Center of Applied Physics and Advanced Detection Systems

# Radiation-tolerant semiconductors and space missions at CAPADS FNSPE CTU

Jakub Jirsa

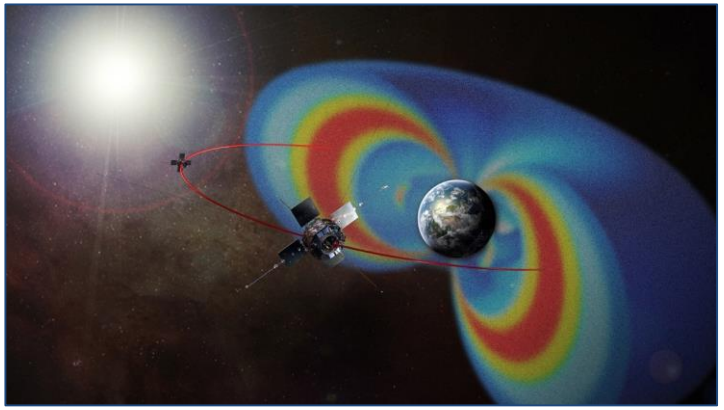
On behalf of Michal Marčišovský

michal.marcisovsky@fjfi.cvut.cz

23.6.2022

# Motivation

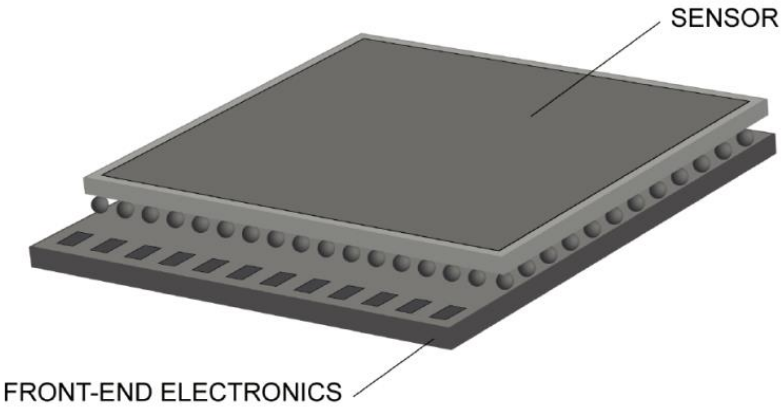
- Monitoring radiation in space environment
  - Multiple components
  - Broad energy spectrum
  - Flux variation
- Potential risk to human health and to electronic systems
- Detector capable of measurement radiation in space
  - Flux
  - LET (Linear energy Transfer)
  - Determine character of radiation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



# Pixel detectors technology

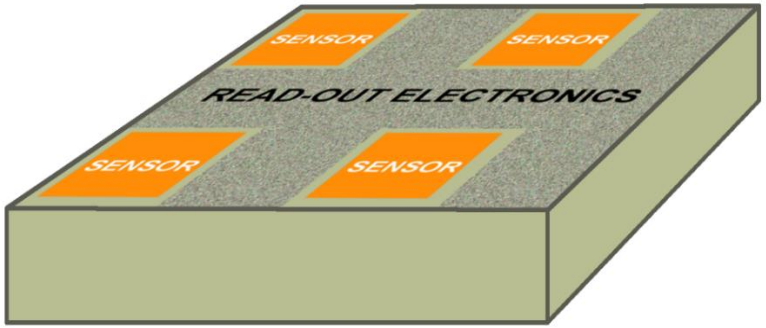
## Hybrid

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




## Monolithic

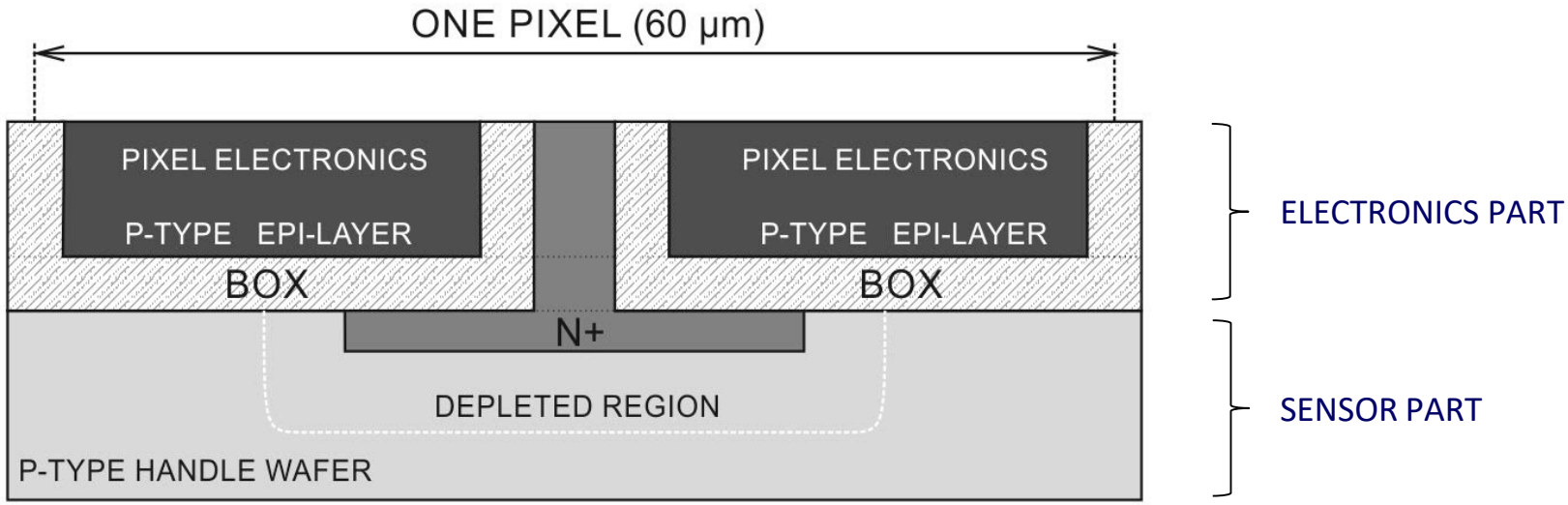
- Sensor and electronics implemented in the same silicon substrate
- A commercial process in European foundry
- Detector is processed in one foundry
- Many types SOI-MAPS, DMAPS, IN-MAPS
- Detector volume usually not fully depleted



# SOI MAPS

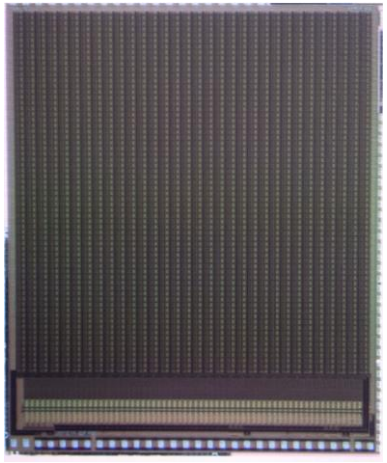
- SOI MAPS (Silicon On Insulator) 180 nm CMOS technology (European foundry)
- Wafer thickness: 300 µm
- Depletion Depth: 37 µm at bias voltage – 150 V

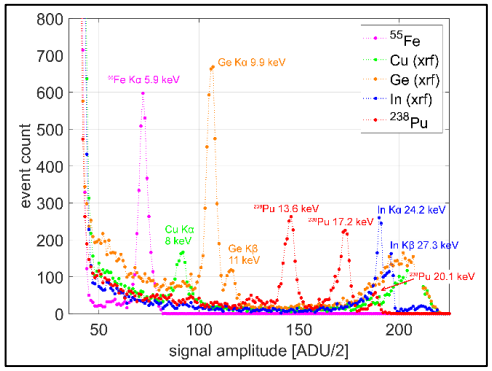
$$l_{DEP} \approx \sqrt{V_{BIAS}}$$

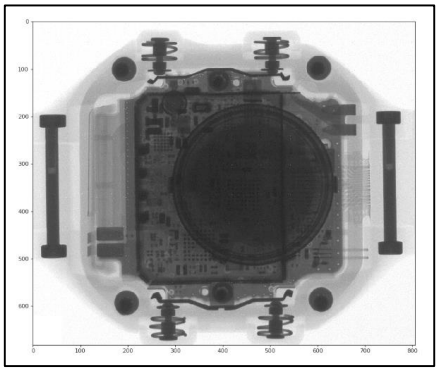


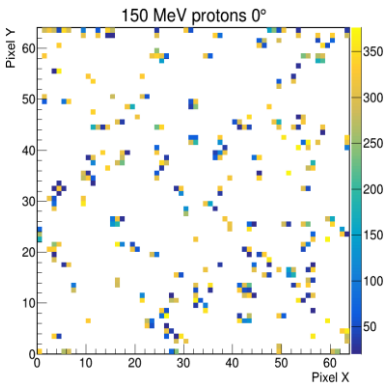
# X-CHIP - 04

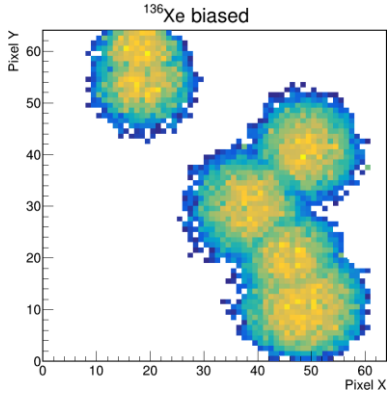
- Monolithic pixel detector for particle detection, radiation and soft X-ray imaging and energy measurement
- 64 x 64 pixel, 60 µm pixel pitch, sensitive area 3.84 x 3.84 mm
- Signal dynamic range 1 – 10 $ke^-$
- Two modes of operation – photon counting, ADC mode
- SPI and LVDS readout
- Approximately 3M transistor







# SpacePix - features

- **Monolithic Active Pixel Sensor (MAPS) ASIC**
- Array of 64×64 pixels
- Pixel size: 60×60 $\mu m^2$
- Sensitive area: 3.84×3.84 $mm^2$
- 64 column parallel SAR 10 bit ADCs
- Power supply voltage: 1.8 V (chip core), -150 V (diodes)
- Power consumption: < 50 mW
- Design complexity: 1.15 M transistors
- **Special Functions:**

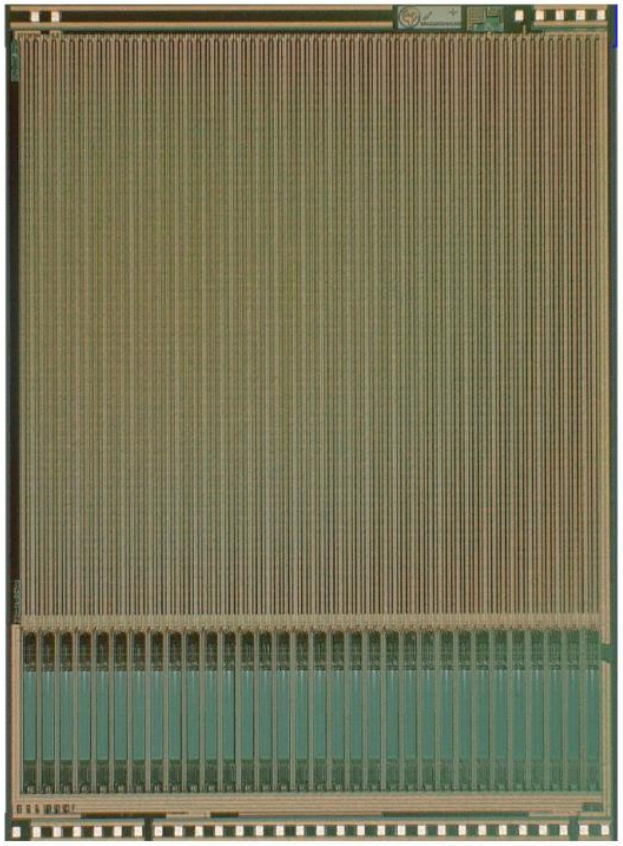
  Backside signal processing

  Readout modes: SPI/LVDS

  Hit trigger output

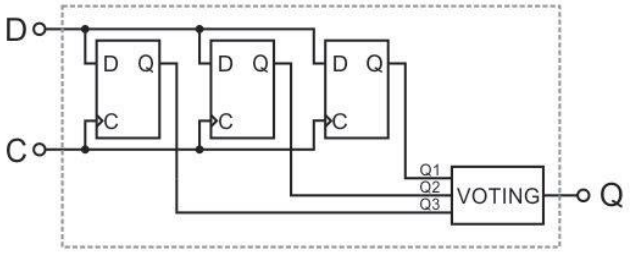
  Thermometer

  Radiation hardened



# SpacePix – radiation hardening

TRIPLICATED FLIP-FLOP

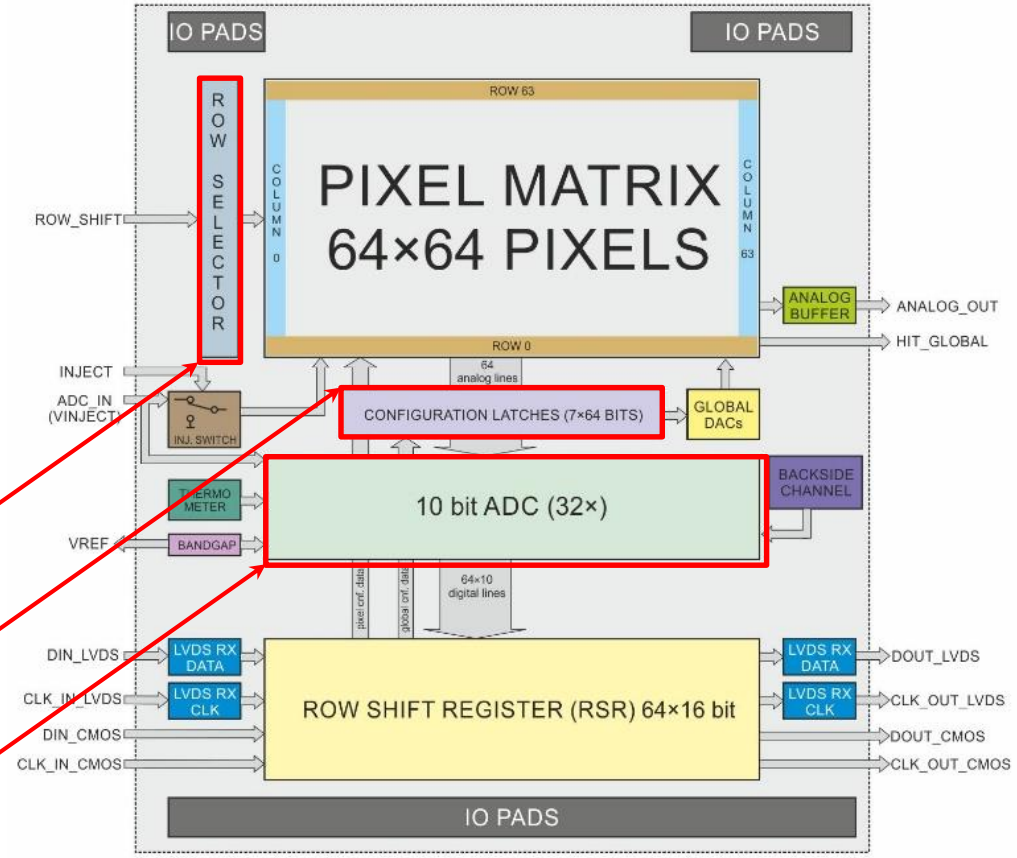



| Q3 | Q2 | Q1 | Q |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 0 |
| 0 | 1 | 0 | 0 |
| 0 | 1 | 1 | 1 |
| 1 | 0 | 0 | 0 |
| 1 | 0 | 1 | 1 |
| 1 | 1 | 0 | 1 |
| 1 | 1 | 1 | 1 |

**triplicated flip-flops**

**triplicated flip-flops**

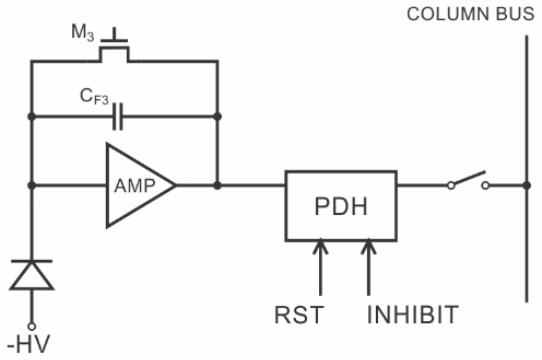
**asynchronous ADC (no FSM needed)**

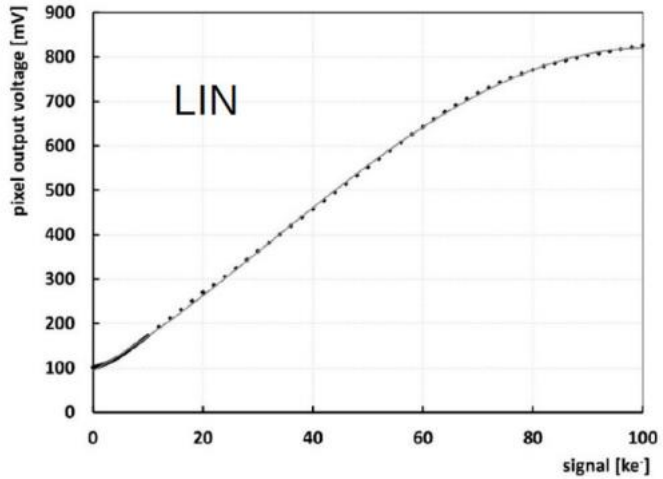


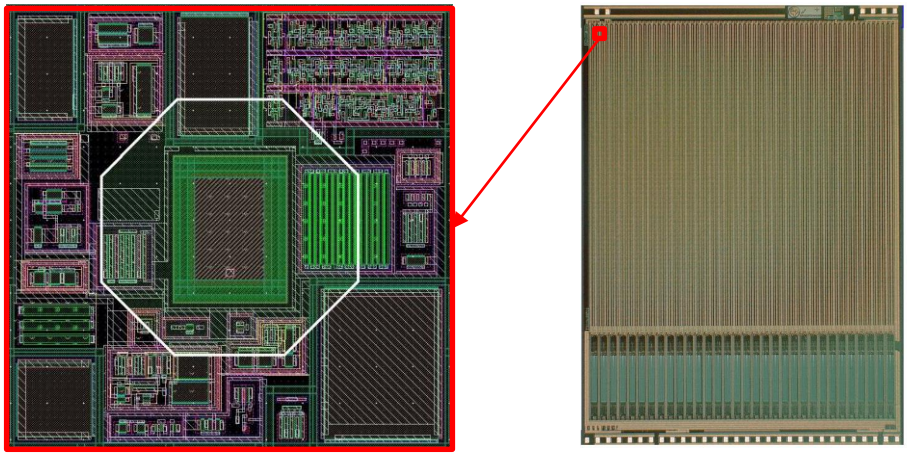
# SpacePix – pixel architecture

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

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



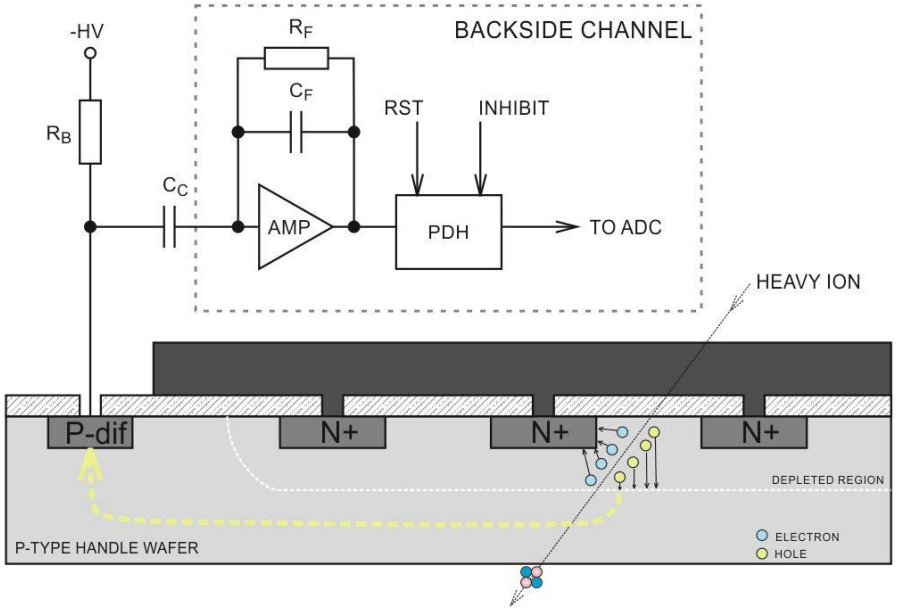



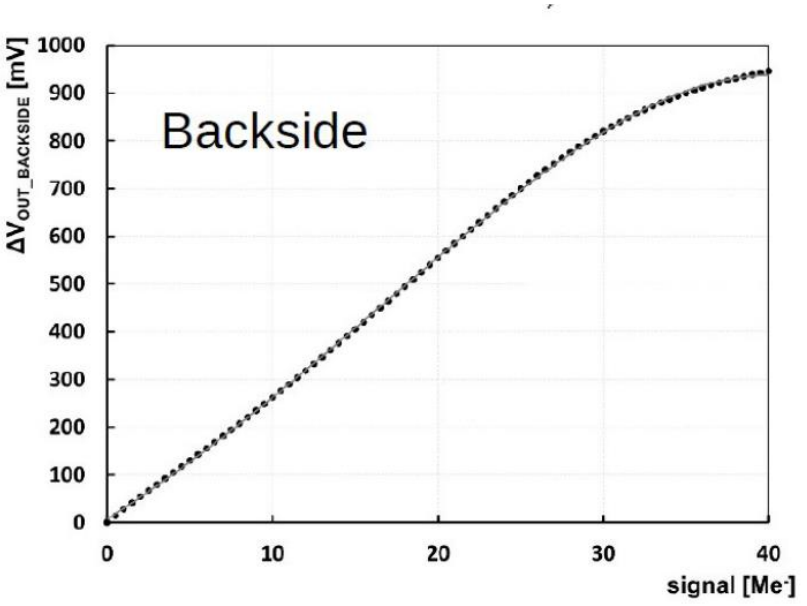



# SpacePix - backside

- Heavy ions do heavy ionization => possibly saturate the pixels
- Backside signal extraction turns SpacePix-2 into single pixel
- Signal range: 500 ke$^-$ up to 30 Me$^-$

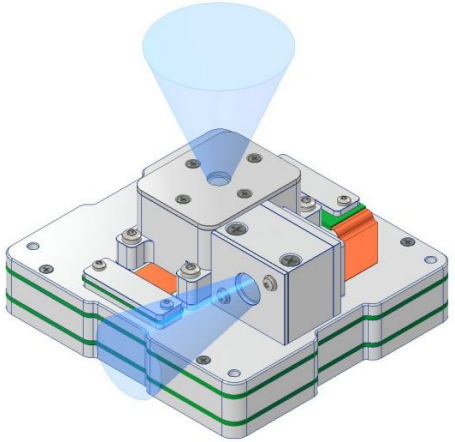
  Energy range: 1.8 MeV – 100 MeV

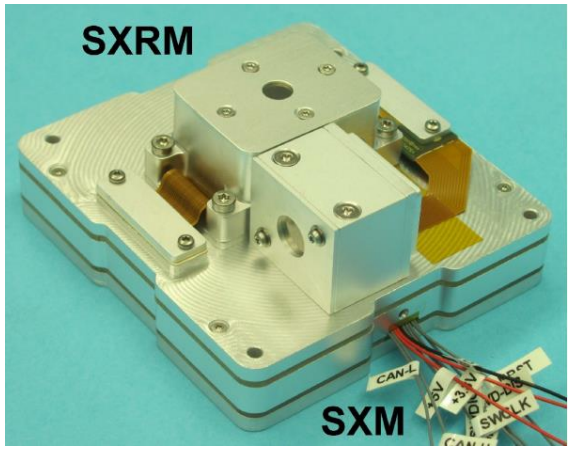


# 2SD – Vzlusat2

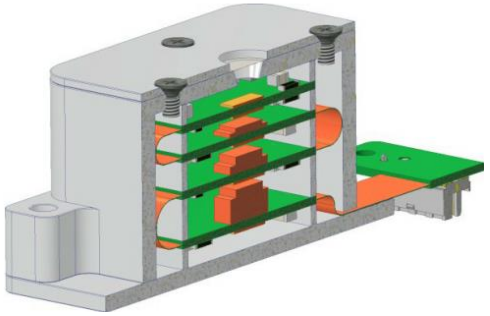
- Based on PC/104 format to fit to any CubeSat
- Accommodates two detectors
  - SXRM detector
  - SXM detector
- Electronics based on COTS
- Motherboard
  - Main MCU (100MHz)
  - Communication protocol CAN bus
- Sensor board
  - Power supply for both detectors
  - Power telemetry + temperature monitoring

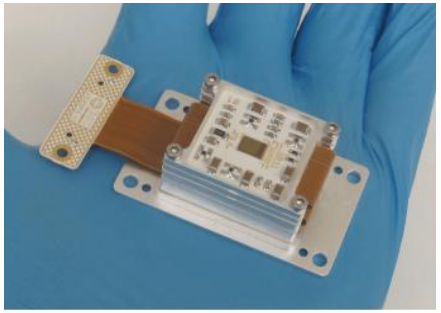


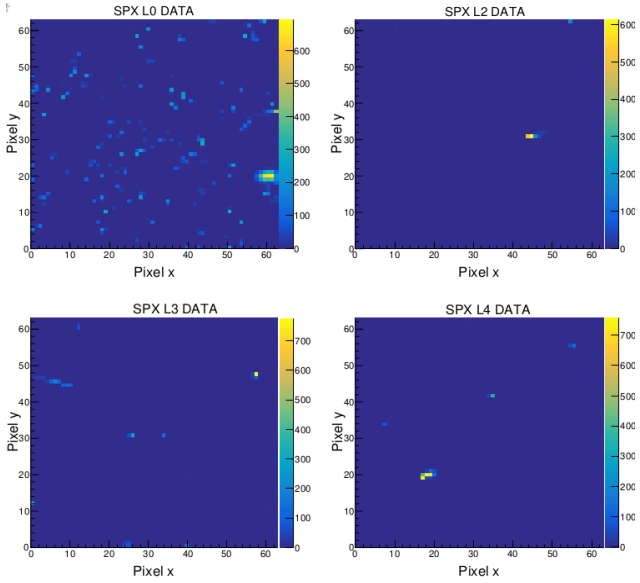


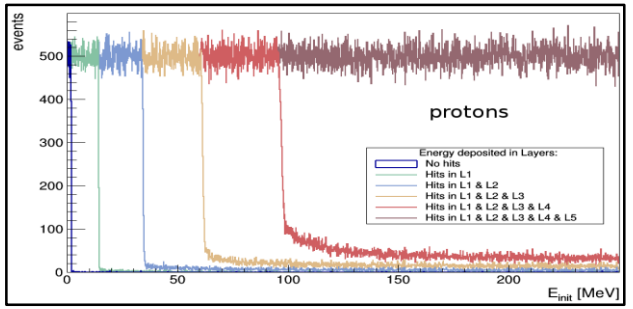
# SXRM

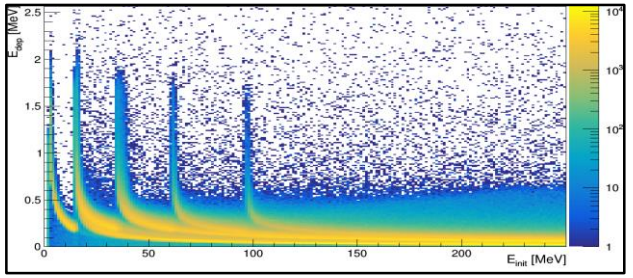
- SXRM: Four plane telescope with five SpacePix2 sensors
- Features: LET measurement, tracking, flux measurement
- Ranges: electrons: 80 keV – 10 MeV
  protons: 1.5 MeV – 150 MeV
  ions: up to 50 MeV





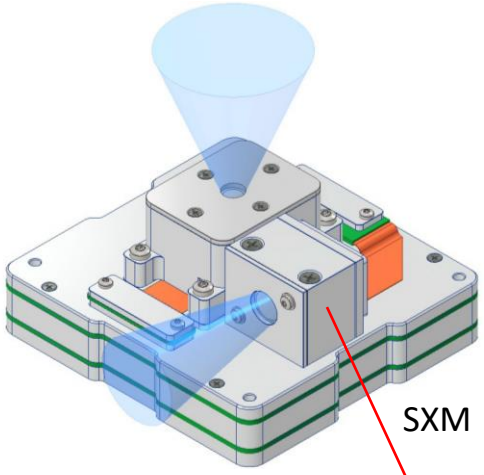


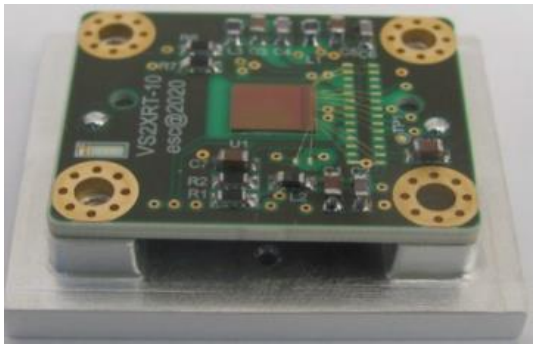



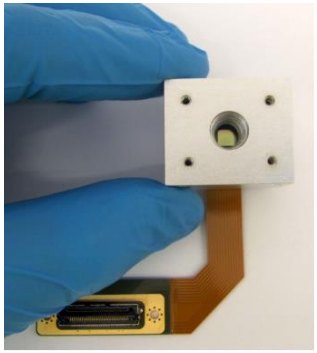



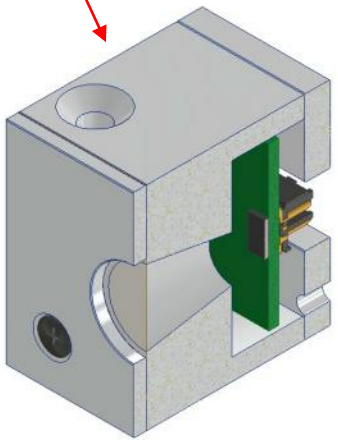
# SXM

- Soft X-ray Monitor (SXM)
- Pixel detector based on X-CHIP 03-SXR
- Sensitive to photons from 2 to 18 keV





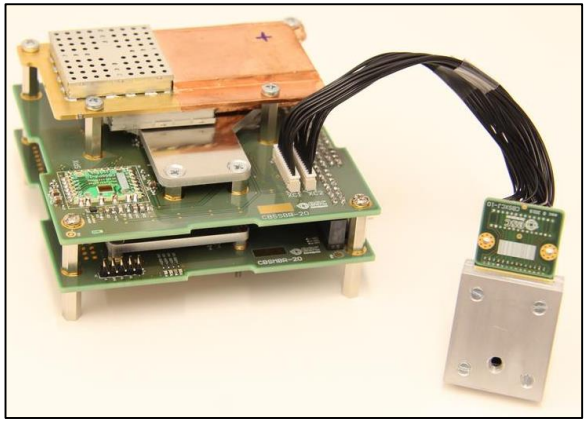


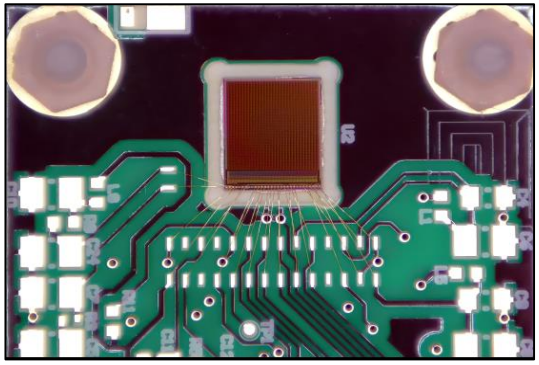
# LVICE$^2$ phase 0/A/B1

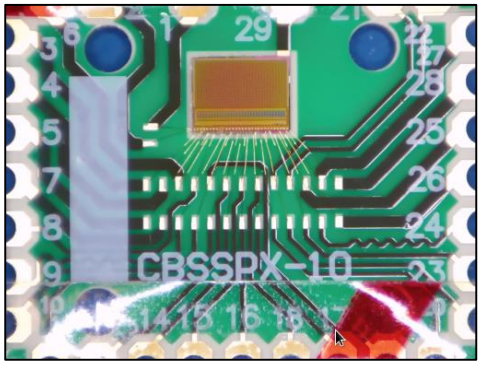

- Ambitious mission to cislunar space
  - ESC Aerospace, Space Exploration
  - CTU FNSPE/FME/FEE, FMP CUNI, ASCR NPI/IAP
- Scientific objectives:
  - Observation of Kordylewski clouds
  - Study of solar wind turbulence in interplanetary space and in the lunar wake
  - Measurement of the energetic particle spectra during the solar maximum
  - Investigation of possibility of solar wind monitoring for space weather purposes by a CubeSat

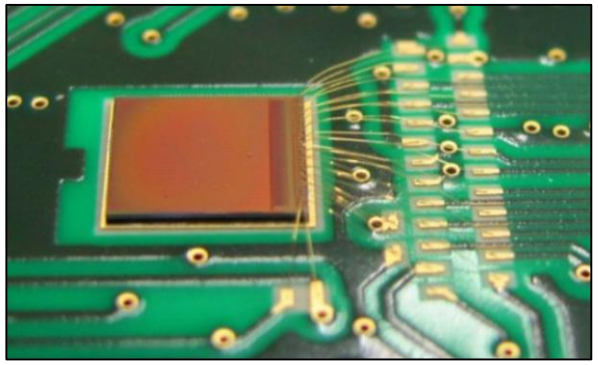
# Conclusion

- We have introduced 2 ASICs for space weather monitoring
- With collaboration of ESC Aerospace we have developed and tested SXRM and SXM telescopes
- We have successfully lunched our instruments in Vzlusat-2 mission
- Currently we are preparing for LVICE[2]








# Thank you for your attention