The prototype Schwarzschild Couder Telescope: a Medium-Sized Telescope for the Cherenkov Telescope Array

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Abstract. The Schwarzschild-Couder Telescope (SCT) is a dual-mirror telescope designed for the Cherenkov Telescope Array Observatory (CTAO) to observe very-high-energy gamma rays (20 GeV to 300 TeV). It features a dual-mirror system and a high-resolution camera with an 8° field of view (FoV) for enhanced angular resolution and background rejection. A prototype (pSCT) is operational at the Fred Lawrence Whipple Observatory (FLWO) in Arizona, with a 2.7° FoV SiPM array. The pSCT recently detected the Crab Nebula with 8.6 standard deviations of significance. The focal plane is currently being upgraded to improve sensors and expand the FoV from 2.7° to 8°. An overview of the pSCT project, its results, and the camera upgrade will be presented.

1 Introduction to the CTAO project

The Cherenkov Telescope Array Observatory (CTAO) is a next-generation ground-based observatory designed to detect very high-energy (VHE) gamma rays, ranging from 20 GeV to 300 TeV. When gamma rays interact with the atmosphere, they produce an electromagnetic cascade that emits Cherenkov light, which can be detected by ground-based telescopes. The CTAO project will operate at two sites: one in the northern hemisphere at Paranal, Chile, and one in the southern hemisphere at La Palma, Spain. The array will use telescopes of three sizes: Small-Sized Telescopes (SST), Medium-Sized Telescopes (MST), and Large-Sized Telescopes (LST), each designed to cover different energy ranges. The southern site will cover an area of 3 km², while the northern site will cover 0.25 km² [1].

2 SCT Project

For the CTAO, two types of medium-sized telescopes (MSTs) are being considered: the Davies-Cotton (DC) telescope and the Schwarzschild-Couder telescope (SCT) prototype. The SCT design features a dual-mirror configuration, with a 9.66 m primary mirror and a 5.4 m secondary mirror, (see a picture of the pSCT in Fig.1) [2]. In contrast to the DC telescope, the SCT uses silicon photomultipliers (SiPMs) instead of traditional photomultiplier tubes (PMTs), offering advantages in compactness and resolution. The SCT optical system minimizes optical aberrations and focuses Cherenkov light onto a compact, high-resolution camera, which significantly improves image quality compared to the DC telescope.

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Figure 1. Picture of the pSCT installed in Arizona.

3 Current Status of the pSCT Camera

The pSCT camera is divided into two sections: the inner part, which contains the camera modules, and the outer part, which serves as a protective cover [2]. Each camera module consists of 64 SiPM pixels, and the full camera will have 177 modules, totaling 11,328 pixels. The current operational camera of the pSCT is equipped with 25 central modules covering a 2.7° field of view (FoV), (see Fig.2) corresponding to a square Field of View (FoV) of 2.7°. The camera includes front-end electronics (FEE) for signal amplification and digitization,

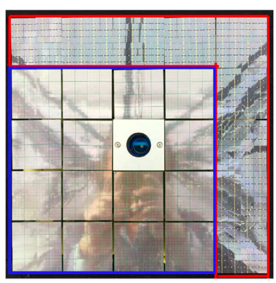

Figure 2. The pSCT camera is equipped with 15 modules featuring Hamamatsu MPPCs (circled in red) and 9 modules with Fondazione Bruno Kessler (FBK) High Density (HD3) SiPMs (circled in blue). The central slot is used for the telescope pointing procedure.

improving the camera's performance. The current camera uses FBK SiPMs produced in collaboration with the National Institute of Nuclear Physics (INFN) [3] [4].

The SiPMs mass production is completed. 48 wafers of SiPMs were produced in Lfoundry for a total amount of about 20k SiPMs. Quality check with IV measurements on wafer were performed and the assembly on SiPM matrices for pSCT telescope is ongoing. The Near Ultra Violet high density Metal-in-Trench (NUV-HD-MT) SiPMs developed for CTAO applications were tested and will equip the entire camera. They are characterized by reduced cross talk probability (<5%), maximum photon detection efficiency (PDE) (close to 50% at 400 nm) for wavelengths ranging between 420 nm to 450 nm. Also NUV-HD MT technology is well suited for Cherenkov light detection with a maximum PDE >60% (see Figs. 3 and 4) [5]. The new electronics will include the SiPM Multichannel ASIC for high Resolution Cherenkov Telescope ASICs (SMART), designed specifically for Cherenkov tele-

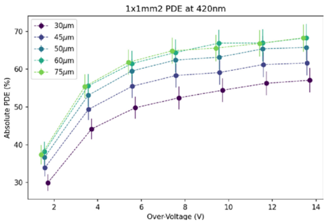

Figure 3. PDE at 420 nm as a function of over-voltage for $1 \times 1\,\mathrm{mm}^2$ HD-MT SiPMs with varying cell pitches.

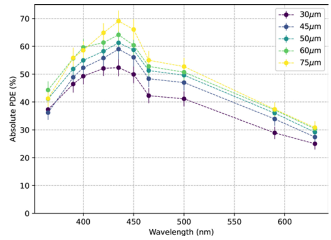

Figure 4. PDE as a function of the incident light wavelength. Measurements for $1 \times 1\,\mathrm{mm}^2$ SiPMs at approximately 8 V of excess bias, with varying cell pitches.

scopes to improve resolution, reduce noise, and optimize signal processing (see Figs. 5, 6).

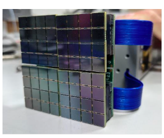

Figure 5. FPM including SiPMs.

Figure 6. Picture of the single module.

The SMART ASIC provides 16 independent channels, each with two paths: a fast path for photon counting and a slow path for measuring the mean current of the SiPMs. The ASIC includes a 20-bit register for controlling gain and bandwidth, along with an 8-bit DAC for tuning the SiPM bias. The testing of the SMART ASIC demonstrated excellent performance, with less than 1% defective units, and the ASIC showed optimal response to laser signals, confirming its readiness for integration into the upgraded camera [6]. It is coupled to the TARGET-C devoted for sampling and digitization an the T5TEA for trigger [7].

4 Crab Nebula Observation

In January 2020, the pSCT successfully detected the Crab Nebula [8], marking a significant milestone. The telescope conducted ON/OFF observation runs, collecting 21.6 hours of ON-source data and 17.6 hours of OFF-source data. A statistical significance of 8.6 standard deviations was achieved in the detection of the Crab Nebula. Data from the VERITAS telescope, located nearby at the FWLO, were used for simultaneous observations, providing additional validation. The pSCT and VERITAS observed the same events, enabling a direct comparison of gamma-ray events and cosmic-ray events.

A detailed analysis of the pSCT data revealed an excess of counts at the position of the Crab Nebula, demonstrating the pSCT's capability to detect gamma-ray sources with high sensitivity. A gamma-ray event was captured by both the VERITAS and pSCT telescopes, showing the potential for complementary observations between these instruments.

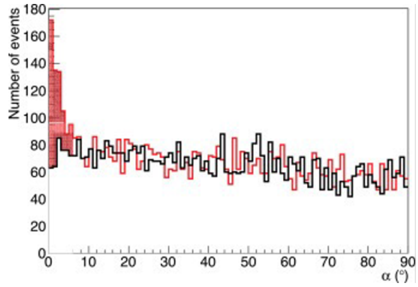

Figure 7. Comparison between counts acquired during ON-source observations (red histogram) and counts acquired during OFF-source observations.

5 Future Prospects & Conclusions

The ongoing upgrade of the pSCT camera and its electronics will allow the telescope to further improve its angular resolution, background rejection capabilities, and overall performance. Once the camera is fully upgraded, it will cover a wider 8° field of view, enhancing its ability to observe more sky area and detect gamma-ray sources across a broader energy range (100 GeV to 10 TeV). The new electronics will also help manage noise better and improve the timing and accuracy of Cherenkov signal detection.

The pSCT represents a major advancement in high-resolution Cherenkov telescopes, thanks to its dual-mirror design, the use of SiPMs, and the optimized camera system. The successful detection of the Crab Nebula confirms the telescope's capabilities, and the ongoing upgrades will further enhance its performance. With these improvements, the pSCT is expected to make significant contributions to gamma-ray astronomy, especially within the CTAO project, which aims to provide a highly sensitive and detailed map of the universe in high-energy gamma rays.

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