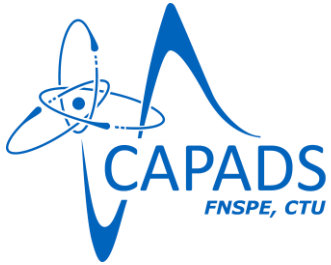

Center of Applied Physics and Advanced Detection Systems

SpacePix Radiation Monitor – a compact multi-layer particle telescope

Jakub Jirsa[1], Pavel Broz[2], Josef Gecnuk[1], Zdenko Janoska[1], Anezka Kabatova[1], Vladimír Kafka[1], Anhelina Kostina[1], Michal Marcisovsky[1], Maria Marcisovska[1], Petr Suchanek[2], Pavel Staněk[1], Peter Svihra[1], Richard Sysala[2], Lukas Tomasek[1], Matej Vaculciak[1], Pavel Vancura[1], Jan Vesely[2]

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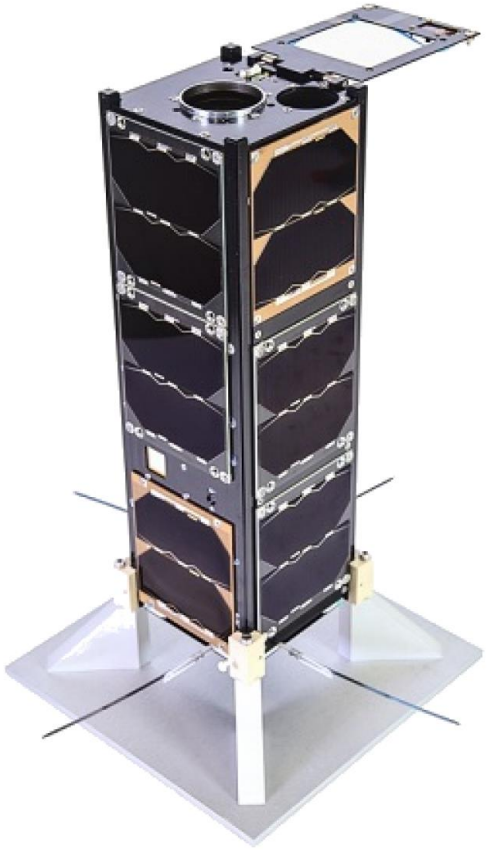
8.9.2022

Outline

- CAPADS Introduction
- Motivation
- Monolithic SOI Technology
- SpacePix-2 ASIC & SXRM instrument
- X-CHIP-04 ASIC & SXM instrument
- 2SD & VZLUSAT-2



CAPADS introduction

Detection system at CAPADS:

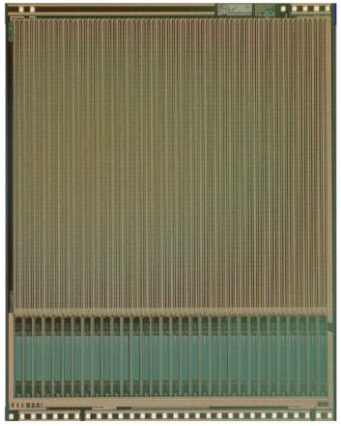
- Hybrid detectors
- Strip detectors
- Gamma dosimetry
- Silicon monolithic detectors
- Detectors for radiotherapy
- Own process 15 kΩcm Si

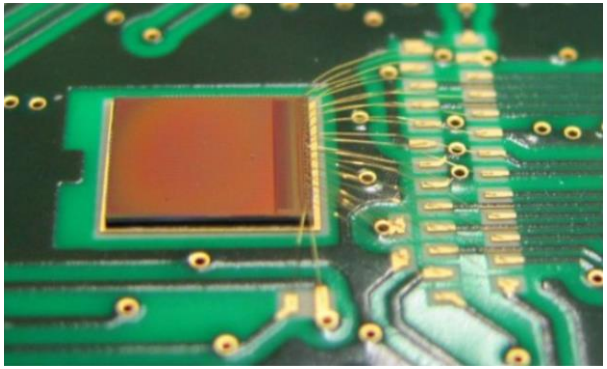
Participation in many research projects:

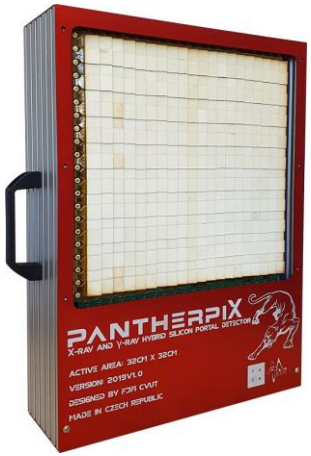
- CERN (ATLAS, RD50, RD53)
- BNL, FNAL
- STAR

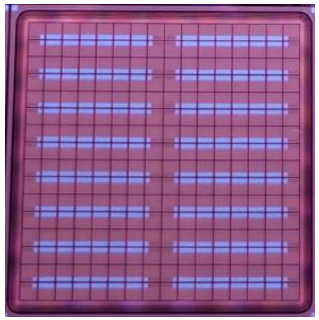
Variable technology

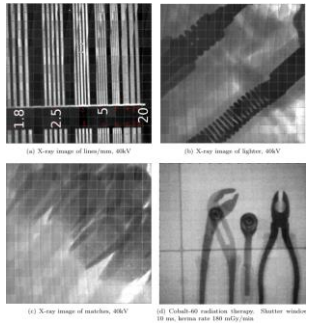
- CMOS 180 nm (SoI)
- CMOS 150 nm
- CMOS 65 nm





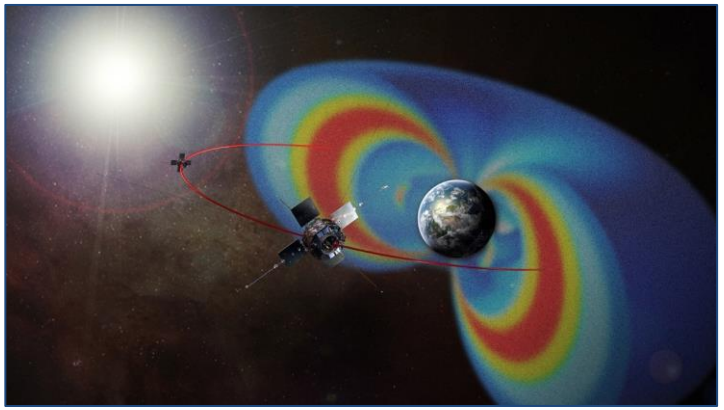


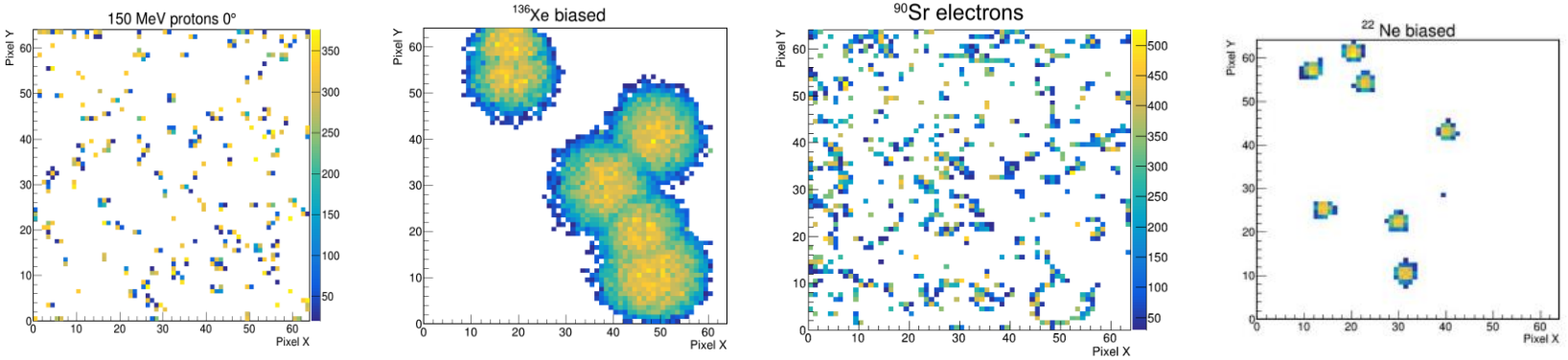




Motivation

- Monitoring radiation in space environment
  - Multiple components
  - Broad energy spectrum
  - Flux variation
- Potential risk to human health and to electronic systems
- Detector capable of measurement radiation in space
  - Flux
  - LET (Linear energy Transfer)
  - Determine particle type (e^-, p^+, ion)
  - Determine direction of incoming particles





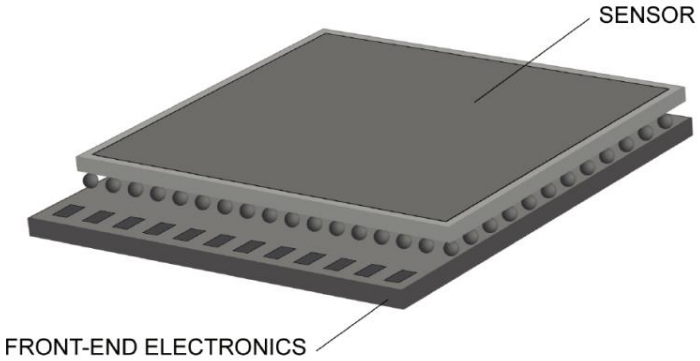
Pixel detector technology

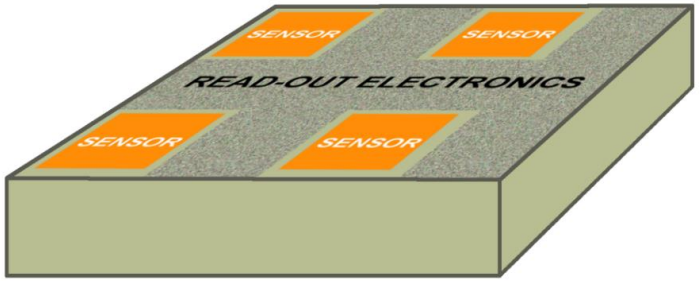
Hybrid

- Sensor and readout electronics on separate wafers
- Mature detector technology
- Large material budget
- Complicated assembly
- Expensive

Monolithic

- Sensor and electronics implemented in the same silicon substrate
- A commercial process in European foundry
- Detector is processed in one foundry
- Several types SOI-MAPS, DMAPS, IN-MAPS
- Detector volume usually not fully depleted

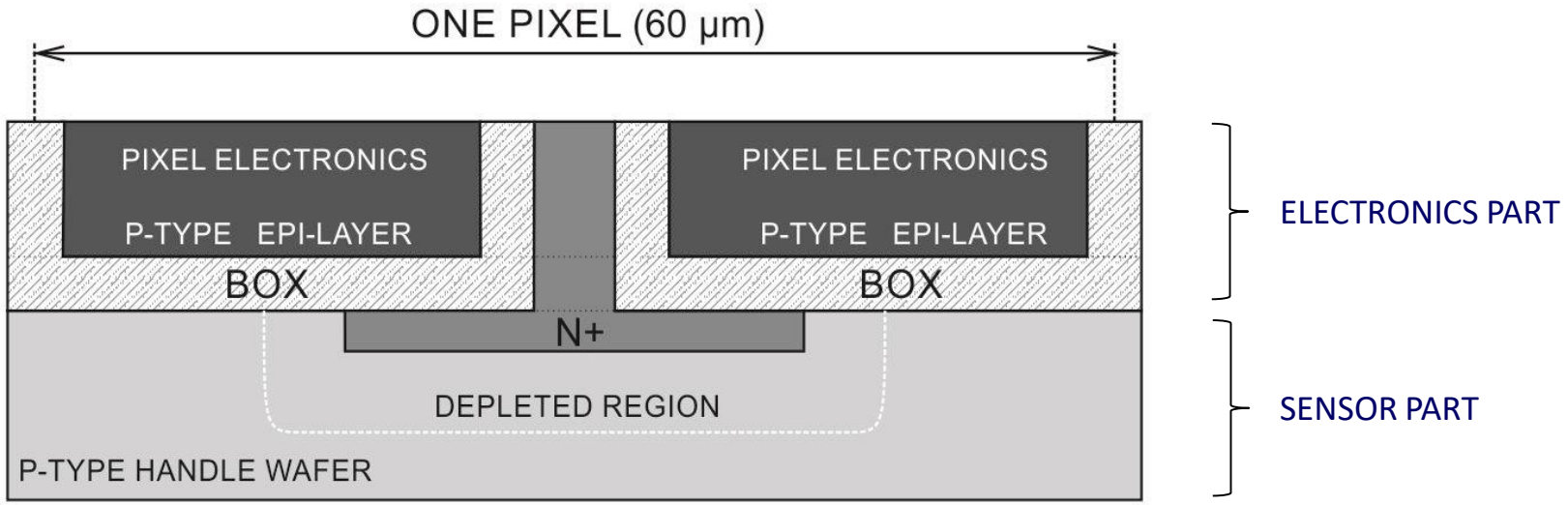




SOI MAPS

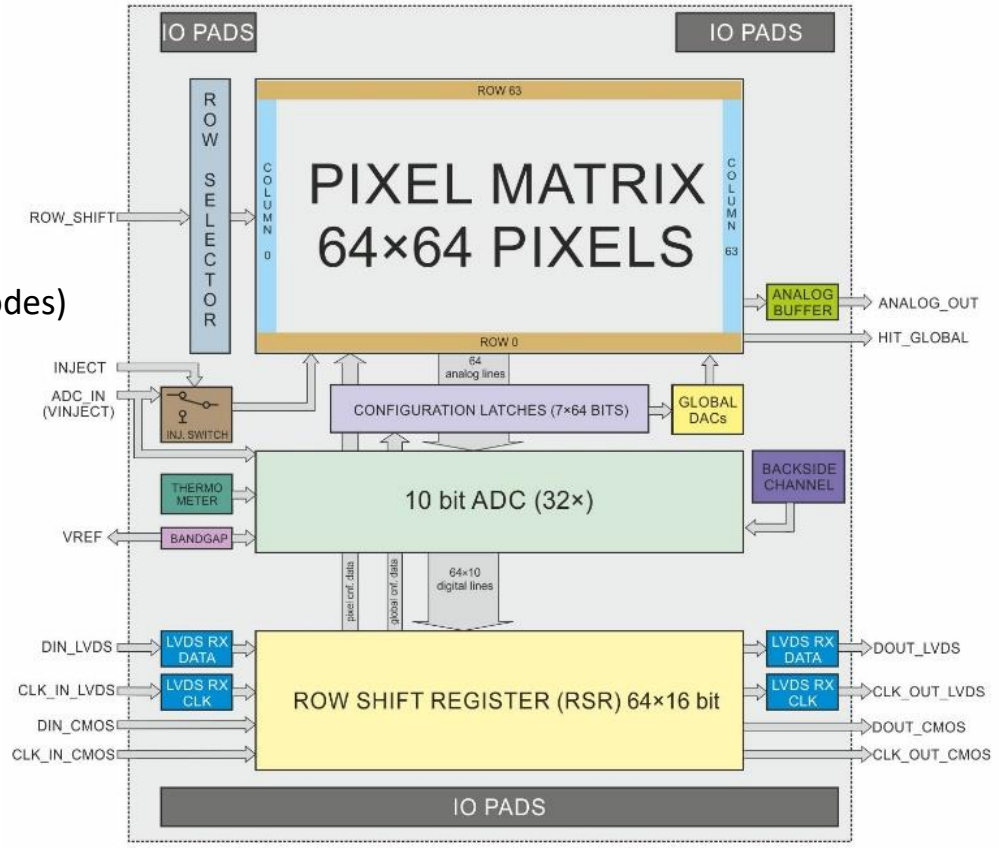
- SOI MAPS (Silicon On Insulator) 180 nm CMOS technology (European foundry)
- Wafer thickness: 300 µm
- Depletion Depth: 37 µm at bias voltage – 150 V

$$l_{\mathrm{DEP}} \approx \sqrt{V_{\mathrm{BIAS}}}$$



SpacePix - features

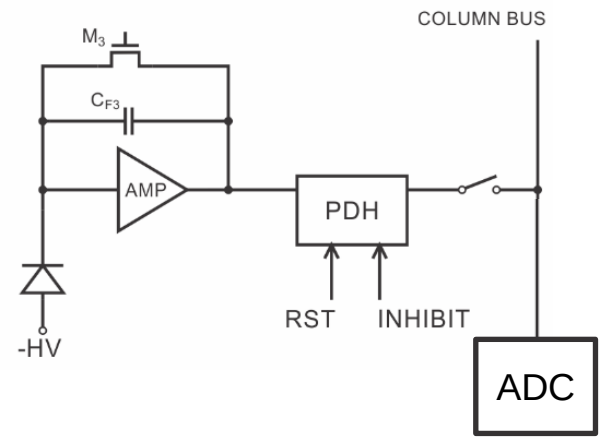
- **Monolithic Active Pixel Sensor (MAPS) ASIC**
- Array of 64 × 64 pixels
- Pixel size: 60 × 60 µm^2
- Sensitive area: 3.84×3.84 mm^2
- 32 column parallel SAR 10 bit ADCs
- Power supply voltage: 1.8 V (chip core), -150 V (diodes)
- Power consuption: < 100 mW
- Design complexity: 1.15 M transistors
- **Special Functions:**
  - Backside signal processing
  - Readout modes: SPI/LVDS
  - Hit trigger output
  - Thermometer
  - Radiation hardened

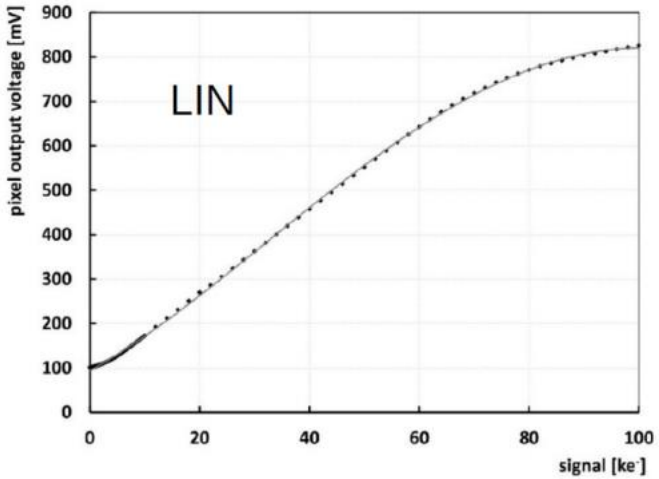


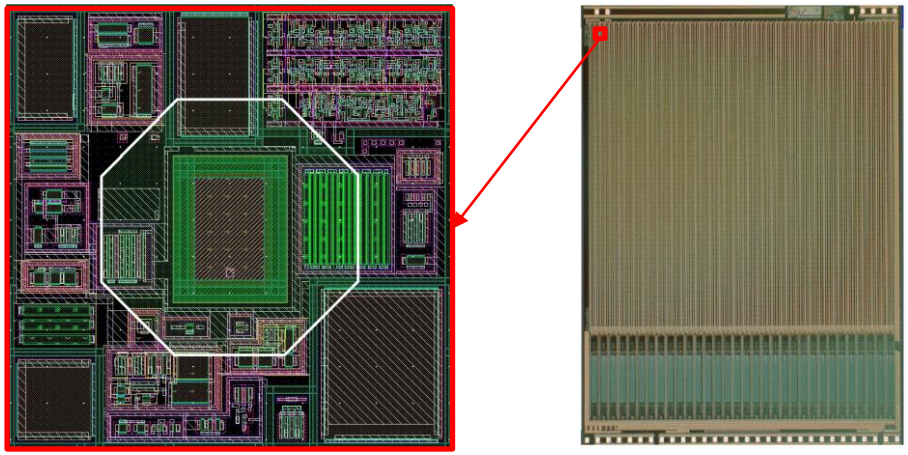
SpacePix – pixel architecture

- **Integrated blocks:**
  - Charge Sensitive Amplifier (CSA)

    Signal range: 2 ke^- - 80 ke^-
  - Peak Detector Hold (PDH)
  - Discriminator, DAC, 6-bit memory

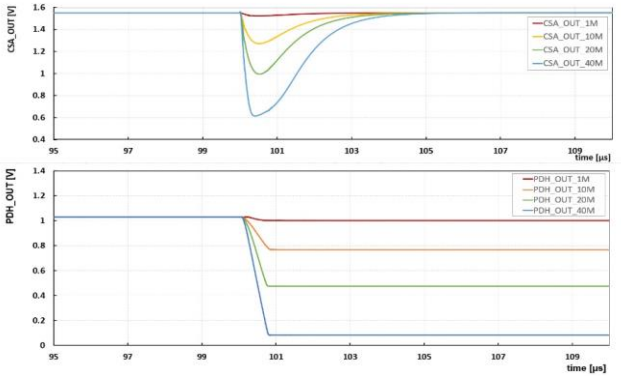


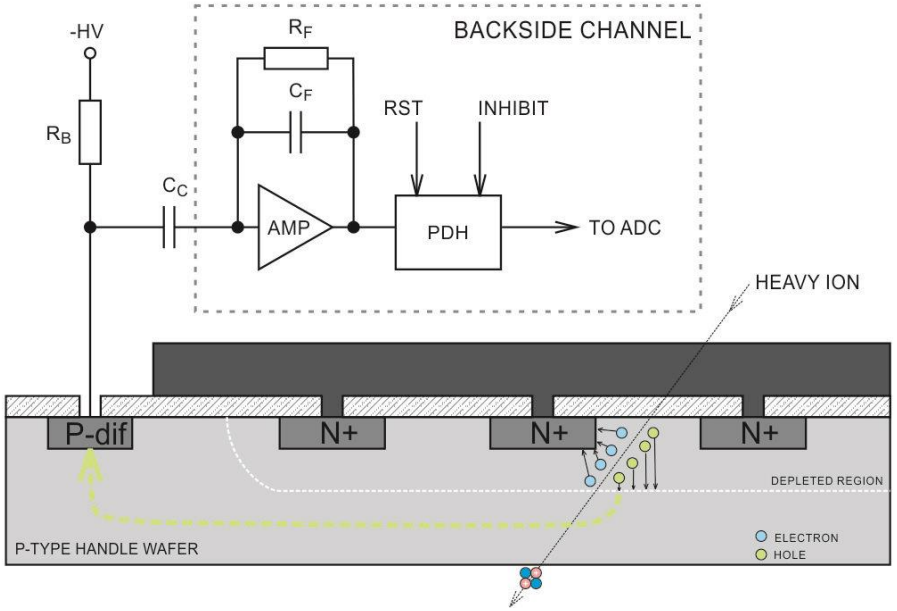


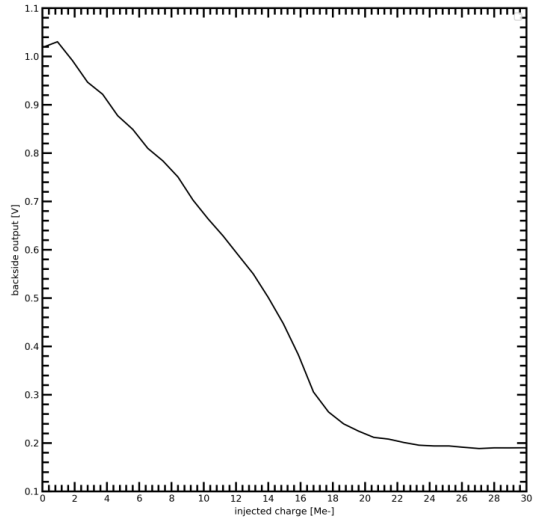


SpacePix - backside

- Heavy ions do heavy ionization => possibly saturate the pixels
- Backside signal extraction turns SpacePix-2 into single pixel
- Signal range: 1 Me^- up to 30 Me^-



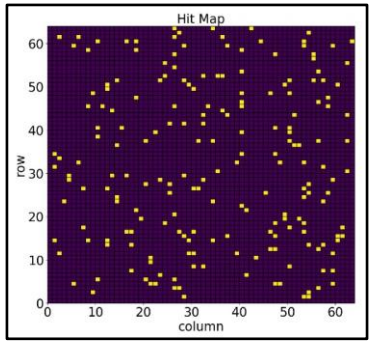


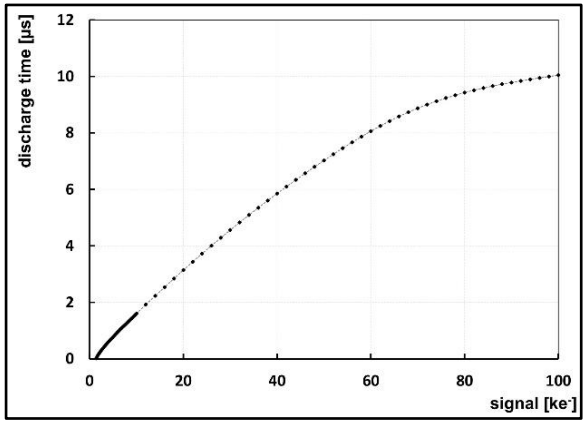


SpacePix – flux and dead time

SpacePix operation cycle

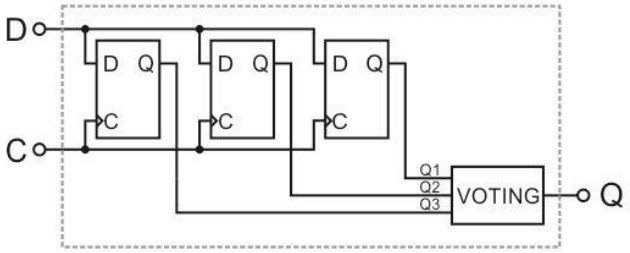
- Not more than one hit per pixel per exposition
- Maximum measurable flux limited by minimum exposition time
- Minimum exposition time limited by CSA discharge time ≈ 10 µs => minimum exposition time ≈ 200 µs
- Assuming 5% single pixel hit occupancy => **maximum electron/proton flux ≈ 7×10^6 particles/cm^2·s**





SpacePix – radiation hardening

TRIPLICATED FLIP-FLOP

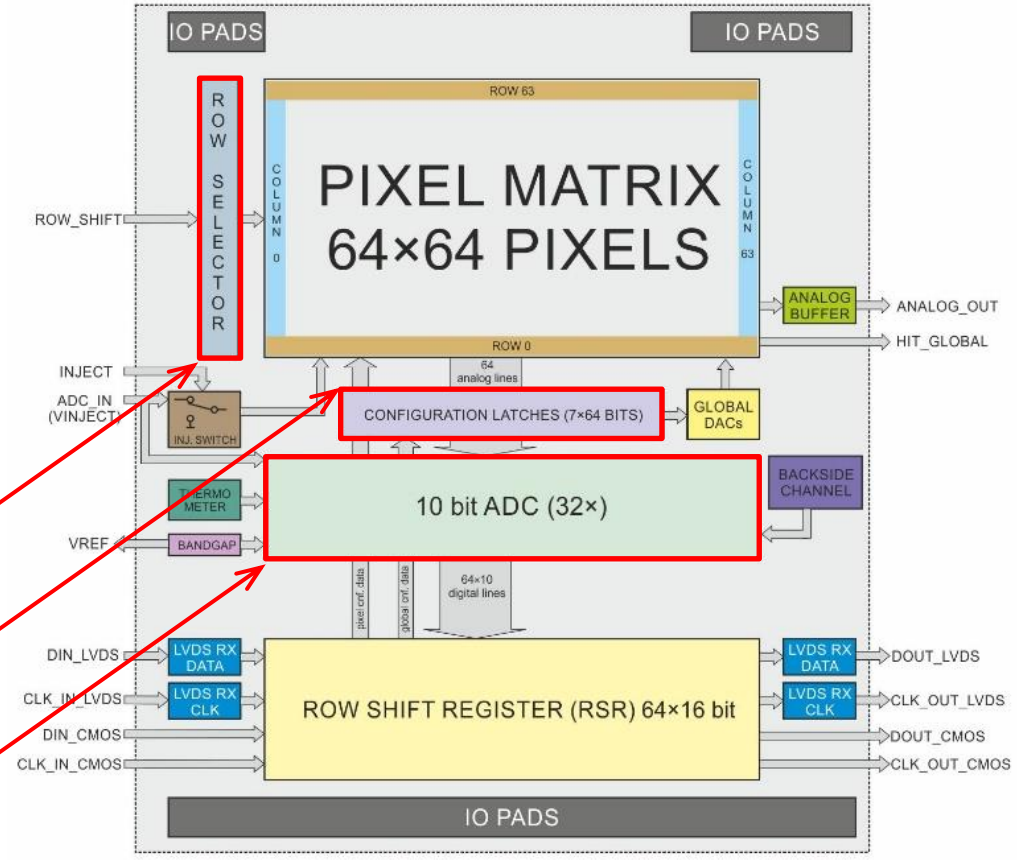


Q3	Q2	Q1	Q
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	1
1	0	0	0
1	0	1	1
1	1	0	1
1	1	1	1

triplicated flip-flops

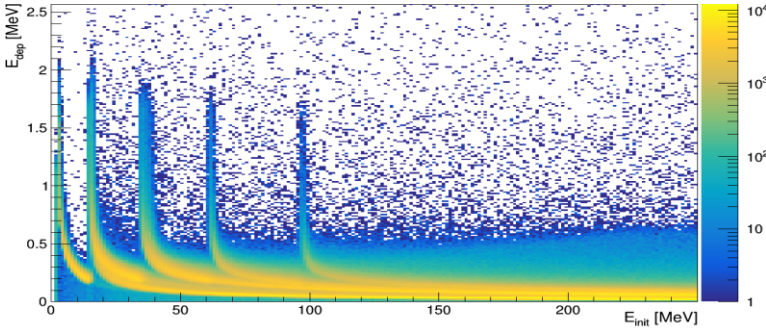
triplicated flip-flops

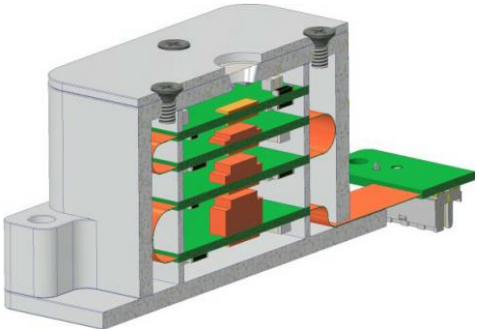
asynchronous ADC (no FSM needed)

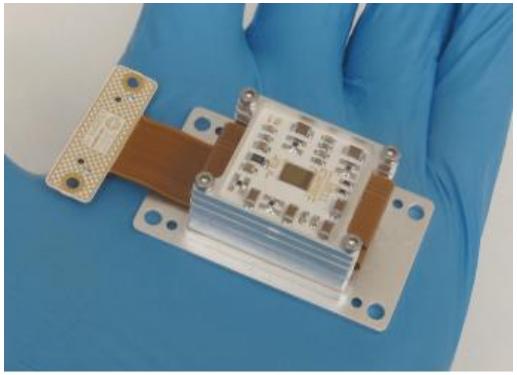


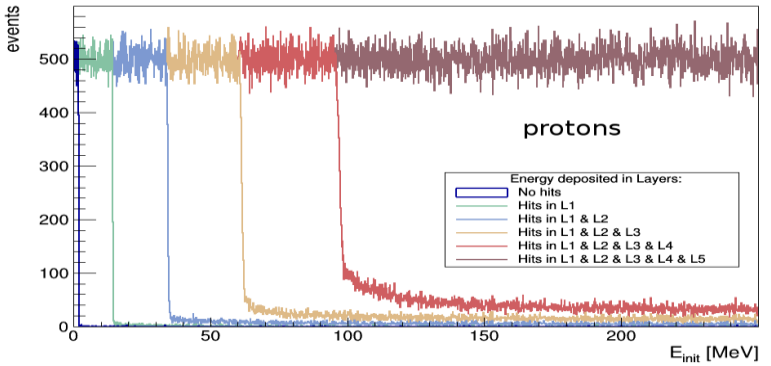
SXRM

- SXRM: Five plane telescope with five SpacePix-2 sensors
- Features: LET measurement, tracking, flux measurement
- Ranges: electrons: 80 keV – 10 MeV
  protons: 1.5 MeV – 150 MeV
  ions: up to 800 keV/µm



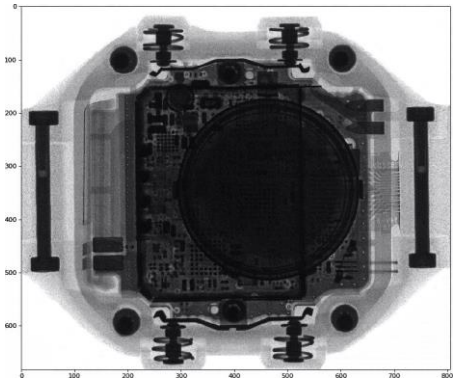


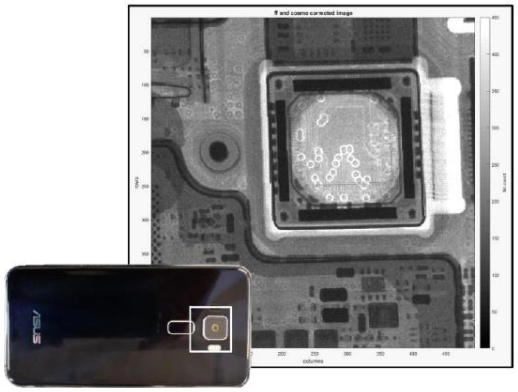


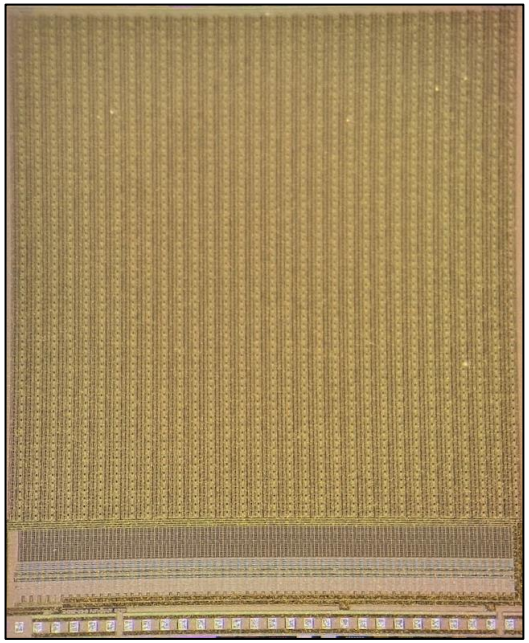


X-CHIP-04

- Monolithic pixel detector for particle detection, radiation and soft X-ray imaging and energy measurement
- 64 × 64 pixel, 60 µm pixel pitch, sensitive area 3.9 × 3.9 mm^2
- Signal dynamic range 1 – 8 ke^-
- Two modes of operation:
  - photon counting (16-bit counter)
  - ADC mode (10-bit column ADC)
- SPI and LVDS readout
- Power consumption < 50 mW
- Approximately 3.5 × 10^6 transistors



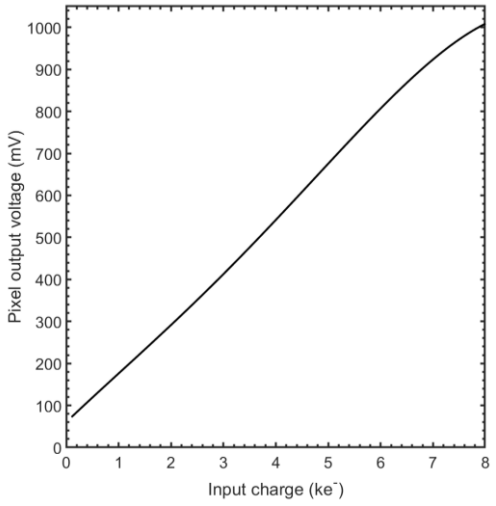


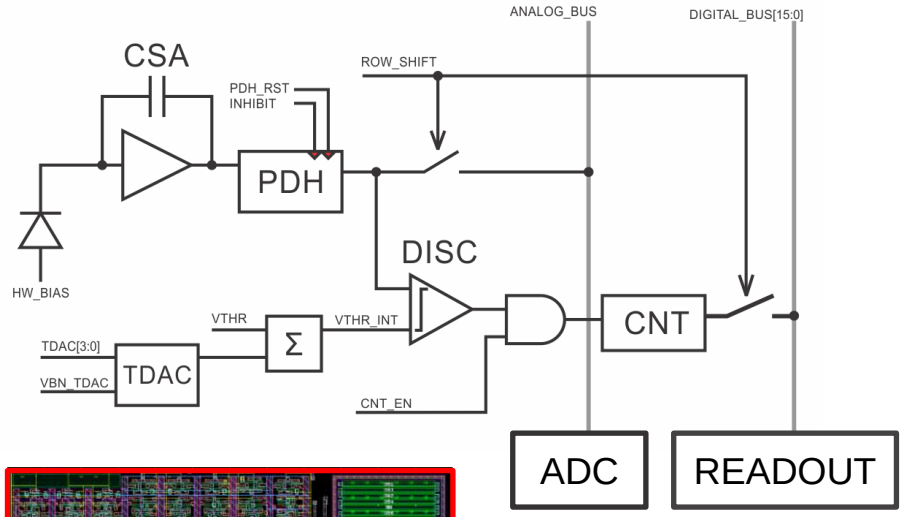


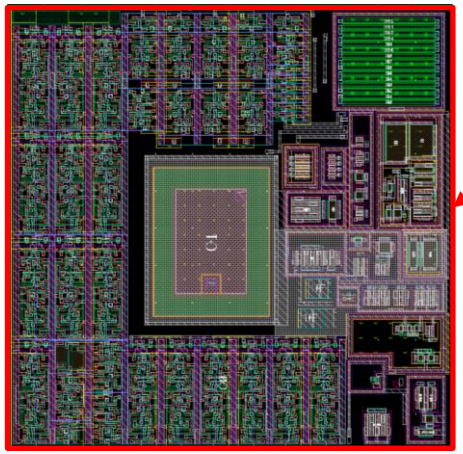
X-CHIP-04 - pixel architecture

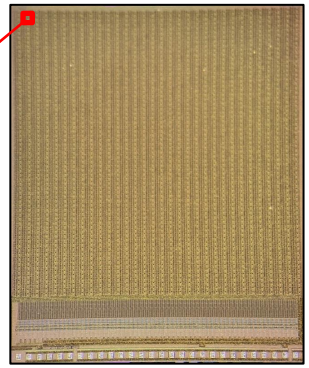
- **Integrated blocks:**
  - Charge Sensitive Amplifier (CSA)

    Signal range: 1 ke^- - 8 ke^-
  - Peak Detector Hold (PDH)
  - Discriminator
  - TDAC, with threshold tuning (4-bit)



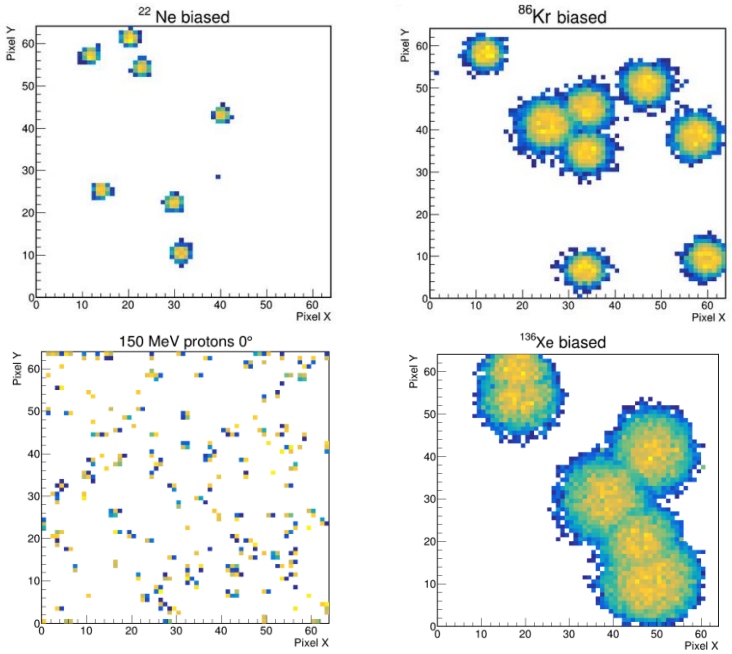


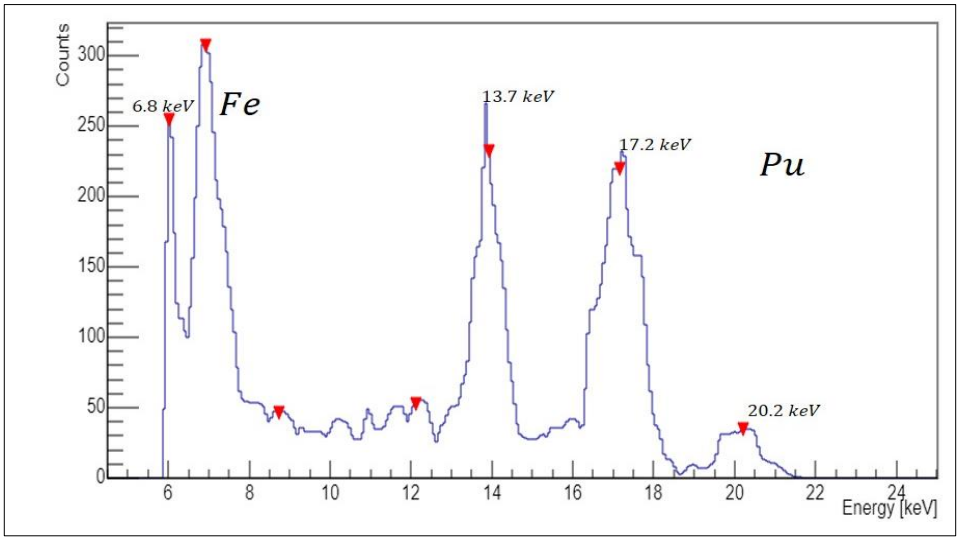


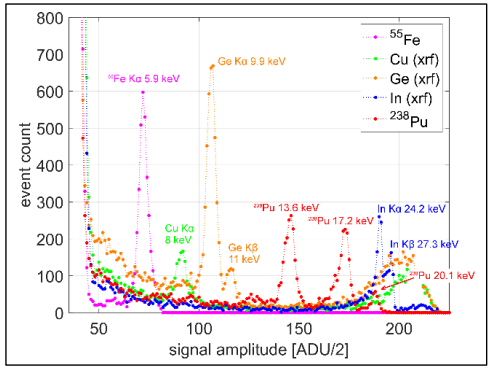


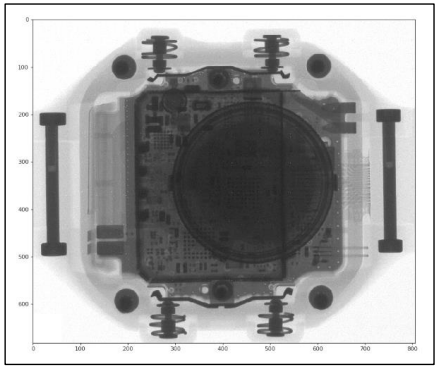
X-CHIP-04 - measurements

- Spectrum measurement of various elements
- Proton measurements
- Heavy ions (Kr, Xe, Ne, etc.)
- X-ray imaging
- SEU and TID testing



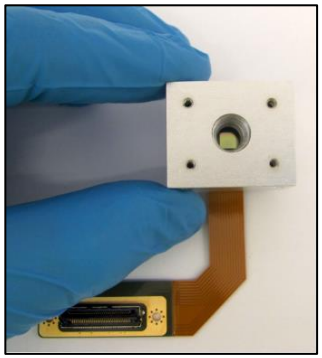


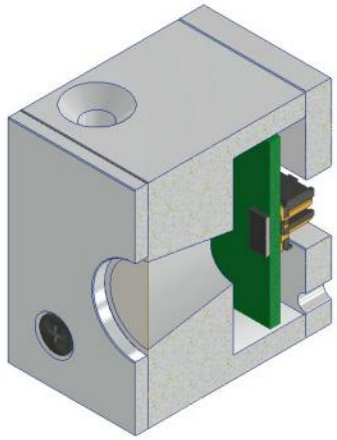


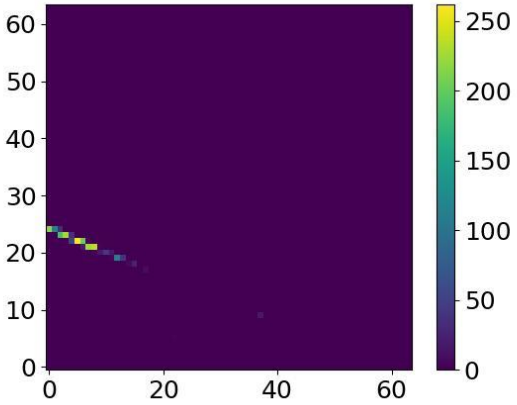


SXM

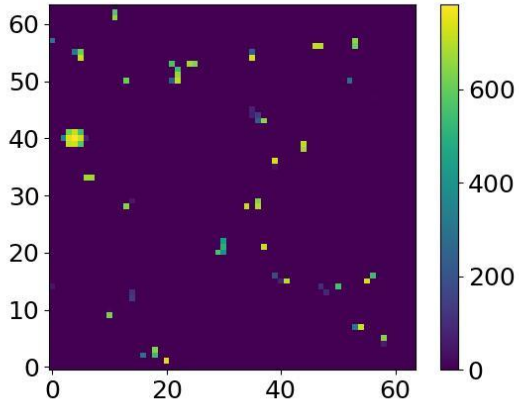
- Soft X-ray Monitor (SXM)
- Pixel detector based on X-CHIP
- Sensitive to photons from 4.5 to 20 keV



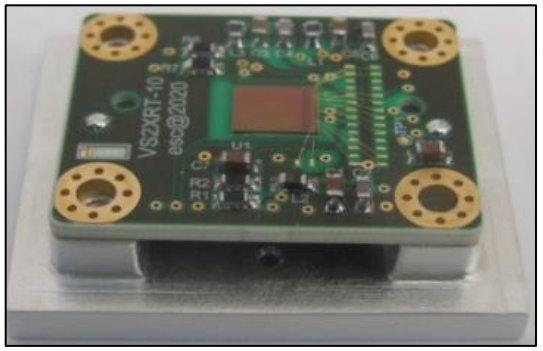




Proton interaction

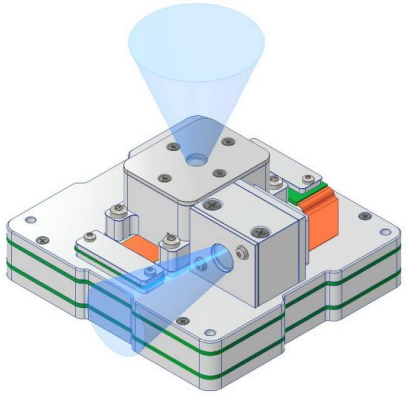


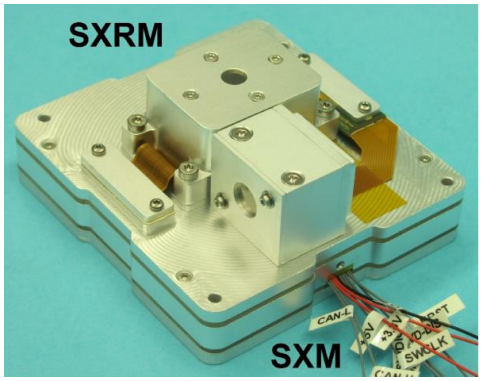
Electrons, protons and ion at SAA



2SD – instrument

- Based on PC/104 format to fit to any CubeSat
- Accommodates two detectors
  - SXRM detector
  - SXM detector
- Electronics based on COTS
- Motherboard
  - Main MCU (100MHz)
  - Communication protocol CAN bus
- Sensor board
  - Power supply for both detectors
  - Power telemetry + temperature monitoring



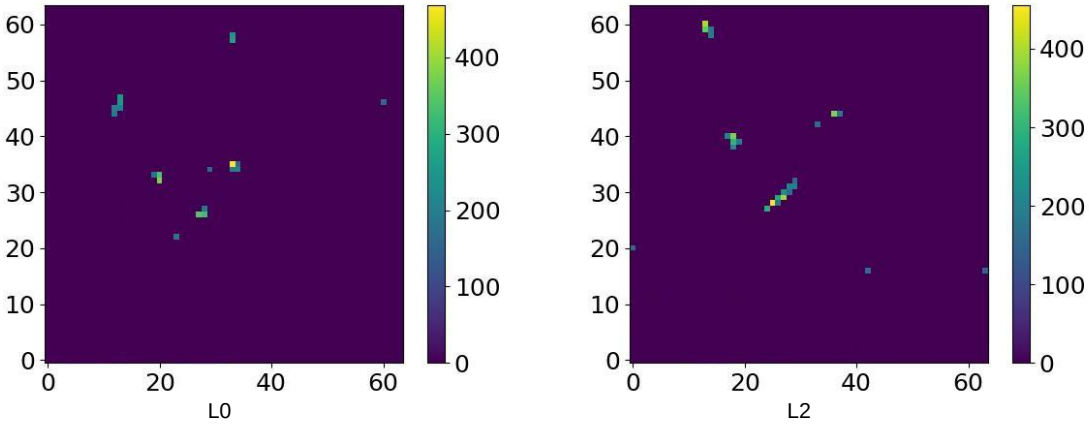


2SD - electronics

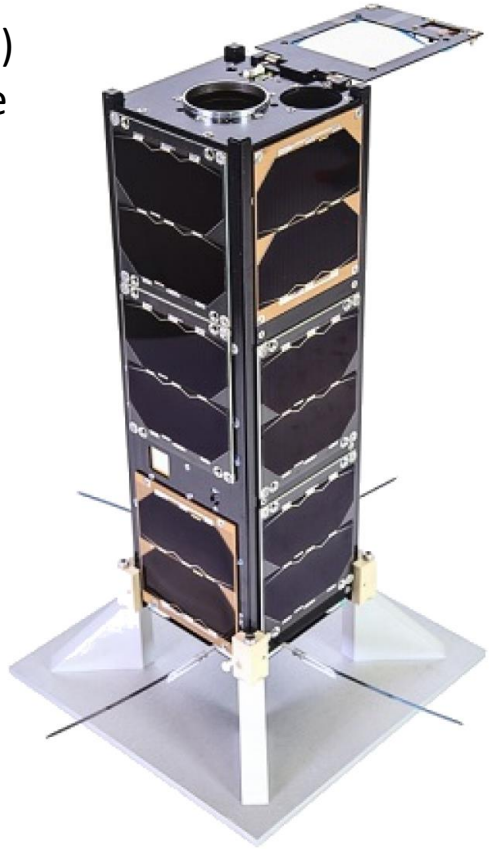
- Two PCBs called Motherboard and Sensor board
- Motherboard
  - Main MCU (100 MHz, capable 400 MHz)
  - System memory for configuration (MRAM 0.5 MB)
  - Data memory (NOR 128 MB)
  - Communication I/F with S/C (CAN bus)
- Sensor board
  - Power supply for both detectors
  - 12x 1.8 V for ASICs
  - 2x -150 V for bias
  - Power telemetry + temperature
  - Communication I/F between motherboard and detectors

2SD – VZLUSAT-2

- Czech technological mission launched 13.1.2022 (Falcon 9)
- 2SD detectors have finished commissioning in July and are now acquiring data
- Sun synchronous orbit (SSO)
  - Altitude 550 km
  - Inclination 97.7°



Protons pass through several layers



LVICE^2 – phase 0/A/B1

- Ambitious mission to cislunar space
  - ESC Aerospace, Space Exploration
  - CTU FNSPE/FME/FEE, FMP CUNI, ASCR NPI/IAP

- Scientific objectives:
  - Observation of Kordylewski clouds
  - Study of solar wind turbulence in interplanetary space and in the lunar wake
  - Measurement of the energetic particle spectra during the solar maximum
  - Investigation of possibility of solar wind monitoring for space weather purposes by a CubeSat

Conclusions

- We have introduced 2 ASICs for space weather monitoring
- We have tested SpacePix and X-CHIP under various beams and performed SEU testing
- In collaboration with ESC Aerospace we have developed and tested SXRM and SXM telescopes
- In collaboration with ESC Aerospace the telescopes were integrated in 2SD instrument
- We have successfully lunched and tested our instruments in Vzlusat-2 mission
- Currently we are preparing for LVICE^2

Thank you for your attention