NSF Major Research Instrumentation Program

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

Fourth Year Report
August, 2013

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Research and Education Activities & Summary of Findings

We have now completed fabrication and assembly of the major portions of the new AO system and fully tested the new infrared detector for the Shane telescope. Plans are to install the AO system on the telescope for first light tests in November, to get first light on the new science detector by March 2014 and to initiate science observations in second semester 2014. We are roughly one and a half years behind our original schedule as outlined in the proposal. This slip is entirely in time, not in budget. We have been approved for no-cost extension to August 2014. Hence this report is an interim report.

The AO system fabrication and assembly has proceeded well with the completion of all the major optomechanical components this year and assembly and alignment of the optical train now in process (see Figures 1 and 2). Due to an early emphasis on computer-aided design and detailed planning the mechanical assembly has come together with remarkably little difficulty. However, we have experienced an unfortunate delay in receiving some of the fixed powered optics. As reported in last year's report, the AO electro-optics components, the wavefront sensor cameras and deformable mirrors, have all been delivered and have passed acceptance testing in our lab.

We encountered a delivery delay for the fixed off-axis parabolic reflectors used in the AO pupil relay because of a non-performing vendor. This has been remedied by going to go to a second supplier but has added a slip in beginning the optical alignment process due to the failed first delivery and the second fabrication lead. We have still not received one of these key optics, which the second vendor is putting best effort to deliver ahead of schedule. However it remains uncertain whether this will arrive on time for the go/no-go decision on the November engineering run.

The new infrared science detector was characterized at the desired science readout modes and exposure times, using a test vacuum cryo dewar. During this process, custom low-level software (developed by UCLA for the MOSFIRE project) was integrated and checked out and the desired high-level exposure control software was implemented. The detector will be installed in the existing IRCAL dewar in the winter months of FY14 in order to minimize disruption of ongoing science observing campaigns with the present AO system (the weather usually precludes AO observing during the winter).

Adaptive Optics System Fabrication

The adaptive optics system consists of optical table, mounts for the deformable mirrors, the wavefront sensor, the tip/tilt sensor, other fixed optics, and a kinematic mount for the infrared science camera dewar. Our goals for the instrument included maintaining point-spread-function stability to the diffraction-limit for long-exposure spectroscopy when guiding off of a faint natural guidestar. The flow-down in the design process identified key mounts: the tip/tilt positioning stage (x-y positioning), the tweeter deformable mirror mount (tilt and x-y positioning), the dichroic splitter stage (tilt), and the kinematic mount of the science camera (position and tilt). After extensive finite element analysis to confirm the designs, the customized portions of these mounts were fabricated at UC shops. The tweeter deformable mirror mount was

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tested for deflection performance on a tilt stage and metrology setup, which validated that the design approach is meeting performance requirements.

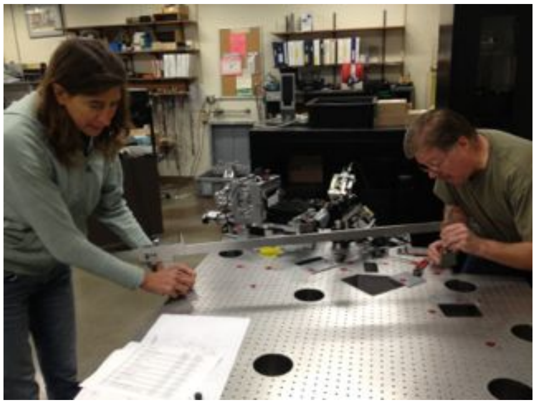

Figure 1. Engineer Renate Kupke and machinist Jim Ward mark the key points of the optical path on to the optical table surface.

Several items on the table are motorized stages: a stage to change dichroic splitters, stages for focusing the wavefront sensor to the laser guide star, a stage to select lenslet arrays in the wavefront sensor, field steering mirrors for the wavefront sensor, and a stage to move the tip/tilt sensor around the field. All of these stages and their mounts, with the exception of one stage to hold internal calibrator source fibers, have been fabricated and are now mounted on the table. The motorization, including installation of the motors, motor drives, the wiring for control, encoder feedback, and safety limit switches, is complete. The final check out of these stages, involving setting software limits and motor servo parameters, is in progress.

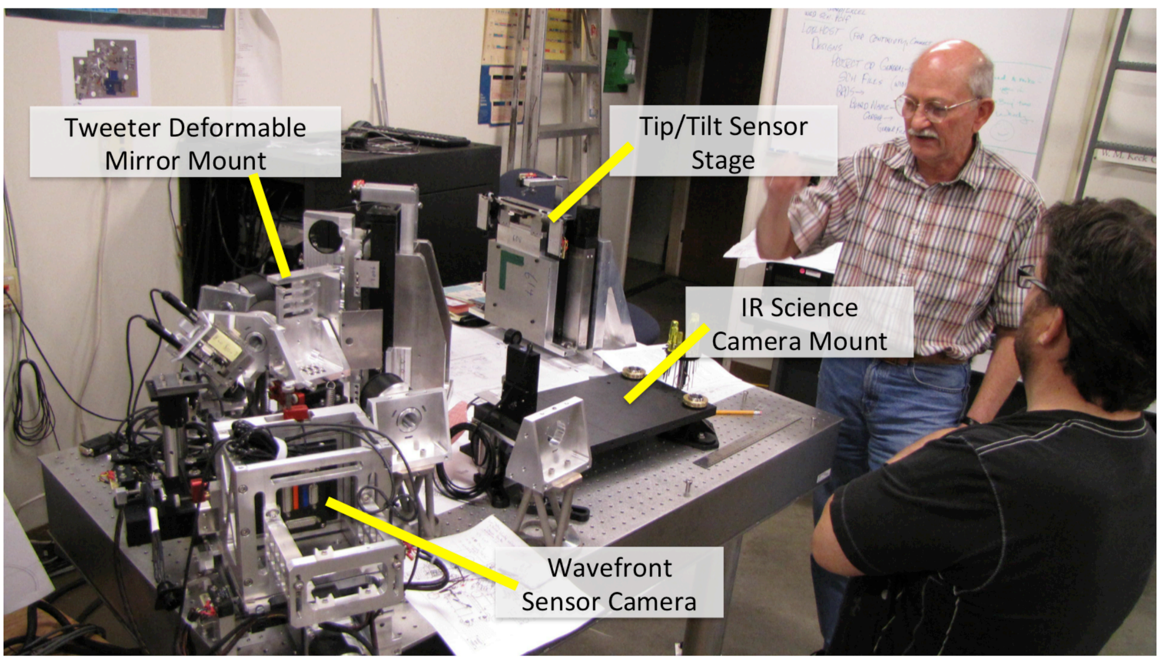

Figure 2. Engineers Jerry Cabak and Daren Dillon overview the assembled optical table components. Deformable mirrors, Tip/tilt camera and infrared science camera dewar are not installed.

Testing of the Infrared Science Detector

The infrared science detector array is a 2048x2048 pixel Teledyne "Hawaii-2RG" (H2RG) engineering grade device. This device has a usable area of 1248x2048 pixels, where the pixels are denoted science grade. As described in our previous reports, this area covers the entire AO science field at twice the spatial resolution and allows for spectroscopy at a three times the spectral resolution of the current camera.

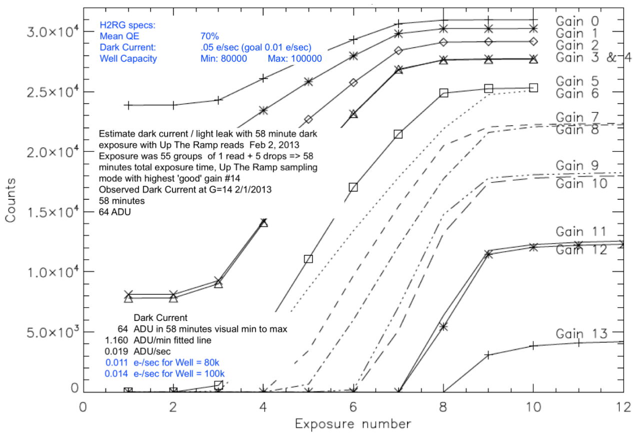

Figure 3. Our testing of the H2RG infrared science detector shows that the device we received meets manufacturer published goals for dark current. This has enabled us to move on to predict science signal to noise vs exposure time will exceed our initial expectations.

The detector has undergone extensive testing at cryogenic temperatures inside a test dewar in our lab. Figure 3 shows some of the results. Our conclusion is the detector is exhibiting the desired high quantum efficiency and noise characteristics as expected from manufacturer specifications, and is performing over the range of operating modes that infrared observers prefer to use, both for direct imaging and grism spectroscopy.

Astronomy graduate student Srikar Srinath has made prediction calculations of the throughput and emissivity of the AO system, and using the measured detector characteristics charted the predicted exposure time versus science object brightness (Figure 4). The signal-to-noise improvements that the new AO system plus detector will have over the old system is a factor of 13, exceeding our original predictions at the time of the proposal of about a factor of 12.

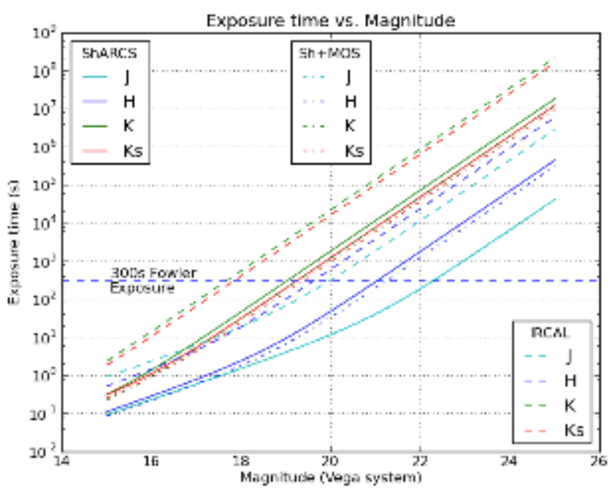

Figure 4. Exposure time versus object magnitude curves predicted for the new Shane adaptive optics system and science camera (ShaneAO + ShARCS).

Modifications needed to the dewar include a new positioning wheel for the focal plane masks (correcting a persistent slit positioning problem in IRCAL), a new pupil cold-stop (correcting a mis-sized pupil stop in the old system which allowed in too much thermal background and placing it upstream of the Wollaston prism used in polarimetry so that it masks a single image of the pupil instead of two), and new mounts for the imaging optics and the detector itself. The design has passed internal review and the engineered components will be machined in the coming months ahead of when the dewar is brought down for modification over the winter.

Laser Guidestar

In conjunction with 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 laser has been delivered to UCSC and is now undergoing engineering upgrade to make it suitable for mountaintop operation. The system consists of two infrared fiber lasers, a 1583 nm

Nd:YAG and a 938 nm Er:YAG, which are combined in a nonlinear crystal (PPSLT) to create the 589 nm sodium line at 10 watts output power. The 1583 laser has been tuned up to full power output (15 watts). The 938 nm laser, intended to run at 10-15 watts, needs new pump diodes, which are now on order, and a modified system of cooling before it can be brought to full operating power. The cooling modification is now in progress.

An important decision to be made about the laser is whether to locate the sum-frequency combiner (the nonlinear crystal and fiber feed optics) at the base of the launch telescope, which is mounted on the side of the Shane telescope, feeding it with the two infrared fibers, or to locate the sum-frequency combiner in laser enclosure on the dome mezzanine and feeding the launch telescope with the 589 nm light through a high-power transport fiber. The later option requires a specialized photonics crystal transport fiber. We've performed the calculations with the assistance of others who have successfully used this type of fiber with high-powered lasers in the past and we believe it will work for our laser with its present pulse and multi-line spectral format. We have arranged to obtain such a transport fiber on semi-permanent loan from the Keck Observatory, which originally intended it for use with their new laser but subsequent tests determined was not suitable for their use. The alternative approach of mounting the sum-frequency combiner on the telescope would bypass the risk of the transport fiber (the existing IR amplifier fibers can be used for transporting the two IR lines) but will require a robust and gravity-flexure independent alignment of the fibers to the nonlinear crystal. The analysis leading to this decision is ongoing.

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.

Rachel Rampy graduated with a PhD in Physics in March, 2013, with the thesis "Advancing Adaptive Optics Technology: Laboratory Turbulence Simulation And Optimization Of Laser Guide Stars." She has subsequently been hired as a postdoctoral researcher at the Keck Observatory. The laser-sodium atomic modeling component of her thesis determined the optimal parameters for a pulsed laser to enhance guide star return. The predictions for the fiber laser are that it will produce from five to ten times the return signal per watt of launched power compared to the dye laser now used (recent analysis shows it is likely closer to ten). The increased return enables the AO system to use smaller subapertures in its wavefront sensor, which gives finer sampling of the wavefront resulting in higher Strehl images.

Principal Discipline Impact

Concomitant with the tradition of new instrumentation development at the Lick Observatory, the ShaneAO system will be pioneering new techniques and technologies that will be applicable to future instruments on the giant telescopes of which the University of California is a partner: the W.M. Keck Observatory 10 meter telescopes and the proposed new 30 meter telescope, the TMT. This system strives to achieve extraordinarily high Strehl performance using innovative technologies such as a MEMS adaptive deformable mirror, a pulsed laser guidestar, and a woofer-tweeter control architecture with sharpening of the tip/tilt star. These technologies are included in the design concepts for AO systems on the large telescopes, but will be tested for the first time on sky in this system on the Shane telescope. The system also functions as a testbed for innovative real-time control techniques such as a wind-predictive control algorithm that will increase the AO control bandwidth and relax the required guide star brightness. In a related project, we plan to experiment with laser uplink wavefront correction, also using a MEMS deformable mirror. The laser beam uplink correction will enhance the return by sharpening the laser guide star spot. The new AO system will be able to evaluate the effect on AO system performance at the detailed level and tight wavefront error tolerance requirements associated with the future Keck and TMT AO systems.

Physical Resources Impact:
The University of California Observatories is currently evaluating its present shops and laboratories infrastructure for its future role developing instruments on the large telescopes. ShaneAO construction is forging a path with the application of modern design and fabrication techniques in order to achieve its degree of high optical precision and a predictable performance from design. These experiences will instruct our direction for new facility requirements, and will impact the overall observatory model for the work flow in the design and assembly of next generation instruments. Specific examples are the use of automated computer-aided-design to fabrication flow (e.g. 3-d printing), the use of automated machining and assembly (automated milling, precision coordinate measurement), prescription materials, the balancing of in-house operations to outsourced specialty work, and a coordinated project management system for all projects at the observatory.

Technology Transfer Impact:
We are working with two deformable mirror manufactures who have a significant commercial interest in advancing their technologies. The laser coatings on MEMS deformable mirrors are a prime example of a cutting-edge technology that we are evaluating (their development, our testing with a high power laser fluence). Both of these partners market their mirrors to the broader optics and photonics industry.