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Progress on the University of Hawaii 2.2-meter adaptive secondary mirror

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ABSTRACT

We report on progress at the University of Hawaii on the integration and testing setups for the adaptive secondary mirror (ASM) for the University of Hawaii 2.2-meter telescope on Maunakea, Hawaii. We report on the development of the handling fixtures and alignment tools we will use along with progress on the optical metrology tools we will use for the lab and on-sky testing of the system.

Keywords: adaptive secondary mirror, ground-layer adaptive optics

1. INTRODUCTION

Adaptive secondary mirrors (ASM) bring two key gains to ground-based astronomical adaptive optics (AO) systems. They minimize the thermal background of the AO system by avoiding the need for an optical relay for the AO system and the windows and cooling infrastructure to cool the optical relay. Avoiding the optical relay also maximizes the optical throughput of the system which benefits instruments working at all wavelengths. ASMs are also a natural way to implement an AO system that provides a correction over a wide field of view (e.g. a ground-layer adaptive optics system). At some astronomical sites such a correction can be obtained over fields of view in excess of 16-18 arcminutes.[1] An optical relay for such an instrument requires large optics due to the large angles involved and the requirement for both a good pupil image and good image quality in the final focal plane across the field of view. An ASM again provides a natural way to achieve these corrected fields of view, in principle, for all instruments on the telescope.

The requirements for an ASM are, however, challenging. The principle one being that the ASM must be operational either as the adaptive element or as a fixed/static optical mirror with an extremely high level of reliability. A typical astronomical ground-based facility on Maunakea, Hawaii operates with an engineering downtime of less than a few percent over the course of a year. For many facilities the secondary mirror is removed only once every few years for a new optical coating. Achieving this level of reliability remains a challenge and limits the larger scale adoption of the approach.

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We are developing on an ASM based on a variable reluctance actuator developed by TNO[2] for the University of Hawaii 2.2-meter telescope in Hawaii.[3] The variable reluctance actuator provides more than an order of magnitude gain in force output and electrical efficiency over voice coil actuators and should result in simplified overall system compared to voice-coil based ASM.[2] The specifications for the ASM are given in Chun et al (2020) and are summarized in the table below.

Table. University of Hawaii 2.2-m ASM Basic Specifications	
Mirror Diameter	620mm
Mirror Shape	convex hyperboloid, $\kappa = -3.604$
Optical Shell thickness	3.5mm
Actuator Count	211 actuators
Actuator Pitch	39mm
Overall Mass	$\sim$ 55kg (fixed secondary $\sim$72 kg)

Progress on the component development and actuator testing are given in this conference proceedings by Jonker et al.[4] In this paper we present the progress on the integration and test fixtures for testing the ASM in the lab and on the telescope at the University of Hawaii.

2. TELESCOPE INTERFACE

The University of Hawaii 2.2-meter telescope has provisions for swapping between two different secondary mirrors at any time. It does this via a top-end that can rotate about two of the telescope secondary support spiders to place either of two secondary mirrors into the optical train. The secondary in the beam faces the primary mirror while the unused secondary faces outward. Originally this system was used to provide both a Cassegrain focus and a Coude focus. The Coude focus is no longer used so the ASM will replace the Coude secondary but will mimic the optical prescription of the Cassegrain f/10 secondary. The ASM will stay mounted to the telescope but when not in use will be in the stowed "upward looking" position. It takes about 10 minutes to switch between the fixed and adaptive secondary.

The secondary mirrors mount to the telescope's secondary focus stage via two fixed triangular plate that moves along the optical axis to provide focus adjustments. The mirror cells of the Coude and Cassegrain secondary mirrors mount to this triangular plate and are manually positioned in translation perpendicular to the optical axis (x- and y-) and in tilt (theta-x and theta-y) when they were first installed. No adjustments are made to the secondaries other than focus and top-end swaps preserve the positions to better than 300 microns. We note that the entire telescope structure is very stiff and the deflection of the top end with respect to the primary mirror is less than about 200 microns from Zenith to the horizon. The ASM will be required to (1) follow a similar one-time alignment to position the ASM on the optical axis and with the proper tilt with respect to the axis of the primary mirror and (2) fit within the volume of the existing fixed Coude secondary. The volume constraint is due to the limited focus range of the secondary mechanism. This restricts the height of the overall ASM structure to about 150mm. We allocate most of this space to the body of the ASM due to stiffness/dynamic considerations but this complicates how we position/align the ASM when we mount it to the interface plate.

2.1 Alignment Tools and Fixturing

Given the space restrictions for mechanically interfacing the ASM to the telescope we chose to separate the alignment and mechanical mounting of the ASM to the telescope interface plate. In particular the translation and tilt alignment adjustments are moved to the outside of the mirror and reside at the corners of the triangular interface plate while three flexures that ultimately hold the mirror to the interface plate reside long the edges of the triangular plate. When the ASM is first mounted to the telescope we first hold it in place using three alignment fixtures, one in each corner of the triangular interface plate, via a set of posts mounted to the side of the ASM that end with a spherical end. These spherical balls rest in a push-pull mechanism that allows us to translate and tilt each corner of the ASM. An image of one of the fixtures is show in Figure 1 mounted to a mock up of the telescope interface plate and a dummy ASM structure that mimics the weight and handling fixtures of the final ASM. The ASM is aligned using the existing fixed secondary as a reference. We match the x/y position of the center of the ASM and the tilt of the ASM with that of the fixed f/10 secondary.

Once the ASM is in the correct position we mechanically interface three flexures that extend from the back of the ASM to the edges of the triangular plate. These mount via a set of blocks mounted to the plate that allow for translation and tilt of the ASM with respect to the plate. Once the ASM is secured and held in place by these mounts/flexures we remove the alignment fixtures at the corners of the triangular plate.

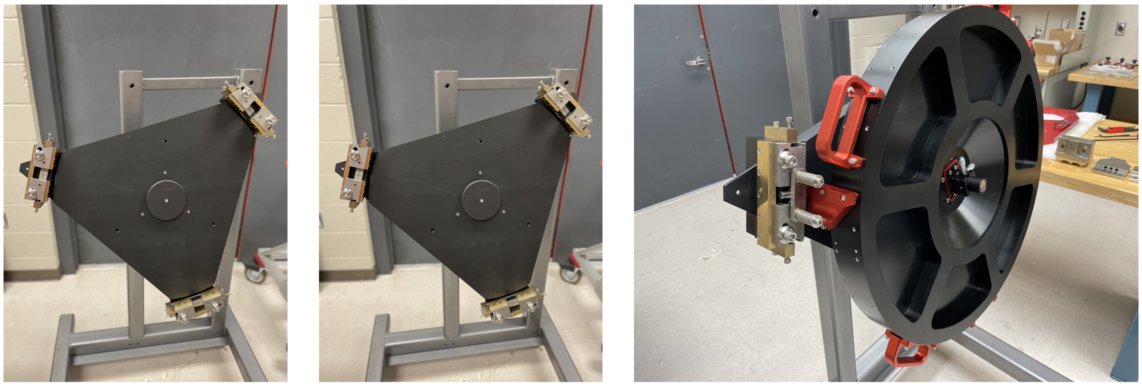

Figure 1. (LEFT) Mock up of the telescope interface plate with the three alignment fixtures. The ASM (or any of our dummy ASM) attach to the alignment fixtures via a set of spherical ball that are mounted to the side of the ASM. The alignment fixtures provide translation and tilt adjustments. Once aligned the ASM is held in position via a set of three flexures (not shown) behind the mirror that attached to the edges of triangular plate. (CENTER) An alignment mirror is used for a rough alignment of the alignment fixtures. The alignment mirror is setup to mimic the center location and center tilt of the ASM using an alignment fixture that mounts to either the ASM or the alignment mirror. (RIGHT) A mock up of the ASM that mimics the weight and handling fixtures is used to work through handling procedures.

2.2 Alignment Tools Tests

The placement and alignment of the ASM on the telescope will be done in three stages. In the first step the three push-pull alignment fixtures are roughly positioned the apex of the ASM at the same location as the current fixed f/10 secondary. This is done using a light-weighted structure with a small flat mirror at the center. The structure uses the same three spherical ball interface as the ASM and the flat mirror is translated and tilted to mimic the center of the ASM (x,y,z, and theta-x, and theta-y). Using this alignment mirror allows us to (1) minimize handling and work around the ASM and (2) allows us to practice the procedures in advance of receiving the ASM in Hawaii. Once the alignment fixtures are in the correct location, we will replace it with the actual ASM and do a final fine alignment. Next we need to mount the ASM to the triangular plate via its mounting flexures. These three flexures mount to the back of the ASM and interface with the telescope's triangular interface plate via a set of blocks that allow for variations in the position and tilt of the ASM. When the ASM is attached to the telescope via the flexures, we remove the alignment fixtures. This procedure is expected to be a one-time process and the ASM is not expected to come off the telescope once its installed. Should we need to remove the ASM, the alignment fixtures can be reinstalled and provide a mechanical reference for the position of the ASM.

3. LAB TESTING SETUP AND FIXTURING

3.1 Handling Cart

A handling cart for the ASM was constructed to facilitate testing and moving the ASM safely when in the lab and at the telescope in preparation for installation. The cart also provides a safe means to rotate the full assembly and will be used by TNO in the assembly of the ASM. For lab testing the cart provides a means to hold and position the ASM for testing. It will interface with the phase deflectometry setup described in the next section. At the telescope, the cart will also be used to handle and orient the ASM so that it can safely lifted and placed on the telescope interface plate using the overhead crane.

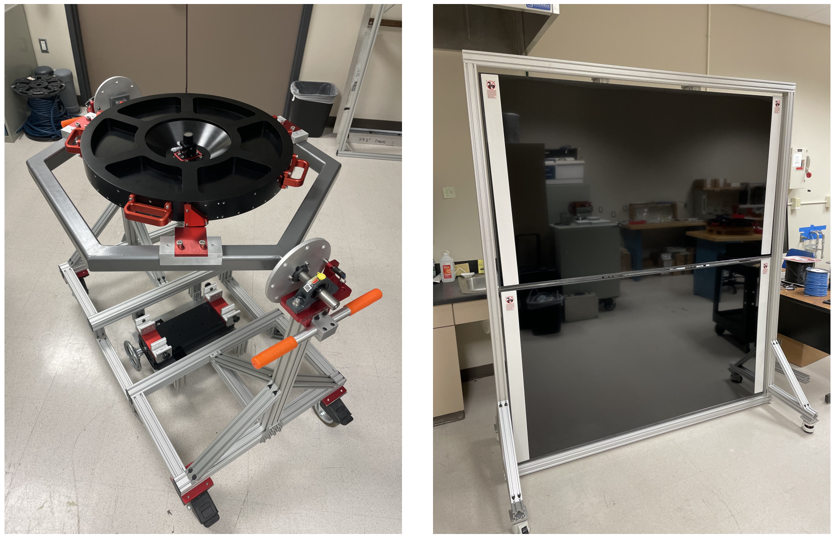

Figure 2. (LEFT) The ASM Handling Cart, used to safely move the ASM in the lab and also during the ASM assembly, is shown with the dummy ASM installed. Note that it mounts to the cart via the same three ball interfaces. (RIGHT) The phase measuring deflectometry setup with two 75-inch LED screens. The stand is roughly 1.7m on a side.

3.2 Phase Deflectometry

A key lab calibration for the ASM is to verify the overall function and performance of the ASM once it arrives in Hawaii and to calibrate the influence functions of each actuator on the ASM. For these tests our principal full mirror metrology tool will be phase measuring deflectometry (PMD).[5] The basic idea behind PMD is that one can trace rays from points on an object (e.g. screen pixels) to a position on the mirror that are reflected into the camera. By finding the rays that trace between the camera, mirror, and screen, one can deduce the gradients across the surface of the mirror. The reader is referred to Zhang et al. 2022 in these proceedings for more information on our particular setup but we note here that a key difference between our deflectometry setup and previous astronomical uses of PMD is that our mirror is convex so we require multiple screens to act as the object in the system. For the UH88 ASM we use two 75-inch LCD monitors and a overall setup size of roughly 2m x 2m x 2m. Challenges with this PMD setup include ensuring that the screens are well aligned with respect to each other and that they are not warped or distorted. These metrology calibration issues are especially important to get the absolute scale for the measurements. However, we note that (1) the influence functions are a differential measurement and (2) we will have a handful of capacitive sensors built into the ASM to provide sub micron metrology at a few discrete places about the ASM. We plan to use these to provide a final calibration of the scale of the PMD measurements. This simplifies the requirements on metrology of the PMD setup itself although systematic errors from things such as tilts between screens are not removed in a differential measurement.

4. TELESCOPE TEST SETUP

A key performance test for the ASM will be to quantify the delivered image quality in a single-conjugate AO mode and comparing it to theoretical (or simulated) performance. For this, we are developing a wavefront sensor, real-time controller, and science camera specifically for this integration test. We will eventually integrate the ASM with the Robo-AO-2 system[6] which will enable other modes of operations.

4.1 Integration Wavefront sensor and scoring camera

The integration wavefront sensor for the UH88 ASM is a 16x16 Shack-Hartmann wavefront sensor with an approximately 4.5 arcsecond/subaperture field of view and 0.55 arcseconds/pixel. The wavefront sensor uses a commercial off-the-shelf CMOS camera that reads out at 1kHz frame rates and is integrated with the real-time software we use with the ‘imaka ground-layer demonstrator at the telescope. During the ASM integration and initial testing we will limit our observations to bright stars. A similar COTS CMOS scoring/science camera is incorporated within the integration wavefront sensor package via a beamsplitter cube. The integration wavefront sensor and camera are small enough that they can be fitted just above the telescope's wide-field imaging camera. This facilitates observations with the ASM.

4.2 On-sky control

To be able to close the loop, control matrices will need to be generated. Two approaches are possible: the first one makes use of pseudo-synthetic interaction matrices based on measured influence functions and a model of the wavefront sensor.[7] The pseudo-synthetic matrices are fitted to optimise alignment parameters, such as centering, rotation and magnification. The second approach, developed in the context of this ASM project is called DO-CRIME (Dynamic On-sky Covariance Random Interaction Matrix Evaluation).[8] It is a purely heuristic method which relies on applying a set of random (but known) commands $\mathbf{c}$ on the deformable mirror and recording the associated wavefront sensor telemetry $\mathbf{m}$; the interaction matrix is then given by $IM = < \mathbf{m} \cdot \mathbf{c}^\mathbf{T} > \cdot < \mathbf{c} \cdot \mathbf{c}^\mathbf{T} >^{-\mathbf{1}}$. The commands covariance matrix is diagonal thus trivial to invert, and the estimation of the interaction matrix can be improved by applying a high pass filter both to the commands and the WFS telemetry, to filter out the low temporal frequency component of the atmosphere. DO-CRIME[*] is integrated to the imaka RTC, as it has already been tested on the sky at the telescope.

5. CONCLUSIONS

We have made progress on the handling and testing setups in preparation for the arrival of the ASM from TNO. Additional work on the phase deflectometry and the transmissive Hindle sphere tests[3] will continue in anticipation of the delivery of the ASM in 2023.

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[*] The crime being committed is to send random commands to the deformable mirror, but this allows to improve the performance in the end, so in this case, crime does pay...