A stratospheric and satellite CubeSat format probe capable of detecting relativistic runaway electron avalanches

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Facilities and advanced detector technologies

Abstract. In planetary atmospheres, runaway electron avalanches could happen due to large scale electric fields, which accelerate electrons to energies about 0,1 – 10 MeV. This phenomenon is not fully understood. Nowadays, most of the satellite data is obtained on low orbits. However, runaway breakdown can also occur at altitudes of less than 30 km. In this case, most of the radiation is scattered without reaching the satellites on high orbits. The formation of charged particles in the atmosphere can affect the results of other experiments. It is important to have the most proper model of this phenomenon. Project goal is to create a stratospheric CubeSat format probe capable of collecting data about these events at an altitude of ~ 30 km and above. The purpose of the experiment is to observe changes in the fluxes of both high-energy electrons and radiation, as well as an analysis of possible correlations of the measured parameters. We developed a concept of the probe, performed structural analysis of the CubeSat CAD model, and created a detector prototype, consisting of a thick polystyrene scintillation counter, wrapped with mylar, and connected to two SiPM SensL MicroSB-30035-X13 to collect statistics.

Introduction

Nowadays, most of the satellite data is obtained on low orbits. The formation of charged particles in the atmosphere can affect the results of numerous experiments [1, 2]. Therefore, it is important to fully understand how beams of charged particles interact using the qualitative profile characteristics of the electron flux revealed as a result of data processing.

Interest in this area increased significantly after it was presumed that runaway breakdown (avalanche growth of high-energy (0.1 – 10 MeV) electrons) can occur due to the relativistic particles interaction peculiarities with the nuclei of atoms in the air, releasing their energy in the form of intense radiation in the hard part of the spectrum – emitting TGF (Terrestrial Gamma-ray Flashes) photons [1,3].

Recent observations have shown that breakdown can also occur at altitudes of less than 30 km. In this case, most of the radiation is scattered without reaching the satellites on high orbits [1]. Therefore, the creation of a probe for detecting these events is very relevant.

We consider two possible design choices of the CubeSat format probe prototype capable of detecting these events (for function in the stratosphere or on low orbits). The essence of the experiment is to observe the changes in relativistic electron fluxes, which presumably are the sources of TGF.

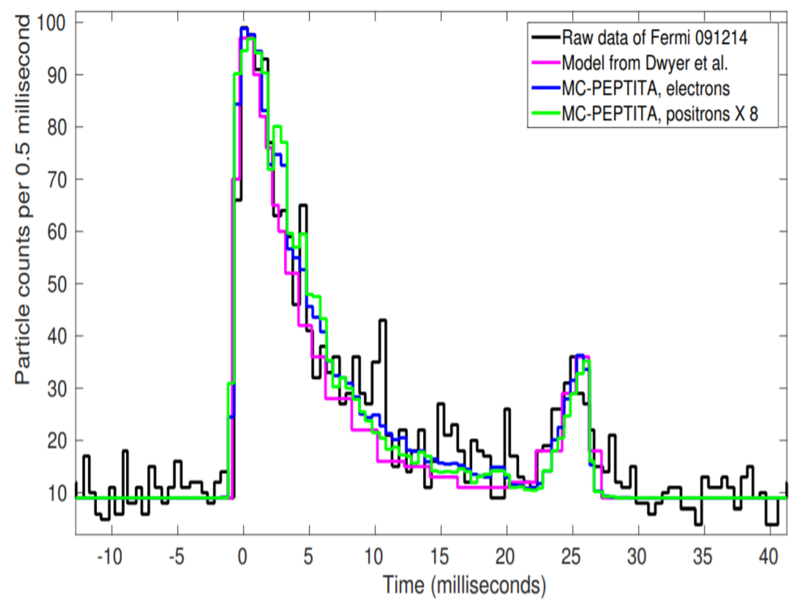
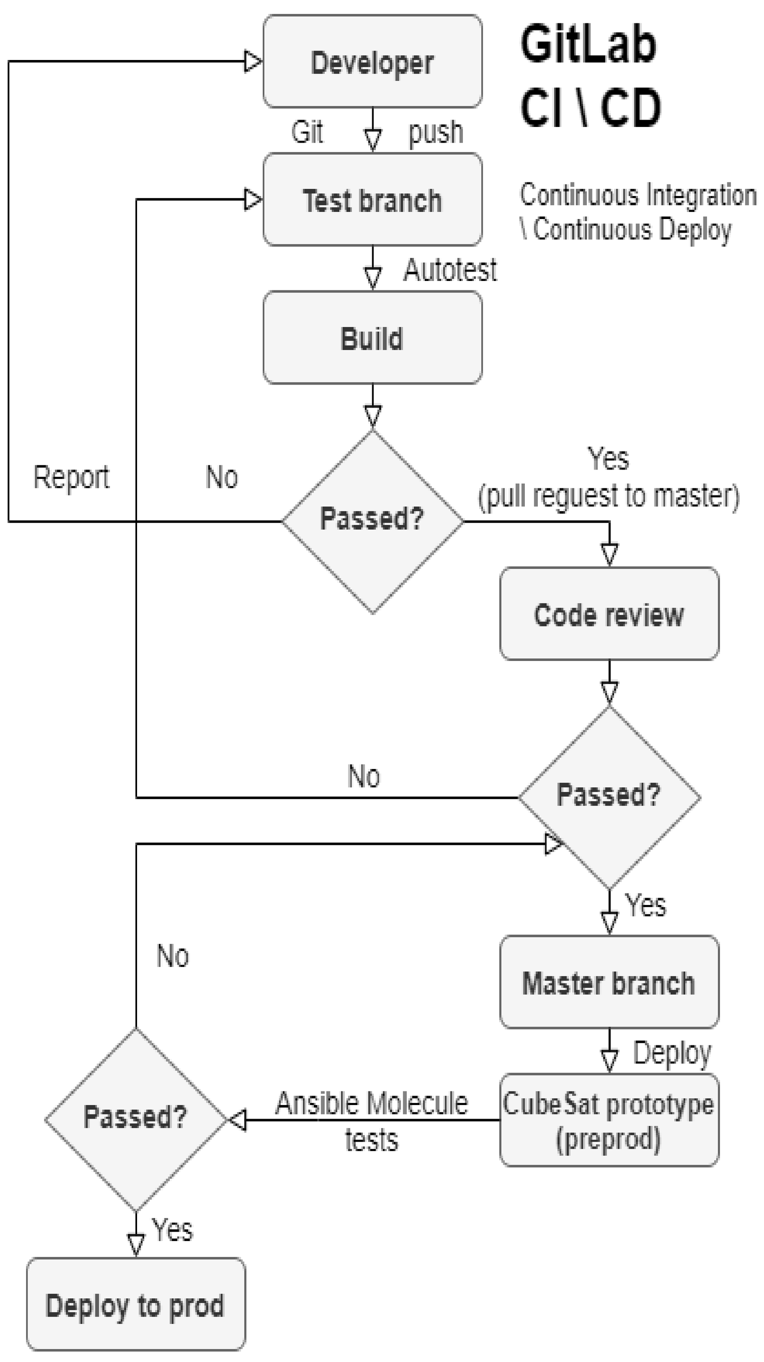


Figure 7. An example of the time profile of TGF X-rays in the range E> 300 keV according to FERMI / GBM data. The time scales of changes in the intensity of electron fluxes are similar. Adapted from [3].



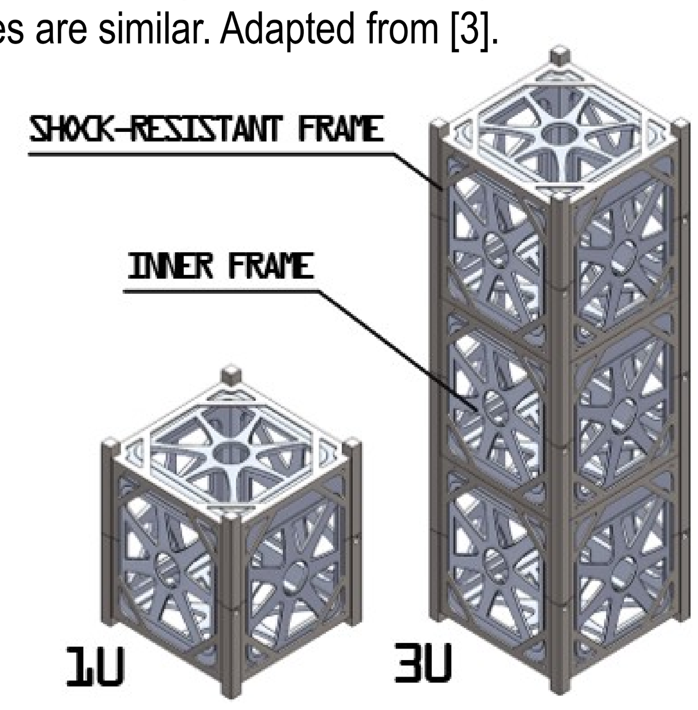


Figure 8. GitLab CI \ CD pipeline (Continuous Integration \ Continuous Deploy).

Figure 9. Conceptual design of the CubeSat format probe structure.

CubeSat format probe concept

During development of the CubeSat format probe conceptual design, two configuration options were considered for the mission (Fig. 9). The body of the device consists of a shock-resistant outer frame and an inner frame. Shielding or solar panels can be easily placed between them, which makes it possible to use the probe design in various configurations. This design was created to protect electronics from extreme conditions during a stratospheric balloon launch and from stress out of the subsequent landing.

Results

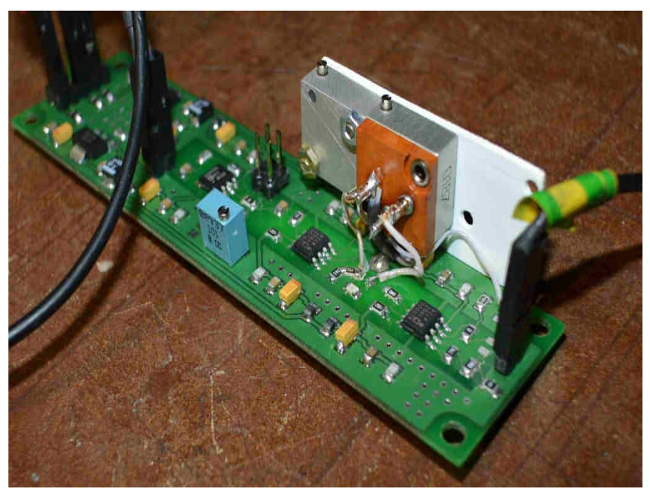
In this project, we present the detector prototype for a CubeSat application, as well as development and two possible design versions of a CubeSat format probe. Furthermore, we are trying to show that using DevOps practices and tools in the CubeSat format probe software development increases the effectiveness of delivering application patches at high velocity: evolving and improving software at a faster pace than while using traditional software development practices.

By analyzing the data of events recorded with a scintillation detector, it is possible to study the time resolution of the charged particles interaction beam dynamics, since they correspond to the characteristic durations of statistically significant fluctuations on these time resolution profiles.

The results of detector testing calibrations showed that a developed detector (similar to the beam monitor detectors used in the calibrations of the GAMMA-400 gamma-telescope [5, 6]) can successfully register electron fluxes causing TGF (both secondary cosmic rays and those arising during breakdown).

Experimental Setup

Fig. 1 shows the detector prototype, consisting of a 3 mm thick polystyrene scintillation counter with dimensions 15×15 mm^2 wrapped with mylar and connected with silicone grease BC-630 with two parallel silicon photomultipliers (SiPM) with an area of 3×3 mm^2 (SensL MicroSB-30035-X13 [4]), which was developed similar to charged particle detectors used in the beam monitor for calibrations of the GAMMA-400 gamma-telescope [5, 6]. The signals from each pair of silicon photomultipliers (SiPMs) are amplified by four two-stage high-speed shaper-preamplifiers (Fig. 2) based on Analog Devices AD8000 [7, 8], generating output signals with rise-time of ~ 3.5 ns (Fig. 3).



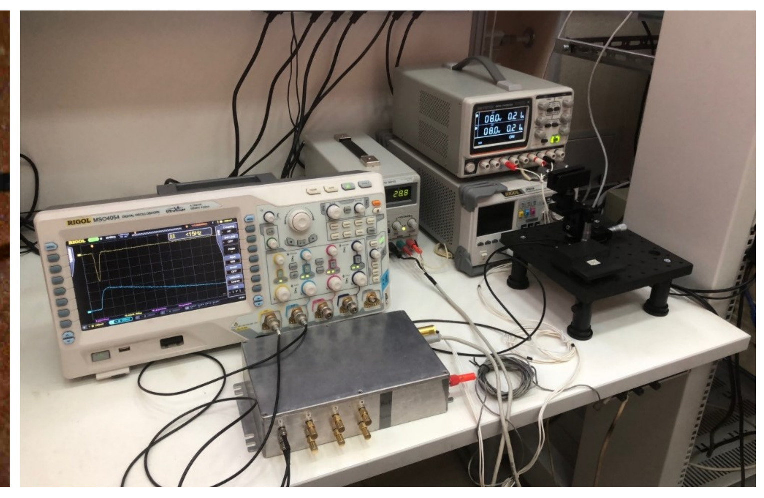


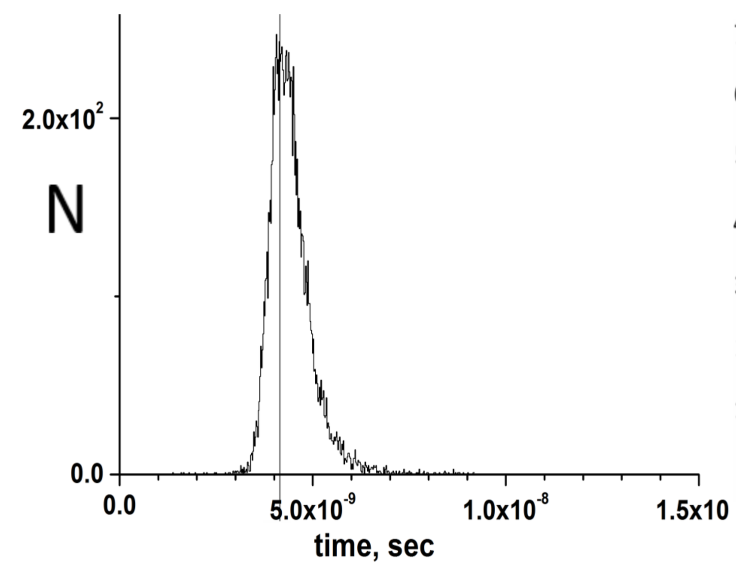
Figure 1. Detector prototype.

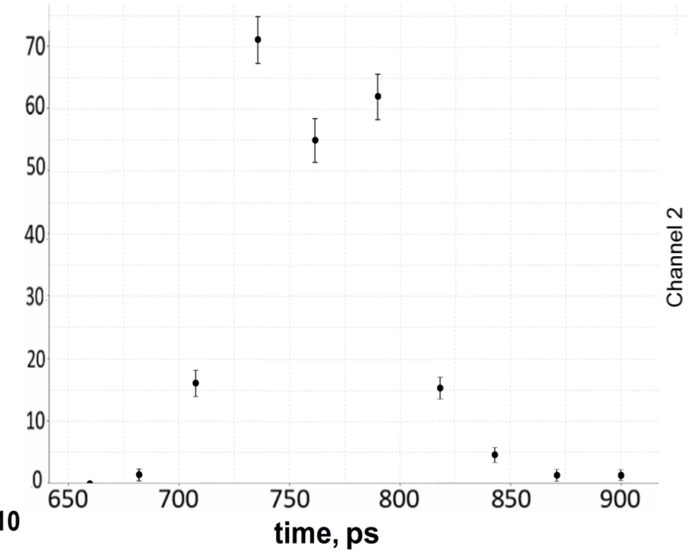
Figure 2. Preamplifiers board.

Figure 3. Detector prototype connected to RIGOL MSO4054 oscilloscope.

Furthermore, it is possible to vary the dimensions of the scintillation detector used in the design (Fig. 1) without any change of the electronic components, which makes it possible to effectively use it in various configurations of the CubeSat format probe (Fig. 9).

The results of the beam monitor detectors calibration on the SR-25 "PAKHRA" synchrotron showed that such detectors are suitable for recording the time resolution profiles of electron fluxes causing TGF (Fig. 4-7).





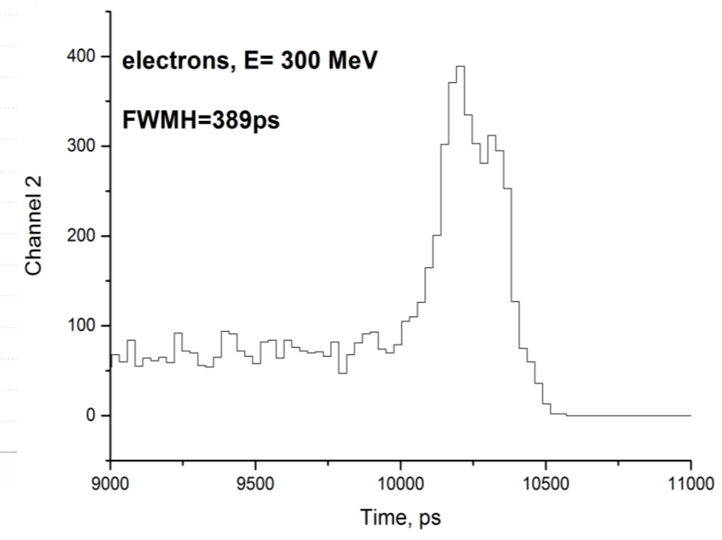


Figure 4. Signals distribution from the beam monitor (results of the beam monitor separate detector calibration on the SR-25 PAKHRA synchrotron).

Figure 5. Results of the beam monitor time resolution measurements (for one electron bunch).

Figure 6. Signals distribution from the beam monitor by time resolution measurements.

To simplify and reduce the cost of the development, we choose SBC Beaglebone Black [9] based on the SoC AM3358x Sitara processor [10] and the KubOS framework for software development (in addition to the framework itself, a custom Linux system is used). This flight software framework for satellites provides the ability to work with sensors and other equipment through already written APIs, that allow us to concentrate on writing scripts and programs for data processing [11].

This implements the possibility of simple updating in a couple of commands, using files of a special format. In the development and maintenance of software, we are using DevOps practices [12] and tools, which will allow us to write the correctly working code as efficiently and quickly as possible. Fig. 8 shows the pipeline we will be using. Tools such as GitLab, Ansible, unit tests are used [13, 14].

Conclusion

Further development includes several stages: finalizing the hardware platform, testing the prototype in laboratory conditions, creating an inertial navigation system for the probe, optimizing the software, making the final test launch to the stratosphere, and a standard sample of the device for function on low orbits.

The possibility of adding a CsI (Tl) crystal (cesium iodide, activated by thallium) or BGO (bismuth orthogermanate) to the project is also being considered. This will allow detecting the radiation from the TGF itself.

A preliminary version of a test sample of the probe body was successfully discussed in [15].

The phenomenon studying in this project has not been clearly defined. The results of the work may be of interest to high-current electronics, and the data processed can be used to correct the results of other experiments in this subject area.

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