating temperature limit and had to be switched off – gaps in data.



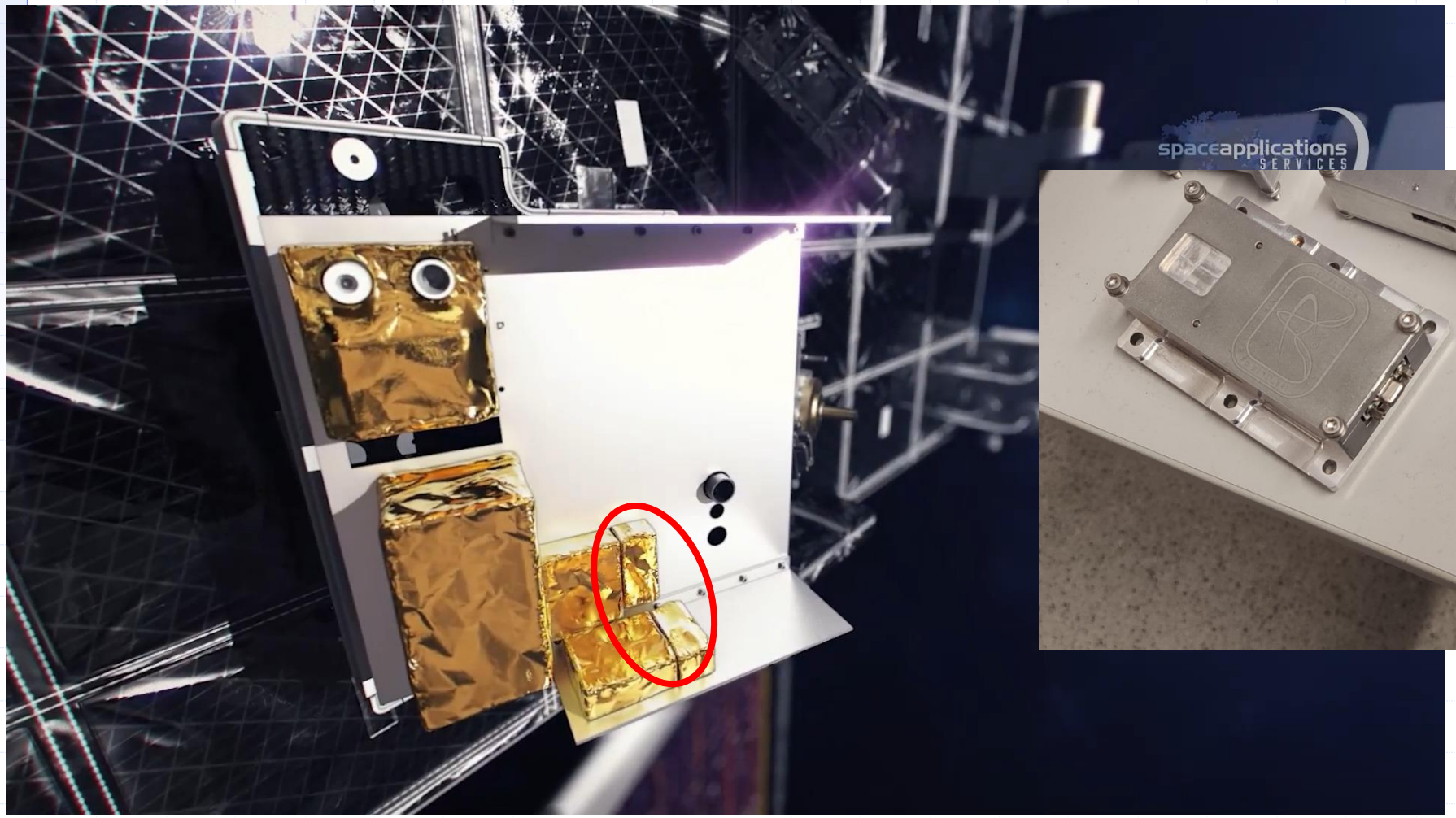


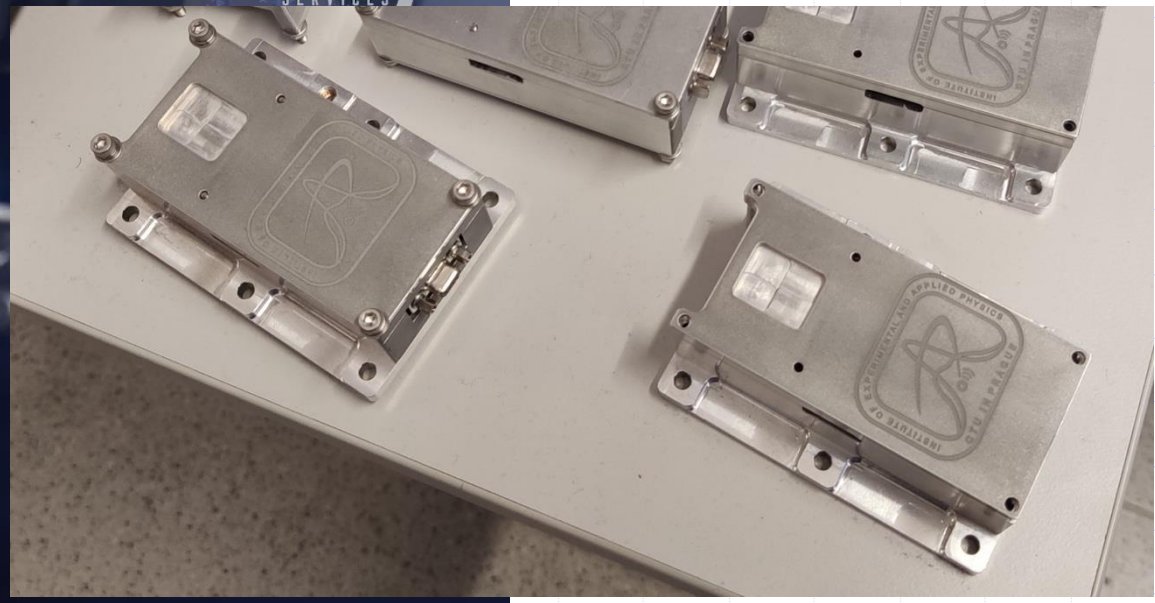
No visible effect of the magnetic field on number of detected particles.

Heki returned on Earth – we will beam test the experiment.

HardPix Radiation Spectrometer – ERSA Gateway

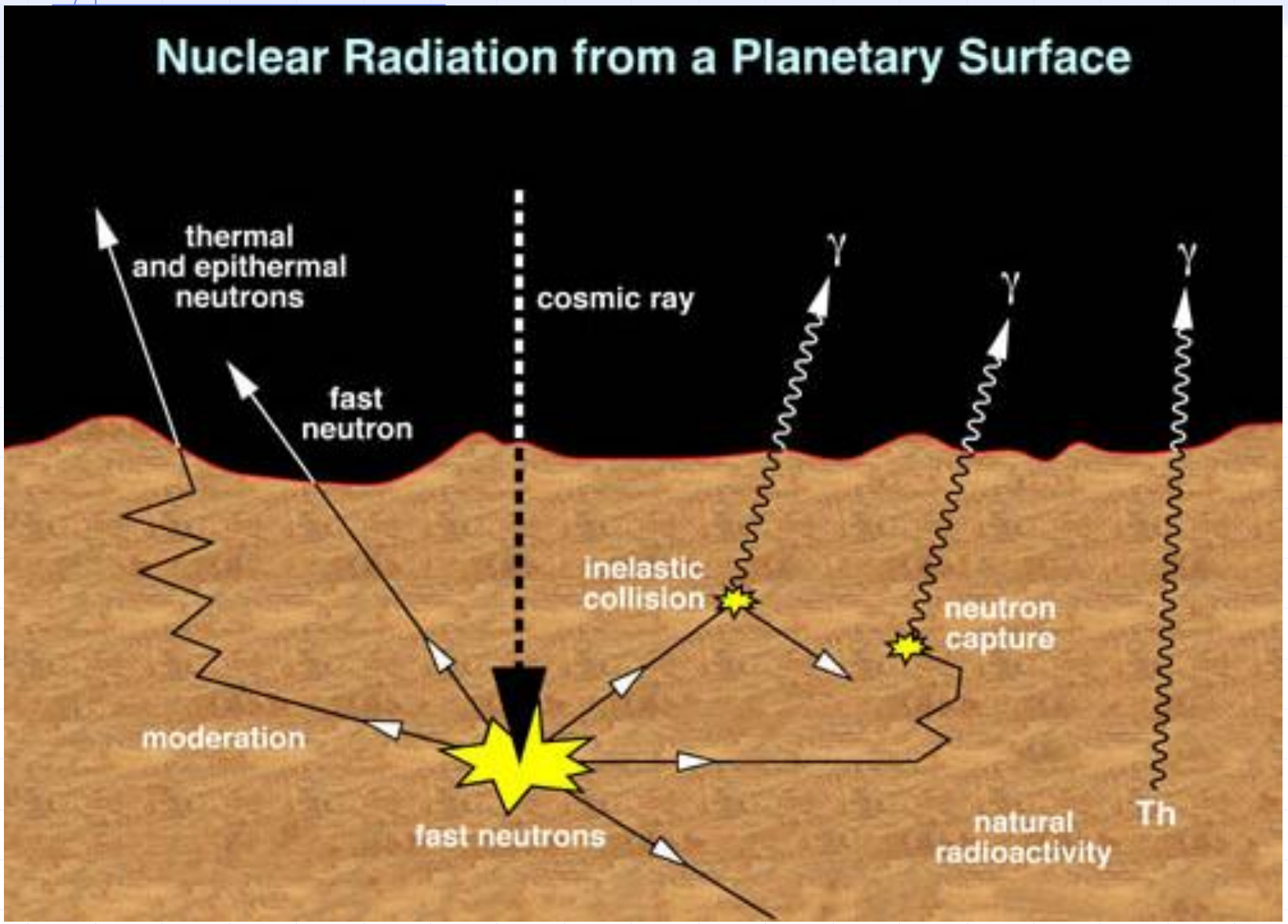
2x HardPix was supposed to be part of the scientific instrument suite from ESA called European Radiation Sensors Array (ERSA) placed outside Lunar Gateway. Waiting for another mission opportunity.





Credit: SAS Belgium

HardPix will still go to the Moon to search for water



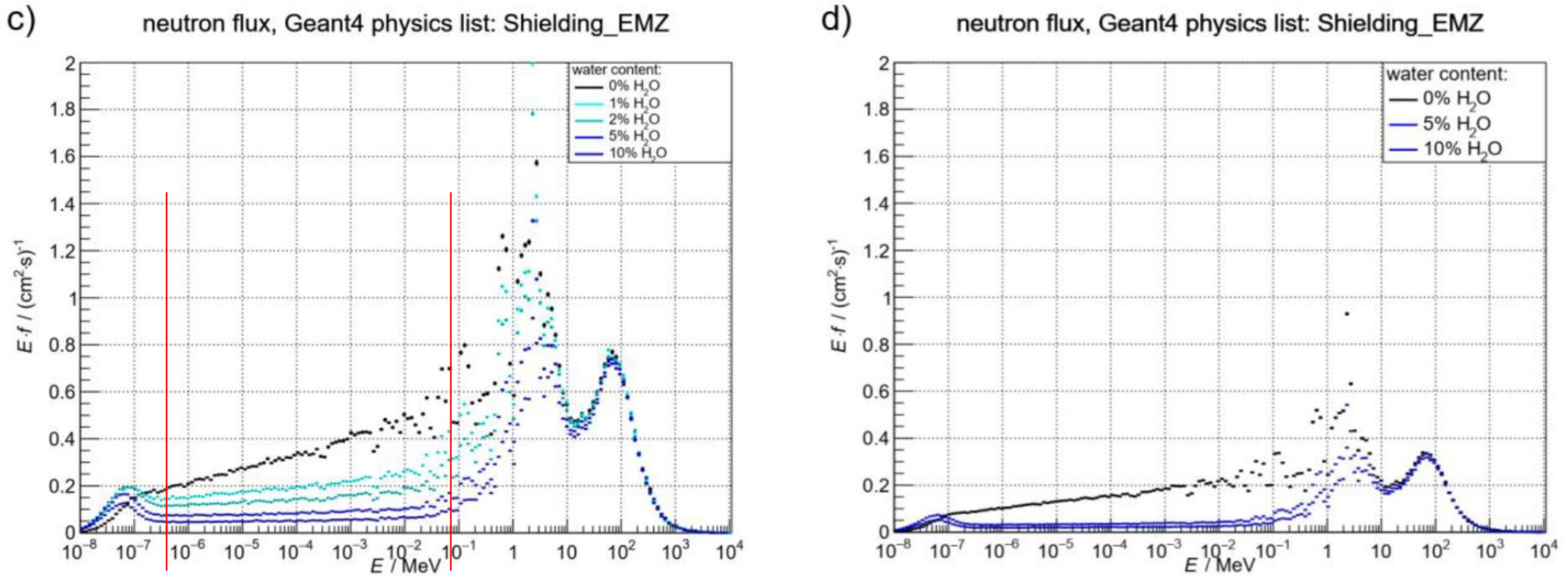
Galactic cosmic rays (GCRs) constantly interact with the nuclei in the lunar subsurface and produce high energy neutrons. Neutrons are always created fast, as they have to be liberated from the atomic nuclei, which are generally strongly coupled systems of protons and neutrons.

These neutrons scatter in the regolith and lose energy or are absorbed by neutron capture reactions.

Water detection using neutrons

Applied Physics
ersity in Prague

In the presence of hydrogen in the subsurface material, epithermal neutrons will scatter and lose energy more efficiently, leading to a **decrease of epithermal neutron flux** and **initial increase of thermal neutron flux followed by its decrease**. Such variation to the background neutron flux is then a clear signature of enhanced hydrogen abundance.



Things to notice:

- very low natural neutron flux means either very large detector or long measurements – orbital probes
- large dependence of flux on GCR – online monitoring necessary
- large change between dry and wet regolith

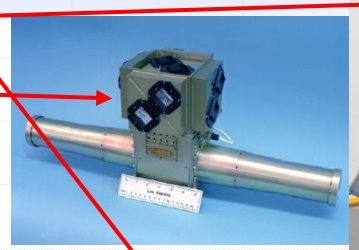
Credit: DLR

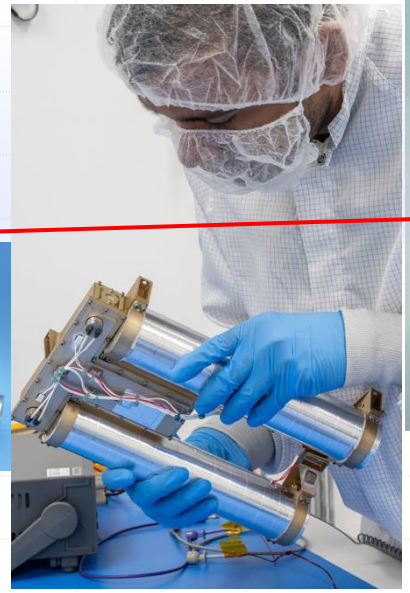
Figure 1: Neutron flux on the lunar surface for different water mass fractions calculated with Geant4/PLANETOCOSMICS for primary GCR nuclei (Z=1-28) for a) solar minimum conditions, i.e. GCR intensity maximum, and b) solar maximum conditions, i.e. GCR intensity minimum. Figures c) and d) contain the identical neutron flux as a) and b) respectively but in lethargy representation.

Neutron spectrometers used in space

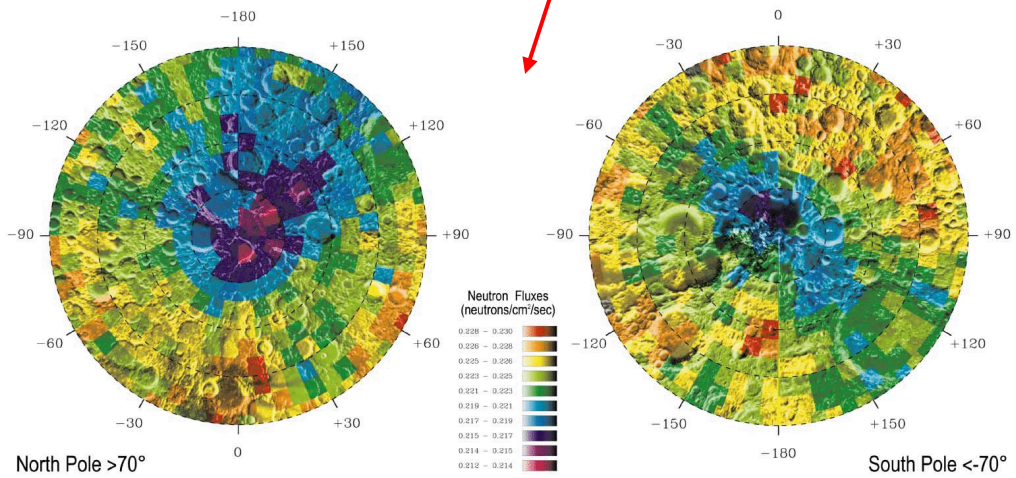
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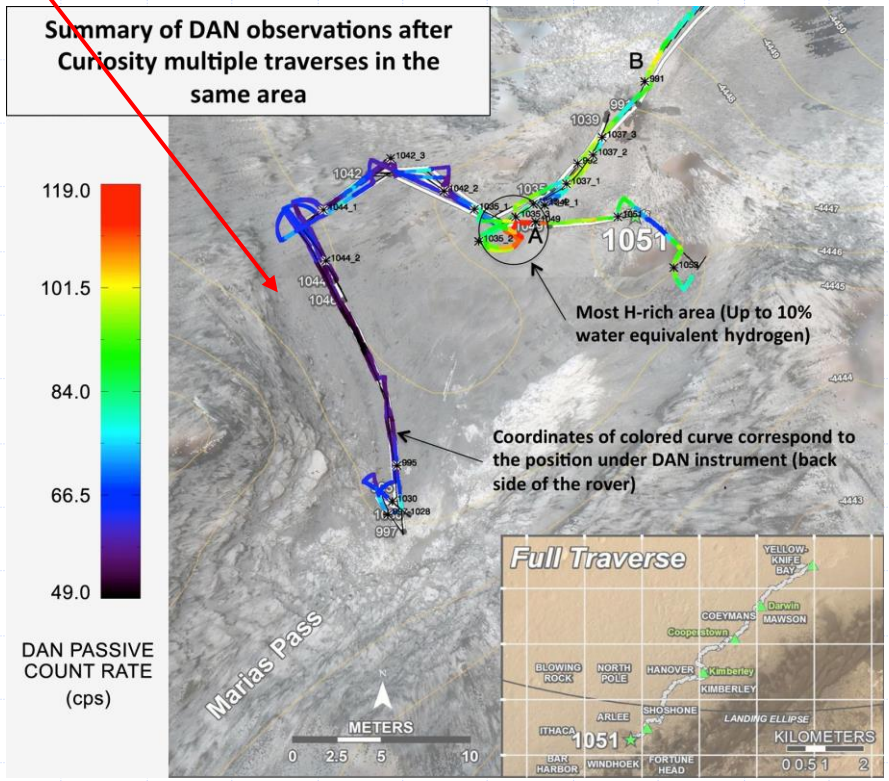
- Methodology is verified on Moon and Mars: Curiosity rover DAN, Lunar Prospector Neutron Spectrometer, Mars Odyssey HEND, TGO FREND, BepiColombo MGNS, Lunar Reconnaissance Orbiter LEND, Mars Odyssey MONS, MESSENGER GRNS, Dawn GRaND, Chang'e 4 LND.
- Usually in the form of 3He gas proportional counters
- 3He made from tritium
- Pressurized cylinders (10 bar)
- High voltage to collect charge
- Majority of above made by Russian IKI – Igor Mitrofanov,







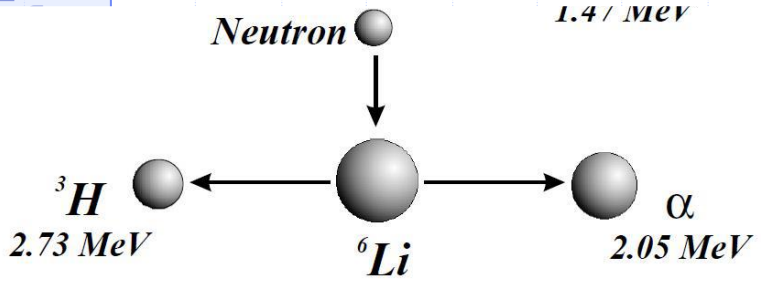




Neutron HardPix

Neutrons need to be converted to ionizing particle first through interaction with converter layer

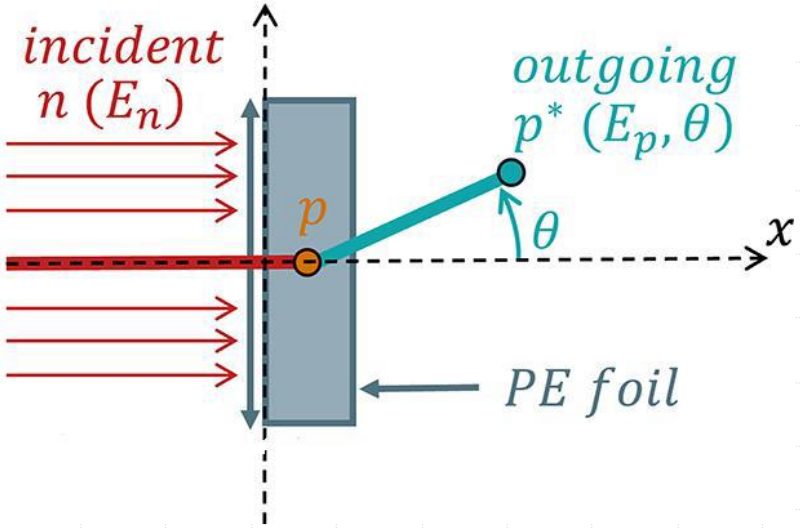
Physics Prague
Institute of Ex Czech



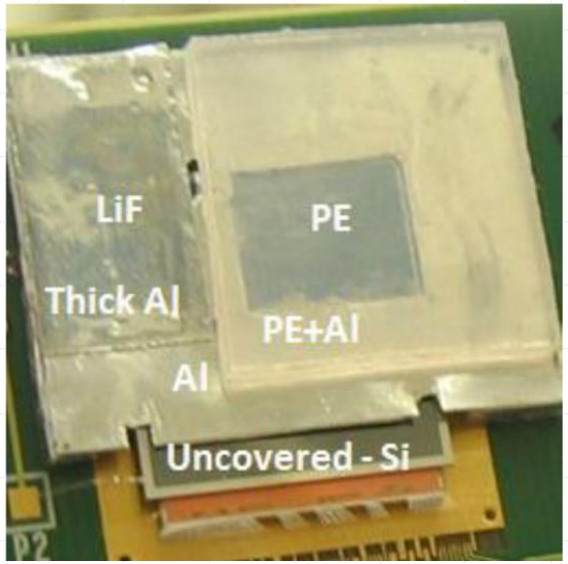
Thermal and epithermal converter uses 6Li in the form of LiF film for stability.

Energy separation is done by covering the converter layer with Cd or Gd which blocks thermal neutrons. Total – epithermal = thermal





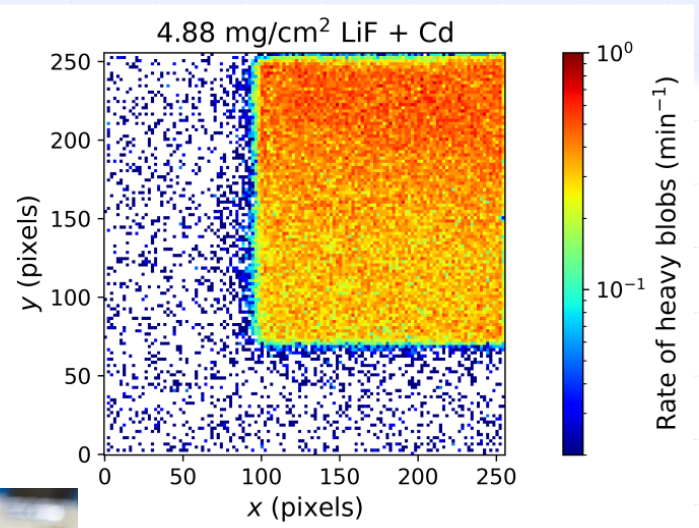
Fast neutron converter uses PE. Fast neutrons have non-zero probability of interaction with Si sensor. To filter background, an uncovered reference sensor is needed.

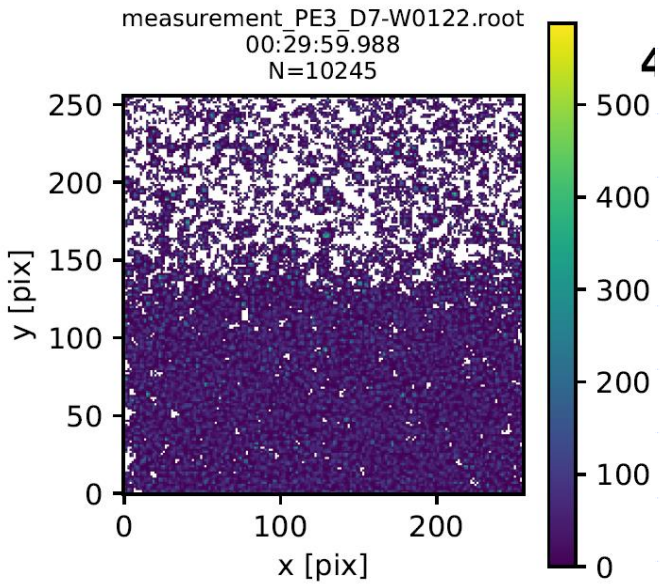


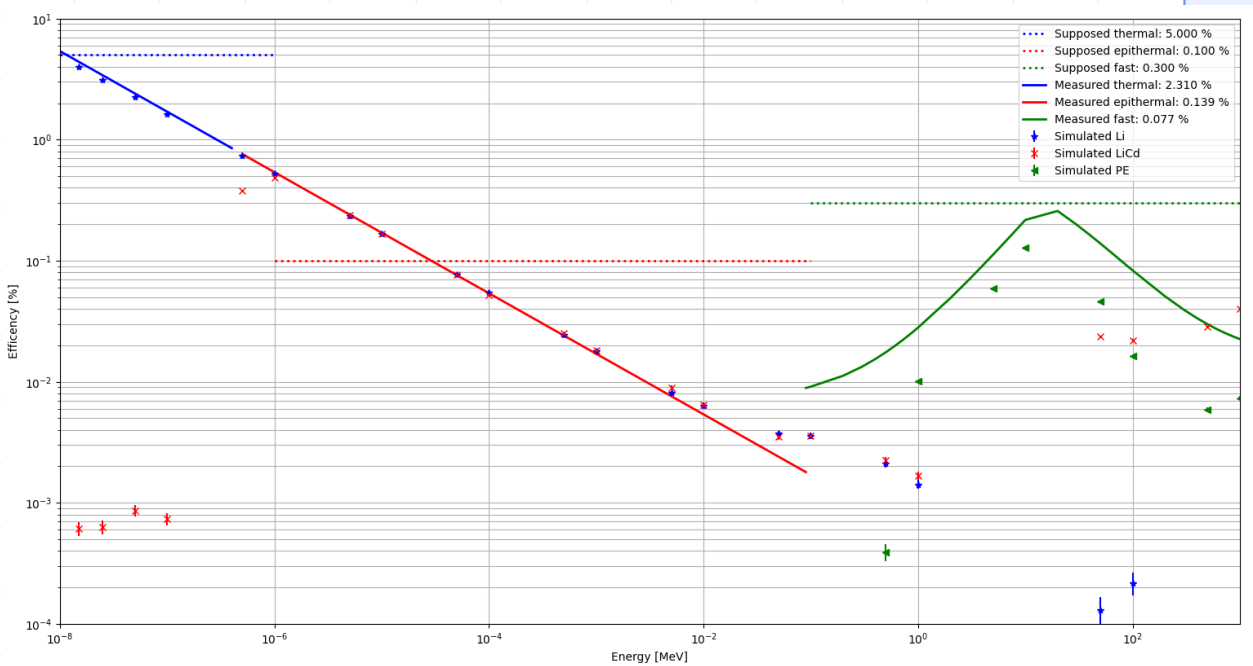
Neutron HardPix detection efficiencies









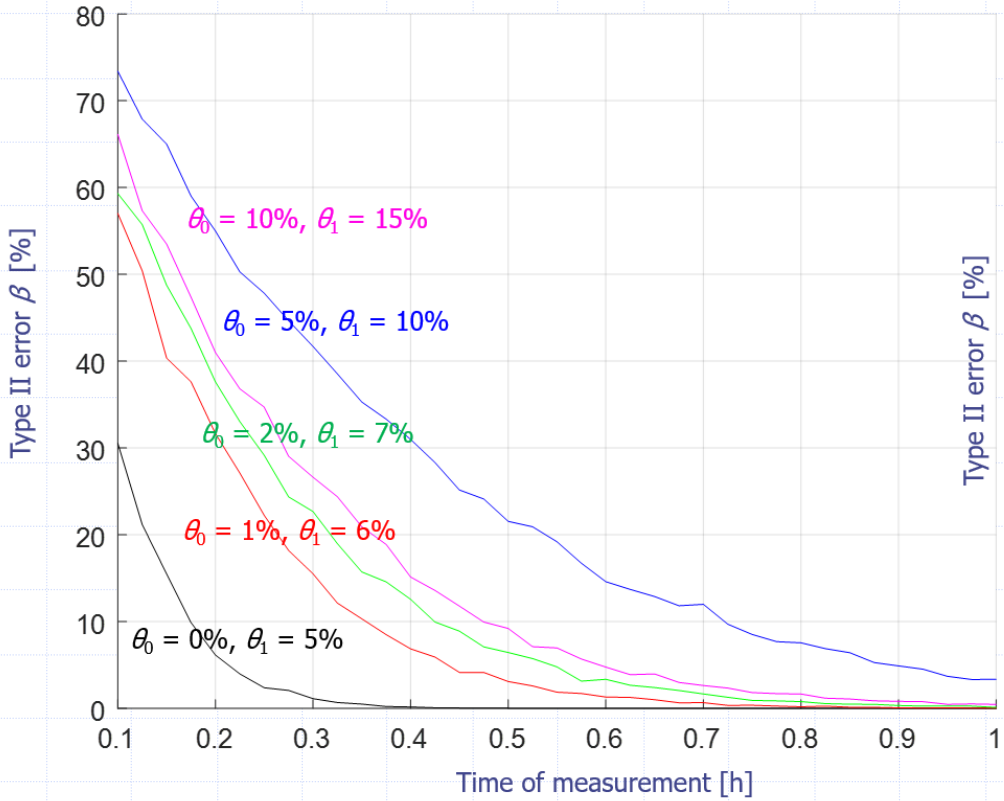


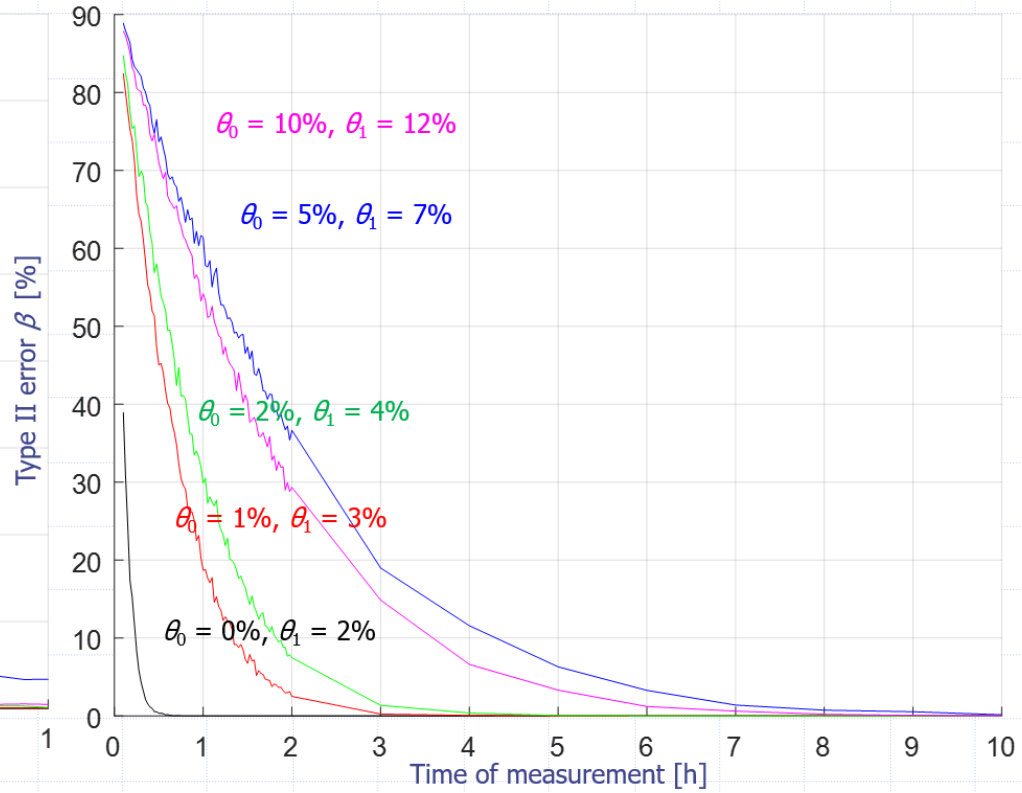
Thermal neutron detection efficiency averages 2.7%, while fast-neutron efficiency peaks at 0.3% near 16 MeV.

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Likelihood-ratio test

- The Likelihood-ratio test statistic (Neyman–Pearson lemma). : $S(n_1, n_2, n_3) = 2 \ln \frac{\mathcal{L}(n_1, n_2, n_3; \theta_0)}{\mathcal{L}(n_1, n_2, n_3; \theta_1)}$
- Simulations show that for setup where one TPX sensor is dedicated to each energy range (thermal, epi, fast, reference), we should be able to detect ~2% water mass ratio variation within a 2h measurement.
- This is for situation without background – we need to test in a mixed field with background similar to conversion products (protons..)

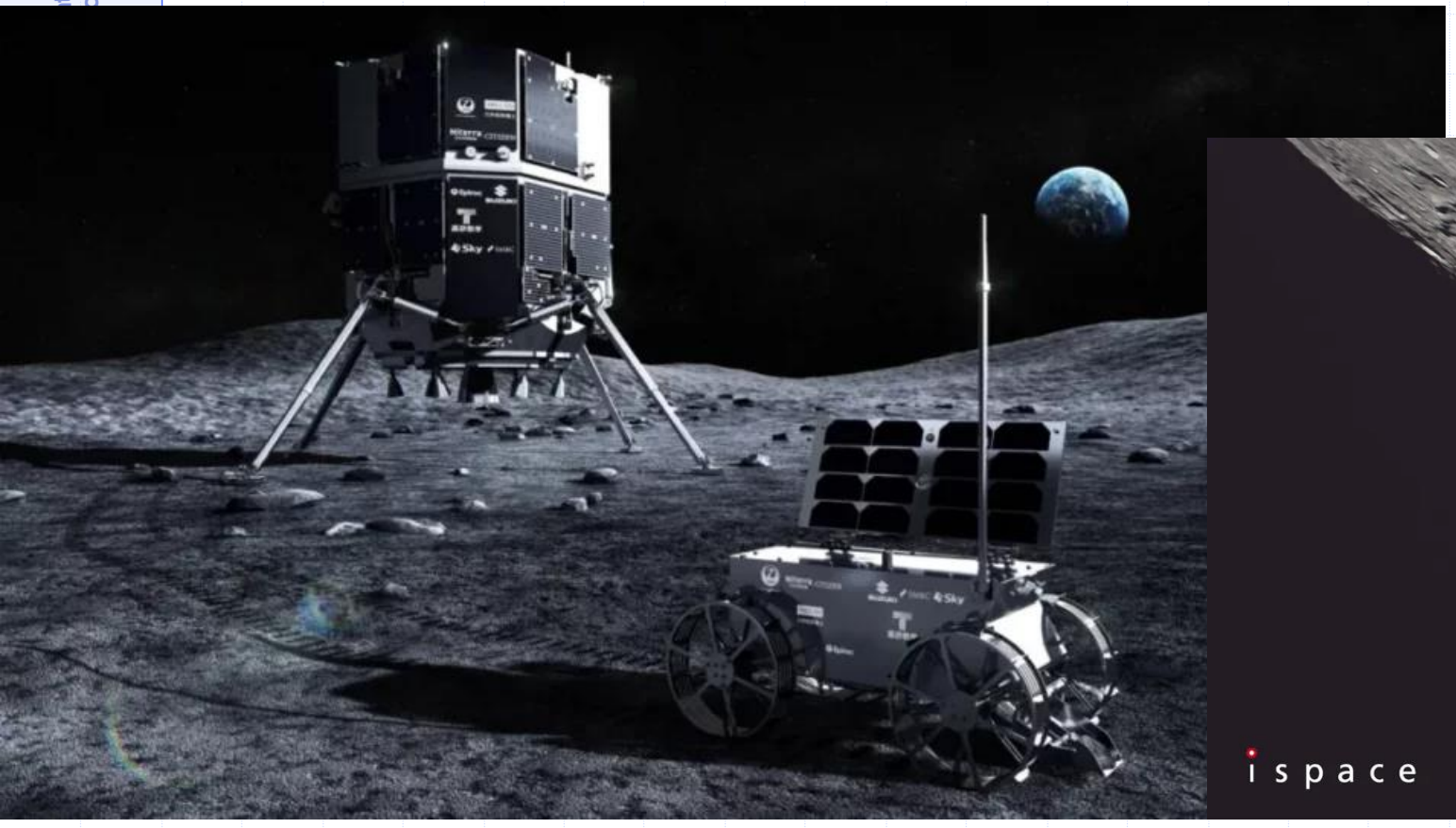




MAGPIE

The Mission for Advanced Geophysics and Polar Ice Exploration (MAGPIE) led by ispace Europe (LU) supported by ESA and JAXA for launch in 2029.

ispace rover with Neutron HardPix, Ground penetrating radar (CENSSS – Rimfax), drill+mass spectrometer by TUM & OU UK



First ispace lander failed to land in April 2023.

Second attempt on June 5th 2025 failed as well.



Lunar biology experiments

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Apart from lunar water mapping, Neutron HardPix can be used to monitor biology experiments on lunar surface for neutron dose rate.

Proposal submitted by NASA+CTU for such payload, results expected soon.

What's next for HardPix?

4 units flew in space

3 FMs ready to launch

Lunar missions in preparation

Running ESA project to enhance measurement capabilities (proton and electron incident energies determination close to NGRM), onboard processing to lower the data transfer rate

Thank you

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Czech Technical University in Prague

HardPix development funded by **ESA Contract No. 4000135884/21/NL/CRS**

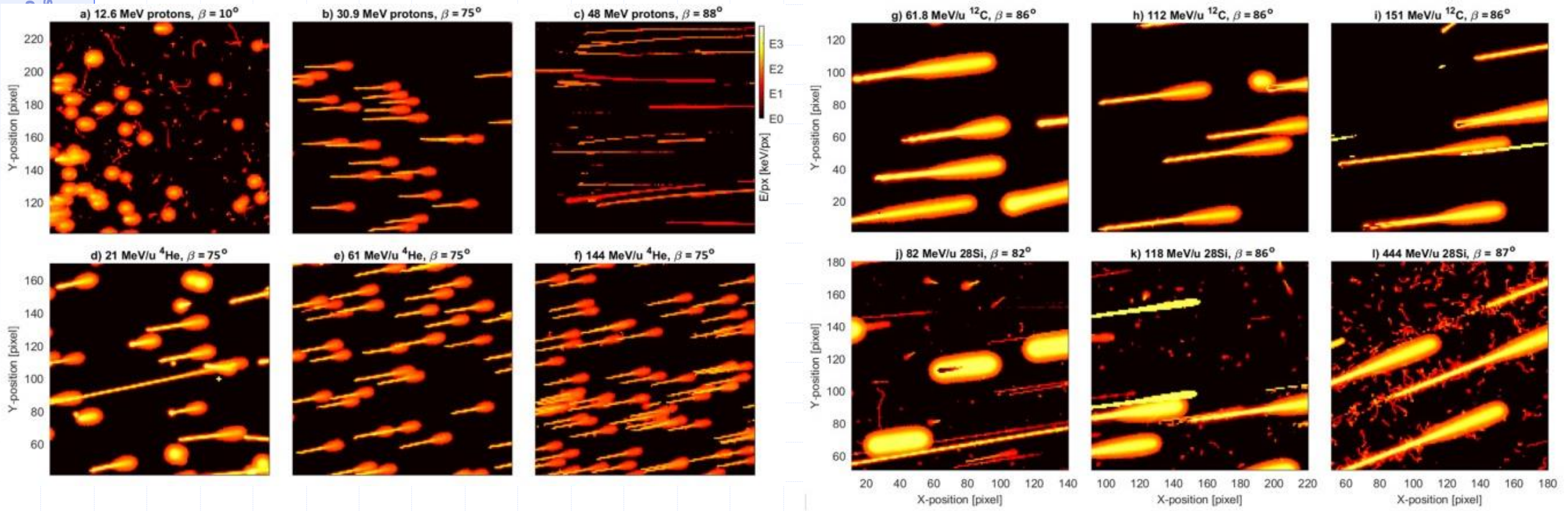
Neutron Spectrometer **HardPix** Science Performance Maturation and Calibration study funded by **ESA Purchase Order N. 5001039803**

MAGPIE mission study funded by **ESA Contract No. 4000146915/24/NL/MGu/ov**

Contact: robert.filgas@cvut.cz

HardPix Radiation Spectrometer – protons and ions

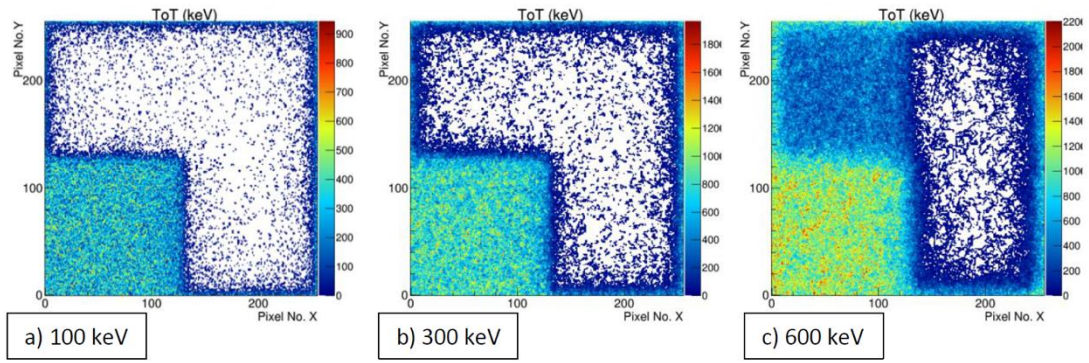
- Proton energy spectroscopy using energy deposition curves



Credit: C. Granja et al. (2018)

HardPix Radiation Spectrometer – electron spectroscopy

- Previous Timepix missions measured only deposited energy
- HardPix is equipped with stopping filters and provide kinetic energy of particles in several energy bins





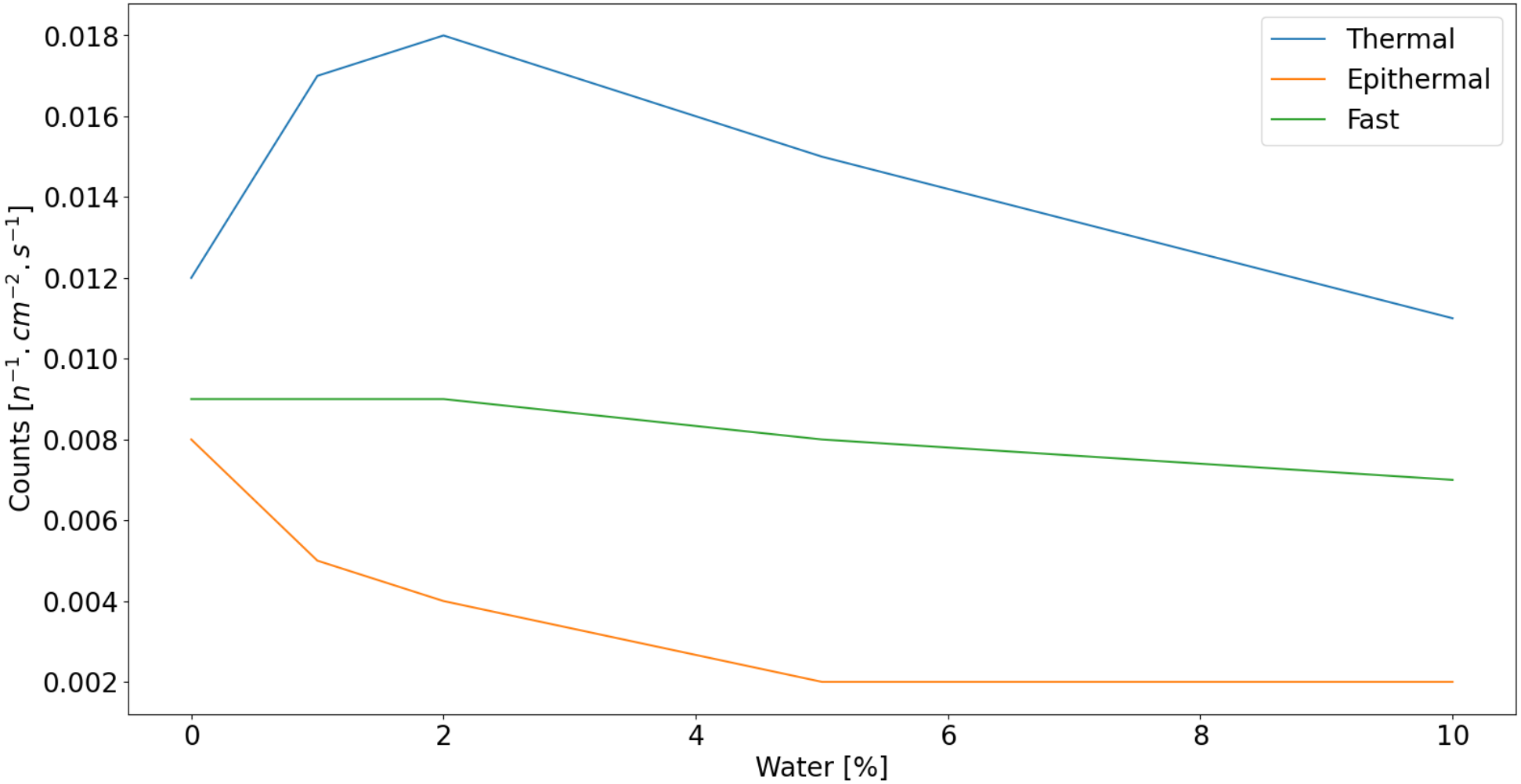


Estimated countrates expected on lunar surface

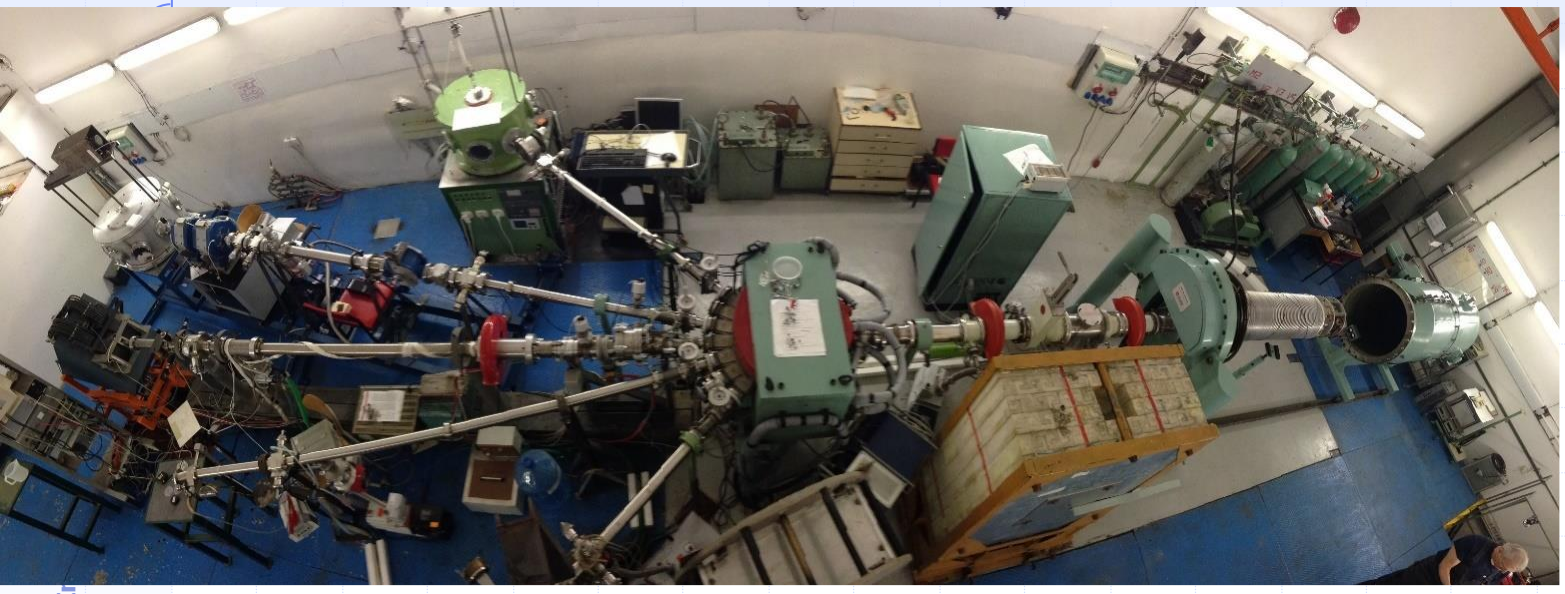
Institute of Experimental and Applied Physics
Czech Technical University in Prague

Similar detected count rate above dry regolith – preliminary setup of one sensor dedicated to each energy bin

Epithermal neutrons good for low humidity detection (1-5%), fast neutrons good for higher humidity (>5%)



Experimental verification – Van de Graaff



Quasi mono-energetic neutrons in relatively wide energy range (100 keV - 17 MeV).

Sand and PE pellets/blocks to thermalize neutrons and simulate neutron field on lunar surface



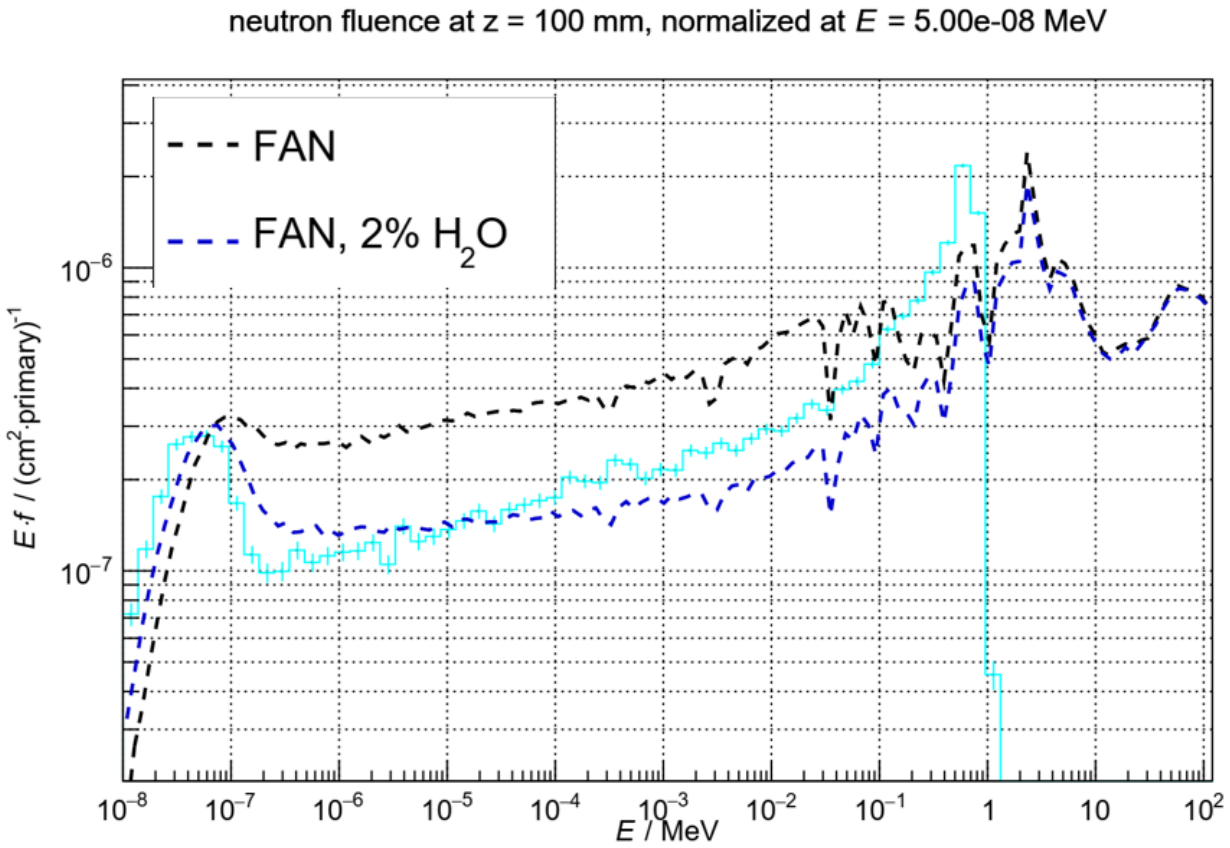


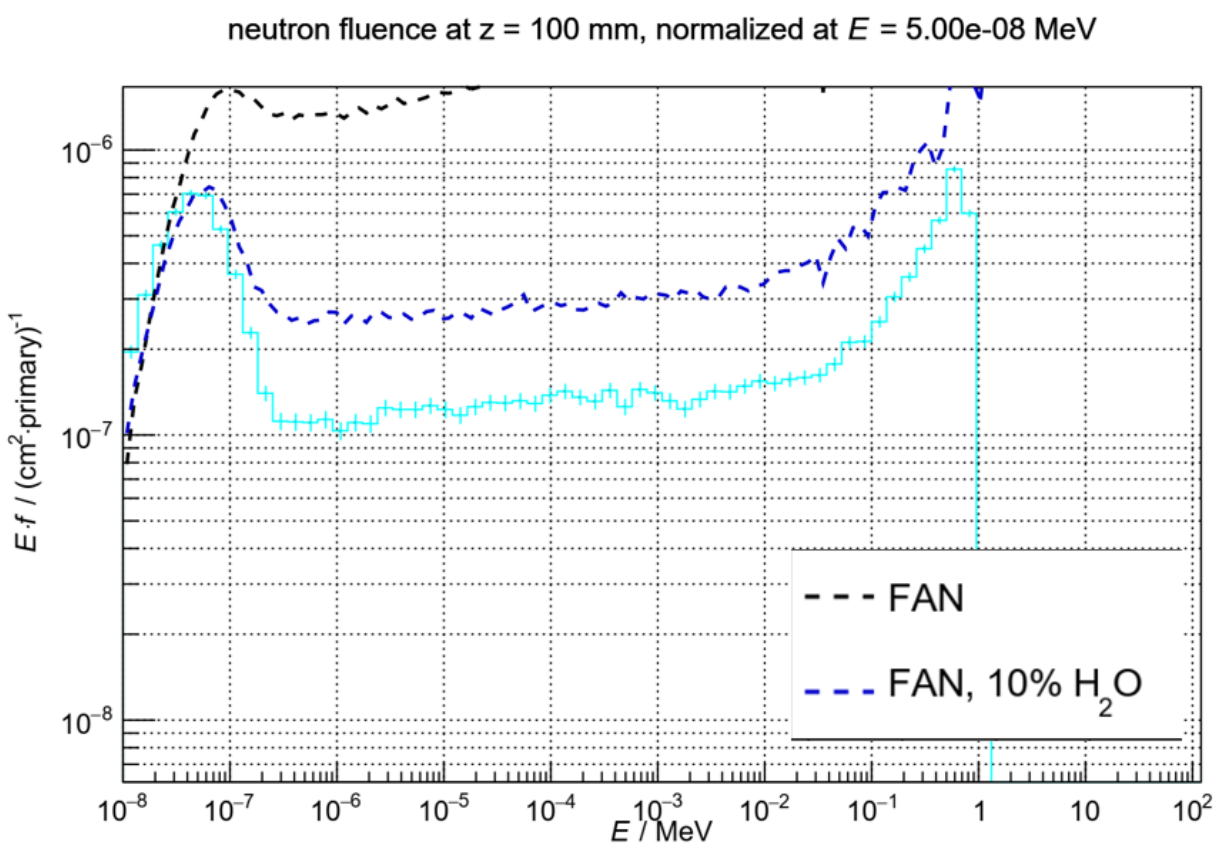


Problems replicating lunar environment at VdG

Using fast neutrons requires much (tons) material to thermalize enough neutrons

We used the lowest VdG setting (1 MeV neutrons) – no detection in fast neutron detector

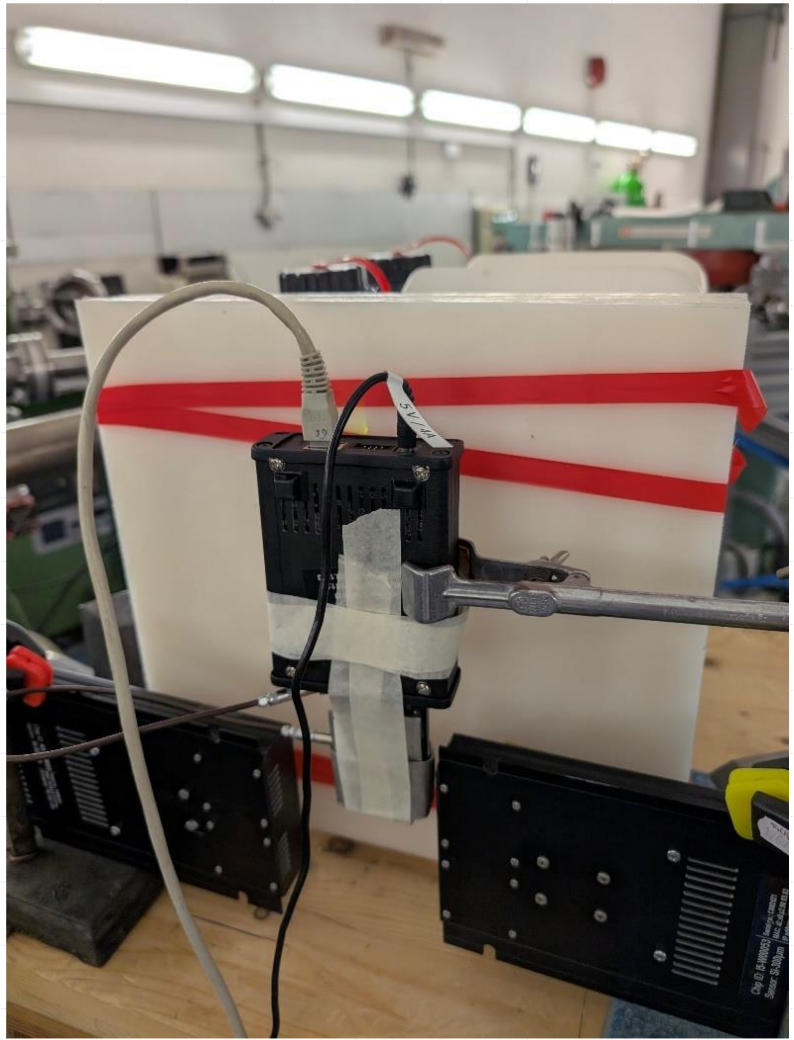




Experimental setup

Two HDPE barrels 15 cm thick filled with SiO2 followed by PE blocks with thickness of 2, 3, 4 and 5 cm to somewhat approximate regolith with 1%, 2%, 5% and 10% water mass ratio.

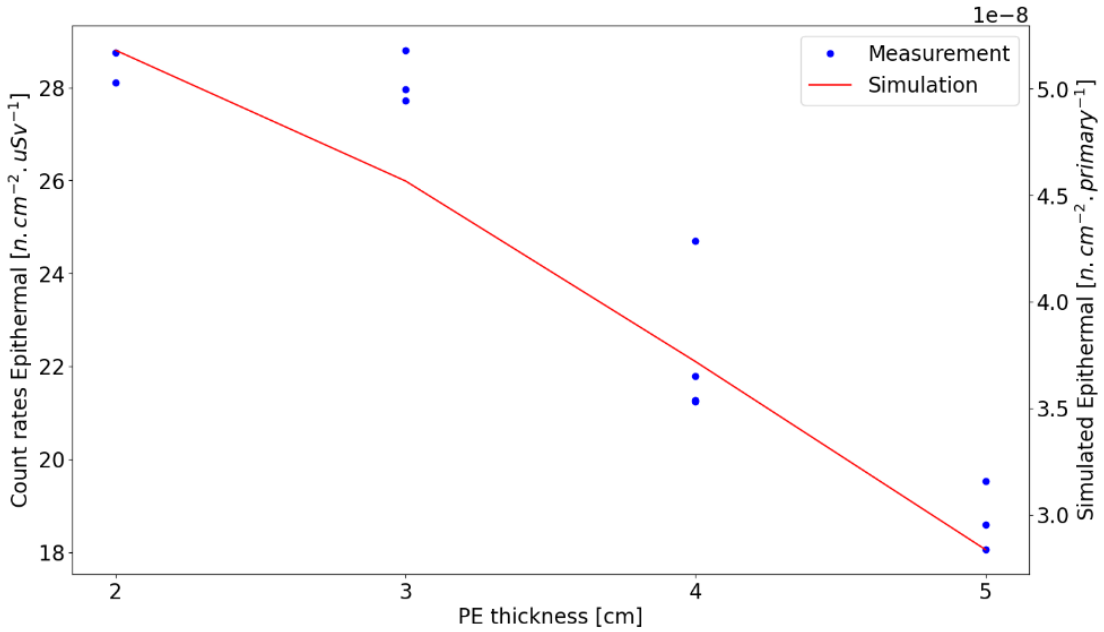




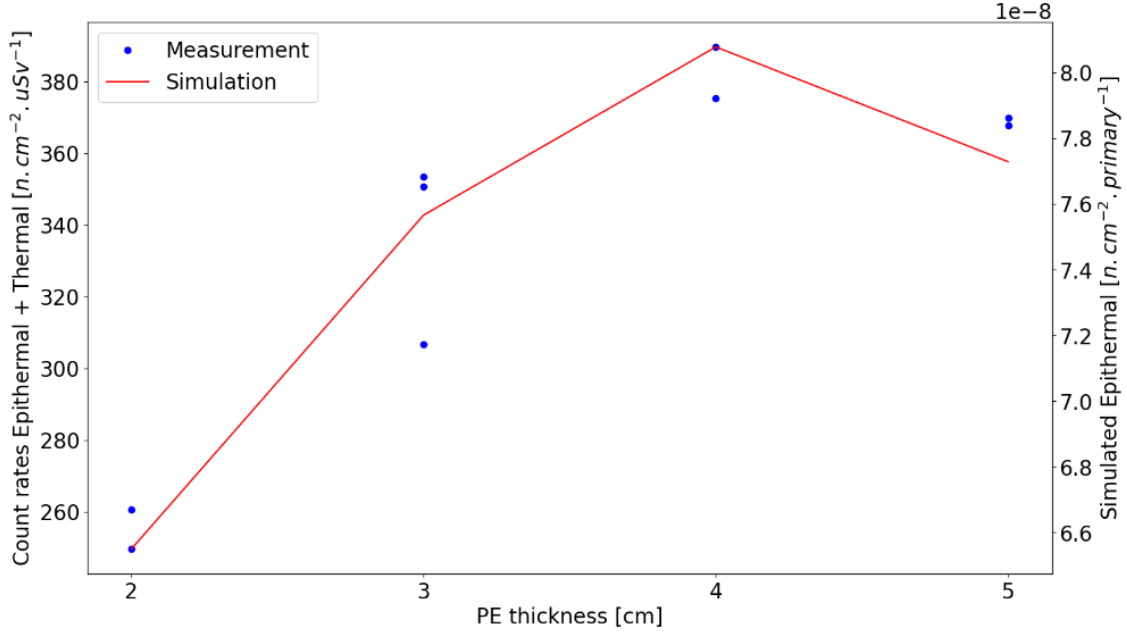
Experimental verification – Neutron HardPix works

While we were unable to precisely reproduce neutron spectra on top of the lunar regolith at our VdG facility, produced neutron environments were sufficiently similar to verify the performance of tested neutron spectrometers in thermal and epithermal neutron regions.

Neutron HardPix breadboard measurements showed a very good agreement with simulations, validating its performance as a neutron spectrometer in the environment similar to one expected on the lunar surface.



Epithermal



Thermal + epithermal