SpacePix2 MAPS for space radiation detection and first results from the VZLUSAT2 mission

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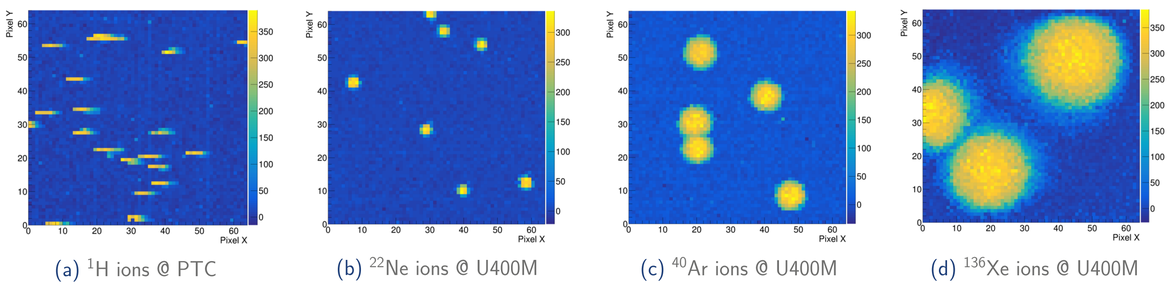
Introduction

- All space missions, manned or robotic, need to deal with cosmic radiation in order to protect sensitive electronic devices and health of the astronauts.
- Radiation in space has several components with large variation of flux and deposited energy, but the most important (with regard to radiation effects) are charged particles: electrons, protons, and heavy ions.
- The pixel detectors are optimal tools to measure cosmic radiation with high precision.
- We present a novel, low-power monolithic pixel detector SpacePix2 [1] developed in a 180 nm PDSoI technology optimized for space missions ranging from LEO to interplanetary space [2].

The SpacePix2 sensor

- Radiation-tolerant sensor based on a PD 180 nm SoI CMOS technology using Monolithic Active Pixel Sensor (MAPS) ASIC design [3].
- It features a 64 $\times$ 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 – 30Me$^-$
- Low-power ($<$ 50 mW) detector processing $10^6 - 10^7$ pixel hits cm^{-2}s^{-1}
- The threshold for total ionizing dose (TID) $\sim$ 2 kGy at 15 Gy/m
- Capable of dE/dx measurements of electrons, protons and heavy ions
- Pattern recognition techniques (clustering, topologies) and partial reconstruction of particle trajectory used in data processing units



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

Figure 1: 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

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

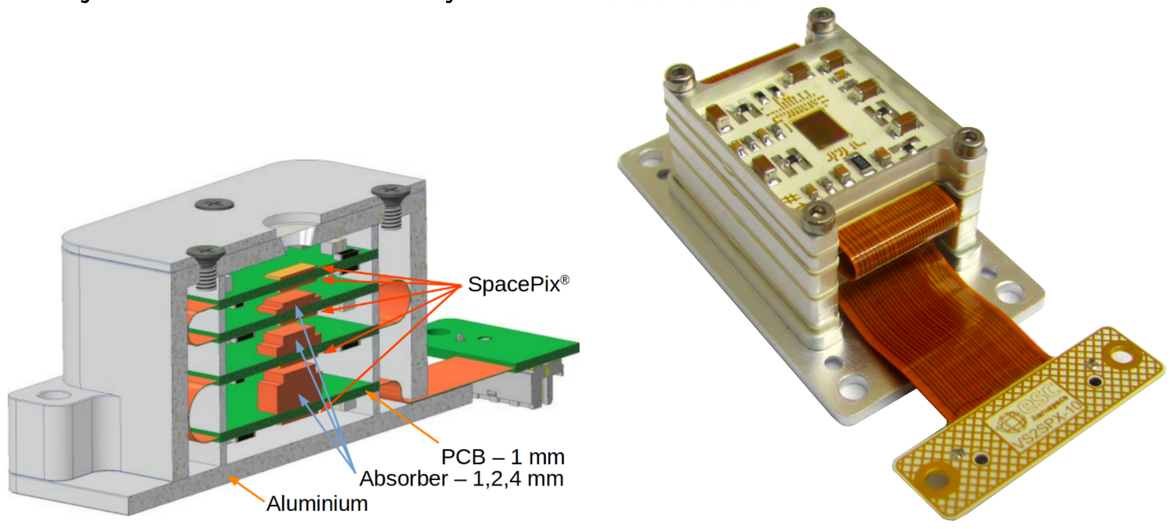


Figure 2: Model of the SXRM particle telescope (left) and radiation monitor based on the SpacePix2 detector (right).

SXRM at VZLUSAT2 mission

- SXRM is a part of the Czech nanosatellite VZLUSAT2 mission [4], as a component of the Space Dosimetry System Demonstrator (2SD).
- 2SD is radiation detector system designed for CubeSat and smallest platforms that consists of:
  - SXRM with Cu absorber
  - Soft X-ray Monitor (SXM) based on X-CHIP-03 [3]
- The VZLUSAT2 mission was launched in January 2022 on the SpaceX Falcon 9 launch vehicle.

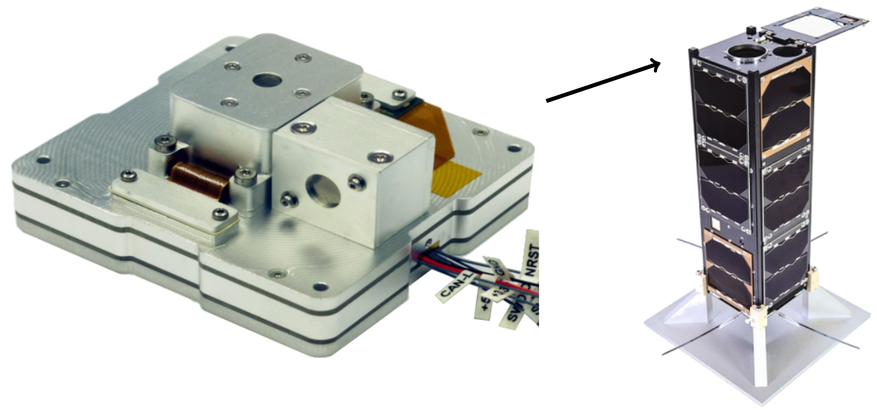
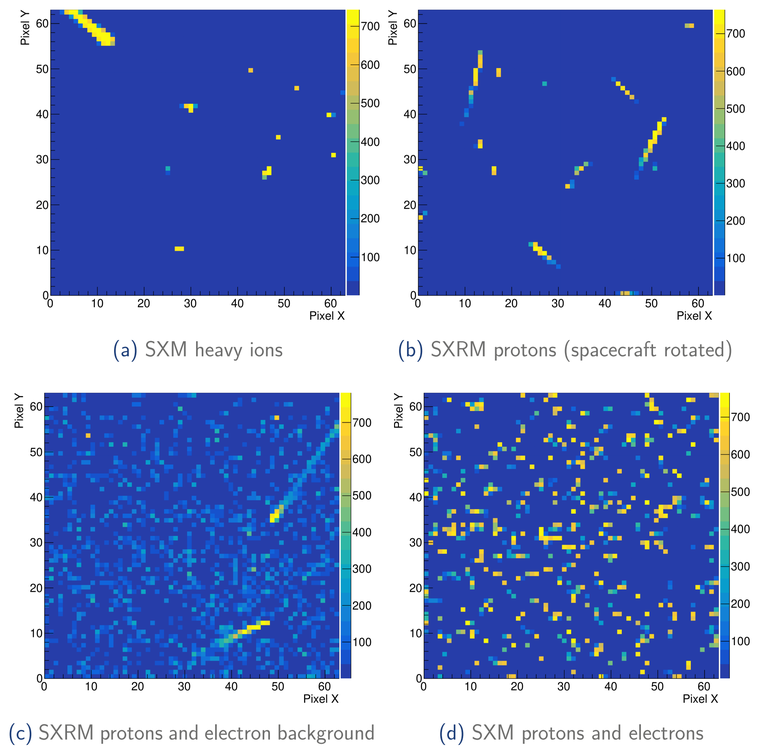


Figure 3: Space Dosimetry System Demonstrator - 2SD (left) and Czech nanosatellite VZLUSAT2 (right).

VZLUSAT2 mission results

- After the commissioning phase, first data have been received from the VZLUSAT2 mission.
- The examples of received data from the first SXRM layer from the South Atlantic Anomaly (SAA) with an exposure time of 20 ms are show here.
- The ion impacts are clearly visible as well as proton and electron signatures.

Figure 4: VZLUSAT2 deployment [4].



(a) SXM heavy ions (b) SXRM protons (spacecraft rotated)

(c) SXRM protons and electron background (d) SXM protons and electrons

Figure 5: Received VZLUSAT2 data, SAA at the first layer with 20 ms exposure time.

Conclusions

The SXRM is a low-power, highly-miniaturized proton, electron and heavy ion monitor with individual particle identification, classification and tracking capabilities. The dynamic range of the SpacePix2 ASICs and multiple particle ionization dE/dx sampling will allow event reconstruction and identification using pattern recognition algorithms implemented in the DPU. The five-layer SXRM prototype in 2SD instrument is currently being tested onboard the VZLUSAT2.

The SpacePix2/3 ASICs are available free of charge for non-commercial research purposes.

References

[1] P. Vancura et. al., SpacePix2: SOI MAPS Detector for Space Radiation Monitoring.

[2] M. Marcisovska et al., TID and SEU testing of the novel X-CHIP-03 monolithic pixel detector. *Journal of Instrumentation*, 15(01):C01043, jan 2020.

[3] M. Havranek et al., X-CHIP-03: SOI MAPS radiation sensor with hit-counting and ADC mode. In *2018 IEEE Nuclear Science Symposium and Medical Imaging Conference Proceedings (NSS/MIC)*, pages 1–4, 2018.

[4] VZLUSAT-2 Czech technological nanosatellite., `https://www.vzlusat2.cz/`.

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