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2. The results of scientific research on completed space missions obtained by Russian scientists in 2014-2015

Experiment RELEC onboard the Vernov spacecraft

The main goals of RELEC (Relativistic ELECtrons) mission are the following:

- transient luminous events (TLE) observation in wide range of electromagnetic spectrum. Terrestrial Gamma Flashes (TGF) and Transient Luminous Events (TLE) are considered as TLE
- studying of magnetosphere relativistic electron precipitation and acceleration and its acting on the upper atmosphere.

The scientific instruments were installed on the small spacecraft named Vernov in honor of one of the founders of Russian space program academician Sergey Nikolaevich Vernov. The spacecraft was based on “Karat” platform, developed and manufactured by the S.A. Lavochkin space corporation. It is presented in Figure 1.

Fig. 1. Vernov spacecraft.

The mission parameters:

- mass – 283 kg;
- orientation accuracy – 6 angular minutes;
- stabilisation accuracy – 0.0015^{o}/s;
- data rate – 5 Mbit/s.
- The satellite orbit is solar-synchronous with apogee 830km, perigee 640 km, inclination 98.4^{o}, period 100 min.

The main operational mode is monitor observation when the all instruments are switched on and operate simultaneously. The regular data transfer to the Earth is about 1,2 Gbyte per day. Satellite was launched 2014, July, 8.

The RELEC set of instruments includes two identical detectors of X- and gamma-rays of high temporal resolution and sensitivity (DRGE-1 & DRGE-2), three axe directed detectors of energetic electrons and protons DRGE-3, UV TLE imager MTEL, UV detector DUV, low-frequency analyzer LFA, radio-frequency analyzer RFA, module of electronics intended for commands and data collection BE. The photo of the instruments is presented in Figure 2.

Fig. 2. The photo of the RELEC scientific instruments.

During the on-board experiment all instruments connected with electronic unit BE, which is used for power supply, data collection and instrument operating mode control.

The DRGE instrument is designed for the observation of gammas of atmospheric and astrophysical origin, and precipitation of the magnetospheric electrons of relativistic and subrelativistic energy.

The instrument consists of three boxes, two identical boxes DRGE-1, DRGE-2 and box DRGE-3. Physical and technical parameters of the instrument are presented in Table 1. The DRGE-1 and DRHE-2 detector axe are directed toward to the local nadir with accuracy $\pm 3^{o}$. The axes of the DRGE-3 box are directed in a following way: DRGE-31 detector axis is directed to the local zenith, DRGE-32 axis

is directed principally against the satellite velocity vector and DRGE-33 axis is directed normally to the plane formed by two other detectors axe. The axes direction accuracy is $\pm 3^{o}$. The field of view of each detector is not shaded by other spacecraft's elements within 60^{o} from the axis.

Table 1.

	DRGE-1(2)	**DRGE-3**	**Total**
Energy range photons electrons protons	 0.01-3 MeV 0.5-10 MeV 10-100 MeV	 0.05-3 MeV 0.2-15 MeV 5-100 MeV	
Detector effective area	$4\times120=480$ cm^2 (for 4 detectors)	2.5 cm^2	
Field of view	2π sr ($\pm90^{o}$)	1.2 sr ($\pm60^{o}$)	
Mass	~10.4 kg (for one box)	~2.8 kg	~23.6 kg
Size	$0.36\times0.36\times0.18$ m^3	$0.23\times0.3\times0.18$ m^3	
Data volume	~150 MBt/day	~70 MBt/day	~370 MBt/day
Power consumption	~9 W (for one box)	~7 W	~25 W

Both DUV and Telescope-T instruments are intended for the studying of the processes in the upper atmosphere by means of the measurements within UV and IR ranges: afterglow resulted from burn-up of the micrometeorites and

objects of human activity in space, bursts of natural (altitude electric discharges) and industrial origin.

The DUV instrument is one box consists of two photodetectors based on PMTs. The size of the instrument is 130×95×65 mm, mass is 0.7±0.04 kg, power consumption under regular conditions and voltage of 27 V is not more than 2.5 W. The DUV instrument is placed out of the pressurized container on the outer surface of the spacecraft in such a way, that its field of view is not shaded with other elements within $\pm 25^{o}$ from the axis.

The Telescope-T (MTEL RELEC) instrument is able to detect fine structure of atmosphere afterglow in UV (300-400 nm) and red (600-700 nm) ranges. It is one box including two micro-electro-mechanical mirrors (MEMM), two multi-anode PMTs (MAPMT) and electronics.

The instrument size is 500×123×77 mm, mass 3.9±0.2 kg, power consumption with the 27 V voltage no more than 8.0 W. The instrument is placed on the outer surface of the spacecraft, its axis is directed to the nadir with accuracy $\pm 3^{o}$. Its field of view is not shaded with other elements within $\pm 25^{o}$ from the axis. Time resolution is 10 mks.

The complex of low-frequency (LFA) and radio-frequency (RFA) analyzers is intended for electromagnetic wave components and plasma current measurements within wide frequency range. The instruments meters are placed on the special boom and on the thermo-stated panel also. They function properly and keep their characteristics under conditions of underpressure (to 10^{-14} mm Hg) and at the temperature from -30 up to +50º C for the boxes on the platform, and from -150º C up to +150º C for the boxes on the boom. All meters have no resonance frequencies lower than 40 kHz.

The LFA instrument consists of 6 units including three-component fluxgate magnetometer D-FM and its electronic unit BE-FM, induction magnetometer IM, two identical electrometers or complex wave probes KWZ-1, KWZ-2 and spectral

analysis processor PSA(SAS3-R). Mutual orthogonality of three measuring axis is provided by D-FM unit construction. Fluxgate magnetometer allows measure constant magnetic field in the value range no less than 64000 nT, its meter component nonorthogonality no more than 1^{o}, digitizing frequency 250 Hz.

The RFA instrument consists of electronic unit RFA-E and antenna RFA-AE, which able to measure three electric field components of electromagnetic wave in the range from 50 kHz to 15 MHz. The frequency resolution of the instrument is 10 kHz and time resolution is 25 ns. Parameters of LFA-RFA compex are presented in Table 2.

Table 2.

LFA instrument			
Unit	**Size** (mm)	**Mass** (kg)	**Power consumption** (W)
D-FM	Ø(40±0.3)x62	0.13±0.01	< 0.1
BE-FM	148.4x85x40	0.3±0.03	< 0.25
KWZ-1, KWZ-2	Ø(64±0.3)x(325±0.8)	0.40±0.04	< 0.25
IM	Ø(24±0,3)x212	0.15±0.015	< 0.1
PSA(SAS3-R)	150x200x40	1.1±0.1	< 5
RFA instrument			
Unit	**Size** (mm)	**Mass** (kg)	**Power consumption** (W)
RFA-E	(192±0.2)x(149±0.2)x(91.5±1)	1.5±0.2	< 10.0
RFA-AE	54x26x66	0.2±0.02	< 0.1

The BE instrument provides power supplying, command inputs and high accuracy time pulses on the all instruments as well as scientific and telemetry data collection from instruments and its transmission on the satellite on-board systems. It consists of three boxes, one box of power controller and two identical boxes of data controllers, the main and the reserve. The total mass of the instrument is 2.1 kg, power consumption is 5 W, transmitted information daily volume is about 1.2 Gbyte.

During the experiment the following important scientific results were obtained:

- about 10 000 UV and red bursts were recorded; observations of UV bursts in the active thunderstorm areas from the “Tatiana-2” satellite were confirmed; at the same time UV-bursts certainly not associated with thunderstorm activity were also detected, some of them were observed at high latitude;

- airglow in UV and red ranges of industrial origin was found; it could be associated with operation of low-frequency transmitters, while modulation rate is, probably, detected in the ionosphere as a result of non-linear processes;

- several candidates to the atmospheric gamma-bursts were recorded; they are not accompanied by any intensity bursts within other ranges of the electromagnetic spectrum, which could raise their direct association with lightnings or intracloud discharges;

- several space gamma-bursts of astrophysical and solar origin were recorded, their temporal and spectral characteristics were determined;

- variety of magnetospheric electrons precipitations were detected, including those in the gap between the inner and outer radiation belts; significant electron fluxes in the low-latitude areas under the radiation belts were recorded.

Currently the analysis of the scientific information from the RELEC instrument is in progress.

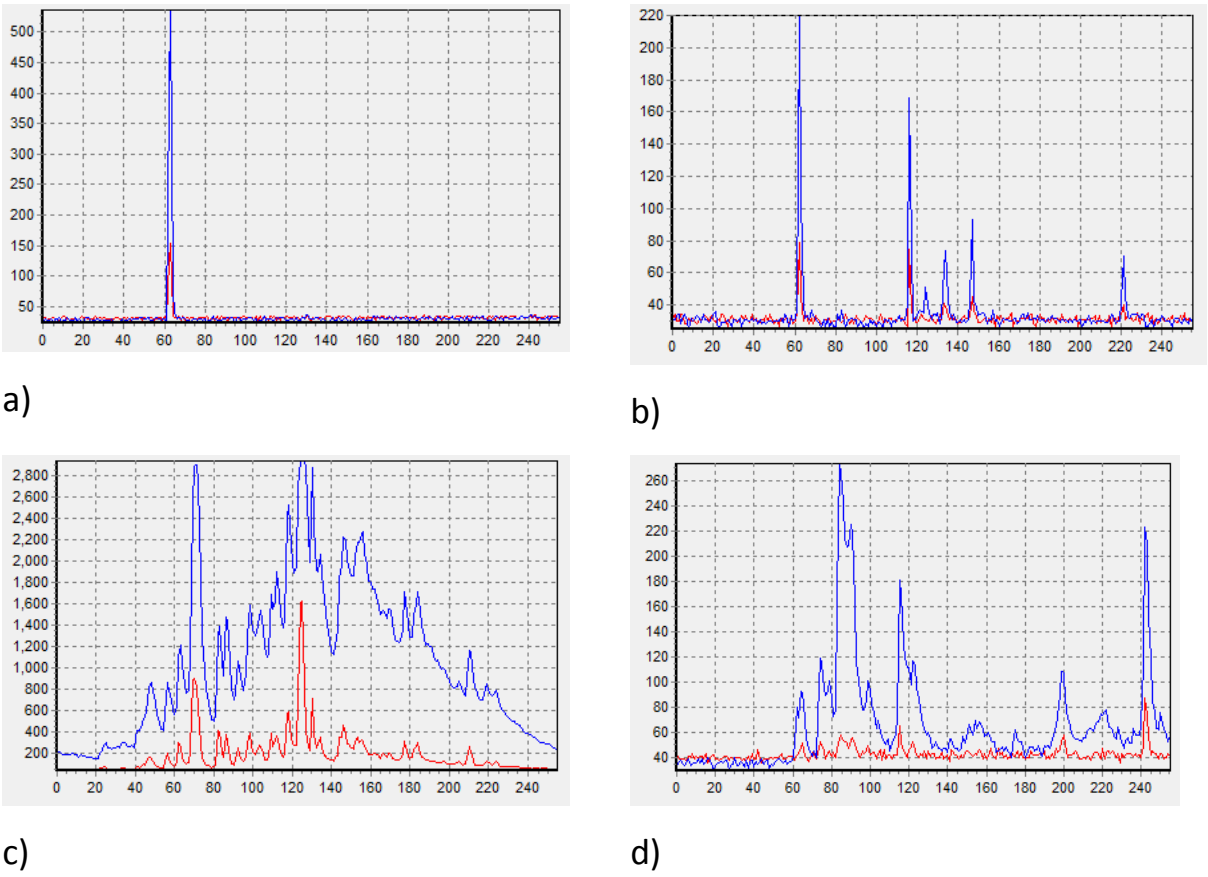

Fig 2. Examples of various TLE waveforms, a) and b) – short pulses in UV and IR channels, c – long events, d) – UV flashes without significant signal in IR channel.

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References

1. Panasyuk M.I., Svertilov S.I., Bogomolov V.V., et al. RELEC mission: Relativistic electron precipitation and TLE study on-board small spacecraft, Advances in Space Research, 2016, 57(3), 835-849, doi 10.1016/j.asr.2015.11.033
2. Svertilov S.I., Panasyuk M.I., Bogomolov V.V., et al. High-altitude discharges and precipitation of the magnetospheric electrons as elements of the global electric circuit: the data of the space experiment RELEC onboard the Vernov spacecraft, Report at the 2nd All-Russian conference "Global electric circuit"October 5-9, 2015, Geophysical observatory Borok, Russia.