Space Detector TUS for Extreme Energy Cosmic Ray Study

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The TUS project (EECR study from space by observation of the atmosphere fluorescence) came to the construction stage. The UV sensor of the TUS detector is operating on board the ”Universitetsky-Tatiana” satellite. Results of UV measurements are presented.

1. The current status of the TUS project.

The TUS project in RF space agency is aimed to study of Extreme Energy Cosmic Rays (EECR). The space detector and scientific goals of the project were described in the previous publications [1,2]. In 2005 the research and development stage of the project was finished and in 2006 the construction stage has been started. Launching of the EECR detector is planned in 2009-2010 on board the SSP that will be separated from the Foton-4 satellite (Special Construction Bureau ”Progress”, Samara, Russia). The SSP orbit height expected to be 450-500 km and the SSP operation period will be of 2-3 years.

The main parameters of the EECR detector are presented in Table 1. In Fig. 1 an accommodation of the TUS detector on the SSP is presented. For details of the detector construction see [3].

In 2005 the main efforts were directed to the operation in space of the TUS photo sensor unit, launched on board the ”Universitetsky-Tatiana” satellite. This operation approved the basic design of the TUS photo detector and gave interesting results on a near UV light radiated from the night atmosphere.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mirror area, ( m^2 )</td>
<td>2</td>
</tr>
<tr>
<td>Pixel resolution, ( \text{mrad} )</td>
<td>10</td>
</tr>
<tr>
<td>FOV, ( \text{degree} )</td>
<td>10</td>
</tr>
<tr>
<td>Energy Threshold, ( \text{EeV} )</td>
<td>70</td>
</tr>
</tbody>
</table>

Table 1

Parameters of the TUS detector.
2. Photo sensor unit on board the "Universitetsky-Tatiana" satellite.

The light sensor of the detector is the photomultiplier tube (PMT) of Hamamatsu type R1463 (13 mm tube diameter, multi-alcali cathode, UV glass window). At the entrance window the collimator is mounted. Collimator puts limit to the field of view of the detector (14°). It also restricts the PMT’s cathode area open for the light to \( S = 0.4 \, \text{cm}^2 \). The aperture of the detector is \( S_\omega = 0.02 \, \text{cm}^2 \, \text{sr} \). In front of the PM tube window the UV filter cuts the light with wavelength \( \lambda > 400 \, \text{nm} \). In Fig. 2 spectral characteristics of the sensor are presented.

Presented in Fig.2 factors restricted the sensor sensitivity to the wavelength range 300-400 nm.

The block-diagram of the signal analysis in the detector is shown in Fig. 3. Signals from both PM tubes are coming to the multiplexer and then to 10 bits ADC.

The main feature of the electronics is the use of FPGA for digital analysis of the signals after ADC. UV intensity is measured by the digital oscilloscope method with time samples different for different tasks. Digital integration is used for selection and registration of various event types.

For details of the unit operation see [4].

3. Results of the photo sensor testing experiment.

In approximately 1.5 year of operation in space the photo sensor unit proved to be stable in sensitivity (in 10% error). As a reference source of UV light the average back scattered moon light was used. The background light produced by cosmic charge particles in sensor glass proved to be negligible to compare with the atmosphere glow. In measurements of the near UV (\( \lambda = 300 - 400 \, \text{nm} \)) intensity along the satellite circulations the previous results from measurements on balloons and on satellites were confirmed. At moonless nights the minimal observed intensity is \( 3 \times 10^7 \, \text{ph/cm}^2 \cdot \text{s} \cdot \text{sr} \), the maximal intensity is \( 10^8 \, \text{ph/cm}^2 \cdot \text{s} \cdot \text{sr} \).

We did not find extraordinary UV light excess above the large cities. In detector field of view 14° the largest city light in UV range is 2-3 times more than the UV intensity over ocean at moonless night.

At moon nights the UV intensity depends on
the moon phase, its local zenith angle and on the albedo coefficient of clouds. The maximal UV intensity at moon night is $3 \times 10^9$ ph/cm$^2$·s·sr. The UV intensity is over $10^9$ ph/cm$^2$·s·sr only in 25% of the moon month night time.

The use of the digital oscilloscope allows us to select and to record the temporal profiles of the short UV flashes. Two oscilloscope variants were operating: 1. the trace length- 4 ms, time sample 16 $\mu$s, integration time 256 $\mu$s and 2. the trace length 64 ms, time sample 256 $\mu$s, integration time 4 ms. In one satellite circulation both oscilloscopes select the largest signal in the corresponding integration time. In Fig. 4 examples of UV flashes recorded by the second oscilloscope are presented.

From photon numbers registered by the detector the number of UV photons radiated in the atmosphere was estimated as $10^{22} - 10^{23}$ photons. They correspond to energy radiated in UV range of $10^{11} - 10^{12}$ erg. In some flashes with the saturated signals this energy is much larger- going up to $10^{13}$ erg. The rate of UV flashes with energy threshold $10^{11}$ erg is $\simeq 1$ per circulation.

The registered UV flashes are concentrated in the equatorial region: 50 of 83 flashes are in the latitude range $10^\circ N - 10^\circ S$. Their energy and time duration are similar to the observed in equatorial region special kind of discharges- "elves" and "sprites".

4. Conclusion.

The experience of operation of the TUS detector prototype in space allows us to finalize the TUS design and to start its construction. The main technological problem is a quality of the mirror- concentrator (see [3]). The TUS photo detector may operate in wide range of the atmosphere UV background intensity that will allow us to look for the highest energy events with a duty cycle of 20-25%. Simulation of the EECR event registration in the TUS detector shows that at zenith angles $> 60^\circ$ the expected energy threshold is of about 100 EeV and in 2-3 years of operation the detector may register tens of EECR events if there is no GZK cut-off in the energy spectrum. The most interesting goal of the experiment is a search for the anisotropy in arrival directions of EECR events in all sky observation allowed by the orbital detector.

The TUS detector will be able also to make a research in additional scientific fields: atmospheric UV flashes, a search for micro meteors and sub-realitivistic dust grains (see [5]).
REFERENCES


