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The atmosphere UV background phenomena measured by detector on-board "Tatiana" satellite

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Abstract: Near UV detector on-board the "Universitetsky-Tatiana" satellite has observed the atmosphere glow at night side of the Earth. Digital oscilloscopes help to select transient luminous events and to measure their temporal profiles in time scale of 1-64 ms. Data from those detectors were analyzed for prediction the duty cycle of future space detectors of ultra high-energy cosmic rays.

Introduction

One of the most interesting astrophysical problems pointed out by Greisen [1], Zatsepin and Kuzmin [2] – the cosmic rays spectrum cut off at energy 5 10^{19} eV is still not solved, at least the last ICRC data of ground- based arrays were contradictory. In this situation the study of EAS generated by Extreme Energy Cosmic Ray (EECR) of energy E>5 10^{19} eV by space-based fluorescence detectors seems to be the most effective and perspective. The first EECR space mission "TUS" will be launched in 2010 [3]. To develop this detector adequate to its scientific goal it is necessary to know the ultraviolet (UV) night atmospheric radiation. This data are important for energy threshold and detector duty cycle estimations, for choosing the triggering system and regime of operation. Here the data obtained from the UV detector of "Universitetsky-Tatiana" (below "Tatiana") satellite is presented and recommendations for the TUS operation are formulated.

UV detector onboard "Tatiana" satellite

UV detector operated on board the MSU satellite "Tatiana" during January 20, 2005- March 7, 2007 is presented in Fig.1.

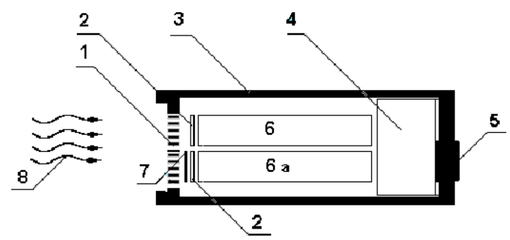

Figure 1: Two PM tubes in the UV detector. 1- collimator, 2 - UV filter, 3 - detector box, 4 - electronics, 5 - socket , 6 - opened PMT, 6a - closed PMT, 7 - cover, 8 -UV radiation.

The detector consists of two PM tubes. The opened one is used for atmospheric UV radiation measurements, and the closed one - for estimate of the background from the charge cosmic ray particles passing through detector elements (in the experiment data from this PM tube proved a negligible background from charge particles). The collimator, situated in front of the first PMT limits the field of view to 15° and decreases the effective area of PMT to 0.4 cm^2 . The geometry factor of the open detector is 0.02 cm^2 sr. The detector efficient wavelength range is λ=300-400 nm. It is determined by the UV filter cutting the light with wavelength λ>400 nm and the quantum efficiency of the PMT cathode decreasing at λ<300 nm.

UV detector was monitoring the night atmospheric UV radiation every 4 seconds measuring the average signal in integral time 64 ms. The high voltage on PMT depends on UV intensity and changes every 1 second automatically in order to maintain the anode current constant. It allows us to measure UV radiation in wide range of intensities (from ~10^7 photon/cm^{2}sr s to ~10^{13} photon/cm^{2}sr s).
The detector is able to select and measure a short UV flashes with the help of two digital oscilloscopes with traces of 4 and 64 ms (every trace has 256 time samples of 16 and 256 μs correspondingly). Triggering of the oscilloscopes was set for selecting the brightest event in one satellite circulation on the night side of the Earth (the satellite telemetry was limited for transmitting data on all flashes).
For details of the detector operation see paper [3] and for the first "Tatiana" results [4].

"Tatiana" data on the UV intensity

During more than 2 years of its operation the "Tatiana" satellite provided map of UV intensity practically above all Earth's surface with different moon phases and its heights over the local horizon. A general trend of the measured data is presented in Fig. 2. In rare circulations when high Northern and Southern latitudes 60º-70º are available for night observation the detector observes aurora glow (shaded high latitude area in Fig. 2, the UV intensity ~$1\cdot10^9$ photon/cm^{2}sr s). In Fig. 3 and 4 examples of such measurements at moonless night are presented. One can see that at middle latitudes UV intensity is order of magnitude less than in aurora but still is much higher (~10^8 photon/cm^{2}sr s) than expected intensity from star light (~10^7 photon/cm^{2}sr s). Points of maxima of this middle latitude glow are also presented in Fig. 2. Those points are observed in 2 near equator "ovals" shaded in Fig. 2. Border of those ovals is not constant. The same kind of "ovals" were observed at wavelength 135.6 nm [5], the origin of such "ovals" is presumably ionosphere turbulences.

At moon nights the average UV intensity grows with the moon phase, but not linearly, Fig. 5, as the new (old) moon sets down (rises) in one circulation. During full moon nights the UV intensity has maximum of $3\cdot10^9$ photon/cm^{2}sr s above the cloud cover.

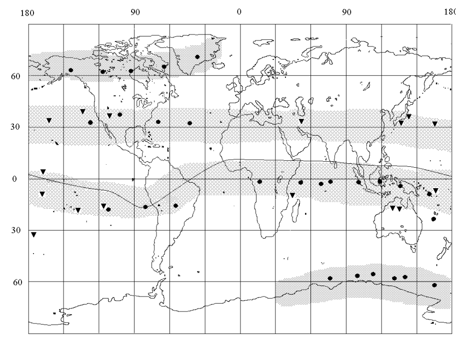

Figure 2: ●- night UV intensity maxima observed in circulations when high latitudes are available, ▲- UV intensity maxima observed in circulations when only equatorial and middle latitudes are available. Shaded are aurora "ovals" (latitudes ~60º) and order of magnitude fainter glow "ovals" near equator.

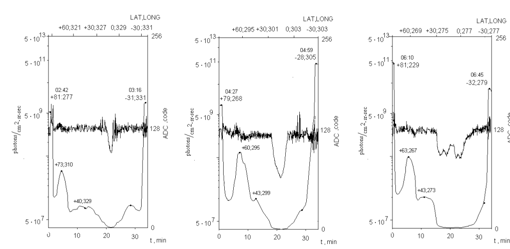

Figure 3: Examples of UV intensity measurements in circulations containing aurora oval. The Northern hemisphere, December 2005. UV intensity is presented by thin line (pay attention to nonlinear scale in left Y-axis). Thick line presents ADC code values which are significant for measurement of minimal UV intensity.

UV flashes

Digital oscilloscope method allowed us to measure transient UV flashes. Examples of UV flashes are presented in Fig. 6.

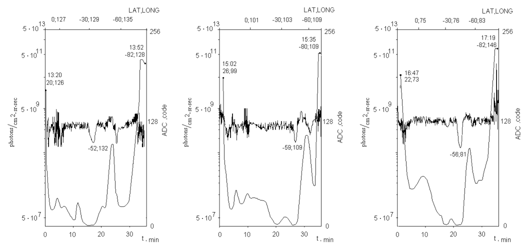

Figure 4: Same as in Fig. 3, the Southern hemisphere, July 2005.

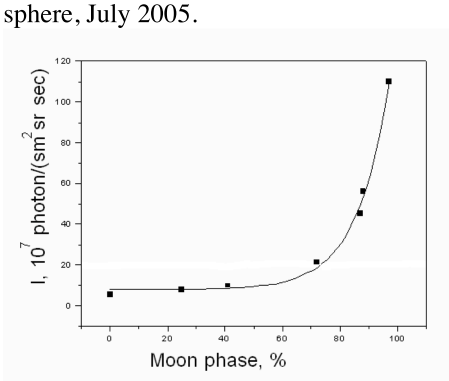

Figure 5: Dependence of UV intensity (averaged over one circulation) on the moon phase.

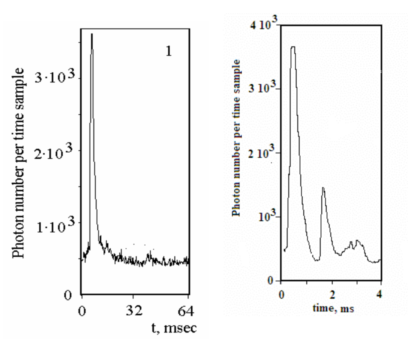

Figure 6: Examples of UV flashes. Left panel- oscilloscope trace is 64 ms. Right panel- the trace is 4 ms.

The main features of measured flashes are as follows:

1. most of them are detected in the tropical region of the Earth (at latitudes from 23.5° N to 23.5° S), see Fig.7.
2. UV energies delivered in the atmosphere are observed in the range of 10KJ – MJ.
3. flash duration is 1 - 100 ms
4. rate of flashes is of about one per circulation.

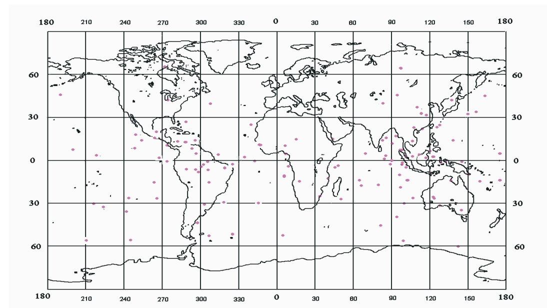

Figure 7: Distribution of UV flashes over the Earth.

Such features are similar to characteristics of TLE (transient luminous events: sprites, elves) detected before in visual observations from satellites, aircrafts and ground. Digital oscilloscope data shows various temporal profiles of the events – from single ms pulses to comparatively long (up to 64 ms) structured pulses. There is no evident correlation of the UV flash geographical coordinates with the continents (as usual for the case of lightning), many flashes were detected above equatorial ocean. At the same time correlation with the cloud formations is evident.

TUS duty cycle and energy threshold

The data obtained from "Tatiana" satellite allow us to estimate duty cycle and energy threshold of UHECR detector, such as TUS. The TUS electronics will operate in similar way to the "Tatiana" electronics: voltage on the PM tubes will follow the changing of UV background intensity. So, in principle, the UHECR detector will operate during all nights independent of moon phase, but with various energy threshold which increases with root square of the UV background intensity I_{uv}. Energy threshold can be calculated as function of I_{uv} from the selected value of ratio Signal/Noise. In our case Signal is the number of photo electrons in the pixel measuring the EAS maximum:

$$Signal = \frac{E_{thr}}{1.3} \frac{S\Delta \times 5 \times \eta k \zeta \chi}{4\pi R^2}$$

here E_{thr} is threshold energy in GeV, 1.3 is coefficient for energy transfer to electron number in EAS maximum, S is the mirror area, Δ is the pixel size (in m of the atmosphere), 5- is fluorescence yield in photons per m per electron, η is quantum efficiency of PMT cathode, *k* – takes into account fluorescence absorption in the atmosphere, χ – coefficient of mirror reflection, ζ – average light collection coefficient of the pixel light guide.

Noise in the detector pixel is root square of the number of photo electrons in time t , needed for detection of Signal, t=Δ/c:

$$Noise = (I_{uv}\omega S\eta \frac{\Delta}{c})^{0.5}$$

where I_u – UV-radiation intensity, c is velocity of light (in m/sec as Δ is in m), ω is pixel solid angle, other parameters were defined above.

Table 1.

Moon phase, %	UV intensity ph/cm^{2}sr s	TUS energy threshold (EeV)	TUS duty cycle
0- 40	10^8	50	15 %
0- 75	$2\cdot10^8$	100	23 %
0- 100	10^9	300	30 %

Defining energy threshold as the energy value in equation Signal/Noise=3 and taken the following TUS parameters: S=2 m^2, ω= 10^{-4} sr, η = 0.2, *k*=0.7, χ=0.8, ζ=0.75, Δ/c= 12 μs we have the thresholds presented in Table1 (the third column) for upper value of the moon phase range presented in the first column.

For case of near horizontal EAS (zenith angle θ>60°) the EAS maxima are above the cloud cover (see more detailed simulation of the EAS registered by TUS in [3] and for those EAS the duty cycle depends only on the background UV intensity, which is presented in the last column of Table 1. Maxima of near vertical EAS may be covered by clouds and the duty cycle for measuring vertical EAS depends on portion of clear atmosphere on route of the satellite. Roughly speaking the duty cycle for detection of vertical EAS is twice less than presented in Table 1.

The UV flashes of the type detected in the “Tatiana” space experiment may play significant role in triggering the TUS detector. For a certain prediction of the TUS detector triggering the energy spectrum of UV flashes has to be measured.

SINP MSU in cooperation with other institutions have plans to continue the experimental study of UV flashes with more informative detectors, capable to register energy spectrum of UV flashes and obtaining images of the flashes in the atmosphere.

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