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SpacePix3

SOI MAPS detector for space radiation monitoring

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18th Trento Workshop on Advanced Silicon Radiation Detectors

Motivation

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

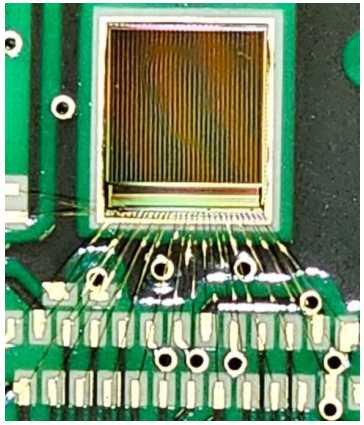
- Detector has to be able to measure:
  - flux variations
  - linear energy transfer (LET), pattern recognition, particle identification

- Other important detector parameters for space:
  - large dynamic range
  - low power consumption

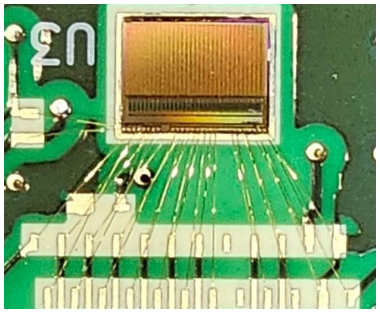
Development history of SpacePix detectors

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

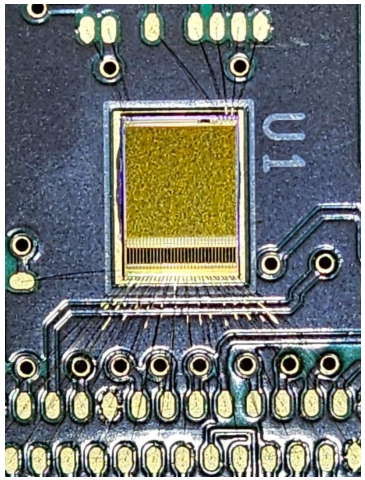
2018 | 2020 | 2022 | 2023



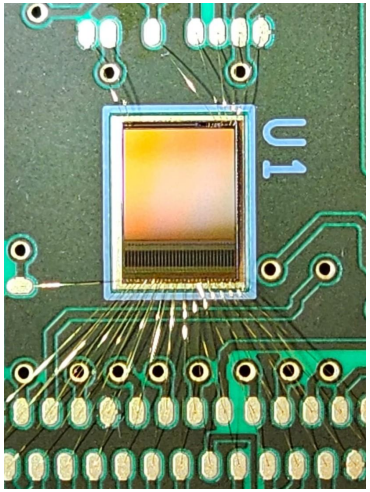
- 180 nm SOI CMOS process
- 1 - 10 ke^- signal range
- 10-bit single-ended column-parallel SAR ADCs
- Soft X-ray imaging



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

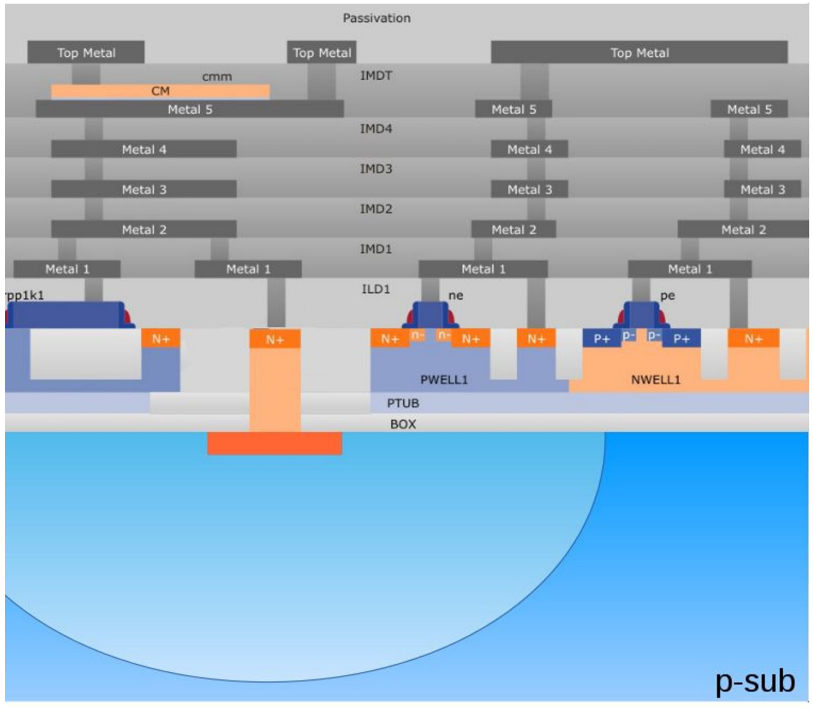


- Digitization signal from backside channel extending signal range up to 30 Me^-
- 10 – bit asynchronous column-parallel SAR ADCs with differential architecture



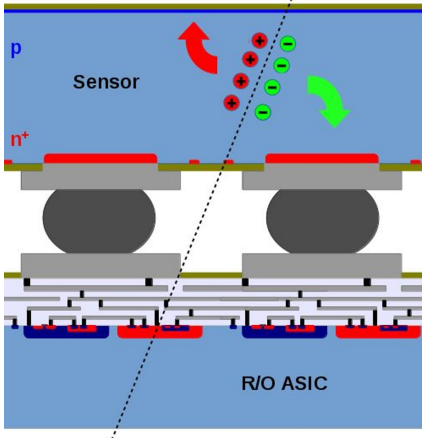
- Improved version of SpacePix2
- SAR ADC bugfix
- New feature: used defined data sampling at falling or rising edge

SOI 180 nm technology



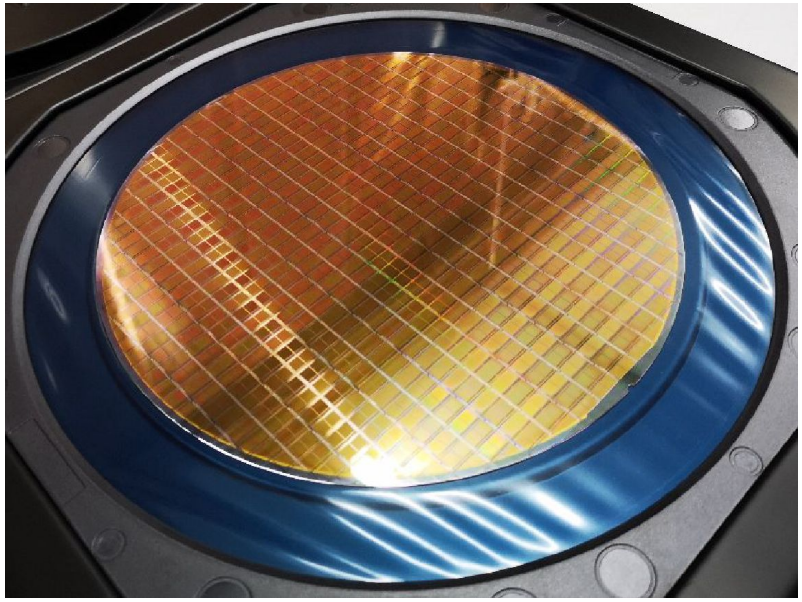
technology cross-section

- Sensor part and readout electronics are integrated on the common substrate.
- Particles are detected in handle wafer.
- Depletion region is approximately 37 µm at bias voltage -150 V.
- Bit flip cross-section was found to be low compared to a bulk CMOS, TID threshold is 1.6 kGy [1] for dose rate 16.2 Gy/min.
- Handle wafer thickness is 300 µm. We have done 50 µm thinning on single wafer, untested so far.



hybrid dectector cross-section

- Hybrid detectors have sensor part and readout electronics separated
- Absence of sensor off-chip contact makes SOI process more reliable in space.

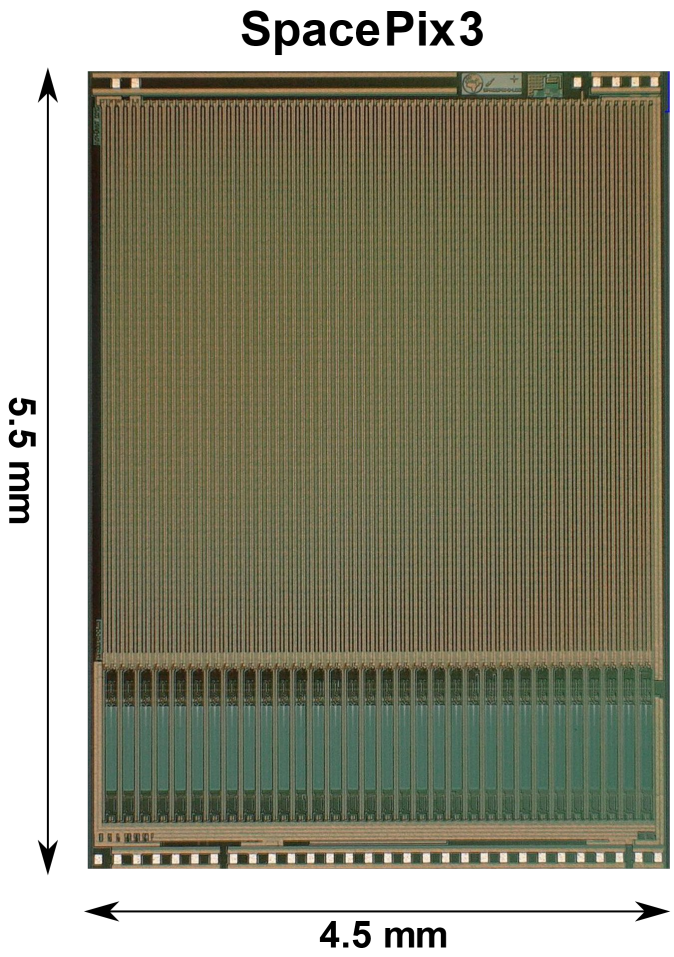


180 nm SOI wafer

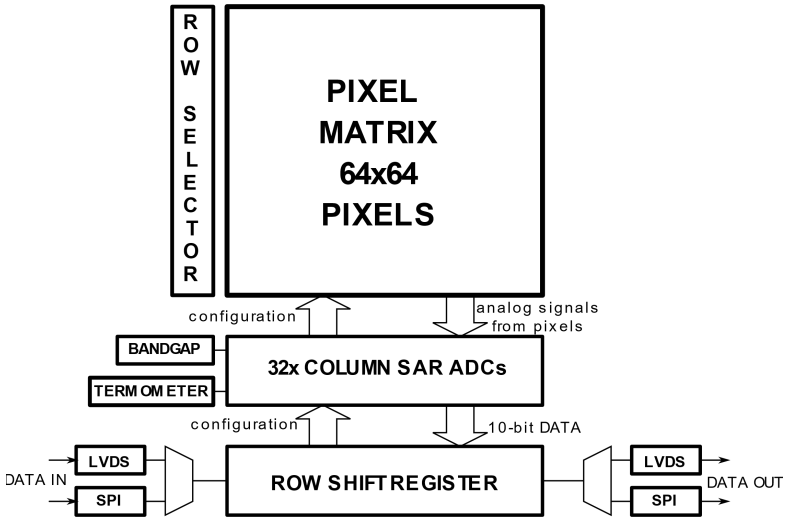
[1] MARCISOVSKA, M., et al. TID and SEU testing of the novel X-CHIP-03 monolithic pixel detector. *Journal of Instrumentation*, 2020.

SpacePix3 – parameters

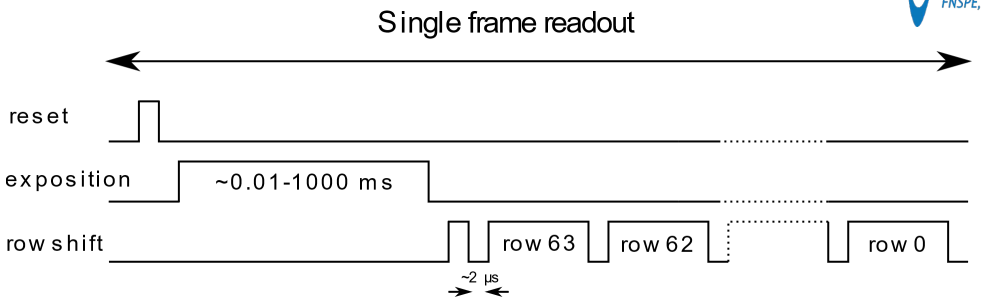
- **SOI MAPS detector for monitoring space radiation**
- 180 nm process
- 64 x 64 pixels
- with pixel pitch 60 µm
- chip size 4.5 x 5.5 mm^2
- 10-bit fully differential asynchronous column-parallel SAR ADCs
- **signal range: 1 ke^- – 65 ke^-**
- **backside channel digitization** extending signal range up to **30 Me^-**
- SPI (50 MHz) a LVDS (400 MHz) readout modes
- **current consumption: 43 mA**
- radiation hardened by design:
  - asynchronous SAR ADC controller
  - triplicated logic in configuration registers and row selector
- special functions:
  - integrated thermometer
  - testing structures
  - chip select pin



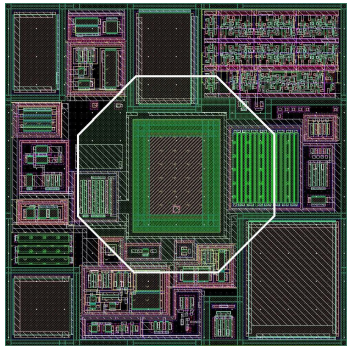
SpacePix3 - architecture



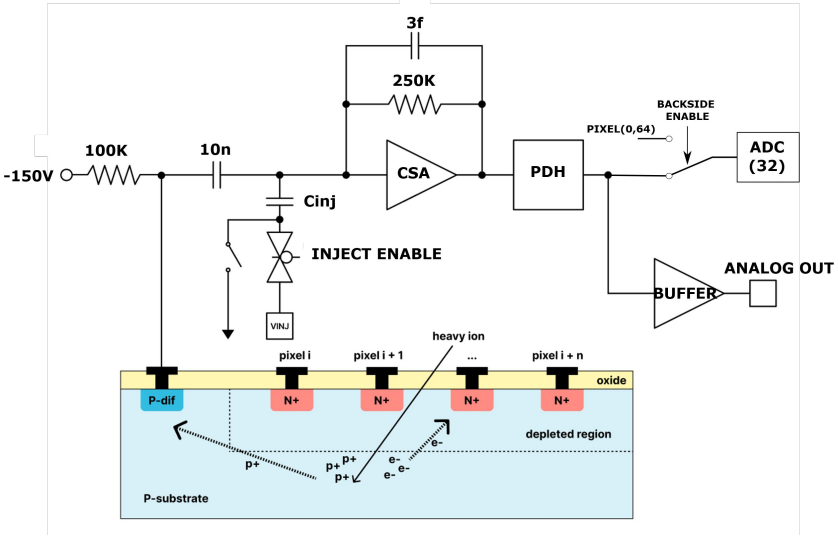
Block diagram



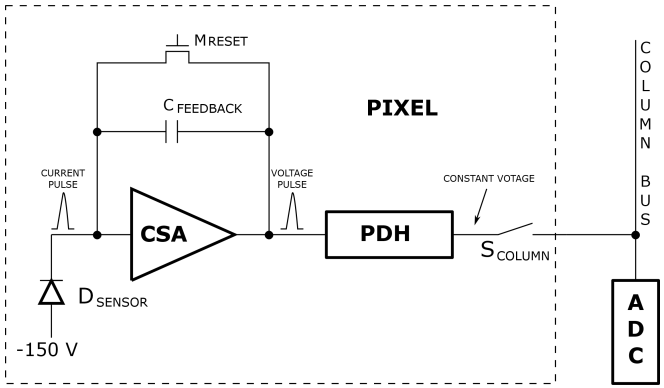
- Frame based readout
- Exposition time 0.01-1000 ms
- Max. 5000 frames/s
- Max. flux 10^5-10^6 particles/cm^2.s



Pixel layout



Functional diagram of SpacePix3 backside channel



Block diagram of SpacePix3 pixel

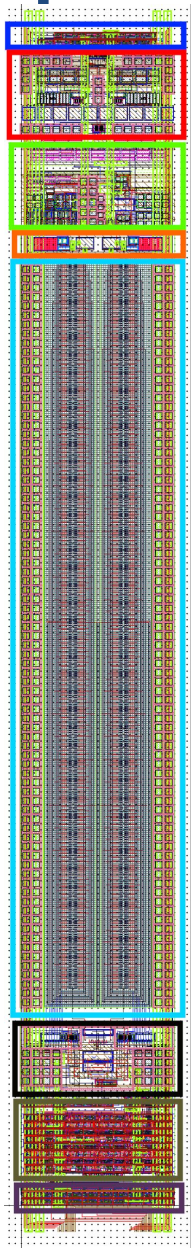
CSA gain: 9.5 µV/e$^-$

Noise: 110 e$^-$

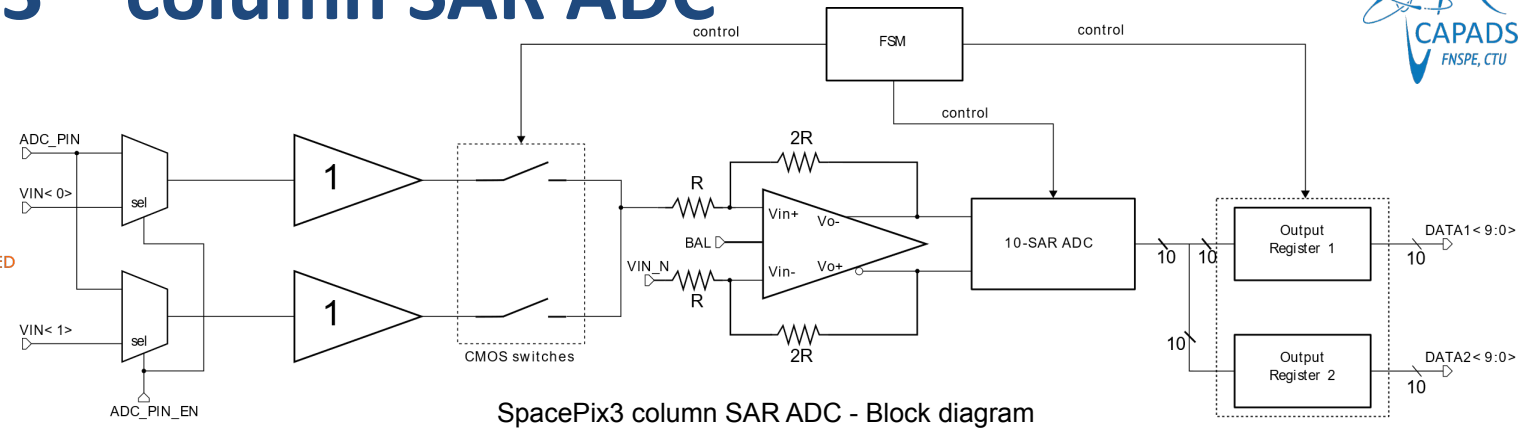
$C_{FEEDBACK}$: 9.1 fF

Range: 1 ke$^-$ - 65 ke$^-$

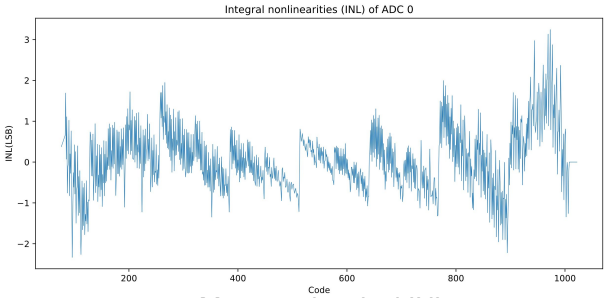
SpacePix3 – column SAR ADC



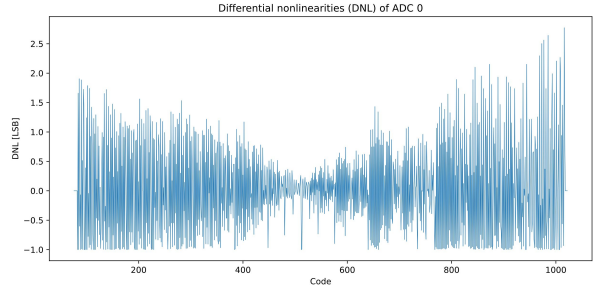
Layout design



SpacePix3 column SAR ADC - Block diagram



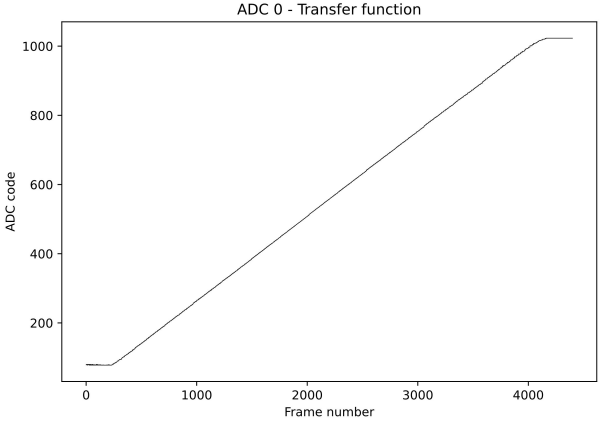
Measured typical INL



Measured typical DNL

parameter	SpacePix2	Spacepix3
DNL (LSB)	5	2
INL (LSB)	6	3
ENOB	7.13	8.8
Speed (MS/s)	4	
Number of bits	10	
Area (μm^2)	120 x 923	
Architecture	differential	

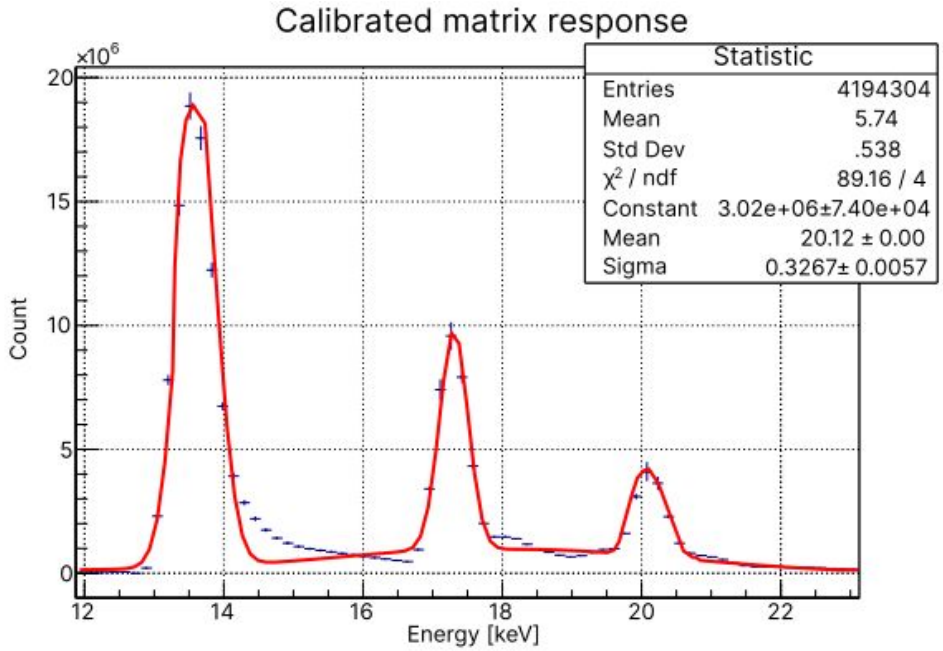
Comparison table between SpacePix2 and SpacePix3 ADCs



Measured typical transfer function

[2] VANČURA, P., et al. A low power asynchronous column-parallel 10-bit analog to digital converter with a high input impedance. *Journal of Instrumentation*, 2022, 17.05: T05016.

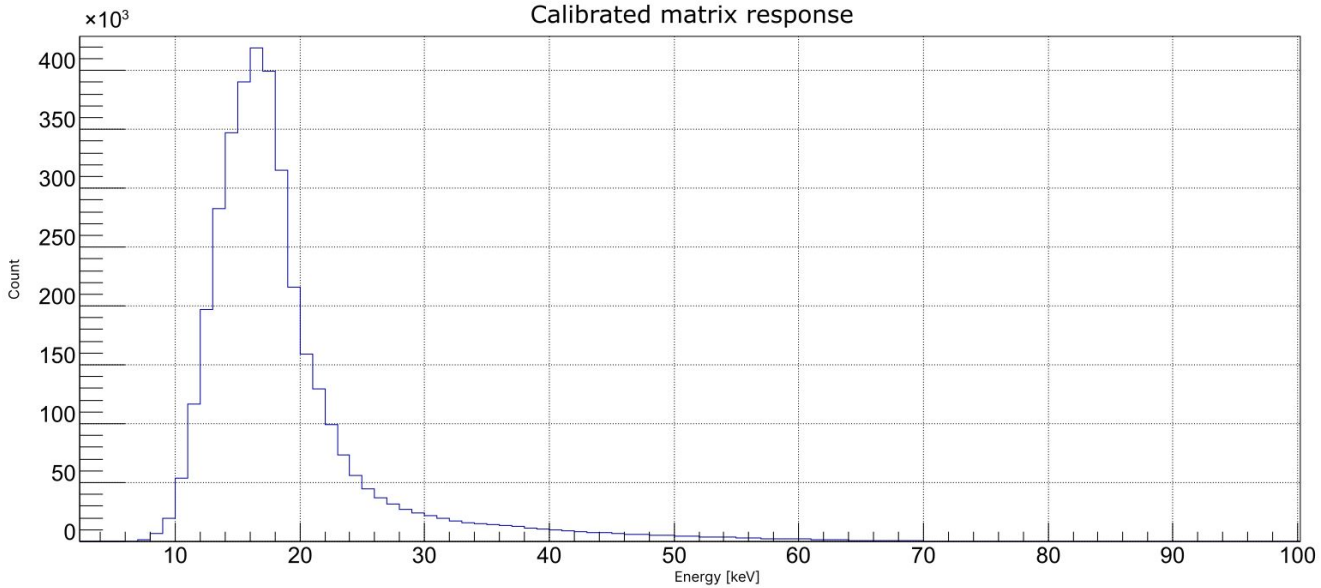
Spectrum measurement examples



Pu-238 measured with SpacePix3

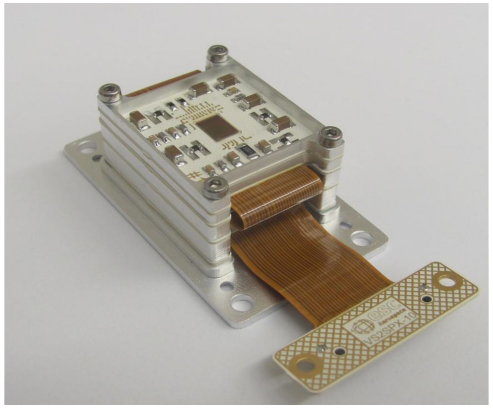
- → Lα - 13.6 keV
- → Lβ - 17.06 keV
- → Lγ - 20.3 keV

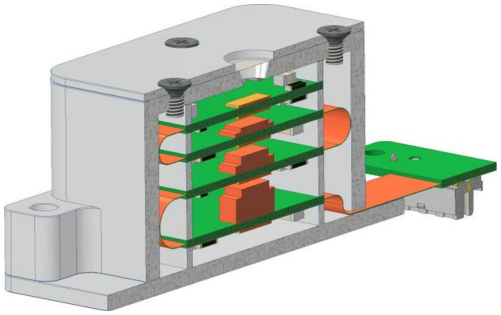
Sr-90 measured with SpacePix3



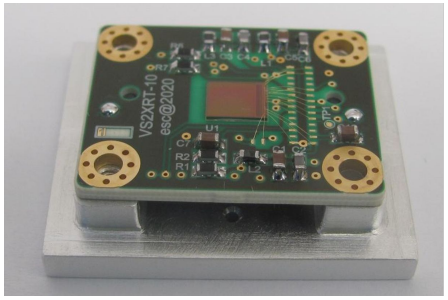
SpacePix2 on VZLUSAT-2 cubesat

Spacepix Radiation Monitor (SXRM)

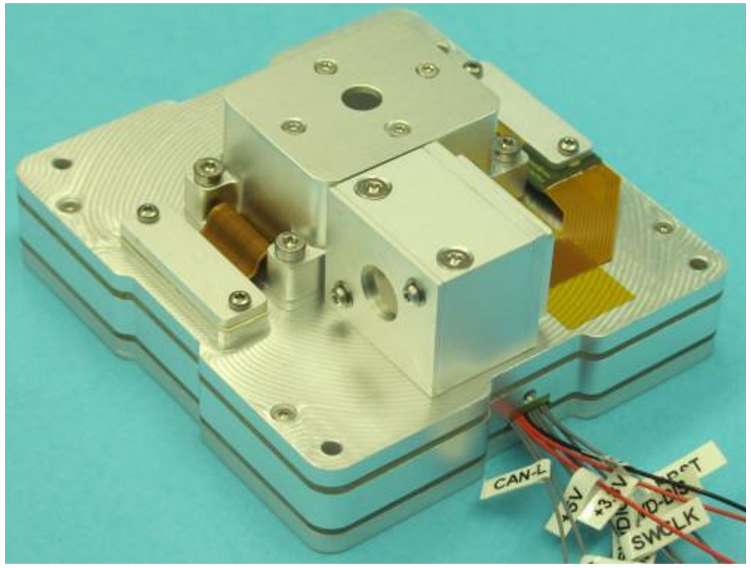




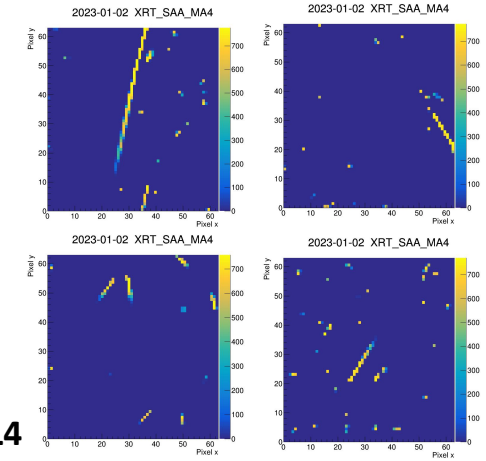
X-CHIP-03 (XRT) PCB



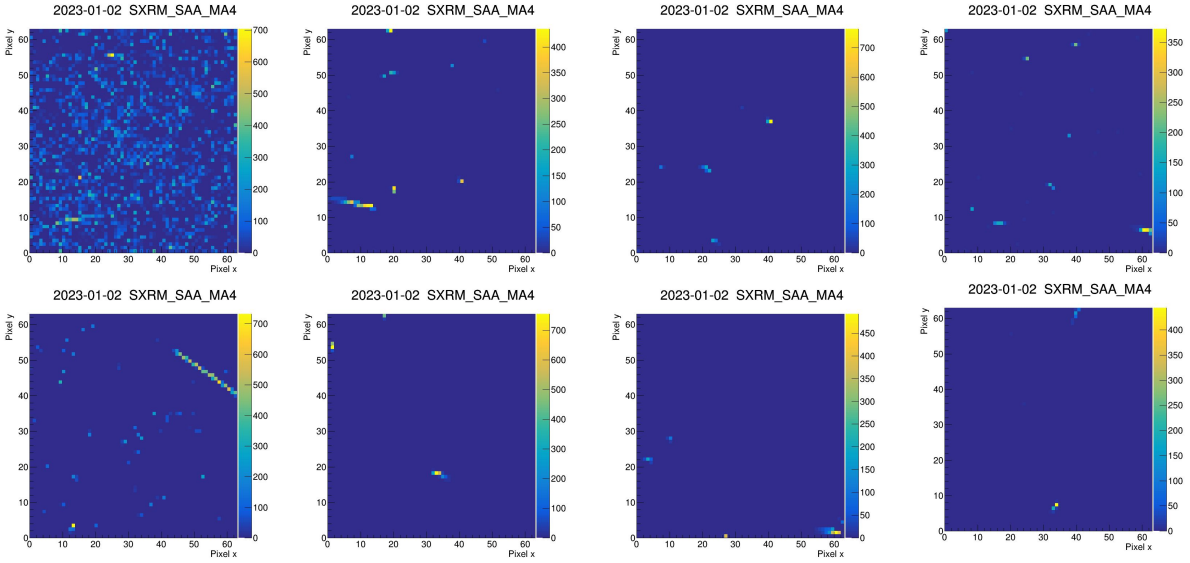
2SD™ space dosimetry demostrator



flythrough SAA 02/23 (XRT)



flythrough SAA 02/23 (SXRM), layers L0, L2, L3, L4

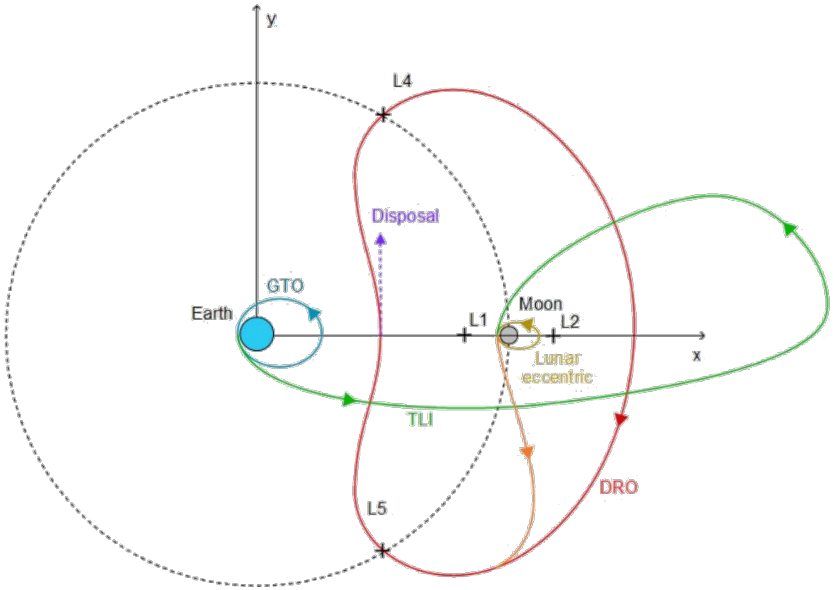


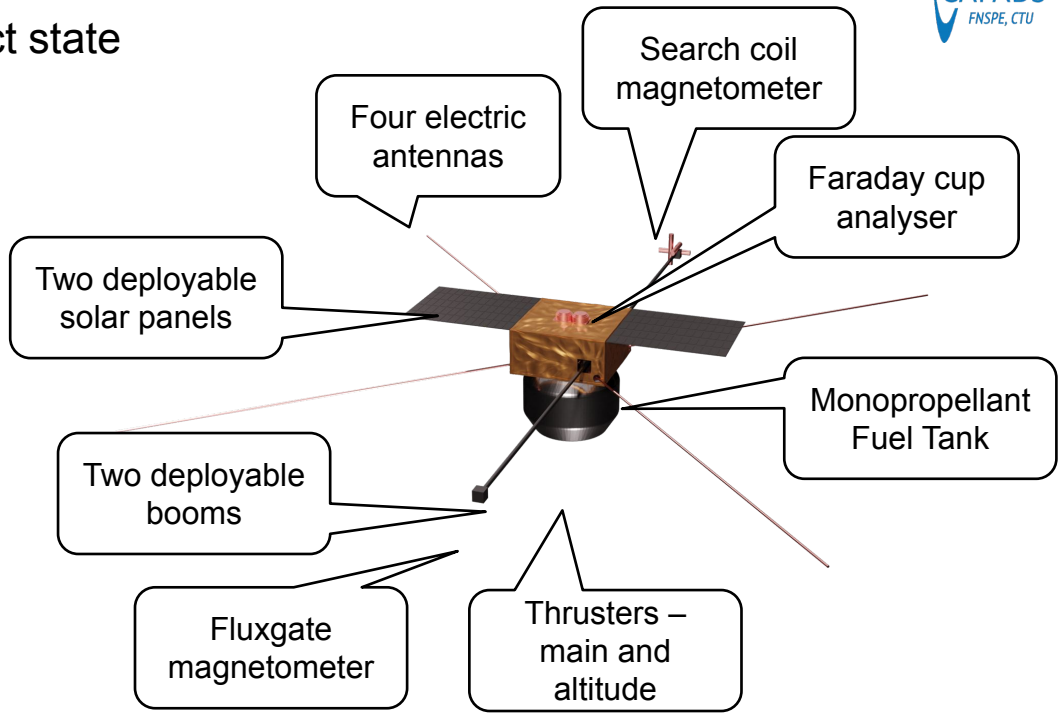
LVICE² – Lunar Vicinity Complex Environmental Explorer

- Dimensions: 55×55×60 cm³ in compact state
- Weight: ≅ 50 kg dry, 100 kg wet
- 1500 m/s Δv
- **Launch in 2027**

Mission brief

- Launch to GTO
- TLI and lunar ballistic capture
- 1 year on LEEO to study Lunar wake
- Transfer to DRO
- 2 year study of Kordylewski clouds
- Disposal to heliocentric orbit





Solar wind study

- Faraday Cup Analyzer - measurement of solar wind ion flux
- Fluxgate magnetometer - precise vector measurement of the solar wind magnetic field
- Search coil magnetometer - study of plasma turbulence at low frequencies
- Electric antennae - study of plasma turbulence at high frequencies
- AMR magnetometer - a secondary instrument for Fluxgate magnetometer calibration and measurement of CME events

Study of interplanetary dust

- Foil dust detector (FDD) - study of micrometeoroid and dust fluxes in the Kordylewski clouds, based on several layers of PVDF piezoelectric foils
- Piezoelectric dust detector (PDD) - a vibration detector on the spacecraft body to study impact of larger particles

Study of ionising radiation

- PARDAL² - composed of two parts: RADIVA (inorganic and plastic scintillators for photon and neutron measurements) and the **SXRM (SpacepiX Radiation Monitor, measuring properties of electrons, protons and heavy ions) based on developed Spacepix3 ASICs**
- SPACEDOS - a silicon LET spectrometer measuring energetic deposition of particles and their biological effects

Conclusions

- SpacePix3 is new MAPS detector for space radiation monitoring designed in 180 nm SOI process.
- Benefits of SpacePix3 detector are:
  - low power consumption
  - large signal range, 1-65 ke- pixel, up to 30 Me- backside.
- SpacePix2 is active detection element of Spacepix Radiation Monitor currently on orbit on VZLUSAT-2 cube-satellite.
- **Next mission**: The LVICE^2 scientific satellite, manufactured entirely in the Czech Republic, will study the space environment around the Moon and at Lagrange's L4 point, from 2027.
- **SpacePix3 and X-CHIP-04 ASICs are available free of charge for non-commercial R&D purposes.**

Thank you for your attention!

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MINISTRY OF EDUCATION,
YOUTH AND SPORTS

References

[1] MARCISOVSKA, M., et al. TID and SEU testing of the novel X-CHIP-03 monolithic pixel detector. *Journal of Instrumentation*, 2020, 15.01: C01043.

[2] VANČURA, P., et al. A low power asynchronous column-parallel 10-bit analog to digital converter with a high input impedance. *Journal of Instrumentation*, 2022, 17.05: T05016.

[3] VANČURA, P., et al. SpacePix2: SOI MAPS detector for space radiation monitoring. *Journal of Instrumentation*, 2023, 18.01: C01002.