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

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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 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 numerous experiments. Therefore, it is important to have the most proper model of this phenomenon. Project goal is to create a stratospheric CubeSat format probe capable of detecting these events at an altitude of about 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 and created a detector prototype, consisting of a thick polystyrene scintillation counter wrapped in mylar and two SiPM SensL MicroSB-30035-X13 readout.

1. Introduction

The formation of charged particles in the atmosphere can affect the results of various 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 consisting 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 [3].

Recent observations have shown that runaway breakdown can also occur at altitudes less than 30 km. In this case, most of the electrons are scattered without reaching the satellites on high orbits [1]. Thus, 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 operating in the stratosphere or on low orbits). The experiment observes the changes in relativistic electron fluxes, which presumably are the sources of TGF.

2. Experimental setup
This section presents the experimental setup and describes the methodology of the research, development, and testing of the detector prototype. For the detection of electron fluxes causing TGF, we developed a polystyrene-based detector. Application of the polystyrene scintillation counter in this project is determined by a number of properties, including high resistance to mechanical stress, weak dependence of light output from temperatures, and low decay time.

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

![Figure 1. Detector prototype.](image1)

![Figure 2. Preamplifiers board.](image2)

![Figure 3. Signals distribution from the beam monitor (results of the beam monitor separate detector calibration on the SR-25 PAKHRA synchrotron).](image3)

![Figure 4. Results of the beam monitor time resolution measurements (for one electron bunch).](image4)

The results of the beam monitor detectors calibration on the SR-25 "PAKHRA" synchrotron showed that such detectors are suitable for registration of time resolution profiles of the electron fluxes causing TGF (figures 3 and 4).
Furthermore, it is possible to vary the dimensions of the scintillation detector used in the design without any change of the electronic components, which makes it possible to effectively use it in various configurations.

2.1. Development
To simplify and reduce the cost of the project, we choose SBC Beaglebone Black [8] based on the SoC AM3358x Sitara processor [9] and the KubOS framework for software development (in addition to the framework itself, a custom Linux system is used).

KubOS flight software framework for satellites provides the ability to work with sensors and other equipment through already written APIs that allows us to concentrate on writing scripts and programs for data processing [10]. This implements the possibility of simple updating in a couple of commands.

To optimize software development, we are using DevOps practices [11] and tools, such as GitLab, Ansible Molecule (Ansible testing tool) [12, 13]. The pipeline is shown below (figure 5).

![GitLab CI CD pipeline](image)

**Figure 5.** GitLab CI CD pipeline (Continuous Integration Continuous Deploy).

![Conceptual design of the CubeSat format probe structure](image)

**Figure 6.** Conceptual design of the CubeSat format probe structure.

2.2. CubeSat format probe concept
During development of the CubeSat format probe conceptual design, two configuration options were considered for the mission (figure 6). 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.
3. Conclusion
In this paper, 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.

The results of detector testing calibrations showed that the presented prototype (similar to the beam monitor detectors used in the calibrations of the GAMMA-400 gamma-telescope [6, 7]) can successfully register electron fluxes causing TGF (both secondary cosmic rays and those arising during breakdown).

Further development includes several stages: finalizing the hardware platform, testing the prototype under laboratory conditions, optimizing the software, testing the prototype during the final launch to the stratosphere, and preparing a standard sample of the device for function on low orbits.

The possibility of adding a detector based on a CsI (TI) (Cesium Iodide, activated by Thallium) or BGO (Bismuth Germanate Oxide) crystal with thickness of 2-3 X_0 (which is sufficient to spectrometry) to the project is also being considered. This will allow detecting X-ray and gamma emission from the TGF itself.

The phenomenon of TGF has not been clearly defined. The results obtained from the described experiment may be of interest to high-current electronics. By analyzing the data of events registered 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.

A preliminary version of a test sample of the probe body was successfully discussed in [14].

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