Observations with a pinhole camera from a high volcano in Mexico

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Abstract: The ultra high energy cosmic rays (UHECR) space studies are the next step in the cosmic ray physics. The 2D studies of the extended air showers and others luminous phenomena is a growing and interesting area. In particular using the simplest optical device, the pinhole camera, and a multi anode photo multiplier allow us to record fast and bright events. This configuration was proposed to use in the third stage of the University Space Program, the M. Lomonosov satellite. In this work, we present the results of calibration and some observations made at the Pico de Orizaba Volcano as performance test, some transient luminous events and micrometeorite traces recorded during 2010-2011.

Keywords: UHECR, TLE, Instrumentation.

1 Introduction

The UHECR ground detection apparently is reaching its practical border. To install ground based observatories of many thousands of square kilometers seems to be impractical. So, the next step may be following the Prof. Linsley proposal [1]: use the entire earth atmosphere as a target and detect the fluorescence light produced by the Extended Air Showers (EAS) from space. To do this, it is necessary to evaluate and monitor the UV light background level at the same conditions as close as the detection mode wanted. The UV light has several sources and varies with the geographical location, the seasons among other meteorological phenomena. One of the main results of the Tatiana I and II [2,3] missions was to evaluate the UV light background and report some of the sources, its time scale and geographical distribution. It is necessary to mention that those measurements were made by a single channel detector and it is not possible to record the space-time evolution of the luminous phenomena. In order to extend and evaluate the UV light background measurement it is necessary to use a 2D instrument, as it was proposed [4] to use a pinhole camera due its robust and simple mechanical and optical configuration with a Multi Anode Photomultiplier (MaPMT) as a recording device. The advantages of a wide and deep field of view allow us to study several fast and bright transient luminous events (TLE).

Pinhole camera

The optimal imaging quality in a pinhole camera is achieved if the hole size is equal to the detector pixel size. The size of the pixel of the MaPMT used (Hamamatsu H7546B) is of about 2 mm. Assuming the camera hole equal to this size and taking the TLE UV intensity and time duration from [3] it is possible to estimate the signals in the pixels of the pinhole camera. Efficiency of the MaPMT pixels to UV is around 20% for wavelengths $\lambda = 300-400$ nm and decreases below $\lambda = 300$ nm. We assume that UV flash images cover a circular area of 40 km diameter (as it was measure in a typical TLE by video cameras) with uniform intensity over the circle, so it is necessary to have two detection modes, one covering a wide field of view and other that allow us to record with more detail the evolution of the TLE. According to this, we use two optical configurations, a) Short Focal Distance (SFD) as monitoring mode, using a single hole of the front plate of the camera and b) Long Focal Distance, as main acquisition mode, in which the light reach each pixel of the MaPMT located at 200 mm from the front plate of the camera by a the matrix of holes as it is shown in figure 1. In the first option the FOV of the camera is wide and the signal in one pixel give us a quick estimation of the position of TLE. The energy released as UV light in the atmosphere is determined by the pixel signal. In the second setup a detailed image of the UV flash in space and time is obtained. Both options could be combined in one instrument capable to observe TLE images in multi-aperture device known as “camera obscure”.

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As this instrument was designed as a space-based experiment, a typical TLE observed from a distance of 500 km (our estimated value for the orbit height), the pixel size for the SFD covers a 40 x 40 km area instead of the LDF configuration, for which each pixel covers a 5 x 5 km area.

Camera electronics

The Fig 2 shows the block diagram used for the signal processing of each MaPMT when a luminous event will appear. First, those modules connected by continuous lines correspond to the SFD and the dashed ones to the LFD. Both electronic boards have the same structure in hardware but different configuration according to the parameters of each kind of observed event. Each board has a FPGA Xilinx XCV100 series. This FPGA controls the multiplexing and the digitalization of the 64 analog signals from each MaPMT. Also control and monitored the high voltage supplied to the MaPMT in order to protect it if a bright or long lasting event appears. The FPGA stores all the configuration and operation parameters from the PC and communicate it thru parallel port. The FPGA of the SFD is the camera obscure main processor, because controls also the LFD data.

The command controls of each FPGA are defined by the user by LabView graphic programmable interface. With the same software we construct a data base in order to process and plot the registered events.

4 Camera Testing and Calibration

To obtain the amplitude of the signal recorded, it is used a 10 bits ADC and for the gain control we use an 8 bit ADC. Each ADC has a code represented by N and M respectively. To obtain the signal voltage in each anode of the MaPMT, we consider the detection area, the recorded amplitude and the integration time of the signal. The automatic high voltage control of the MaPMT allows us to register the brightest phenomena as the gain of the detector is set, adjusting the voltage according to the background light level. To obtain the single photoelectron response, we found the optimal operational voltage for PMTs. To do this, we checked the single photoelectron (SPE) spectrum as a function of supplied voltage with a controlled LED pulse. The SPE spectra curve obtained is shown in Figure 3. We selected 950V as operational voltage. From the analysis of 35,000 events, from each MaPMT, we found the mean charge produced by a single photo-electron response (SPE) and the SPE pulse height distribution.

A useful way to test and calibrate the performance of the pinhole camera, consist in to record the transit of the Moon image crossing every pixel. A telescope mounting base was used to fix the pinhole camera in order to point and track the moon image into a given pixel. In the SFD mode, the crossing time of the MaPMT is about ~60 s. In LFD mode, the crossing time by the MaPMT, will be shorter: ~25 s. In SFD mode, the current will quickly rise to the maximum value and then fall sharply when moon image goes out of the pixel. In LFD mode, the signal from moon will rise and fall continuously having maximum when the moon image is fully inside the limits of the pixel area.
The pinhole camera was tested and calibrated measuring the Moon luminosity. By positioning the camera for observing the Moon image in a SFD 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 intensity. The Figure 4 shows a typical signal profile of a Moon crossing by the FOV in the SFD operation mode.

Results

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The pinhole camera was installed in a commercial telescope mount in order to point and track to any sky position. In particular, we present the results of several observational runs at the Pico de Orizaba Volcano at 4300 m.a.s.l. during 2010 and 2011. In general, the camera was pointed at zenithal distances lower than 30 degrees, in order to minimize the atmospheric absorption. Among others, there are some types of events recorded: TLE, micrometeorite ion traces and some others that need a further study.

The figure 5 shows the signal recorded by a TLE. The reading process of the signal is recorded as a vector, and then, a reconstruction program it is used to display the 2D image.

Another luminous phenomena recorded it is shown in the Figure 6. The circular pattern observed need a further study, but it may be originated by a very close interaction of a secondary particle. It is interesting to note that almost all the photons reach nearly at the same time and the same energy the MaPMT.

An example of a meteoric ion trace recorded is shown in the figures 7, 8, 9 & 10. It is possible to reconstruct the time evolution of this frame sequence. Note that the ionized path was longer than the FOV.

Figure 3. Single Photo-electron amplitude spectra for the MaPMT. 1- The pulse eight distribution of the baseline. 2- The mean of the baseline. 3- SPE pulse height distribution. 4- The mean of the Gaussian. 5- Is the mean pulse height without baseline.

Figure 4. Signal profile of the Moon crossing the FOV in the SFD operation mode.

Figure 5. TLE recorded by the pinhole camera. The duration was about 320 ms and the energy released is about 4 kJ.

Figure 6. A circular pattern recorded at the Pico de Orizaba, in a nearly vertical position with a moonless and cloudless night.

Figure 7-10. Examples of meteoric ion traces recorded by the pinhole camera.
5 Conclusions

The pinhole camera described here fulfills the design specifications as it can be seen by the recorded events. As a robust and simple optical 2D instrument, it can be proposed to install it in a space borne mission as a rover of more complexes missions, to evaluate the possibility of UHECR space detection. The operation of this type of devices will be useful to extend and improve the observation network of atmospheric luminous events from mountains or higher places in a remote way.

6 References

[1] Linsley, J. 1979, Astronomy Survey Committee (Field Committee) Report

