Transient UV flashes in the upper atmosphere as a background for the orbital detector TUS operation

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Orbital ultra high energy cosmic ray (UHECR) detector TUS (tracking ultraviolet set-up) is prepared for launching on-board Lomonosov satellite. The TUS space experiment is aimed to study energy spectrum and arrival distribution of UHECR at energy range above 10^{20} eV. TUS detector will operate in various UV night atmosphere background. Fast UV flashes (lightning, transient luminous events) are an important part of background. These transient events will effect operation of trigger system and decrease duty cycle of UHECR detectors especially above thunderstorm regions where frequency of lightning could be very high. New measurements of transient events were performed by UV detector on board Universitetsky-Tatiana-2 satellite. Influence of transient luminous events on operation of UHECR detector TUS is discussed.

1. Introduction

The TUS detector planning to be lauhched on-board Lomonosov satellite in 2015 [1]. The main goal of the TUS experiment is aimed to study energy spectrum and arrival distribution of UHECR at energy range above 10^{20} eV. Detector contains a large Fresnel-type mirror-concentrator (2 m^2) that focuses UV light generated by EAS particle disc to photo receiver, which consists of 256 PM tubes (matrix of 16×16 PM tubes with a spatial resolution in the atmosphere near 5 km) and readout electronics. Photo receiver placed in its focal plane. Image of EAS particle disc moves along photo receiver pixels and produce sequent in time signals in one or more pixels.

On October 20th, 2009 microsatellite Universitetsky-Tatiana-2 (Tatiana-2) was launched on the solar synchronous orbit with inclination of 98° and altitude of 850 km. The main goal of the scientific program of this satellite was study of space near the Earth by measuring charge particle fluxes at the orbit and radiation from the atmosphere. Radiation from the atmosphere was measured by detectors in two ranges of wavelengths: 240 – 400 nm (UV) and 610 – 800 nm (red-IR) [2, 3]. Both detectors were photomultiplier tubes. Detectors were oriented to nadir and covered the atmosphere area of effective diameter 300 km (effective area $7\cdot10^4$ km^2).

2. Results of UniversitetskyTatiana-2 satellite mission

During the operation time from October 2009 to January 2010 detectors of UV and red-IR radiation, installed on board Tatiana-2 satellite have registered more than 2000 transient events in the atmosphere with duration 1-128 ms (average rate $5\cdot 10^{-5}$ events/km^2 hr) with different temporal profiles and number of photons produced in the atmosphere. Selected transient events are distributed in wide range of photon numbers (10^{20} – 10^{26}).

The global distribution of all detected by Tatiana-2 events has an evident component concentrated above continents in equatorial region (America, Africa, Indo-China). There are some regions which transients avoid–deserts of Sahara and Australia. In the most active areas (south America, Africa, Indonesia, Australia) the transient rate is of about $6\cdot10^{-4}$ events/km^2hr.

Measured ratio of number of photons radiated in red-IR range to number of photons radiated in UV related to excitation of molecular nitrogen indicates a high altitude (> 50 km) of the events [4].

A lot of transients were detected out of thunderstorm areas, in cloudless region thousands km away of thunderstorms. This fact allowed us to assume that transient events are not only direct consequences of lightning.

There is strong correlation of transient event temporal profile with number of photons Q_a in transients: events with $Q_a < 5\cdot10^{21}$ are mostly short single pulse (< 5 ms); events with the large photon numbers $Q_a > 10^{23}$ are mostly longer in time, with duration of tens – hundred ms.

Differential distribution of transients over photon numbers

Q_a shows two ranges with a changing exponent of power law approximating the differential distribution: “-1” for $10^{21} < Q_a < 10^{23}$ and “-2” for $Q_a > 10^{23}$. Cause of the exponent change could be a possible difference in origin of “small” and “large” flashes. Events with larger photon numbers may be

related to Transient Luminous Events (TLE) recently measured by space video cameras and spectrometers [5]. Events with small photon numbers may be related to one of TLE kind events: “elves”.

Those «small» UV flashes could be important part of background for UHECR observation. Number of fluorescent photons initiated by EAS of energy ~10^{20} eV is ~10^{16} - much less than photon number in transients (~10^{21} photons). Measurements of “small” flashes by TUS detector will be interesting for physics of the atmosphere as TUS will be the first instrument capable to look for space-temporal structure of such small flashes with very large aperture. TUS detector will register flashes up to ~ 10^{24} photon without signal saturation.

3. UV flash modeling

Transient events in the atmosphere measured by Tatiana-2 detectors are very different from fluorescence radiating by EAS initiated by UHECR. EAS fluorescence is much shorter in time (tens of microseconds against milliseconds of atmospheric transients) and image of EAS fluorescent source looks like a point of 1 km size moving through the atmosphere with velocity of light. Measured transients are much longer in time and larger in space scale (from tens to hundreds km). Nevertheless the rate of atmospheric transients is so high to compare with UHECR rate 10^{-6} events/km^{2}hr that triggering by atmospheric flashes may be dominant for TUS trigger system. Registered atmospheric UV flashes may imitate the EAS image if random fluctuations of signals are taken into account. In this way “small” flashes could be more dangerous for imitation as they are closer to EAS events in photon number. Early stage of transients is of special interest as at early stage its signal being close to EAS size and duration may imitate EAS.

For analysis of possible EAS imitation by transients a model of UV flash in the atmosphere was developed with characteristics (duration, number of photons, temporal profile) measured in experiment. The model is close to TLE model of “elves”. The developed model is based on emission of nitrogen molecules excited by an electromagnetic pulse (EMP) with a radial front propagating up in the ionosphere from parent lightning. The total number of photons (Q), emitted by such flash is defined as the integral of the glow over all coordinates in the ionosphere layer in total glow time. In our simulation we are interested in glow expected in a field of view (FOV) of the detector. In this case the ending of the glow is over when the area of intersection of the EMP sphere and the ionosphere layer will go out of the detector FOV.

The temporal profile of the transient glow in the detector is determined by velocity of EMP sphere expansion, position of the ionosphere layer, ready to produce glow, and position of the center of the flash in the detector’s FOV.

It is important to note that described model was adjusted to experimental data on temporal characteristics of small short flashes (signal rise time ~200 ms, signal fall time ~750 ms) [6].

In contrast to expected EAS image an atmospheric flash appears simultaneously at large number of pixels. The flash image changes much slower than “point-like” EAS image moves through the detector.

4. Conclusion

Data on atmospheric flashes obtained in Tatiana-2 satellite mission have shown existence of UV flashes less intensive than usual TLE. Their rate is much higher than the rate of UHECR events. Those small events may present important background in measurements of UHECR from space. In the first approximation the analyzed events could be distinguished from UHECR events. The simulation of TUS measurements of TLE is important for further data analysis.

5. References

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