SpacePix Chip Evolution for Space Dosimetry

- VZLUSAT-2 Flight Results and SpacePix3 Lab Characterization

11.6.2025

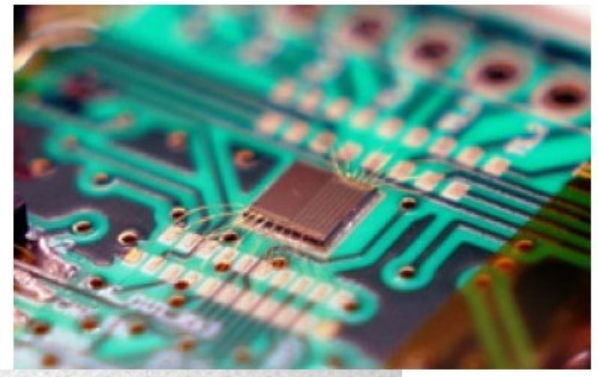
Radek Novotný
for the CAPADS team

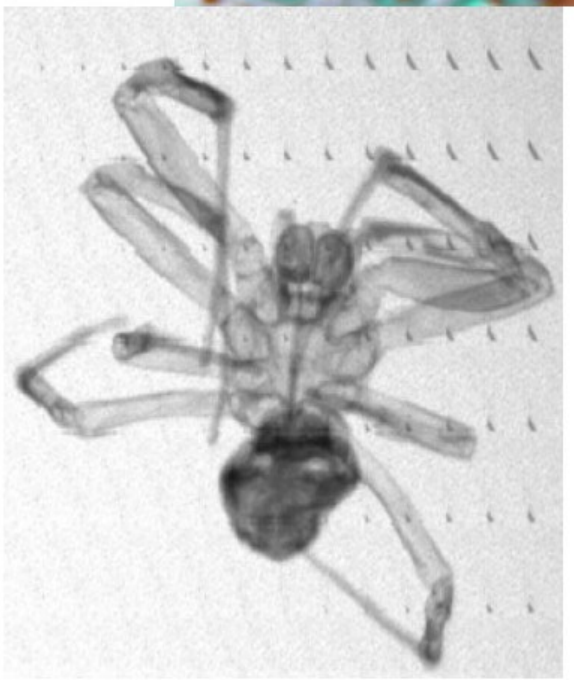
Zdenko Janoška, Vladimír Kafka, Josef Knapek, Anhelina Kostina, Jiří Kulda,
Monika Kuncová, Mária Marčišovská, Michal Marčišovský,
Radek Novotný, Marek Strnad, Peter Švihra, Lukáš Tomášek

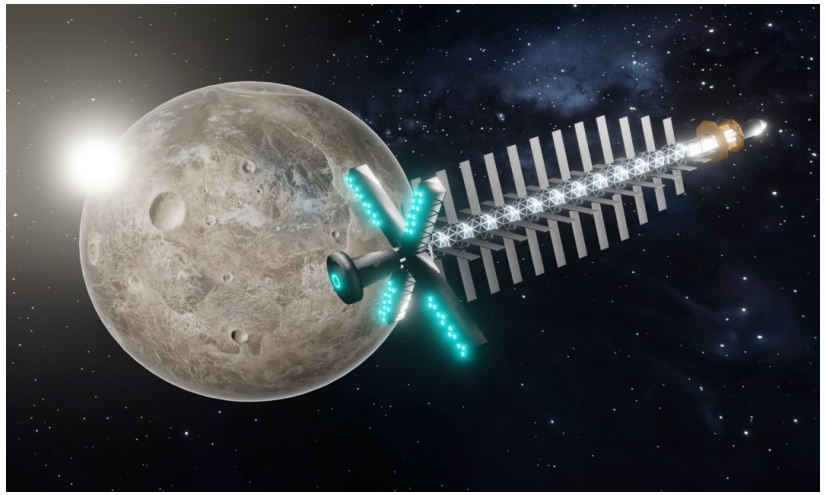
Who are we

Center of Applied Physics and Advanced Detection Systems (CAPADS) is research group at the Faculty of Nuclear Sciences and Physical Engineering of the Czech Technical University in Prague

- Research topics:
  - Chip design of monolithic and hybrid detectors for future high energy physic experiments, medical and space applications or plasma diagnostics
  - Silicon carbide detectors
  - Quantum astrometry
  - Space nuclear propulsion studies



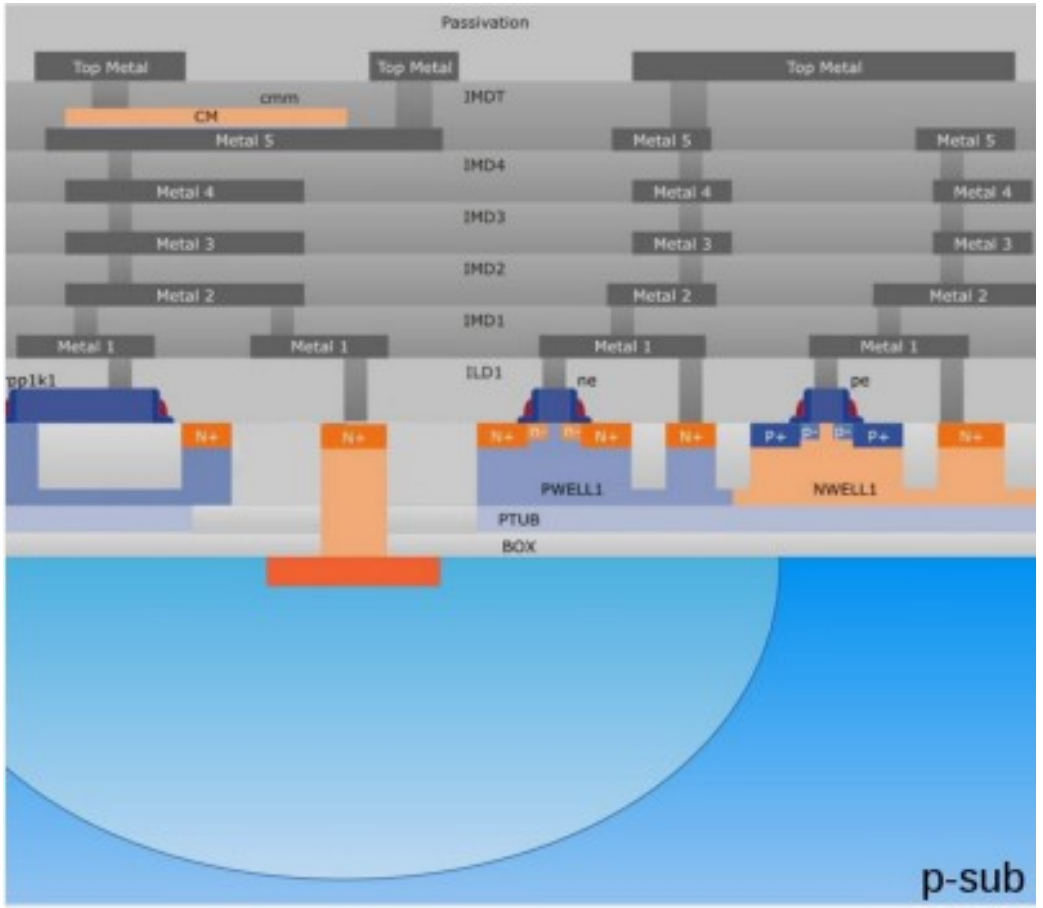




Introduction to SpacePix

- SpacePix detector family is based on monolithic sensors designed for sapce dosimetry measurements
- It is designed in SOI MAPS 180 nm

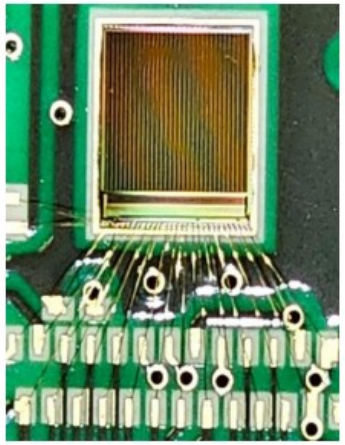
- Monitoring space radiation is important for:
  - terrestrial and space technological infrastructure (especially electronic systems)
  - human health protection, space dosimetry
  - space radiation research



SpacePix chip evolution

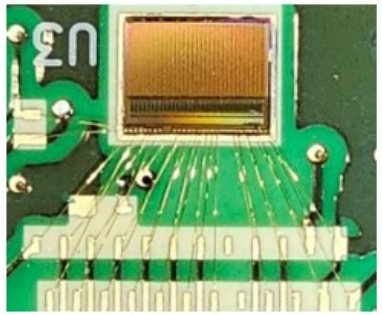
XCHIP-03 → **SpacePix1** → **SpacePix2** → **SpacePix3**

2018



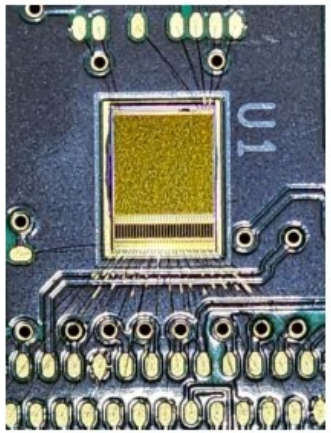
- 180 nm SOI CMOS process
- 1 - 10 ke$^-$ signal range
- 10-bit single-ended column-parallel SAR ADCs
- Soft X-ray imaging

2020



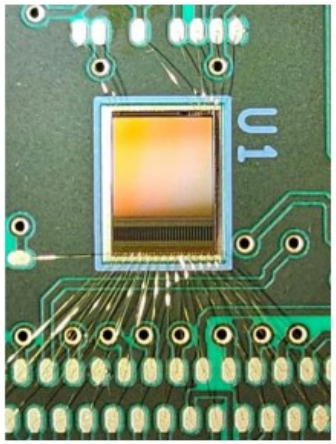
- The first SpacePix test chip
- Extended dynamic range 1 ke$^-$ - 65 ke$^-$
- 8 – bit asynchronous column-parallel SAR ADCs with differential architecture

2022



- Digitization signal from backside channel extending signal range up to 30 Me$^-$
- 10 – bit asynchronous column-parallel SAR ADCs with differential architecture

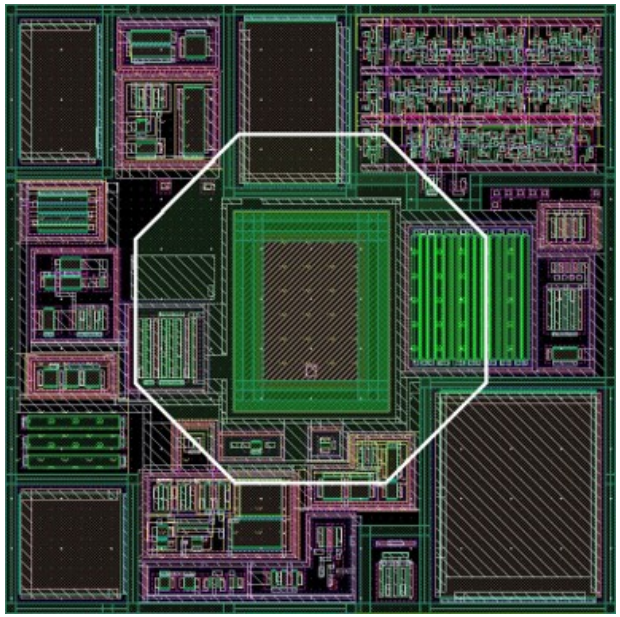
2023

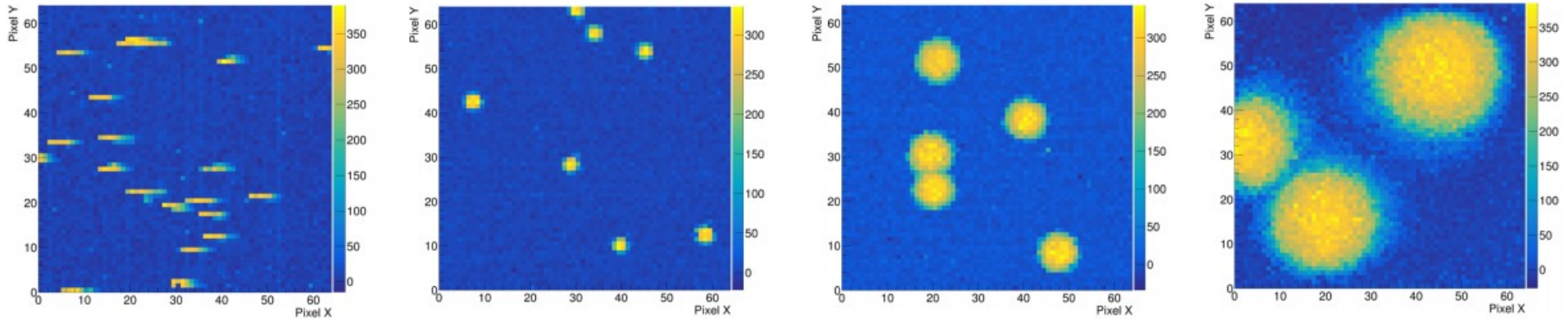


- Improved version of SpacePix2
- SAR ADC bugfix
- New feature: user defined data sampling at falling or rising edge
- optimized CSA, PDH and ADC ranges

SpacePix2 main parameters

- It features a **64×64** pixel matrix with **60 µm** pixel pitch
- For digitization it uses fast **10-bit** asynchronous differential SAR ADC
- Signal dynamic range from Pixel side: **2-80 ke$^-$**, Backside: **0.25 - 30 Me$^-$**
- Low-power (**<50mW**) detector processing 10^5 - 10^6 pixel hits $cm^{-2}s^{-1}$
- The threshold for total ionizing dose (TID) ~2 kGy at 15 Gy/min
- Capable of dE/dx measurements of electrons, protons and heavy ions



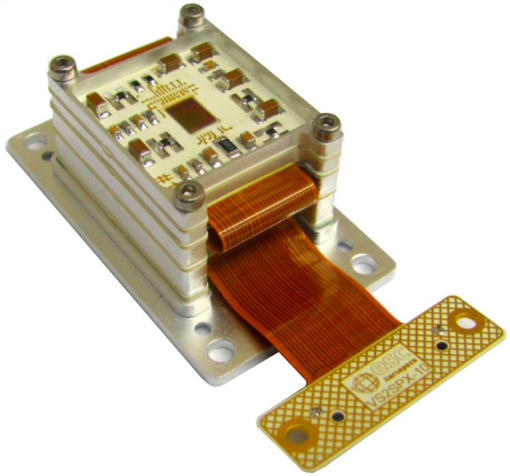


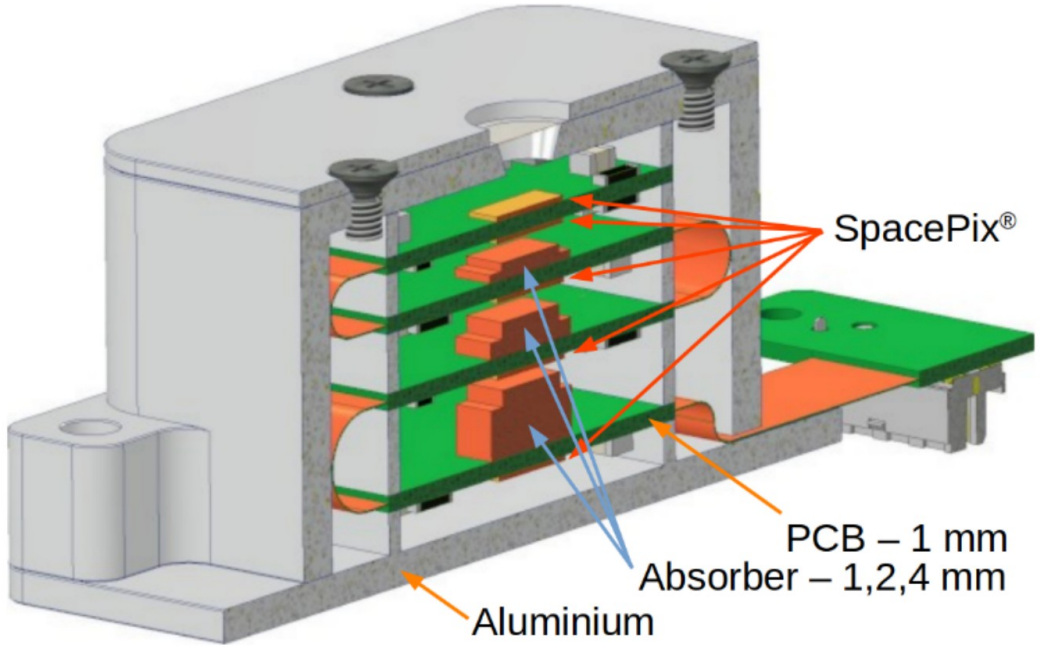
(a) ^{1}H ions @ PTC (b) ^{22}Ne ions @ U400M (c) ^{40}Ar ions @ U400M (d) ^{136}Xe ions @ U400M

Visualization of the deposited energy (in ADC units) for the accelerated ions. The visualized ion hits are pedestal-subtracted (except for (a)) and the axes show the pixel coordinates.

The SpacePix Radiation Monitor (SXRM)

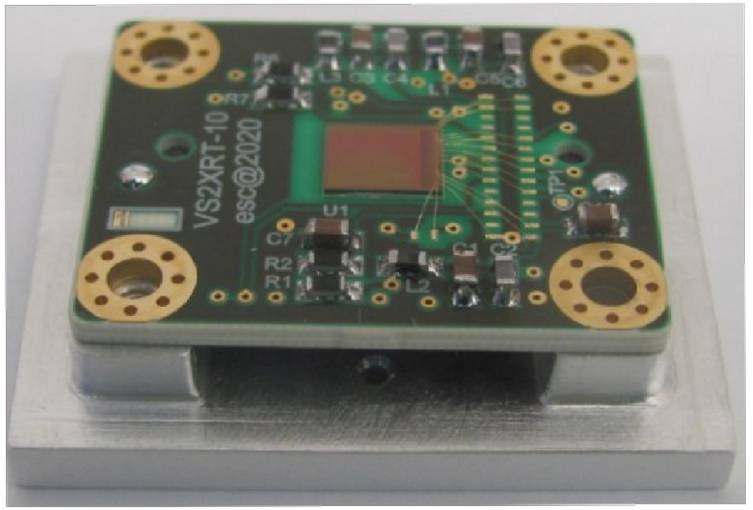
- SpacePix2 is designed for standalone operation, in a particle telescope or with a scintillator
- SXRM consist of 5 SpacePix2 sensors separated by the absorber
- Dimensions of the SXRM envelope: 41×32×26 mm^3
- Weight less than 60 g (Al case) or 135 g (Inconel)
- The detection modules are connected to a rad-tolerant microcontroller unit
- Power supply voltage is 1.8 V with HV bias of -150 V
- Projected GEO lifetime: 10 years





Soft X-ray Monitor (SXM)

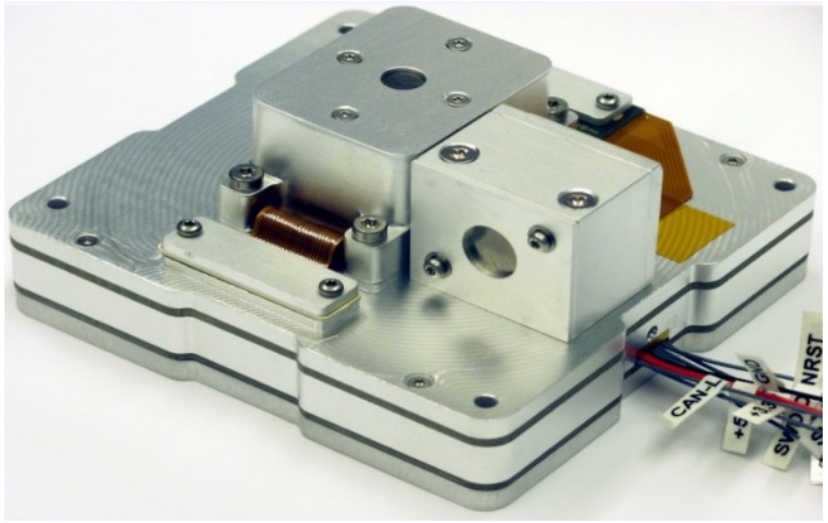
- The SXM detector is based on single chip XCHIP-03
- XCHIP is parallel branch for the SpacePix family detectors (now already at version 4)
- It aims for different energy range and particles (soft x-rays) and it features hit counting mode and ADC mode
- Photons in range: 3–30 keV
- Uses Al block for shielding and drilled cone as input aperture

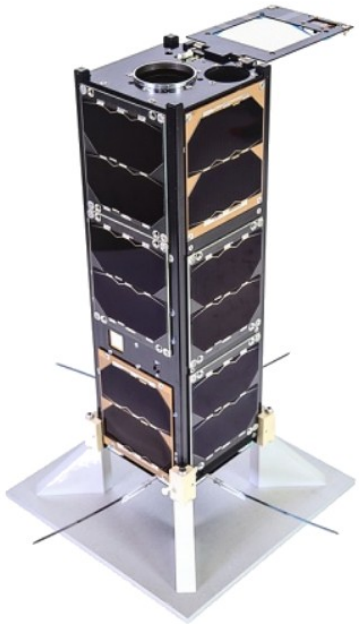


esc Aerospace

VZLUSAT-2 mission

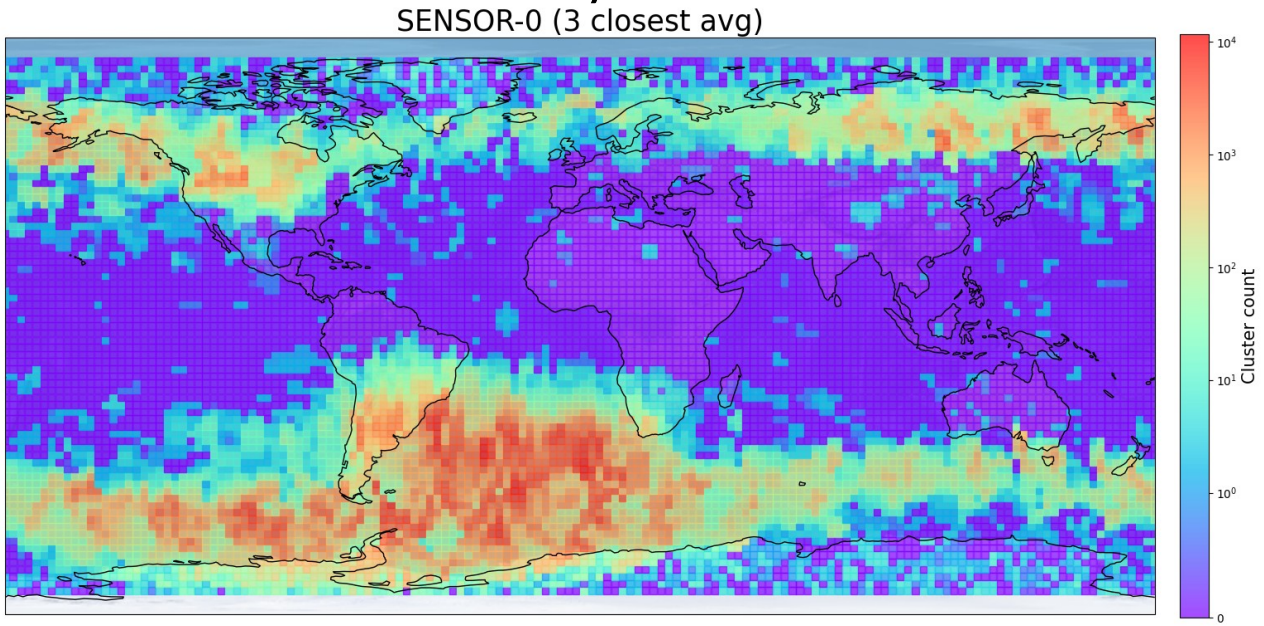
- SXRM and SXM are part of the Czech nanosatellite VZLUSAT2 mission, as a component of the Space Dosimetry System Demonstrator (2SD)
- The VZLUSAT2 mission was launched in 2022 on the SpaceX Falcon 9 launch vehicle
- Sun-synchronous polar orbit with inclination approximately 97.3° and altitude ranging between 521 km and 543 km (Now Perigee: 398.8 km – de-orbiting soon)

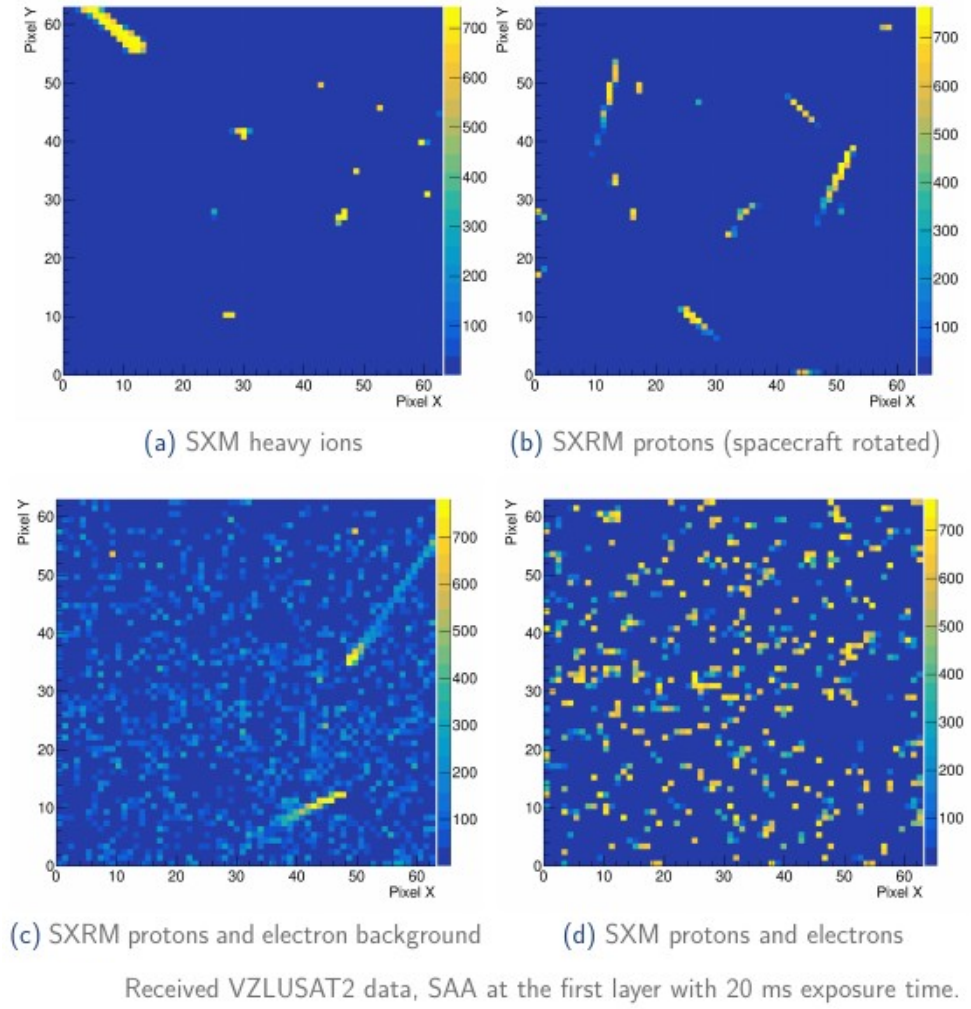




VZLUSAT-2 results

- The example of the measured signatures shows good performance of the detector
- Multiple readout modes to save bandwidth
- The correlation between measured data and the flight trajectory highlights the presence of the South Atlantic Anomaly



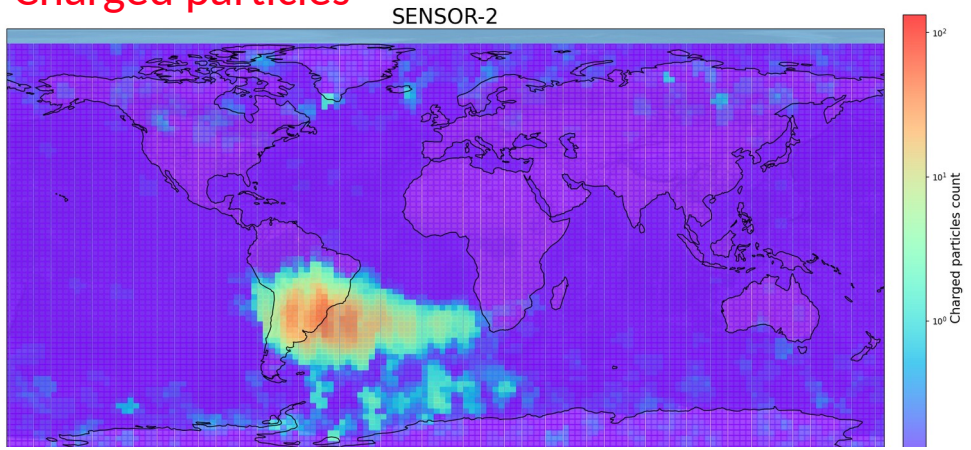


Received VZLUSAT2 data, SAA at the first layer with 20 ms exposure time.

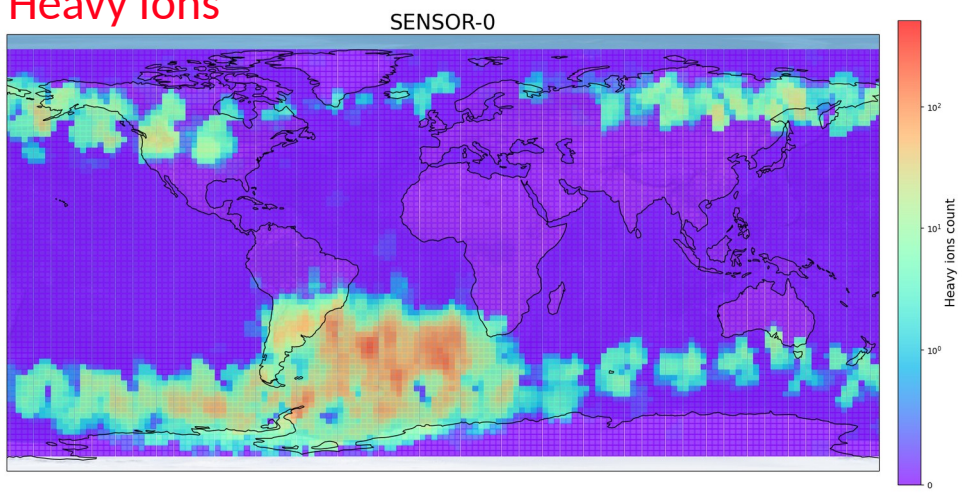
VZLUSAT-2 results

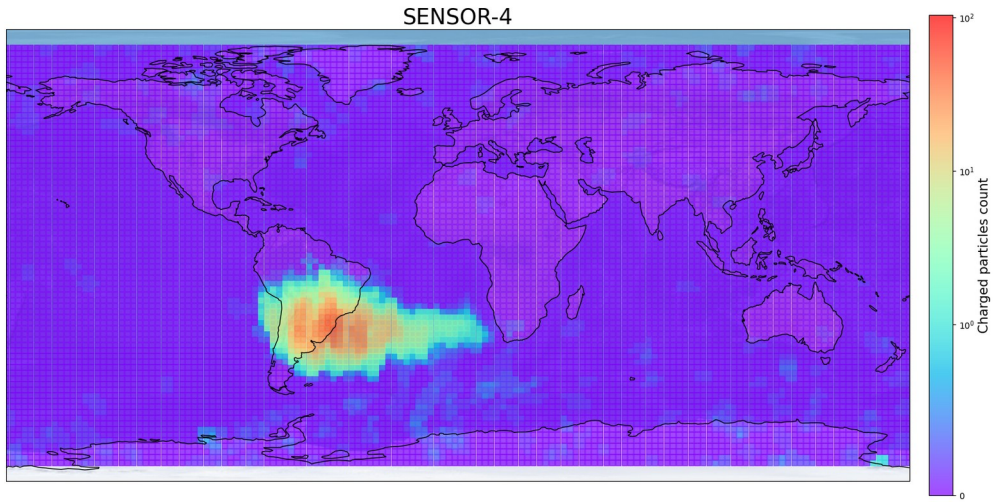
- Pattern recognition techniques (clustering, topologies) and partial reconstruction of particle trajectory used in data processing units
- Second layer (SENSOR-1) was unfortunately damaged during launch which complicates particle identification and tracking

Charged particles



Heavy Ions

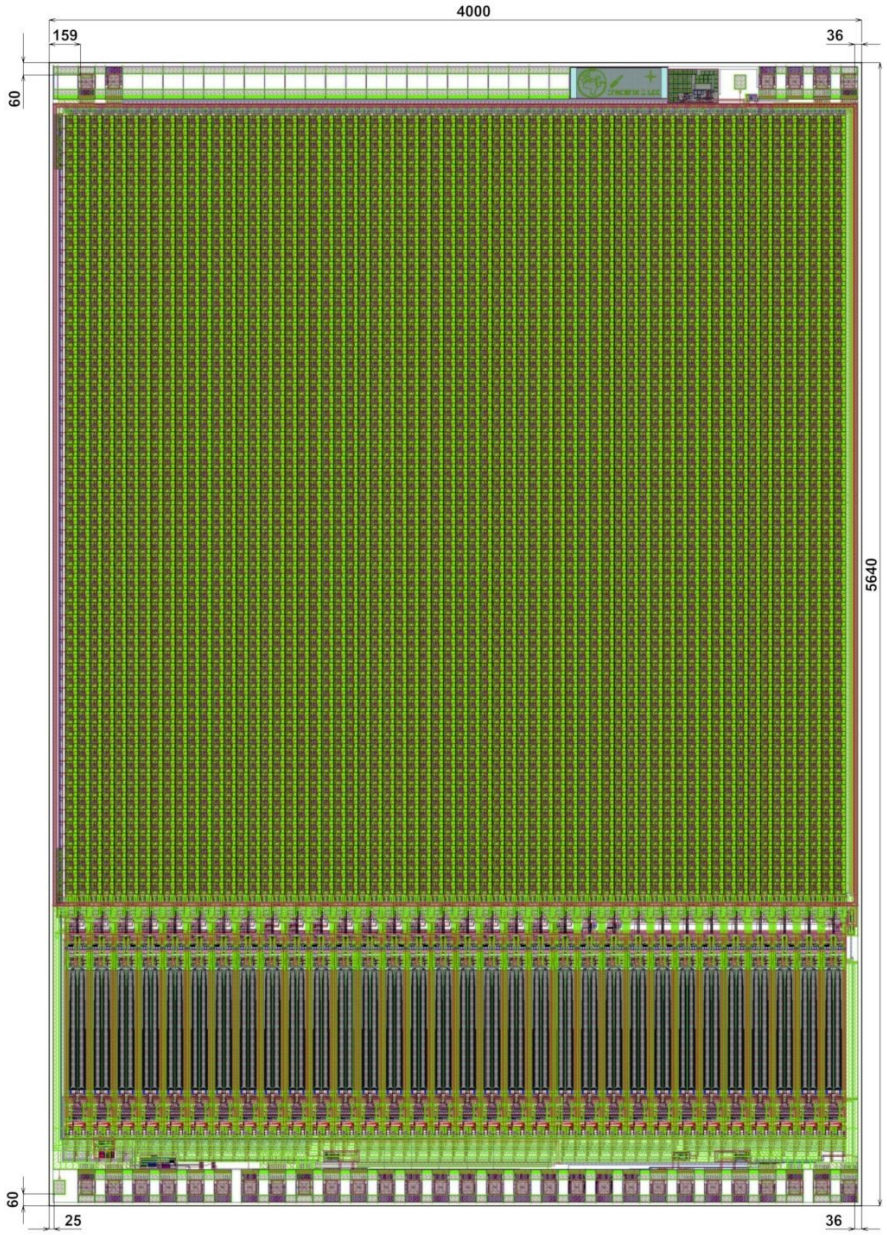




SpacePix3

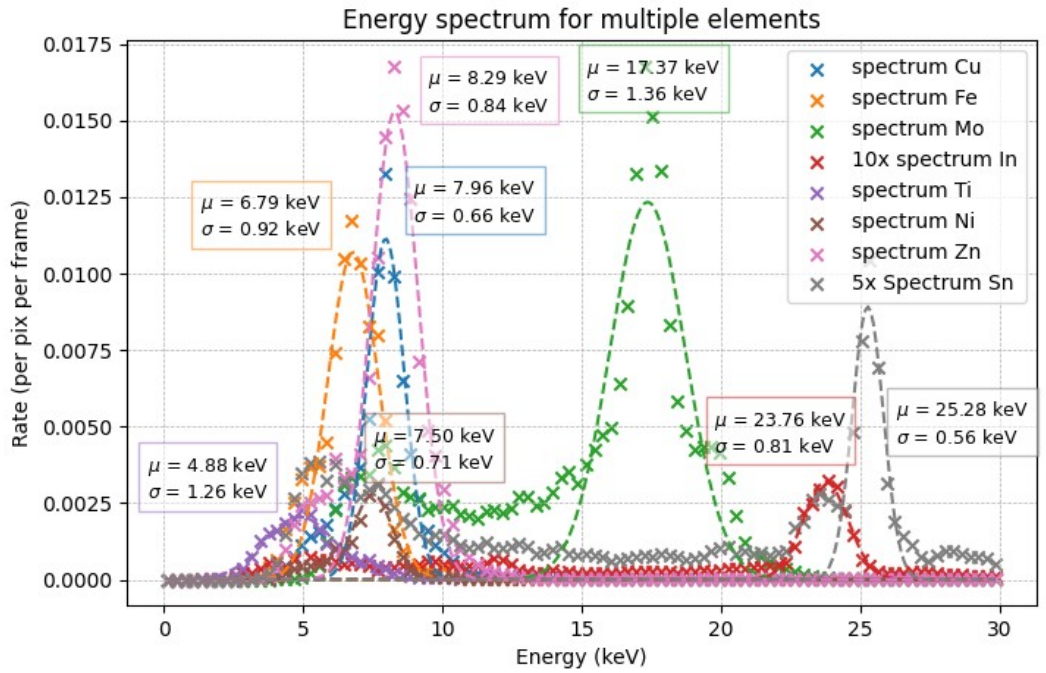
- Improved based on data from VZLUSAT-2 mission
- SPI (50 MHz) a LVDS (400 MHz) readout modes
- Bug fix in SAR ADC
- Optimized CSA, PDH and ADC ranges
- Reduced power consumption: ~31 mA (SPI mode)
- New feature: user defined data sampling at rising or falling edge

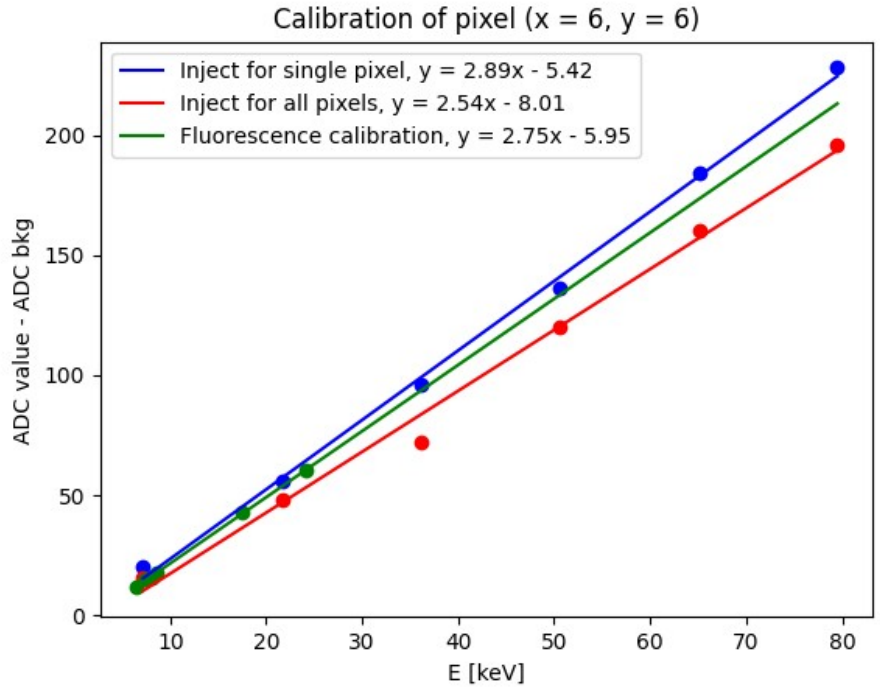
- Engineering run together with XCHIP-04 => many available samples ()
- Manufacturing cost estimate of single chip is ~$100



SpacePix3 calibration

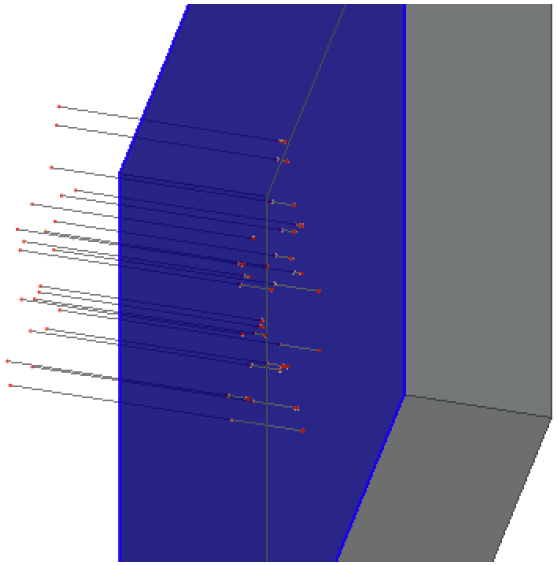
- Calibration based on the X-ray fluorescence (very low detection probability due to thin Si sensitive layer)
- Possibility to calibrate with build in inject (single pixel vs. all pixels at one)
- Good linearity up to 80 keV (but very low cross-section probability)

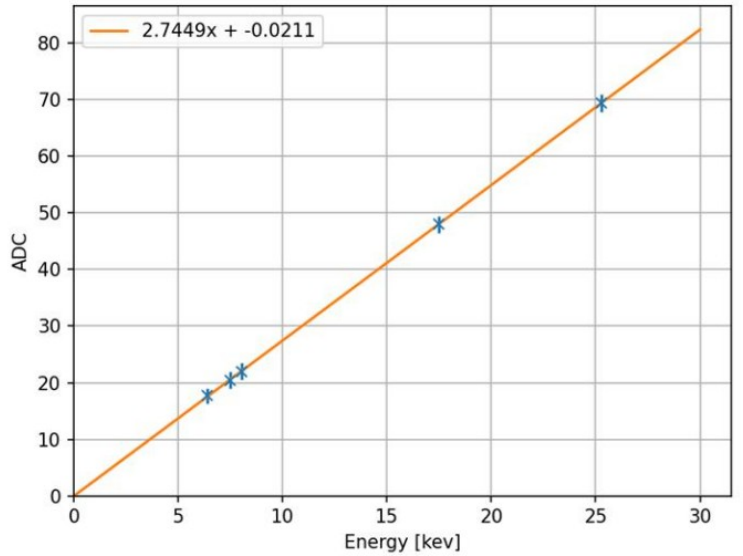


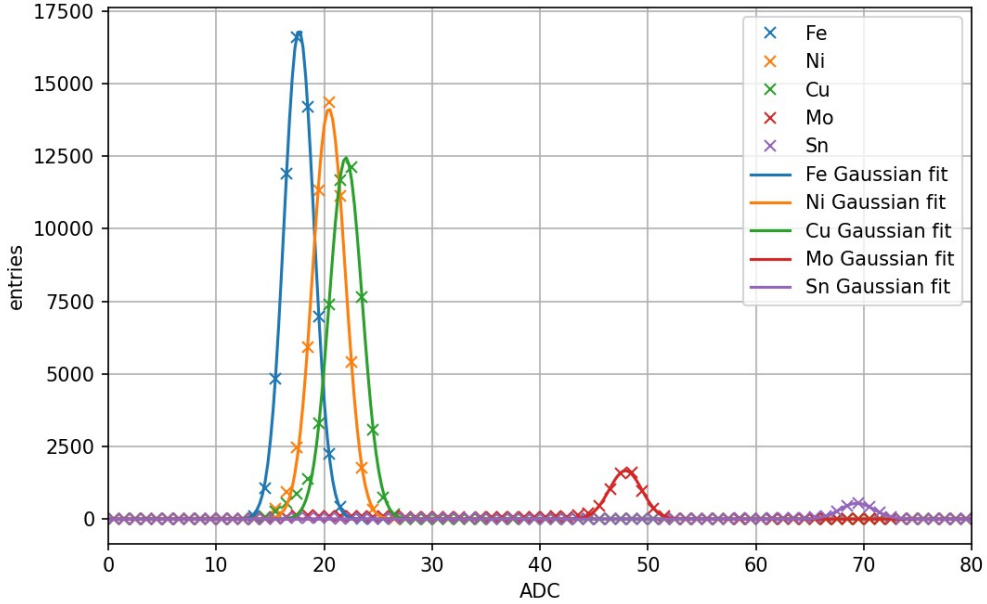


SpacePix3 simulation

- Improved simulation based on VZLUSAT-2 mission
- Introducing Allpix squared for detector response (https://allpix-squared.docs.cern.ch)
- first plans to match response of ADC calibration to reality and later move to more detailed MIP and alpha particle results

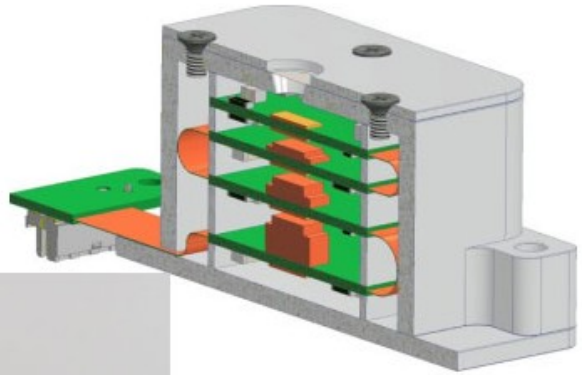


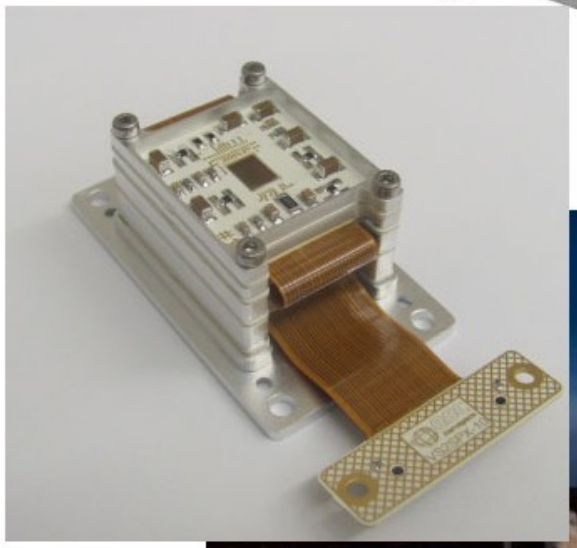


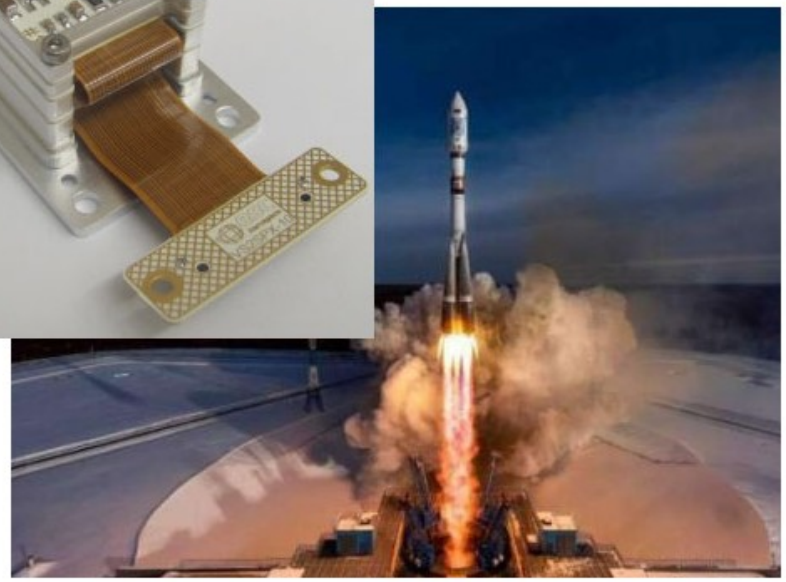


Summary

- We have designed a detector for space dosimetry systems
- Demonstrated its capabilities in space
- Continue in detector development



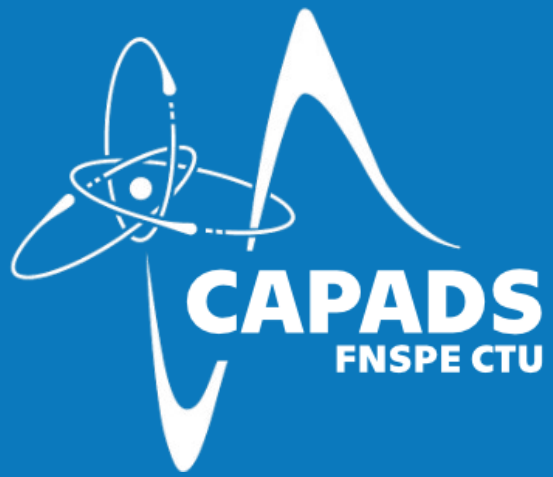




- As we are university based group, SpacePix3 and X-CHIP-04 ASICs are available **free of charge for non-commercial R&D purposes**.

- We are developing new readout electronics and searching for new missions

Thank you for your attention!



https://capads.fjfi.cvut.cz