BELISAMA on Mount Aragats

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Context: Observation of TGF from space and Earth

The TARANIS satellite and its XGRE instrument:

TARANIS, the Celtic god of thunder and lightning, was the name of a CNES satellite dedicated to observe gigantic luminous events 30 to 90 km high occurring above large storm clouds like those that form in the intertropical belt. Discovered 20 years ago, such transient luminous events (TLEs)—variously called 'elves', 'sprites' and 'blue jets'—remain shrouded in mystery. Short duration gamma-ray flashes, called TGF, sometimes accompany them. The correlation between these TLEs and TGFs is one of the scientific questions the TARANIS mission should have answered.

The TARANIS microsatellite should have flown over thousands of TLEs and TGFs for at least two years. Its scientific instruments were to detect these events and record their luminous and radiative signatures at high resolution, as well as the electromagnetic perturbations they set off in Earth's upper atmosphere. The system was designed to observe stormy regions with a view to detecting TLEs and TGFs as the satellite travels above the phenomena at around 700 km of altitude. For this purpose, it was equipped with several experiments in optical fast imaging, electric and magnetic field measurement, electron detection and X and gamma-ray photon measurement. Launched in November 2020 by a Vega-C rocket, the satellite failed to access its orbit 8 minutes after launch.

Our expertise in gamma spectrometry led our group to design and develop the XGRE (X, Gamma ray and Relativistic Electrons detector) instrument onboard TARANIS, dedicated to the detection and measurement of TGF and TEB ("Terrestrial Electrons Beams"), electrons generated during the passage of gamma photons from TGFs into the atmosphere.

The XGRE instrument, with a total area of 900 cm^2, had to distinguish electrons and photons and measure their energy deposits in the 20 keV - 10 MeV range. It should have dated each TGF and TEB with an accuracy of the order of one microsecond and triggered the other instruments. In addition, it should have roughly (30 °) located the emitting zone and measure as precisely as possible the position of the low energy spectral cut indicating the thickness of the atmosphere passed through. The instrument had three sensors, sandwiches composed of two plastic scintillators enclosing a lanthanum bromide scintillator (LaBr3). Plastic scintillators are well suited to detecting electrons and LaBr3 is a very fast and high-resolution gamma ray spectrometer.

The BELISAMA citizen-science project:

The BELISAMA project, conceived in parallel to the XGRE development at APC, is an experiment that aims to better understand TGF and gamma-ray glows and try to catch them from ground. It is conceived around a detector, described below, that we placed in different places in France, in high schools, institutes (e.g. Meudon astronomical observatory) or dedicated places on Pyrenean Mountains.

The BELISAMA detector is a descendant of the detectors conceived in Japan to look at gamma-ray flashes during storms. These studies have led to the first detection of atmospheric nuclear photo-dissociation (Enoto, T. et al., Nature, 551, 481, 2017). One of the member of this team, Yuuki Wada, collaborates with us to design and develop our new BELISAMA detector based upon SiPM and scintillator crystal.

BELISAMA also invites citizens to learn about natural radioactivity. It is an educational project with multiple interests and applications: impact on climate and health, discovery of the research process in science, participation in a detection system around an instrument and a network, introduction to the measurement of local radioactivity from a citizen perspective.

We make discover to the high school students natural gamma-ray radiation, whether of terrestrial origin (natural radioactivity) or atmospheric (TGF). Participants can measure this radioactivity with our detector, specially developed at APC for this project. Students can also share their data with those obtained from other detectors through a dedicated website (which also provides access to all information on the scientific areas of the project):

http://www.belisamaedu.fr

Link with IRSN and OpenRadiation :

IRSN (Institut de Radioprotection et de Sureté Nucléaire) is the governmental institute specially designated to monitor radioactivity levels in France. This institute is a partner of the BELISAMA project and the measurements made by our various detectors in high schools and institutions should be added to the measurement IRSN-controlled network. This network, called OpenRadiation, is a citizens' science initiative where the citizens themselves make the measurements and transfer them on a dedicated website: www.openradiation.org

allowing to have in real time the level of radiation on the territory. This initiative also allows citizens to form their own opinions about radioactivity and nuclear energy. IRSN engineers are experts in monitoring radioactivity and cosmic-rays induced radiations in different places and situations through the use of multiple scintillators, such as plastics, NaI, BGO, … and intervene in front of our high school teachers and students.

Proposed instrumentation:

We propose then to install our BELISAMA detectors at the Mount Aragats observatory to detect TGF from the ground and particles induced by cosmic-rays. The BELISAMA instrument is made of two main parts, the detector electronic boards and the detector itself. Detector is made with a scintillating crystal (we use GAGG as it is fast, non-hygroscopic and luminous) readout by a SiPM. The SiPM signal is transferred to the electronics boards via a cable.

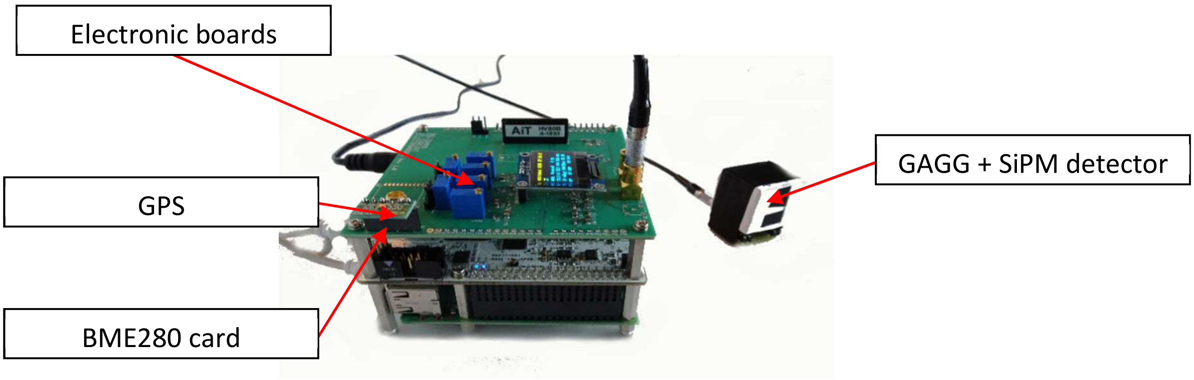
Electronics board is composed of three superimposed boards. The top one provides the analogic treatment of the signal and its digitalization. It contains also a DC/DC which converts the 5V voltage from the bottom board into the 27 V needed by the Onsemi SiPM. On this board, we can see also a screen in the figure below, which gives information on the instrument parameters. We have a BME280 card, which records atmospheric parameters, such as temperature, pressure and air humidity. This card also contains a GPS receiver which measures the detector position regularly (this was adapted for measurement in planes). There are several potentiometers to set the gain of the detector.

The middle board is a FPGA board that controls the whole system, acquires SiPM, BME280 and GPS data and send the data to the third one, a Raspberry Pi3 microcomputer. The Raspberry enables an Internet connection to the external world. The data are either sent via Internet or stored on the Raspberry SD card. The system is thus completely autonomous, needing only an electric plug and an Internet connection to work. In the existing system, the data are sent automatically once every day to our server in Paris, but this can be adapted to the way the data need to be stored in the observatory.

For each detected photons, the arrival time (in 10 ns units) and pulse height value is registered. The system has been proven to work up to around 10000 cts/s. It can theoretically access higher count-rates (its time resolution being around 30 microseconds), but was never tested at these rates.

The present version of our instrument is mounted with a 2x2x1 cm^3 GAGG crystal that is fast and luminous. We have demonstrated by simulations that it is well suited for TGF and gamma-ray glow detection. It can be used also to monitor natural radioactivity up to a few MeV.

We propose also to add beside another detector provided by IRSN and composed of a 3” BGO crystal readout by an Hamptek TB5 electronics, which can generate one energy spectrum every 1 second. This BGO instrument will extend our experiment to several MeV energies, and its large surface area will allow to detect much fainter events than what is expected to be detected by BELISAMA.



View of the BELISAMA detector

Scientific outcomes:

Terrestrial Gamma ray Flashes (TGF) are bursts of gamma rays very likely to be produced during the first stages of the development of positive intra-cloud lightning. They are produced by bremsstrahlung of avalanches of relativistic runaway electrons accelerated by an electric field in thunderstorms. Other high-energy electric atmospheric events are produced in thunderstorms, for instance gamma ray glows that does not show the same characteristics: longer duration and flux way less important. However, they show the same energy spectrum, proving that the same physical phenomena are implied.

Recently, this field of research is going through great advances with the report of new types of high-energy events produced in thunderstorms, observed during the ALOFT airborne campaign in summer 2023 [*Østgaard et al., AGU23, oral presentation, 2023*]. Those events are different in duration and fluxes: microglows are short gamma ray glows lasting tens to hundreds of milliseconds; flickering gamma ray flashes (FGFs) are less fluent TGFs, and are produced in the form of pulsating TGFs during 10-100 ms.

Those new observations revive the questions of the link between those events, their impact on the thunderstorm, and more generally their impact on the global electrical circuit of the Earth and on its atmosphere. Trying to detect those events from the ground could also bring clues to answer these questions.

Using BELISAMA at sea level, as it is done in high schools in France, the probability to be able to detect a TGF or a gamma ray glow is very low due to the bad signal to noise ratio (SNR). However, this SNR increases of a factor of ~10 (estimated with simulations) for a detection altitude of 3,200 m, like on Mount Aragats. This project would bring the first high-energy events observed with BELISAMA. This citizen project would be very interesting to follow for high school students, to participate and detect themselves the events in the data, and take part of a real scientific research project. They will be able to see the differences in the gamma ray background in Mount Aragats, compared to different places in France.

Of course, it would be a great opportunity for our team to analyse these measurements and compare them to the instruments already installed on Mount Aragats, such as the electric field mill, and maybe other gamma ray spectrometers. We hope that several observations of gamma ray events would bring important new information for this research field, that this will help the understanding of these events, and answer important questions of the high-energy physics in atmosphere.