Characterization and particle visualization of mixed radiation fields in space

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Research carried out in frame of the CERN Medipix Collaboration
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IEAP CTU Prague + Pixel detectors Medipix/Timepix: Space applications: Projects/Payloads

- **Space**
  - **Timepix SATRAM payload** for ESA Proba-V satellite/CSRC: launch 2Q 2013
  - Online **miniaturized quantum dosimeter** for ISS/NASA: deployed 3Q 2012
  - **Pixel detector payload** for ESA BEXUS Ballon / Ch. Univ.: 2011
  - **Particle & Neutron Tracker** for ESA Lunar Lander (2018): *mission cancelled*
  - **Micro-tracker** & **Wide FoV particle telescope** for ISS/ESA Columbus Module: *proposed 2013*

- **Mission-related services**
  - **Neutron Facilities** in the Czech Republic for **Calibration and Testing** of Neutron-Sensitive Devices
  - **Portable Calibration Gamma-Ray Source**
  - VdG accelerator: **tunable ion + monoenergetic neutron source**: radiation detector testing
Timepix SATRAM – ESA Proba V satellite

- SATRAM Space Application of Timepix Radiation Monitor
- goal/task: characterization of mixed radiation field including neutrons in orbit/space + radiation monitoring
Timepix
SATRAM – ESA Proba V satellite

ESA’s PROBA-V satellite (a), payload external accommodation on the bottom side (b), payload detail (c)

Assembled SATRAM payload (photo from top)
Cluster analysis software with examples of the different recognized cluster shapes.

Timepix response to mixed radiation ($\alpha$, p, e, X-rays)
Timepix
SATRAM – ESA Proba V satellite

ESA Bulletin No. 153, Feb 2013, pg. 19

http://esamultimedia.esa.int/multimedia/publications/ESA-Bulletin-153/

ESA Vega rocket, launched 7 May 2013

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Online miniaturized Timepix Quantum Dosimeter for the International Space Station (ISS)

5 independent detectors launched in space since 3Q 2012, all running, taking data

HW + Know-how + SW

1,4 cm

Database

Doserate uSv/h Total Dose mSv Status

Running

Start Stop

0.229 0.050

Time Scale: 24 Hours

Graph
Timepix detector in the highly miniaturized LITE architecture (a) customized for the ISS (b) as deployed with an on-board laptop via USB port (c) in a NASA Module at the ISS (d). Work done in cooperation with NASA and the University of Houston.
Online miniaturized Timepix Quantum Dosimeter
Single particle visualization & tracking

Frame containing 400 MeV 56Fe, 85°, measured at HIMAC, Japan

Cluster analysis algorithm is successfully working in ATLAS-MPX network
Online miniaturized Timepix Quantum Dosimeter
Single particle determination of linear energy transfer LET

\[ l = \text{Length} - \text{Width} \]
\[ L = \sqrt{l^2 + 300^2} \]
\[ \text{LET} = \frac{E}{L} \]
Timepix at ISS: High sensitivity radiation monitoring

Time evolution of flux of ionizing particles onboard ISS
In addition to the intrinsic 2D spatial information, detailed analysis of the characteristic tracks can give also the angle of incidence to the plane of the pixelated sensor.

Custom-made plug-in SW packages automatically distinguishes and evaluates single particles and determines their 3D direction.
Timepix particle µ-tracker + RISESAT
Rapid International Scientific Experimental Satellite
RISESAT

Timepix particle μ-tracker particle telescope

Particle micro-tracker of a stack of several Timepix detector chipboards with common motherboard and single integrated readout interface (left). Illustration of principle of particle telescope on two pixelated sensors determining the direction of trajectory of the particles (middle) providing direction information and spatial visualization of the origin of the particles (right).

Timepix μ-tracker for the RISESAT satellite consisting of two separate devices with synchronized operation. Spacewire prototype of one device (a), payload engineering model (b) and its position in the 50 Kg micro-satellite (c).
RISESAT
Rapid International Experimental Satellite

**Specification**

<table>
<thead>
<tr>
<th><strong>Size and weight</strong></th>
<th><strong>Launch cost:</strong> $1 \text{ g} = 100 \€ \rightarrow 1 \text{ Kg} = 100 \text{k}€</th>
</tr>
</thead>
<tbody>
<tr>
<td>size</td>
<td>Smaller than W 500 x D 500 x H 500 mm</td>
</tr>
<tr>
<td>weight</td>
<td>less than 55 kg</td>
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</table>

<table>
<thead>
<tr>
<th><strong>Orbit</strong></th>
<th><strong>Launch cost:</strong> $1 \text{ g} = 100 \€ \rightarrow 1 \text{ Kg} = 100 \text{k}€</th>
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<tbody>
<tr>
<td>type</td>
<td>Sun Synchronous Orbit</td>
</tr>
<tr>
<td>local time</td>
<td>9:00–15:00 (planned LTDN 9:00)</td>
</tr>
<tr>
<td>altitude</td>
<td>between 500 – 900 km</td>
</tr>
<tr>
<td>inclination</td>
<td>approx. 98 deg</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Attitude determination and control</strong></th>
<th><strong>Launch cost:</strong> $1 \text{ g} = 100 \€ \rightarrow 1 \text{ Kg} = 100 \text{k}€</th>
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<tbody>
<tr>
<td>method</td>
<td>3-axis stabilization</td>
</tr>
<tr>
<td>pointing accuracy</td>
<td>$&lt; 0.1^\circ$ (Reqs.), $&lt; 0.01^\circ$ (Objectives)</td>
</tr>
<tr>
<td>pointing stability</td>
<td>$6''/s$</td>
</tr>
<tr>
<td>sensors</td>
<td>star sensor (2), FOG (3-axes),</td>
</tr>
<tr>
<td></td>
<td>magnetometer (3-axes), GPS receiver (1),</td>
</tr>
<tr>
<td></td>
<td>course and accurate sun sensors (4π)</td>
</tr>
<tr>
<td>actuators</td>
<td>reaction wheels (4)</td>
</tr>
<tr>
<td></td>
<td>magnetic torquers (3-axes)</td>
</tr>
</tbody>
</table>

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<thead>
<tr>
<th><strong>Power supply</strong></th>
<th><strong>Launch cost:</strong> $1 \text{ g} = 100 \€ \rightarrow 1 \text{ Kg} = 100 \text{k}€</th>
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</thead>
<tbody>
<tr>
<td>solar cells</td>
<td>GaAs multijunction cell</td>
</tr>
<tr>
<td></td>
<td>10 series x 5 parallel x 3 panels</td>
</tr>
<tr>
<td></td>
<td>(Deployable panels and one body panel)</td>
</tr>
<tr>
<td></td>
<td>10 series x 1 parallel + 10 series x 2 parallel</td>
</tr>
<tr>
<td>battery unit</td>
<td>9 series x 2 parallel NiMH (3.7Ah, 18V)</td>
</tr>
<tr>
<td>max. power generation</td>
<td>$&gt; 100 \text{ W}$</td>
</tr>
<tr>
<td>max. power consumption</td>
<td>$&gt; 50 \text{ W}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Communication</strong></th>
<th><strong>Launch cost:</strong> $1 \text{ g} = 100 \€ \rightarrow 1 \text{ Kg} = 100 \text{k}€</th>
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</thead>
<tbody>
<tr>
<td>command uplink</td>
<td>UHF, &lt;2400bps at Sendai station, Japan</td>
</tr>
<tr>
<td>HK downlink</td>
<td>S-Band, 0.1W, 38400bps</td>
</tr>
<tr>
<td></td>
<td>main: Sendai station, Japan</td>
</tr>
<tr>
<td></td>
<td>sub: Kiruna station, Sweden</td>
</tr>
<tr>
<td></td>
<td>sub: Thai station, Thai</td>
</tr>
<tr>
<td>Mission Data downlink</td>
<td>X-band, max. 2.45Mbps</td>
</tr>
</tbody>
</table>

Launch configuration

After panel deployment
Cyclone - 4 Launch Vehicle

At this moment, the Ukrainian Yuzhnoye engineering office is working on the development of Cyclone-4, a new Cyclone series vehicle to be commercialized exclusively by ACS. The Cyclone series of launch vehicles is one of the most successful series of rockets ever developed, with only six failures in 226 launches. The Cyclone series pre-launch operations are automatic, which increases launch safety, and reduces the personnel necessary for the launch operation.
RISESAT satellite

Timepix µ-tracker payload

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RISESAT + Timepix particle tracker
Particle visualization + telescope

Radiation sensitive Timepix chip (14 x 14 mm²)

EM payload

Visualization of direction of energetic particles with single layer Timepix

RISESAT satellite with Timepix payload for particle telescope

Enhanced visualization of direction of energetic particles with two-layer Timepix → particle telescope
Timepix Particle tracker
Energetic radiation: Atmosphere & Hadron Therapy

Registration of atmospheric cosmic rays at 10 km (a) and 221 MeV synchrotron protons at grazing angle (b) by Timepix. The images correspond to the entire sensor area (14 mm × 14 mm) which consists of an array of 256 × 256 sq. pixels of pitch size 55 μm. The white depth is a measure of the energy deposited per pixel. Single particles are detected and distinguished by their characteristic tracks resolving electrons (fast, slow, delta), muons and energetic and recoiled ions. Directional information can be obtained with μm resolution.
Medipix2 + Balloon flight (BEXUS)

Rack with electronics

Vacuum testing of all components

Complete freezer test
Medipix2
Balloon flight (BEXUS)

Payload containing two Timepix detectors

Experiment and detectors after recovery
Detection of cosmic rays in the stratosphere: Medipix2

Jaroslav Urbar, IEAP CTU, Ch. Univ. Prague
Medipix2
Balloon flight (BEXUS)

Detection of cosmic rays at the stratosphere: Timepix
Medipix2
Airline flight (12 km altitude)
Timepix based radiation micro-tracker

**ESA lunar lander (2018)**

Payload proposal submitted 2012, mission cancelled end 2012
Timepix based radiation telescope/μ-tracker
ISS/ESA Columbus Module (proposal 2013)

Timepix stack particle micro-telescope (phase I) for the ESA Columbus Module at the ISS. The directional distribution of energetic charged particles will be produced in a wide field-of-view.
IEAP CTU Prague + Pixel detectors Medipix/Timepix: SSA: Space weather

Detailed characterization of mixed radiation fields

- p, α, ions, e−, muons, neutrons, X-rays: particle species resolving power
- Detection, Radiation Monitoring, Quantum-Dosimetry*
- Tracking, Visualization, Directional information (particle telescope)
- Spectrometry, Coincidence spectroscopy, fragmentation, ...

- Single-quantum sensitivity, noiseless detection, high signal-to-noise ratio
- Wide dynamic range (particle flux, particle energies, particle types)
- Linear-energy transfer (LET) measurement, low level threshold ≈ 4 keV
- High spatial resolution (sub-pixel resolution ≈ µm)
- Directional angular resolution: ≈ 1° (single sensor), ≈ 0.1° (stack telescope)
- Absolute/wide field-of-view: 4π (no collimators, full sky mapping)

- Integrated electronics, compact/miniaturized size, low weight, low power

* IEAP CTU Prague patent
Pixel detector Timepix: Tracking visualization: Directional information

20 MeV electron: track + angular determination of IN/OUT trajectory vectors
IEAP CTU in Prague

R&D Radiation Detectors, Radiation Spectroscopy, 2.5 MeV VdG ion accelerator

Clean room (a), X-ray micro-tomography unit and X-ray pencil beam test bench (b), Van de Graaff accelerator and beam guides (c).
Space applications

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