UVscope: an instrument for multi-wavelength study of the diffuse Night Sky Background light

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***Abstract*. UVscope is a rugged and portable photon detector working in single photon counting mode, developed at IASF-Pa to support the experimental activity in the high-energy cosmic rays field. The apparatus is designed to measure the diffuse Night Sky Background light in the UltraViolet wavelength range where the atmosphere fluorescence process mainly takes place. The UVscope instrument is based on a multi-anode photomultiplier and is equipped with a motorized filter wheel where a set of filters can be accommodated, so allowing to perform consecutive measurements at the different filter wavelengths. UVscope has operated at different locations as in Italy (Contrada Pomieri, Sicily) and in Argentina (Pierre Auger Observatory, Pampa Amarilla).**

***Keywords*: UHE cosmic ray, VHE gamma ray, night sky background, atmosphere fluorescence**

I. Introduction

The Earth atmosphere constitutes the ideal detector for the Ultra High Energy Cosmic Rays: these particles, interacting with the atmosphere, give rise to propagating Extensive Air Showers accompanied by isotropic emission of fluorescence light (in the UltraViolet wavelength region around 300-400 nm) induced in air by the secondary charged particles present in the shower as result of a complex relativistic cascade process. The shower originated by the cosmic ray is embedded in the diffuse Night Sky Background (NSB) light, and both of them are influenced by the local properties of the atmosphere. The analysis and understanding of the diffuse NSB light in the UV band then provide several important information in characterizing the environment in which the shower takes place and propagates; sky transparency and variations in the NSB light can also be used to extract atmospheric parameters essential in the reconstruction of cosmic rays detected by fluorescence experiments.

In the following we will briefly describe a stand-alone portable apparatus designed to measuring sky transparency and diffuse NSB light in the UV band. The apparatus is the UVscope instrument, a relatively low cost detector developed at IASF-Pa. The instrument is mounted on a tripod than can be remotely-controlled to point to a precise position in the sky. UVscope allows to measure the relative intensity of the main atmospheric fluorescence lines with respect to the diffuse NSB light integrated in the wavelength band of around 300-400 nm. Due to its feature in measuring sky transparency and diffuse NSB light, UVscope can be successfully used as sky-monitoring apparatus of observation sites in several fields, including the case of Cherenkov telescopes devoted to the Very High Energy gamma-ray astronomy.

II. Instrument description

UVscope is essentially a light detector working as photon counter; its sensitive unit is a high speed response photomultiplier with efficiency extended to the UV band. UVscope was developed to support the experimental activity in the high-energy cosmic rays and gamma rays field. It works in single photon counting mode to allow the detection of very low light level as encountered, in narrow wavelenght bands, in measuring the diffuse Night Sky Background; anyway, it can be used in other fields that require measurements of low light level in the B and UV bands. It is built in a rugged and portable configuration to ease measurement on-field. The UVscope apparatus basically consists of:

i) a photon detector working in Single Photon Counting mode, coupled to its front-end and acquisition data electronics units and to a disk emulator interface card for computer connection;
ii) a collimator to regulate the angular aperture of the detector and to protect its sensitive area against stray light;
iii) a motorized filter wheel on which a set of UV filters can be accommodated, so allowing to observe the sky at the different wavelengths.

The apparatus is completed by a power generator box, a motorized tripod, a GPS receiver, a weather station, and a personal computer for acquisition and remote control. Fig.1 shows UVscope mounted on the tripod.

The UVscope sensitive unit is a Multi Anode Photo Multiplier Tube (MAPMT) manufactured by Hamamatsu, series R7600-03-M64, which allows moderate imaging properties with its 64 anodes arranged in a matrix of 8×8 pixels [2]. The MAPMT has a bialkali photocathode deposited on an UV-glass window; this ensures a good Quantum Efficiency (QE) for wavelengths

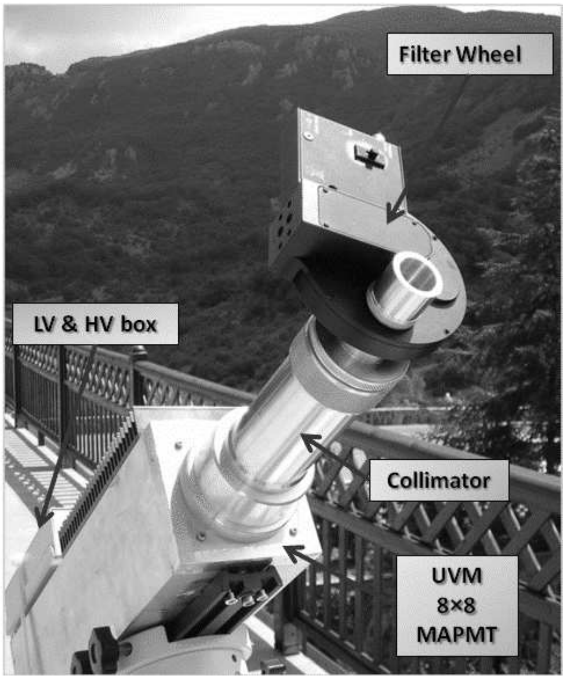

Fig. 1: UVscope placed on the motorized tripod.

longer than 300 nm with a peak of more than 20 % at 420 nm, as shown in Fig.2.

The MAPMT is coupled to the 64-channels Front-End Electronic (FEE) unit working in Single Photoelectron Counting (SPC) mode, a well-established technique used to measure the number of output pulses from the photo-sensors corresponding to incident photons [3]. In the SPC mode, the electronics noise is kept negligible [4]: small pixel size (as in the R7600-03-M64 case) is required to minimize the probability of photoelectrons pile-up within intervals shorter than the given acquisition time unit. The FEE unit amplifies and discriminates the signals coming from the MAPMT anodes. A signal amplifier and a programmable threshold discriminator are provided for each of the 64 channels; a programmable threshold allows to both equalize Input Offset Voltage differences among the discriminators and gain differences among the 64 anodes. The MAPMT is connected, through a socket, to the FEE which is in turn coupled, through a backplane, to the programmable Data Acquisition (DAQ) and handling unit, as shown in Fig.3. Signals detected by the FEE are sampled by DAQ (internally managed by a reprogrammable FPGA) and then acquired according to suitable and flexible user algorithms. The data read-out is achieved by an external computer connected through an interface card which emulates a disk unit universally recognized by any Operating System. The UVscope sensitive unit, the FEE and DAQ units and the interface card are enclosed in an unique compact box; the power unit, that supplies and distributes low and high voltages, is in an external container.

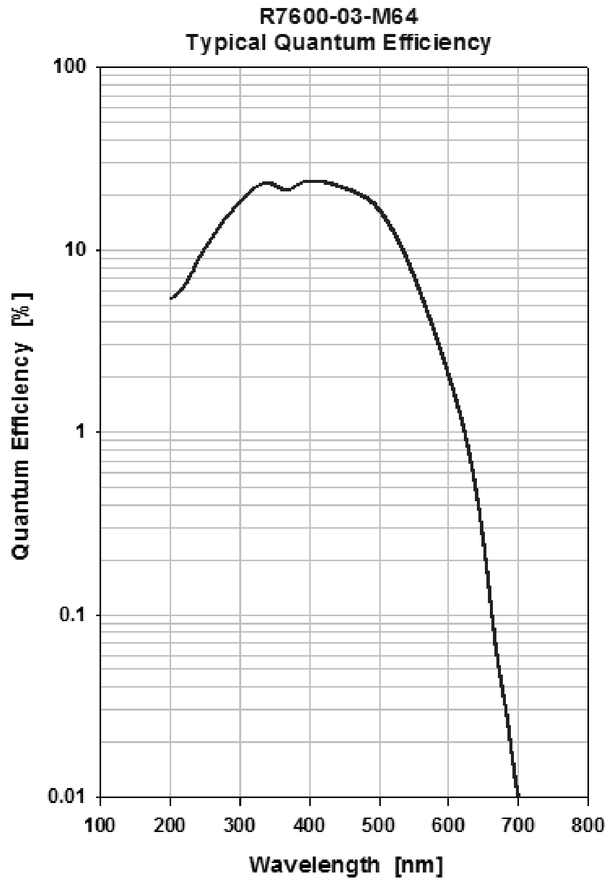

Fig. 2: Typical Quantum Efficiency curve for the R7600-03-M64 MAPMT.

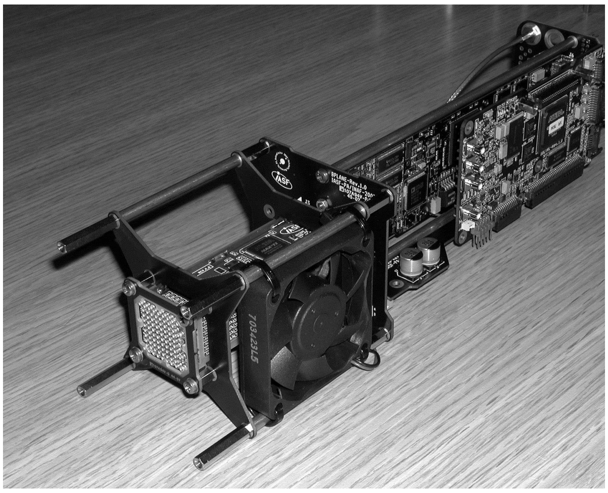

Fig. 3: Inside UVscope: the site for the MAPMT allocation, the FEE and DAQ units connected through the backplane, and the cooling system.

The UVscope collimator is a 157.85 mm length metal cylinder black-colored inside; on its top is applied a thin disc with a rectangular entrance pupil of about 4×4 mm^2 to adapt itself to the pixel geometry of the sensitive unit. The collimator protects the sensitive area of the detector against stray light and regulates its angular aperture: the entire UVscope, formed by 8×8 pixels, will see an effective solid angle of the order of 43.11 deg^2, equal to a square field of view with side of effective aperture of 6.56^o.

A further basic component of UVscope is the motorized filter wheel where a set of different optical filters can be accommodated; the wheel allows to perform consecutive measurements at the different wavelength bands. The filter wheel currently utilized is the model FW-MOT-25 by Andover Corporation which can allocate up to 6 filters, 25 mm diameter each. The filter selection can be manually or remotely controlled; the access time between two adjacent filters is of the order of 0.4 seconds. Normally, during the measurements on field, the main filters used are three narrow band interferential filters centered at 337, 355, and 391 nm (corresponding to the main Nitrogen emission lines) and a wide pass UV filter (M-UG6) chosen for its high transmission in the range of the Nitrogen fluorescence spectrum. One of the remaining two allocations in the wheel is ”closed” to monitoring the dark current noise of the MAPMT, while the last position is maintained ”open” to have a reference on the entire wavelength interval in which the MAPMT is sensitive.

The UVscope apparatus is mounted on a motorized tripod with equatorial monitoring and positional accuracy of the order of 1 arcminute; the system is completed by a personal computer for acquisition and remote control, a GPS receiver for synchronization, and a weather station which allows to register on computer all those measurements of main interest, as temperature, humidity, barometric pressure, wind, that will be taken into account during the off-line data analysis.

Table I summarizes the main UVscope parameters [6].

TABLE I: The ”numbers” of UVscope

Detector:	
Photomultiplier	Hamamatsu R7600-03-M64
Type	8×8 MAPMT head-on
Cathode	Bi-alkali
Dynode	Metal Channel
Window	UV glass
Size (external)	25.7 mm × 25.7 mm
Rise Time	1 ns
Pixel Size	2.26 mm (0.82 deg)
Pixel Solid Angle	0.67 deg^2 (2.05×10^{-4} sr)
Pixel Geometrical Factor	3.63×10^{-3} mm^2 sr
Collimator Length	157.85 mm
Entrance Pupil Area	17.68 mm^2 (4.19 mm ×4.22 mm)
UVscope Angular Size	6.56 deg × 6.56 deg
Motorized Filter Wheel:	
Number of allocations	6
Narrow Band Filters	337 nm, 355 nm, 391 nm
Wide Band Filter	M-UG6 (280-430 nm)
Time Step	0.4 s between adjacent positions

III. Calibration, uniformity, relative gain

To calibrate the instrument, a two steps approach was followed that avoided the use of expensive calibrated light sources or detectors. First the MAPMT uniformity was tested in laboratory, so to obtain a relative calibration for all its 64 pixels. Then it was carried out an absolute calibration of the entire UVscope apparatus, which is an integrated system where filters and collimator contribute to the total detection efficiency; the absolute calibration was performed tracking a star with a stable and well known emission spectrum.

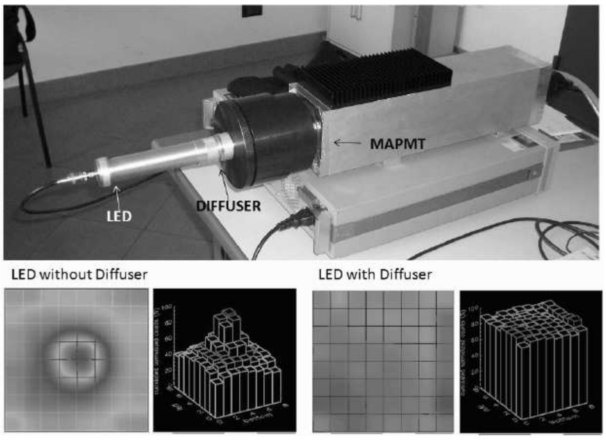

Fig. 4: Relative calibration of UVscope in lab. The upper panel shows the configuration adopted; the bottom panels refer to response (counts per second) of the MAPMT to the LED light in case of absence (left) and presence (right) of the diffusion disk.

The set-up used in laboratory for the relative calibration, as shown in Fig.4, comprises a LED, centrally inserted in an aluminum tube, acting as light source emitting in the 400 nm range and connected to a pulse generator; an acrylic hollowed cylinder (called ”drum”), posed in front of the MAPMT, which allows the multiple reflection of light; and a diffusion disk placed in front of the drum. To distribute uniformly the LED light a little hollow Teflon cylinder, terminated by a black plastic disk, was put on the LED. Such a configuration prevents direct LED light to go straight on, and allows only partial lateral light reflecting on the walls of the aluminum tube to be conveyed to a diffusing disk inserted on the other side of the tube, and to continue up to the end of the drum. In this way it was possible to measure the uniformity of the pixels and hence to evaluate their relative gain [7].

The reference star used for the absolute calibration is Vega, whose spectrum outside the atmosphere is known within 5% [8]. The measurement was executed at Contrada Pomieri, a Sicily mountain site, by tracking the star along his path in the sky. Apart from the ”closed” and ”open” locations and the wide pass UV filter (M-UG6), the wheel was equipped with three narrow-band filters (337, 351, and 391 nm) to measure, in three different wavelengths, the Vega spectrum. These three ”narrow” points were then used to ”scale” the ”nominal” curve of the MAPMT Quantum Efficiency quoted by Hamamatsu; at each filter wavelength, the ratio between scaled and nominal curves corresponds to the product of the Collecting (CE) and the Triggering (TE) efficiencies. The measurements so performed indicated that [5], for the MAPMT used, the CE and TE components reduce the MAPMT efficiency to about 84% of the nominal one quoted by Hamamatsu.

IV. Conclusions and future plans

The techniques adopted to evaluate the relative pixel gains and to obtain the absolute calibration have been developed and consolidated using both laboratory and on-field measurements. A further step will be the calibration of the MAPMT in lab using an optical bench; this will allow the cross-checking with what done with Vega and possibly improve the accuracy of the measurements.

References

[1] *The UVscope Web pages*, http://www.iasf-palermo.inaf.it/IASF/UVscope/

[2] Hamamatsu, *R7600-03-M64 PhotoMultiplier Tube MultiAnode*, http://sales.hamamatsu.com/en/products

[3] O. Catalano, M.C. Maccarone, B. Sacco, *Astroparticle Physics*, Vol.29, N.2, pp.104-116 (2008)

[4] G. Agnetta, S. Giarrusso, G. La Rosa, F. Russo, *Preliminary test of an instrument module for very fast UV and Visible applications*, GAW-FEE-0006-070730 (2007)

[5] M.C. Maccarone, O. Catalano, G. La Rosa, A. Segreto, R. Caruso, A. Insolia, *Nuclear Physics B* vol. 190 C, pp. 257-262 (2009)

[6] M.C. Maccarone, O. Catalano, G. La Rosa, A. Segreto, *The UVscope' Handbook. Progress Report* , IASF-Pa/UVscope Int.Rep. (2009)

[7] O. Catalano, *Note on the relative calibration of R7600 MAPMT*, IASF-Pa/UVscope Int.Rep. (2009)

[8] L. Colina, R. Bohlin, F. Castelli, *Absolute Flux Calibrated Spectrum of Vega*, ISC CAL/SCS-008 (1996)