Timepix detectors in Space: From radiation monitoring in low earth orbit to astroparticle physics

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Hybrid pixel detectors (HPD) of Timepix [1,2] technology have become increasingly interesting for space applications. While up to date, common space radiation monitors rely on silicon diodes, achieving particle (mainly electron and proton) separation by pulse-height analysis, detector stacking, shielding or electron removal by a magnetic field, the key advantage of HPDs is that, in addition to the energy deposition measurement, particle signatures in the sensor are seen as tracks with a rich set of features. These track characteristics can be exploited for identification of particle type, energy, and its trajectory. Determining these pieces of information on a single layer bypasses the need for sensor stacking or complex shielding geometries, so that HPD based space radiation devices provide science-class data with a large field of view at an order of magnitude lower weight and approximately half of the power consumption compared with commonly used space radiation monitors.

The first Timepix (256 x 256 pixels, 55 µm pitch) used in open space is SATRAM (Space Application of Timepix Radiation Monitor), attached to the Proba-V satellite launched to low earth orbit (LEO, 820 km, sun-synchronous) in 2013. Up to now, 9 years after its launch, it provides data for mapping out the fluxes of electrons and protons trapped in the Van-Allen radiation belts [3]. Figure 1 shows the in-orbit map of the ionizing dose rate and illustrates the different radiation fields in polar horn region (Fig. 1b), the South Atlantic Anomaly (Fig. 1c) and in a region shielded by Earth's magnetic field (Fig. 1d) as measured with SATRAM. Noiseless detection of individual particles allows to detect even rare signatures of highly ionizing events.
In the present contribution, I will discuss different data analysis methodology, relying on track feature analysis, novel machine learning approaches (e.g. [5]) and using statistical interpolation.

Based on the success of SATRAM, advanced and miniaturized space radiation monitors based on Timepix3 [2] and Timepix2 [4] technology have been developed for the European Space Agency (ESA). These will be flown on the GOMX-5 mission (launch in 2023) and used within the European Space Radiation Array. Large area Timepix3 detectors (512 x 512 pixels, 55 µm pitch) were developed for the demonstrator of the penetrating particle analyzer [5] (mini.PAN), a compact magnetic spectrometer (MS) to precisely measure the cosmic ray flux, composition, spectral characteristics and directions. Mini.PAN employs position-sensitive (pixel and strip) detectors and (fast) scintillators to infer the particle type and velocity of GeV particles (and antiparticles) passing through the instrument's magnetic field by measuring their bending angles, charge deposition and time-of-flight. It will measure the properties of cosmic rays in the 100MeV/n - 20GeV/n energy range in deep space with unprecedented accuracy, providing novel results to investigate the mechanisms of origin, acceleration and propagation of galactic cosmic rays and of solar energetic particles, and producing unique information for solar system exploration missions. We will describe the mini.PAN development status, challenges imposed by the space environment, and outline how a MS purely relying on latest generation hybrid pixel detectors could simply instrument design, reduce the PAN mass budget and provide high rate capabilities.

References:

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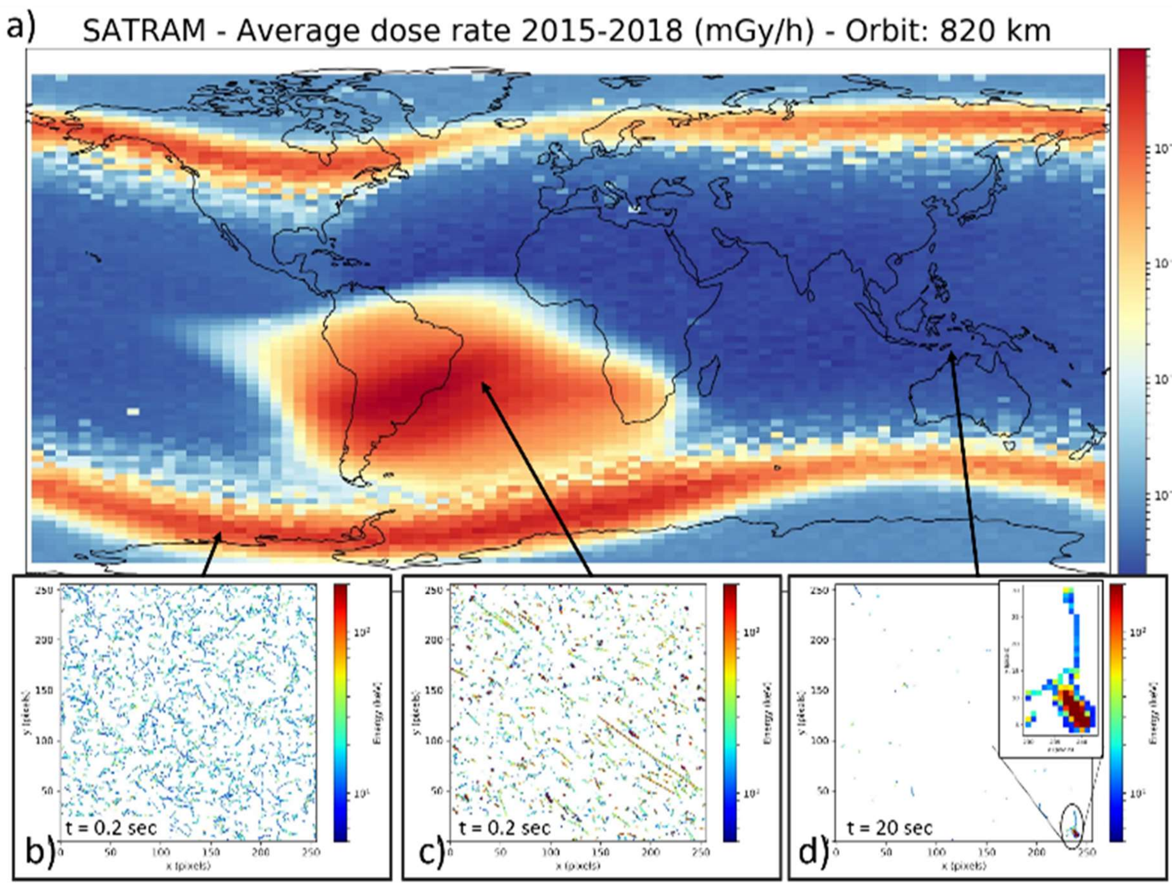

Figure. 1. (a) Average ionizing dose rates measured with SATRAM from 2015-2018; (b) Snapshot of the radiation field found in the polar horn region dominated by electrons; (c) Mixed electron and proton field in the South Atlantic Anomaly; (d) Frame with a highly ionizing particle found in the region out of the radiation belts, where fluxes are much lower due to the screening effect of the magnetic field.

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