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ScienceDirect

Advances in Space Research 57 (2016) 835–849

ADVANCES IN SPACE RESEARCH
(a COSPAR publication)

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RELEC mission: Relativistic electron precipitation and TLE study on-board small spacecraft

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Received 11 August 2015; received in revised form 24 November 2015; accepted 26 November 2015
Available online 5 December 2015

Abstract

The main goal of the Vernov mission is the study of magnetospheric relativistic electron precipitation and its possible influence on the upper atmosphere as well as the observation of Transient Luminous Events (TLE) and Terrestrial Gamma Flashes (TGF) across a broad range of the electromagnetic spectrum.

The RELEC (**R**elativistic **Elec**trons) instrument complex onboard the Vernov spacecraft includes two identical X- and gamma-ray detectors of high temporal resolution and sensitivity (DRGE-1 and DRGE-2), three axis position detectors for high-energy electrons and protons (DRGE-3), a UV TLE imager (MTEL), a UV detector (DUV), a low frequency analyser (LFA), a radio frequency analyser (RFA), and AN electronics module responsible for control and data collection (BE).

The RELEC mission conducts the following experiments:

– simultaneous observations of high-energy electron and proton fluxes (within the energy range of ~0.1–10.0 MeV) and low-frequency (~0.1–10 kHz) electromagnetic wave field intensity variations with high temporal resolution (~1 ms);

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http://dx.doi.org/10.1016/j.asr.2015.11.033

– fine time structure (~1 μs) measurements of transient atmospheric events in UV, X- and gamma rays with an optical imaging capability with a resolution of ~1 km in wide field of view (FOV);
– measurements of electron flux pitch-angle distributions in dynamical ranges from ~0.1 up to 10^5 part/cm^2/s;
– monitoring of charged and neutral background particles in different areas of near-Earth space.

Keywords: Transient energetic phenomena; Charged particles; Upper atmosphere

1. Introduction

The atmospheric transient energetic phenomena (TEP) are the main subject of scientific research in the RELEC experiment onboard the Vernov spacecraft. Terrestrial Gamma Flashes (TGRF) and Transient Luminous Events (TLE) are considered here as TEP.

TGRFs and TLEs are observed both in the stratosphere and mesosphere, i.e. at the source altitude from about 12 km up to a few dozen kilometers (Cummer et al., 2014). They are accompanied by short rising electron fluxes and electromagnetic radiation bursts across a very wide bandwidth, ranging from radio waves up to gamma rays, including optical frequencies.

The optical phenomena known as sprites, elves, and blue jets are TLEs.

The characteristics of TLEs including spatial and temporal structure, rate of occurrence, and optical brightness in different ranges are found in Vaughan and Vonnegut (1989), Fisher (1990), Lyons (1994), Boeck et al. (1995), Winckler et al. (1996), Boccipio et al. (1995).

The intensive atmospheric X-ray and gamma-ray bursts were detected from space experiments in thunderstorm areas (Fishman et al., 1994; Nemiroff et al., 1997).

TGRFs and TLEs might be the consequence of physical processes resulting from a different kind of high-energy release over short time intervals (between 10^{-6} and 10^{-3} s). However, despite more than 20 years of experimental and theoretical research, there are no clear interpretations of such phenomena.

The runaway electron breakdown (REB) predicted in 1992 and studied in detail theoretically (Gurevich et al., 1992; Dwyer et al., 2012) has come to be of great interest in discussions of such phenomena. For example, REB has been utilized to explain the phenomena of thunderstorms, including giant high-altitude discharges, anomalous X-ray bursts, and powerful Terrestrial Gamma-Ray Flashes (TGRFs). The characteristic feature of this breakdown is its occurrence in electric field values lower than those typical for breakdown fields in clouds. Yet seed electrons are necessary for the initiation of such events. In this context, high-energy cosmic rays may play a principal role in the evolution of breakdown fields (Gurevich and Zybin, 2004). Auger showers (or Extensive Air Showers – EAS) generated by high-energy cosmic rays contain huge amounts of high-energy electrons that may serve as seeds for REBs. The electron motion in thunderstorms' electric fields results in powerful radio pulses (Gurevich et al., 2006), accompanied by TGRFs or TLEs. Electrons from ambient populations of secondary cosmic rays are accelerated by positive or negative dipoles in thunderstorm clouds and initialize relativistic runaway electron avalanches (RREA) (Chilingarian, 2014), direct proof of which was obtained on Aragats (Chilingarian et al., 2011).

The simultaneous observation of radio, optical, and gamma emission as well as electrons detected directly subsequent to their propagation by the thunderstorm electron-gamma ray avalanche will provide direct confirmation of both the theory of runaway electron breakdown and the mechanism for altitude discharges initiated by the strong electric fields characteristic of thunderstorms.

The thunderstorm activity can produce upward traveling beams of relativistic runaway electrons at altitudes 60–80 km (Bell et al., 1995; Lehtinen et al., 1997). Electrons with energies of E ~1 MeV and above are able to penetrate to penetrate the Earth's magnetosphere and feed the radiation belts. According to (Lehtinen et al., 2000), high-altitude discharges with REBs can be one of the inner radiation belt sources. Such electrons may produce long (about 20–30 ms) signals in gamma ray detectors. However, attempts at direct measurements of runaway electrons by means of the large area electron detector onboard the Tatiana-2 satellite did not produce any tangible results (Sadovnichy et al., 2011).

Nevertheless, the detection of electrons by the CGRO (Dwyer et al., 2008) and positrons by the RHESSI (Briggs et al., 2011) space missions may be considered as indirect evidence of the occurrence of runaway electron avalanches occurring in areas of thunderstorm activity. Double peaks separated by ~15 ms in the gamma ray light curve were observed during these experiments. The second of these peaks has been interpreted as the result of positron annihilation and electron and positron Bremsstrahlung produced within the spacecraft materials as the result of electron and positron beams reflected from the conjugate mirror point. According to these results, by different estimations, the positron component of such events can reach as high as 11% (Briggs et al., 2011).

Relativistic electrons, which are seeding, the altitude discharges in the mesosphere may penetrate to the