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Status of the TUS space detector preparation for UHECR study

L. TKATCHEV[5], V. ABRASHKIN[1], V. ALEXANDROV[2], Y. ARAKCHEEV[1], J. COTZOMI[3], A. DIAZ[3], G. GARIPOV[4], V. GREBENYUK[5], A. GRINYUK[5], N. KALMYKOV[4], B. KHRENOV[4], S.H. KIM[6], O. KLIMOV[5], P. KLIMOV[4], V.KOVAL[1], O. MARTINEZ[3], S.W. NAM[6], D. NAUMOV[5], A.OLCHEVSKY[5], M. PANASYUK[4], I.H. PARK[7], J.H. PARK[7], E. PONCE[3], C. ROBLEDO[3], A. ROSADO[3], A. PUCHKOV[8], S. SHARAKIN[4], , V.TULUPOV[4], B. SABIROV[5], H. SALAZAR[3], O. SAPRYKIN[8], NGUEN MAN SAT[5], L. VILLASENOR[9], I. YASHIN[4].
[1]*Special Construction Bureau (SCB) " Progress", Samara, Russia.*
[2]*Department of Applied Research of Moscow State University, Moscow, Russia*
[3]*University of Puebla, Puebla, Puebla, Mexico.*
[4]*D.V. Skobeltsyn Institute of Nuclear Physics of Moscow State University, Moscow, Russia.*
[5]*Joint Institute for Nuclear Research, Dubna, Moscow region, Russia.*
[6]*Yonsei University, Seoul, Korea.*
[7]*EWHA Woman University, Seoul, Korea*
[8]*Rocket Space Corporation "Energia", Consortium "Space Regatta, Korolev, Moscow region, Russia.*
[9]*University of Michoacan, Morelia, Michoacan, Mexico.*
tkatchev@nusun.jinr.ru

Abstract: The space TUS detector of UV fluorescence light radiated by EAS of Ultra High Energy Cosmic Rays (UHECR) is under preparation for the launch in 2009-2010. The TUS instrument will have ~2 sq. m. mirror - concentrator area and 256 PMT pixels in the photo receiver at the mirror focal surface. The TUS mission is now planned for operation at the Small Space Apparatus separated from the main Foton-4 satellite launched by SCB "Progress". The "Universitetsky-Tatiana" satellite data on the night atmosphere UV glow helps to organize the trigger system effectively separating EAS events from the background atmospheric events. The TUS detector will be used not only for UHECR study bur also for observation of other atmospheric phenomena of UV radiation.

Introduction

Since the previous ICRC2005 meeting the satellite launching plan of the Samara Special Construction Bureau " Progress" has changed and the TUS (Tracking Ultra-violet Set up) mission (Abrashkin et al, [1]) is now planned for operation at the Small Space Apparatus (SSA) separated from the main Foton-4 satellite, due to be launched in 2010. SSA is a new universal platform being designed for operation with space instruments having mass 50-100 Kg, power consumption of 60-100 Wt at the orbits of 500-400 km heights. The platform will be oriented in space due to a scientific task of experiments.

In transportation mode TUS as the SSA is placed above the Foton-4 body so that its mirror could be accommodated in full size of 1.8 m diameter, Fig.1. The TUS photo receiver is placed at the side of the SSA body and in operation mode it is put to the focal plane of the mirror by an arm. Fig. 2 presents the TUS detector in the operation mode.

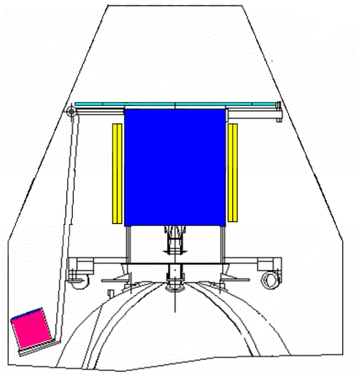

Figure 1: TUS at SSA in the transportation mode.

Status of detectors

In the new design the mirror-concentrator consists of 6 Fresnel and a central parabolic mirror segments. The mirror segments will be arranged on one plane of honeycomb plastic base. In a new design the full mirror area is 2 m^2, the focal distance is 1.5 m. For mirror design details see Tkatchev et al [2], this conference.

In the Fig. 3 are presented 3D-drawing of the mold that will be used for the new Fresnel mirror modules production. The electronic 3D-drawing needs for the precise on-line measurement of his shape on the special tool ECLIPCE that provides 3D –measurements with accuracy of ~5 microns for the complicated surfaces in the volume about 0.7x0.7x0.3 m^3. The ECLIPCE tool and PC with dedicated software will be used to check production of the mold and Fresnel mirror modules. Such measurements results to the size and position of focal spots and their distributions for different mirror rings that is needed during the R&D activity and for proper MC simulation of the TUS optical system also.

The new steel mold is under production now with the DNC facility. Aim is to produce and test technological Fresnel mirror of carbon plastic during this year. Two steel molds were produced up to now with a facility without DNC system and a few Fresnel mirror modules of epoxy resin and carbon plastic were fabricated already.

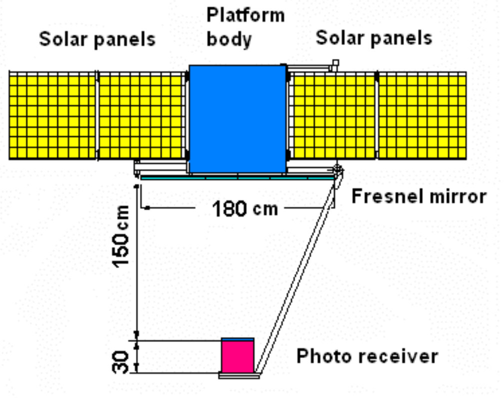

Figure 2: TUS at SSA in operation mode.

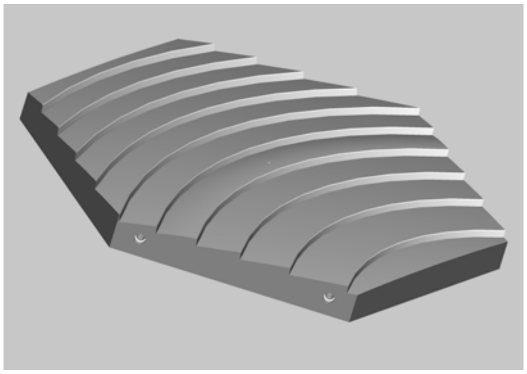

Figure 3: 3D-drawing of the mold for the Fresnel modules production.

The special software package for the analysis of the ECLIPCE raw data measurements for the mirror and mold was developed. In the Fig. 4 the results of the first steel mold measurements is presented as it looks after the raw data analysis.

The photo receiver design is as in the previous case [1]. In part of the photo receiver the multi-anode PM tubes will be placed, instead of single PMTs, to check the technology of the next space detector JEM-EUSO, see Ebisuzaki et al [3], this conference. A new type of Micro pixel Avalanche Photo Diodes (M-APDs), which have high signal gain, high photon detection efficiency, high single electron resolution were developed in Institute of Nuclear Research (Moscow) and Joint Institute of Nuclear Research (Dubna). They will be tested for the use in space conditions, see Zheleznykh et al [4], this conference.

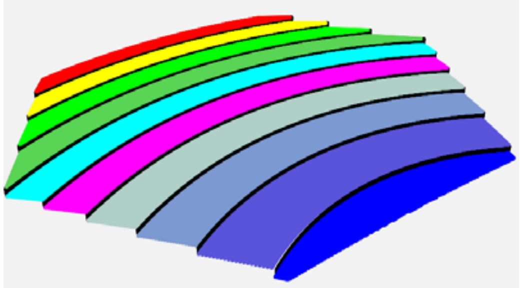

Figure 4: The results of the mold measurements with the ECLIPCE device.

The TUS electronics general approach is the use of multi-channel digital oscilloscope converting pixel signals to digits in needed for EAS measurement short integration time ~1µs. Slower signals from other atmospheric phenomena are also selected and analyzed in the digital part of the electronics by sampling signals in different time intervals, namely: 0.8 µs for EAS, 16 µs for TLE and sub-relativistic dust grains, 256 µs for longer TLE, 4 ms for meteors. The data is finally recorded in a standard number 256 of oscilloscope samples.

Electronics for 256 pixels is divided to 16 PMTs clusters. From every pixel a signal goes to the multiplexer controlled by the generator with frequency 1/0.8x16=20 MHZ. One ADC is used for 16 pixels. Digital information goes to FPGA where every signal is considered by the de- multiplexer restoring the pixel address. Then signals go to 4 oscilloscopes with different time samples. Trigger system works in 2 stages: 1. at the first stage pixel signal greater than pixel noise "σ" by times "a" are selected, 2. at the second stage addresses of pixel selected in the 1-st stage are analyzed, if "n" neighbor pixel signals are in coincidence during coincidence time "t", a final triggecommand for recording the data of the corresponding oscilloscope (256 time samples, 128 samples before the trigger time and 128 samplesafter) is generated.

Four oscilloscopes are triggered separately- by a trigger condition selected for every oscilloscope. The oscilloscope parameters (oscilloscope time sample, integration time) and the trigger conditions (values "a", "t" and "n") are given in FPGA but it could be changed by commands from the mission center during the flight. For selection of vertical EAS (only one pixel is triggered) an additional condition of high signal in one time sample of 0.8 µs (back scattered Cherenkov signal) is applied for selection of useful events.

Oscilloscopes are working permanently but with various event rate as the PMT's voltage (gain) is controlled by the UV light level at the tubes cathodes. At the dayside gain of the tubes is very low and triggering by the selected conditions is not expected. At the night side the gain come up to a regular "operation" level and the TUS detector start to select useful events. In this design the TUS detector will operate as at moonless nights so at full moon nights. In the last case the energy threshold will be higher as the pixel noise is higher.

"Universitetsky-Tatiana" satellite and simulation results

In 2005 the UV detector comprising one pixel of the TUS receiver was launched on board of the "Universitetsky-Tatiana" satellite. The "Universitetsky-Tatiana" data (see, Garipov et al, [5]) on UV transient flashes opened a new field of interest for the TUS experiment- a search for mechanism of the transient luminous events (TLE) by study the time-space image of TLE at its initial faint stage. The TUS electronics was updated, as mentioned above, for study of different types of UV events: EAS, TLE, meteors and sub-relativistic dust grains.

Data of the "Universitetsky-Tatiana" detector on background UV light are taken into account in simulation of the UHECR registration. Simulation of the UHECR event registration was improved to compare with the previous results (see Abrashkin et al, [1]). New results include the increased area of the mirror- concentrator, its focusing parameters, light collection efficiency by light guides, losses of light in reflection at the mirror surface and light guide surfaces. Efficiency of event selection by triggered several pixels for zenith angles in the range $\theta=60^{o}$ -90^{o} and primary EAS energies 40-100 EeV was tried in simulation of electronics operation. Event selection of "vertical" EAS ($\theta<60^{o}$) having a signal from scattered back Cherenkov radiation was also tried.

Particle flux intensities in 30-50 EeV energy range measured in the "Pierre Auger Observatory" experiment (Sommers, [6]) and in the HiRes experiment (Sokolsky, [7]) have been used to evaluate the UHECR rate in the TUS detector. Extrapolation of the energy spectra above 50 EeV has been carried both under hypothesis of a constant power law index $\gamma=1.84$ (i.e. no cut off) and with a steep index $\gamma=3$ for E>50 EeV (as favored by HiRes data). Results are presented in Table 1.

Table 1. Integral UHECR intensity used in estimates of the TUS detector performance.

Energy E, EeV	50	100	200
$I_1(>E)$, events/km^2 y sr	0.023	0.0065	0.0018
$I_2(>E)$, events/km^2 y sr	0.014	0.0018	0.00022

At the orbit height 500 km, in the range of zenith angles θ=60°-90° for duty cycle 20% the TUS geometrical factor is 1000 km^2 sr per year. The best quality events with EAS maximum position in inner part of photo receiver (14x14 pixels) will be registered with geometrical factor 770 km^2 sr per year. In the range of zenith angles θ<60° for duty cycle 10% the geometrical factor is 1500 km^2 sr per year. Expected full rate of particles with energy threshold E=50 EeV is 57 particles per year for the case of no cut-off and 35 particles per year for the case of cut-off. To justify the existence of cut-off the TUS detector has to operate during 3 years when the full statistics of particles over threshold energy 200 EeV will be 14 (no cut-off) and 2 (cut-off). A long operation is also important for search of the neutrino induced EAS. Operation in 3 years is possible if the starting orbit of SSA is not less than 500 km height.

An attention was paid to a search of a possible global asymmetry of UHECR arrival directions (see Kalashev et al, [8] this conference). The prospects of detecting global asymmetries predicted by two distinct scenarios of the origin of UHECR: the Galactic dipole asymmetry expected in the super heavy dark-matter scenario and asymmetries expected if sources of UHE protons follow the distribution of visible matter in the Universe. The first space-based detector of UHECR particles, TUS, will be able to test the predicted asymmetries.

Conclusion

In 2005 the small prototype of the TUS detector with UV detector comprising one pixel of the TUS receiver was launched on board of the "Universitetsky-Tatiana" satellite and successfully tested.

The TUS full scale mission is in preparation and planned for operation as the Small Space Apparatus due to be launched in orbit at 2009-2010.

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