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Transient luminous event phenomena and energetic particles impacting the upper atmosphere: Russian space experiment programs

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[1] In Russia several space missions are now planned to study transient luminous events in the atmosphere and high-energy charged particles at satellite altitudes. The experimental goal is to investigate the origin of the high-energy electrons and gamma ray quanta for specific transient luminous events (TLEs) and their role in the ionosphere-magnetosphere system. Simultaneous measurements of electrons at the orbit of the satellite and TLE atmospheric radiation in many wavelength bands will be performed in two missions, Tatiana-2 and RELEC. In the TUS mission UV transient event detection will be accompanied by measurements of the weak UV emission from the "seed" electrons of extensive air showers of extremely high-primary energies.

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1. Introduction

[2] New geophysical phenomena connected with electrical discharges in the upper atmosphere, such as "Sprites," "Elves" and "Blue jets," accompanying "ordinary" lightning were discovered recently, and now are studied with growing intensity. Those phenomena in visible and UV light are defined as transient luminous events (TLE) and interpreted as light produced by an electrical discharge between cloud tops and the ionosphere. But some experimental data, for example anomalous X-ray and gamma ray flashes (bursts) are not accounted for by this standard theory; they indicate a possible important role of high-energy electrons. From this viewpoint, a new discharge mechanism involving runaway electrons is of great interest [*Gurevich and Zybin*, 2001]. This new physical phenomenon was predicted earlier [*Gurevich et al.*, 1992], and has been studied theoretically in detail in [*Roussel-Dupré et al.*, 2008; *Lehtinen et al.*, 1997]. Observations were made aboard the Compton Gamma Ray Observatory (CGRO) and RHESSI of intensive gamma ray bursts [*Fishman et al.*, 1994; *Smith et al.*, 2005] above intense thunderstorms. Duration of the gamma ray bursts is a few milliseconds, and the energy spectrum is like that for electron bremsstrahlung with energies up to 10 MeV. The intensity of photons in such a burst detected in near-Earth orbit (400–500 km altitude) is rather high, about 100 photon $\mathrm{cm^{-2}s^{-1}}$. The theory of runaway breakdown (RB) predicts that visible and UV light should accompany the gamma ray burst. This theory suggests that some "seed" electrons start RB at the top of clouds. An interesting problem is the origin of such electrons. A plausible suggestion is that they are produced by energetic cosmic ray particles penetrating deep into the atmosphere. Also possible is that "thermal runaway" electrons [*Moss et al.*, 2006] play a seed role. Less likely but very interesting are seed electrons produced by high-energy particles precipitated from the Earth's magnetosphere.

[3] We know from balloon [*Makhmutov et al.*, 2003] and space [*Friedel et al.*, 2002; *Dmitriev and Chao*, 2003; *Bucik et al.*, 2005; *Dmitriev et al.*, 2005] experiments that energetic electrons precipitate from the Earth's radiation belt at high latitudes (the phenomenon was called EPE, Electron Precipitation Events). Study of EPE dynamics is of great interest because charge particle acceleration may play important role in energy balance between particle and EM

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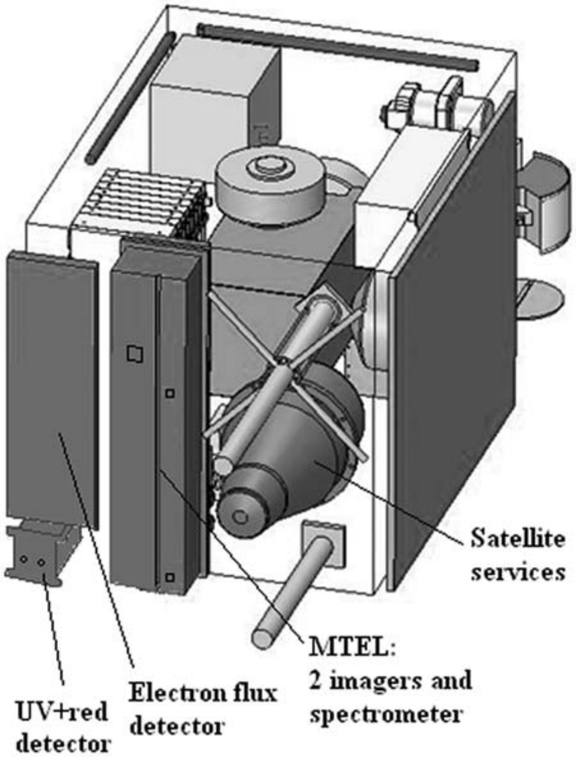

Figure 1. TLE detectors on board the Tatiana-2 satellite.

fields of EPE zones. Also important is the applied aspect of the EPE problem in view of significant input of energetic electron radiation on spacecrafts. Due to high-penetration ability electrons could pass through sufficiently thick layers of shield and make radiation defects in any place of a satellite.

[4] It was shown that the EPE fluxes substantially increase during geomagnetic disturbances. The precipitation may deplete the Earth outer radiation belt (ORB) [*Lorentzen et al.*, 2001; *Dmitriev et al.*, 2002; *Green et al.*, 2004]. The relativistic electron precipitation could be either gradual (with a typical time of hours) or very fast, much shorter than 1 second. In the latter case these electrons may be responsible for UV flashes observed by *Garipov et al.* [2005]. However, the association between EPE and TLE has not yet been shown, because of the lack of experimental data.

[5] Seed electrons produced by cosmic rays should be also studied in more details. For example, intense fluxes of electrons produced in extensive air showers (EAS), generated by very high-energy primary cosmic ray particles, may trigger TLE. In order to distinguish between different sources of electrons initiated TLEs, we should develop sophisticated methods of measuring gamma ray flashes, TLEs and seed electrons simultaneously.

[6] On the other hand, high-energy electrons generated in the atmospheric discharges could be an additional source for filling up the ORBs. In the equatorial region ($L \sim 1$–2), where most of the atmospheric electrical discharges occur, those electrons are the only source responsible for generating sporadic, short-lived ORBs. The low-intensity atmospheric air glow symmetrical about the magnetic equator as observed by *Christensen et al.* [2003] and *Vedenkin et al.* [2009] is an interesting evidence in favor of this hypothesis.

[7] In view of the above considerations, the development of space instrumentation to observe atmospheric transient luminous event phenomena in various wavelength ranges simultaneously with measurements of electrons at the satellite orbit are very important. Space observations have the advantage of covering a large area of the atmosphere needed for such a search and of measuring the rare events of high-energy electron enhancements and gamma ray flashes. To understand the nature of atmospheric electric discharges it is necessary to make remote observations in radio, optical, ultraviolet, hard X-ray and gamma ray bands, with a high time resolution. With these goals several space missions are being prepared as a collaboration of the authors and institutes listed at the title of the paper. The current status of four such future missions is presented below.

2. Universitetsky-Tatiana-2 Mission

[8] Since the Chapman conference (May 2009) the Universitetsky-Tatiana-2 (Tatiana-2 in short) satellite was launched on 17 September 2009 into a sun-synchronous orbit at a height of 820 km, inclination 98.8° as one of the Meteor program satellites. The Tatiana-2 instruments include the following (see Figure 1).

[9] 1. The UV (300–400 nm) and Red (600–700 nm) detector capable of detecting the temporal profiles of TLEs over time interval of 128 ms, with the resolution 1 ms in a field of view (FOV) of 16°.

[10] 2. The MEMS telescope (TLE imager) operating in the wavelength range 300–400 nm with FOV = 11°, taking data from 64 pixels in time samples 0.04 ms over time interval 4 ms and growing time samples at later intervals (up to 0.16 s). The second MEMS telescope with longer focal length gives "magnified" image of the event in area selected by data from the first telescope (for details see *Park et al.* [2008]).

[11] 3. The spectrometer with 8 bands over the wavelength range 300–800 nm, and the ninth channel with open window, following the TLE time evolution in several spectral windows. The band wavelengths were chosen to be close to the wavelengths of important transitions of excited nitrogen molecules. The brightest lines are 2P (λ = 314–378 nm) and 1N (λ = 390 nm) in near UV range. In Red range the brightest lines are 1P (λ = 600–1000nm). Spectra will be measured with the same time resolution and in the same FOV as the images measured by the telescopes.

[12] 4. The electron flux detector of area 350 cm^2, capable of detecting temporal profiles of the electron fluxes in the same timescale as the TLE detectors. Energy threshold for electrons penetrating to the scintillation plate of the detector is $\cong$0.5 MeV, minimum energy release measured in the scintillation plate is $\cong$1 MeV.

[13] The goals and instrumentation of the Tatiana-2 mission are discussed in more detail by *Garipov et al.* [2009].

3. Chibis-M Mission

[14] The main goal of Chibis-M mission is study of high-altitude atmospheric discharges. Total spacecraft mass with support systems, construction and scientific instruments is

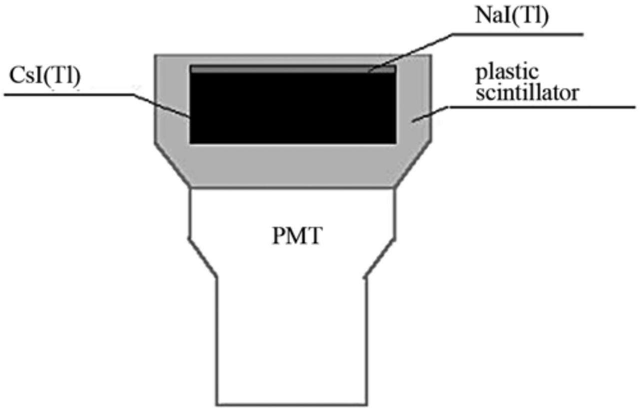

Figure 2. Phoswich detector DRGE.

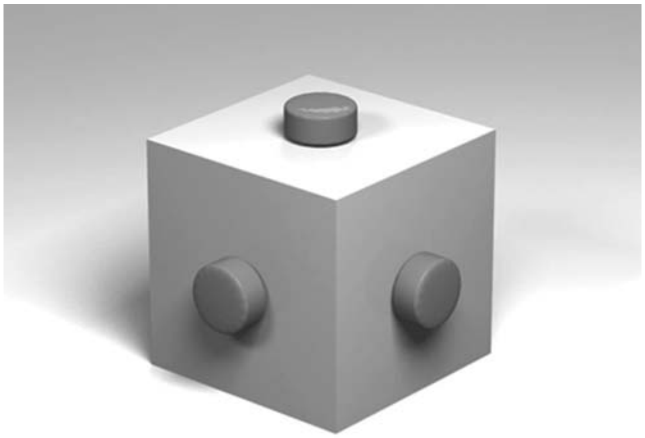

Figure 3. Three axis DRGE instrument.

40 kg. The satellite is expected to be launched in 2010 as a bypass mission of the "Progress-TM" space vehicle servicing the ISS. Its orbit will be ISS-like (inclination 51°) with height 500km. The scientific payload includes the following instruments: (1) X-ray/gamma detector (range of energies 50–500 KeV), (2) UV detector (wavelengths 300–400 nm), (3) radio frequency analyzer in (20–50 MHz) band, (4) video camera in visual range (spatial resolution in the atmosphere 300 m), and (5) plasma-wave compound (0.1–40 KHz).

[15] The microsatellite "Chibis-M" is under construction in the Institute of Cosmic Research. For details of the Chibis instrumentation see *Klimov et al.* [2009] in this issue.

4. RELEC Mission

[16] The RELEC satellite will be launched in approximately 2011 into a sun-synchronous orbit to height of about 750 km. The aim of the RELEC mission is studying precipitation of magnetosphere relativistic electrons and their impact on the Earth atmosphere (ionosphere) including the observations of fast transient phenomena in the upper atmosphere. It will provide combined observations of UV/X/gamma radiation and charge particle fluxes, as well as electromagnetic fields. The goals of RELEC mission are (1) simultaneous observations of energetic electron and proton fluxes (energy range 0.1–10 MeV) and low-frequency (0.1–10 kHz) electromagnetic wave field intensity variations; (2) fine temporal measurements of transient atmospheric events in radio (0.1–15 MHz), UV, X- and gamma ray with a possibility of UV-optical imaging with high space resolution ~km in a wide FOV; and (3) measurements of electron pitch angle distribution in fluxes of a dynamic range from 0.1 to 10^5 particles cm^{-2} s^{-1}.

Table 1. Physical Parameters of the DRGE-1 and DRGE-2 Scintillation Detectors

Parameters	Values
Energy Range	0.01–2.0 MeV
Total area	~800 cm^2
Effective area	~200 cm^2
Temporal resolution	0.1 ms
Sensitivity	~5 · 10^{-9} erg/cm^2

[17] The RELEC set of instruments includes (1) two identical detectors of X- and gamma rays of high temporal resolution and sensitivity (DRGE-1 and DRGE-2), (2) three axis directional detector of energetic electrons and protons DRGE-3, (3) the UV flash detector and UV imager MTEL, (4) the low-frequency radio analyzer NchA, (5) the radio-frequency analyzer RchA, and (6) dosimeter module DOSTEL and the electronic unit BE.

[18] The DRGE-1,2 instruments are based on two identical NaI(Tl)/CsI(Tl)/plastic scintillation phoswich detectors both looking toward the Earth, Figure 2. Their physical parameters are presented in Table 1.

[19] The DRGE-3 instrument consists of three identical NaI(Tl)/CsI(Tl)/plastic scintillation phoswich detectors, directed along three Cartesian axes, see Figure 3. Its physical parameters are presented in Table 2.

[20] The UV flash detector and MTEL imager are the same instruments as in the Tatiana-2 project.

[21] The low-frequency analyzer NChA consists of two electric field meters, induction magnetometer, a Ferro-probe magnetometer with separate electronic unit and spectrum-analyzer unit (see Figure 4). It provides measurements of two electric field components and one (or two) magnetic field component(s) in the frequency band 20 Hz to 20 kHz, with 1024 spectral channels, with a frequency step of 20 Hz and a time resolution of 2s.

[22] The RChA instrument is an electronic module to measure the electrical and magnetic components of radio frequency emissions in the frequency range from 100 kHz to 15.0 MHz. The instrument has three H field antennas, three dipole E field antennas on the corresponding H/E antenna

Table 2. Physical Parameters of the DRGE-3 Detector

	Electrons	Protons
Energy range	0.01–10.0 MeV	1.0–100.0 MeV
Geometrical factor	~2 cm^{2}sr	~2 cm^{2}sr
Temporal resolution	0.1 ms	1.0 ms
Sensitivity	~10 particles/cm^{2}s	~10 particles/cm^{2}s

Table 3. Physical Parameters of the RChA Instrument

Parameters	Values
Frequency range	0.1–15 MHz
Spectrum resolution	10 kHz (from 0.1 to 1.0 MHz) 100.0 kHz (from 1.0 to 15.0 MHz)
Dynamic range [dB]	70.0 (TBC)

booms, and the electronics box. The main characteristics are presented in Table 3.

[23] The DOSTEL instrument is a dosimeter unit intended for background radiation measurements.

[24] Ground-based support of the RELEC mission, with optical and VLF/ELF measurements of thunderstorms and lightning activity, is also planned.

5. TUS Mission

[25] The TUS detector is the main part of the Moscow State University "Mikhail Lomonosov" satellite. The TUS scientific payload has mass of 60 kg, electric power 60 W, orientation to nadir ±3°. The "Mikhail Lomonosov" will be launched to sun-synchronous orbit of 500 km height and inclination $\cong 90°$ in 2011. Its operational lifetime is expected to be ≥ 3 years. The TUS detector main goal is the detection of extremely energetic cosmic rays generating extensive air showers (EAS) which in turn radiate UV fluorescence in the atmosphere. For this goal a large mirror-concentrator is needed: the TUS mirror area is 2 m^2. In the mirror focal plane 256 pixels will make an image of the atmosphere fluorescence in wavelengths of 300–400 nm in a FOV of 9°, see Figure 5. The pixels cover an area of the atmosphere of 4000 km^2. Pixel signals are sampled each $0.8\mu s$, enabling to detect the movement of the EAS particle disc. The primary EAS energy will be measured from the number of EAS particles (mostly electrons) in the maximum of shower development. The number of EAS electrons is proportional to the amount of UV fluorescence radiation produced by the EAS in the atmosphere. In the hypothesis that EAS electrons are "seed" electrons for runaway breakdown in the atmosphere, in the presence of high electric field a bright UV flash should arise immediately after the detection of EAS.

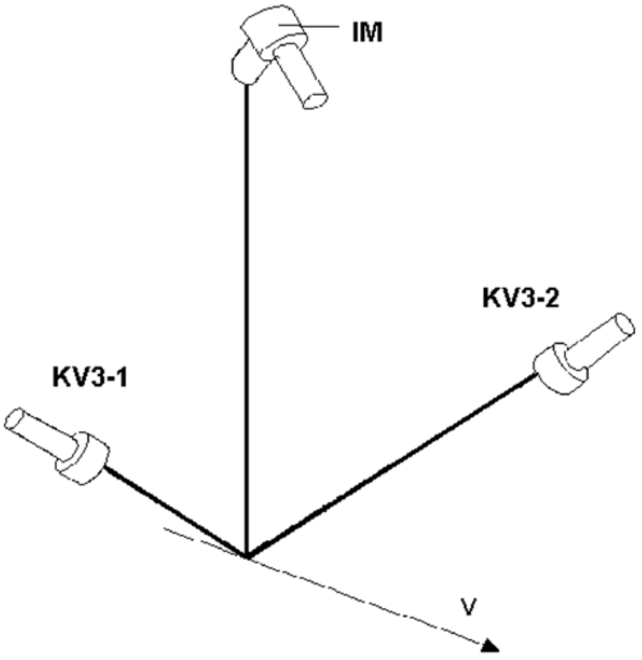

Figure 4. Low-frequency analyzer NChA.

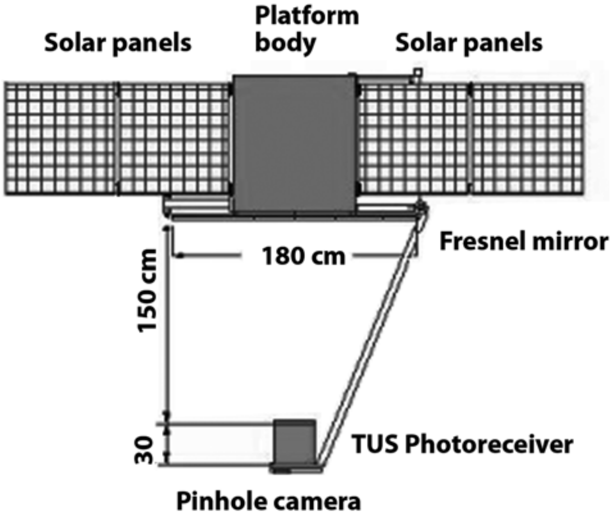

Figure 5. TUS detector.

[26] Independent of EAS detection the TUS detector will select and measure the early stage of the atmospheric electric discharges. In the bright stage of the atmospheric UV flash, the detector pixels will be saturated. For observation of the UV flash bright stages an additional instrument, the pinhole camera, is introduced to the TUS receiver. It operates in the same FOV independently of the main TUS instrument and will allow us to select and measure the bright atmospheric UV flashes. The pinhole camera aims are similar to previous missions, with addition of a search for TLE early stage by the main TUS detector.

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