Status of the Schwarzchild-Couder Medium-Sized Telescope for the Cherenkov Telescope Array

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Abstract. The Cherenkov Telescope Array (CTA) is planned to be the next-generation very-high-energy (VHE; E>100 GeV) gamma-ray observatory. It is anticipated that CTA will improve upon the sensitivity of the current generation of VHE experiments, such as VERITAS, HESS and MAGIC, by an order of magnitude. CTA is planned to consist of two graded arrays of Cherenkov telescopes with three primary-mirror sizes. A proof-of-concept telescope, based on the dual-mirror Schwarzchild-Couder design, is being constructed on the VERITAS site at the F.L. Whipple Observatory in southern Arizona, USA, and is a candidate design for the medium-sized telescopes. The telescope's construction will be completed in early 2017, and the status of this project is presented here.

INTRODUCTION

The next-generation VHE observatory, CTA [1], is expected to provide coverage between ~20 GeV and ~300 TeV, and improve upon the sensitivity of the current generation of VHE experiments by an order of magnitude. CTA should detect hundreds of new VHE sources, and enable studies of the VHE sky with unprecedented angular, spectral and temporal resolution. In addition to providing unique new capabilities for VHE astronomy, to ensure the maximum scientific output of the facility, the CTA consortium will operate the facility as an open observatory, providing access to data in the VHE band to members of the wider astronomical community for the first time.

The current baseline design of CTA consists of two arrays of Cherenkov telescopes located in the Southern and Northern Hemispheres. The arrays will include telescopes of small (D~4 m; southern site only), medium (D~12 m) and large sizes (D~23 m), which focus on providing coverage for different parts of the VHE band. Historically Cherenkov telescopes were constructed with segmented, single-mirror designs of either Davies-Cotton (DC; effectively spherical) or parabolic shape. However, for CTA several telescopes with dual-mirror designs are being prototyped for use as the small- and medium-sized telescopes, in addition to those with classical designs. Although these dual-mirror systems are more complex and have significantly tighter alignment requirements, they offer a number of advantages. The most-significant of these advantages is their improved optical performance across their field of view compared to DC telescopes. The Schwarzchild-Couder design provides a much reduced plate scale, and a uniform optical point-spread function (i.e. unaffected by spherical or comatic aberrations) over a wide field of view (FoV). The smaller plate scale enables the use of compact cameras for imaging this wide FoV, which in turn enables the use of integrated, higher-efficiency photo-sensors, and ultimately results in a much higher resolution camera. Because the higher resolution camera allows a more precise reconstruction and characterization Cherenkov images, an array of dual-mirror telescopes should outperform an array of comparably-sized single-mirror instruments.

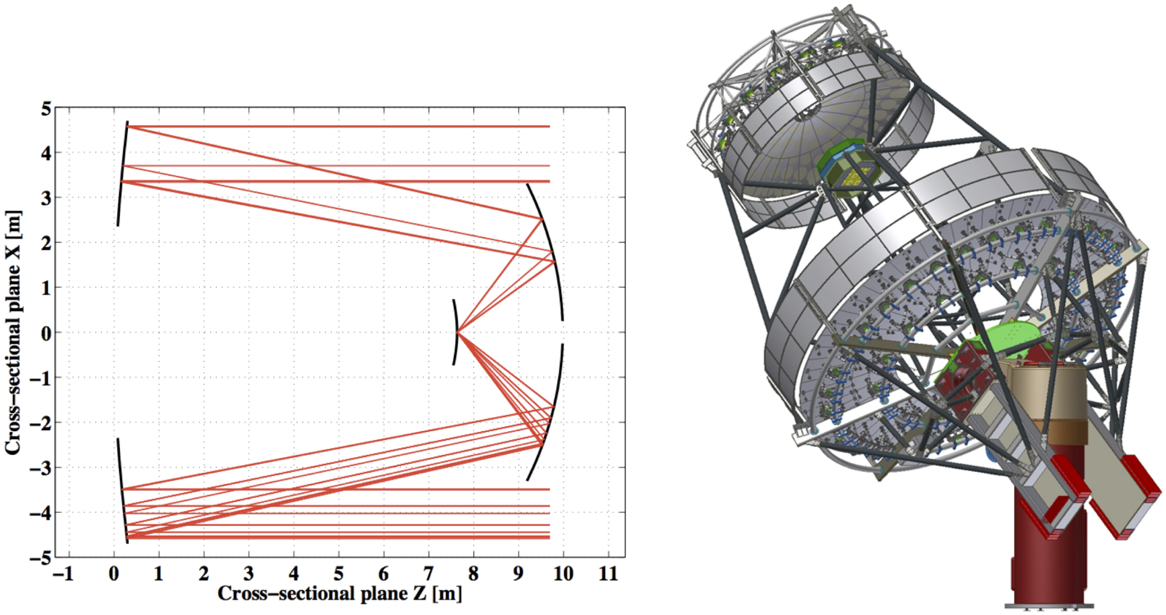

FIGURE 1. Left: Schematic for the optical design of the Schwarzchild-Couder telescope. Right: Conceptual drawing of the proof-of-concept SCT being constructed at the F.L Whipple Observatory in Arizona, USA.

The Optical Support Structure

The design of the Schwarzchild-Couder telescope (SCT) employs a novel aplanatic optical system composed of two aspheric mirrors [2]. Figure 1 shows the schematic of the optical design for the SCT [2]. The proof-of-concept, medium-sized Schwarzchild-Couder telescope being constructed for CTA is called the pSCT, and is also shown in Figure 1 . The pSCT will have a primary mirror of 9.7 m aperture, a secondary mirror of 5.4 m aperture, and a focal length of 5.6 m (f/D ~ 0.58). The telescope's steel optical support structure (OSS) will support its camera, mirrors and auxiliary systems, and will be mounted to a main plate, along with a counterweight structure, onto the elevation axis of a positioner composed of a head / yoke and a tower. The pSCT's positioner is very similar to that constructed for the prototype medium-sized telescope with Davies-Cotton design, with the major differences being a reduced height of the tower and some technical improvements (e.g. the addition of stow pins, higher strength bearings in the azimuth system, casted head / yokes, etc). The pSCT's positioner was successfully installed in February 2016, and the successful assembly and erection of the major components of the OSS was completed by August 2016 (the OSS was ~90% complete at the time of the conference). Figure 2 shows the assembled pSCT OSS and positioner at three different elevation angles. The assembled system has also been driven in azimuth. The metrology of the primary and secondary dishes was measured after their installation on the telescope structure and is within specifications.

As can be seen in Figure 1, baffles will be placed around the primary and secondary mirror structures, primarily to contain / eliminate reflected sunlight during the daytime for safety reasons, but also to reduce the night sky background scatter. These will be installed in ~November 2016, after the installation of cables and conduit on the OSS. To eliminate reflected sunlight, it is also required that the telescope be parked during daylight hours facing north at elevation angles that change throughout the year. These are -5 degrees, +20 degrees, and +45 degrees. Stow pins, one for each of altitude and azimuth, are used to secure the telescope during high winds. More details regarding the OSS and the positioner can be found in [3] and [4], respectively.

The SCT Mirror Surface

As can be seen in Figure 3, the SCT mirror surface will consist of 72 mirror panels of 4 different shapes. The primary mirror surface will contain an inner ring of 16 panels, and an outer ring of 32 panels. The secondary mirror surface will consist of an inner ring of 8 panels, and an outer ring of 24 panels. Each panel is relatively large (~1 m^2), and

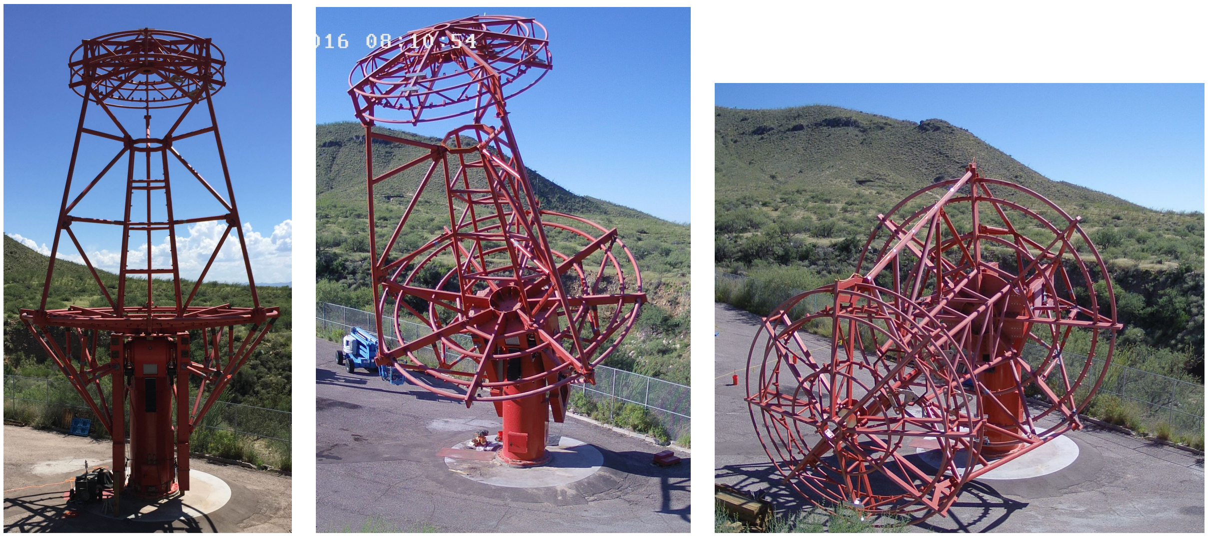

FIGURE 2. The completed OSS and positioner for the pSCT in September 2016 shown at three different elevation angles.

the overall primary mirror area of ~50 m^2 area is about half that of VERITAS or HESS. More details on the pSCT optical system can be found in [5] After the mirrors are aligned using the equipment described in [6], the optical point spread function for the SCT is expected to be around 5', which corresponds to a physical size of 8 mm on the focal plane.

The 48 primary mirror panels panels were produced by Media Lario Technology (MLT) in Italy using cold-glass-slumping technology. Here, two thin (1.7 mm) sheets of glass are placed on each side of a 30 mm aluminum honeycomb core, and slumped over a mandrel. All glass panels were given a multi-layer reflective coating by BTE in Germany and ~2/3 have been delivered to the pSCT team. The remaining panels will be delivered in Fall 2016. The metrology and reflectivity of the received panels were tested, and on average are within specifications. Figure 4 shows two coated primary mirror panels in the UCLA testing facility.

In early 2016, the fabrication of the 24 panels for the demagnifying secondary mirror surface of the pSCT represented the main technological hurdle for the pSCT project. A two step process has since been successfully developed to produce these panels. This process includes hot slumping of flat, 12 mm float glass sheets over a mandrel, followed by fine figuring using cold slumping techniques similar to those for the production of the primary mirror panels. Three panels have successfully been fabricated using this technique, and their metrology is within specifications. Figure 5 shows these panels, along with the result of one set of metrology measurements. Similar to the primary surface, these panels will be coated by BTE. Although mandrels have been fabricated for both the inner and outer ring of secondary mirror panels, the pSCT team is planning to produce only the outer ring of 16 panels for the initial proof-of-concept testing. Delivery of these panels is expected in late 2016. The inner ring will only be produced if sufficient resources are identified in the future.

The primary and secondary mirror panels will all be mounted onto independent mirror panel modules which hold and align each panel. Each module (shown in Figure 5) consists of a Stewart platform, controller board, multiple edge sensors and a mounting triangle. More details on these modules and the mirror alignment systems can be found in [6]. The primary mirror panels are currently being integrated onto the mirror modules, packed into custom-made boxes, and will be delivered in four, sequenced shipments to the pSCT / VERITAS site in Fall 2016. Each module will be installed on the OSS using a crane and specialized lifting fixture. A similar effort will commence in early 2017 for the secondary mirror panels.

The Camera

An 11,328-pixel, silicon photomultiplier (SiPM) camera was developed for the SCT [7]. The camera concept is shown in Figure 6, and consists of an outer enclosure that interfaces with the telescope structure and acts as an environmental

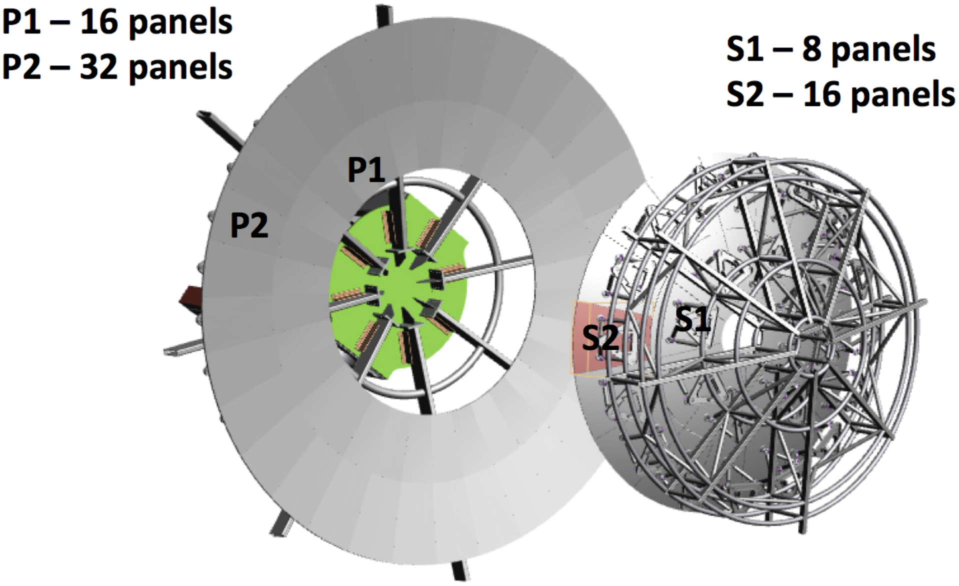

FIGURE 3. The conceptual mirror layout for the SCT.

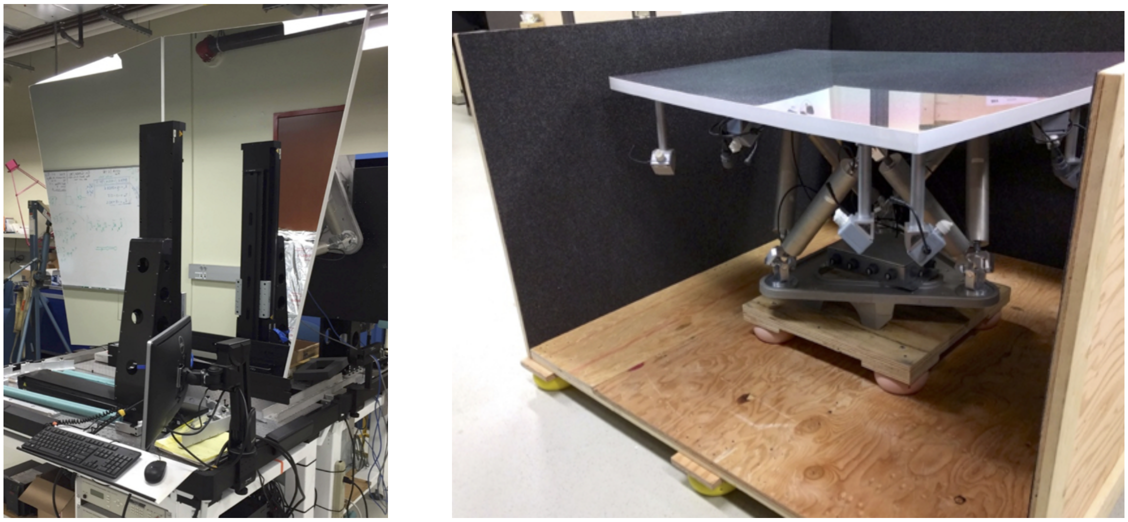

FIGURE 4. Left: SCT primary mirror panels undergoing testing and integration at UCLA. Right: A fully-integrated primary-mirror panel ready for shipping to the pSCT site.

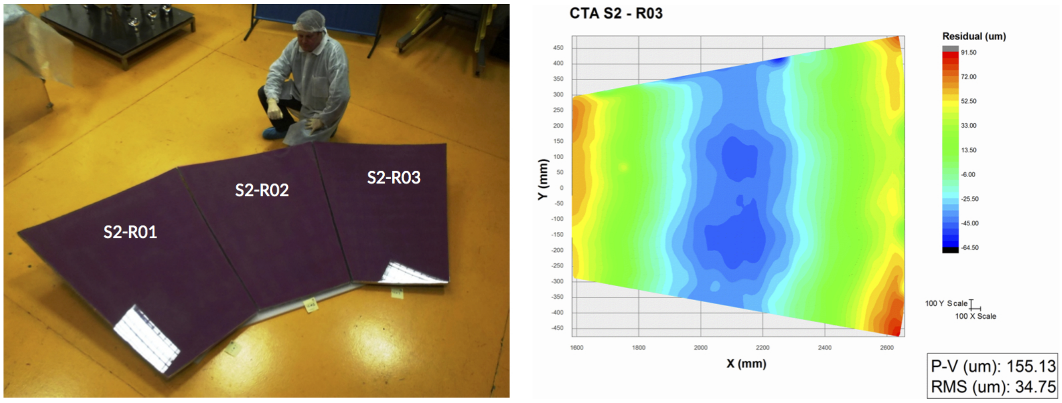

FIGURE 5. Left: Three SCT secondary mirror panels. Right: Results of metrology testing for one of these mirror panels.

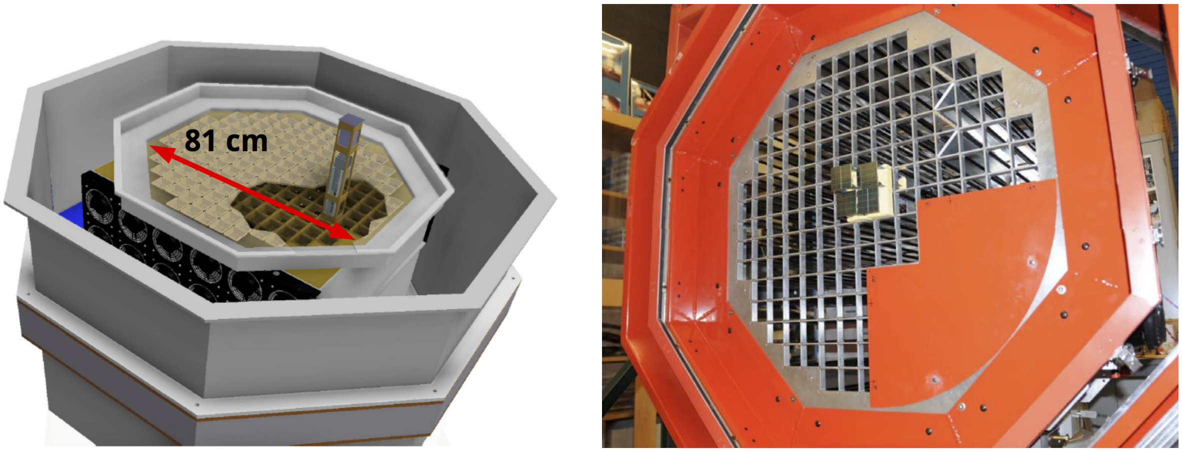

FIGURE 6. Left: Conceptual design of the SCT camera. Right: The nearly complete pSCT camera.

shield for an inner camera detector, whose surface is 81 cm width, which corresponds to an 8° FoV. The inner camera detector of the pSCT will use the Hamamatsu S12642-0404PA-50(X) as the photon sensor and this device consists of 16 SiPMs (see Figure 7). Groups of 4 SiPMs are connected in parallel to form each pixel with a size of 6.5 x 6.5 mm^2 (0.064°). The camera detector has a modular design, with each module containing pixels on an 8 by 8 square grid of 5.4 cm width along with their complete readout electronics. A fully equipped SCT camera has 177 of these modules (shown in Figure 7), and the pSCT will have 16. Although the S12642 was selected for the pSCT, SiPM devices are rapidly improving and the SCT team is considering newer devices for the future. Ongoing work with FBK has shown promise, with SiPMs already produced with similar size to those in the pSCT and having better response in the UV/blue, better suppression of the NSB, at least 2.5 times lower optical cross talk, and an after-pulsing rate $<1\%$.

The complete readout electronics are contained within the SCT camera. The front-end processing and digitization of signals, as well as the first-level triggering are performed in the camera modules. Nine backplanes, on a 3 x 3 grid, handle the communication between camera modules and servers, distribution of trigger information and power, etc. Of particular note is that the first-level trigger and digitization is handled by an application-specific integrated circuit (ASIC). The pSCT uses the TARGET 7 chip [8], which has 16-channels each equipped with a switched capacitor array providing a buffer depth of ~16 microseconds at a sampling rate of 1.0 GS / s. More details regarding the pSCT data acquisition system can be found in [9].

As of Summer 2016, the pSCT camera mechanics and electronics were completely fabricated, and the remaining work consisted of TARGET calibration and module integration which will be completed in Fall 2016. Figure 6 shows the partially populated pSCT camera. It is anticipated that a fully-functional camera will be delivered to the pSCT site in late 2016, and installed on the telescope OSS using a crane and special mounting jig shortly thereafter.

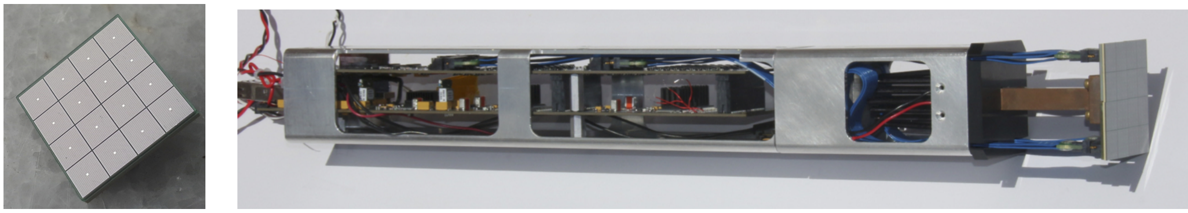

FIGURE 7. Left: One tile of the Hamamatsu S12642-0404PA-50(X) used in the SCT prototype. Right: One fully assembled pSCT camera module.

Conclusions

The dual-mirror Schwarzchild-Couder design presents a number of challenges, but also distinct advantages for Cherenkov telescopes. A total of three telescopes based on this design have been prototyped for potential use in CTA, and the pSCT is the only one of these designs considered for the medium-sized class of telescopes. The goal of the pSCT project is to achieve better performance, for comparable cost, than the slightly-larger (~12 m aperture) medium-sized Davies-Cotton design, in particular with respect to the resolution of the recorded Cherenkov light images. While the SCT optics are indeed challenging, all research and development for the project is complete and encouraging. The construction effort for the pSCT is ongoing and should be complete in early 2017, after which the performance of the telescope can be validated.

ACKNOWLEDGMENTS

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