

## Status of the Space Experiment TUS for UHECR Study

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### Abstract

The TUS space experiment for studying the energy spectrum, the composition and arrival directions of Ultra High Energy Cosmic Rays (UHECR) is in preparation. R&D stage of the TUS project is close to the end. At present the first prototypes of the detector are under testing. The PM tube selected for the TUS photodetector and the corresponding electronics are being tested on the Moscow State University satellite "Tatiana". The preliminary results of measurements of the UV light from the atmosphere by this detector and the fluorescent radiation of shower electrons measured in the MACFLY experiment at CERN are presented. At Mexican mountains the TUS prototype started to measure the temporal profiles of UV signals in the atmosphere. Design and development of the space mirror-concentrator was continued: the first samples of the mirror segments were constructed and tested.

### 1. Introduction

The problem of origin of UHECR is among the most interesting astrophysical problems and different approaches for UHECR measurement are important for reliable estimate of their parameters. The TUS set up accommodated on the Russian satellite was proposed [1] and developed [2],[3] as the first stage of the KLYPVE project for studying UHECR from space by observing fluorescent and Cherenkov radiation generated by UHECR particles in the atmosphere. In the last years the TUS detector prototypes were constructed and tested in space and at mountains. The first results of the prototype operation are presented.

### 2. TUS detector unit prototypes

**The TUS Fresnel mirror.** The TUS segmented Fresnel mirror - concentrator of 6 standard modules is under construction. The size of one module is 58 cm, the mirror thickness in transportation mode is of about 15 cm. In operation mode the full area of the mirror is 1.4 m<sup>2</sup>. The focal distance of the mirror is 150 cm. The first prototype of ensemble-disassemble tool was produced and tested. The mirror segments itself are made of carbon plastic as replicas of the steel mold. The carbon plastic was chosen as a basic mirror material due to its high temperature stability. A few carbon plastic samples were produced for tests, their surfaces were covered

**Table 1.** Optical parameters of protection layers for TUS carbon mirror samples

Protection material	SiO <sub>2</sub>	Nb	Cr+Al
Total absorption coefficient, $A_s$	0.11±0.01	0.42±0.01	0.45±0.01
Black body radiation value, $\epsilon$	0.035±0.005	0.20±0.02	0.045±0.015
Coefficient of mirror reflection, %	90	56.0	49.6

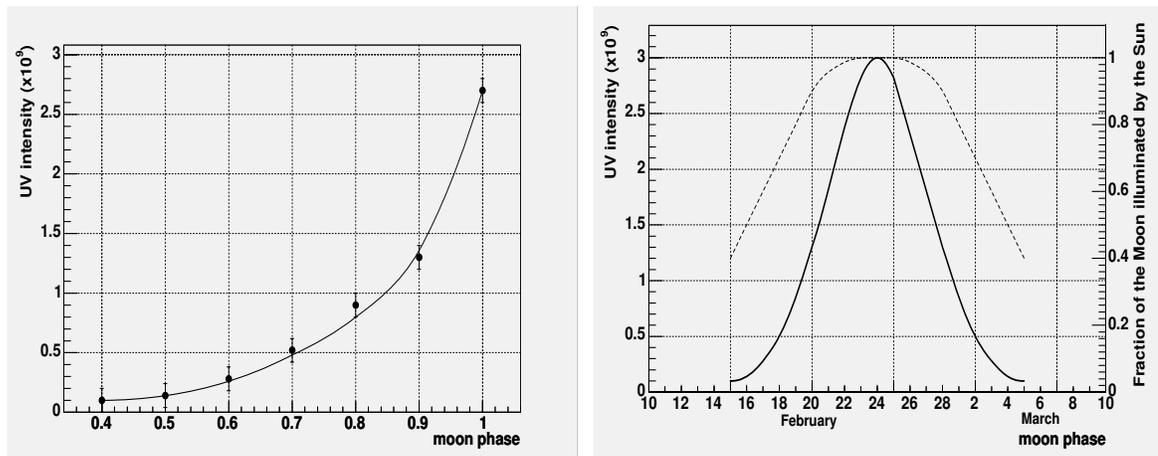
by aluminum of 0.1 micron layer followed by a protection layer on their top. Different materials were investigated for this protection: SiO<sub>2</sub>, Nb and Cr+Al of the same thickness. Results of optical tests are given in Table 1

**Photo receiver and electronics.** The image of the EAS is detected by the photo receiver in the focal plane of the mirror. The photo receiver consists of the matrix of  $16 \times 16 = 256$  PMTs (Hamamatsu type R1463, 13 mm tube diameter, multi-alkali cathode, UV glass window). The UV filter covering all pixels is transparent in wavelength range 250-410 nm. The multi-alkali cathode was chosen as a compromise between high sensitivity to fluorescent light in wavelength range 300-410 nm and stability of the cathode performance in wide range of temperatures, [4]. A single photo electron (p.e.) signal is well resolved by the selected PMT. The p.e. signal was measured as a function of the tube voltage and this characteristic is used for measuring signals in p.e. number. Every 16 PMTs have a common voltage supply and are controlled by one DAQ unit. The main feature of the electronics is the use of FPGA (of XILINX type) for digital analysis of the signals after ADC. The UV signal profile is measured by the digital oscilloscope method with time samples appropriate for different tasks. Digital integration is used for selection and registration of various event types. The times of integration and sampling are also taken appropriate for different tasks. The photo receiver is supposed to operate in a wide range of atmosphere light background.

**Fastwel on board computer.** A single plate TUS computer prototype Geode-TM GX1/300 MHz with low consuming is under R& D tests: CPU686E processor, 128 B SDRAM, 2.5" Flash-memory 512 B (SD25B-256-100), total energy consuming 15 W. It may operate between -40 and +80 C and has radiation hardness of 300 Krad. The software is under development. It should provide the data acquisition, the useful event selection in 2 steps triggering, the control measurements of PMT's gain and UV background, the data keeping and transfer to the mission center, the receiving of commands for the TUS detector management.

**Testing of the TUS photodetector prototype on the board of "Tatiana" satellite.** The launch of the Moscow State University satellite "Tatiana" is used to test the TUS photo sensors and their electronics and to measure the UV light emitted by the Earth atmosphere. The "Tatiana" satellite was launched on January 20, 2005 to the orbit of height 950 km and inclination 82°. The UV detector consists of 2 PMTs. A collimator at the entrance window of the first PMT limits the field of view of the detector to 14°. The PMTs cathode aperture is  $S\omega=0.02 \text{ cm}^2 \text{ sr}$ . The entrance window of second PMT is closed, the PMT is dedicated to the charged particle background measurements.

The PMT is operating all the time: either at night or day side of the Earth with a constant anode current controlled on-line by the measured light intensity. At day side the gain is decreased to be smaller than 100, at night side the gain reaches its maximum  $3 \cdot 10^6$ . Two set of signals are recorded and sent as a result of measurement to the mission center: the PMTs voltage code and the ADC code. Results of the UV intensity monitoring during a moon month are summarized in Figure 1 where the average intensity per satellite circulation (night side) is presented. The maximum UV intensity  $3 \cdot 10^9 \text{ photons/cm}^2 \text{ s sr}$  was measured during the full moon nights. The minimum UV intensity  $3 \cdot 10^7 \text{ photons/cm}^2 \text{ s sr}$  was measured at several locations in ocean and Siberia at moonless nights. We do not find extraordinary UV light excess above the large cities. In the detector field



**Figure 1.** UV intensity in photons/cm<sup>2</sup> s sr as a function of the moon phase  $m$  (fraction of the Moon illuminated by the Sun) (left panel). Day-to-day UV intensity and moon phase (dotted line) variation (right panel).

of view  $14^\circ$  the largest flux of city's light in UV range is 2-3 times higher than the UV intensity over ocean at moonless night. The measurable signals from the second "blind" PMT are observed only when the satellite crossing the "South-Atlantic (Brazilian) Anomaly". Even in this region the noise from charged particles is less than 10% of the signal from the UV light of the atmosphere at moonless night. In one month of operation we do not observe a decrease of the PMT cathode efficiency in spite of all day operation of the tube. We do not observe either the after-exposure anode current after the satellite transfers from the day to the night side of the Earth.

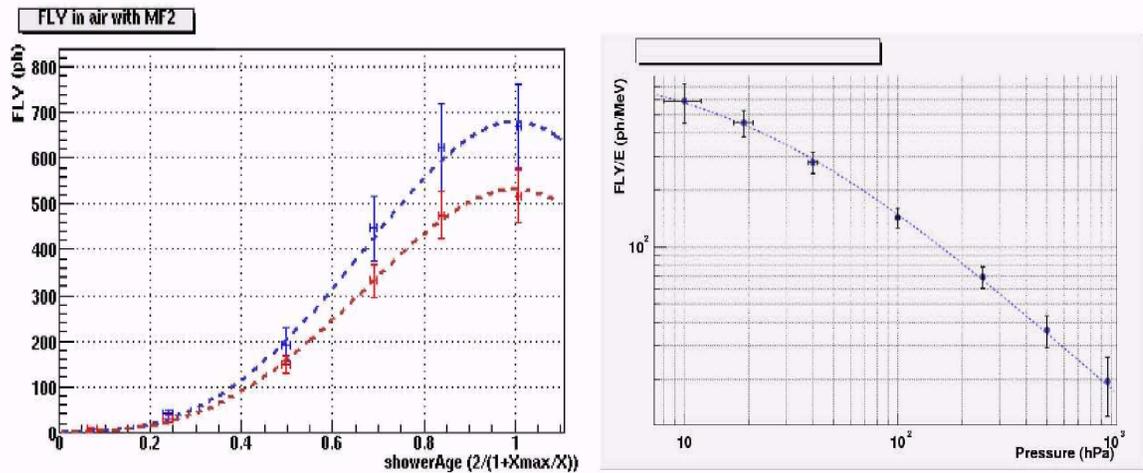
The use of the digital oscilloscope allows us to select and to record the temporal profiles of the fast UV flashes. UV flashes of energy  $10^{11} - 10^{13}$  erg in 1-10 ms intervals were detected. They are concentrated in the equatorial region. Their energy and time duration are similar to an observed in the equatorial region special kind of discharge- a "sprite".

**TUS prototype at the Mexicans mountains.** A small prototype of the TUS detector, comprising the photo receiver module of  $4 \times 4$  PMT pixels in focus of the spherical mirror of the area  $0.3 \text{ m}^2$ , is under testing at the Puebla University (Mexico) mountain site, at the altitude of 4.5 km. The aim of the testing is determination of the absolute pixel signal in measurement of the known light intensity of stars and study of the EAS signal to noise ratio. Transparency of the atmosphere at the altitude of 4.5 km is twice higher than at sea level due to less atmosphere pressure and is stable due to less aerosol contamination.

### 3. The fluorescent light measurements in MACFLY experiment

An accurate measurement of yield of the fluorescent light produced by charged particles in air is of great interest for current and future cosmic ray experiments using fluorescent detection technique. Today accuracy is limited by 20-30% which is not sufficient for the required precision of the experiments involved in Super - GZK cutoff enigma resolution. Therefore new measurements of fluorescence yield were done using CERN SPS beams. The MACFLY detector consists of two parts: MF1 and MF2. MF1 was designed to detect fluorescence photons produced by the collimated beam of electrons/positrons/pions/muons. MF2 was designed to detect the fluorescent light produced by the shower initiated by the beam of charged particles dumping off the pre-shower. In Figure 2 some preliminary results are shown.

In the left panel of Figure 2 the dependence of fluorescent light yield (FLY) on the shower age measured with



**Figure 2.** Left panel: fluorescent light yield of 50 GeV electron beam in air at 500 hPa pressure (blue line) and at 100 hPa pressure (red line). Right panel: the  $FLY/E_{dep}$  pressure dependence in air for 50 GeV electron beam.

MF2 is shown. The upper and bottom lines correspond to 500 hPa and 100 hPa air pressure respectively. The curves in dotted lines are proportional to  $E_{dep}$  and simulated with GEANT4. In the right panel of Figure 2 the pressure dependence of the ratio  $FLY/E_{dep}$  measured in air with MF1 is shown. The dotted line is proportional to Kakimoto model[5].

#### 4. Conclusions

In 2005 the stage A of the space TUS project has to be finished. Results of testing of the TUS units and particularly results of testing of PMT and electronics in space confirmed the proposed TUS design.

#### 5. Acknowledgements

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