Center of Applied Physics and Advanced Detection Systems
Faculty of Nuclear Sciences and Physical Engineering
Czech Technical University in Prague

SpacePix3

SOI MAPS detector for space radiation monitoring

P. Vančura, J. Gečnuk, Z. Janoška, J. Jirsa, V. Kafka, A. Kostina, D. Lednický, M. Marčišovská, M. Marčišovský, L. Tomášek, P. Staněk, M. Strnad, P. Švihra

E-mail: pavel.vancura@fjfi.cvut.cz

24th International Workshop on Radiation Imaging Detectors, Jun 25-30 2023, Oslo

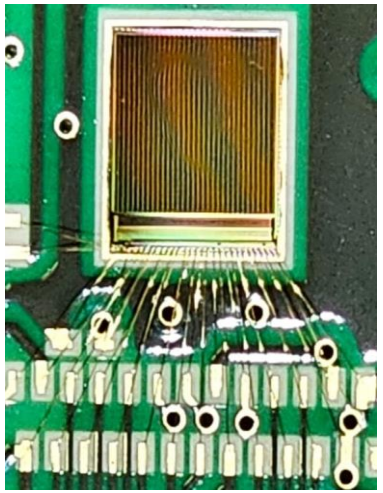
Motivation

- Monitoring space radiation is important for:
  - terrestrial and space technological infrastructure (especially electronic systems)
  - human health protection, space dosimetry
  - 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 of flux and deposited energy
  - low power consumption

Development history of SpacePix detectors

XCHIP-03

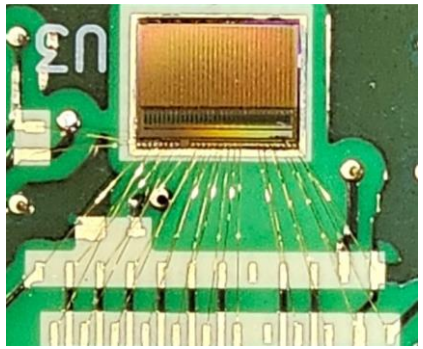
2018



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

SpacePix1

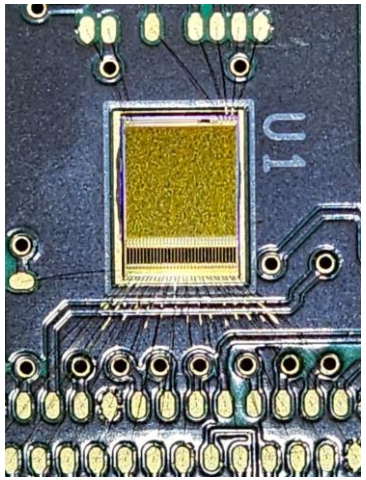
2020



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

SpacePix2

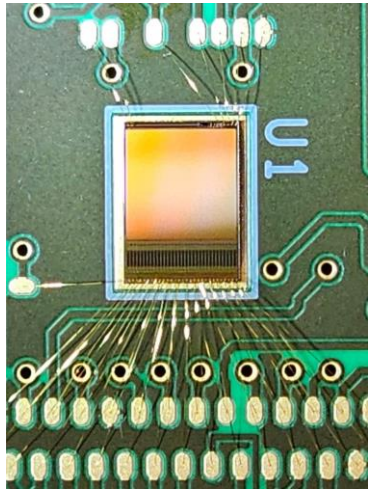
2022



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

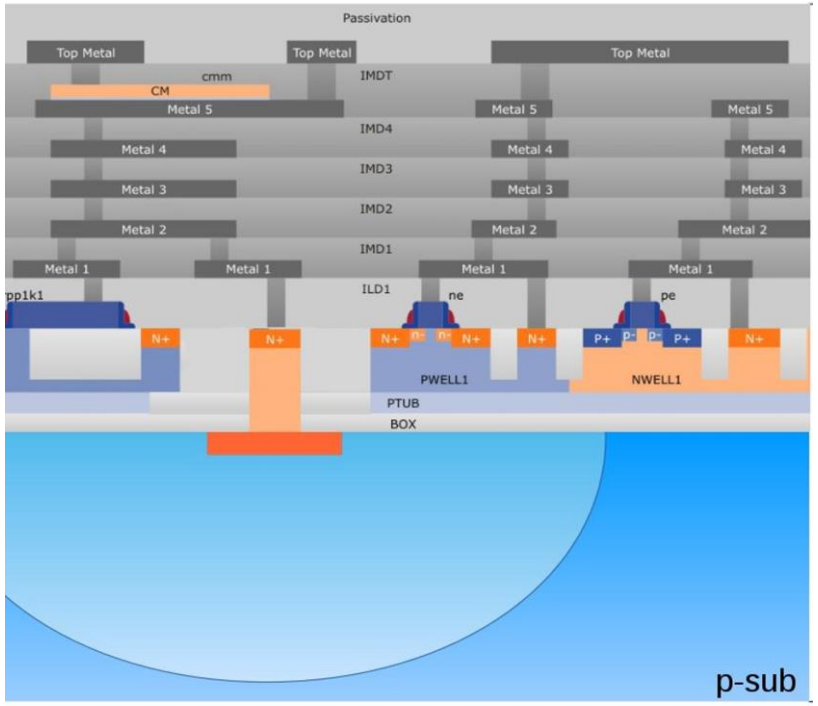
SpacePix3

2023



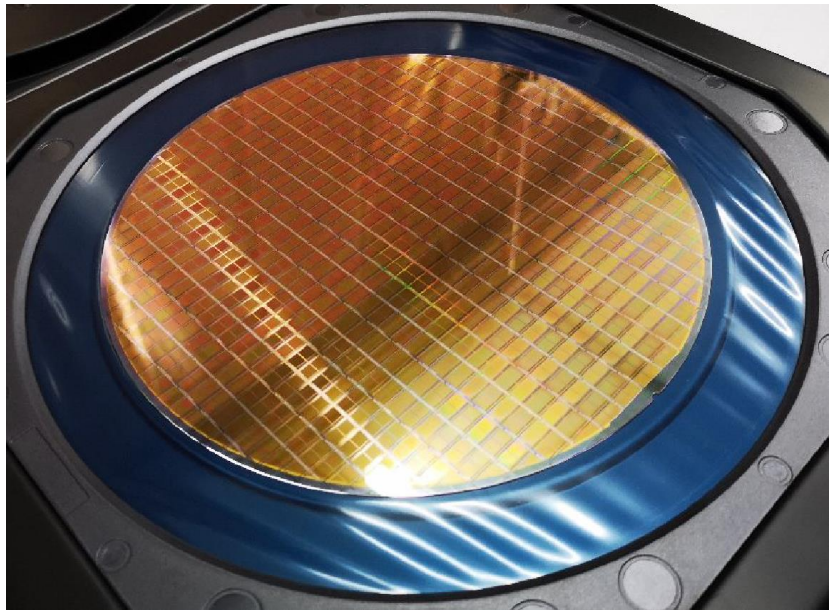
- Improved version of SpacePix2
- SAR ADC bugfix
- New feature: user defined data sampling at falling or rising edge
- optimized CSA, PDH and ADC ranges

SOI 180 nm technology

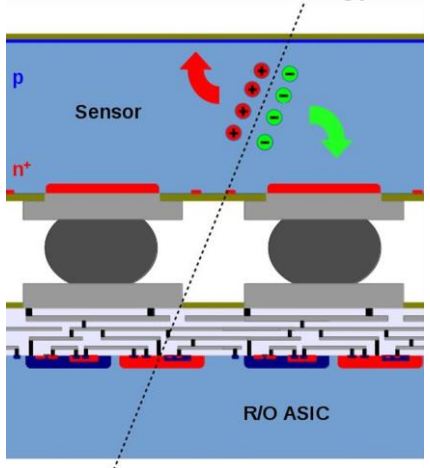


technology cross-section

- 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 2 kGy [1] for dose rate 26 Gy/min.
- Handle wafer thickness is 300 µm. We have done 50 µm thinning on single wafer, untested so far



180 nm SOI wafer



hybrid dectector cross-section

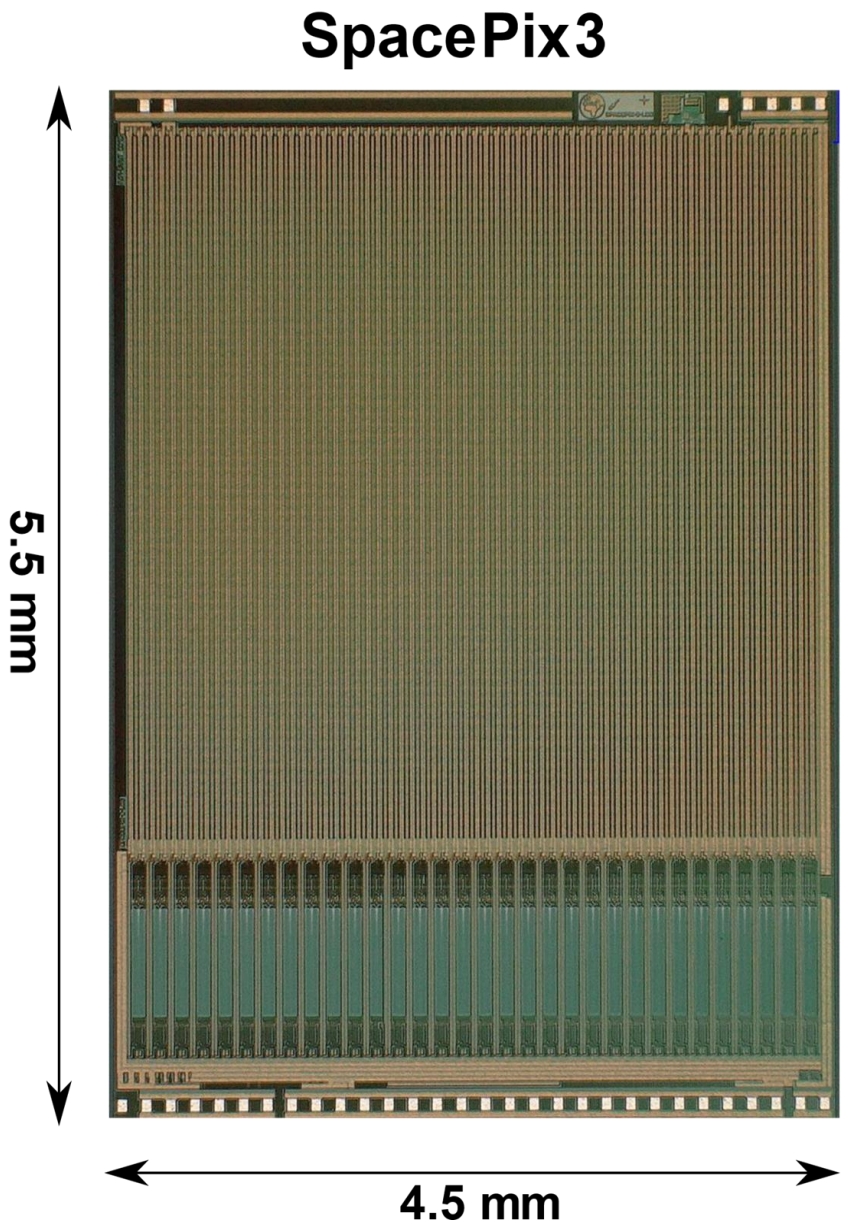
- Hybrid detectors have sensor part and readout electronics separated
- Absence of sensor off-chip contact makes SOI process more reliable in space.

Poster by Maria Marcisovska: SpacePix3 - response characterization and total ionising dose testing for space applications

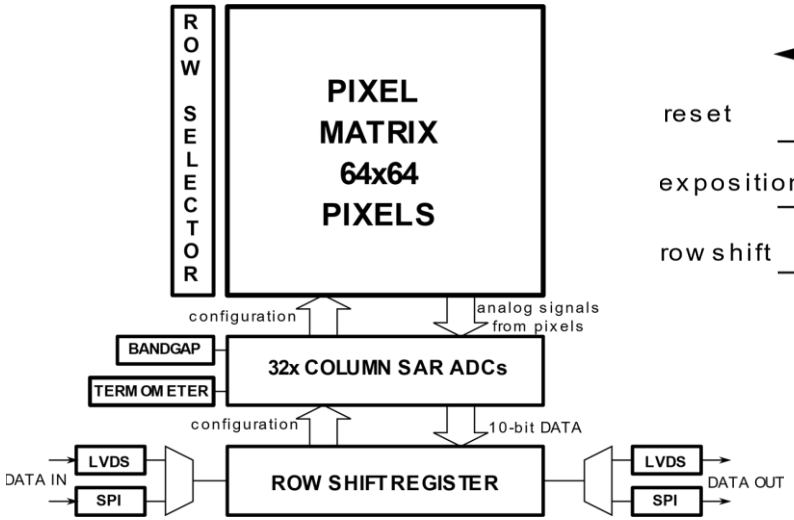
[1] MARCISOVSKA, M., et al. TID and SEU testing of the novel X-CHIP-03 monolithic pixel detector. *Journal of Instrumentation*, 2020.

SpacePix3 – parameters

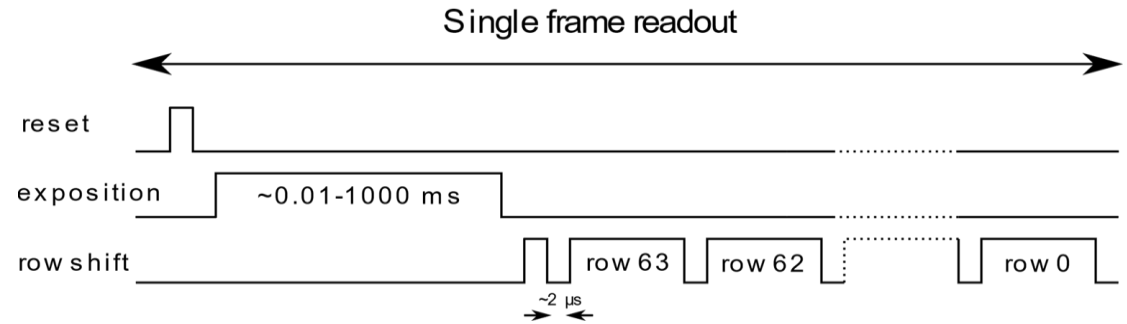
- **SOI MAPS detector for monitoring space radiation**
- 180 nm process
- 64 x 64 pixels
- with pixel pitch 60 µm
- chip size 4.5 x 5.5 mm^2
- 10-bit fully differential asynchronous column-parallel SAR ADCs
- **signal range: 1 ke^- – 65 ke^-**
- **energy range: 3.6 keV – 288 keV**
- **backside channel digitization** extending signal range up to **30 Me^-**
- SPI (50 MHz) a LVDS (400 MHz) readout modes
- **current consumption: 31 mA (SPI mode)**
- radiation hardened by design:
  - differential SAR ADC design
  - triplicated logic in configuration registers and row selector
- special functions:
  - integrated thermometer
  - testing structures
  - chip select pin



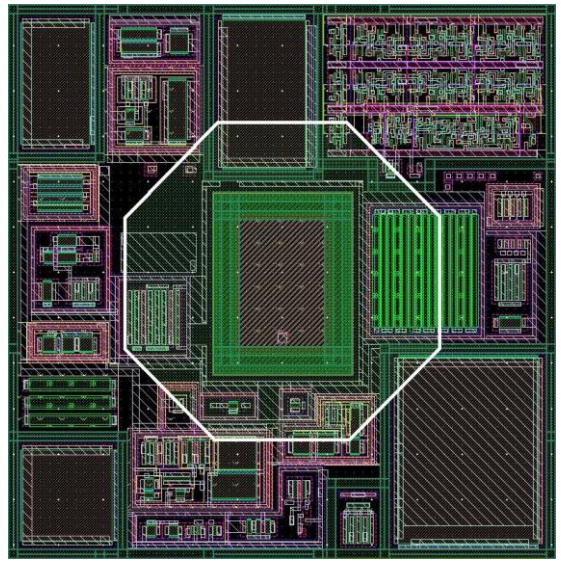
SpacePix3 - architecture



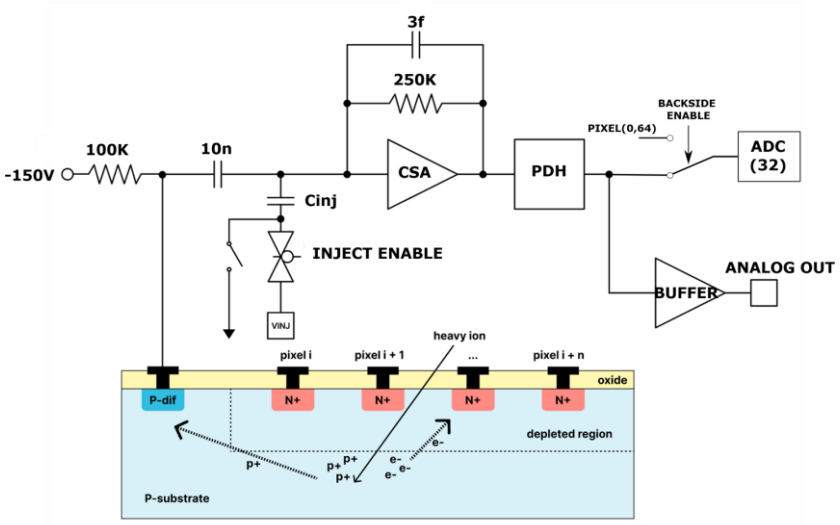
SpacePix3 Block diagram



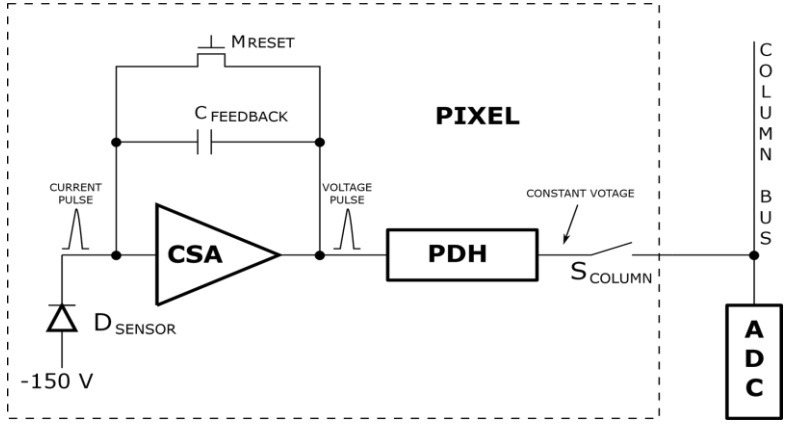
- Frame based readout
- Exposition time 0.01-1000 ms
- Max. 5000 frames/s
- Max. flux 10^5-10^6 particles/cm^2.s



Pixel layout



Functional diagram of SpacePix3 backside channel



Functional diagram of SpacePix3 pixel

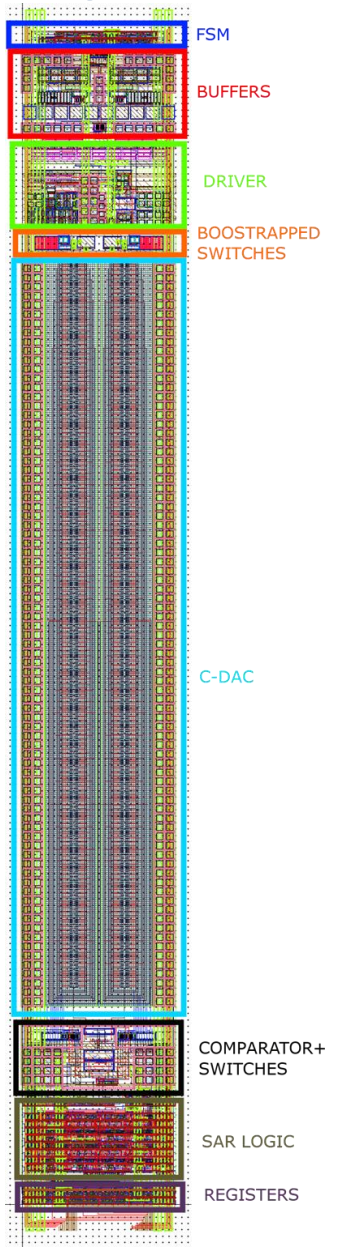
CSA gain: 9.5 µV/e$^-$

Noise: 110 e$^-$

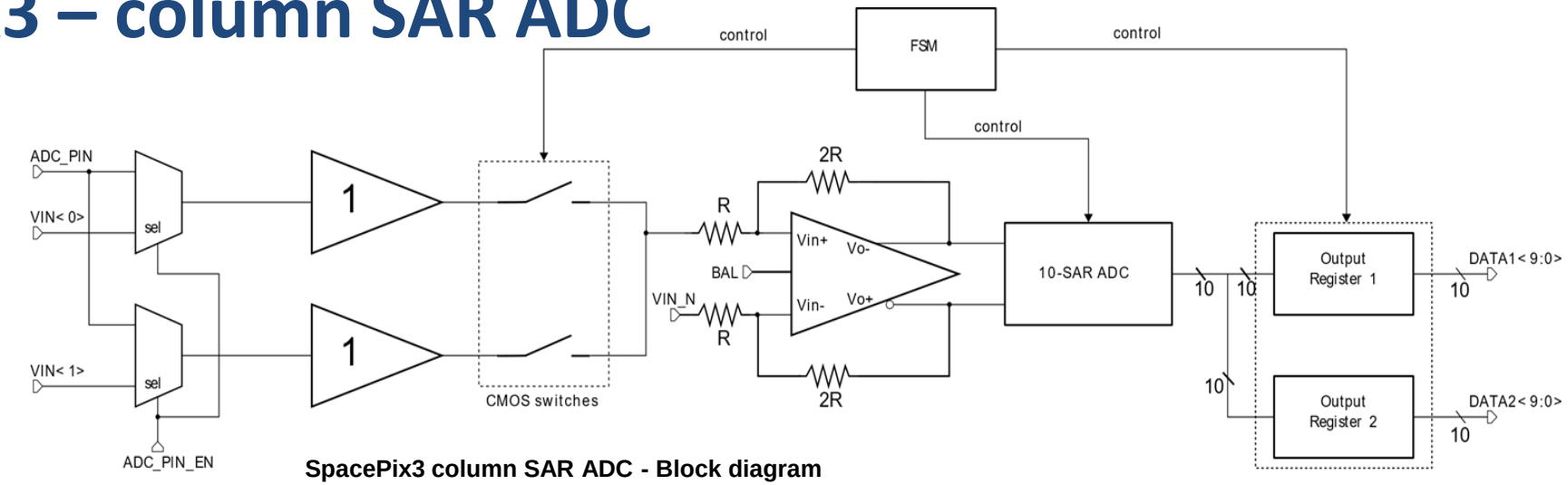
$C_{FEEDBACK}$: 9.1 fF

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

SpacePix3 – column SAR ADC



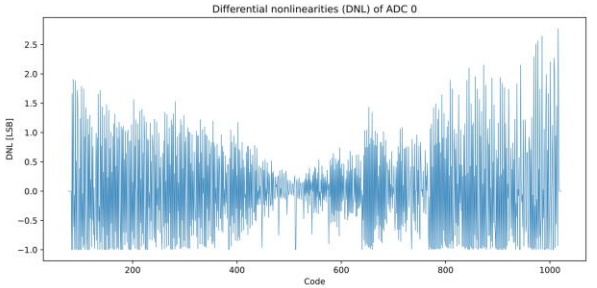
Layout design



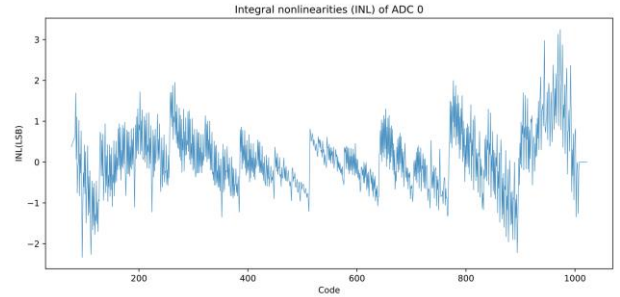
SpacePix3 column SAR ADC - Block diagram

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	

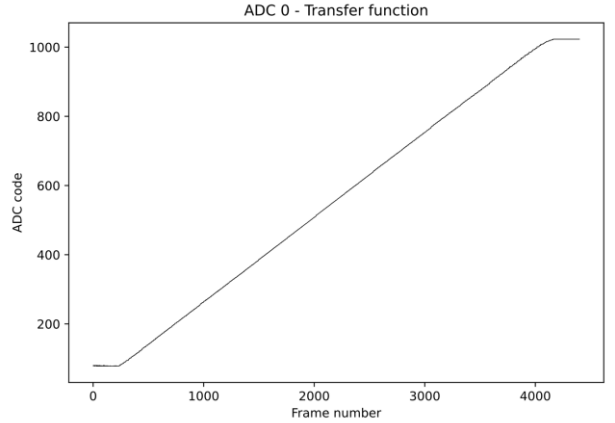
Comparison table between SpacePix2 and SpacePix3 ADCs



Measured typical DNL



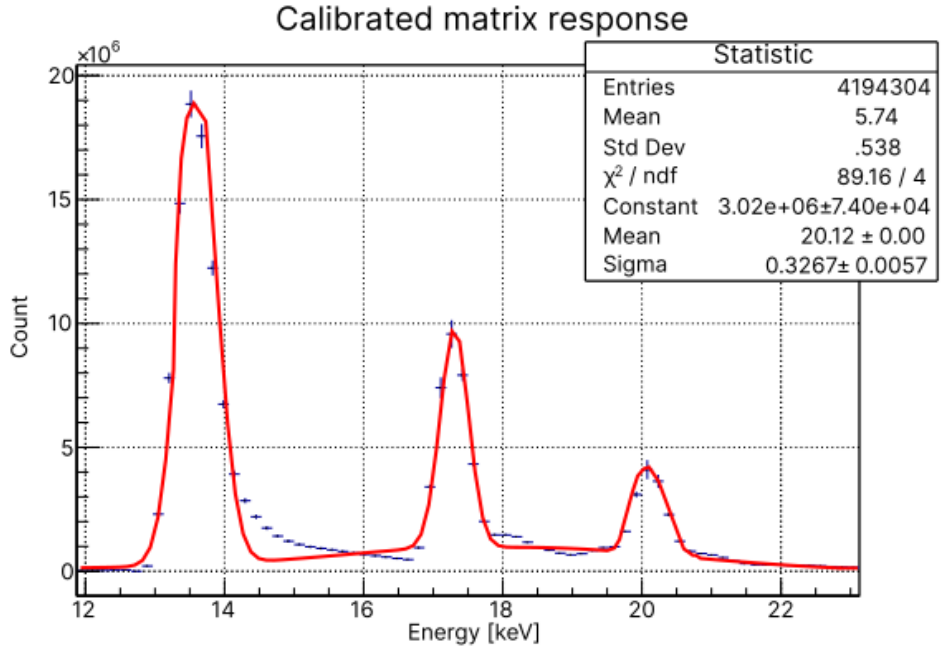
Measured typical INL



Measured typical transfer function

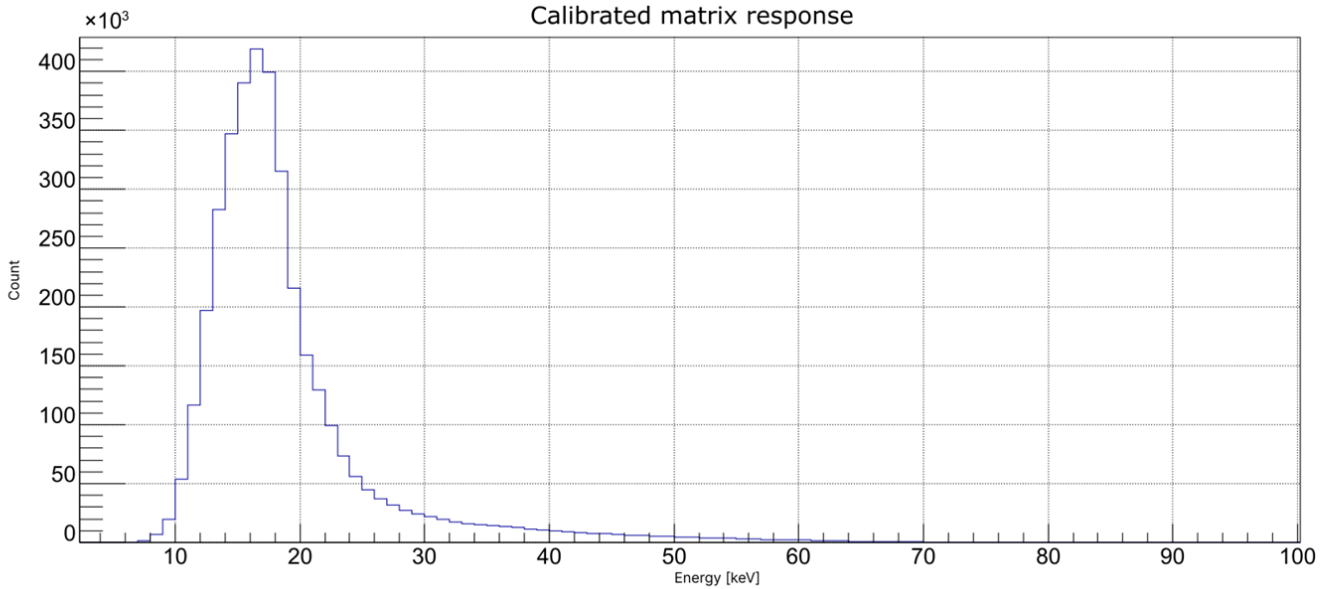
[2] VANČURA, P., et al. A low power asynchronous column-parallel 10-bit analog to digital converter with a high input impedance. *Journal of Instrumentation*, 2022, 17.05: T05016.

Spectrum measurement examples



Pu-238 measured with SpacePix3

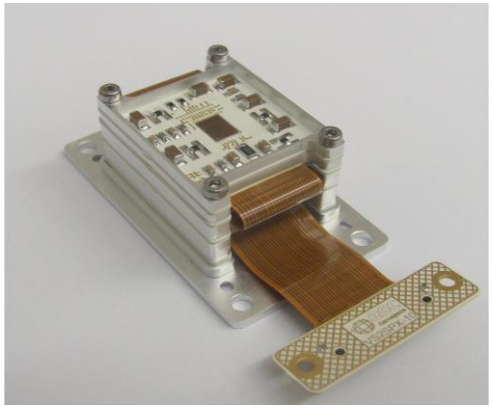
- ➔ Lα - 13.6 keV
- ➔ Lβ - 17.06 keV
- ➔ Lγ - 20.3 keV

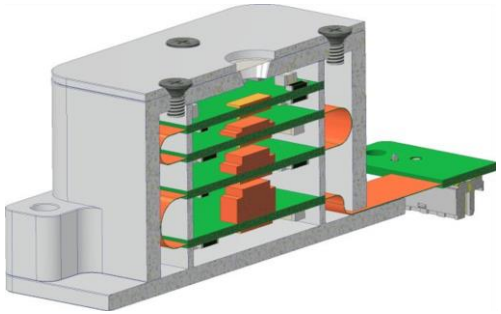


Sr-90 measured with SpacePix3

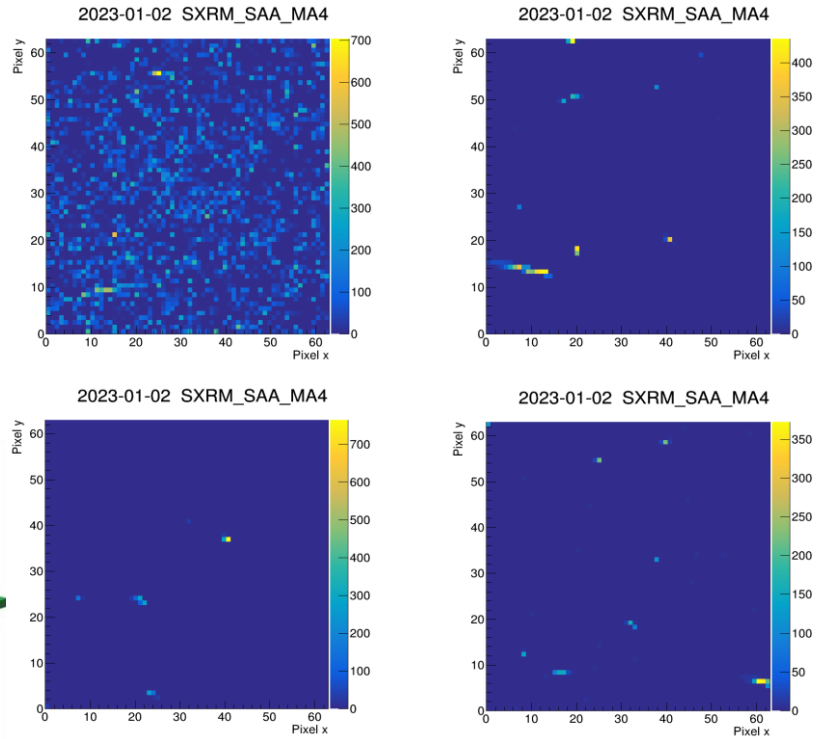
SpacePix2 on VZLUSAT-2 cubesat

Spacepix Radiation Monitor (SXRM)

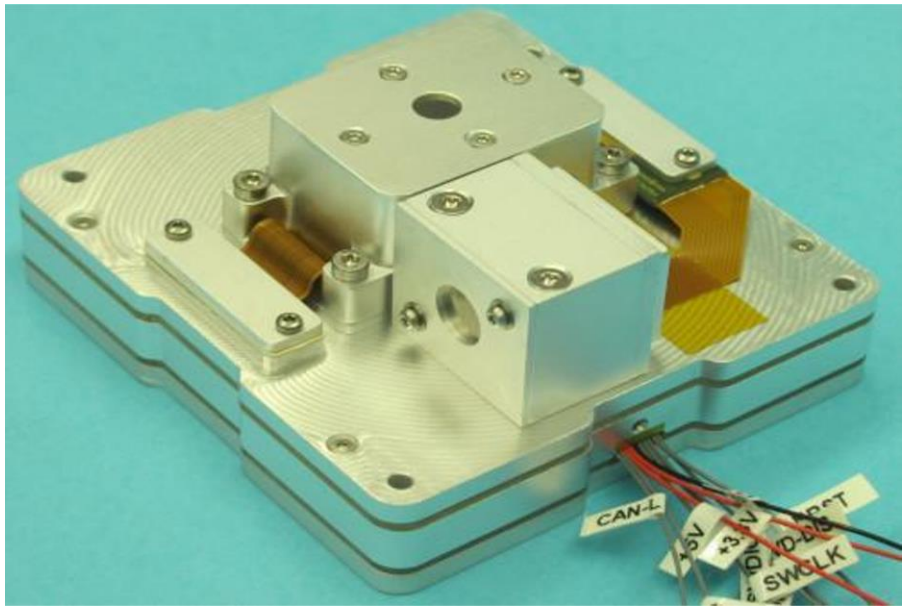




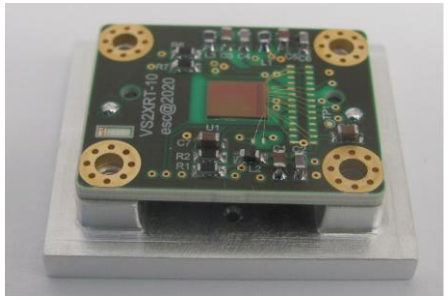
flythrough SAA 02/23 (SXRM), layers L0, L2, L3, L4



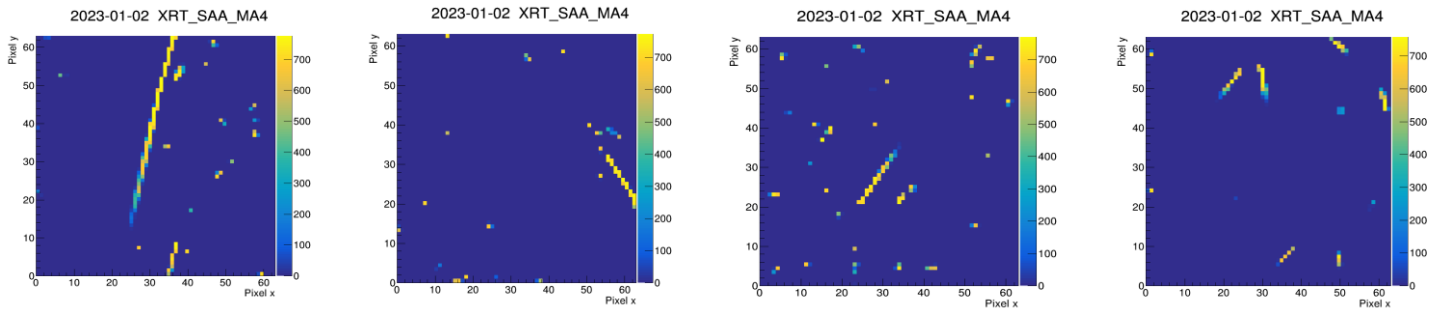
2SD^{TM} space dosimetry system demostrator



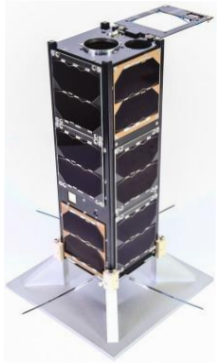
X-CHIP-03 (SXM) PCB



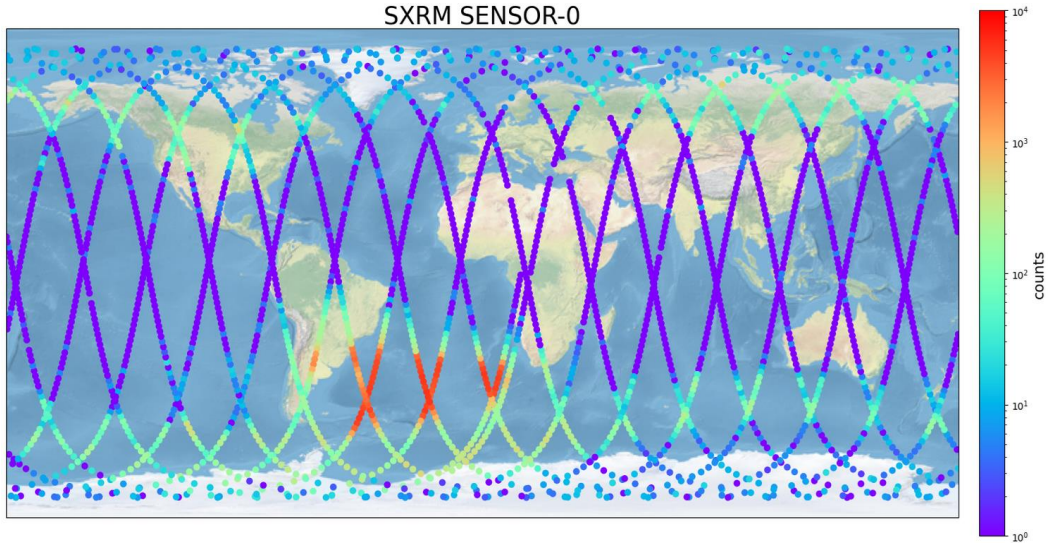
flythrough SAA 02/23 (SXM)

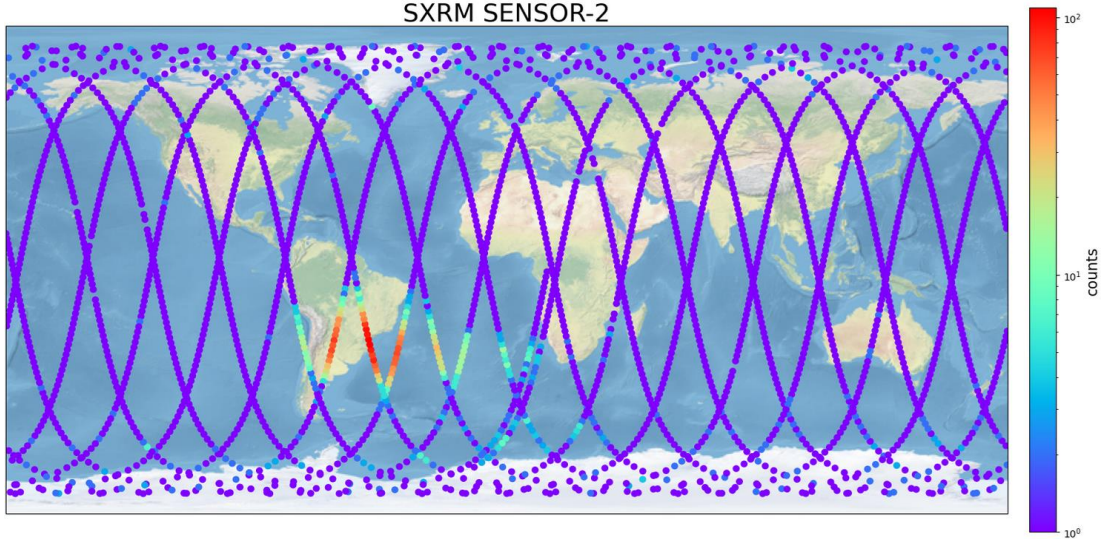


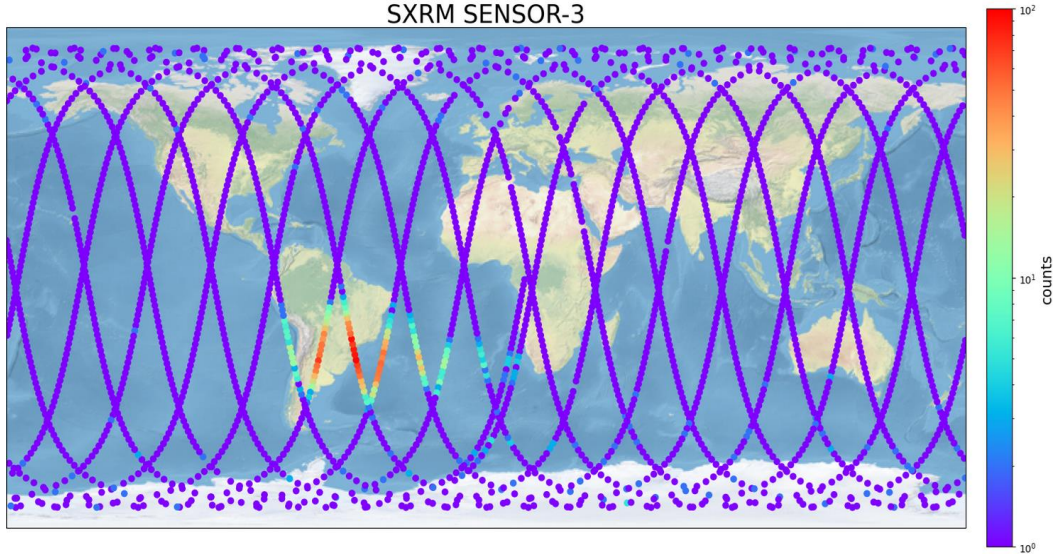
VZLUSAT-2

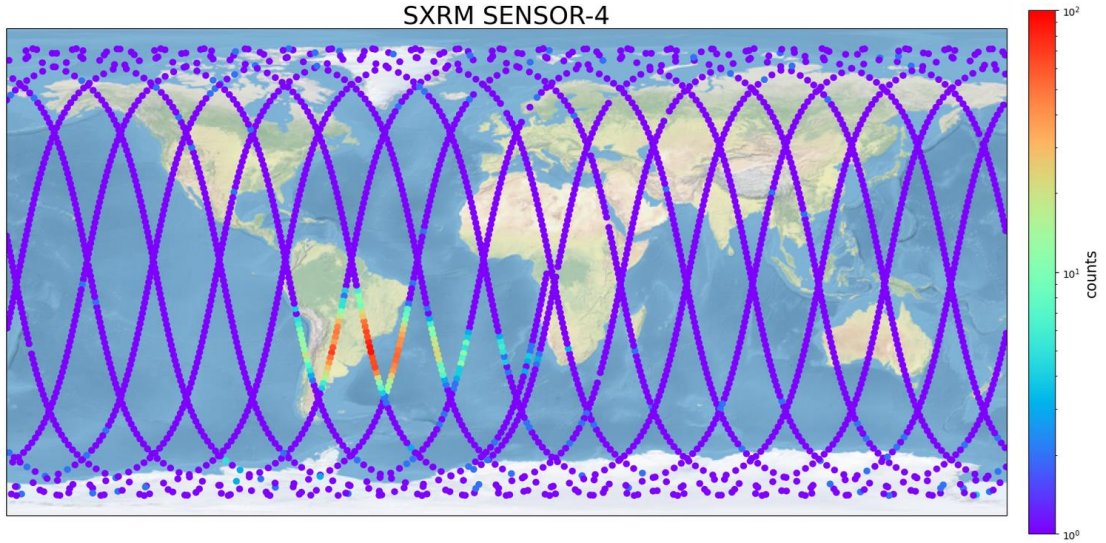


SXRM data - ground track plot per one day









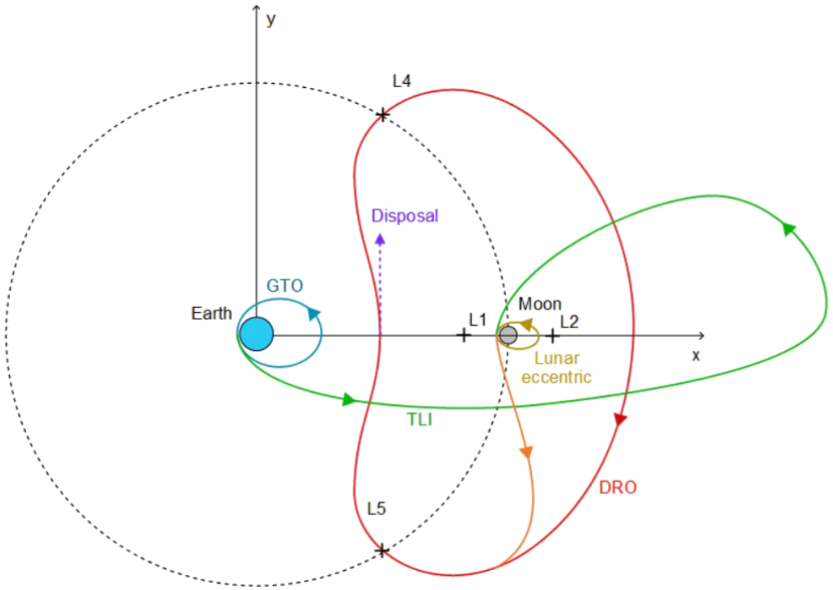
See poster by Pavel Stanek: SpacePix Radiation Monitor: Data from the First Year of Operation in Orbit

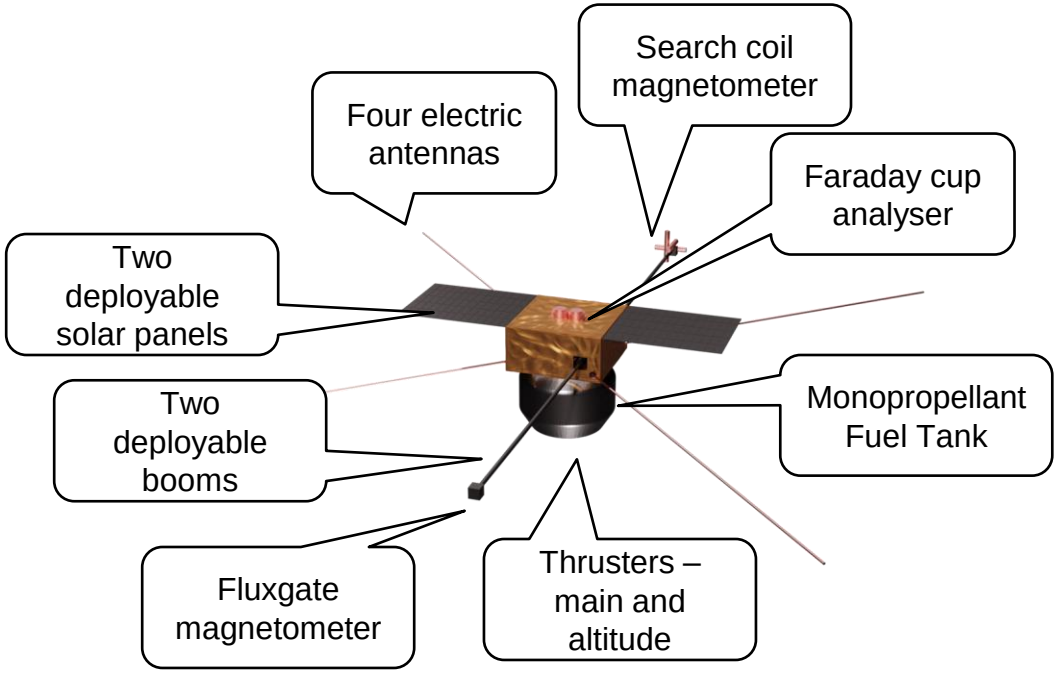
LVICE² – Lunar Vicinity Complex Environmental Explorer

- Dimensions: 55×55×60 cm³ in compact state
- Weight: ≅ 50 kg dry, 100 kg wet
- 1500 m/s **Δ**v
- **Launch in 2028**

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, 31 mA (in SPI mode)
  - 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**: If selected in ITT3, the LVICE^2 probe, manufactured entirely in the Czech Republic, will study the space environment around the Moon and at DRO around L4 and L5 points
- **SpacePix3 and X-CHIP-04 ASICs are available free of charge for non-commercial R&D purposes**

Thank you for your attention!

The work was supported from European Regional Development Fund-Project

"Center of Advanced Applied Science"

No. CZ.02.1.01/0.0/0.0/16-019/0000778.

EUROPEAN UNION
European Structural and Investment Funds
Operational Programme Research,
Development and Education

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