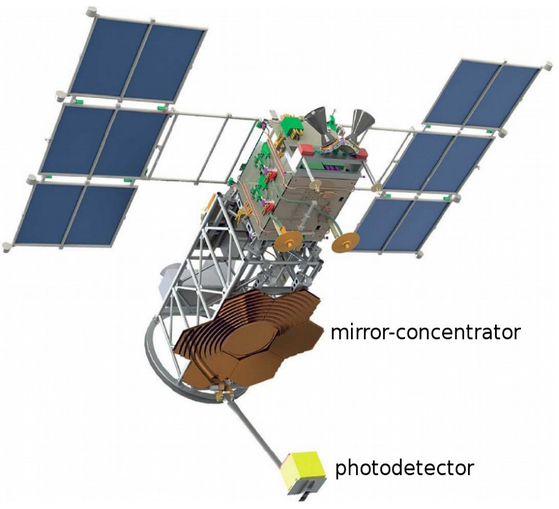


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# The TUS space photodetector relative calibration in flight

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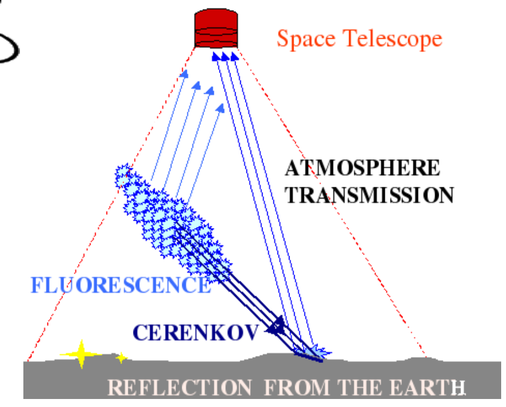
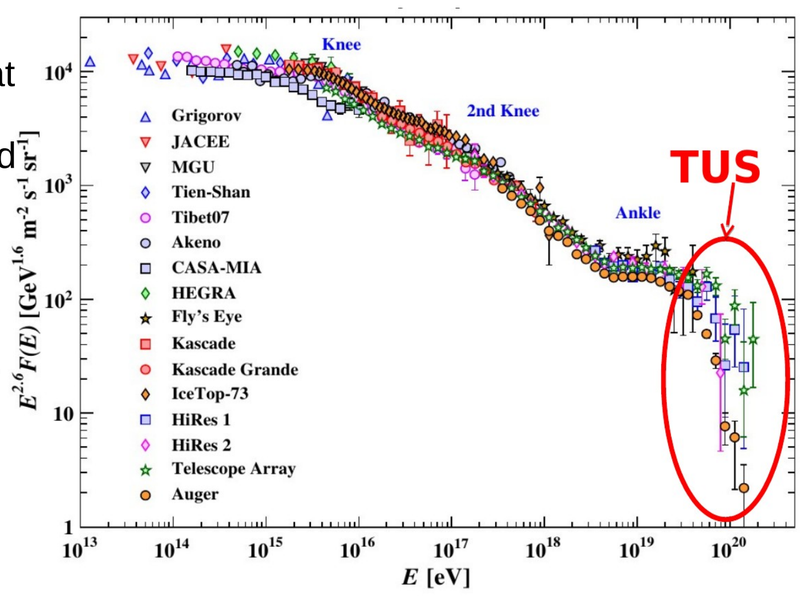



| | |
|---|---|
| Mass | < 60 kg. |
| Power | 65 W. |
| Data rate | 200 Mbytes/day |
| Number of pixels | 16x16 PMTs |
| FOV | ±4,5 degree. |
| Duty cycle | 30% |
| Altitude | 500 km |
| Pixel: | 10 mrad(5x5 km) |
| Mirror area | 1,8 $m^2$. |
| Focal distance | 1,5 m |
| Period | 94 min |

The TUS space experiment is aimed to study the energy spectrum and arrival direction of Ultra High Energy Cosmic Rays (UHECR) at E ~ $10^{20}$ eV by measuring the fluorescence yield of the Extensive Atmospheric Shower (EAS) in the atmosphere. The fluorescent and Cherenkov radiation of the EAS generated by UHECR particles should be detected in the Earth's atmosphere on the night side of the space orbit at altitudes 400–500 km. The multifunctional "Lomonosov" satellite, with the TUS detector on board, was launched from the newly built Cosmodrome Vostochny on April 28, 2016. The satellite has a solar-synchronized orbit with an inclination of 97˚, a period of ~94 min, and a height of about 470-500 km. The TUS detector consists of two main parts: a modular Fresnel mirror-concentrator and a photo-receiver matrix. A PMT quantum efficiency is ~20% for the wavelength of 350 nm.



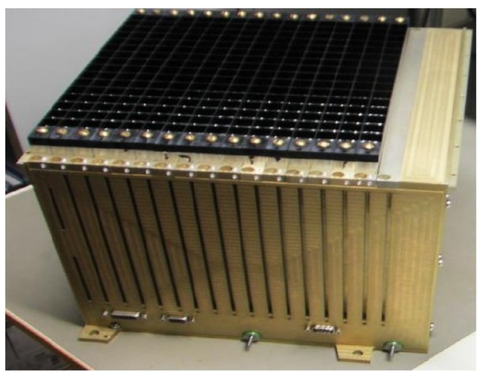
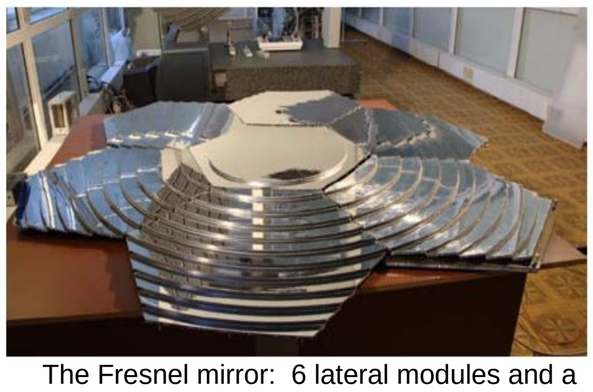



Photo receiver box.

Launch of the "Lomonosov" satellite on April 28, 2016.

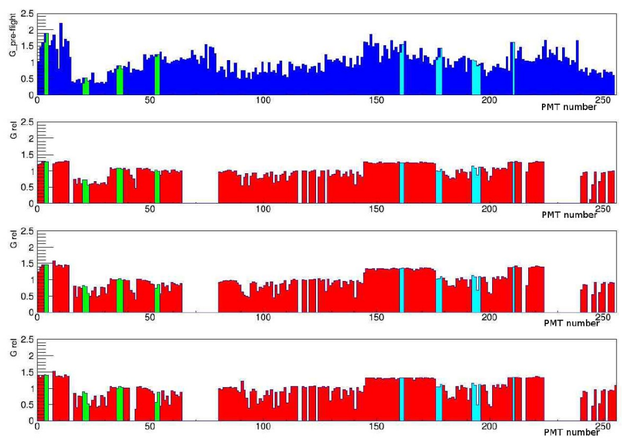


The Fresnel mirror: 6 lateral modules and a central one.

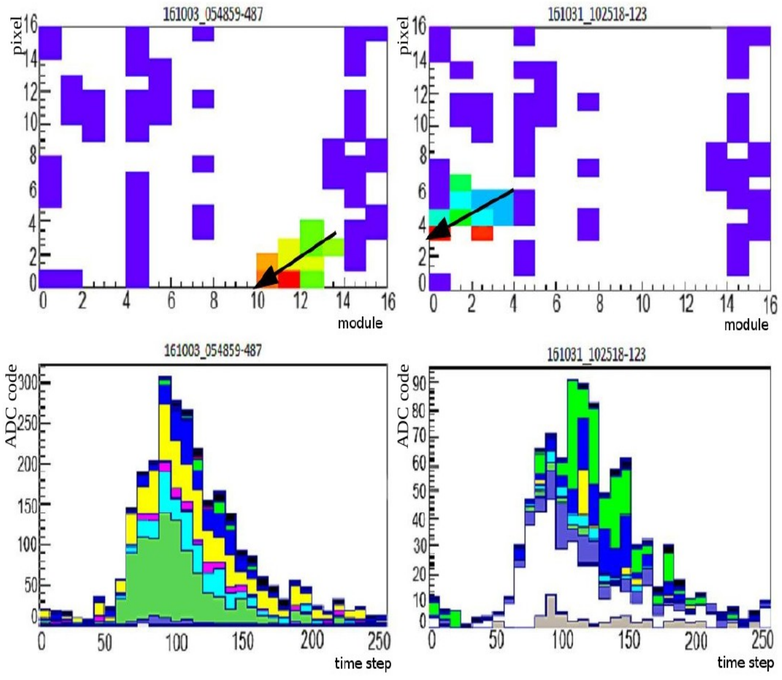
**TUS has a two-level trigger**. The first-level trigger is a threshold trigger: the photodetector modules board calculates a moving sum of PMT signals during 16 time steps in each channel and looks for an moving sum value above a threshold level. The second-level trigger is a pixel-mapping trigger. This procedure selects cases of sequential triggering of spatially contiguous active pixels that are also adjacent in time, allowing for the selection of events with a special spatial-temporal pattern.

-The TUS electronics can operate in four modes intended for detecting various fast optical phenomena in the atmosphere on different time scales (1 time step): 0.8μs, 25.6 μs, 0.4 ms, 6.6 ms

During the first days of operation ≈20% PMTs were broken due to HV tuning system failure.For the same reason, the properties of the remaining PMTs are changed.
Calibration of PMT gains was done based on analyzing background data itself.




Relative PMT gain coefficients for all 256 channels according to pre-flight measurements (top) and reconstructed from background data for first 3 half-years of operation.The light color corresponds to the PMT of the selected events



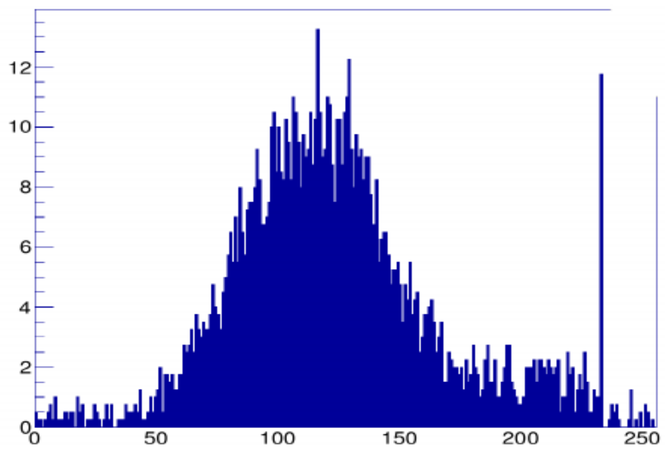

The EAS candidates. Upper plots – image of event with hit pixels and not-working (blue) ones.
Bottom plots – the amplitude variation of time for selected hit pixels.

For calibration all time sequences (256 time steps) in all pixels (224 working pixels) of all received events were classified into 2 categories: pure "background" pixels and possibly containing signal of any origin. Comparison with Monte-Carlo simulated signals shows that the tails of above distributions of real data are significantly wider than what would be expected from pure Poisson based background signal. Therefore the tails are presumed to contain non-background signals and central part to not contain significant contamination to background.

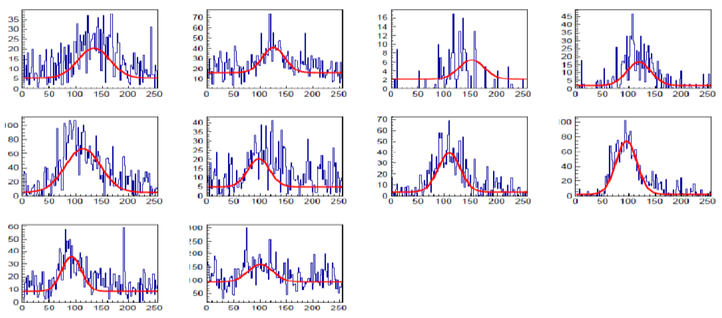
-During two years of operation, the TUS detector has measured about 200000 events in EAS mode.

- More than 80% of events registered by TUS have noise-like waveforms.

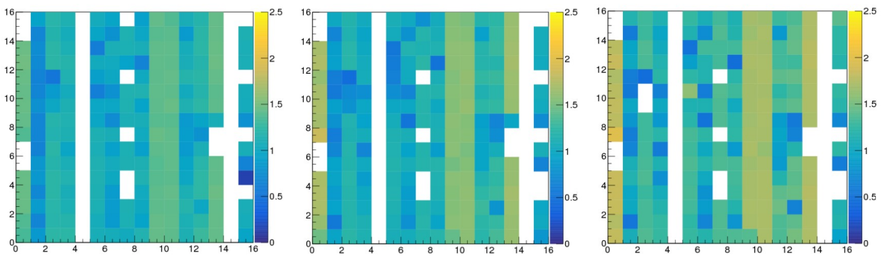
-The TUS detector has measured numerous UV transient flashes in the EAS mode with different temporal dynamics and spatial structure.



MC event. E = 10 $^{20}$ эВ, θ = 60°



Time distributions of the EAS signals in the hit PMT pixels of the EAS candidate event №487.



Calibration of PMTs and comparison to pre-flight measurements. Relative PMT gain calibration was done by analyzing background events and is presented here for 2 statistically independent subsets of data (left and center). Pre-flight measurements (right) are shown with 2 PMT modules that later stopped working turned off for comparison.

## Conclusion:

-The TUS detector is operating on board the "Lomonosov" satellite. TUS proved the possibility of registration of UHECR from the space orbit.
-During the search for an UHECR EAS a large number of events of various origins that take place in the atmosphere of the Earth were observed. These events may contain some genuine EAS events.
-As a result, at least two EAS candidates were selected and preliminary have been analyzed.
-Calibration of PMT gains was done based on analyzing background data itself.
-A more detailed analysis of this and other EAS candidate events, which were found in the TUS detector data, is in progress.