GRB OBSERVATIONS ON CUBESATE SATELLITES IN THE UNIVERSAT–SOCRAT PROJECT

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Multi-channel astronomy is one of the most important and rapidly developing field of modern physics. The well known result of multi-channel observations is simultaneous detection of gravitational wave and gamma ray bursts associated with neutron star merger event. This observation open a new window to study the Universe, and actually triggered the broad scale study of astrophysical phenomena in hard X-Rays and gamma rays by orbital experiments together with ground based observations of gravitational waves, neutrino and ultra-high energy cosmic rays. From this perspective it appears that small satellites of CubeSat type are quite appropriate for multi-channel observations of astrophysical transients because it is the cheapest way to realize all-sky monitoring observations by orbital instruments. Presently at D.V. Skobeltsyn Institute of Nuclear Physics of the M.V. Lomonosov Moscow State University (SINP MSU) a new project named Universat–SOCRAT is under development which is intended for operational monitoring of near-Earth's radiation environment and monitoring of electromagnetic transients in the optical, UV, X-ray and gamma ranges. Here we discuss the first results of charged particles, gamma quanta fluxes and UV-emission measurements from the upper atmosphere in several CubeSat missions, which were successfully launched in 2019, 2020.

1. Introduction

One of the most important and interesting fields of modern physics and astrophysics is the study of extreme processes and phenomena leading to the most powerful explosions, acceleration of particles to the maximum possible energies, generation of superstrong gravitational and electromagnetic fields. Such phenomena include cosmic gamma-ray bursts (GRBs) associated with the collapse of massive stars (hypernovae), merging of relativistic compact objects (neutron stars and black holes), leading to the generation of gravitational waves and short-term increases in gamma-ray fluxes, nonstationary processes in neutron stars with a superstrong magnetic field (magnetars), dynamic processes in the nuclei of active galaxies, pulsars and close binary systems, which can be associated with the acceleration of particles to high and extremely high energies and the generation of high and ultrahigh energy neutrinos.

Despite the fact that these extreme phenomena have been studied very intensively in recent years, there are still many unsolved problems. As for GRBs, this is, first of all, the definition of the mechanism of functioning of the "central engine", the formation of relativistic jets and the propagation of relativistic shock waves in them, the so-called shells. The related problems concern with the study of the possibility of particle acceleration on relativistic shock waves, and of the conditions for generation of polarized electromagnetic radiation. In this regard, especially important information can be obtained as a result of multi-wavelength observations of the so-called intrinsic emission of a GRB, especially in the optical and gamma ranges. Among the observational tasks, it should be noted that it is necessary to observe GRBs with the maximum possible temporal and spectral resolution, as well as at a high level of sensitivity, which will make it possible to expand the range of observed burst sources up to the most distant objects in the Universe ($z \sim 10 - 12$). The study of the fine temporal structure of GRB intrinsic emission, as well as of the so-called precursors, including their observations in the optical range, is very actual.

An important task is studying of the so-called short hard GRBs, includes the need to discover their intrinsic optical emission. It is known, that such bursts are associated with the processes of neutron stars merging in close binaries; therefore, their study is particularly relevant after recent discovery of gravitational-waves bursts generated during the merger of relativistic compact objects.

Considering the relevance of studying extreme astrophysical phenomena, it should be emphasized that for further progress in understanding their nature, multi-wave (at least simultaneous in the optical, X-ray and gamma ranges), multi-channel and multi-satellite observations are required. Multi-channel observations mean the simultaneous detection of events by space-based and ground-based facilities, including ground-based optical, radio and gamma telescopes, gravitational-wave antennas, and facilities designed to detect neutrinos and ultra-high energy cosmic rays. Multi-satellite observations are necessary to ensure the detection of each GRB on several spacecraft in order to localize the GRB source using the triangulation technique.

2. Advantages of CubeSat constellation for GRB observations

The main success of multi-channel astrophysical observations is connected with simultaneous detection of gravitation wave and gamma-ray burst in August 17, 2017 from neutron star merging [1]. It seems that one of the cheapest and very effective ways of multi-channel and multi-satellite observations of such events and GRBs in general is use of small satellites grouping, in particular the CubeSat constellations. Due to the relatively low cost and ease of manufacture, it is possible to carry out more, or less regular launches of CubeSat satellites as a by-pass mission. Thus, a constellation of nano-satellites can be created, which will significantly increase the efficiency of space radiation and electromagnetic transient monitoring.

The solution for the localization problem can be achieved by applying the triangulation method for observations of the selected area with different satellites. For this purpose the number of CubeSats should be launched for the joint observations of a given burst. To realize the triangulation technique in minimal variant 3-4 CubeSats are necessary (see Fig. 1). Optimally they should be launched as by-pass mission together with the main spacecraft of multi-satellite group, i.e. on the near circular solar-synchronous orbits with altitude about $400 - 600$ km, inclination about $98°$ and longitude deviation of the ascending node $< 5°/year$. The error box of GRB source localization is defined by time delay of signals detected on each satellite. The longer delay the more accurate will be localization. Delay itself depends on distance between satellites, i.e. the larger distance corresponds to the longer delay. In the case of near-Earth orbits the distance between satellites is limited by about $10\ 000 - 15\ 000$ km, because all satellites should be from one side of the Earth to avoid the screening of GRB source. By this the necessity of maintaining of given distance between satellites is a separate technical problem. It can be solved by the use of thrusters. Off cause CubeSat constellation can be used also for observations of transient events from the Earth atmosphere, including Terrestrial Gamma Ray Flashes (TGF) and monitoring of space radiation. However, there will be other requirements to the distance between satellites in the case of triangulation technique application for TGFs. In the last case the given area of Atmosphere should be observed by all satellites of grouping, thus the maximal distance should be no more than about 1000 km. For successive realization of multi-satellite mission for GRB observations certain conditions should be met:

- presence of satellite Internet (global star/iridium) plus high frequency transmitter;
- stabilization better than $1°/s$, satellite orientation on the "Zenith–Nadir" axis and velocity vector with accuracy $+/-10°$, information on satellite axes orientation with accuracy $0.1°$;
- possibility of quasi-autonomous navigation, in particular with the use of millisecond pulsars as beacons;

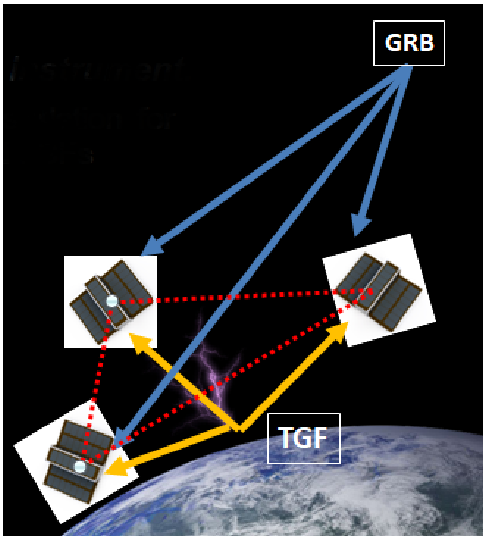


Fig. 1. The CubeSat constellation in minimal configuration.

- different data types, such as monitoring, event-by-event, telegrams about burst triggers (GCN);
- data daily volume no less 100 Mb;
- exact timing is needed;
- orientation accuracy $\sim 1°$ is useful;
- fast telegrams are needed;
- necessity of charge particle variation control.

The last demand is particularly actually if the satellites are launched to the polar orbit because of the problem of false triggering by electron precipitation rises. It can be solved by monitoring of electron flux with the use of special electron detectors or instruments which are able to select true gamma-quantum flux rises on the background of electron precipitation. The last is illustrated by Figs 2, 3, on which the examples of GRB imitations by electron precipitation and the map with such imitation distributions from the BDRG/Lomonosov data [2] are presented.
For instruments, that can be used for GRB detection on-board CubeSats one of the main criteria is the detector area, that is sufficient for GRB registration, should be larger $\sim 50cm^2$ in the energy range of photons from ~ 20 keV up to several MeV. Such detector units can also be used to detect TGFs and X-ray and gamma ray emission of solar flares.
We note, that presently the space project of Moscow University Universat-SOCRAT is under realization. In the frame of this project the launches of a number of satellites including CubeSats, that can be used as the base of constellation for GRB study, is foreseen.

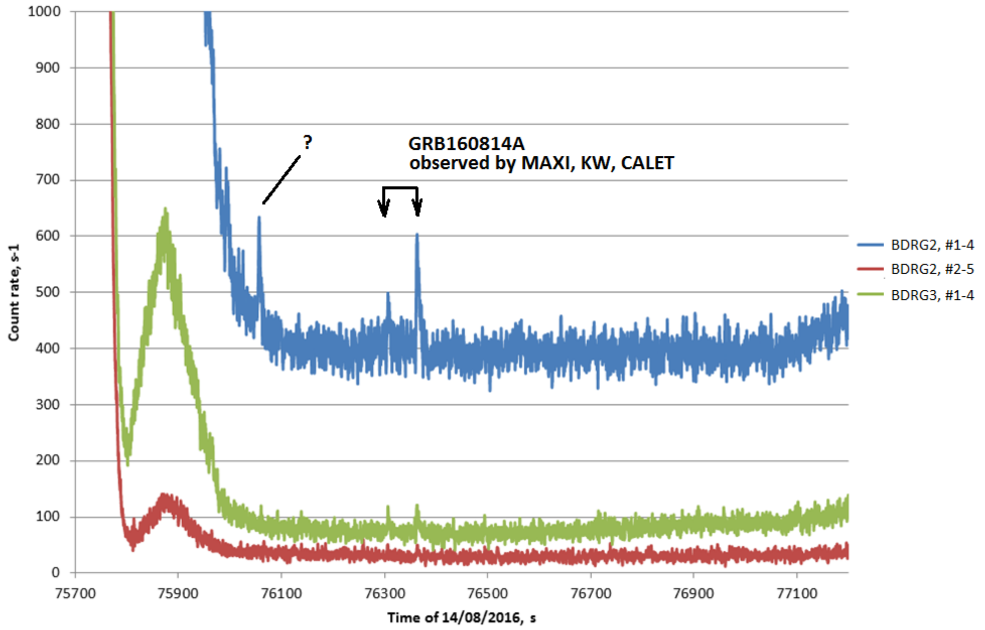


Fig. 2. Example of GRB and burst imitations by magnetosphere electron precipitation detected BDRG/Lomonosov near radiation belts.

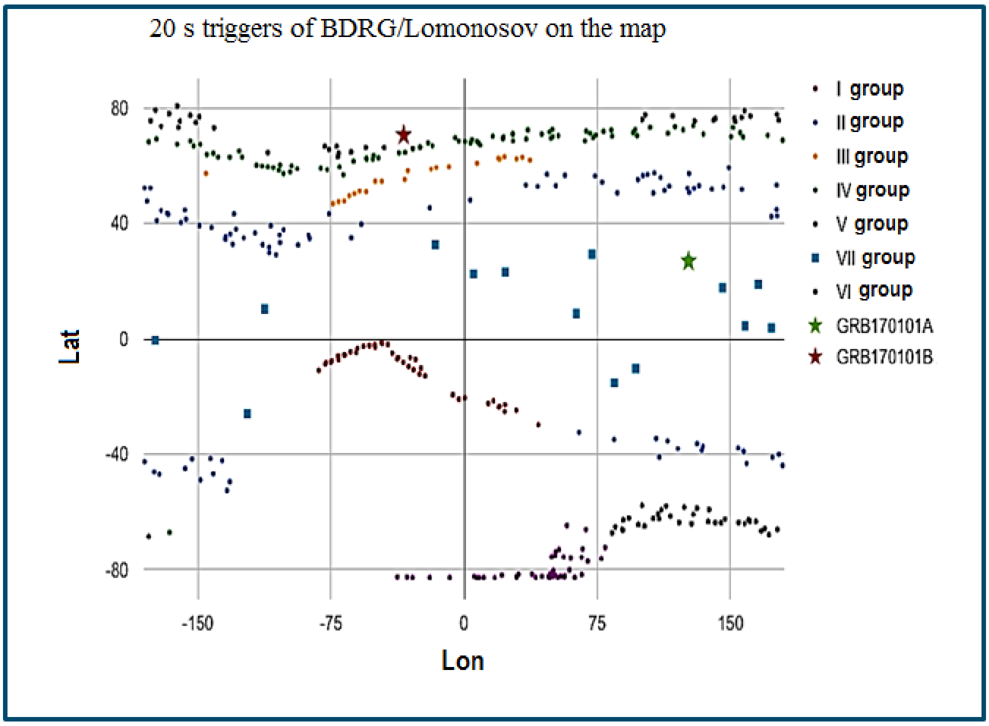


Fig. 3. Geographic distribution of different types of BDRG/Lomonosov triggers. By stars the real GRBs are marked.

2.1. *Universat–SOCRAT space project.*

Under the Universat–SOCRAT project it is planned to create a grouping of small satellites for real time monitoring in the near-Earth space of potentially dangerous hazards, i.e. the radiation environment; dangerous objects of the natural (asteroids, meteors) and technogenic origin (space debris), as well as electromagnetic transients (cosmic gamma-ray bursts, optical, ultraviolet and gamma ray flashes from the Earth's atmosphere [3,4].

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 1500 km and an inclination of $\sim 80°$ and on an elliptical orbit with an apogee of about 8000 km, a perigee of 600–700 km, inclination 63.4° and argument of perigee $\sim 310°$.

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. Payload of all three satellites also should include the special electronic unit for data collection from detector units, its transmission to the board systems and feeding too the instruments power supply and commands.

The basic multi-satellite group can be supplemented with nano-satellites of the CubeSat type. Due to the relative cheapness and ease of manufacture, it is possible to carry out more or less regular launches of satellites as a by-pass mission. Thus, a constellation of nanosatellites can be created, which will significantly increase the efficiency of space radiation and electromagnetic transient monitoring.

The use of several nano-satellites of CubeSat type equipped with several multidirectional spectrometers of energetic protons and electrons will provide a solution of the problem of elaboration of a three-dimensional dynamic model of radiation in near-Earth space. For this, the satellites should be launched onto specially selected orbits and provide measurements that will allow us to calculate the current distribution of particle fluxes in a large volume of near-Earth space, i.e. from low orbits to geostationary, and, as a result, determine the current levels of radiation doses for a wide range spacecraft orbits, and also give a forecast of the radiation situation at low altitudes. Simultaneous measurements of particle fluxes on several spacecraft located at different points in near-Earth space will also allow sufficiently reliable separation of temporal and spatial effects in detected variations of the instrument output readings.

The nano-satellite constellation also gives advantages for GRB and TGF study. As it was mentioned above, the crucial point from this view is necessity of good localization of the transient source. This can be achieved with the use of triangulation technique. In the case of GRB observations about 3–4 satellites will be enough. As for TGF study, optimally the spacecraft grouping should consist of 16 satellites pairwise launched in 8 double orbits, i.e. for each pair of orbits the angle between the planes of the orbits should be about For the all constellation spacecraft the main operational mode of the most instruments is on duty mode when the all instruments are switched-on and operate continuously. Instrument switching between the operational modes is carried out by commands from the Earth or by the internal programs. To optimize the payload energy consumption, the data exchange between instrument electronic and satellite board should be foreseen, including information on changing the parameters of the spacecraft power system and payload switching into energy-saving modes (changes in the instrument operating modes or their partial switching-off).

2.2. *Instruments for gamma transient monitoring*

Instruments for study of gamma transients in the Universat-SOCRAT project will include gamma-ray flash monitor (GFM), and a tracking gamma-ray spectrometer (TGS) of the high resolution and sensitivity, that will be sensitive also to neutrons with energies from about 1 MeV up to dozens of MeV [5]. The separate unit for data analysis and control of GFM and TGS should be also foreseen in the payload. This unit should contain digital electronics unit that will provide the record of data stream with a time resolution of $\sim 10\mu s$, and generate the triggers enabling the detection of different type events, including GRB/TGF flux increases. The data record must be referenced to the UTC time with an accuracy of $\sim 10\mu s$ to allow the positioning of the burst, if observed simultaneously by several space missions, using triangulation, and for the comparison with the data of ground based lightning nets.

To realize the triangulation technique sufficiently light X-ray and gamma-ray detectors aimed for the GRB/TGF detection only, without spectrometer capabilities, will be used on the CubeSats. The composition of each spacecraft of small satellite constellation of the cubesat type should include gamma-ray detectors in the amount of:

— Cubesat 1U – 1 instrument;

— Cubesat 3U – at least 1 instrument;

— Cubesat 6U – at least 3 instruments.

If one instrument is installed on the satellite, its axis should be directed along the nadir - zenith axis to nadir, and the field of view should not be obscured within $\pm 60°$ from the axis of the instrument in the nadir direction. If two instruments are

installed on the spacecraft, their axes should be normal to each other, while the axis of one detector should be directed along the nadir—zenith axis to nadir, and the axis of the other detector should be directed along the spacecraft velocity vector in the case of the orbital orientation of the spacecraft (along the line "zenith - nadir" and the velocity vector), while the field of view should not be obscured within $\pm 60°$ from the axis of the detector. If three instruments are installed on the spacecraft, their detector axes should be normal to each other, directed along mutually perpendicular edges of the cube, as if forming a Cartesian coordinate system, while the axis of one detector should be directed to the nadir, the other along the velocity vector, the axis of the third should complement the three-axial coordinate system to complete. Each gamma detector should be placed in a cubesat-type spacecraft in such a way that the surface of its input window coincides with the surface of one of the side faces of the satellite. The instrument should consist of detector assemblies and electronics boards. Various options for the use of detector units are considered. In the simplest version there are considered 4 detector units each from scintillation crystals with a size of $45 \times 45 \times 5$ mm, viewed by a photo-sensor. There are considered as possible scintillators CsI(Tl) crystals (a cheap option) or Ce:GAGG (an optimal option). For signal pickup, photodetectors such as tube photomultiplier tubes (PMTs) or silicon PMT arrays (Si-PM) can be used.
To provide identification of different types of space radiation (electrons, gamma-quanta), a variant with a fosphich detector can be used when a combination of a plastic scintillator/inorganic scintillator (CsI(Tl) or Ce:GAGG), viewed by a single photodetector, is used while the separation of signals from different scintillators is carried out by analyzing the time profiles of the PMT output signals.
A multi-pixel version of the detector can be also considered when it consists of individual crystals (pixels) of a relatively small size, each of which is viewed by its own photodetector. In this case, a variant can be considered both using standard arrays of silicon PMTs, and using original photodetectors and corresponding non-standard electronics.

2.3. *Instruments for electromagnetic transient monitoring in ultraviolet and optics*

Instruments for study transient luminous events (TLEs) in UV and optical bands should include position sensitive spectrometer, i.e. small lens telescope with high time resolution for spectral measurements of TLE and lightning and UV and infrared (IR) detector-photometer, which is similar to that used in Tatiana-2 and Vernov missions [6]. This instrument will be added by channels in far UV range. It allows comparison with data of previous experiments on study UV flashes in the Atmosphere. Spectral measurements are necessary to determine the type and altitude of TLE generation as well as to reveal lightning discharges by typical 777 nm line and by the absence of signal in the range of oxygen absorption lines about 762 nm. Axes of both instruments should be directed toward Nadir with open angles about

90°.
For the TLE observations on the CubeSats will be used compact UV detector with a wide field of view (AURA-2) or its improved version, i.e. telescope (AURA-2T) [7]. These instruments are the development of the AURA (Atmospheric Ultraviolet Radiation) detector already launched on board the VDNH-80 satellite. In this instrument SiPM MicroFC-60035-SMT silicon photomultipliers with a sensitive area of 6×6 mm, spectral sensitivity from 300 to 800 nm, a maximum spectral sensitivity at 420 nm, and a quantum efficiency of about 41% at 420 nm are used as photodetectors. Silicon photomultiplier tubes, unlike traditional PMTs used for fast photometry, have a number of advantages that are significant for experiments on small spacecraft. It is compact (thickness about 1 mm), low voltage ($25 - 70$ V) and low weight. The main advantages of the new detector options are high temporal resolution ($1\mu s - 10ms$) and spatial resolution, higher sensitivity due to an increase in the area of the optical system.
The operation of the detectors in the monitoring mode under the condition of simultaneous operation on several spacecraft will make it possible to control transient activity in the Earth's atmosphere, both of thunderstorm and extra-thunderstorm nature with a large exposure. Cartography and monitoring of UV transients is an important task for understanding the interconnections of various energetic processes in the atmosphere. Also, the quasi-stationary UV glow of the atmosphere can be an additional indicator of the state of the geomagnetic situation and the effect of the solar wind on the atmosphere and magnetosphere of the Earth.

3. First results of Moscow University CubeSat missions

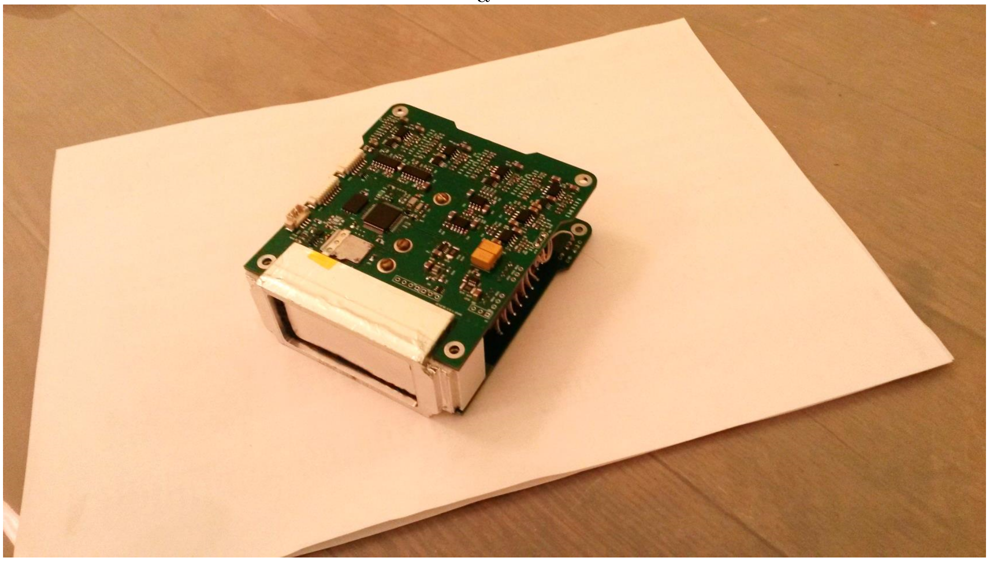
The first stage of the Universat–SOCRAT program began to be implemented on July 5, 2019 after a successful launch from the Vostochny cosmodrome of three nanosatellites of the cubesat type (SOCRAT, AmurSat, VDNH-80). These satellites are equipped with instruments DéCoR (Detector of Cosmic Radiation) for monitoring space radiation, as well as prototypes of instruments for observing transient phenomena in the Earth's atmosphere. In particular, scintillation fosphich detectors, which are prototype of the instrument intended for gamma transient observation on cubsats, are installed on two satellites (AmurSat, VDNH-80). These instruments detect charged particles and gamma rays in the energy release range of 0.1 - 2.0 MeV. The geometric factor of these instruments is $\sim 50cm^2sr$. One of the cubesats (VDNH-80) also contains an optical photometer AURA, consisting of four silicon photomultipliers, whose input windows are covered by different light filters. Thus, the instrument provides observations of the Earth's atmosphere in the range from ultraviolet to red. The satellites were launched into a sun-synchronous orbit with an altitude of $\sim$ 800 km. This creates favorable conditions for monitoring space radiation in various areas of near-Earth space, including zones of captured radiation, areas of precipitation, etc. Such an orbit also allows observations of flash phenomena both in the near-equatorial atmosphere and at high latitudes.

The implementation of the Universat-SOCRAT program was continued by the successful launch on 28 September 2020 of three more spacecraft of the cubesat type, on which DeCoR and AURA-2 instruments are installed. One of them, the DECART 6U satellite, contains three identical DeCoR instruments installed in such a way that their axes are mutually normal to each other, which makes it possible to estimate the angular distributions of the detected fluxes. DeCoR devices are also installed on the Norbi 6U satellite, developed jointly with the Novosibirsk State University, as well as on the Yarilo-2 spacecraft of the 1.5U format, developed jointly with the N.E. Bauman Moscow State Technical University. The AURA-2 instrument is operated on-board of DECART satellite.

3.1. *Parameters, structure and functioning principles of DeCoR payload*

The DéCoR payload is an instrument for measuring the fluxes and spectra of charged particles and gamma rays in the energy release range of 0.1 - 2 MeV. The main scientific goals are the study of fast variations of electron fluxes in the areas of precipitation and the slot between radiation belts, as well as the study of the dynamics of particle fluxes and gamma rays at low orbits in dependence on geomagnetic conditions. An important factor that allows more efficient scientific research is the installation of the instrument on two satellites, sequentially flying through the same region of near-Earth space. A photo of the instrument and sketch of detector unit are shown in Fig. 4.
The DeCoR instrument is adapted in order to be mounted in the cubesat satellite body. Its detector is a two-layer assembly of a plastic scintillator and a CsI (Tl) crystal (see Fig. 4b). The detector has a sensitive area of $\sim 18cm^2$. The assembly is viewed by two PMTs. Separate digitization of the initial and final parts of the PMT output pulse ("Fast component" and "Slow component") from each PMT allows determining the scintillator in which the interaction took place from the pulse shape analysis pulse and, thus allows separate measuring of electrons and gamma ray fluxes. Data and commands are exchanged with the satellite's on-board systems by the instrumentmicrocontroller of the device using the UART protocol. For the accumulation and storage of scientific data non-volatile memory with a capacity of 16 MB is foreseen in the instrument. For transmission to the Earth, the DeCoR instrument generates both monitoring data (particle counting rates 1 time per second) and detailed data about all interactions in the detector with a time resolution of $20\mu s$ (so call event by event mode), which are accumulated in the instrument's memory by a command that determines the moment of interesting time from the view of the researcher . The main way to conduct a scientific experiment is to regularly collect and transmit monitoring data to the Earth, as well as activate from time to time the detailed recording mode on pre-calculated sections of the satellite trajectory passing through the zones of possible variations of the trapped and quasi-trapped particle fluxes.

a



b

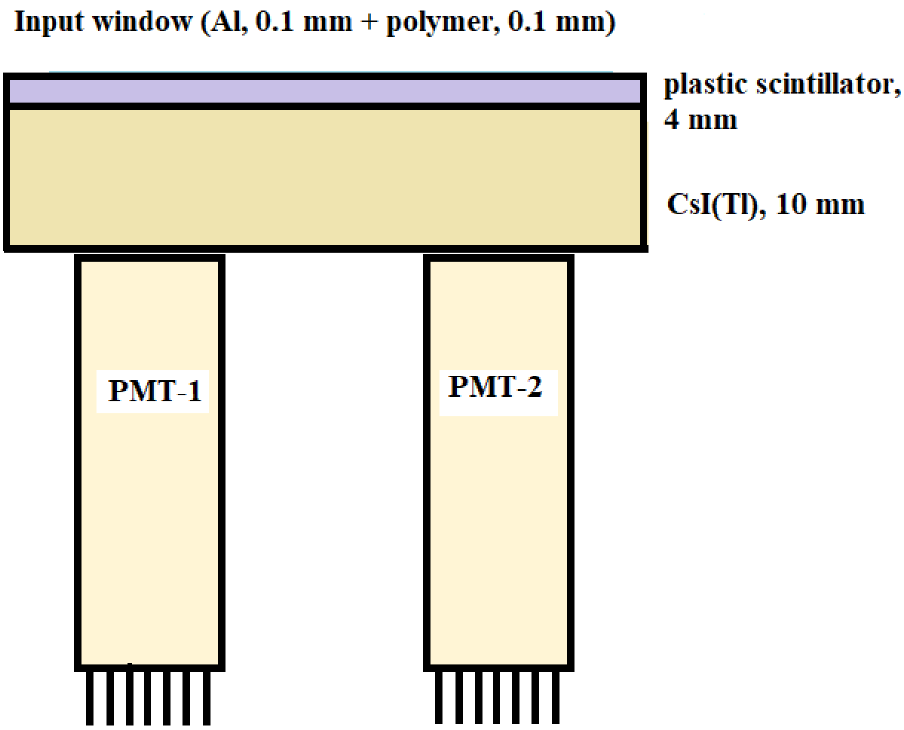


Fig. 4. The photo (a) and general view (b) of DeCoR instrument.

After viewing data of the "Monitoring" type, the researcher identifies the time points at which the flow variations of interest actually occurred. For these moments, detailed data is requested for transmission to Earth. The used data transfer rate allows you to transmit detailed data about an interesting phenomenon, for example, about the precipitation of magnetosphere electrons lasting several minutes, for A magnetometer is also installed in the DeCoR instrument, which makes it possible to measure the magnitude of the magnetic field along three mutually perpendicular axes. Using the outputs of this magnetometer allows taking into account spacecraft rotation in the study of trapped and precipitating electrons and even use it to estimate the pitch-angle distribution of particles. The magnetometer data are included directly in the monitoring information frames containing the parameters of the measured radiation.

3.2. *The results of observations with DeCoR instrument on-board AmurSat and VDNH-80 satellites*

Space missions with AmurSat and VDNH-80 satellites were the first Moscow University experience of monitor observations on cubesats. Due to technical problems, first of all connected with necessity of solar battery charging and limited transmitter capabilities, during both missions data were obtained from DeCoR instrument for about hundred and a half orbits. Taking into account that background conditions appropriate for GRB observations were on about a half of orbit, real instrument field of view about 1 sr and GRB detection threshold about $5 \cdot 10^{-7} erg/cm^2$, the expected number of detecting GRBs was no more than one. Really there were no detected any significant gamma-quantum flux increasing, which can be discussed as GRB candidates. Nevertheless sufficiently rich experience was obtained in view of radiation monitoring, especially of electron flux variation study by two spacecraft.

As noted above, an important advantage of multi-satellite experiments is the possibility of simultaneous measurements at different points in the near-Earth space on the one hand and measurements in the same regions with sequential passage of satellites through them on the other. Such measurements are illustrated in Fig. 5, 6, which show the orbital projections of the AmurSat and VDNKh-80 satellites and the outputs of two DeCoR instruments installed on these satellites, which were recorded on March 18, 2020. The difference in the positions of the satellites was about half of the orbit, so at the same time one spacecraft was taking measurements in the North Polar Region, and the other in the South.
Instruments on both satellites were switched on over Kaluga-city, when the satellites were moving in the direction of the northern polar region. At the moment of switching on the DeCoR instrument on the VDNH-80 satellite, the AmurSat cubesat was in the southern hemisphere, so the DeCoR instrument on it was switched on after ~ 45 minutes. At the same time, the AmurSat satellite continued to move along a similar trajectory with the VDNH-80 spacecraft.

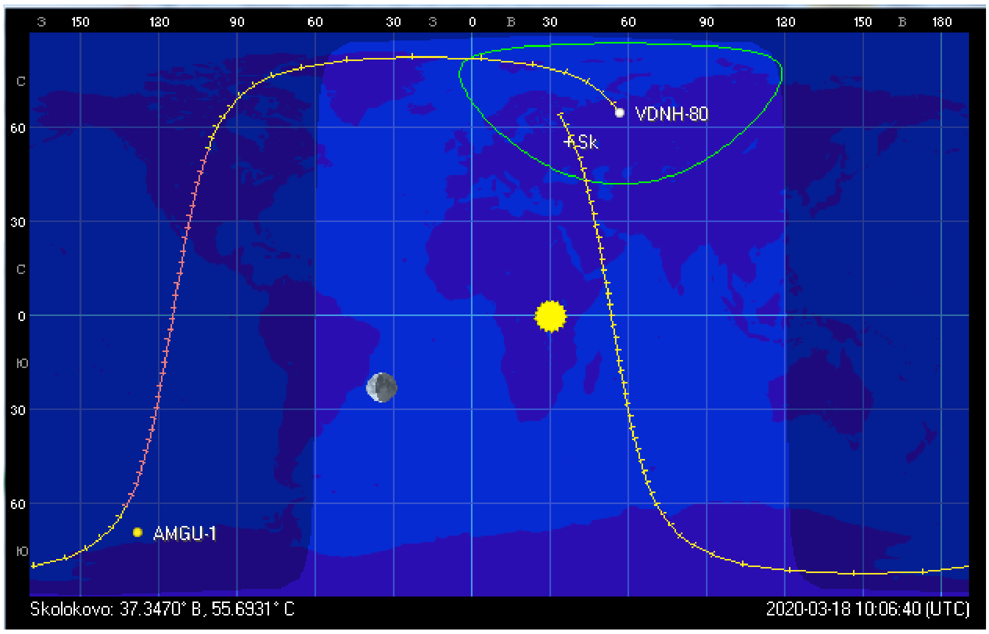


Fig. 5. Projection of VDNH-80 satellite orbit onto the Earth map when the DeCoR instrument was switched on March 18, 2020.

The orbital projection of the VDNH-80 satellite during the switching on of the DeCoR instrument on March 18, 2020 is shown in Fig. 5. It also shows the position of the AmurSat satellite at the moment when the DeKoR instrument was switched on the VDNH-80 satellite. The DeCoR instrument on the AmurSat satellite was switched on in ~ 45 minutes above the communication point in Kaluga, thus, the data array transmitted from the AmurSat satellite corresponds to a trajectory close to that shown in the figure.

The time variation of the counting rate of electrons with energy > 300 keV along the orbit of the VDNH-80 satellite, recorded in the monitor mode with a time resolution of 5 s are shown in Fig. 6a. The maxima are clearly visible at the moments when the satellite is in the outer radiation belt of the Earth, as well as some small increases in the polar region. Significant increases in the counting rate near the geomagnetic equator are also clearly visible.

The counting rates in a similar channel of the DeCoR instrument installed on the AmurSat satellite are shown in Fig.6b. Noteworthy is the repeatability of the features visible when two satellites pass the same polar region with an interval of ~ 45 minutes. During the flight of the geomagnetic equator, a smooth increase in the electron counting rate is also seen. The moving average line shows modulation with a period of ~ 40 s associated with the rotation of the satellite. As noted above, the presence of such modulation indicates that the electron flux is non-isotropic in the

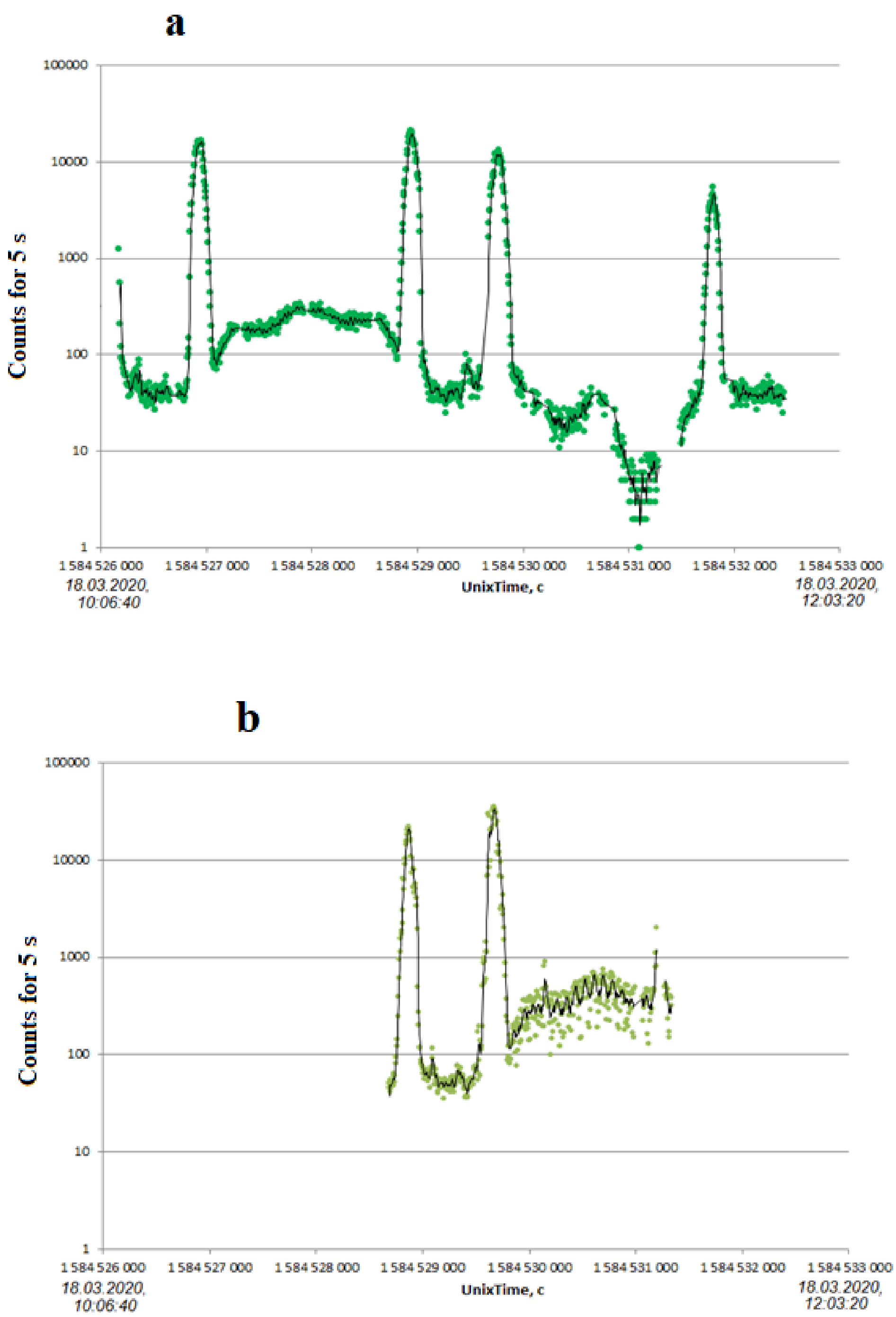


Fig. 6. Time variation of the count rate for electrons with energy¿ 300 keV, recorded in the monitor mode of the DeCoR instrument operated on-board VDNH-80 satellite on March 18, 2020 (a), similar readings of the DeCoR instrument on -board AmurSat satellite (b).

near-equatorial regions.

3.3. *The first experience of observations with DéCoR instruments on-board Norbi and DEKART satellites*

Just now the stage of flight tests of Norbi and DEKART missions was completed and regular observations were begun. The example of DeCoR instrument data obtained from Norbi CubeSat on July 14, 2021 is presented in Fig. 7. There it can be seen the monitor time dependent (with 5 s time resolution) count rates in plastic detector (mainly electrons) and CsI(Tl) (mainly gamma quanta) recorded for several consequent orbits. All typical variations caused by the near-Earth radiation flux distribution can be seen. There are seen peaks connected with the crossing of the outer belt regions and South–Atlantic Anomaly, as well, as in precipitation areas.

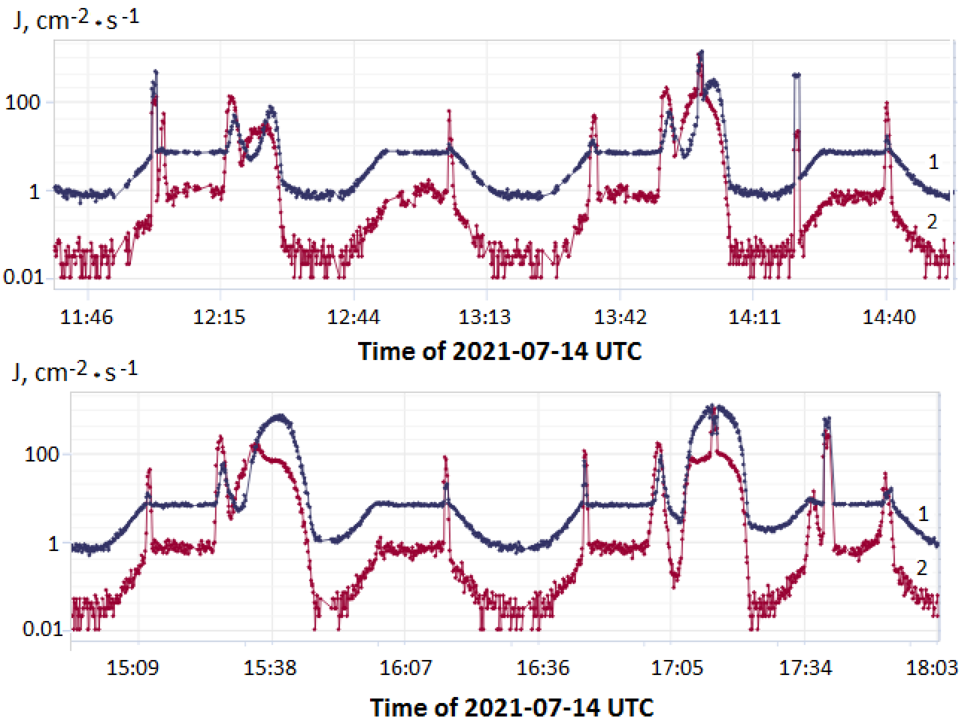


Fig. 7. Time variation of the count rate for electrons with energy > 300 keV (red curve) and for gamma-quanta (dark blue curve), recorded in the monitor mode of the DeCoR instrument operated on-board Norbi satellite on July 14, 2021.

It is necessary to note that gamma quantum count rate dependence along the orbit contains the intervals of quasi-constant background that correspond near-equatorial and polar cup regions. These intervals are quite appropriate for GRB detection. Nevertheless on these intervals flux increasing caused by electron precipitation can be observed. The example of such event detected on 04:49 September 28, 2021 is presented in Fig. 8.

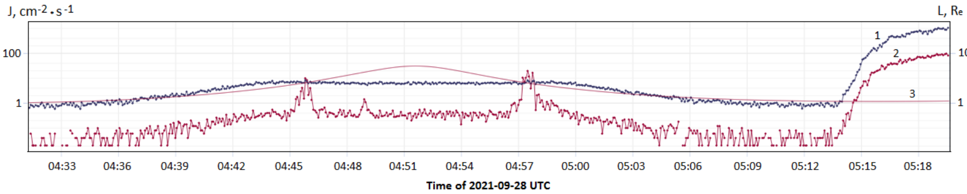


Fig. 8. Time variation of the count rate for electrons with energy¿ 300 keV (red curve), and gamma-quanta (dark blue curve), and L values (violet curve) recorded in the monitor mode of the DeCoR instrument operated on-board Norbi satellite on September 28, 2021.

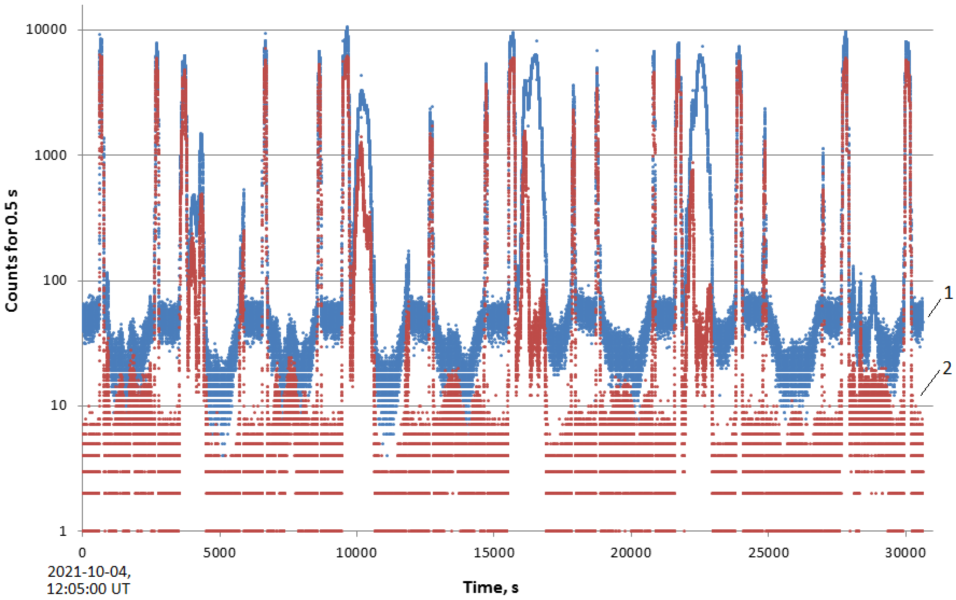


Fig. 9. Time variation of the count rate for electrons with energy > 300 keV (red curve) and for gamma-quanta (dark blue curve) recorded in the monitor mode of the DeCoR detector on-board DEKART satellite on October 4, 2021.

The example of output data from one detector unit of DéCoR instrument on-board

DEKART satellite is presented in Fig. 9. As it could be seen, time dependent gamma quantum and electron count rates, recorded with 0.5 s time resolution along the orbit, are quite similar to those obtained by Norbi satellite. Thus, it gives opportunity for multi-satellite measurements of time effects in near-Earth radiation fluxes and increase probability of GRB detection, including possibility of simultaneous GRB observation on two satellites.

4. Conclusion

The successful realization of the CubeSat missions in frame of Universat–SOCRAT project make it possible for the first time to create a prototype of nano-satellite constellation a space system for monitoring of space radiation and electromagnetic transients including GRBs.
The first stage of this project was beginning from the launching of three CubeSats in July, 2019 and then three CubeSats in September, 2020. The prototypes of the instruments, which should be used in future Universat–SOCRAT missions were tested in these orbital experiments with CubeSats. Results of these tests confirmed that instruments operate well as in terms of command control as in terms of detector parameters. The particle flux measurements carried out during flight tests demonstrate the presence of variations corresponding to the expected changes in outputs at low polar orbit. During flight tests, both monitoring data with a time resolution of ~ 0.5, 1 and 5 s and event by event data with a time resolution of $\sim 20 \mu s$ were successfully obtained from both DeCoR instruments installed on-board launched cubesats. Obtaining and processing of these data allows us to analyze both slow and fast particle flux variations. Thus, flight tests have confirmed the suitability of the instruments for the scientific research for which they were intended including principal possibility of GRB observation.

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