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Pinhole camera for study of atmospheric UV flashes as a source of background in the TUS experiment

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Abstract: The near UV glow of the night atmosphere and near UV transient events in the atmosphere are sources of the background atmosphere phenomena in search for ultra high energy cosmic ray fluorescence signals in the atmosphere. Nature of the UV atmospheric transient events is not known yet and more experimental data on them are needed. Study of space-time development of UV transient events is suggested with the help of a new fast imaging detector: pinhole camera with the multi anode photomultiplier tube. Design and construction of the pinhole camera to be installed at the satellite is presented. The camera mountain testing and calibration are suggested.

Introduction

Importance of UV night atmosphere glow for study of Ultra High Energy Cosmic Rays (UHECR) by space-based fluorescence detectors was underlined in many papers devoted to the instrumentation of UHECR measurements, see, for example, [1] and in this conference [2]. One of the important phenomena in night atmosphere, directly related to UHECR measurement, is TLE (transient luminous events) characterized by very bright (energy in UV up to 0.1-1 MJ) short (duration of 1-100 ms) flashes. The first global measurements of UV flashes were done by the "Tatiana" space detector [1] but still the important characteristics: the lateral distribution of UV glow in one flash and the energy spectrum of flashes are not measured. In this paper we present a new method of TLE measurement- by the imaging pinhole camera. The presented pinhole camera is planned for operation in space experiments devoted to study of processes of electron acceleration in the atmosphere electric discharges and relativistic electron precipitation to the atmosphere from the magnetosphere.

Pinhole camera

The high brightness of TLE allows us to use the simplest pinhole optics for measuring the image in pixels of UV detector, Fig. 1. The hole window is covered by the UV filter transparent to radiation with wavelength $\lambda<400$ nm. The optimal imaging quality in a pinhole camera is achieved if the hole size is equal to a pixel size. Our aim is to measure not only the TLE image but also the temporal profile of the image with time resolution of about 10 µs. Today such a fast photo detector is available only as a Multi-Anode Photomultiplier Tube (MAPMT) with number of pixels up to 256. The size of the pixel in MAPMT is of about 2-3 mm. Assuming the camera hole equal to this size and taking the TLE UV intensity and time duration from [1] one can estimate the pixel signals in the pinhole camera. Efficiency of the MAPMT pixels to UV is high (0.2) for wavelengths $\lambda=300$-400 nm and decreases below $\lambda=300$ nm, so the pinhole camera efficient range of wavelengths is the near UV with $\lambda=300$-400 nm.

For estimate of the TLE image signals the lateral distribution of UV intensity during the event is needed. It was supposed that UV flash is circular with diameter of 40 km (as it follows from examples of TLE measured by video cameras) and that

UV intensity is uniform over the circle. For full UV energy E_{uv} (erg) radiated in TLE the corresponding number of photons of wavelength λ=300-400 nm (with average energy 3.5 eV) is:

$$N_{ph}=E_{uv}/3.5\times1.6\ 10^{-12} \qquad (1)$$

We considered 2 options of the pinhole camera focal distance: 1. focal distance is short so that the circle of diameter 40 km is observed by one pixel and 2. focal distance is long so that the 40 km circle is observed in many camera pixels. In the first option the camera FOV is wide and the signal in one pixel gives the position of TLE. Full energy released in UV in the atmosphere is determined by the pixel signal. In the second option a detailed image of the UV flash in space and time is observed.

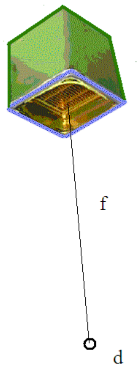

Figure 1: Pinhole camera with MAPMT as a photo detector.

Both options could be combined in one instrument capable to observe TLE images in multi-aperture “camera obscura” as it was suggested in [3] for EAS Cherenkov light observations. In this instrument one multi-pixel photo detector is used for many pinholes, Fig. 2. Distance between pinholes is selected to be equal to the expected size of an object of interest. Then the photo detector receives signal coming only through one pixel. For knowing which hole really receives signal the second short focal distance camera is needed. In our design the multi- aperture camera obscura contains two photo detectors as shown in Fig. 2 (short distance detector uses only one pinhole in a corner of the holes grid). Today we present the design and construction of the first camera with the following technical parameters. Photo receiver is MAPMT H7546B (Hamamatsu) of 64 pixels of size 2x2 mm. Pinholes are of 2 mm diameter. Long focal distance is f=20 cm, pixel size in the atmosphere from the orbit R=500 km is 5 km, area in the atmosphere covered by the receiver is 40x40 km.

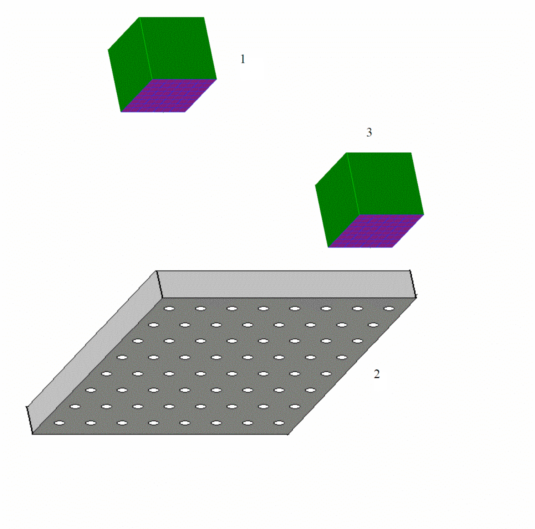

Figure 2: Camera obscura with many apertures. 1- long focal distance photo receiver, 2- many pinholes covering wide FOV, 3- short distance receiver for one pinhole.

Short distance focal distance is 2.5 cm and one pixel of this receiver covers 40x40 km in the atmosphere. The short distance camera covers 320x320 km in the atmosphere.

TLE of energy E_{uv} produces signal (in photo electrons, p.e.) in the short distance camera pixel (pixel quantum efficiency is 0.2) equal to

$$Q_{pe}= N_{ph}\,(E_{uv})\ 0.2kS\ /4\pi R^2 \qquad (2)$$

where $S=\pi d^2/4$- area of the pixel and coefficient k~1 takes into account the signal absorption in the atmosphere. For $E_{uv}\sim10^4$ J (energy threshold in observations [1]), d=2 mm, R=500 km the signal is Q_{pe} =3500 p.e.

The noise σ in the same pixel is a root square of average p.e. in time of TLE t=1-100 ms. In the worst case of UV intensity at the full moon (I_{uv} ~10^9 ph/cm^2 s sr) the noise is:

$$\sigma_{noise}=(I\ \omega\ S\ t\ 0.2)^{0.5}=0.8\text{-}8 \text{ p.e.} \qquad (3)$$

where $\omega=d^2/f^2$- is the solid angle of the pixel.

One can see that the short distance pixel will effectively select TLE of much smaller energy than observed in [1]. For example, at the confident signal level of 10σ we may select UV flashes of energy E_{uv}>200J even at full moon nights. The important problem of energy spectrum of UV flashes will be solved with this short focal distance pinhole camera.

The long focal distance camera will help to observe images in time and space at TLE UV energies high enough for measuring statistically confident signals in the time samples and in the dimensional bins. In long focal distance camera the same diameter pinholes produce much less noise (σ is by f times less, i.e. in our design 8 times less) but the number of pinholes is large (in our design- 64) so the final noise in multi- aperture camera is 8 time larger than in short distance camera. Defining as confident the signal in one time sample equal to 10 p.e. we estimated energy E_{uv} required for our measurement. Time sampling in our design is 1/64 of the oscilloscope trace. In Table 1 we present noise σ in one time sample for full moon nights (the third raw), the TLE UV energy E_{uv} responsible for the signal (the fourth raw) for the time sample (the first raw) and TLE durations T=1, 10 and 100 ms (the second raw). TLE will be measured by three oscilloscopes: 1. trace 1 ms, time sample 16 μs, 2. trace 16 ms, time sample 256 μs, 3. trace 0.26 s, time sample 4 ms.

Table 1.

t_s	16 μs	256 μs	4 ms
T	1 ms	10 ms	100 ms
σ, p.e.	0.8	3.2	13
E_{uv} kJ	4	16	64

In the TLE energy range of ~10-100 kJ events are expected with the rate of about 1 per circulation (data of [1, 2]).

Camera electronics

The block diagram of signal analysis is shown in Fig. 3. Signals from MAPMT (H7546B) pixels are coming to the array of analog multiplexers, Fig. 4. The 64 pixels of MAPMT are processed with only one ADC. For this we use an array of four multiplexers of type ADG706, where each multiplexer selects 1 signal from its 16 input signals according to digital signals applied for control multiplexing. Then with the array of 4 multiplexer boards we obtain and process every signal from MAPMT,

The set values for evaluation and process the signal was made by the parallel port, as shown in Fig. 5.

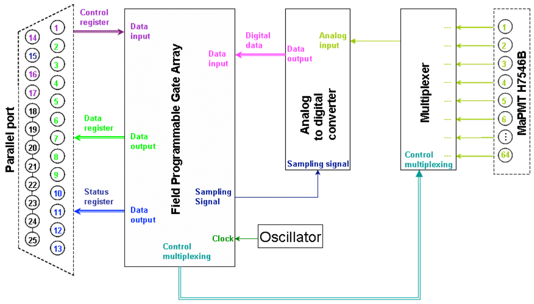

Figure 3: Block diagram of the signal analysis.

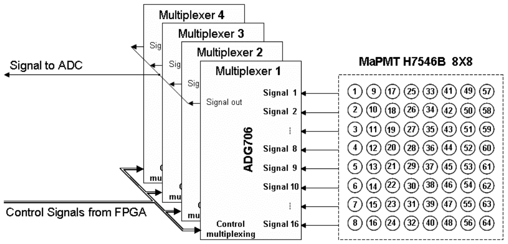

Figure 4: Array of 4 multiplexers boards for processing 64 pixels with one ADC.

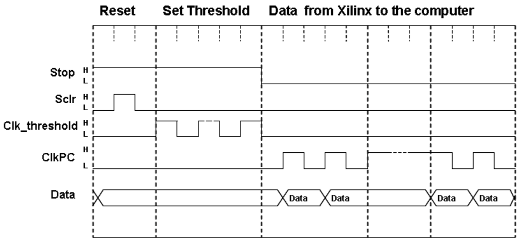

Figure 5: Signal processing by parallel port.

As follows from Fig. 5 the first step in the processing by parallel port is a command to the Field Programmable Gate Array (FPGA, family Xilinx Series XCV100) for initialize all internal functions (initialize to zero the block memory, initialize to zero the counters, initialize the multiplexing). In the next step the parallel port gives a command to FPGA for set internally a threshold value, which would be compared and evaluated with the ADC data. In the third step, the parallel port acquires the data processed by the FPGA. At present the control from the parallel port, the data acquisition and the reconstruction graphic was made using the graphic program LabView.

Camera testing

The designed camera will be tested and calibrated in measurements of the given Moon luminosity. By positioning the camera for observing the Moon image in a short focal distance camera (the Moon angular size ~0.5° is much less than the pixel FOV ~4.6°) it is easy to measure the reference moon luminosity in UV by all three type of oscilloscopes. Expected pixel signal was estimated as follows. In effective camera wavelengths 300-400 nm the Moon luminosity is of about 13% of the full luminosity. As a result the Moon radiation intensity in the above UV range is $J_{uv} \sim 7\ 10^{10}$ photons/ cm^2 s. Amount of the received photons in one time sample t_s is determined by the hole area S=0.03 cm^2 :

$$Q_{st} = J_{uv}\, S t_s\, 0.2$$

Noise of the scattered in the atmosphere moon light is much lower (about 10 times) than the direct moon light signal. The expected number of p.e. in various oscilloscopes time samples and noise σ (in a short focal distance camera) are

$t_s =$	16 μs	256 μs	4 ms
$Q_{st} =$	$6.7\,10^3$	10^5	$1.7\ 10^6$
$\sigma =$	1	4	18

Much less signals will be detected in observation of Aurora and the brightest stars. All of them could be used as stable reference sources of UV radiation (in observation at mountains where the atmosphere transparency is high).

The designed camera will be used not only for space measurements but for monitoring the UV environment of the cities. We plan to observe the back-scattered radiation in wavelengths 300-400 nm above Moscow and Puebla as a possible way to monitor the city sources of UV.

References

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