European Space Projects with Timepix based detectors

Benedikt Bergmann

on behalf of the
Institute of Experimental and Applied Physics
Czech Technical University in Prague
Outline

1. Van Allen Radiation Belts
2. Instrumentation: why Timepix?

3. Ongoing missions (Low Earth Orbit):
   • SATRAM (Space Application of Timepix Radiation Monitor)
   • VZLUSAT-1
   • RISESAT

4. Current development and Future
   • MIRAM – GOMX-10
   • PAN (Penetrating particle analyser)
   • RADMONSSA
   • iSpace – Timepix on the Moon (exploration)
   • Democritos – Moon, Mars and beyond!
Van Allen radiation belts


\[ E_p < 400 \text{ MeV} \]
\[ E_e < 7 \text{ MeV} \]

Temporal fluctuations of the radiation belts

Radiation belts are not stable in time. They react to Solar Flares, Solar Particle Events, interplanetary shock waves, ...

CRRES*) spacecraft observation of the creation of a new electron radiation belt that filled the slot region between 2 and 3 \( R_E \).

*) Combined Release and Radiation Effects Satellite

Instruments for space weather monitoring

**EPT (Energetic Particle Telescope):**
- Dimensions: 13 x 16 x 21 cm$^3$
- Mass: **4.6 kg**
- Power consumption: **5.6 W**
- **Science class instrument**

**ICARE (Influence of Space Radiation on Advanced Components):**
- Dimensions: 28 x 15.5 x 7.1 cm$^3$
- Mass: **2.4 kg**
- Power consumption: **3 W**

**SREM (Standard Radiation Environment Monitor):**
- Dimensions: 20 x 12 x 10 cm$^3$
- Mass: **2.6 kg**
- Power consumption: **2.5 W**
Why Timepix?

• High dynamic range (energy, count rate)
• Single layer particle discrimination capability (electrons, protons, ions)
• Small dimensions and low mass (< 500 g)
• Wide field of view

Ongoing missions:
• SATRAM on Proba-V (820 km, since 2013)
• VZLUSAT-1 (510 km, since 2017)
• RISEPix on RISESAT (500 km, since 2019)
SATRAM
Space Application of Timepix Radiation Monitor
SATRAM:
Space Application of Timepix Radiation Monitor

- Secondary instrument mounted on ESA Proba-V satellite
- Timepix for the first time in open space
- Power consumption of 2.5 W
- Total mass **380 g** (10 x 7 x 5.5 cm³)
- Launched in 2013

Sensor thickness 300 µm
Web visualization

https://satram.utef.cvut.cz/

HETPs: Highly energetic heavy charged particles (ions) → HZE’s
Timepix SATRAM/ESA Proba-V in Open Space
Quantum imaging detection/monitoring of space radiation

nuclear interactions – spallation reactions
SATRAM: Solar proton event (SPE) in September 2017


- 2 SPE (September 6 and 10)
- 1st event with proton energies < 50 MeV (not seen in SATRAM)
- 2nd event with higher energy protons (> 100 MeV) seen

Reference period (no SPE)  

September 2017 SPE
VZLUSAT-1
VZLUSAT-1

- Timepix detector as part of miniature X-ray telescope onboard VZLUSAT-1 Cubesat since 2017. The first Czech satellite since 1996.

- Over 5,000 exposures, monitoring radiation environment at altitude of 500km

Dose rate 6/2017 – 11/2018

SATRAM
detector life time: ≈ 340 days

VZLUSAT-1
detector life time: ≈ 11 hours
VZLUSAT-1 – Exposure to direct sunlight

- UV-triggered solar imaging not properly working due to problems in the attitude recognition system.
- Sometimes radiation from the sun directly hits the Timepix sensor.
Japanese Rapid International Scientific Experiment Satellite (RISESAT)

RISEPix

- Microsatellite (~50 kg, 50x50x50 cm)
- Development led by Tohoku University and Hokkaido University
RISEPix design – Temporal evolution

- Design changed substantially during development – box dimensions needed to remain identical
- Two-layer Timepix stack for improved particle type sensitivity using coincidence information

~2013

~2015

~2019
RISESAT

- Launched to Sun-synchronous orbit ~500 km in January 2019 by Epsilon 4 rocket from the Uchinoura Space Center (JAXA)
- Mission duration 2-3 years.
Present developments and future projects
Miniatuarized Radiation Monitor (MIRAM)

Development of space radiation monitor with:

- Mass < 0.2 kg
- Power consumption < 1 W
- Price < 50 kEUR

Project duration: 2.5 yr (2018-21)

Minipix TPX-3
- Data rate: 0.5 Mpx/s
- On-board data processing
Institute of Experimental and Applied Physics
Czech Technical University in Prague

Goals of experiments:

- Experimental determination of the Timepix2/3 detector response in a heavy ion beam(s)
- Experimental verification of the low power circuit (LPC) functionality (diode)
- First beam test of the Katherine R/O for Timepix2
- Test of coinciding schemes of LPC and Timepix2/3
- First beam test of the MiniPix in Timepix3 technology (pixel detector part of MIRAM)

Fig. 1: Example of an Fe track as seen in Timepix3 (left: Energy [keV]; right: relative Time of Arrival [ns])

18.09.2019

Fig. 2: Pulse height spectrum measured with the single pad diode

Fig. 3: Picture of the experimental setup in GSI. 4 devices under test are mounted on a movable stage (horizontal and vertical movements, rotation) and were operated remotely.

Tested preliminary MIRAM breadboards in Fe Beam (230 MeV/A, 350 MeV/A, 1,000 MeV/A).

Cluster 51999 nPx=625 E=17000.4 keV
MIRAM in Space: GOMX-5 Cubesat

- MIRAM was chosen as a payload for GOMX-5 Cubesat mission, 12U, 20 kg
- Planned launch in 2021
- Technology demonstration of MIRAM
Other projects

(mini.)PAN (Penetrating Particle Analyzer)
- Magnetic spectrometer (strip, pixel + magnet)
- dE/dx in pixel and strip detectors
- TOF (SiPM) for exit and entry
- Mass ~20 kg, power consumption 20 W

RADMONSSA 'RAdiation Detection and MONitoring Space Suit for Astronauts'
- Development of a Timepix-based radiation detection and monitoring suit for space missions.

To the Moon and beyond ... 

**iSpace:**
- Polar Ice Explorer Mission – mapping water/ice deposits on the Moon surface
- Timepix will be used as a neutron detector onboard robotic lunar rover

**Democritos:**
- Space craft with nuclear propulsion for interplanetary space travel
- Jupiter Moon Europa
- Timepix as scientific payload and for dose monitoring

DLR (German Aerospace Center)

Democritos
EUROPE GOES TO EUROPA ...
and MARS / PHOBOS: about 100 t and 70 m
Acknowledgement

The presented results have been born within research activities cultivated at IEAP CTU in Prague. Their achievement would not be possible without extensive partnerships in the frame of the Medipix2 and 3 collaborations, which have been coordinated through CERN since 1999, with significant contributions of the following colleagues:

P. Burian\textsuperscript{1,4}, R. Filgas\textsuperscript{1}, St. Gohl\textsuperscript{1}, C. Granja\textsuperscript{1,2}, M. Holík\textsuperscript{1,4}, J. Jakubek\textsuperscript{1,2}, F. Janssen\textsuperscript{6}, P. Manek\textsuperscript{1}, M. Malich\textsuperscript{1}, A. Owens\textsuperscript{3}, M. Platkevic\textsuperscript{1}, S. Pospíšil\textsuperscript{1}, S. Polansky\textsuperscript{1}, A. Smetana\textsuperscript{1}, D. Turecek\textsuperscript{1}, H. Waage\textsuperscript{1}, Z. Vykydal\textsuperscript{1}, X. Wu\textsuperscript{5} ...

\textsuperscript{1} Institute of Experimental and Applied Physics, CTU in Prague, Czech Republic
\textsuperscript{2} Advacam s.r.o., Prague, Czech Republic
\textsuperscript{3} European Space Agency, Nordwijk, Netherlands
\textsuperscript{4} University of West Bohemia, Pilsen, Czech Republic
\textsuperscript{5} Departement de physique nucleaire et corpusculaire, Universite de Geneve
\textsuperscript{6} DLR (Deutsches Zentrum für Luft- und Raumfahrt, German Aerospace Center)
References


BACK UP
Ongoing space missions

Two Timepix detectors (RISEPix prototypes) as parts of X-ray telescopes onboard NASA sounding rocket. Collaboration with Penn State University, launched April 2018.
Ongoing space missions

Two Timepix detectors (RISEPix prototypes) as parts of X-ray telescopes onboard NASA sounding rocket. Collaboration with Penn State University, launched April 2018.
SATRAM: Space Application of Timepix Radiation Monitor

- Secondary instrument mounted on ESA Proba-V satellite
- Timepix for the first time in open space
- Power consumption of 2.5 W
- Total mass 380 g (10 x 7 x 5.5 cm$^3$)
- Radiation tolerance 1 Mrad for the sensor, 100 krad for the electronics
- Timepix data are correlated with satellite data
- Communication channel allows download up to 10 frames/min
- SATRAM is a platform technology demonstrator
SATRAM

Proba-V

- Minisatellite (158 kg)
- Observe worldwide vegetation
- Altitude ~ 820 km (LEO)
- Period 101.21 minutes
- Latitude 80° N/S
- Launched March 7, 2013
SATRAM: Measured stopping power spectrum

- $e^-$ dominating
- mainly protons
- heavier ions

Institute of Experimental and Applied Physics
Czech Technical University in Prague

Medipix Symposium - Benedikt Bergmann
18.09.2019
SATRAM: Cluster rate distribution

- Cuts on cluster properties (height, linearity, stopping power) for separation of protons and electrons (values deduced from simulation)
- For the analysis only frames with an occupancy of less than 20% were selected