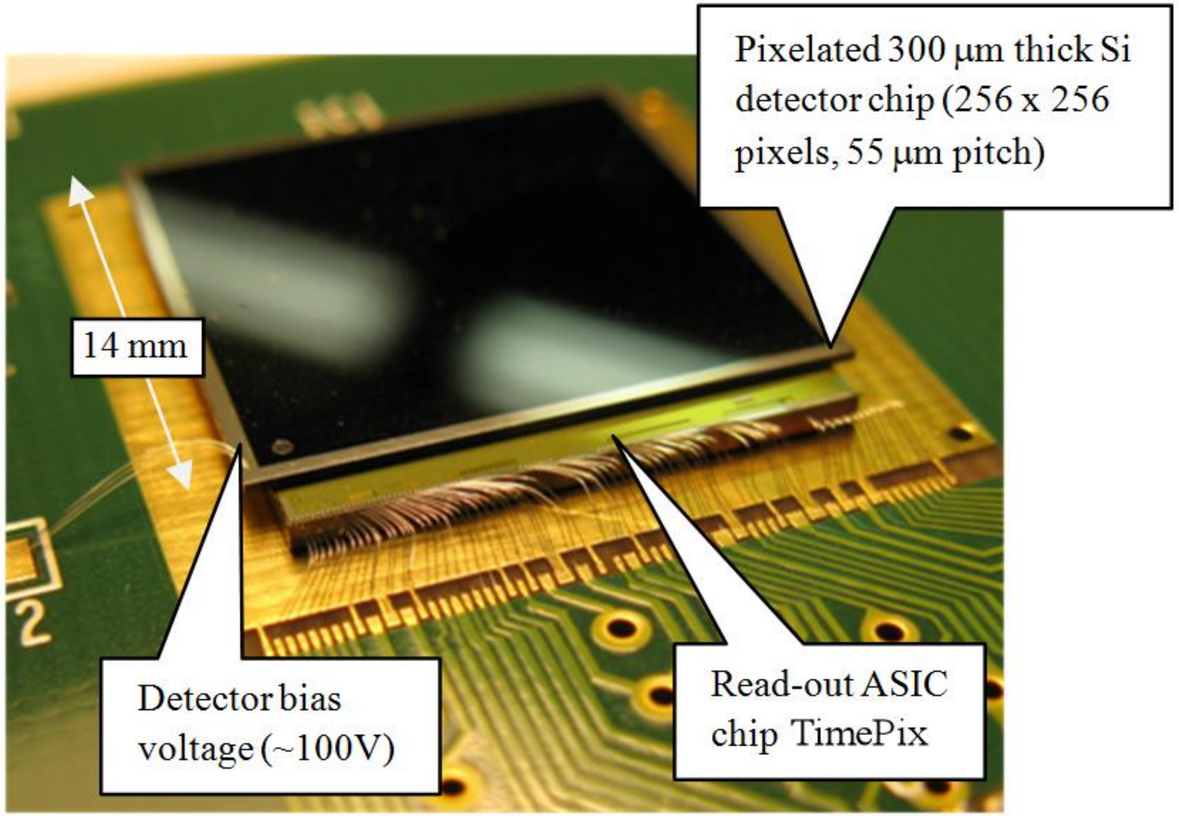
Deep space mission REMEC for GCR monitoring

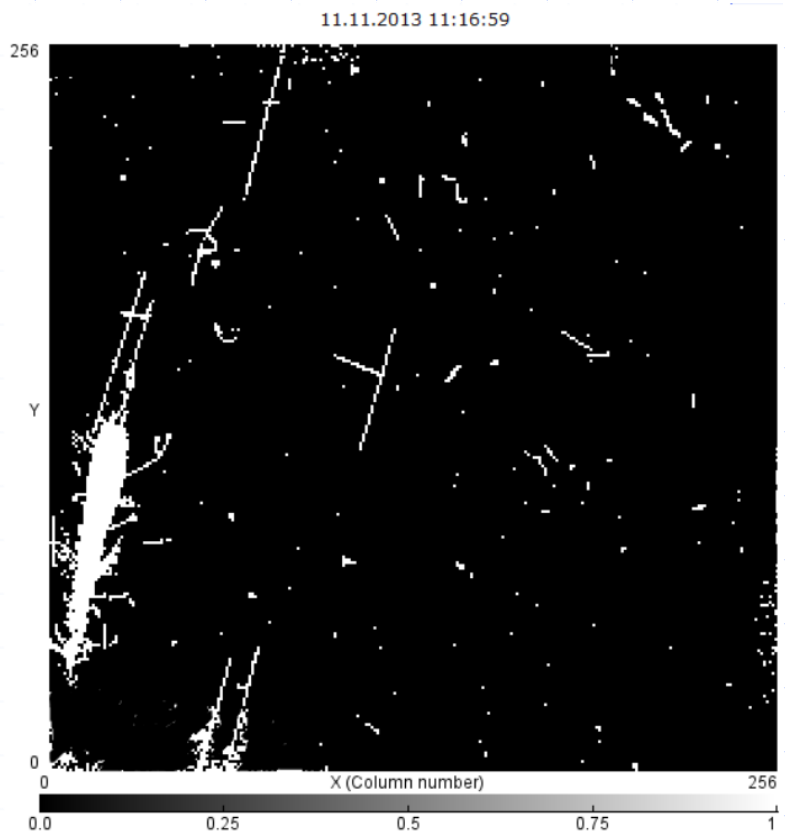
Robert Filgas on behalf of REMEC team

Czech Technical University in Prague

Institute of Experimental and Applied Physics

- IEAP founded in 2002 as a scientific-academic unit of the Czech Technical University oriented toward fundamental experimental research in subatomic physics.
- ~100 employees, mainly PhD students and postdoc researchers.
- Main program is R&D of particle detection techniques and methods (accelerators, medicine, engineering, space).
- Most R&D based on the Timepix – Pixel detector technology developed within the CERN Medipix collaboration.



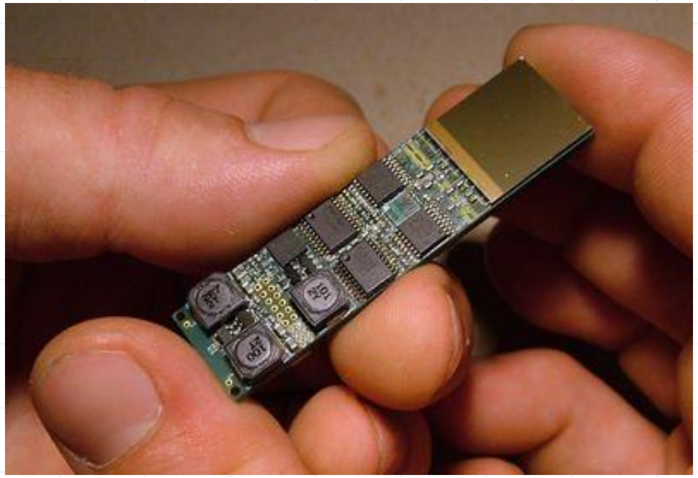


Institute of Experimental and Applied Physics
Czech Technical University in Prague

IEAP Space heritage

- 5 Timepix-Lite detectors deployed onboard ISS in 2012 in collaboration with NASA and the University of Houston.

- Monitoring radiation environment inside the station. Important for the crew safety and protection of the electronic equipment.

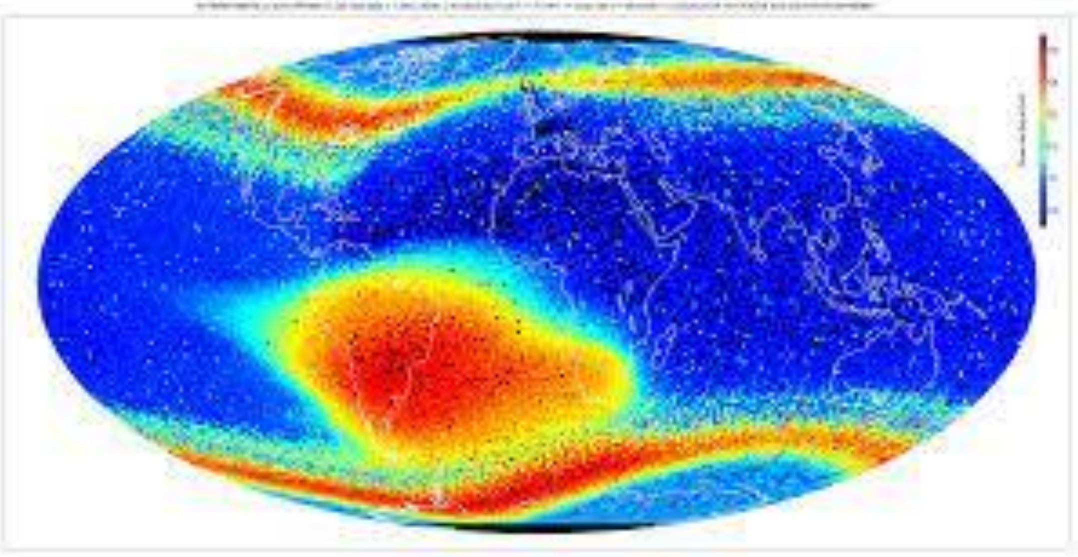


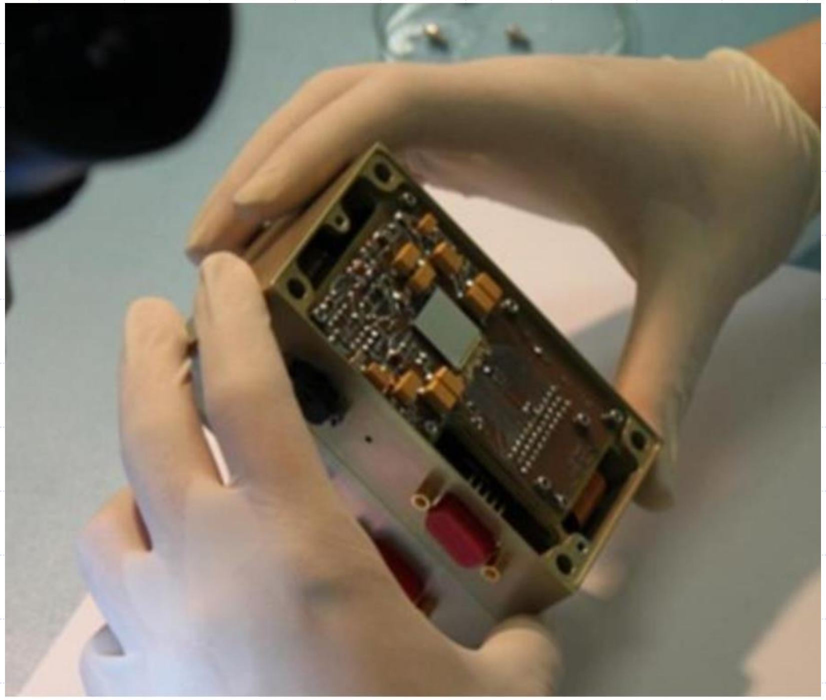
IEAP specialization - miniaturization

Courtesy of NASA

SATRAM

- SATRAM with Timepix detector onboard ESA satellite Proba-V, launched to LEO in 2013. The first deployment of Timepix in open space. Still functioning after 10 years, providing invaluable space heritage.
- High resolution mapping of space radiation at altitude 820 km
- Cooperation of IEAP and BD Sensors.

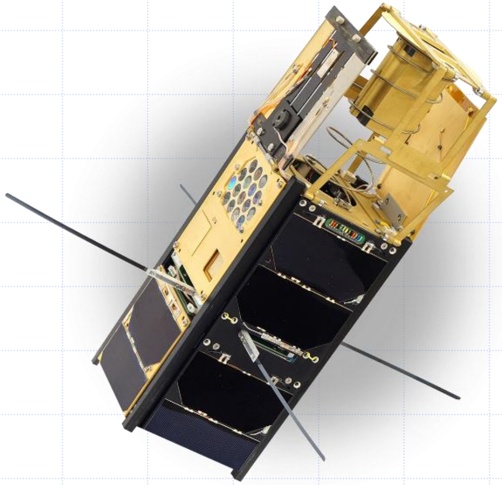


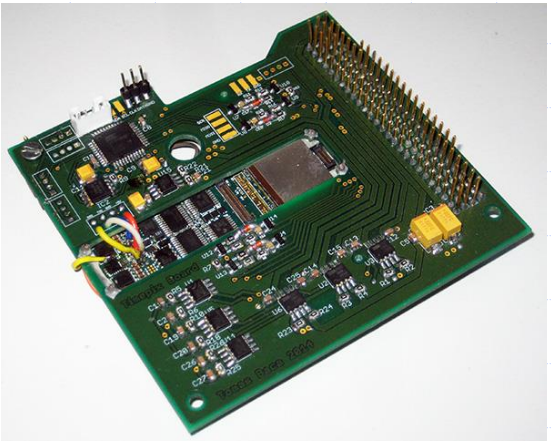


Institute of Experimental and Applied Physics
Czech Technical University in Prague

IEAP CTU Space Heritage

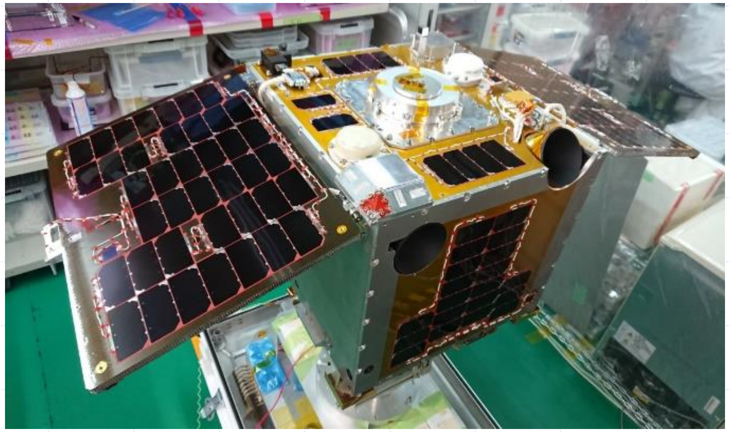
- Timepix detector onboard Czech VZLUSAT-1 cubesat since 2017.

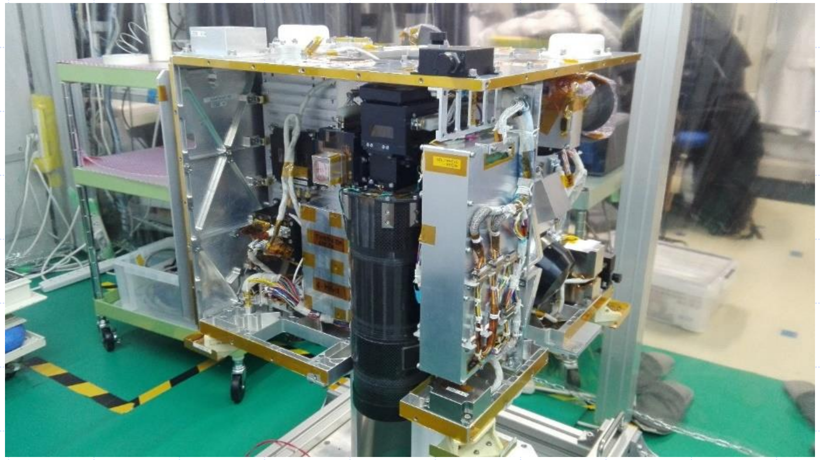




- 2xTimepix detector onboard NASA sounding rocket in 2018.

- 2xTimepix detector onboard Japanese RISESAT since 2019.





Introduction

Institute of Experimental and Applied Physics
Czech Technical University in Prague

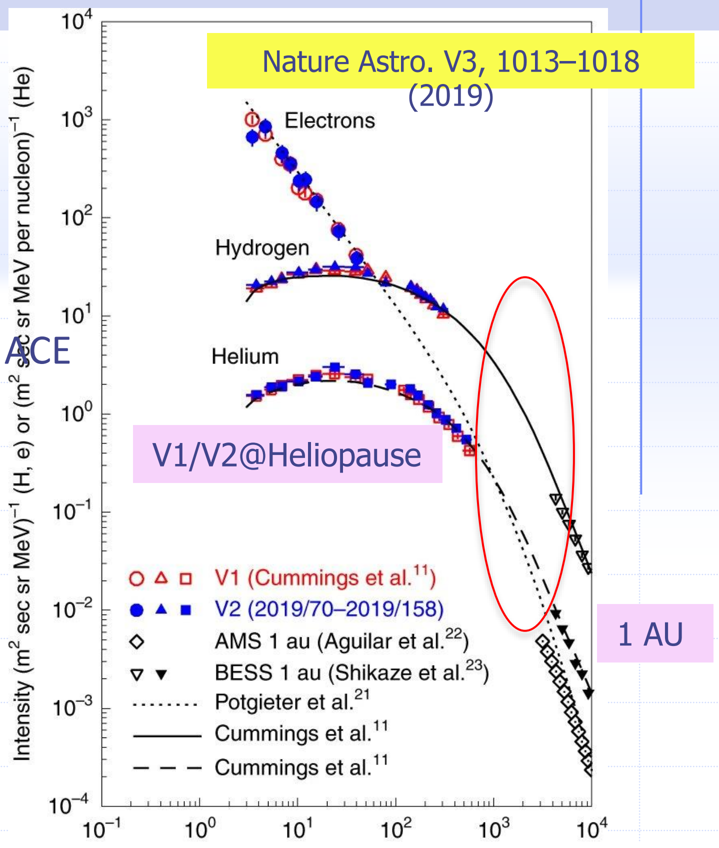
- Space radiation environment is dynamic
  - **Galactic Cosmic Rays (GCR): "static" component**
    - Proton (90%), alpha, HZE ions peaking at energy ranges that are difficult to shield **-> penetrating**
    - Strongly modulated by solar activities, both long term (solar cycle) and short term (solar events)
    - Strongly affected by local magnetic field
  - **Solar Energetic Particles (SEP) from Solar Particle Events (SPE): bursts, rare but intense**
    - Mainly protons; very rare but can be very intense
    - Potential source of accidental exposure during Extravehicular Activities (EVA)
  - **Particles trapped in planetary fields (radiation belts)**
    - Van Allen belts, Jupiter's radiations belts
    - Protons, ions, and electron
  - **Albedo particles**
    - Particles generated at the surface (moon, Mars, …) by GCR/SEP (reflection, activation)

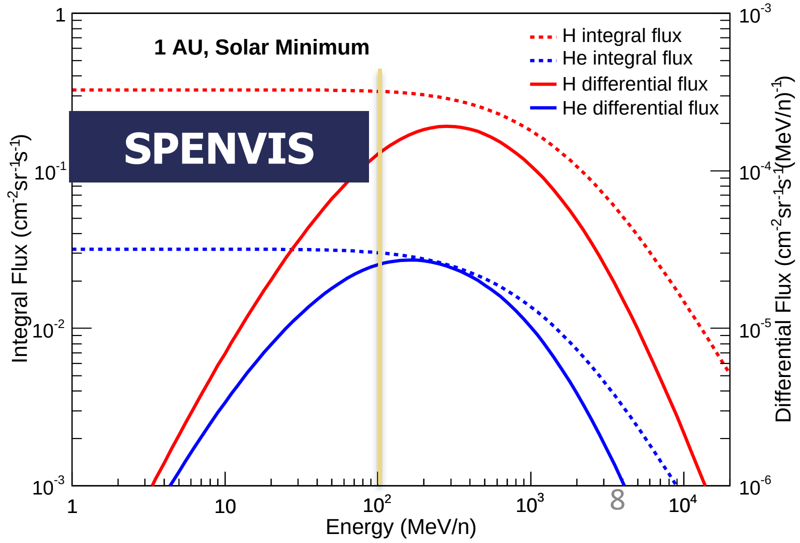
- It is becoming crucial to study and monitor the dynamic and local behavior of energetic particles
  - For long duration deep space manned missions/travel: mission planning and in-situ assessment
- Precise measurements and monitoring of penetrating particles (> 100 MeV/n) in deep space have been lacking due to the difficulties of measuring these particles

Galactic cosmic ray flux in deep space

Institute of Experimental and Applied Physics
Czech Technical University in Prague

- Many instruments measure GCR flux in deep space, but only up to a few 100 MeV/n
  - IMP-8 (1973-2006), GEOS (since 1975), Voyager 1/2 (since 1977), SOHO (since 1995), ACE (since 1997), CRaTER (since 2009), …
- ~GeV flux only measured by LEO/balloon missions at high altitude regions
  - BESS (1993-2008), PAMELA (2006-2016), AMS-02 (since 2011), ...
  - Dependence on geomagnetic cutoff evaluation
- Models can be used to transport the GCR flux within the solar system
  - e.g. ESA's SPENVIS or NASA's Badhwar-O'Neill (BON2020) models
- At 1 AU
  - Flux peaking at ~1 GeV/n
    - **Penetrating -> Important damaging effect to biological organisms**
  - Mainly protons and Helium ions, but also ~1% HZE (high Z and energy) ions
    - A few Hz/cm² at solar minimum
  - **Modulated by solar activities**
    - Variations up to ~x10 at ~100 MeV
- In-situ precise measurement of penetrating (~GeV) particles in deep space can improve both the science and the predicting power of the models



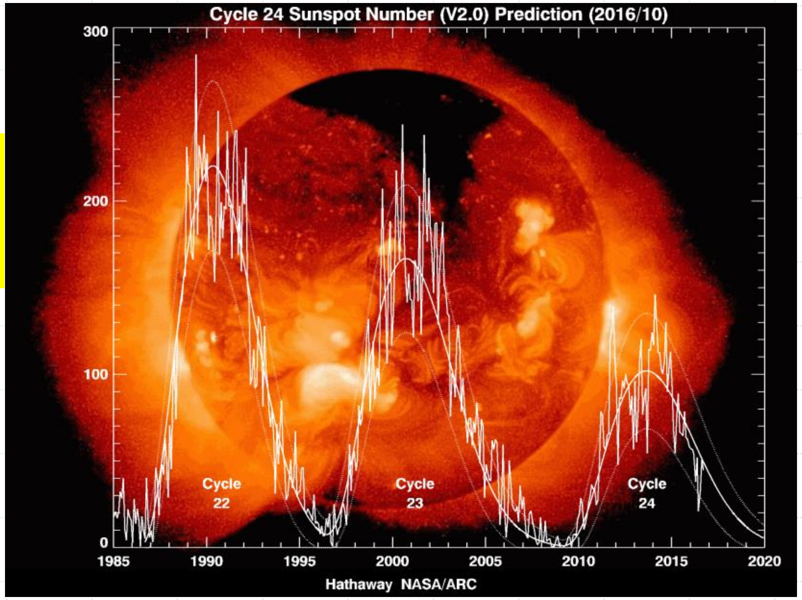


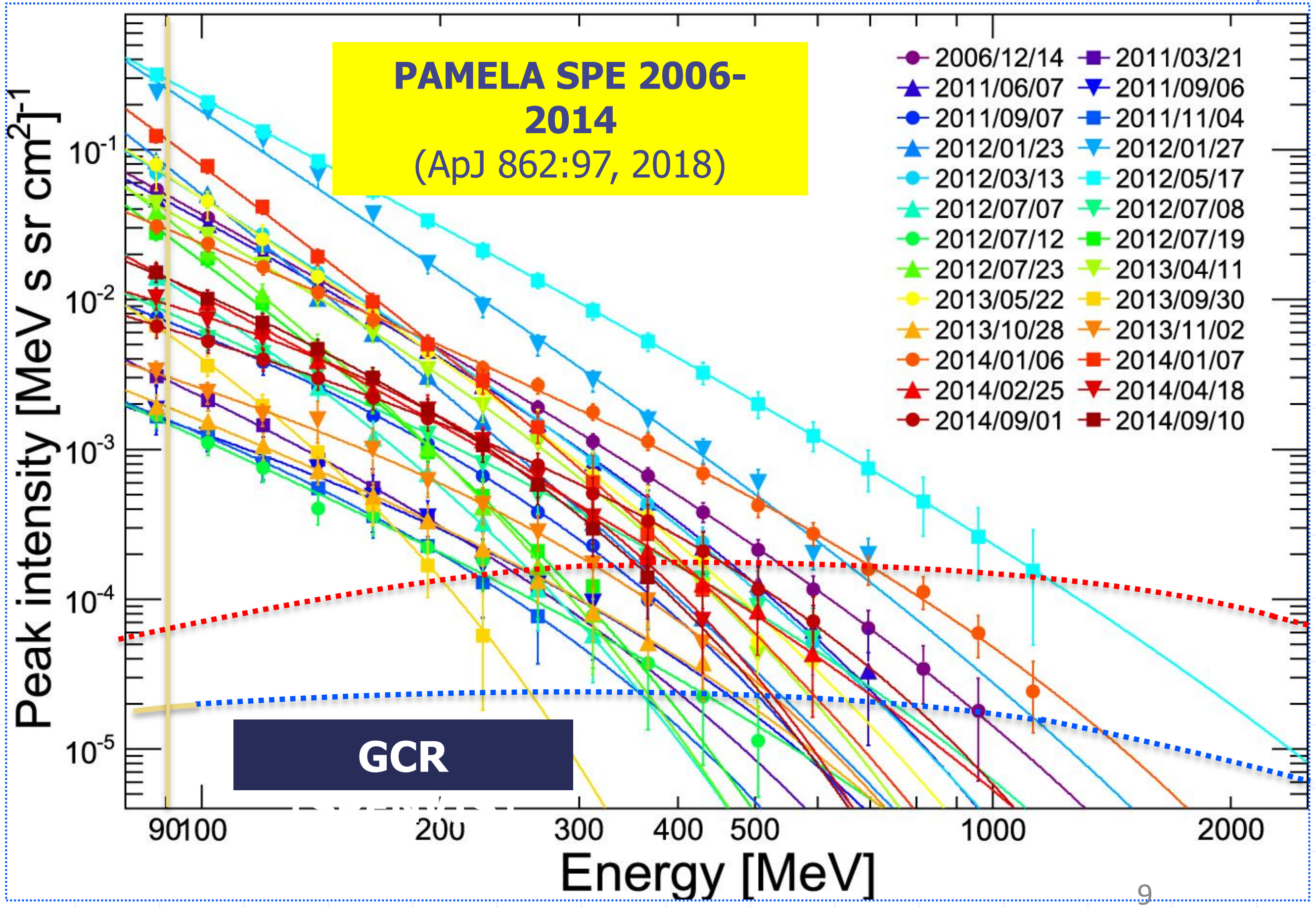
Solar particle events (SPE)

Institute of Experimental and Applied Physics
Czech Technical University in Prague

- SPE are solar events that produce solar energetic particles (SEP)
  - Up to a few days at a time, a few per year on average (correlated to solar cycle)
  - **Definition**: flux of protons at energies ≥ 10 MeV ≥ 10 proton flux unit (1 pfu = 1 particle $cm^{-2}s^{-1}sr^{-1}$)
  - Peak flux of proton >100 MeV can jump by a large factor, up to 1000 pfu
    - Can reach >1000 times of GCR flux
- Comprehensive measurements of these "GeV" solar radiation in deep space with instrument with high-rate capability can provide very useful new input for space dosimetry studies

Sunspot Number (MSFC NASA)



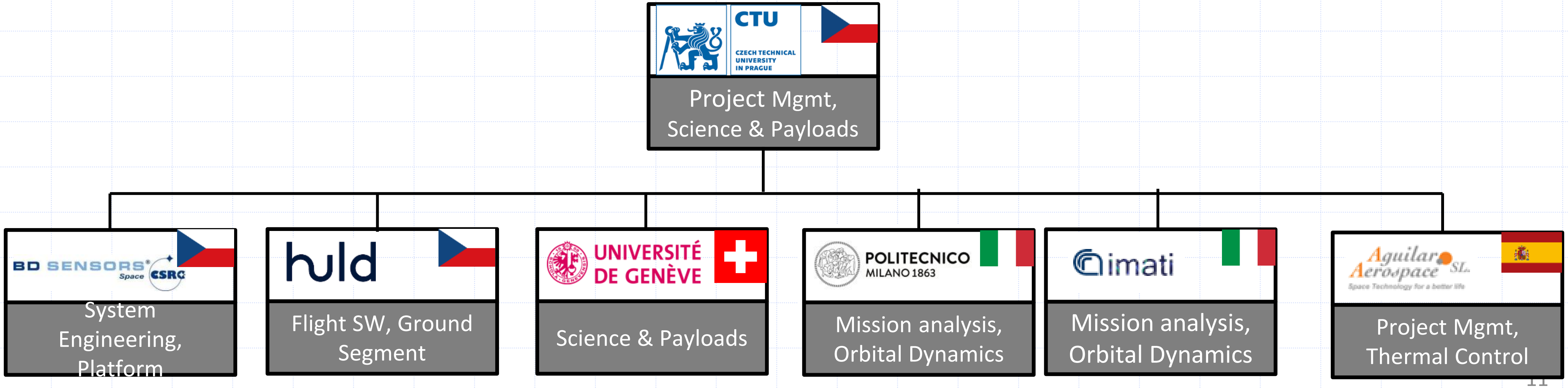


REMEC (Radiation Environment Monitor for Energetic Cosmic rays)

- Science objectives
  - Perform precise flux and composition measurements of GCR in the 10 MeV/n - 10 GeV/n range in deep space to study the origin of these populations and their propagation in the Galaxy and solar system
  - Provide the first precise measurements of the flux, composition and arrival time of Solar Energetic Particles (SEP) in 10 MeV/n –10 GeV/n, particularly during relativistic SEP events. Study solar modulation of GCR
  - Improve space weather models from the energetic particle perspective by monitoring the deep space radiation environment continuously over an extended period in a unique energy band
  - Assess radiation hazard of penetrating particles during solar system exploration missions (Lunar, Mars)

REMEC (Radiation Environment Monitor for Energetic Cosmic rays)

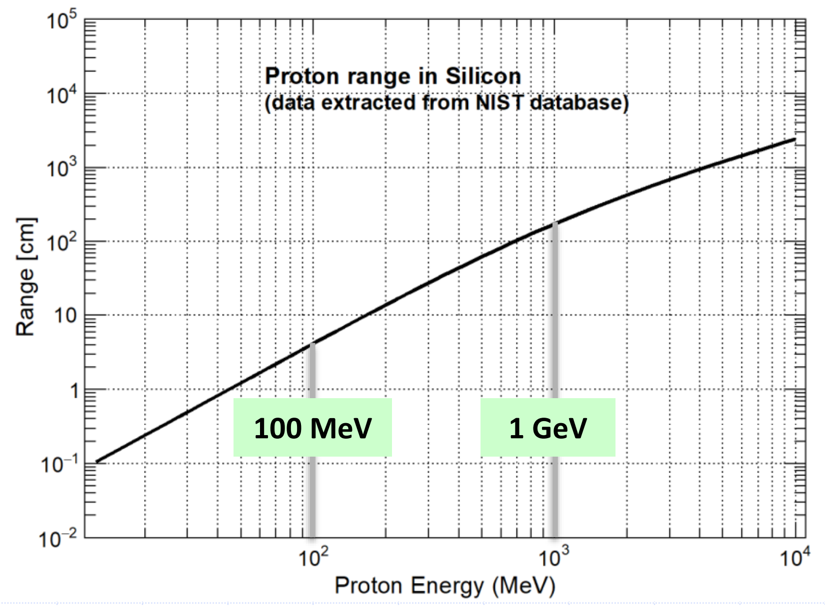
- REMEC has been selected as one of mission concepts for the call *“Ambitious Projects (Mission Proposals) for the Czech Republic: Phase 0/A/B1 Studies”*
  - The goal is to increase reputation and visibility of the Czech industry and academia in global scale by developing, manufacturing, launching and operating a dedicated satellite mission
  - Studies started in 2022, lasting 1 year
  - REMEC is one of the 5 selected mission concepts
  - Down selection by summer of 2023 after all concepts pass Phase A



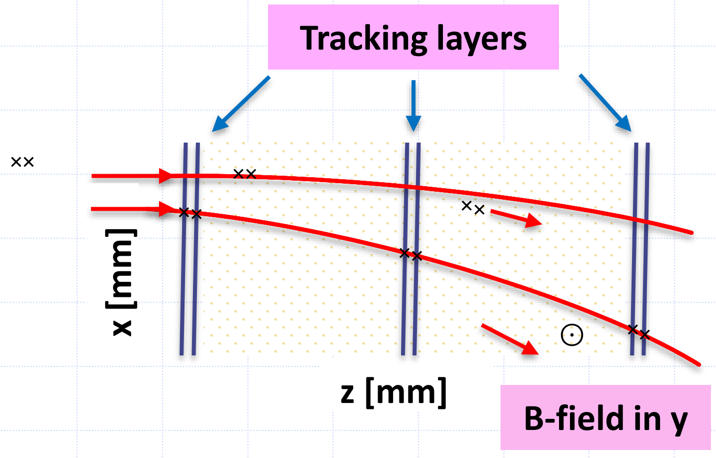
Challenge of measuring GeV particles

Institute of Experimental and Applied Physics
Czech Technical University in Prague

- Energy of GeV particles cannot be measured by the ΔE-E method
  - E.g. only ~4 cm of Silicon needed to stop 100 MeV protons with ionization energy loss
    - **To stop 1 GeV protons 170 cm of Silicon is needed!**
  - Silicon nuclear interaction length = 46.52 cm
    - More likely to produce a **shower of secondary particles** (including the dangerous neutrons)
    - Calorimeter method: **very heavy, with bad resolution**
  - Similarly relativistic electrons shower in thick material



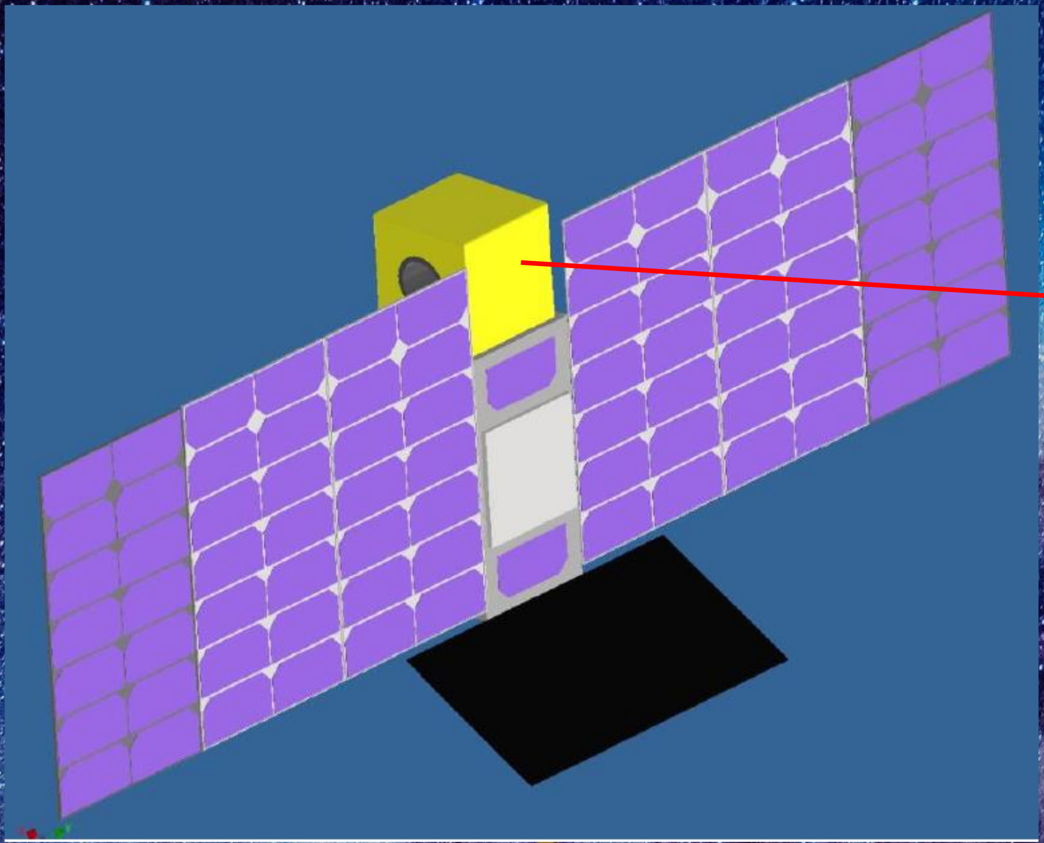
- **PAN**: use a magnetic spectrometer to measure the bending of charged particles in the B-field ⇒ rigidity (p/Z)
  - then infer the momentum and energy with independently measured particle charge Z

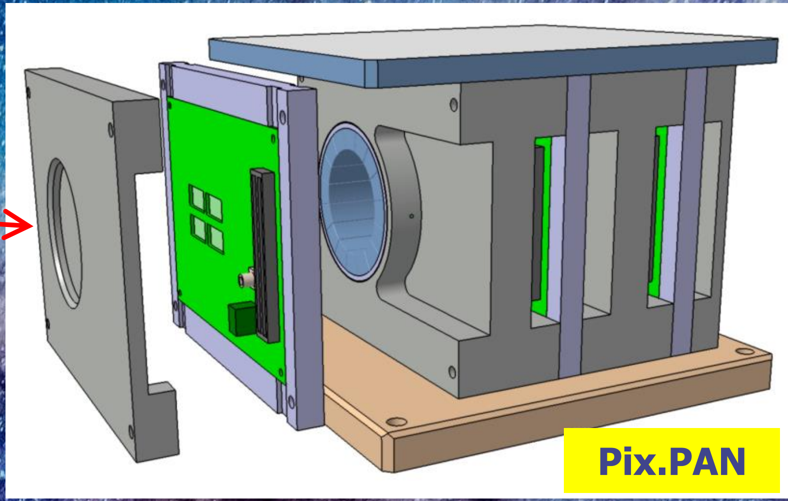


Magnetic spectrometer = magnetic field + tracking detectors

REMEC: The main scientific payload is magnetic spectrometer Pix.PAN

Institute of Experimental and Applied Physics
Czech Technical University in Prague



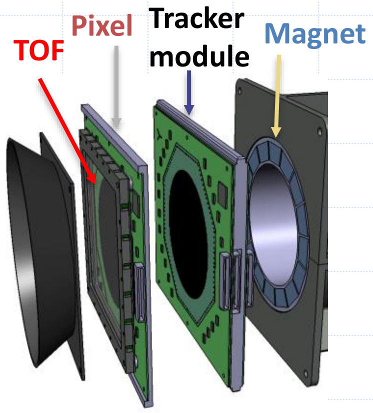


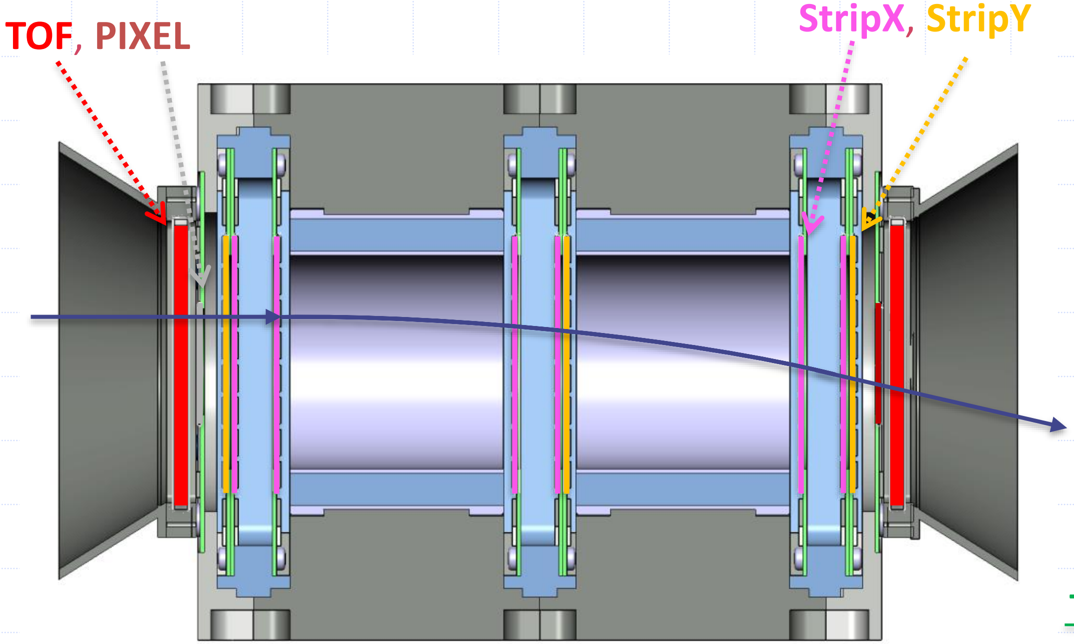
Pix.PAN for REMEC is the improved version of Mini.PAN (Developed by UniGe, INFN Perugia, IEAP CTU under EU H2020 FET-OPEN)

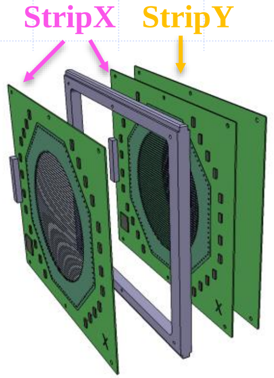
Institute of Experimental and Applied Physics
Czech Technical University in Prague

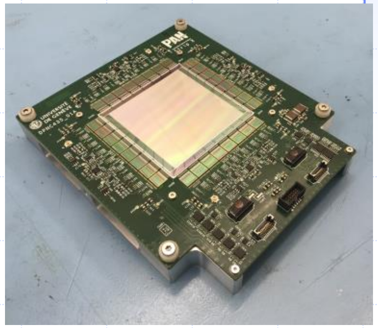
Great simplification

- Mini.PAN: 9 tracker layers (6 StripX, 3 StripY), 2 TOF modules, 2 Timepix3 modules



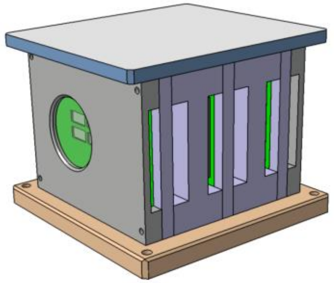


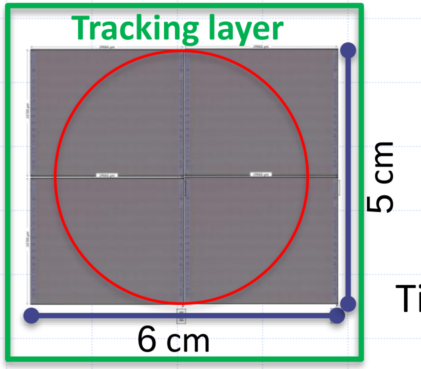




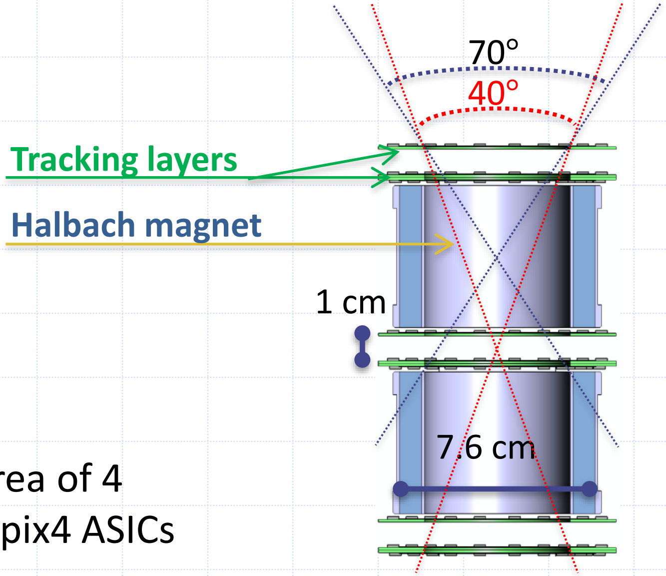
Mini.PAN tracker module

- Pix.PAN: same magnet structure (same geometric factor) but only 6 tracker layers with Timepix4





Area of 4 Timepix4 ASICs



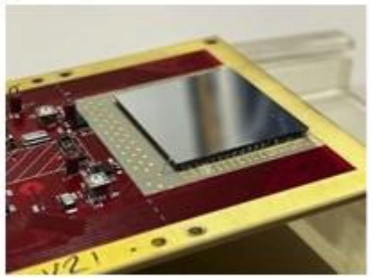
Pix.PAN

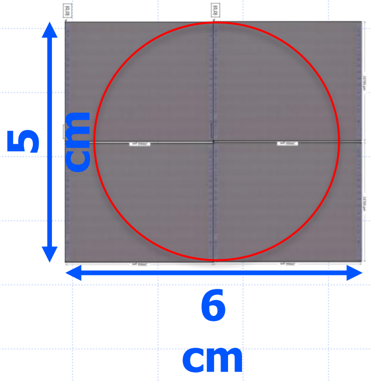
Pix.PAN: advanced option of Mini.PAN with pixel detector only

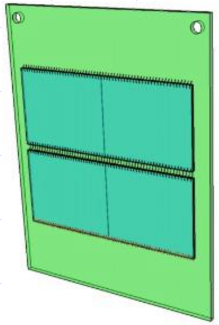
Institute of Experimental and Applied Physics
Czech Technical University in Prague

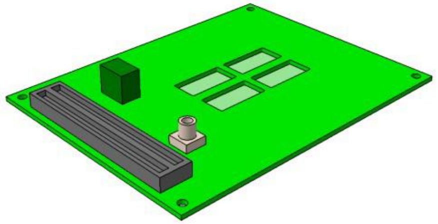
- Pix.PAN: Mini.PAN magnets + 6 silicon pixel layers, each with 2x2 **Timepix4** ASICs
  - Timepix4 produced and validated in 2021

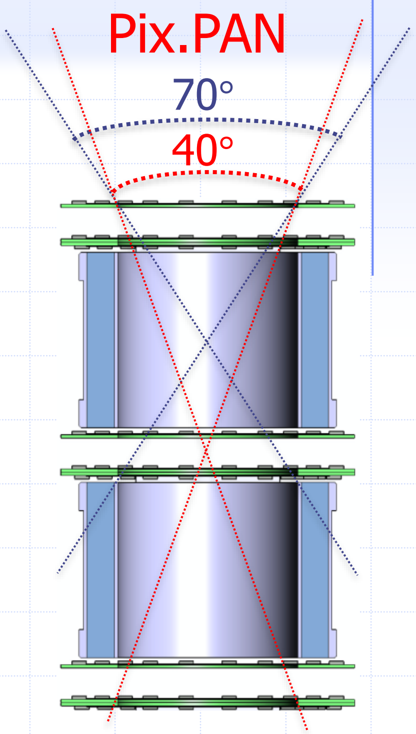
Llopart et al., Journal of Instr, 17, C01044, 2022

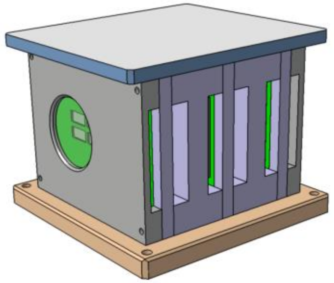








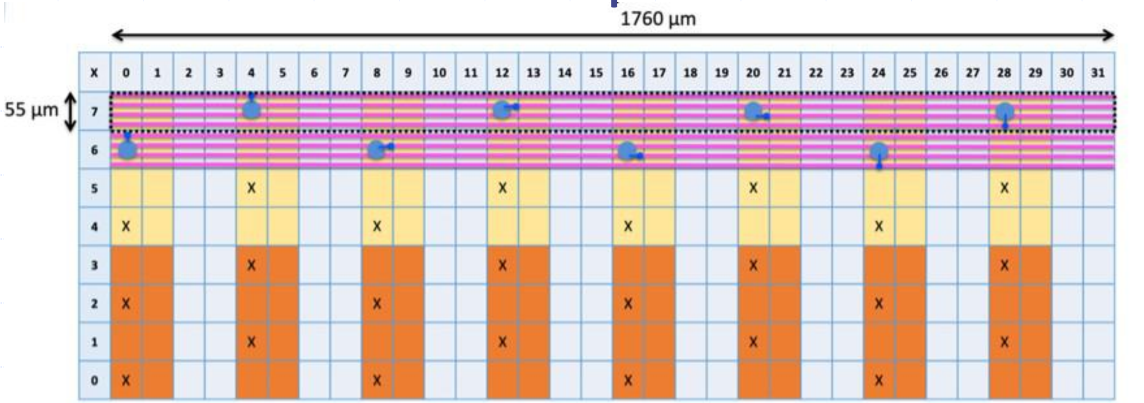


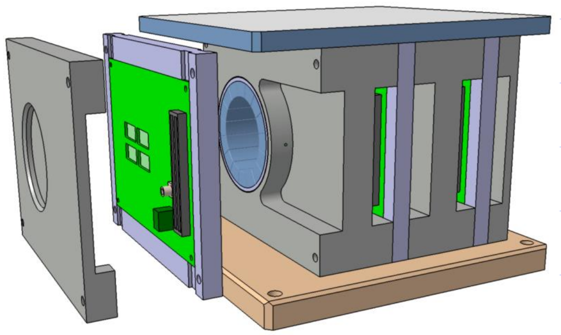


- Advantages of Pix.PAN
  - **Simplicity, robustness and flexibility**
    - Only 1 type of detection element used for the whole instrument
    - Data-driven readout (no trigger needed), ADC/TDC integrated in ASIC
  - **High rate capability, no saturation up to a hit rate of 358 Mz/cm^2**
  - Full analog readout: measure the Z of the particle with dE/dx and cluster profile
  - **Timestamp in 195 ps bins:** Time-Of-Flight for entering side determination, additional handle for particle ID
  - **High TRL -** Timepix series of detectors have been used in particle/nuclear/medical physics, industry, ... and space!

Pix.PAN: low power, low weight, compact

- Reduce power by optimizing the pixel geometry: **good position resolution only needed in the bending direction**
  - “long” pixel: 13.75 µm x 1760 µm ⇒ **hit resolution ≲ 3 µm**, only 1/8 of Timepix4 cells used
    - save 7/8 of front-end analog power consumption plus some part of digital power
  - Design and prototype production in progress with ADVACAM Finland
  - **Goal is to reach ~20W for the spectrometer**





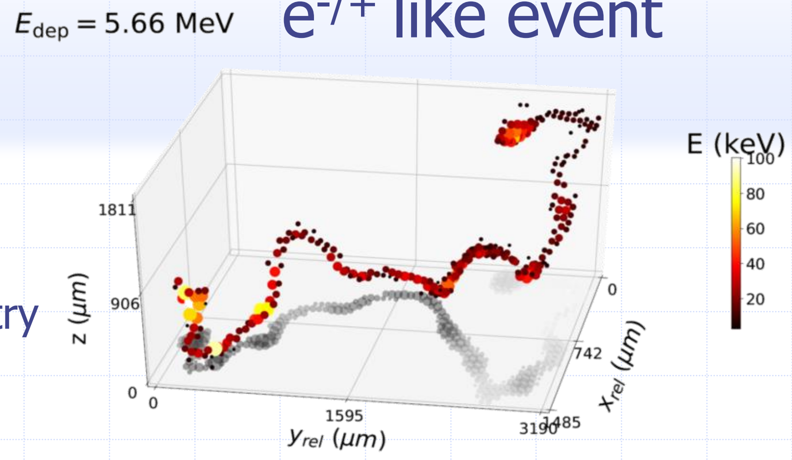
- **Low weight and compact**
  - Each magnet 0.8 kg. Tracking layers very light. Thermal/support structure and readout electronics platform dependent ⟹ **total weight ~15 kg for REMEC**
  - **Sensitive element volume ~8 cm x 8 cm x 15 cm ⟹ overall dimension ~20 cm x 20 cm x 20 cm for REMEC**
- Raw data rate is 40-80 MB/day mainly from GCR (rare high rate bursts from solar events can be cached)

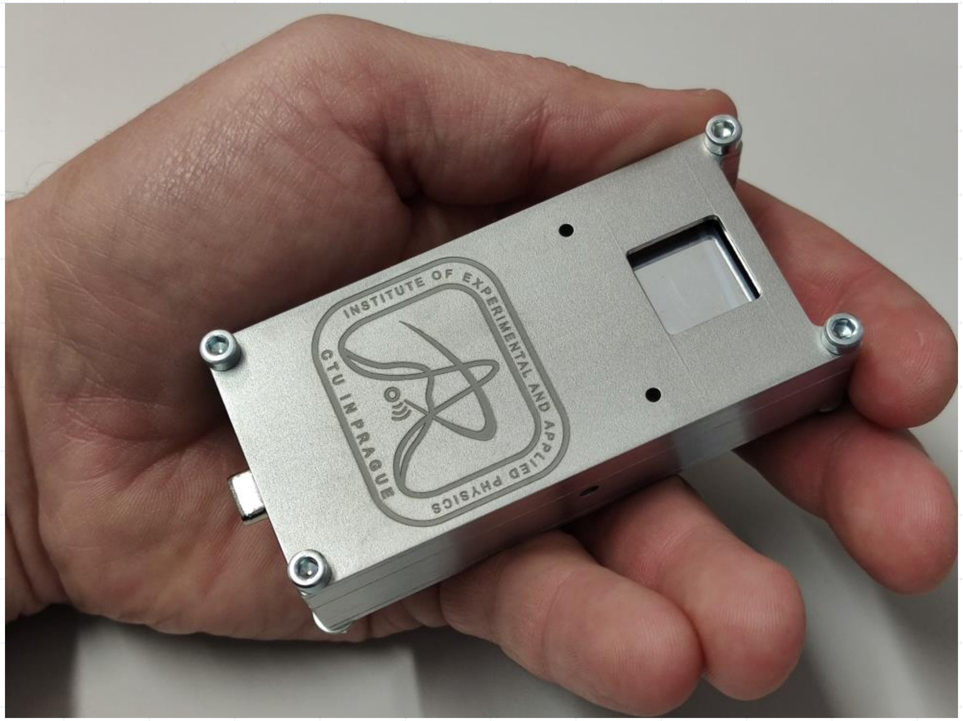
Institute of Experimental and Applied Physics
Czech Technical University in Prague

Pix.PAN supplemented by 2x HardPix Radiation Spectrometers

- Modular design with 1 or 2 Timepix3 layers, COTS or RadHard processor, RS422, CAN or Ethernet interface
- On-board processing – energy spectroscopy, particle identification, dosimetry
- Developed under ESA GSTP project Radiation Monitor System in Package

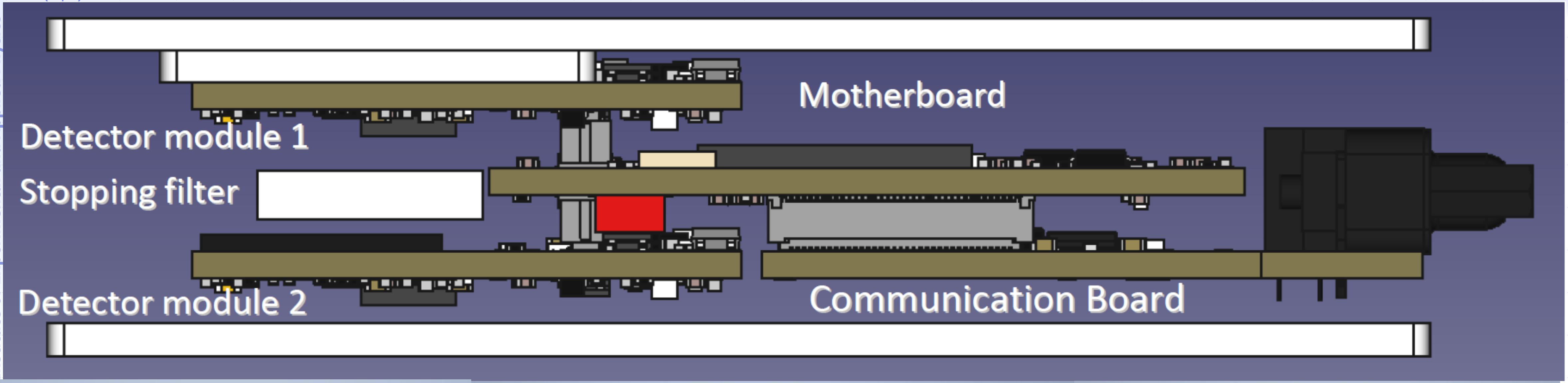
$e^{-/+}$ like event

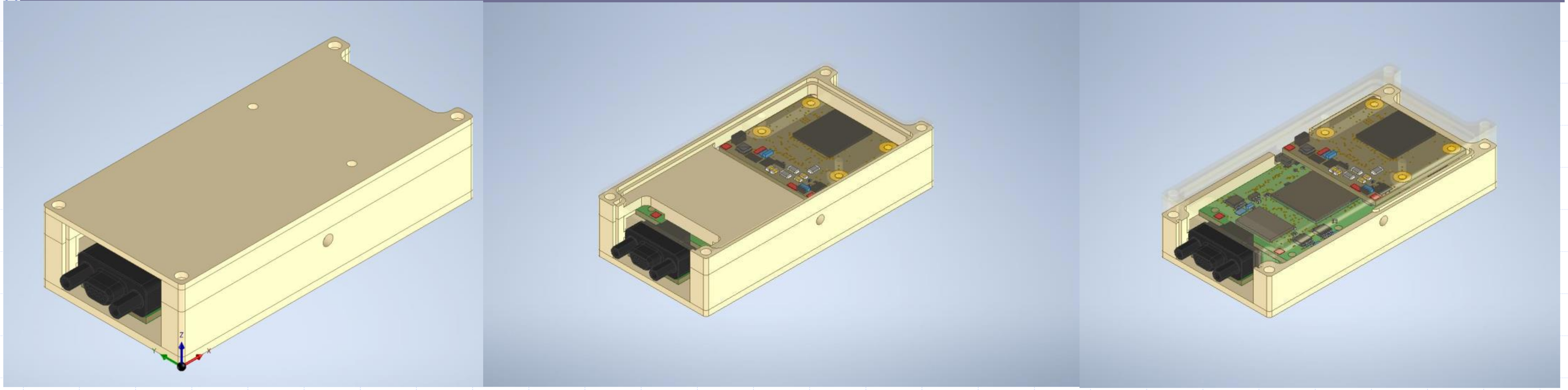




Parameters	Value
Particle types	Electrons, Protons, Ions, X-rays, Gamma-rays
Dimensions	81x40x22mm
Mass	150 g
Power consumption	1.5 – 3 W
Electrical interface	Micro Sub-D (RS-422)
Operational temperature	-20°C to 70°C
Readout chip detector	Timepix3
Sensor area	14 x 14 mm
Sensor material and thickness	Silicon 500 μm
Voltage	5V or 28V
Energy thresholds	3 keV

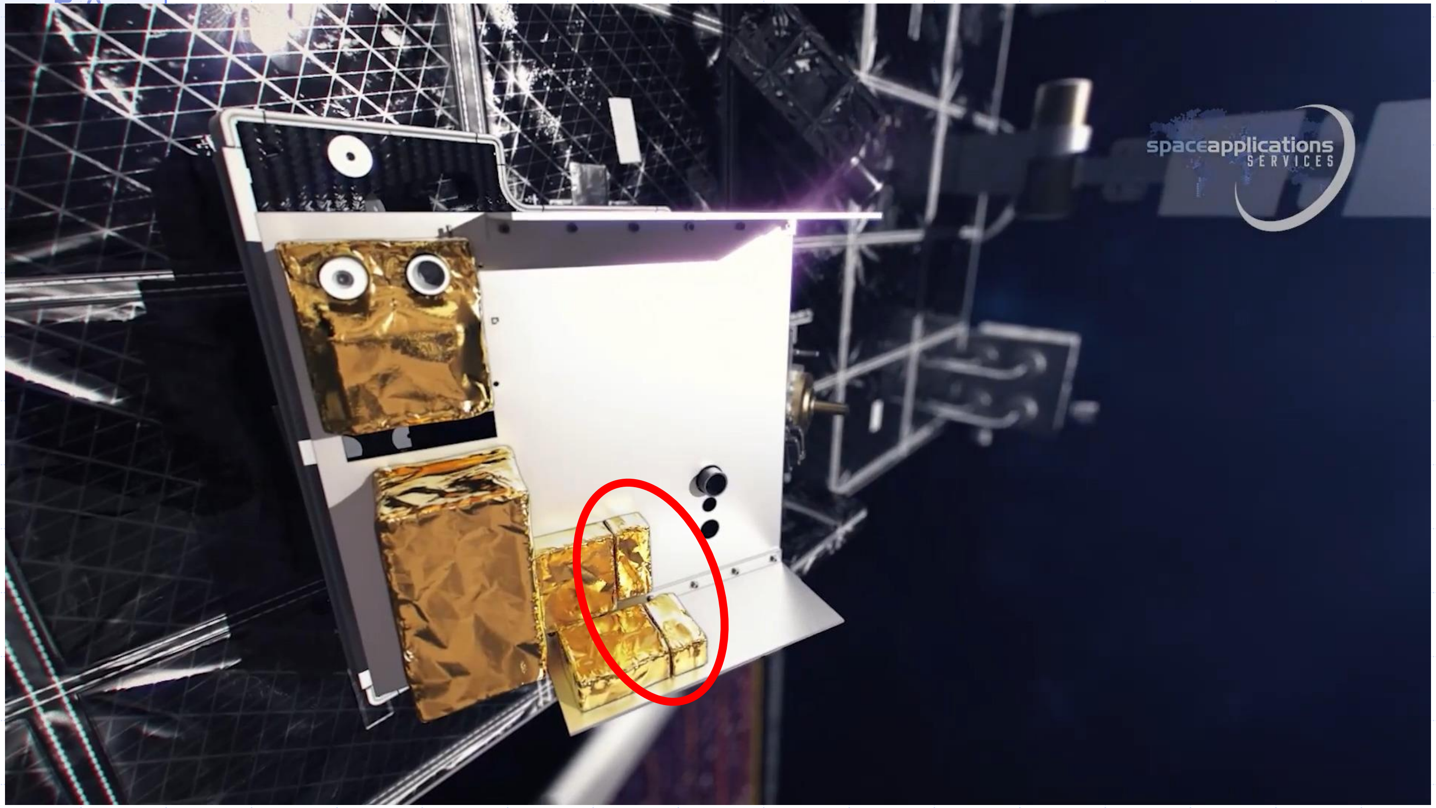
HardPix Radiation Spectrometer



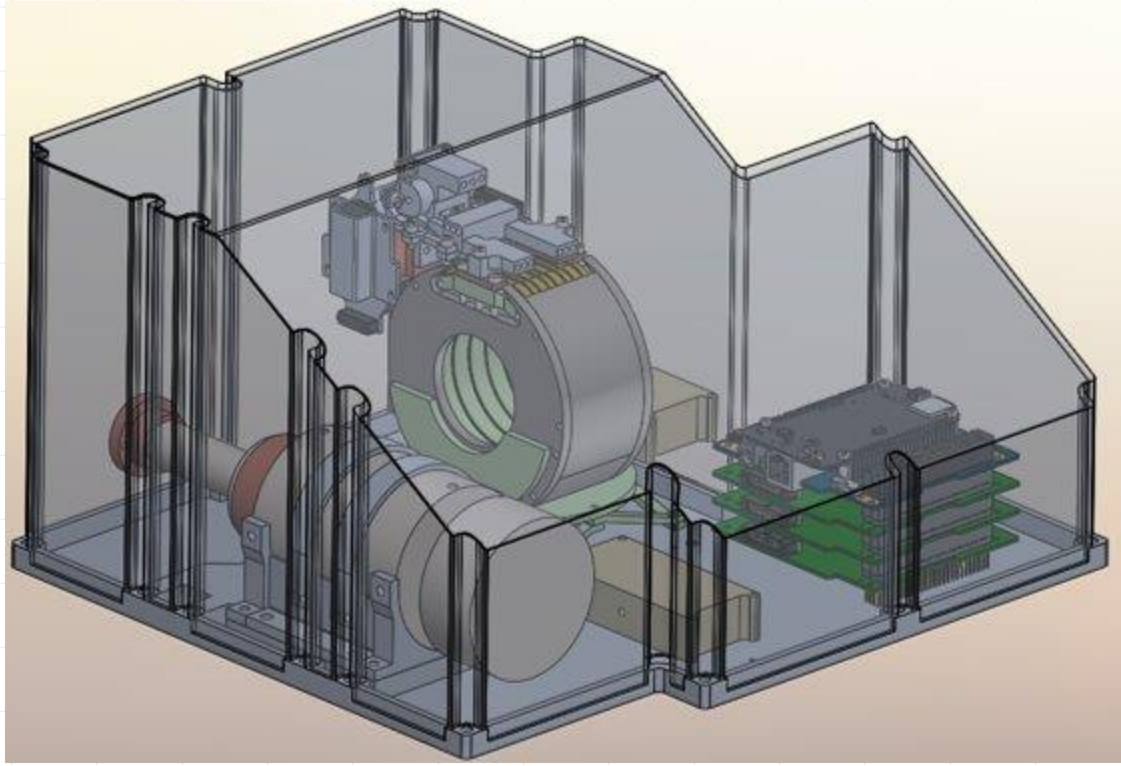


HardPix Radiation Spectrometer – planned missions

Lunar Gateway will host an external scientific instrument suite from ESA called European Radiation Sensors Array (ERSA) including 2 HardPix detectors. ERSA measurements can tell us about the physics of radiation in the solar system, and understand the risks posed by radiation to human spacefarers and their hardware.

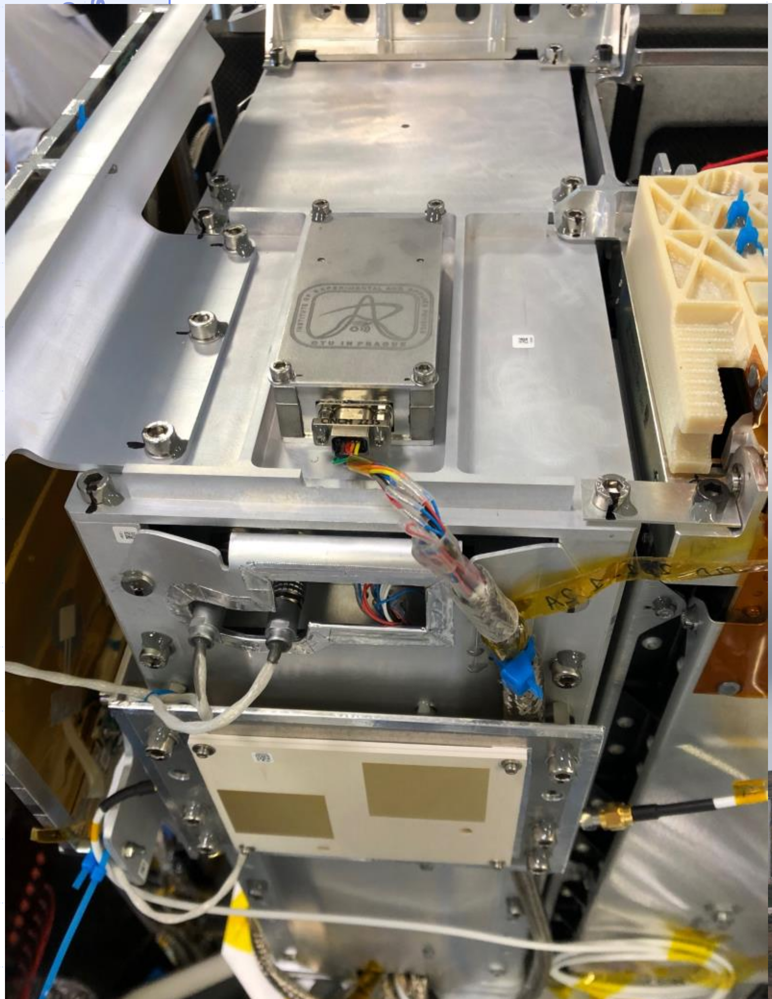


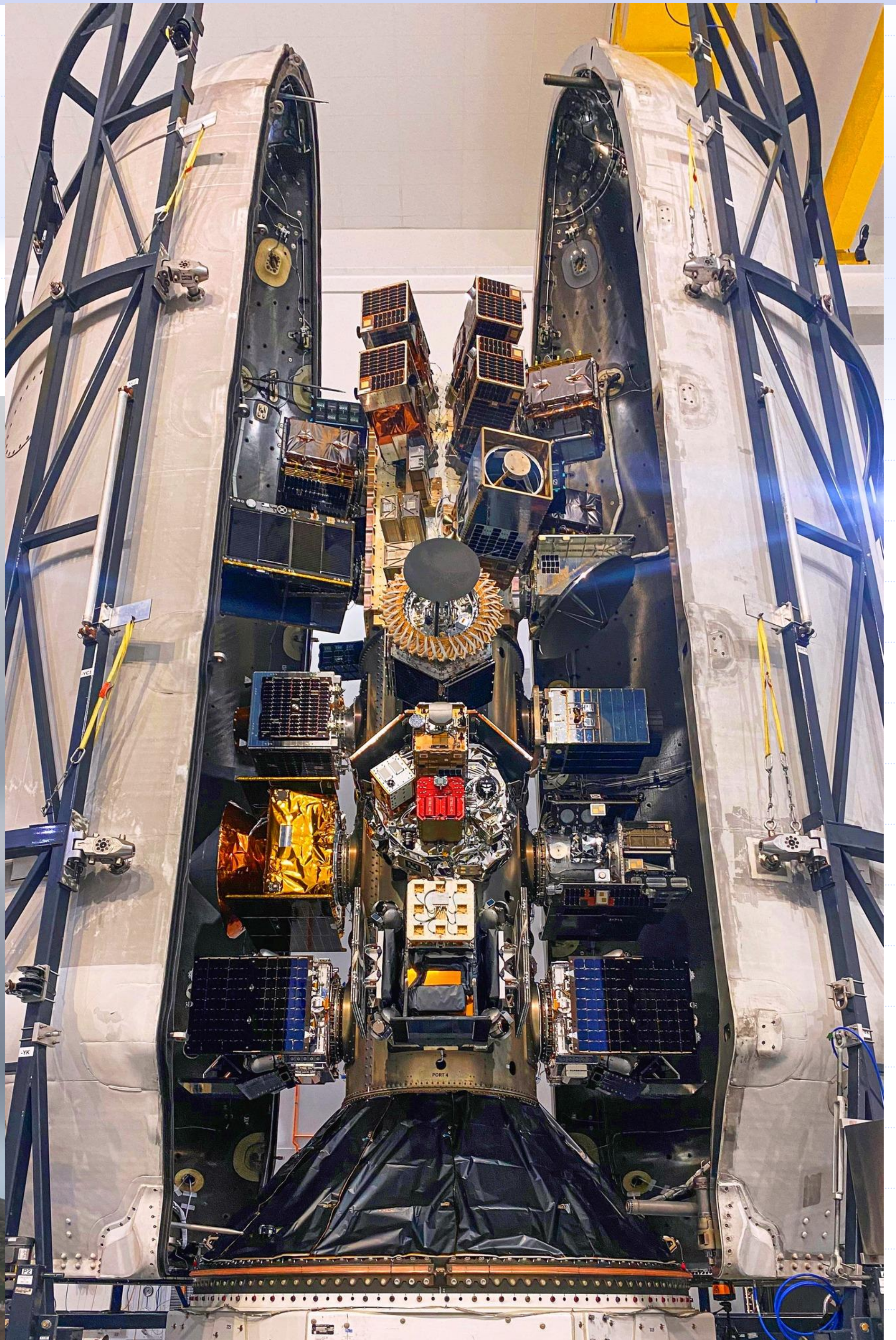
ISS/Nanoracks mission to study radiation field influence by the superconducting magnet by Robinson-Paihau research institute in New Zealand using 2 HardPix detectors. Launch 2024



HardPix in space!

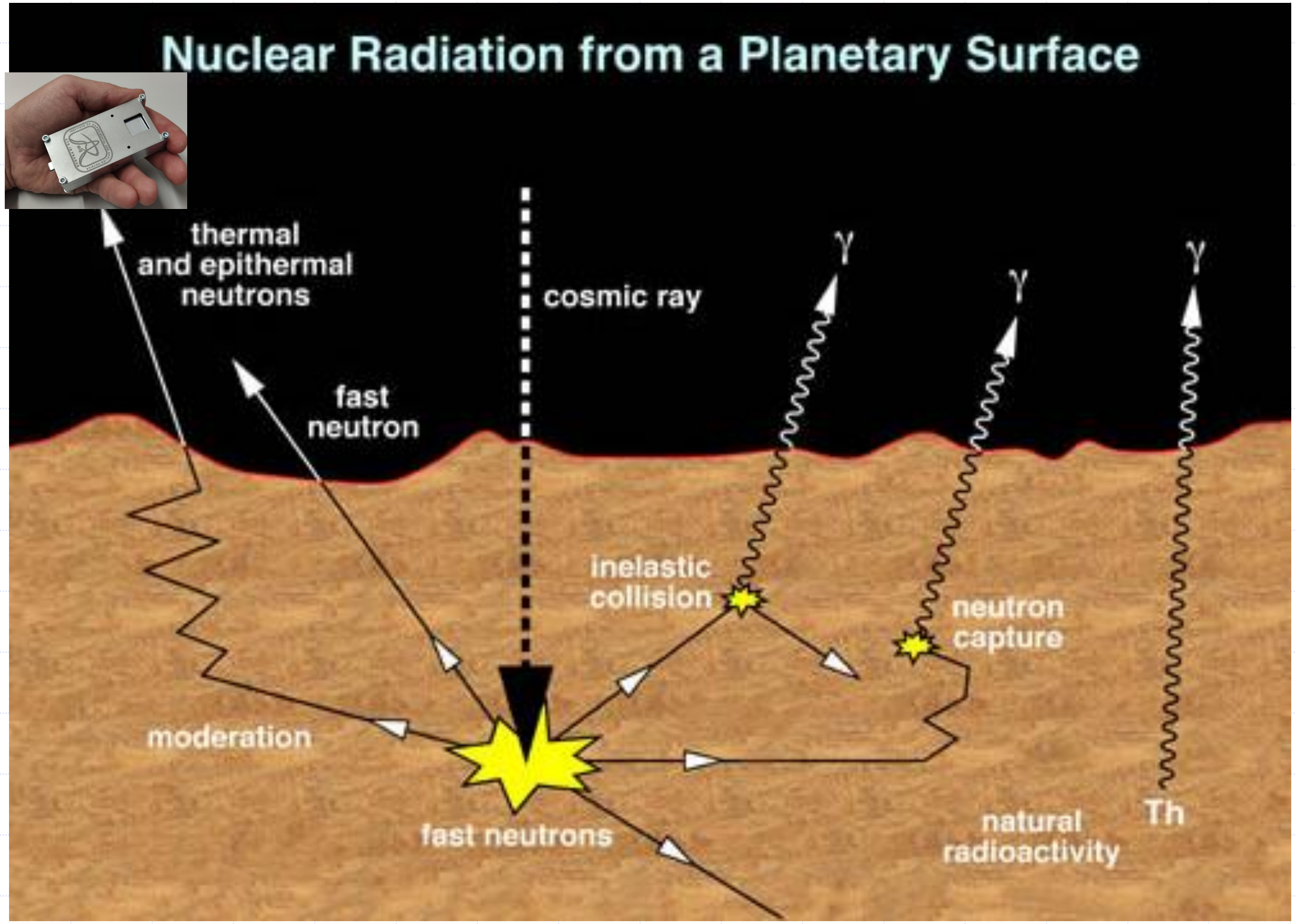
HardPix launched onboard ION satellite by SpaceX Falcon 9 rocket on June 12.
HardPix is part of UKRI STFC SWIMMR (Space Weather Instrumentation, Measurement, Modelling and Risk) programme.



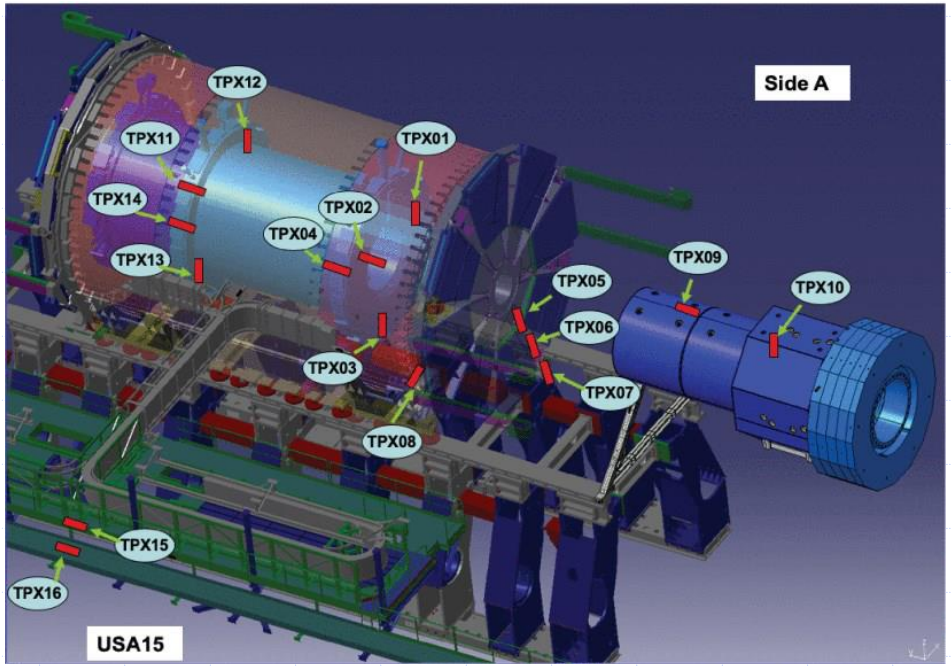


Lunar prospecting – neutron spectrometer

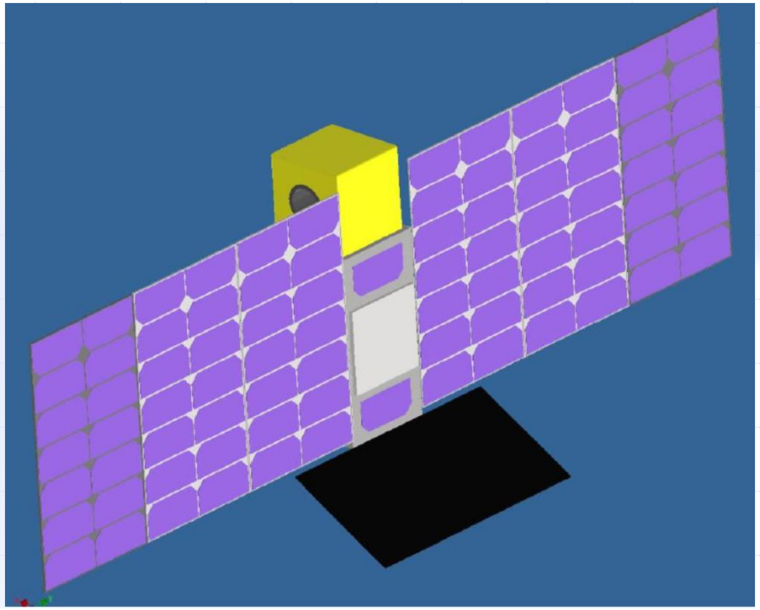
- Equipped with neutron conversion layer, HardPix can perform as a neutron spectrometer, measuring flux variations of thermal and epithermal neutrons scattered by hydrogen, a clear signature of enhanced hydrogen (water-ice) abundance.

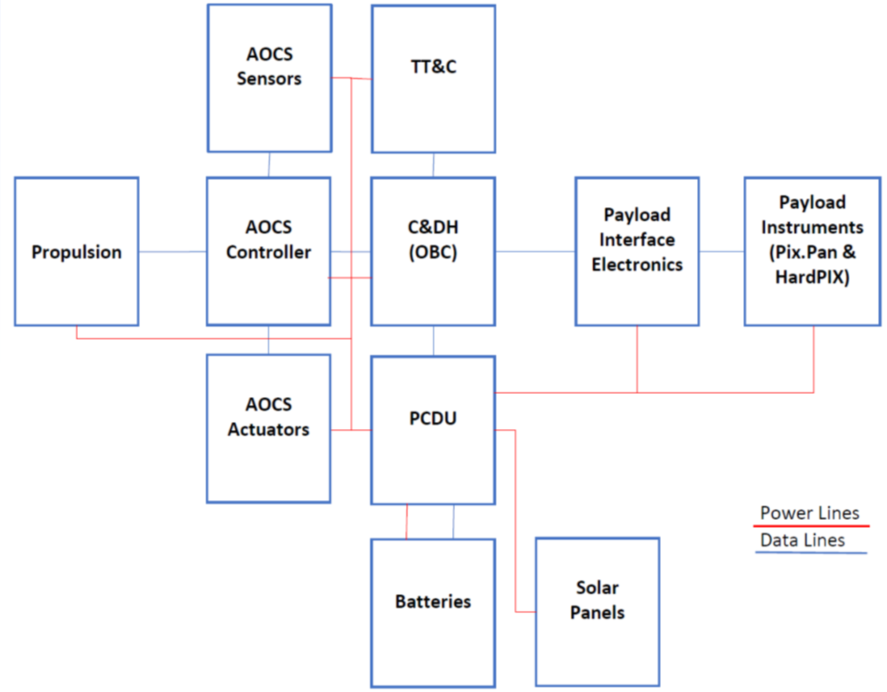


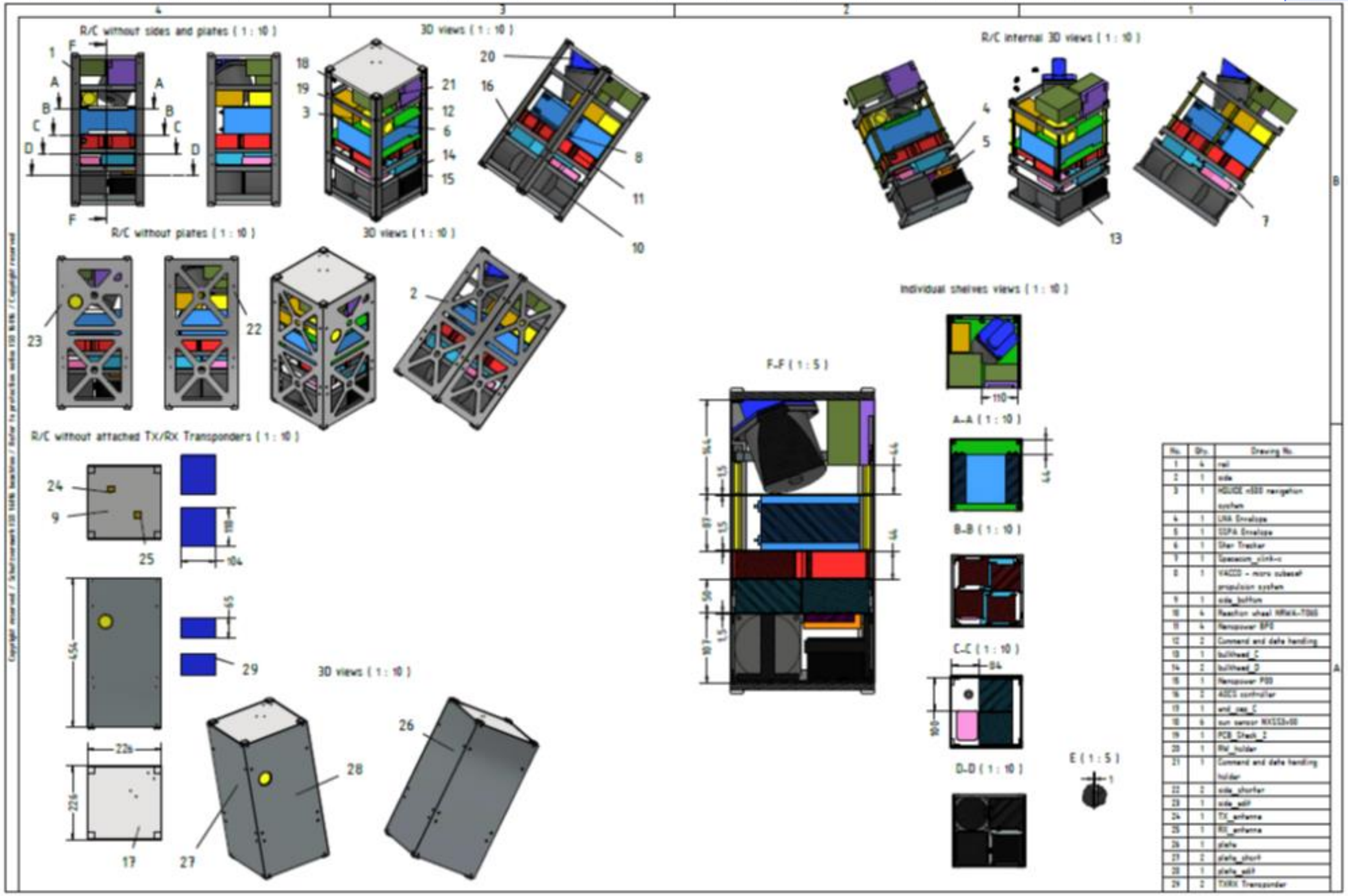
HardPix neutron spectrometer can be placed in lunar rovers (due to its size and mass even in very small ones) and map water presence in lunar subsurface. Neutron detection already tested by network of Timepix detectors in the ATLAS detector at CERN LHC.



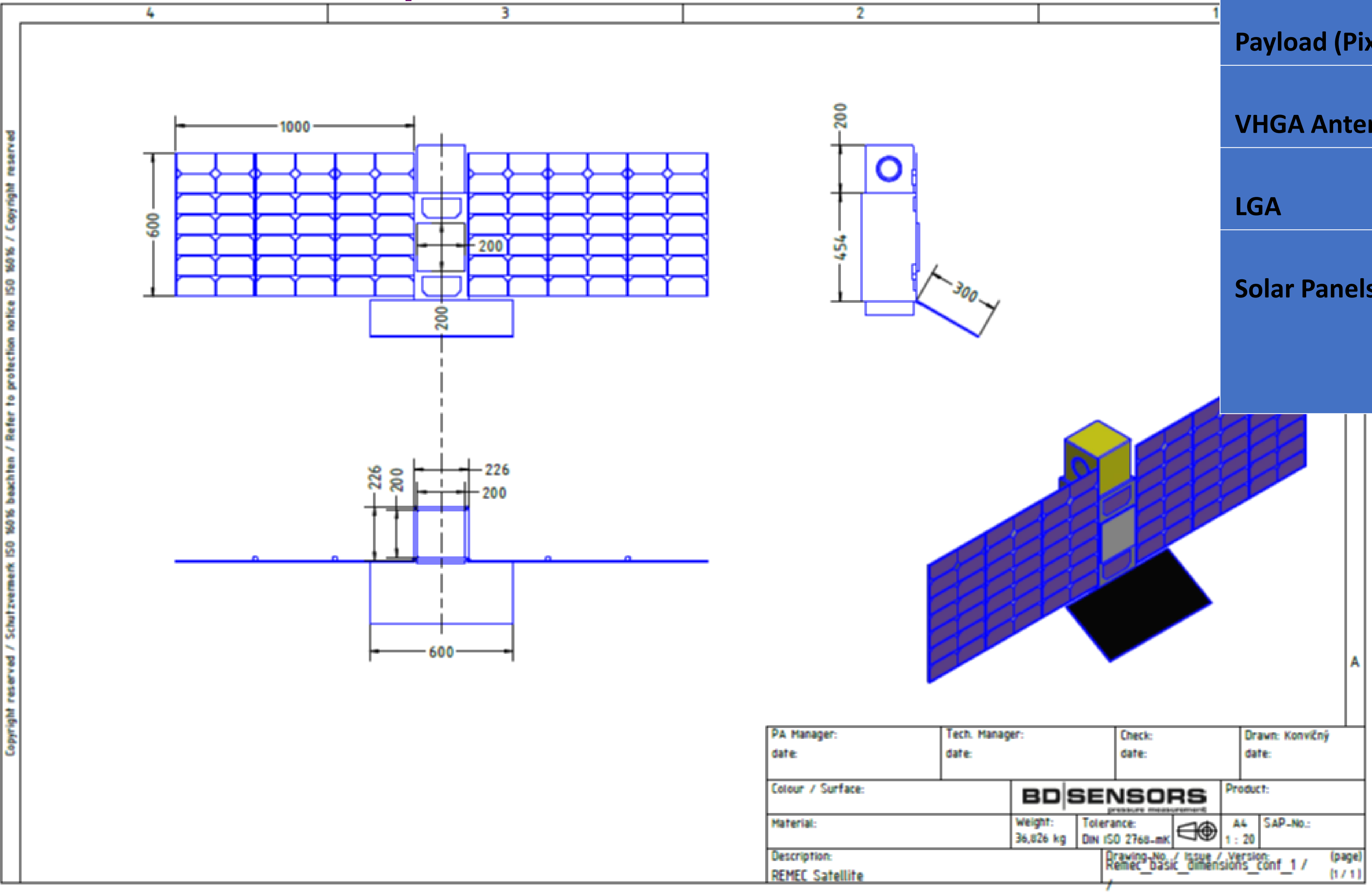
REMEC Spacecraft
architecture, electronics and AOCS accommodation







REMEC Spacecraft dimensions



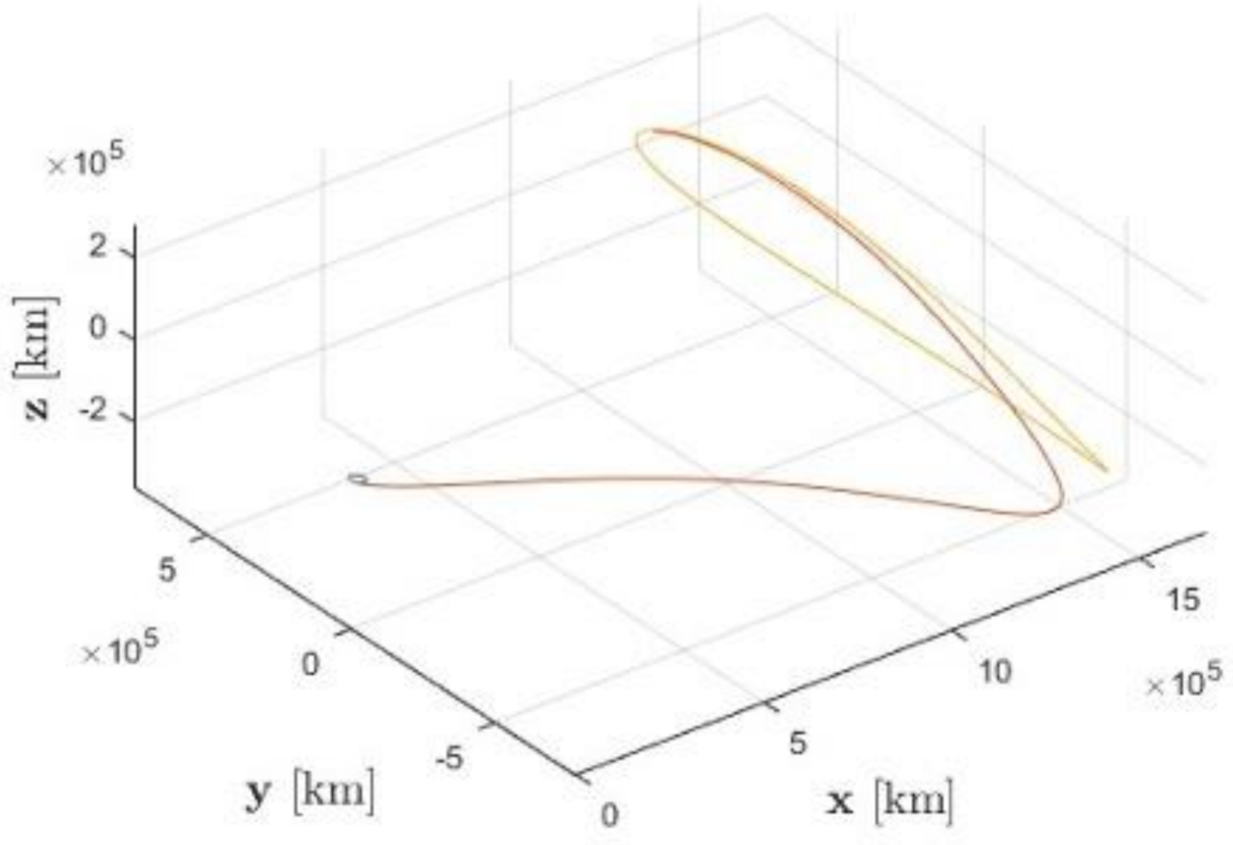
	Dimensions in cm
REMEC PF Body	45.4 x 22.6 x 22.6
Payload (Pix.Pan)	20 x 20 x 20
VHGA Antenna	90 x 30
LGA	20 x 20
Solar Panels	n. 2 wings Wing dimensions: 60x193 for EP conf 60x97 for CP conf

Institute of Experimental and Applied Physics
Czech Technical University in Prague

REMEC Orbits

For the scientific objectives of the mission, the only constraint is to be outside the magnetic field of the Earth. Operationally, we consider most beneficial to use an orbit already exploited in the past, with a low demanding station-keeping effort and with stable thermal conditions. In this regard, Libration Point Orbits (LPO) at L2 both in the Sun-Earth and in the Earth-Moon system can be assumed.

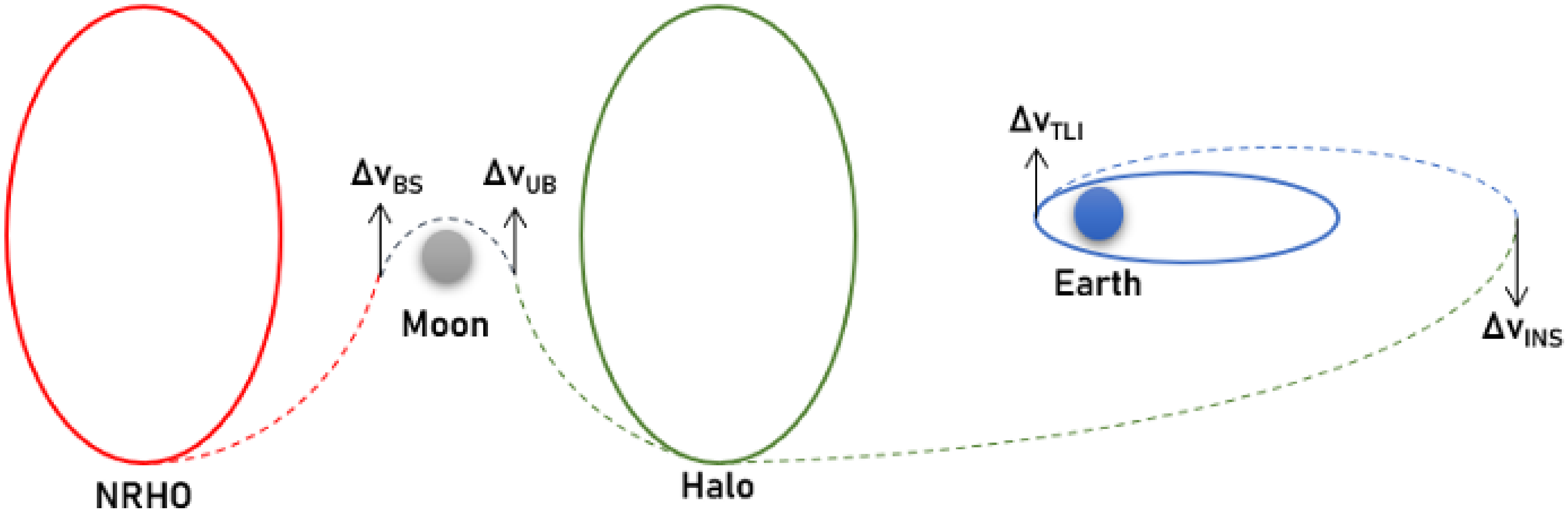
- Baseline - L2 Halo orbit in the Sun-Earth system
  - DeltaV from GTO ~1 km/s
  - Chemical (total REMEC mass ~140 kg) or electrical (total REMEC mass ~83,5 kg) propulsion
  - Ground station INTA or SSC
  - Possible rideshare with ESA Ariel or Plato



REMEC Orbits

Institute of Experimental and Applied Physics
Czech Technical University in Prague

- Backup - NRHO at L2 in the Earth-Moon system
  - DeltaV from GTO ~1.2-1.7 km/s
  - Chemical (total REMEC mass ~184 kg) or electrical (total REMEC mass ~95 kg) propulsion
  - Ground station Panska Ves (Czech Republic)



REMEC

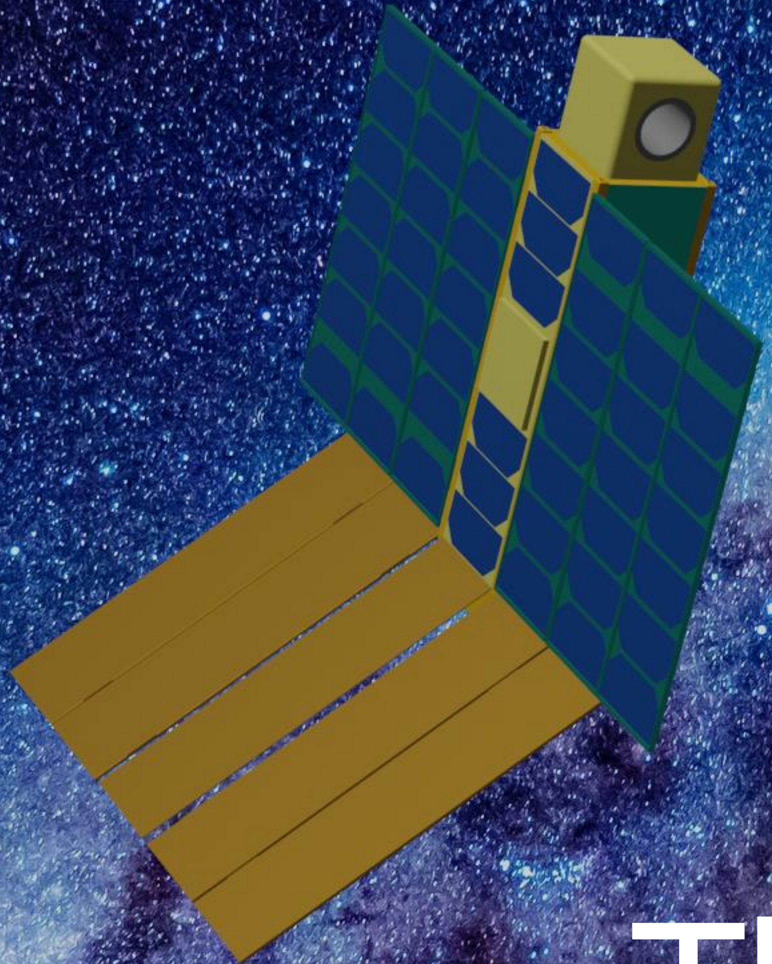
Institute of Experimental and Applied Physics
Czech Technical University in Prague

Launch 2026 – 2029

Mission duration 3 years minimum

- Study of REMEC mission currently past Phase A review
- Pre-selection of mission concepts in September 2023 followed by the implementation phase – 30M Euro budget

- REMEC Challenges:
  - Launcher selection – GTO launch within budget or rideshare
  - TTC in deep space and ground station cost



Thank you

robert.filgas@utef.cvut.cz