Prototype Schwarzschild-Couder Telescope for the Cherenkov Telescope Array: Commissioning the Optical System

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cherenkov telescope array

ABSTRACT

A prototype Schwarzschild-Couder Telescope (pSCT) has been constructed at the Fred Lawrence Whipple Observatory as a candidate for the medium-sized telescopes of the Cherenkov Telescope Array Observatory (CTAO). CTAO is currently entering early construction phase of the project and once completed it will vastly improve very high energy gamma-ray detection component in multi-wavelength and multi-messenger observations due to significantly improved sensitivity, angular resolution and field of view comparing to the current generation of the ground-based gamma-ray observatories H.E.S.S., MAGIC and VERITAS. The pSCT uses a dual aspheric mirror design with a 9.7 m primary mirror and 5.4 m secondary mirror, both of which are segmented. The Schwarzschild-Couder (SC) optical system (OS) selected for the prototype telescope achieves wide field of view of 8 degrees and simultaneously reduces the focal plane plate scale allowing an unprecedented compact (0.78 m diameter) implementation of the high-resolution camera (6 mm/ 0.067° per imaging pixel with 11,328 pixels) based on the silicon photo-multipliers (SiPMs). Th OS of the telescope is designed to eliminate spherical and comatic aberrations and minimize astigmatism to radically improve off-axis imaging and consequently angular resolution across all the field of view with respect to the conventional single-mirror telescopes. Fast and high imaging resolution OS of the pSCT comes with the challenging submillimeter-precision custom alignment system, which was successfully demonstrated with an on-axis point spread function (PSF) of 2.9 arcmin prior to the first-light detection of the Crab Nebula in 2020. Ongoing commissioning activities aim to meet the on-axis PSF design goal of 2.6 arcmin, verify the off-axis performance of the pSCT OS, and develop techniques to maintain alignment stability over telescope structural deformations from pointing and temperature variations. In this contribution, we report on the commissioning status, the optical alignment procedures adopted for segmented OS, and alignment progress to verify and validate design requirements.

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Introduction

The Schwarzschild-Couder Telescope (SCT) optical system is designed to fully correct for comatic and aspherical aberrations. It is made up of 48 primary mirror panels and 24 and secondary mirror panels. Alignment of these segmented panels must be capable of sub-mm and sub-mrad precision, both locally (panel to panel) and globally.

SCT Optical Alignment

To align this system, a star is tracked and the light is traced as it passes through the optical system toward the focal plane, allowing a full understanding of all the components of the system. The light reflected by each panel can be decomposed on the focal plane by defocusing each element into a ring pattern.

In this defocused star ring pattern, each panel is identifiable. See **Figure 1** for alignment schematic. **A)** The aligned panels project a *single point* on focal plane. **B)** Apply a radial tilt of P1 and P2 panels to form *two* rings. **C)** Apply a radial tilt of S2 panels to form a *third* ring.

The defocused star ring patterns (rings P1, P2 and S2) is used as a starting point to align the panels into a focal point (**Fig 1 (A)**).

S1 Panel Alignment

The S1 panels are coupled with all other panels (P1, P2, and S2) and affect the optical point spread function (PSF). A change in the position of the S1 panels requires realignment of the other rings. The following is used to align the S1 panels.

A) P1 panels are rotated tangentially to create a second set of centroids on focal plane. B) S1 panels are rotated tangentially to remove the new centroids, therefore aligning the S1 panels. C) Focal plane image of the projected centroids. Inset: 2 pairs of split images visible by the misalignment of S1 panels, to be merged and corrected.

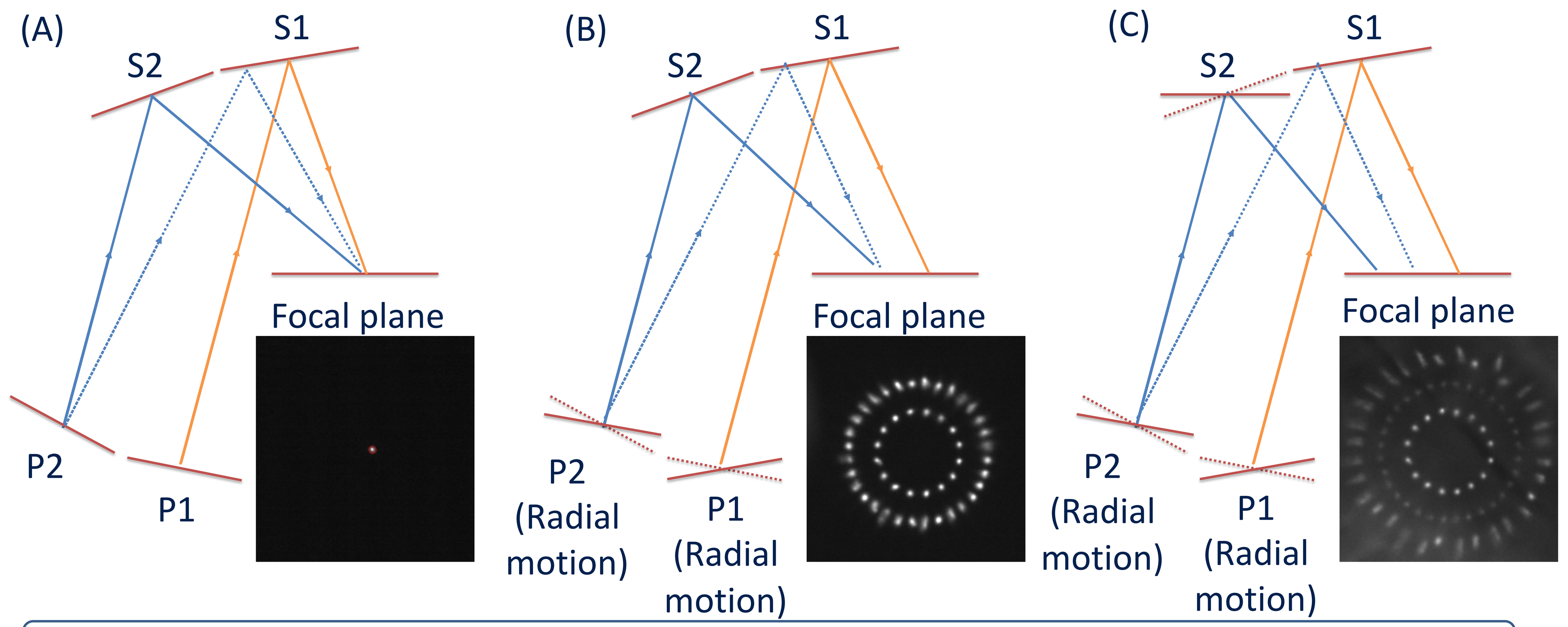

Figure 1. Optical alignment configurations

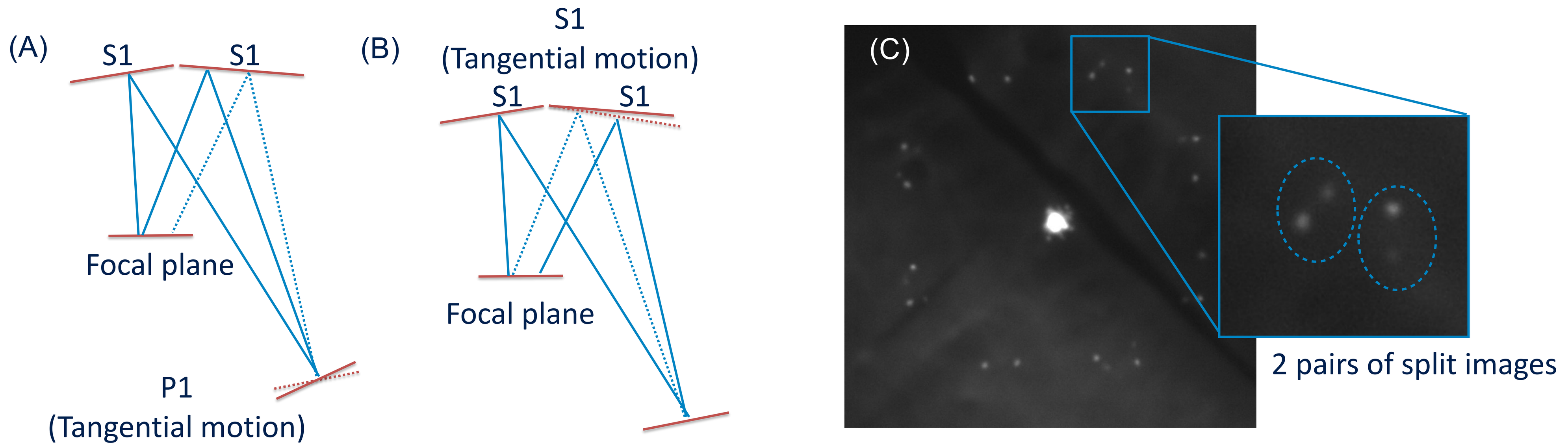

Figure 2. A general overview of the S1 alignment process.

Elevation Dependence of On-Axis PSF

As the pSCT tracks a star, the gravitational load of the optical support structure will deform and affect the on-axis optical PSF. The PSF is defined as $2{\times}max(\sigma_x, \sigma_y)$.

Using the defocused star patterns, we align and save the panel states for the P1, P2 and S2 ring configurations at a range of elevations (Fig 1C). This becomes a database of elevation dependent states. For any elevation, we move the panels to the defocused state by interpolating from the database, and then align the panels from the ring pattern to the focal point. The on-axis optical PSF is measured in the focused state.

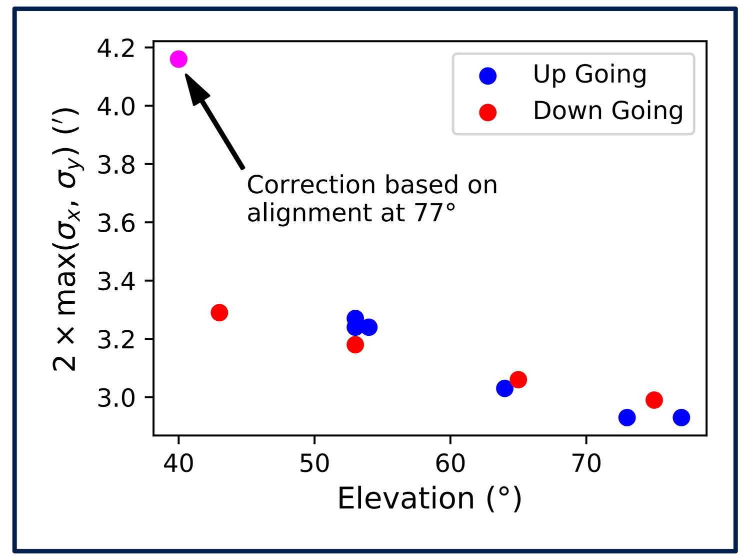

Figure 3. PSF measured per elevation. Panel alignment settings derived without corrections.

Figure 3 shows the stability of the PSF using this procedure, which averages 3.1\` for 30° range of elevation angles. At 40°, the panel alignment setting from 77° was loaded to measure the largest PSF deviation from optimal setting. This larger PSF shows how large the PSF can get if active re-alignment is not attempted.

Summary and Outlook

The method to align S1 was proved successful. This is a crucial step that ensures the correct tip/tilt alignment of all mirror panels of the pSCT. The optical PSF was stable for a wide range of elevation angles, validating the creation of a database of panel configurations that can be used for active alignment corrections based on pointing.

Future work on the optical system includes measurement of the first-order corrections and PSF per panel. Additionally, off-axis alignment will be measured and verified, and GAS components will be commissioned.

ACKNOWLEDGEMENTS

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www.cta-observatory.org/consortium_acknowledgments