NSF Major Research Instrumentation Program

Development of an Enhanced Adaptive Optics System and Infrared Instrumentation for the Shane 3-meter telescope

Third Year Report
May, 2012

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Research and Education Activities & Summary of Findings

As we approach the end of the third year (term is August 1-July 31), we have completed a final design review and are entering the fabrication phase of the program. We are on the order of one year behind schedule from our original plan, which had us on the telescope at this time. This slip is entirely in time, not in budget. We plan to submit a request for no-cost extension of one year to complete through on-telescope commissioning by July 2013. Hence this report is an interim report submitted in advance of the term date.

We held an overall optical and mechanical systems final design review at the end of April 2012. Our design report and a summary of reviewer comments with responses are available as a supplement to this report[2].

The overall design has no major architectural changes from our preliminary design, on which we reported at the end of year 2. The now final design has the specific details worked out in a form ready for parts purchases and shops fabrication. We also have a full costing of remaining purchase items. A number of the long-lead electro-optical items, including the wavefront sensor camera, deformable mirrors, and the science detector, were purchased during the second year. These have all now been received and we have performed the preliminarily acceptance-tests.

Adaptive Optics Design Completion

The second year report described the architecture and operating modes of the instrument. In this report we highlight the progress made during the final design phase.

It is a strong goal of this instrument to allow long-exposure (~4 hour) spectroscopy using only an off-axis tip/tilt star for guiding (multiple co-added reads from the science detector with object too dim to detect on a single read). Since AO provides a diffraction-limited point-spread that has an order of magnitude smaller size than that of the seeing limited PSF, this puts an extraordinary requirement on the stiffness and stability of optical mounts in a Cassegrain mounted system. For the most part, we have reached this goal with careful design guided by finite element analysis and some laboratory prototype testing. Spectroscopy performance is measured with an encircled energy metric. A reasonable spectroscopic performance is achieved if guiding is kept accurate to on the order of one diffraction limit. Imaging performance on the other hand is measured by the Strehl ratio, which would require the guiding to be accurate to on the order of 1/10th the diffraction limit. This tighter goal is probably not possible using passive materials alone and may require an active model-based flexure tracking system. An active system will not be implemented in the first version of the instrument, but is not precluded by the design.

The overall instrument structure mounted at the Cassegrain focus of the Shane telescope is shown in Figure 1. The structure has been analyzed using finite element analysis for stress and deflection under the gravity loads induced during observing. The instrument mounts to the telescope Cassegrain rotation stage, allowing for a settable field rotation (“parallax”) angle. This is useful in spectroscopy science observations to allow lining up the slits in a preferred orientation with respect to the science target of interest. The table is simply supported for minimum stress and an outer frame structure holds analog electronics that are necessary to be

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[2] http://www.ucolick.org/~gavel/ShaneAO/

near the table, with cooling provided by with ducted air flow (ducts not shown) to avoid self-generated turbulence.

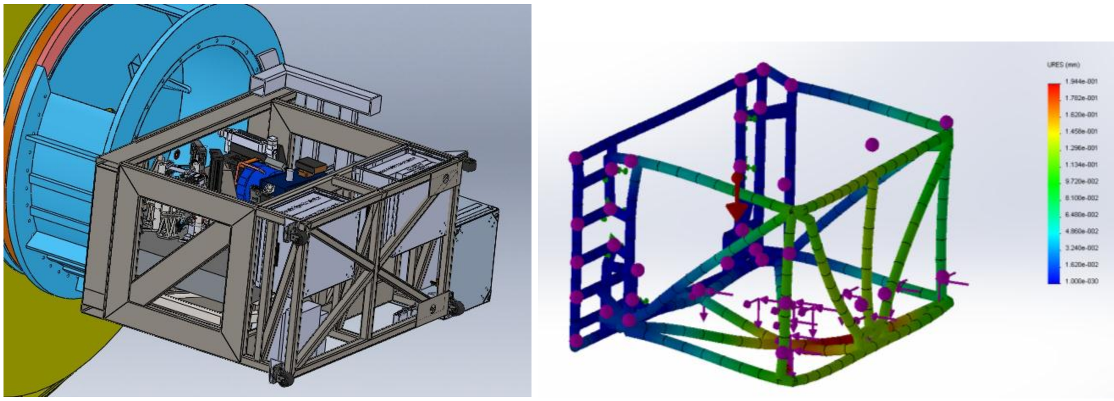


Figure 1. Adaptive optics instrument mounted to Cassegrain focus of Shane telescope (left), along with a finite element analysis of the support structure (right).

The opto-mechanical layout on the optical bench is shown in Figure 2. There are slight changes to angles from our preliminary design which were made to accommodate packaging, but the overall woofer-tweeter arrangement is the same. Tip/tilt star selection within the 60 arcsecond field of regard is achieved by translating the sensor head itself, instead of with field steering mirrors. This provides for easier and more accurate encoding of tip/tilt sensor placement, which is crucial in achieving the guiding stability and accuracy requirements highlighted above. Stability depends on stiffness of optics mounts at some critical locations, so we have prototyped these mounts and measured the performance in precision flexure tests (Figure 3).

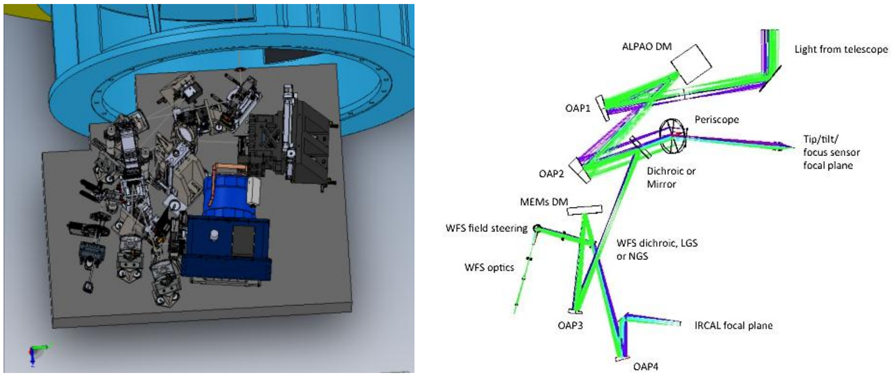


Figure 2. Layout of the optical bench, shown with support structure removed for visibility (left). The optical path with key elements of the AO system labeled is shown on the right.

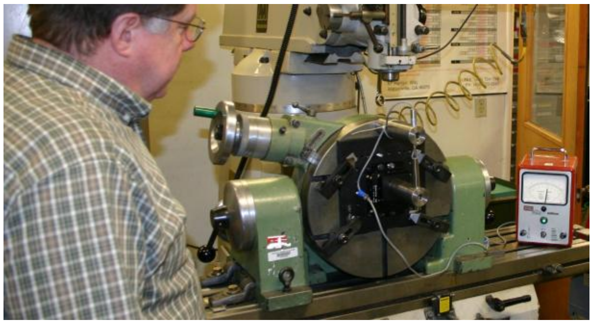


Figure 3. Precision laboratory testing of the deflection of a prototype mount design.

Another important change was made to the tip/tilt star sensor design to integrate a means of "truth" wavefront sensing. The tip;/tilt star sensor was originally intended to measure, in addition to fast tip/tilt, the slow focus drift that results from variations in the height of the sodium layer. The design change now implements a Hartmann sensor that will allow tracking higher order (up to 4th order) aberration biases due to laser guidestar spot shape irregularities. One of our reviewers pointed out that experience has shown these aberrations are not satisfactorily calibrated to the level needed to reach our calibration error budget with only an internal reference.

AO Component Testing

We have received and tested all of the major electro-optic components: the woofer and tweeter deformable mirrors, the wavefront sensor camera, tip/tilt sensor camera, and the science detector.

A novel aspect of this system design is that the woofer deformable mirror is also tasked with correcting the high speed tip/tilt components of wavefront, as opposed to using a separate fast tip/tilt stage for this purpose. The ALPAO 52 woofer deformable mirror has enough actuator range to provide the several arcseconds of tilt to accommodate the usual seeing and telescope shake. We tested this ability in the laboratory (Figure 4), with particular regard to how well the mirror retains an otherwise flat surface over the tilt range, i.e. tilt has minimal coupling to higher order mirror modes. The mirror does quite well; with a tilt deflection of +/- 20 microns (+/- 2.6 arcseconds on sky) the surface is flat to < 200 nanometers rms (Figure 4), a relatively minor amount that will be corrected downstream by the tweeter in closed loop. We also measured the influence functions of each actuator in order to completely characterize the controllable mode space of the woofer.

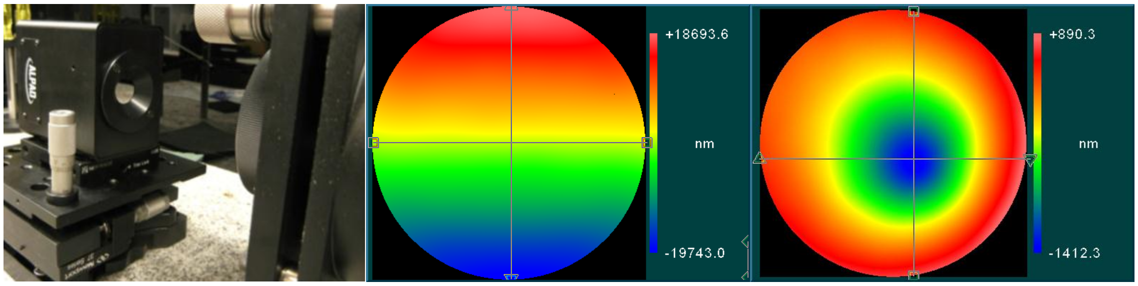


Figure 4. Woofer deformable mirror is tested for tilt range and flatness. Left: test setup showing woofer DM and test interferometer. Center:.interferogram of full range tilt. Right: interferogram of single actuator pull-down.

The MEMS (micro-electro-mechanical system) tweeter mirror was delivered with the wrong window coating, then sent back and returned with the correct window, with throughput test measurement data showing it meets our needs for transmission from the 589 nm laser line through IR K band. In the laboratory we have measured the response curve of each of the 1022 active actuators and mapped their influence functions (Figure 5). An Engineering PhD candidate graduate student, Andrew Norton, is doing the analysis of both the woofer and tweeter deformable mirrors and will use the mode space information to optimize the woofer-tweeter control algorithm.

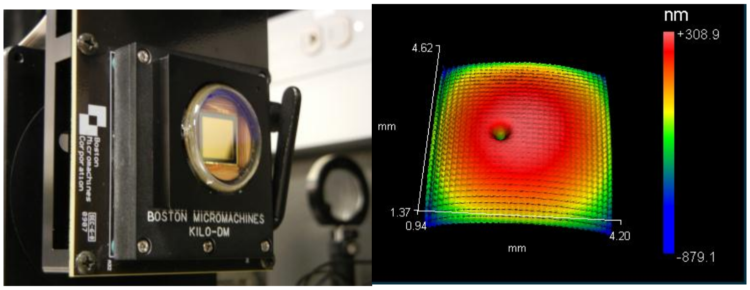


Figure 5. Tweeter deformable mirror. Interferogram of a single-actuator pull-down is shown on the right.

The wavefront sensor camera is a new design Lincoln Laboratories CCID 66 chip that has on the order of 3 electrons read noise per pixel at high frame rate. The noise properties were measured at SciMeasure, Inc., who built the readout electronics and integrated the chip for us.

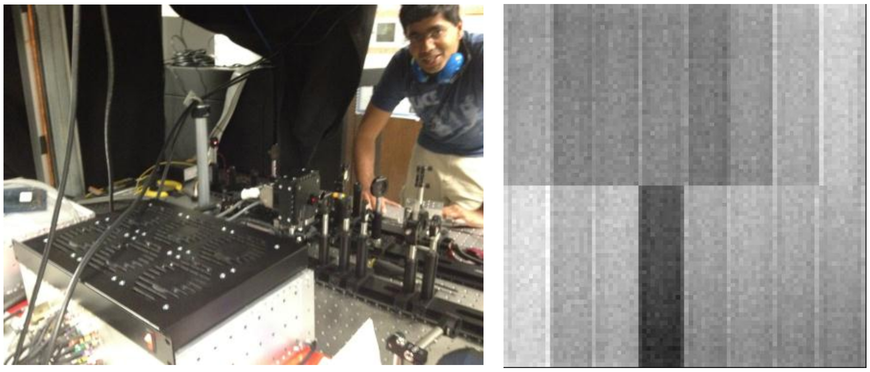


Figure 6. Astronomy graduate student Sri Srinath measures the performance of the wavefront sensor camera in the laboratory testbed (left). Right: a dark frame of the 160x160 array shows the bias and read noise of the individual readout amplifiers.

The tip/tilt sensor camera is an older model CCID 39 chip that has on the order of 6 electrons read noise per pixel at high frame rate, but lower noise at the slower frame rates needed for tip/tilt sensing. This sensor is re-used from the current Lick AO system and has demonstrated acceptable low-noise performance in prior testing. In the new system design, a portion of the sensor array is dedicated to tip/tilt sensing and a portion dedicated to slow wavefront sensing.

Infrared Science Detector Testing

The infrared science detector array is a 2048x2048 pixel Teledyne “Hawaii-2RG” (H2RG) engineering grade device. We have now tested the device at cryogenic temperature in a test dewar (Figure 7).

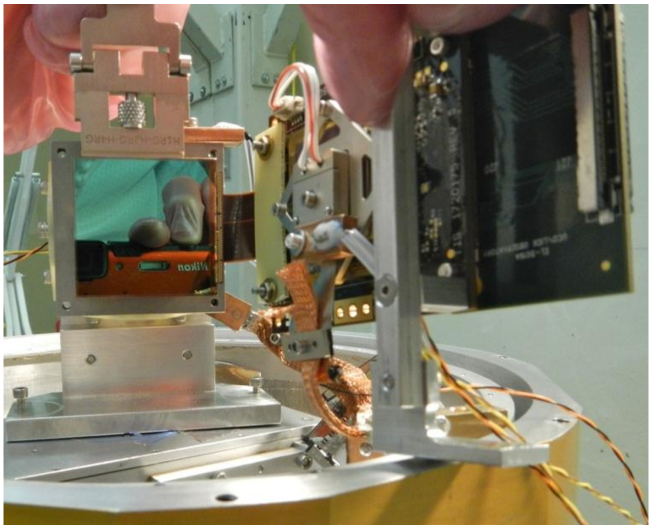


Figure 7. The H2RG infrared detector and drive electronics shown with the cryogenic test dewar.

The engineering grade device designation means that a portion of the array is not readable (Figure 8, left), however the working portion of the array is held to a specification of science grade. Our initial readout tests showed that nearly all the pixels in the good section are responding to light. The ShaneAO science field, set by the anisoplanatic angle of the AO correction, easily fits within the good portion of the array (Figure 8, right). Furthermore the wide geometry of the good portion will allow us to accommodate up to three times higher resolution spectra than the current AO system with a grism-dispersed spectrograph.

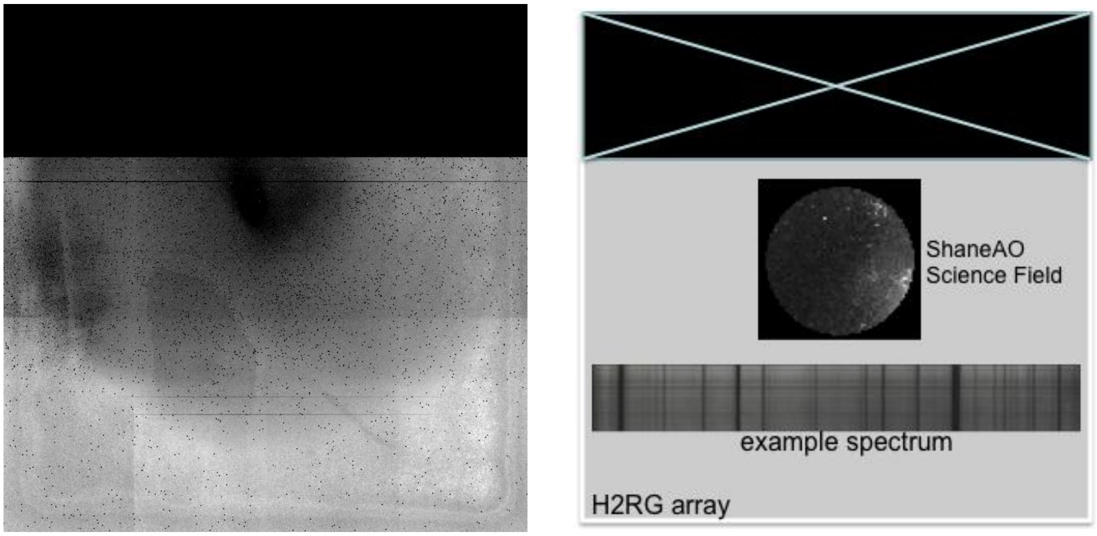


Figure 8. Left: first light readout of the H2RG detector, showing the 800 row failed readout area at the top. A 1248 x 2048 pixel region is usable, which adequately covers the ShaneAO science field (right).

Laser Guidestar

Although technically not part of the NSF MRI project, Lick Observatory plans to install a new guidestar laser to operate with the ShaneAO system. The laser, constructed at Lawrence Livermore National Laboratory (LLNL) with development funding from the NSF Center for Adaptive Optics and the NSF Adaptive Optics Development Program, will provide 10 watts of sodium wavelength (589 nm) output at an optimal pulse and spectral format designed to maximize the guidestar signal return.

The appropriate government agency (the FDA) has approved the laser for shipping from Livermore to UCSC and we have prepared an enclosure space within UCSC’s Laboratory for Adaptive Optics with the necessary safety interlocks and control systems. The start of laser preparation work has been somewhat delayed by unavailability of our qualified laser engineer, whose time is presently taken up with the Gemini Planet Imager integration and test effort.

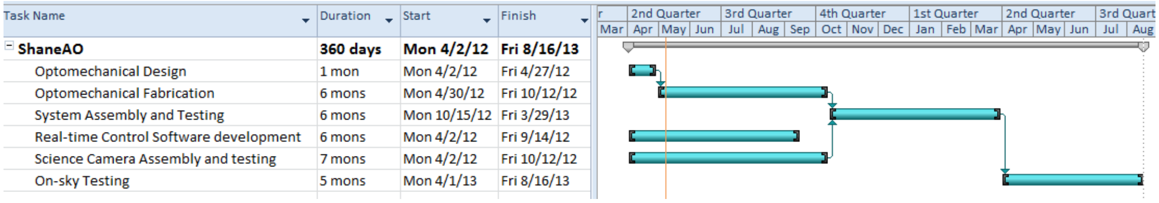
Student Involvement

Four UCSC graduate students have been actively involved in the ShaneAO project: Rachel Rampy (Physics), Rosalie McGurk (Astronomy), Andrew Norton (Engineering), Srikar Srinath (Astronomy). One undergraduate student, Vanessa Molletti (Physics), is also participating.

The students have assisted with laboratory data collection, data analysis, and control algorithm development. Three of the graduate students (Rampy, McGurk, and Norton) are doing their PhD dissertation based on their work on ShaneAO.

Plans to Completion

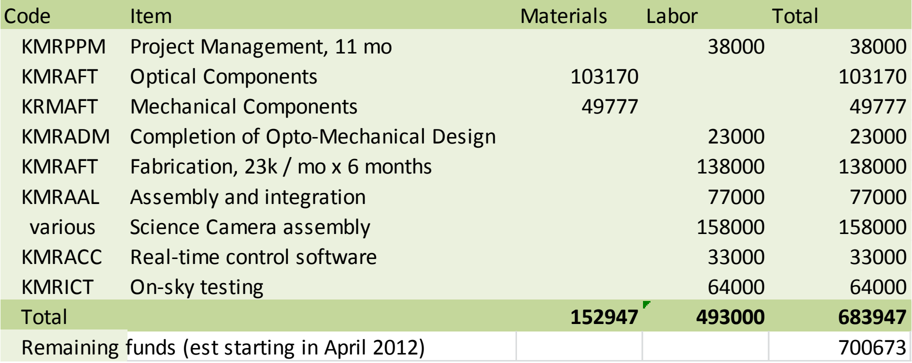
As mentioned in the introduction of this report, we will need a no-cost extension beyond the original end date to complete the fabrication and commissioning of the ShaneAO instrument. The timeline for the completion is shown in Figure 9 and a table of costs in Table 1. As of March 31, 2012, $700K of our original $2,000K grant remains unspent and uncommitted. The key dates in the replan are December, 2012 for completing fabrication of the specialized parts in the Lick Observatory shops, May, 2013 for completed assembly and laboratory testing of the AO system, and June-August, 2013 for on-sky testing and commissioning runs.



Task Name	Duration	Start	Finish
ShaneAO	**360 days**	**Mon 4/2/12**	**Fri 8/16/13**
Optomechanical Design	1 mon	Mon 4/2/12	Fri 4/27/12
Optomechanical Fabrication	6 mons	Mon 4/30/12	Fri 10/12/12
System Assembly and Testing	6 mons	Mon 10/15/12	Fri 3/29/13
Real-time Control Software development	6 mons	Mon 4/2/12	Fri 9/14/12
Science Camera Assembly and testing	7 mons	Mon 4/2/12	Fri 10/12/12
On-sky Testing	5 mons	Mon 4/1/13	Fri 8/16/13

Figure 9. Schedule to completion.

Table 1. Table of remaining costs for Shane AO system as of April, 2012



Code	Item	Materials	Labor	Total
KMRPPM	Project Management, 11 mo		38000	38000
KMRAFT	Optical Components	103170		103170
KRMAFT	Mechanical Components	49777		49777
KMRADM	Completion of Opto-Mechanical Design		23000	23000
KMRAFT	Fabrication, 23k / mo x 6 months		138000	138000
KMRAAL	Assembly and integration		77000	77000
various	Science Camera assembly		158000	158000
KMRACC	Real-time control software		33000	33000
KMRICT	On-sky testing		64000	64000
Total		**152947**	**493000**	**683947**
Remaining funds (est starting in April 2012)				700673