OBSERVATION OF TERRESTRIAL GAMMA RAY FLASHES, COSMIC GAMMA RAY BURSTS AND ELECTRON PRECIPITATION IN VERNOV AND LOMONOSOV SPACE MISSIONS

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Abstract: *The transient electromagnetic events, such as Terrestrial Gamma Ray Flashes (TGF), Transient Luminous Events (TLE) and cosmic Gamma Ray Bursts (GRB) as well as magnetosphere electron precipitation were observed during the space experiment with RELEC (**R**elativistic **Elec**trons) instruments on board Vernov small satellite from July to December, 2014 and on board Lomonosov space mission from April 28, 2016 till now. The solar-synchronous orbits of both satellites provides the favourable conditions for the magnetosphere electron precipitation (MEP) study as TGF and TLE observations in different areas of the Atmosphere including Equatorial and Polar Regions. As the results of observations on Vernov satellite the dozens of candidates in TGFs and thousands of UV and red flashes most likely associated with TLEs and lightning were detected. The MEPs were also observed regularly in different areas of near Earth space. Some of TGF candidates and UV flashes were observed at high latitudes in the regions far away from thunderstorms, but near the MEP areas that could indicate on possible connection between TGF and TLE, i.e. high altitude discharges and MEP. The short-time variations of sub-relativistic and relativistic (0.1 – 3.0 MeV) electron flux variations were detected during Vernov and Lomonosov missions in the different parts of near-Earth space, including Aurora regions. The typical times of such events are in the range from several milliseconds up to dozen of seconds and even minutes. The spatial effects caused by satellite crossing of electron beams or other areas with increased electron density and pure temporal, i.e. burst-like phenomena may be among them. Small satellites, such as Vernov and Lomonosov are very appropriate for study electron precipitation, which can be dangerous for spacecraft technique and biological objects. The experience of Vernov and Lomonosov missions are very important for future project of multi small satellites, which can be used for monitoring of natural and artificial space hazards such as space radiation, transient phenomena etc.*

Study of short-time (10^{-4} – 10^{2} s) variations of gamma-quantum (0.02 – 3.0 MeV) and relativistic (0.3 – 10.0 MeV) electron fluxes was one of the main goals of Vernov [1] and Lomonosov [2] space missions. It gives opportunity in progress of understanding of Transient Energetic Phenomena (TEP) in the Atmosphere and its possible connection with magnetosphere relativistic electron precipitation. By TEP we mean the Terrestrial Gamma Flashes (TGF) and the Transient Luminous Events (TLE), which are the well-known effects possible connected with high altitude electric discharges, such as sprites, elves and blue jets as well as discovered in Tatiana-Universitetskii and Tatiana-2 missions flashes of ultraviolet (UV) and red emission [3].

The Vernov spacecraft was launched in 2014 July, 8 at polar (640×830 km) solar-synchronous orbit with 98.4° inclination and ~100 min period. RELEC complex of scientific instruments included gamma quantum and electron (0.01-3.0 MeV) spectrometer DRGE, UV (240 – 400 nm) and red (610 – 800 nm) photometer DUV, UV imager Telescope-T, low frequency (0 – 40 kHz) NChA (PSA-SAS3) and radio frequency (0.05 – 15.0 MHz) RFA analyzers and electronic unit BE. The satellite orbit allows observations in different areas of the near-Earth space including near Geomagnetic Equator and high latitude regions. This gives a good opportunity to study TGFs as well as electron precipitations.

The main instrument for these purposes is DRGE spectrometer [1]. It consisted of three units, i.e. two identical DRGE-1(2) and one DRGE-3 boxes. Each DRGE-1(2) box contained two identical detector units, which were based on the large area (13 cm in diameter) NaI(Tl)/CsI(Tl) phoswich detectors, each with thin (0.3 cm) NaI(Tl) and more thick (1.7 cm) CsI(Tl) crystals both viewed by photomultiplier tube (PMT) Hammamatsu R877. During the experiment detector axes were directed constantly to the Nadir, the total area of four detectors was about 500 cm^2, which is enough to detect TGF at appropriate sensitivity level. The DRGE-3 unit was used mainly for electron precipitation study.

It consisted of three identical detectors with axes normally directed to each other. First one was directed to the local Zenith, the second one was directed mainly against the satellite velocity vector, and the third one was directed normally to the plane formed by two other detectors axes. Each DRGE-3 detector unit consisted of CsI(Tl)/BGO/plastic phoswich with 0.3 cm thick CsI(Tl) and 1.7 cm thick BGO putted in the anticoincidence cup from plastic scintillator with 0.5 cm walls. The diameter of both CsI(Tl) and BGO scintillators was 1.5 cm. The cylindrical copper collimator with height of 1.0 cm and a 0.1 cm thickness was arranged above the CsI(Tl) crystal. The output data from all DRGE detectors were received in two modes. One is so-called monitor mode, in which mean count rates in given energy channels separate for gammas and electrons, were measured continuously for chosen exposure time (1.6 s mainly) during all observations. The other is "event by event" mode, in which for every detected gamma quantum or electron its energy and time of detection were fixed. It is very effective to study short events such as TGFs with time resolution limited only by detector dead time (~15 mcs).

The same observation technique was used in the Lomonosov mission, which was successively launched in 2016 April, 28. The Lomonosov instruments include the BDRG gamma ray burst monitor (GBM), which consists of three identical boxes with the same NaI(Tl)/CsI(Tl) phoswich detectors as DRGE-1(2). The BDRG instrument boxes are mounted on the spacecraft instrumental panel in such a way, that detector axes are directed normally to each other and detector fields of views (FOVs) cover a half of the sky. Despite the BDRG detectors are oriented to the opposite direction relatively to the Earth, they are also able to study precipitation electrons via bremsstrahlung and to detect TGFs by the use of "bottom" CsI(Tl) crystals, which are not totally screened by satellite constructions.

The DRGE-1 and DRGE-2 large area detectors with axes directed toward the Earth are the main instruments for TGFs observations during the operation of RELEC Vernov in space. The huge number of events which satisfied the trigger criterion was obtained. However, most of them were caused by cosmic rays, particularly heavy charge particles, passing through the scintillation crystals. Such events can be selected effectively from the "energy-time" diagrams which reflect the energy release values pointed against the time of detection. The sample of TGF candidates was selected after excluding events caused by heavy charged particles. The map of selected TGF-candidate source position is presented in Fig. 1. For comparison the distribution of burst-like events imitated by charged particles is also presented there. Despite that the most of selected events are random, about 40 of them may be the real TGF candidates. This is also confirmed by concentration of corresponding points in the regions with high thunderstorm activity, i.e. India, South-East Asia etc.

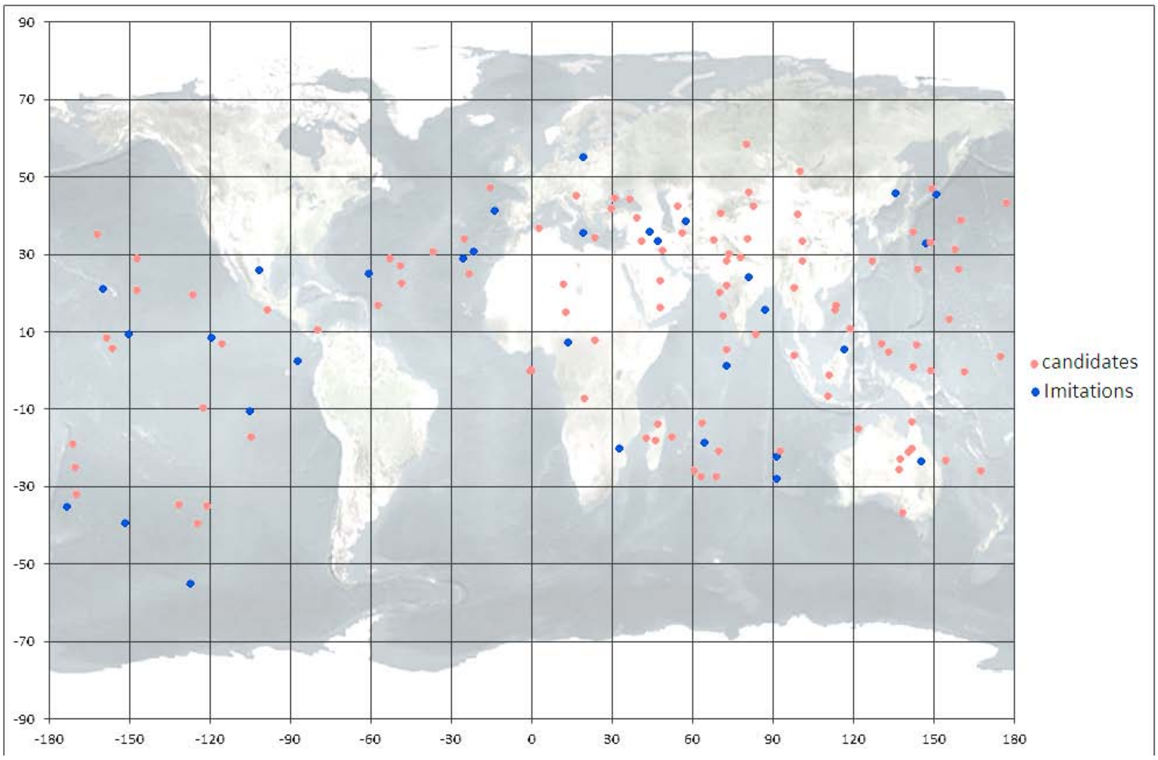

Fig. 1. The map of distribution of TGF candidates. Red points mark the TGF-like events, blue points mark events caused by heavy charged particles.

Among the chosen TGF-candidates events those detected in the polar region under Antarctica are of special interest. There are events detected 02.11.2014 at 03:34:14.051 UT and 22.11.2014 at 05:05:03.025 UT. The sub-satellite points at the time of detection of these events are marked in Fig. 2. These bursts are longer (~2.5 ms) than other events, which duration (<400 mcs) is typical for TGFs usually connected with thunderstorm activity. If take into account this burst source position, its connection with thunderstorm is very unlikely. From the other hand both of these flashes were detected near the areas of magnetosphere electron precipitation.

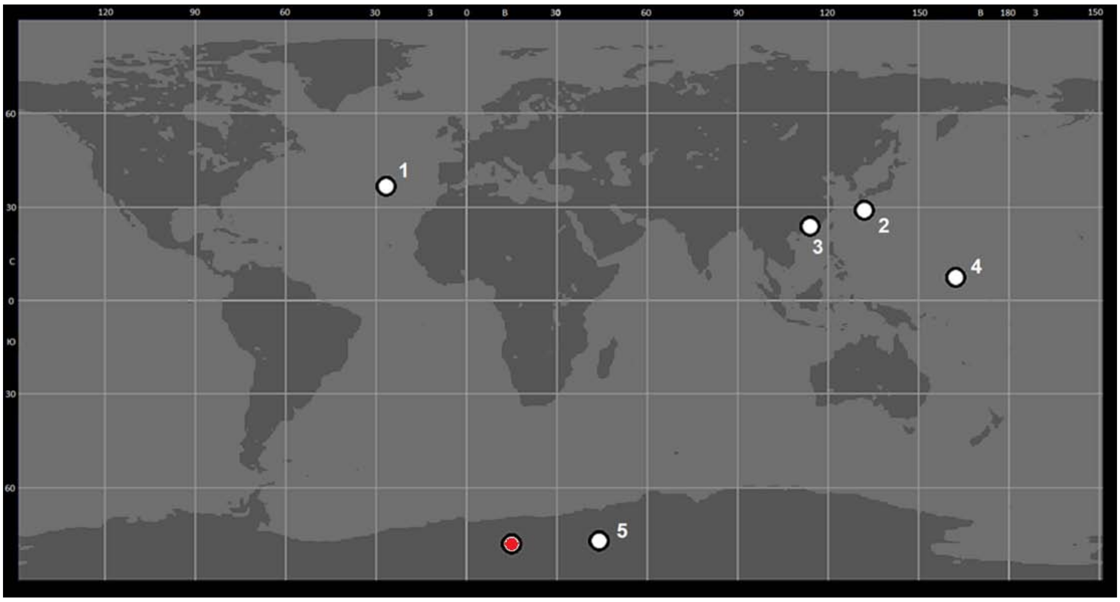

Fig. 2. The map with sub-satellite points in time, when most intensive TGF-like events were detected. The red circle and circle number 5 correspond to gamma ray flashes detected in Polar region.

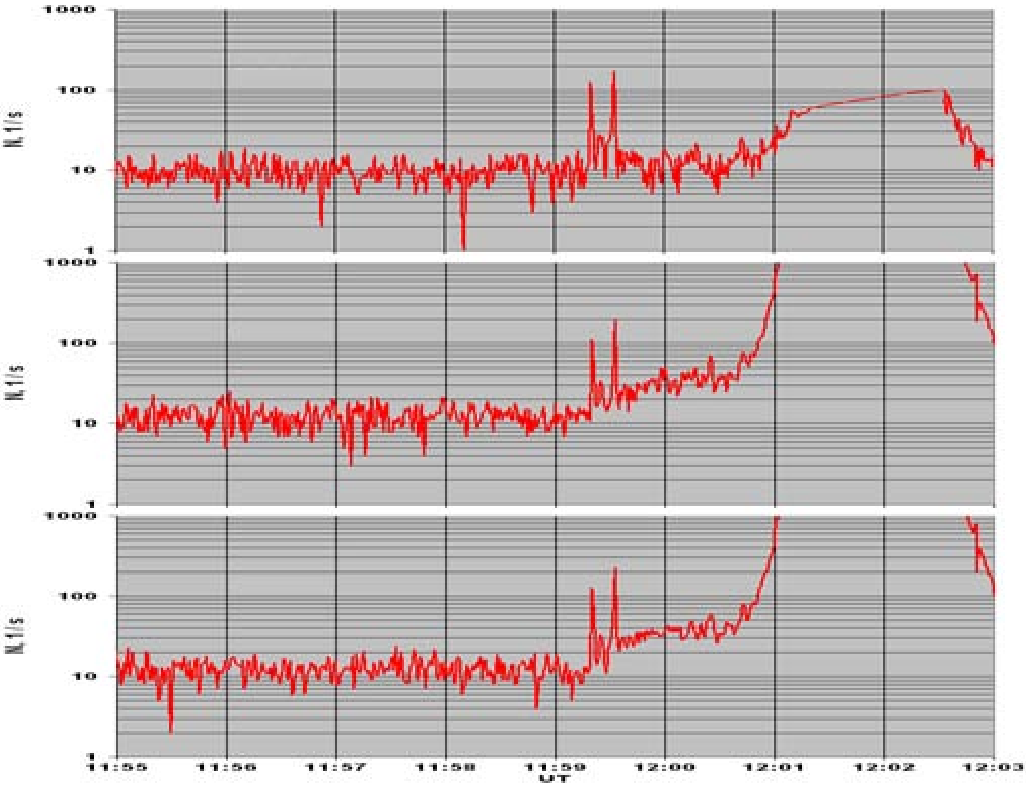

Fig. 3. The time profiles of electron counts along Vernov orbit. Time scale means universal time UT. Top, middle and bottom panels present the time profiles of integral (E > 15 keV) counting rates of bremsstrahlung from DRGE-31, DRGE-32 and DRGE-33 detector outputs, respectively.

As it is well-known, electron precipitations from the Earth radiation belts are caused mainly by electromagnetic wave activity in the different bands from about 0.1 Hz to 15 MHz. Such precipitations were observed repeatedly during the Vernov and Lomonosov missions in the different regions of the near-Earth space including polar areas by the crossing of drift shells at the inner edge of the outer belt. The example of such precipitation from the Vernov data is presented in Fig. 3. The increase amplitude is approximately equal for the all three detectors unlike the count, which corresponds to the outer belt electron flux measurements, when detector (DRGE-31), which axis was directed along the magnetic field line, gave significantly lower count rate in comparison with two others, which axes were directed preferably normally to the magnetic field line. It is the natural sequence of that trapped particles have less isotropic fluxes in comparison with precipitated.

Similar precipitation-like short-time electron flux variations were observed in Lomonosov mission. The example of such events is presented in Fig. 4, in which the time profiles of counting rate in 20 – 35 and 60 – 100 keV energy ranges of two GBM monitor BDRG detectors are shown. Background in the BDRG channels is caused mainly by electron bremsstrahlung, thus, detected count rate variations really reflect the sub-relativistic electron flux variations. The rather short, with duration about a few seconds, count rate increase can be seen evidently at L ~ 10, i.e. at inner edge of outer belt.

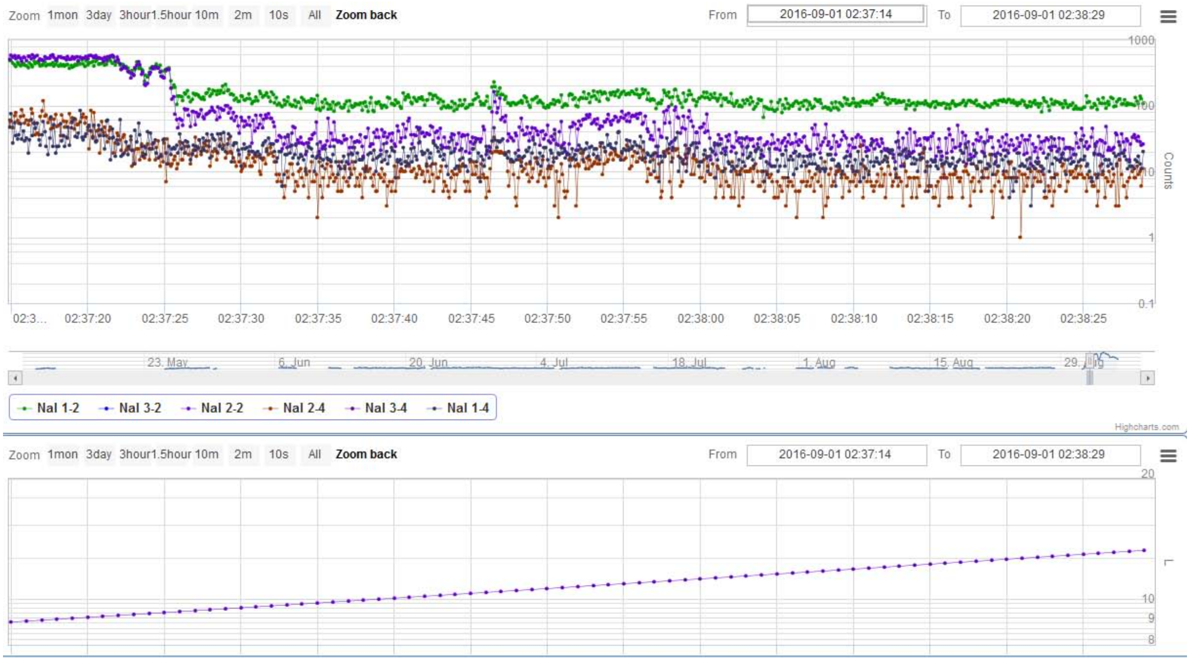

Fig. 4. The time profiles of counting rates in BDRG Lomonosov channels, BDRG-1 20 – 35 keV (green line), BDRG-3 20-35 keV (lilac line), BDRG-1 60 – 100 keV (blue line), BDRG-3 60 – 100 keV (brown line). Time scale means universal time UT. The middle panel: the time profile of L values at the same times as on the top panel.

As it could be seen from the Fig. 4, the presented electron flux variations were observed at Polar regions at some higher L values than precipitation observed in the Vernov mission. Nevertheless, we may assume that it is the same phenomenon caused by electron scattering on the low frequency electromagnetic waves.

Cosmic gamma ray bursts (GRB) were also observed in Vernov and Lomonosov missions. Based on the background features in the orbit of these satellites, gamma-ray bursts could be detected at an acceptable sensitivity level, mainly in the equatorial regions and in the area of the so-called polar cap, where the background count rate level was more or less constant. Because of special trigger mode based on so-called event by event recording, which were realized in both missions, very fine time resolution limited only by the detector dead time ~15 mcs was achieved.

During Vernov mission a few GRB events were detected. Among them was very short burst GRB 141011A with about 50 ms duration. It is supposed that such short GRB are caused by merging of two neutron stars, which also can accompanied by gravitational wave generation.

What about Lomonosov mission, from 2016, June 2017, January 20 gamma-ray bursts were detected. These events were confirmed by data from other spacecraft and presented in the GCN network. If we take into account the shadowing of the detector fields of view by the Earth, the time spent in the regions of captured radiation and the zones of precipitation effective time of GRB observation in Lomonosov mission is about is 20% of total time. By this, the probability of detecting a burst not listed in the GCN catalog does not exceed 10%. Nevertheless, there are several events in the Lomonosov GRB catalog, which were missed by missions specializing in studying gamma-ray bursts, such as Swift, Fermi and Konus-Wind. In particular, the GRB 160908A burst was observed only in the CALET experiment.

Based on a very good experience of Vernov and Lomonosov missions the new space project of M.V. Lomonosov Moscow State University Universat-SOCRAT was proposed. This project assumes the elaboration of multi-satellites for real time monitoring in the near-Earth space of radiation environment, natural (asteroids, meteorites) and artificial (space debris) potentially dangerous objects, electromagnetic transients, such as GRBs, TGTFs, optical and ultraviolet bursts in the Earth atmosphere.

It is intended to install on the satellites the instruments for space monitoring of dangerous objects and hazards, i.e. spectrometers of electrons and protons, complex of instruments for study of transient electromagnetic phenomena including gamma ray spectrometer, detectors of ultraviolet and optical emission and also wide-field optical cameras.

The program of the new project Universat-SOCRAT is based on the results of experiments on board Vernov and Lomonosov satellites intended on the study of extreme phenomena in the Earth's atmosphere and outer space (see, for example, [1, 2]) including the results of observations of high-altitude electromagnetic discharges, precipitation of magnetospheric electrons, gamma-ray bursts of astrophysical and solar origin, as well as observations of space debris by wide-field optical cameras first installed on a spacecraft [4].

Within the framework of the Universat-SOCRAT project several small spacecraft should be launched on specially selected orbits. In the minimal version, the group of satellites should consist of three spacecraft. One spacecraft of medium mass (small satellite) should be launched on a low solar-synchronous orbit with a height of about 500-650 km and an inclination of 97-98°. Two other satellites of lower mass (micro satellites) should be launched on an orbit close to circular with a height of about 1400-1500 km and an inclination of ~80° and on an elliptical orbit with an apogee of about 8000 km, a perigee of about 600-700 km and an inclination of 63.4°.

The small satellite payload should include instruments for monitoring of space radiation, a set of instruments for optical monitoring of hazardous objects, a set of instruments for studying of atmospheric phenomena in the optical range, a set of instruments for monitoring in gamma- range, and special unit for data collection. The payload should also include three-component magnetometer. The payload of each micro satellite should include instruments for space radiation monitoring, a compact gamma spectrometer, a wide field of view optical camera, an ultraviolet detector and an electronics unit for data collection.

The successful realization of the project will make it possible for the first time in the world to create a prototype of a space system for monitoring and helping to prevent space hazards for both ongoing and planned space missions, including high-altitude atmospheric aircraft.

During the project realization, the following tasks should be solved:

- real-time estimation radiation environment in near-Earth space for evaluation of the radiation risks of space missions and the producing of alert signals for decision accept on their control;
- verification of modern computational models of radiation fields in the near-Earth space;
- real-time control of potentially dangerous objects of natural and technogenic origin in the near-Earth space;
- control of electromagnetic transients in the upper Earth atmosphere and space (GRBs, Solar flares).

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