

# Construction of a medium-sized Schwarzschild-Couder telescope as a candidate for the Cherenkov Telescope Array: development of the alignment system

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## ABSTRACT

The Cherenkov Telescope Array (CTA) is an international project for a next-generation ground-based gamma-ray observatory. CTA, conceived as an array of tens of imaging atmospheric Cherenkov telescopes, comprising small, medium and large-size telescopes, is aiming to improve on the sensitivity of current-generation experiments by an order of magnitude and provide energy coverage from 20 GeV to more than 300 TeV. The Schwarzschild-Couder (SC) medium-sized candidate telescope model features a novel aplanatic two-mirror optical design capable of a wide field-of-view with significantly improved imaging resolution as compared to the traditional Davis-Cotton optics design. Achieving this imaging resolution imposes strict alignment requirements to be accomplished by a dedicated alignment system. In this contribution we present the status of the development of the SC optical alignment system, soon to be materialized in a full-scale prototype SC medium-size telescope (pSCT) at the Fred Lawrence Whipple Observatory in southern Arizona.

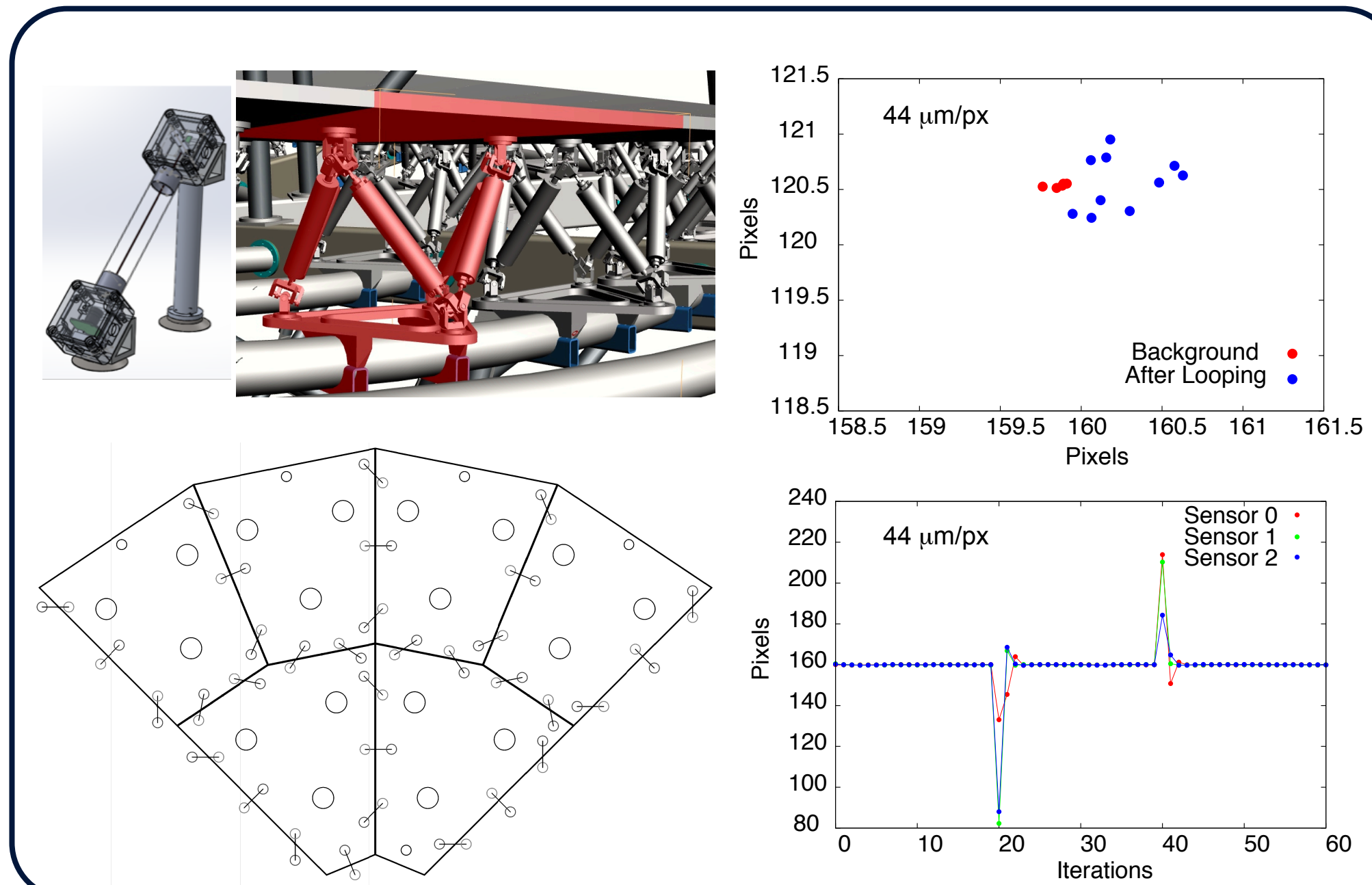


## INTRODUCTION

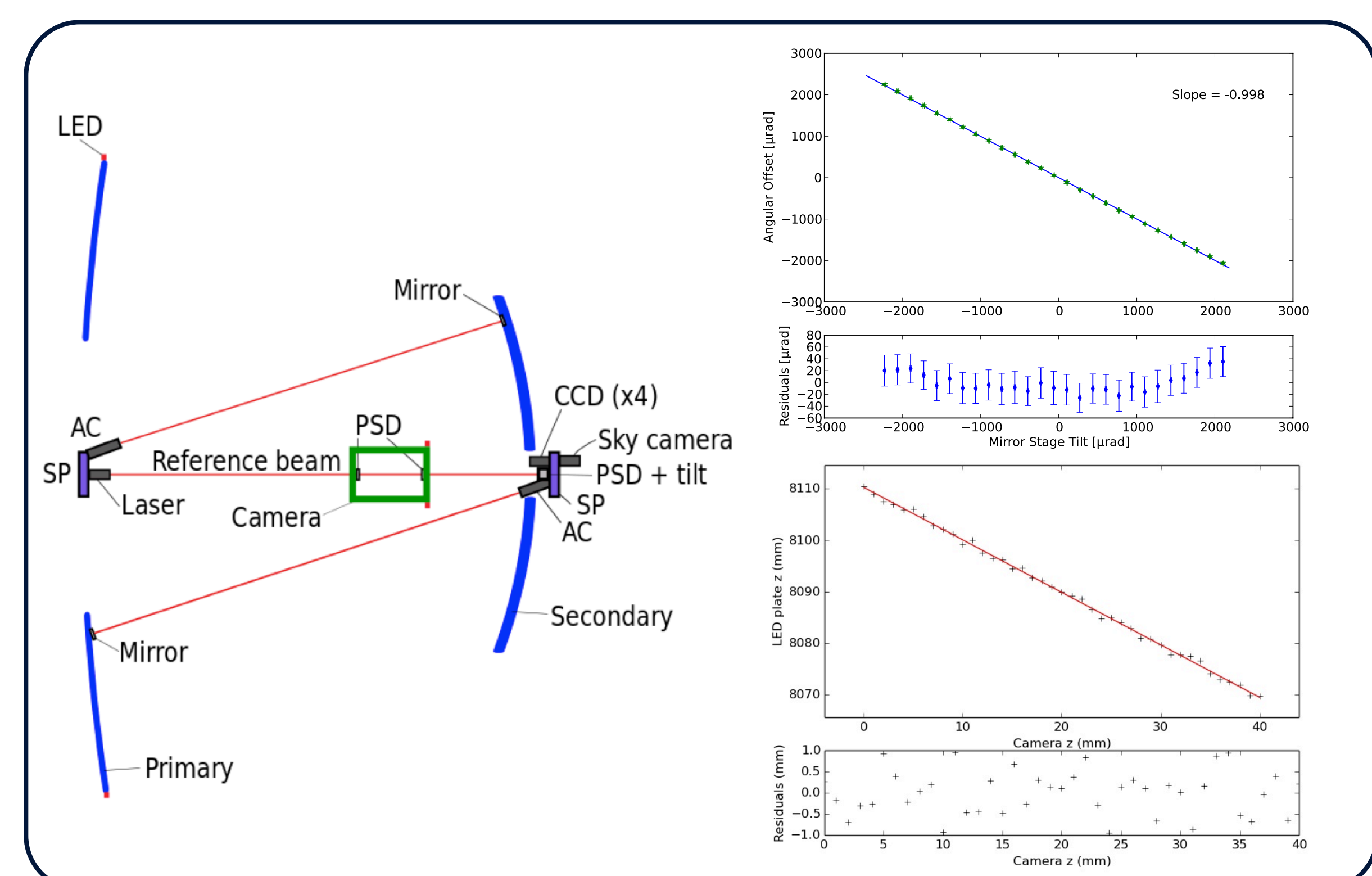
The two-mirror SC optical system for a medium-sized telescope candidate for the CTA is designed to fully correct spherical and comatic aberrations while providing a large field of view and a fine plate-scale, allowing for finely pixelized focal plane instrumentation. The 9.7 m  $\varnothing$  primary mirror (M1) and the 5.4 m  $\varnothing$  secondary mirror (M2) are segmented into 48 and 24 mirror panels respectively. Ray-tracing simulations of the optical system indicated the need for sub-millimeter ( $< 100 \mu\text{m}$ ) and sub-milliradian ( $< 0.1 \text{ mrad}$ ) precision for both global and panel-to-panel alignments. These requirements drive the development of the SC-MST alignment system.

## PANEL-TO-PANEL ALIGNMENT SYSTEM

The panel-to-panel alignment system is designed to effectively detect and correct for misalignment between neighboring panels as well as to continuously monitor the alignment of the optical surfaces' figures. The positioning of each individual mirror panel is achieved by six linear actuators arranged in a Stewart platform (SP) designed to situate the mirror panel with an accuracy better than the required  $100 \mu\text{m}$ . The relative positions of adjacent mirror panels are determined by a collection of mirror panel edge sensors (MPESs). The left panels in Fig. 2 show CAD models for the MPES and SP, as well as a schematic depiction of their arrangement for M2. The control of the SP and the MPESs is performed by a dedicated mirror panel controller board (MPCB) mounted onto an aluminum triangle that interfaces the entire setup with the optical support structure. We define a panel module (PM) as the full setup composed of a mirror panel, and its accompanying SP, MPES, MPCB and mounting triangle. Power and Ethernet are served to each of the 48 PMs in M1 and 24 PMs in M2 by two power and Ethernet distribution boxes (PEDBs), one per mirror.



**Fig. 2** Top-left: CAD models of a MPES and a panel module showing six actuators in a SP arrangement. Bottom-left: 1/4<sup>th</sup> of the M2 showing the locations of the MPESs' pads (blue and red circles) and the SP pads (black larger circles). Top-right: example of hysteresis measurement. Bottom-right: MPES position in pixel coordinates. A perturbation is introduced to the platform position which is corrected by a feedback loop between actuators and MPES in 3 iterations (target position within  $15 \mu\text{m}$ ).



**Fig. 1** Left: Schematic description of the global alignment subsystem showing all relevant components. AC stands for auto-collimator, SP stands for Stewart platform, and PSD stands for position-sensitive device. Top-right: Reconstructed tilt from a prototype auto-collimator placed 8 m from a 5 cm circular mirror mounted on a tilt stage. Bottom-right: Reconstructed translation from a set of six LEDs placed 8 m from a CCD camera.

## GLOBAL ALIGNMENT SYSTEM

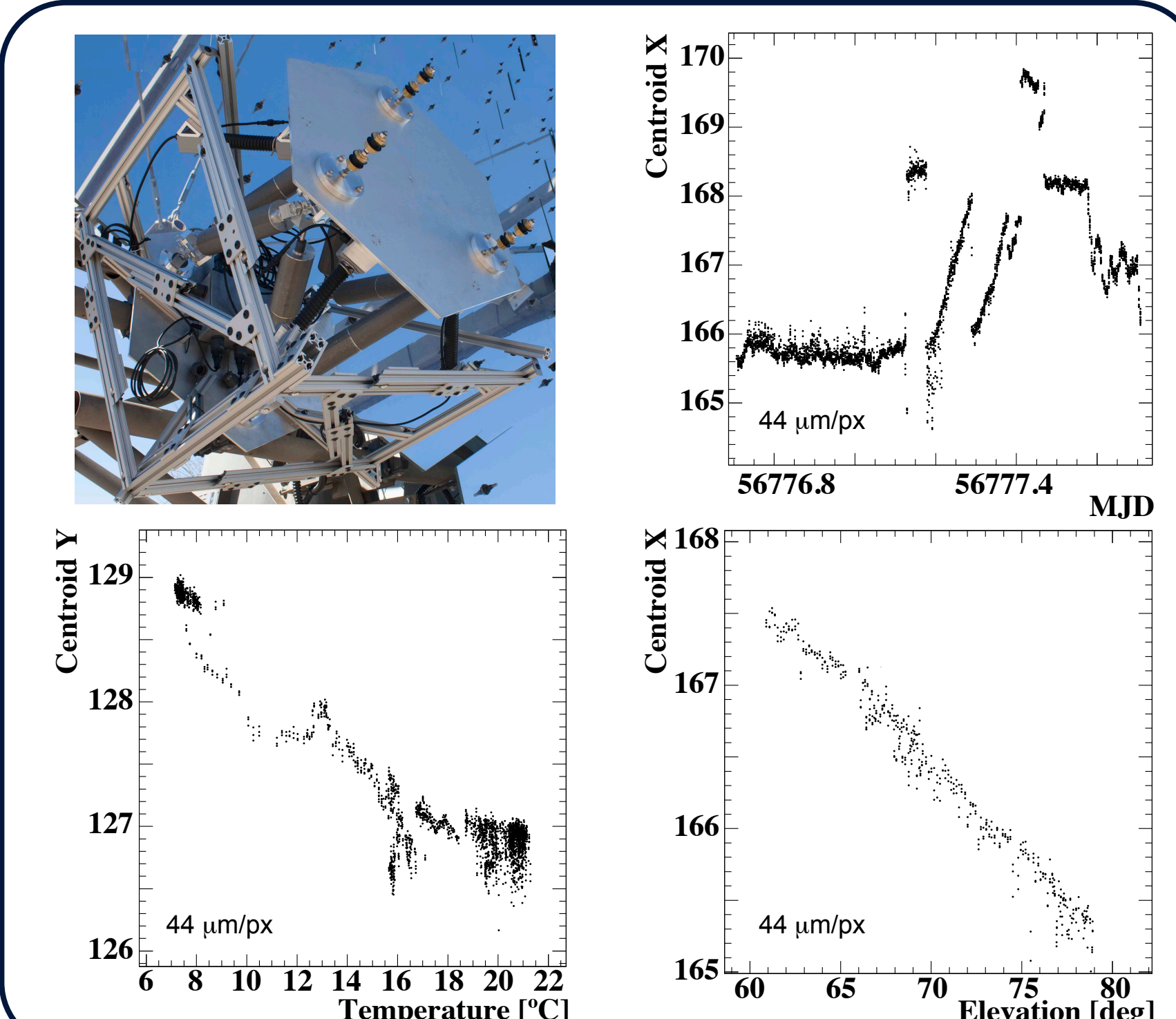
The global alignment system (GAS) is designed to continuously measure relative positions of the main optical elements of the telescope, M1, M2 and the camera focal plane, as well as to detect large-scale spatial perturbations of the M1 and M2 figures. The GAS hardware consists of CCD cameras imaging LEDs to measure the relative translations between M1, M2, and the gamma-ray camera, and auto-collimators to measure the tilts of M1 and M2 (see Fig. 1, left panel). Prototypes of all of the components have been built and tested (see Fig.1, right panels).

## REFERENCES

- B. Acharya et al., Introducing the CTA concept, *Astroparticle Physics* 43 (2013), no. 0 3 – 18.
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## ACKNOWLEDGMENTS

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**Fig. 3** Readings from a single MPES over a 24h period. Top-right: evolution of the centroid X position. Bottom-right: centroid X position drift as a function of T4 elevation. Bottom-left: centroid Y position drift as a function of environment temperature at T4 stow position. Top-left: panel module prototype as installed on T4.

In turn, all the 72 PMs are controlled by a central computer in charge of the telescope's alignment. A PM prototype, along with a PEDB prototype, were assembled at the Fred Lawrence Whipple Observatory and installed on VERITAS telescope 4 (T4) as a first hardware integration test (Fig. 3). The setup ran continuously for 4.5 months starting in early 2014 and demonstrated that all hardware functioned within specifications, as well as positively verified their weatherproofness. The same PM prototype was utilized under laboratory conditions to characterize the PM hysteresis ( $\sigma < 26 \mu\text{m}$ ) and to probe the capability of the PM to move itself to a target position within  $15 \mu\text{m}$  via a feedback loop between the SP actuators and an orthogonal triad of MPESs (Fig. 2, right panels).

## ALIGNMENT CONTROL

The software controls of the alignment system are implemented through the OPC-UA communication protocol such that the entire SC-MST alignment control software easily integrates with the higher-level Array Control system of the CTA.

## CONCLUSIONS

The performance of all hardware components for the global and panel-to-panel alignment systems has been verified to work within specifications and the mass production of the same has been initiated and is compliant with the pSCT construction schedule. For the final SC-MST design, the alignment system will be optimized for mass-scale production based on the knowledge acquired from the pSCT experience.