

## GMT & GMagAO-X

The 25.4m Giant Magellan Telescope (GMT) will be amongst the first in a new series of extremely large telescopes (ELTs). The 25.4 m pupil is divided into seven 8.4 m circular segments in a flower petal pattern. The University of Arizona is developing strategies that will be used for ELT extreme adaptive optics (ExAO) on the up-and-coming ExAO instrument, GMagAO-X.

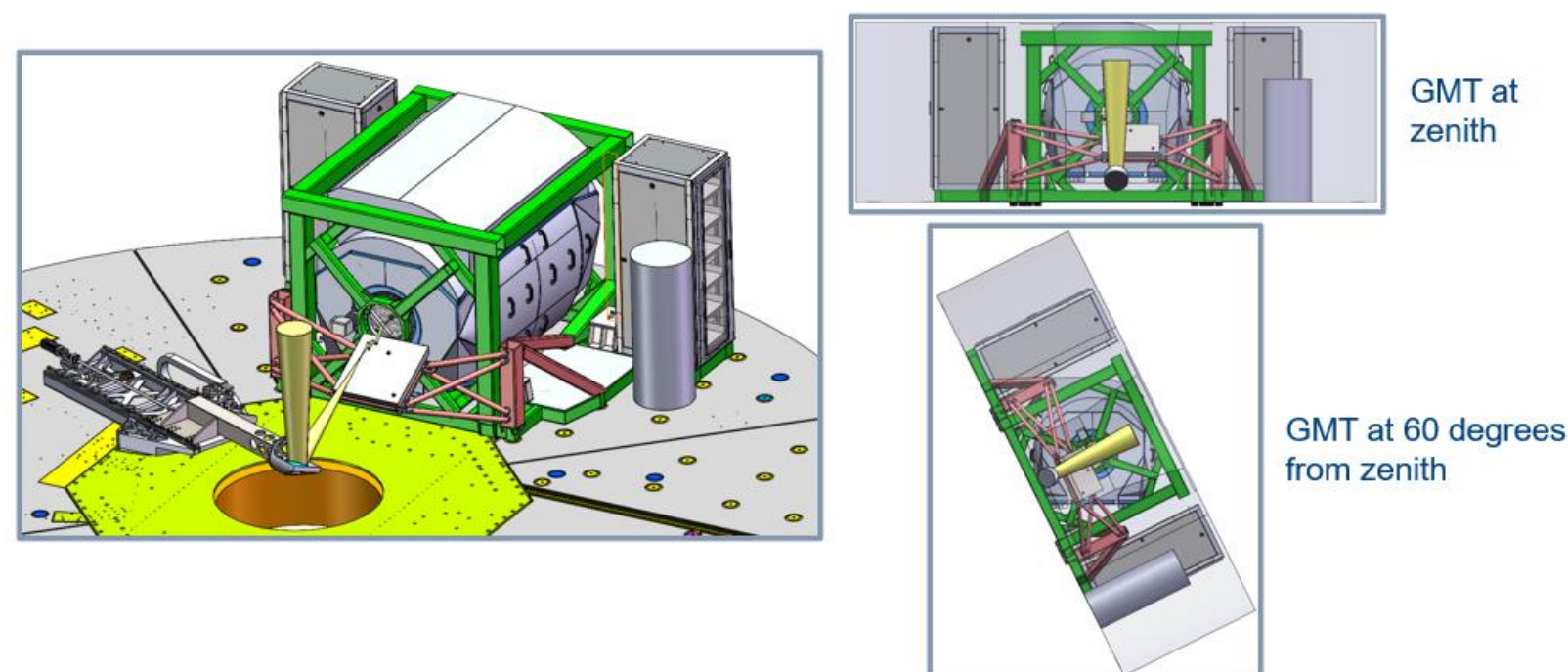


Fig. 1 GMagAO-X will be a gravity invariant folded port instrument.<sup>1</sup>

GMagAO-X is a visible to NIR ExAO system that will be used at first light of the GMT. GMagAO-X is designed to deliver diffraction-limited performance at 6 to 10 mas and extreme contrasts on the order of  $10^{-7}$ . The primary science case will be the characterization of mature, and potentially habitable, exoplanets in reflected light.

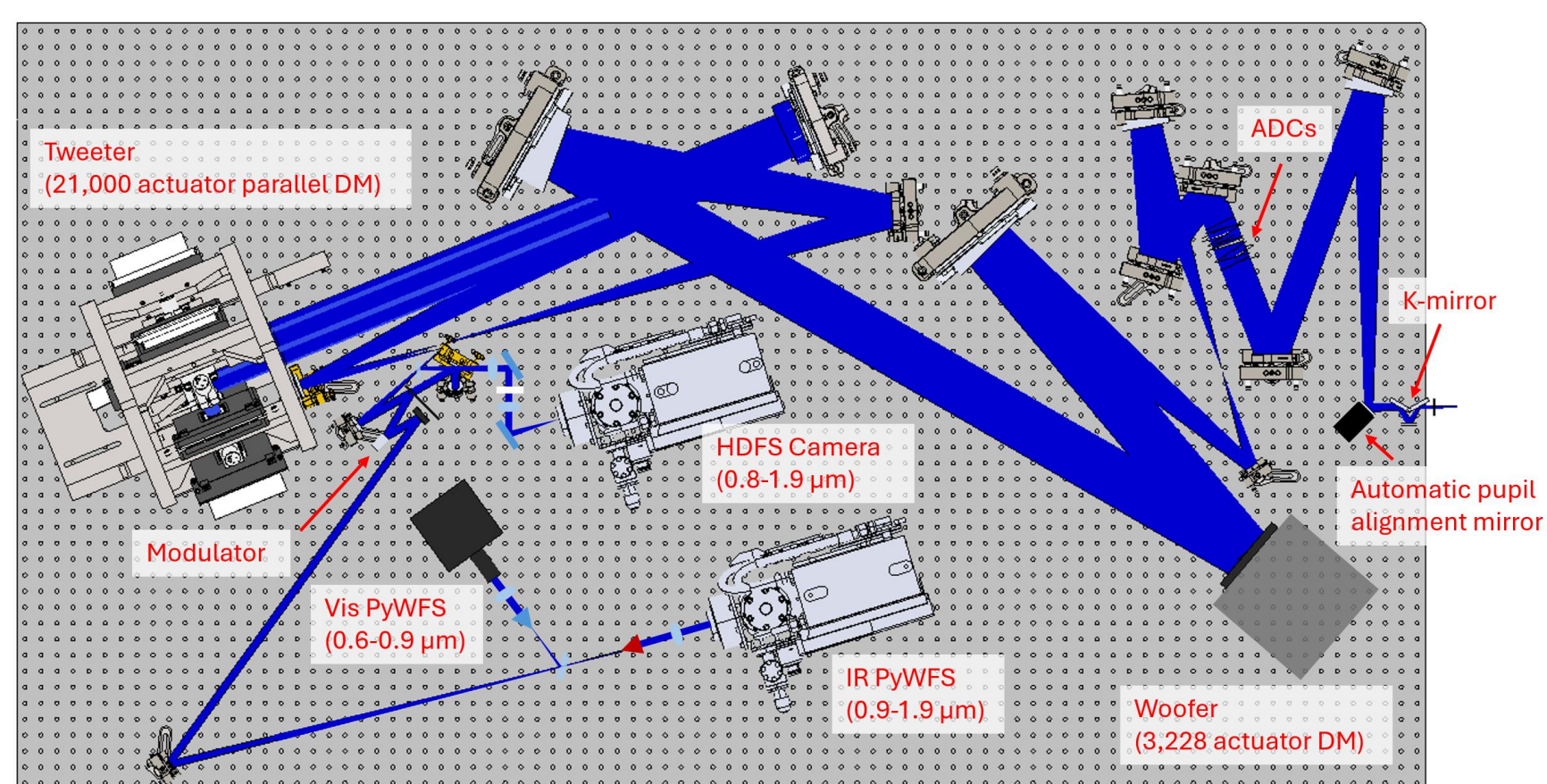


Fig. 2 GMagAO-X, GMT's ExAO system, wavefront sensor layout.

## Parallel DM

Seven 3,000 actuator deformable mirrors working in parallel will be the equivalent of a 21,000 actuator DM.

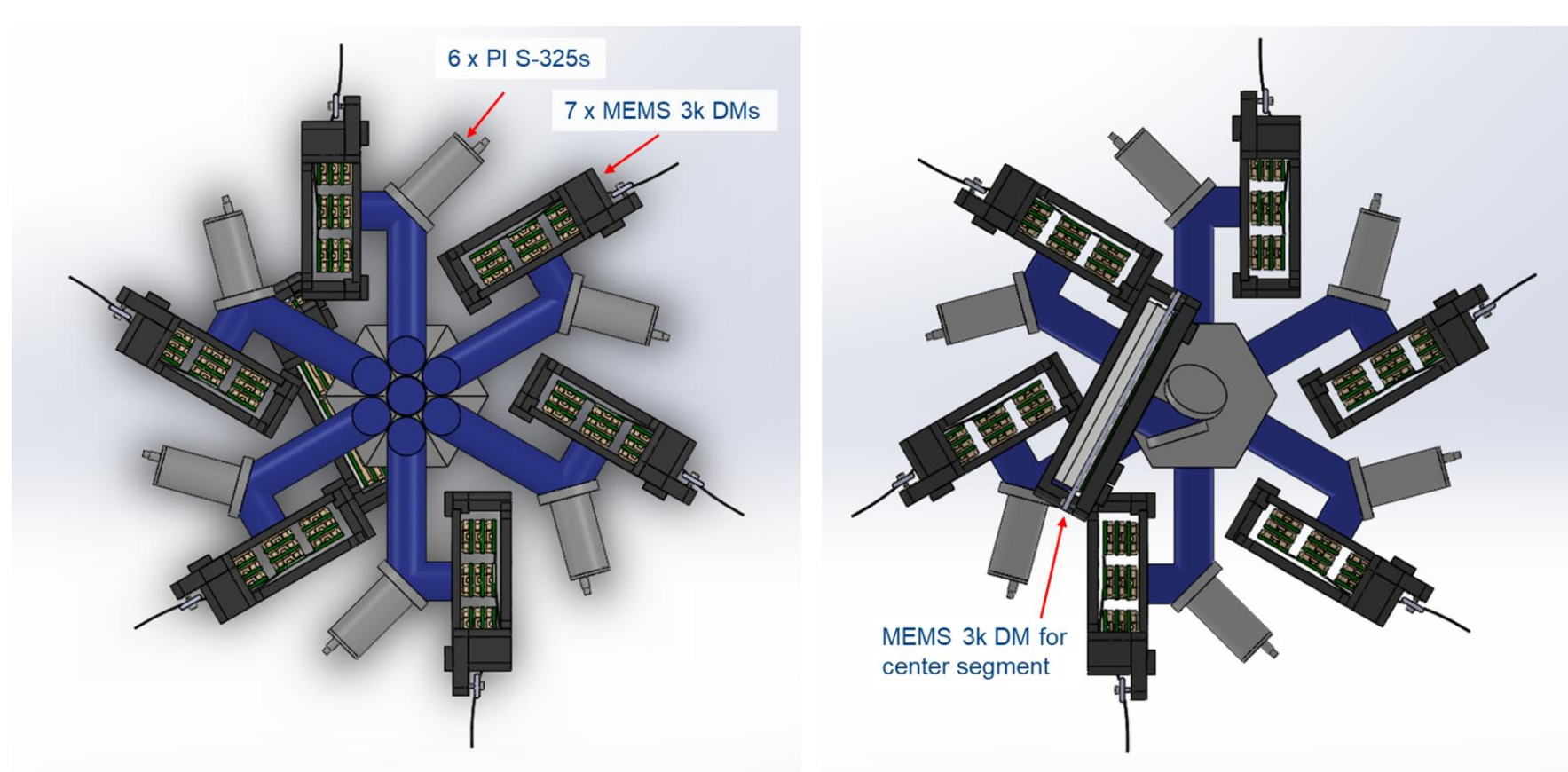


Fig. 3 CAD renditions of Parallel DM<sup>5</sup>

## HCAT

The High Contrast Adaptive optics phasing Testbed (HCAT) was developed to test new wavefront sensing and control approaches for GMT and GMagAO-X, such as the holographic dispersed fringe sensor (HDFS), and the new ExAO parallel DM concept for correcting aberrations across a segmented pupil.

Fig. 4 CAD rendition of HCAT feeding MagAO-X<sup>1</sup>

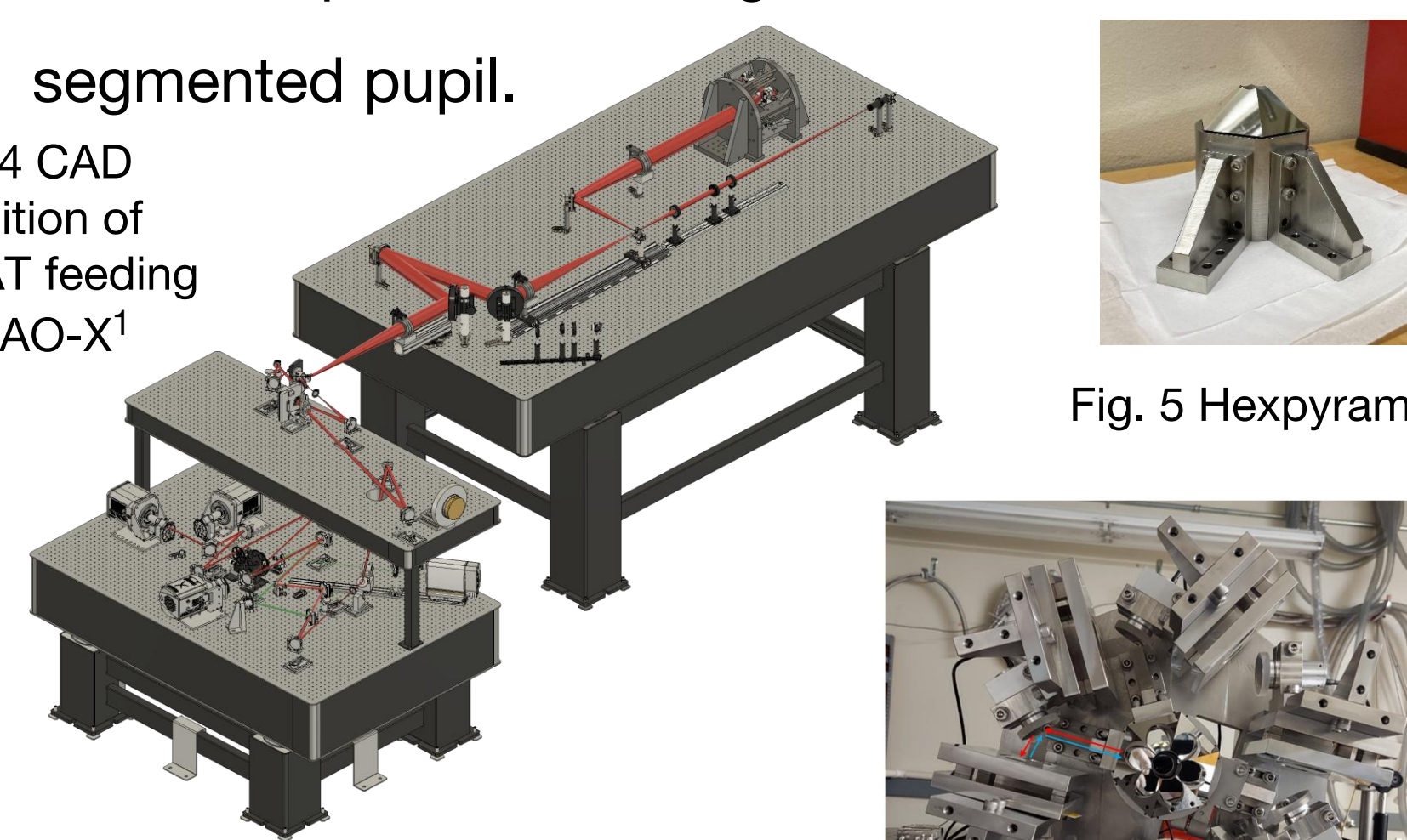


Fig. 5 Hexpyramid<sup>1</sup>

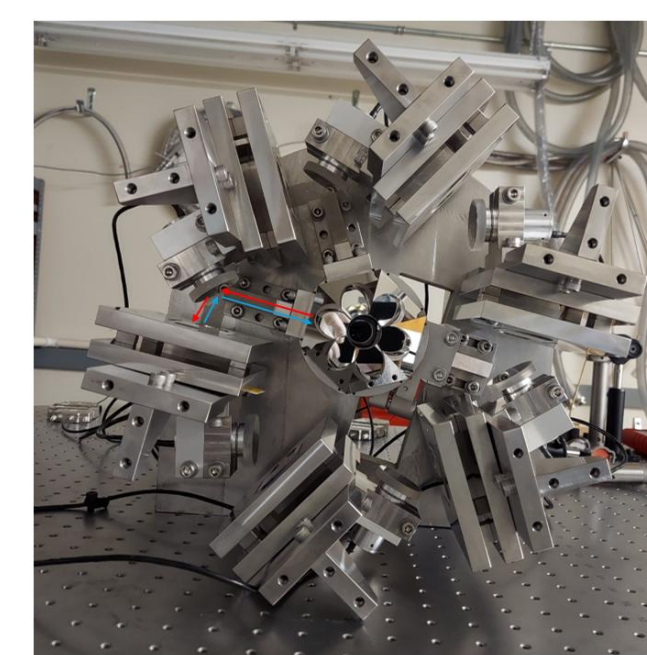


Fig. 6 Open-face parallel DM with mock DMs<sup>5</sup>

## HDFS

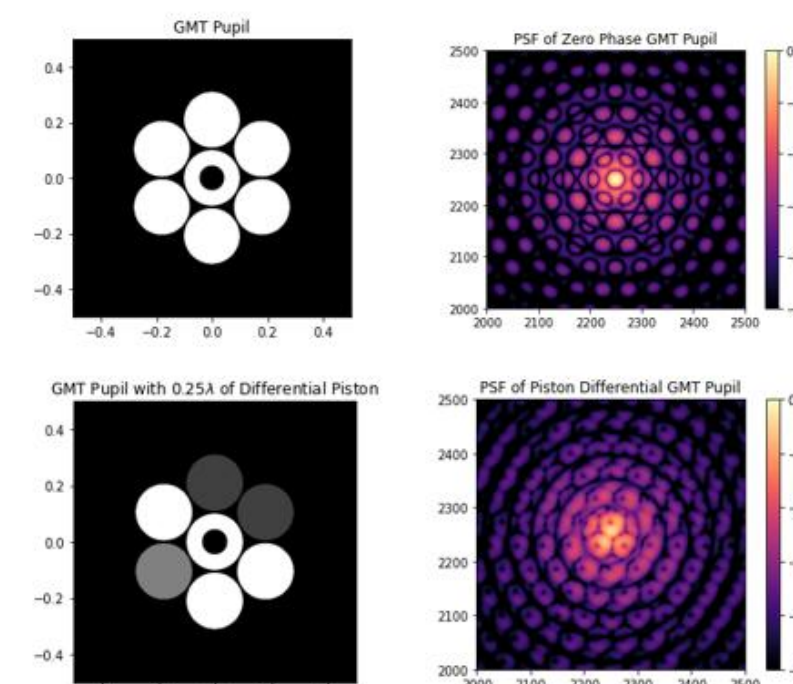


Fig. 7 Differential piston's effect on GMT PSF.

Gaps in the pupil allow "petal modes," wavefront inconsistencies between the large segments, that can introduce differential segment piston into the system. It can be sensed with an HDFS and corrected with a parallel DM.<sup>5</sup>

The HDFS uses a single pupil-plane hologram to interfere the dispersed light from each segment onto different spatial locations in the focal plane.<sup>5</sup>

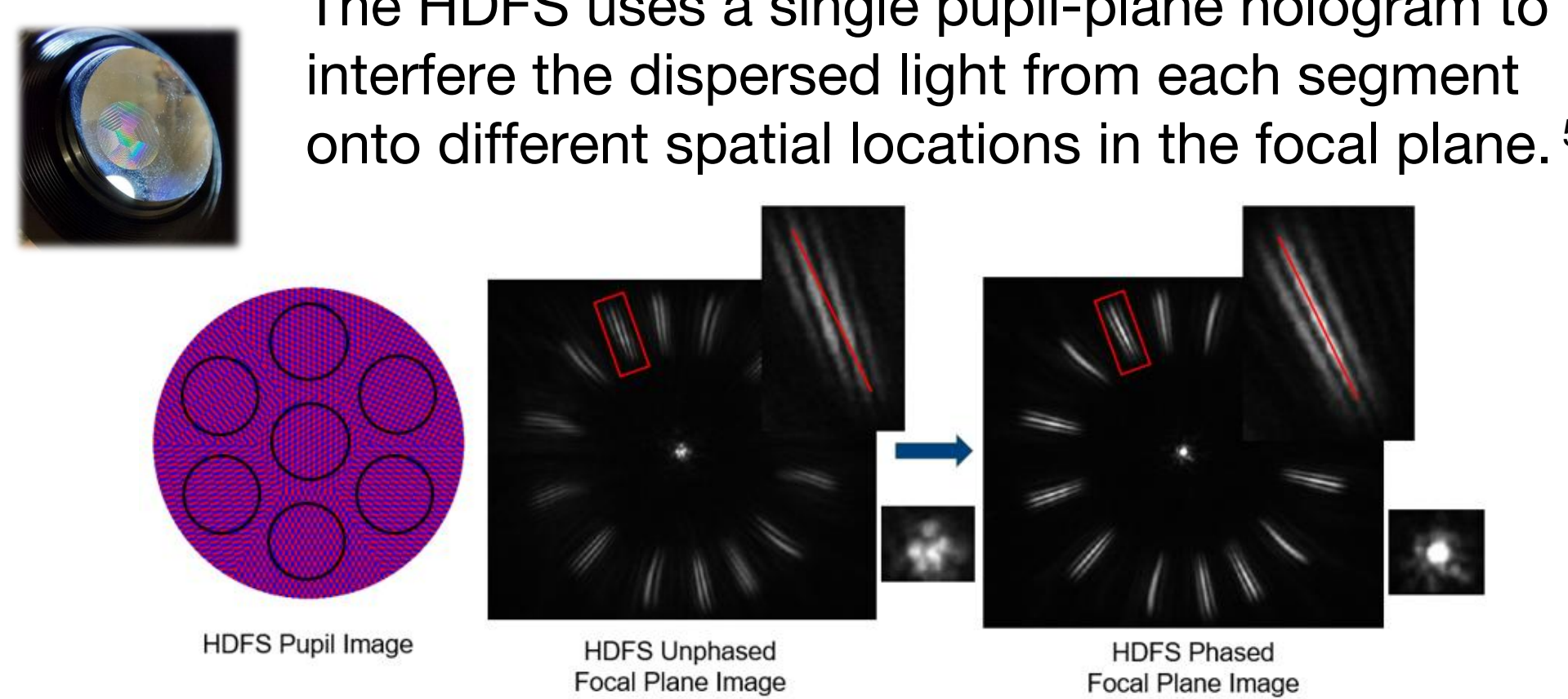


Fig. 8 HDFS optic, a diffraction grating with a high first order diffraction efficiency, and its barber pole fringes used for phasing.<sup>5</sup>

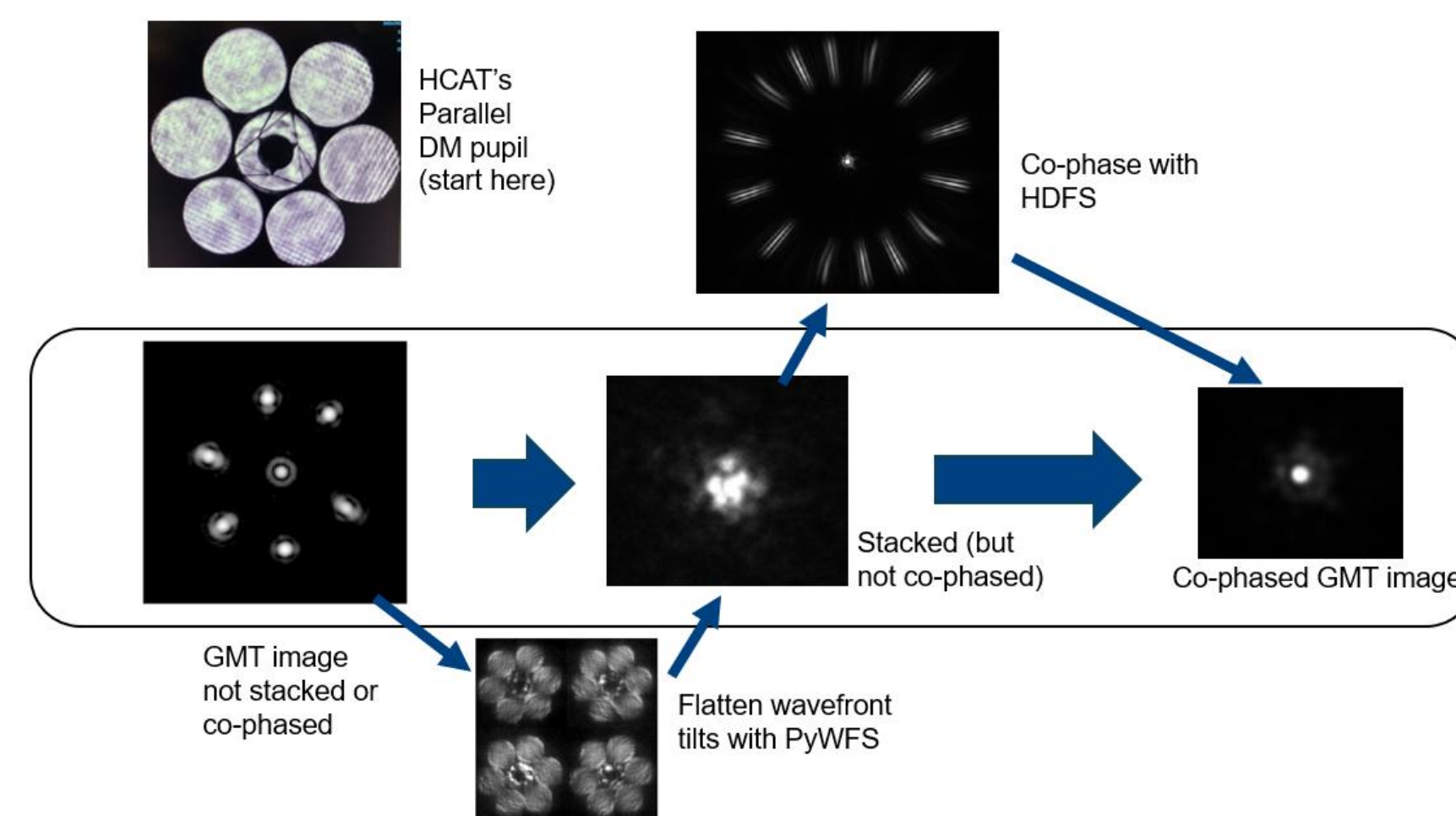


Fig. 9 The unphased GMT begins with 7 distinct PSFs. The MagAO-X PyWFS is used to sense tip/tilt so the PTTs can stack the PSFs into a singular incoherent PSF. The HDFS senses differential piston so the PTTs can then phase to achieve a final coherent PSF.<sup>5</sup>

## On-sky HDFS Results

We wanted to demonstrate HDFS phasing in actual seeing conditions with real residual AOWFE on the March 2024A MagAO-X observing run. Before going on-sky, we used the MagAO-X internal source, MagAO-X internal telescope simulator (of the Magellan Clay), and the NCPC DM to create a six-segment pupil to perform phasing tests.

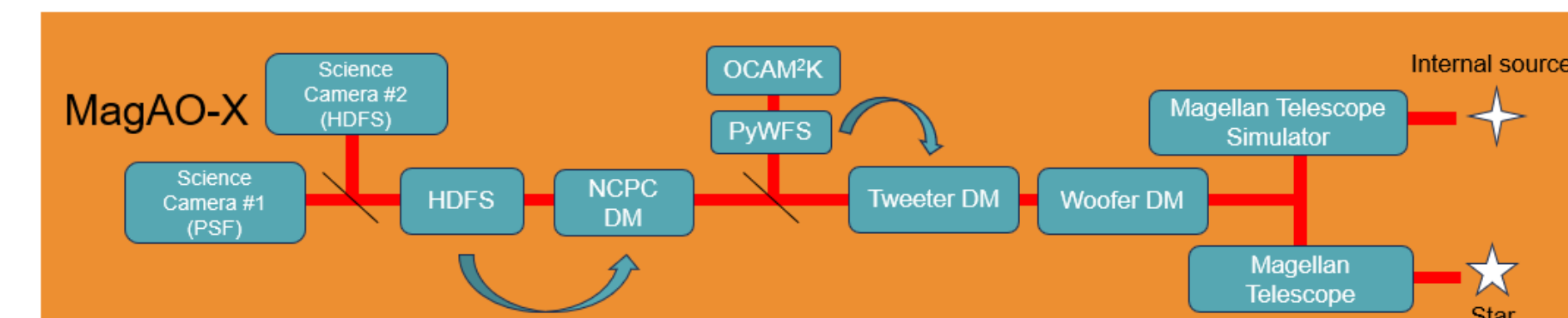


Fig. 10 Experimental setup of on-sky HDFS phasing test.<sup>5</sup>

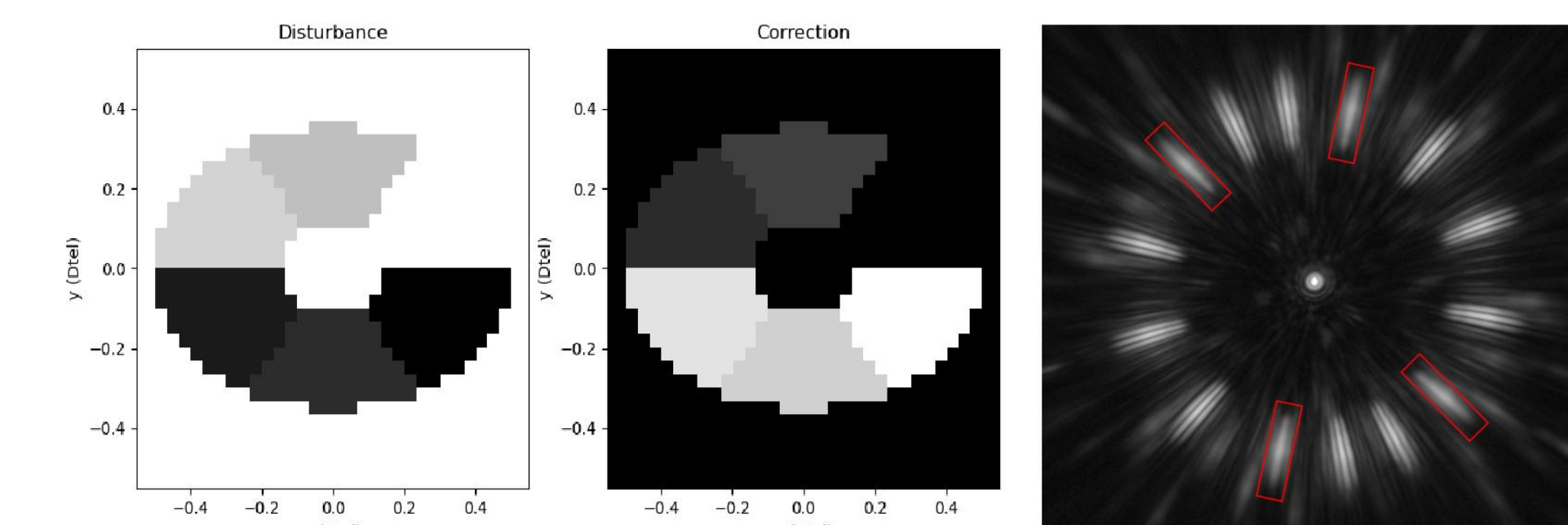


Fig. 11 The pattern imprinted on the NCPC DM to segment the Magellan pupil. The projected differential piston pattern is asymmetric because of the 45 deg incidence angle.<sup>5</sup>

Figure 12 illustrate the HDFS successfully phasing to  $<141$  nm PV WFE, or  $\sim 50$  nm RMS WFE integrated across the whole pupil in median seeing.<sup>5</sup>

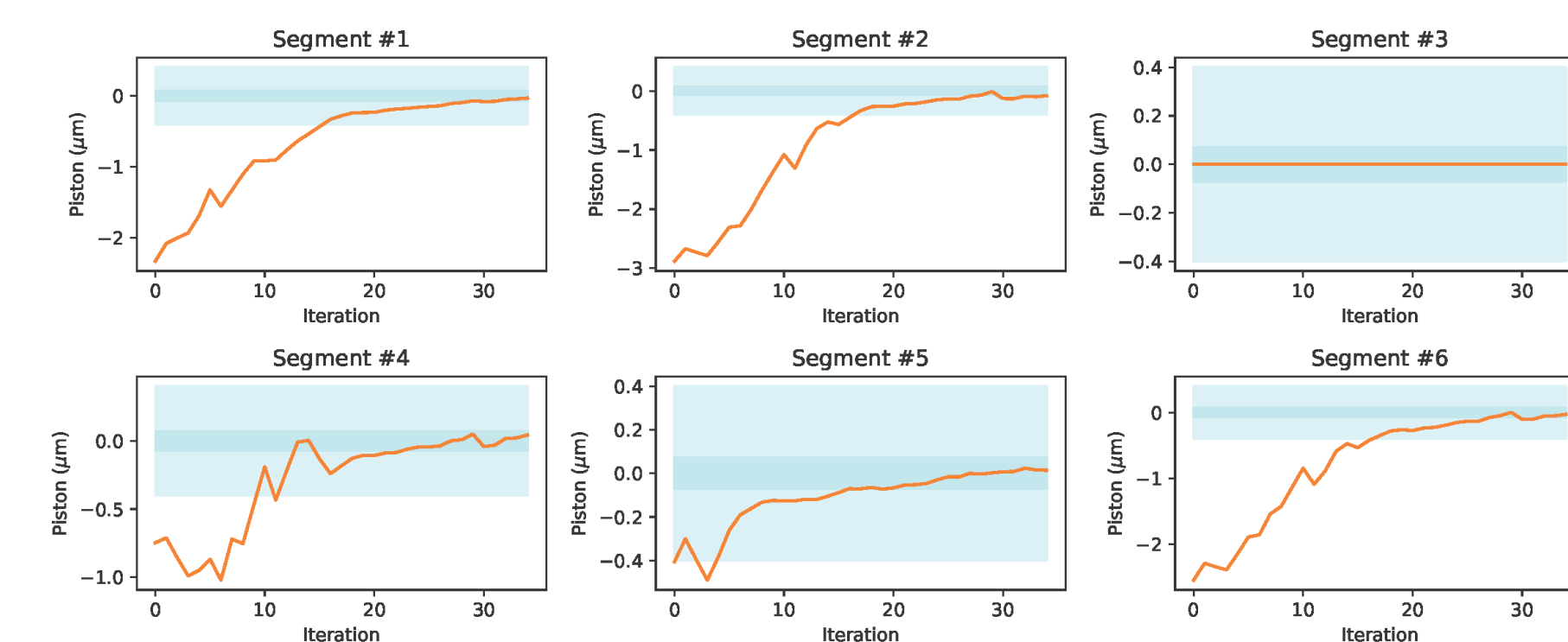


Fig. 12 Trial #2 had 35 iterations and all five segments with input piston converged to  $\pm\lambda/11.3$  at  $\lambda = 800$  nm. Seeing was  $0.7''$ .<sup>5</sup>

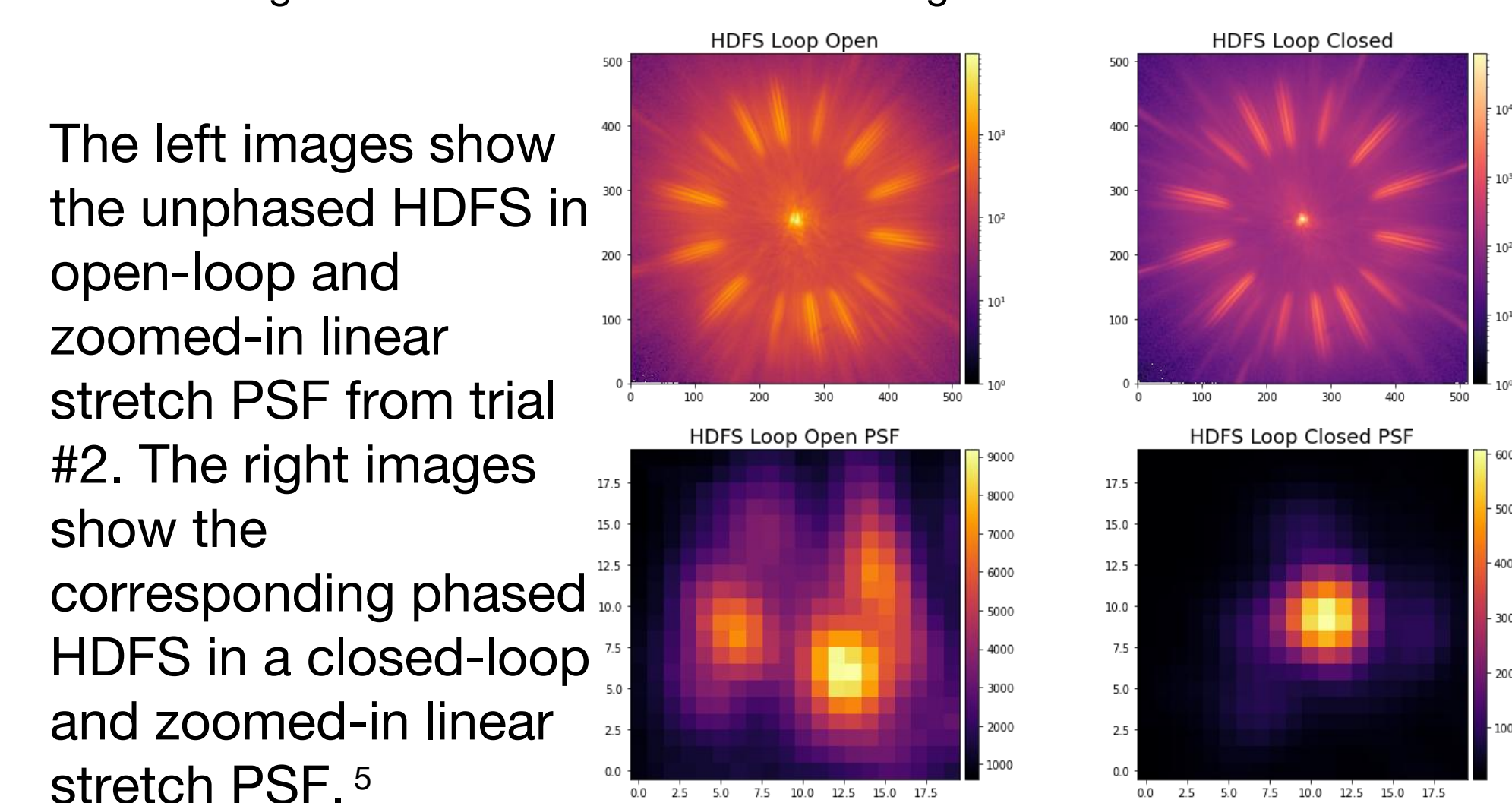


Fig. 13 Open and closed HDFS control loops.<sup>5</sup>

The left images show the unphased HDFS in open-loop and zoomed-in linear stretch PSF from trial #2. The right images show the corresponding phased HDFS in a closed-loop and zoomed-in linear stretch PSF.<sup>5</sup>

With new funding, HCAT will be converted into a GMagAO-X R&D testbed, assessing technologies such as utilizing an unmodulated PyWFS with neural networks to perform the fine phasing post HDFS.

## Acknowledgements

The HCAT testbed program is supported by an NSF/AURA/GMTO risk-reduction program contract to the University of Arizona (GMT-COIN-04535, Task Order No. D3 High Contrast Testbed (HCAT), PI Laird Close). The authors acknowledge support from the NSF Cooperative Support award 2013069 under the AURA sub-award NE09510. Support for this work was also provided by NASA through the NASA Hubble Fellowship grant #HST-HF2-51436.001-A awarded by the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy Inc. (AURA), under NASA contract NAS5-26555. Maggie Kautz received an NSF Graduate Research Fellowship in 2019. Alex Hedglen and Laird Close were also partially supported by NASA's Exoplanet Research Program (XRP) grants 566 80NSSC18K0441 and 80NSSC21K0397 and the Arizona TRIF/University of Arizona "student link" program. We are very grateful for support from the NSF MRI Award #1625441 (for MagAO-X) and funds for the GMagAO-X CoDR from the University of Arizona Space Institute (PI Jared Males) as well. This material is based upon work supported in part by the National Science Foundation as a subaward through Cooperative Agreement AST-1546092 and Cooperative Support Agreement AST-2013059 managed by AURA.

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