Calibration and performance of the UVscope instrument

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Abstract: UVscope is a portable multi-pixels photon detector developed at IASF-Pa to support the experimental activity in the high-energy astrophysics and cosmic rays field. The instrument, working in single photon counting mode, is designed to measure light flux in the wavelength range 300-650 nm. Thanks to its features and operational flexibility, UVscope can be used in a wide field of applications where the knowledge of the environmental luminosity is required as in the case of fluorescence and Cherenkov telescopes. We present the procedure adopted for the absolute calibration of UVscope and its performance.

Keywords: photon detector, single photon counting, diffuse NSB light, fluorescence and Cherenkov telescopes

1 Introduction

The diffuse Night Sky Background (NSB) light is of main interest in the field of high-energy cosmic rays and Very High Energy gamma-rays which, thanks to their interaction with the Earth atmosphere, produce photon showers that can be indirectly detected by fluorescence and Cherenkov telescopes. The transmission of photons (whether Cherenkov or fluorescence) from their generation point to the telescope is affected by scattering and absorption. The same effects influence the diffuse NSB light where the shower photons are embedded. The measurement of the diffuse NSB in the UV and visible bands then provides an important information in characterizing the environment in which the shower takes place and propagates.

The NSB light depends on the geographic and atmosphere conditions, as humidity, pressure, dusts, airglow, moonlight, stars, planets, and so on; pulses of light from the Cherenkov and fluorescence radiation of ordinary air showers also slightly contribute to the NSB light, as well as artificial manmade light sources.

The NSB study in the UV and visible regions is the main aim of the UVscope instrument developed at IASF-Pa whose calibration is described in this paper. UVscope is basically a light detector working as photon counter; its detection unit is a high speed response photomultiplier with efficiency extended to the UV band. Due to its features and operational flexibility, UVscope can be successfully used as a sky-light monitoring and cross-calibration tool at the Cherenkov and fluorescence telescopes sites.

2 The Instrument

The UVscope instrument is widely described in dedicated papers [1, 2, 3]; here we summarize its main features.

UVscope basically consists of: (i) a photon detector working in Single Photon Counting mode, coupled to its front-end and data acquisition 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; (iv) a motorized mount with pointing capability and its supporting tripod. The instrument includes the power unit, a weather station and a personal computer, devoted to the acquisition and remote control. The UVscope mounted on the tripod is shown in Fig.1. In case of long and continuous periods of acquisition, UVscope is properly covered by a light structure, made of aluminium and plexiglass, with an anti-reflection coated quartz window (UV transparency $> 99\%$) placed in front of its entrance pupil.

The UVscope light sensor is currently 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. The R7600-03-M64 MAPMT has a bialkali photocathode deposited on an UV-glass window; this ensures a good Quantum Efficiency for wavelengths longer than 280 nm with typical values $>20\%$ in the range 300–470 nm. The UVscope light sensor is coupled, in DC

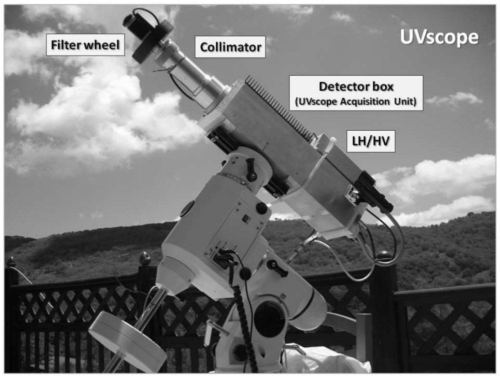

Figure 1: UVscope mounted on its tripod.

mode, to the 64-channels Front-End Electronics (FEE) unit based on the digital Single Photoelectron Counting mode [4] which measures the number of output pulses from the photo-sensor corresponding to individual incident photons. 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 data handling unit. Signals detected by the FEE are sampled by DAQ (internally managed by a reprogrammable FPGA) and then processed according to suitable user-defined algorithms. The data read-out is achieved by an external computer connected through a DELPHIN interface card [5] which allows any Operating System to see UVscope as a virtual disk unit. The UVscope MAPMT, the FEE and DAQ units and the interface card are enclosed in an unique compact box forming the so-called UVscope Acquisition Unit. The power unit, that supplies and distributes low and high voltages, is contained in an external box, as shown in Fig.2.

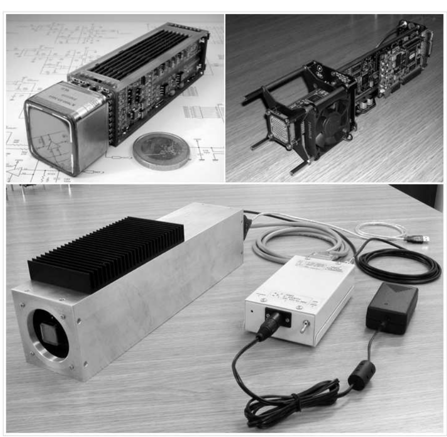

Figure 2: The UVscope Acquisition Unit. Top: FEE unit connected to the MAPMT (left); socket for MAPMT, FEE and DAQ units connected through the backplane, and fan-based cooling system (right). Bottom: the Acquisition Unit in its box and the external power supply box.

To protect the sensitive area of the detector against stray light and regulate its angular aperture, the instrument is equipped with a collimator made of a metal cylinder black-colored inside and where a thin pinhole, acting as entrance pupil, is then applied.

On the top of the collimator, UVscope is equipped with a motorized filter wheel (FW-MOT-25 by Andover Corp.) where a set of different optical filters can be accommodated to perform consecutive measurements in different wavelength bands. In general narrow-band (337, 355, 391, 420 nm) and wide-band (M-UG6) filters are used in our applications; one position is maintained closed to monitor the dark current noise of the MAPMT.

2.1 Imaging Properties

Main advantage of using an imaging system simply based on a collimator instead, for example, a focusing lens is that it avoids the multiple reflections of the light between the MAPMT photocathode and the lens. The instrument angular response can then be obtained by simple geometrical optics. The collimator regulates the fraction of photons that, emitted from the source, arrive onto the photocathode. The Geometrical Factor GF is defined as the ratio between the number of photons arriving at the detector and the number of photons emitted per unit area and solid angle from an isotropic source located at infinite distance; in our applications [3], the distance D_{pupil} between the entrance pupil and the MAPMT photocathode is much greater than the pixel size L_{pixel}, ($L_{pixel}/D_{pupil} << 1$). Under this condition, the geometrical factor GF_{pixel} for a pixel placed at an off-axis angle α_{pixel} from the collimator axis is well approximated by:

$$GF_{pixel} \simeq \frac{A_{pixel} \cdot A_{pupil}}{D_{pupil}^2} \cdot cos^3 \left(\alpha_{pixel}\right)$$

where A_{pixel} and A_{pupil} are the pixel and entrance pupil areas, respectively. The decrease of geometrical factor with the off-axis angles is less than 1% for $\alpha_{pixel} < 4°$.

Both the collimator length and entrance pupil aperture depend on what measurement has to be performed. Entrance pupil with larger apertures increases the geometrical factor so allowing to acquire a higher number of counts per second, as it could be required when using narrow band filters. On the other hand, by reducing the collimator length the solid angle increases and UVscope will see a larger portion of sky. Such a condition could be required when the instrument is used for purposes of cross-calibration of cameras with large field of view, as described elsewhere [6] in these proceedings; in that case we used a collimator 157.85 mm length and an entrance pupil of 4.2×4.2 mm^2 so obtaining a global UVscope field of view of 6.56°×6.56°.

3 Calibration and Performance

UVscope is then an integrated system where filters and collimator contribute to the total detection efficiency. Considering that the collimator geometry can be measured with high precision, the imaging properties of the instrument (field of view, angular resolution) can be varied by changing collimator length and/or pupil size without introducing significative uncertainties in the overall system response. The absolute calibration of UVscope therefore depends essentially on the calibration of its MAPMT light sensor.

The MAPMT detection and UVscope global efficiencies, their dependence from high voltage and threshold values, and the transmission efficiency of both the quartz window and filters have been evaluated in lab, at the IASF–Palermo/INAF Institute and at the Catania Astrophysics Observatory OACT/INAF.

As concerns the MAPMT, several units have been characterized, with a precision better than 10%; nevertheless in the following we will refer to the PM0331 unit, used in lab as well as in very long campaigns of measurement and as support in the calibration of a large aperture telescope with multi-pixel cameras [6].

The UVscope absolute calibration can be also verified on site [1], by measuring the flux of reference stars with stable and known UV spectrum, at different elevation angles and UV bands to correct for the atmospheric attenuation.

3.1 Working Point

To characterize a given MAPMT it is firstly necessary to determine its working point, i.e. what values (high voltage, HV, and discriminator threshold, $Thrd_{mV}$) must be assigned so that the detector works at its best. The setting of the working point values depends on the kind of acquisition we want to perform and a compromise among several parameters is then required. In case of long-time measurement campaigns it is necessary to take into account also the aging of the various components. In several UVscope applications we have to deal with long-time acquisitions and then we are conservative as much as possible, by choosing, for example, HV value highly effective (high counts per second) but within a given consumption level.

To find the operational working parameters of any MAPMT, a practical method consists in obtaining the plateau characteristics of the count rate as a function of HV and $Thrd_{mV}$: the working point is then the pair of values in the flat range where the differential coefficient is the smallest one (minimum slope). This relative calibration has been performed at the IASF–Palermo lab maintaining the inner temperature of the UVscope acquisition unit, close to the MAPMT light sensor, around 37–38°C (these temperatures are compliant with the value that, on average, is registered as maximum inside the instrument during the measurement campaigns). The working point so found for the PM0331 was at HV=-850 V and $Thrd_{mV}$=6 mV.

3.2 Gain Uniformity

To achieve a relative calibration for all its 64 pixels, the MAPMT uniformity was tested in laboratory using (a) the UVscope acquisition unit, (b) a LED, inserted in an aluminum tube, acting as light source emitting at 380 nm and connected to a pulse generator, (c) an acrylic hollowed cylinder (”drum”) which, posed in front of the MAPMT, allows the multiple reflection of light, and (d) a diffuser disk placed in front of the drum to distribute uniformly the LED light onto the MAPMT photocathode. Fig. 3 shows the relative calibration gain map for the PM0331 as obtained at its working point; the standard deviation of the PM0331 inner part (6x6 pixels) is 4% while the mean value on its external frame is about 34% higher than that of the inner pixels due to their major effective extension.

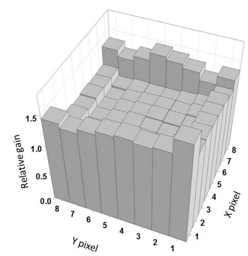

Figure 3: The PM0331 relative calibration gain map.

3.3 Detection Efficiency

At fixed working point, the MAPMT detection efficiency is function of the wavelength λ only and it can be defined as:

$$\varepsilon_{MAPMT}(\lambda) = \varepsilon_{QE}(\lambda) \cdot \varepsilon_{Collect} \cdot \varepsilon_{Trigger}$$

where ε_{QE}, $\varepsilon_{Collect}$ and $\varepsilon_{Trigger}$ are the quantum, collecting and trigger efficiency components, respectively, and where only ε_{QE} is depending on the wavelength. To evaluate the global ε_{MAPMT} detection efficiency we used one of the facilities available at the COLD laboratory, OACT/INAF. The facility is a complex and high precision set of instruments aiming to the electro-optical characterization of light sensors; details are reported in reference [7] and here its main parts are briefly described.

Following from right to left the scheme in Fig.4 we find: a Xenon lamp used as radiation source; a wavelength selection system constituted by a set of filters and by a Czerny-Turner monochromator (FWHM better than 1 nm in the 130–1100 nm spectral range); a beam splitter which directs part of the monochromatic radiation towards a camera hosting a 1 cm^2 reference photodiode (NIST traced) while the remaining part, through a focusing lens and quartz window, is directed towards the detector to be characterized. The facility offers the possibility to characterize MAPMTs providing that a mechanical interface is adapted to its second output branch (UVscope unit location in Fig.4).

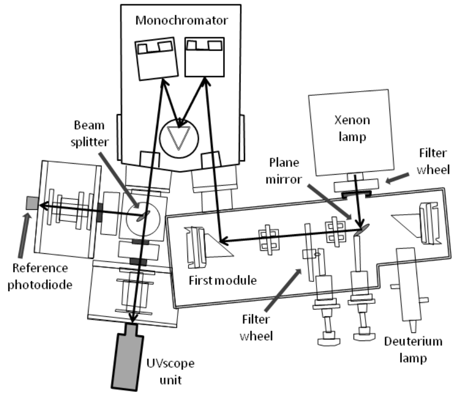

Figure 4: Schematic view of the test facility at the COLD lab. The arrow–line indicates the path of the light.

The photon efficiency ε_{MAPMT} can be obtained by:

$$\varepsilon_{MAPMT}(\lambda) \; = \; \frac{< R >_{MAPMT} (\lambda) \; \cdot \; PD_{QE}(\lambda) \; \cdot \; e}{PD_{current}(\lambda) \; \cdot \; PD_{bs}(\lambda) \; \cdot \; T_{nf}(\lambda)}$$

where $< R >_{MAPMT} (\lambda)$ is the MAPMT average count in the unit time, $PD_{QE}(\lambda)$ is the Quantum Efficiency of the photo-diode, e is the elemental electron charge, $PD_{current}(\lambda)$ is the photo-diode current, $PD_{bs}(\lambda)$ is the beam splitter scaling factor, defined as the ratio between transmitted and reflected light, and $T_{nf}(\lambda)$ is the transmission efficiency of a neutral filter needed to attenuate light going to the MAPMT. Moreover, little corrections for the coated quartz window ($\sim$1%) in front of the MAPMT and the focusing lens (2%) system have been experimentally verified and included in the photon efficiency calculation.

The procedure allows to absolutely calibrate the MAPMT with a very high precision ($> 90\%$). The profile of the MAPMT detection efficiency for two sensitive units is shown in Fig.5, as obtained under the working point chosen for the PM0331 (HV=-850 V and $Thrd_{mV}$=6 mV).

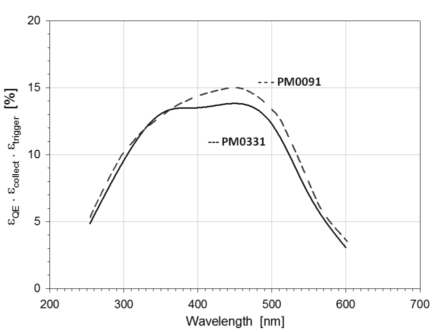

Figure 5: Profile of two MAPMTs detection efficiency as obtained at HV=-850V, $Thrd_{mV}$=6 mV working point.

3.4 Global Efficiency

Apart from the instrument geometrical factor GF_{pixel}, the experimental data acquired with UVscope are function of the MAPMT detection efficiency ε_{MAPMT} and of the filter transmission T_f, both functions of the wavelength, λ. The mean NSB flux, in units of $photons/(m^2 \; sr \; ns \; nm)$ and taking into account the units conversion factors, can be expressed as:

$$< NSB >= \frac{R \times 10^{-9}}{GF_{pixel} \; \cdot \; \Delta\lambda_{eq.} \times 10^{-6}}$$

where R is the observed counting rate per second per pixel (purified from the dark count rate) and $\Delta\lambda_{eq}$ is defined as

$$\Delta\lambda_{eq} = \int_0^\infty \varepsilon_{MAPMT}(\lambda) \cdot T_f(\lambda) \cdot d\lambda$$

The main source of uncertainty comes from the MAPMT characterization and, with smaller contributions, from filters (2%) and geometry (1%). Finally, the overall uncertainty in the NSB flux evaluation seen by UVscope is 10%.

4 Conclusions

The UVscope instrument is an useful tool for a variety of applications, in the wavelengths band 300–650 nm, where precise light intensity evaluation is required. The simple and effective design and its flexibility allows using UVscope as a support instrument for monitoring of sky transparency and study of the diffuse NSB light as well as for non-invasive cross-calibration of large cameras of fluorescence and Cherenkov telescopes.

UVscope is an integrated system where filters and collimator contribute to the total detection efficiency. Nevertheless, considering the high precision achievable in the system geometry, the absolute calibration of the UVscope system essentially depends on the calibration of its light sensor which can successfully performed in lab with very high precision (uncertainty less than 10%).

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