Energetic particle flux variations detected at low altitudes by Space Application of Timepix Radiation Monitor (SATRAM)

St. Gohl$^{12}$, Frantisek Nemec$^2$, Benedikt Bergmann$^1$, Stanislav Pospisil$^1$

$^1$Institute of Experimental and Applied Physics, Czech Technical University in Prague  
$^2$Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic

EGU 2020 - 04./08. May 2020
The Timepix detector

- Developed within the Medipix collaboration at CERN [1]
- Features:
  - $256 \times 256$ pixels
  - $55 \, \mu m$ pixel pitch
  - 14 bits/pixel
  - Minimal threshold: 3.5 keV
- Bump-bonded to readout chip containing in each pixel cell: amplifier, discriminator, digital counter or ADC or Timer
- Single layer particle tracking capability
- Typical sensor materials: Si, GaAs:Cr, CdTe, CZT
Charges, that are created by ionizing particles hitting the sensor, are separated by the applied bias and create signals at the cathode. A clock is running to measure the time a signal stays above certain threshold (ToT). Through calibration the deposited energy can be determined [2]. Another mode is the ToA, measuring the exact time of the particle impact. Modes cannot be used simultaneously in one pixel.
Proba-V

- SATRAM attached to Proba-V prior start (red circle) [3, 4, 5]
- Altitude = 820 km
- Inclination = 98.8°
- Sun-synchronous orbit
- in orbit since May 2013

Energetic particle flux variations detected at low altitudes by Space Application of Timepix Radiation Monitor (SATRAM)
Space Application of Timepix RAdiation Monitor (SATRAM) - Technical details

- Power consumption: 2.5W
- Total mass: 380g (107x70x55 mm)
- Radiation tolerance 1 Mrad for the sensor, 100 krad for the electronics
- SATRAM is platform technology demonstrator

3 frame exposure times: 20s, 0.2s and 0.002s
full information in [6]
Van Allen Belts

Proba-V orbits Earth at the inner edge of the inner belt.

Inner belt:
- Altitude: 1.000 - 6.000 km
- Electrons: 0.1 - 7 MeV
- Flux: $10^8$ cm$^{-2}$ s$^{-1}$
- Protons: 5 MeV - 400 MeV
- Flux: $10^4$ cm$^{-2}$ s$^{-1}$

Outer belt:
- Altitude: 13.000 - 60.000 km
- Electrons: 0.1 - 10 MeV
- Flux: $10^7$ cm$^{-2}$ s$^{-1}$

Due to the slight offset of the belts from Earth's geometric center, the inner Van Allen belt makes its closest approach to the surface at the South Atlantic Anomaly.
Spectra expected in SATRAM orbit. Both spectra were created with the SPENVIS online tool [7] by using the AP-8-MIN and Ae-8-MIN models [8, 9]. Electrons and protons left of the red line do not penetrate the aluminium cover of the SATRAM device and are therefore not measured.
Dose rate

Measured average dose rate for the years 2015 to 2018. The South Atlantic Anomaly (SAA) is clearly visible as well as the higher radiation near the poles.

\[
\frac{dD}{dt} = \sum_{i=0}^{\#\text{pixel}} \frac{E_i}{m_{\text{sensor}} \cdot dt} \quad (1)
\]
Dose rate

Example frame of radiation in an area with low dose rate. The small particle track (1 to 3 pixel) are electrons or X-rays. Long thin tracks represent electrons as well. Roundish tracks with 5 to 10 pixels represent protons hitting the sensor perpendicular. The slightly thicker track in the top right is also a proton. The very long long track is minimum ionizing particle (mip).

Dose rate:

\[
\frac{dD}{dt} = \sum_{i=0}^{\#pixel} \frac{E_i}{m_{sensor} \cdot dt}
\]  

Energetic particle flux variations detected at low altitudes by Space Application of Timepix Radiation Monitor (SATRAM)
Example frame for the polar region. Electrons produce primarily curly tracks which are very thin (1 pixel wide). Lots of them are visible in this frame. The free rectangular area in the bottom left are masked pixels. They became noisy right after the start and are not considered for the analysis.

Dose rate:

\[
\frac{dD}{dt} = \sum_{i=0}^{\text{#pixel}} \frac{E_i}{m_{\text{sensor}} \cdot dt}
\]  

(3)
Example frame for the SAA. The high flux in this region causes a high occupancy in the frame. Lots of proton particles are visible in between (straight tracks 2 to 4 pixels wide). They show the same directionality. The free rectangular area in the bottom left are masked pixels. They became noisy right after the start and are not considered for the analysis.

Dose rate:

\[
\frac{dD}{dt} = \sum_{i=0}^{\#\text{pixel}} \frac{E_i}{m_{\text{sensor}} \cdot dt}
\]  

(4)
Monthly dose rate associated with the respective time of the year. The peaks in the monthly dose rate can be associated with solar events which cause a geomagnetic storm.
Solar Proton Event (SPE) in September 2017

- 2 Solar Proton Events, Sep. 6th and 10th
- 1st event with rather low proton energy ($< 50$ MeV)
- 2nd event with protons $> 100$ MeV
- SATRAM sees clearly 2nd event

Energetic particle flux variations detected at low altitudes by Space Application of Timepix Radiation Monitor (SATRAM)
(a) Measured flux from 04.06. to 16.06.2017 for comparison. No SPE or other events were seen during this time.

(b) Measured flux from 04.09. to 16.09.2017.

The picture on the right side shows the increased dose rate for the time of the event compared to a quiet period on the left.
Cluster shape [10], cluster height and energy loss are used to distinguish between particle species [11].

- $e^-$, X-ray: height $< 300$ keV
- $e^-$: height $< 300$ keV
- Proton: height $> 300$ keV
- $e^-$: $-\frac{dE}{dx} < 10 \frac{MeV cm^2}{g}$
- Proton: $-\frac{dE}{dx} > 10 \frac{MeV cm^2}{g}$
- Same as heavy blob
- $e^-$: $-\frac{dE}{dx} < 10 \frac{MeV cm^2}{g}$
- Proton: $-\frac{dE}{dx} > 10 \frac{MeV cm^2}{g}$

References

St. Gohl IEAP, MFF

Energetic particle flux variations detected at low altitudes by Space Application of Timepix Radiation Monitor (SATRAM)
Energy loss spectrum

- LET spectrum from data
- Time period: 01.01.2015 to 31.12.2017
- Includes electrons, MIP’s, protons and heavier ions
- From simulation: electrons no higher LET than 10 MeV, protons around 100 MeV (black lines)

St. Gohl
IEAP, MFF

Energetic particle flux variations detected at low altitudes by Space Application of Timepix Radiation Monitor (SATRAM)
Energy loss spectrum

First region 0 to 10 MeV
Shows electrons (curly tracks) and mips (long straight tracks)
Energy loss spectrum

Second region 10 to 100 MeV

- Shows typical proton tracks with different angles
Energy loss spectrum

Last region > 100 MeV

- Shows heavy ions which deposit a lot of energy
- some tracks show secondary electrons emitting from the main track
- small tracks represent protons
Separation of electrons and protons

(a) Dominated by electrons

(b) Dominated by protons

Frames with less than 20% occupancy were selected to reduce overlapping tracks which causes an underestimation of the flux in the center of the SAA.

(c) Dominated by Ions
Revisited the data for analysis of dynamic events in the magnetosphere.

Geomagnetic storms seen by SATRAM in the years 2015 to 2018.

Selection criteria: Dst < -100nT; set as 0-point in the time axis.

Data from 1 day prior event and 6 days after.

9 storms selected plotted on top of each other.
Interplanetary shocks seen by SATRAM in the year 2017

Events chosen from Harvard-Smithonian Center for Astrophysics

Data from 1 day prior event and 6 days after

10 shocks selected and plotted on top of each other

Interplanetary Shocks

Relative time [h]

Interplanetary shocks seen by SATRAM in the year 2017

Events chosen from Harvard-Smithonian Center for Astrophysics

Data from 1 day prior event and 6 days after

10 shocks selected and plotted on top of each other
Summary:

- SATRAM is in space for 7 years
- First successful demonstration of a Timepix working in open space
- Measurement of dose rates depending on orbital position
- Development of a strategy for particle identification
- Separation of electron, proton or ion dominated fluxes
- Start of a new analysis of space weather observed by SATRAM

Future plans:

- Further analysis on space weather events and include data from other spacecraft (e.g. DEMETER, TARANIS)
- Application of machine learning tools for better separation of electrons and protons


**ESA Mission overview.** 2013. URL: http://www.esa.int/Our_Activities/Technology/Proba_Missions/Proba-V_carrying_radiation_detector_from_CERN_to_space.

**SATRAM aboard Proba-V.** 2013. URL: http://www.esa.int/spaceinimages/Images/2013/04/SATRAM_payload_aboard_Proba-V.


