NSF MRI Project

# MRI: Development of Enhanced Adaptive Optics System and Infrared Instrumentation for the Shane 3-m Telescope

First Year Report
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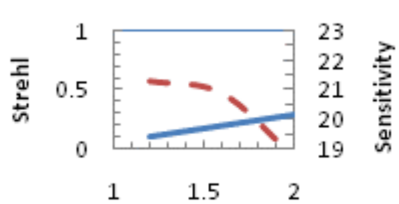
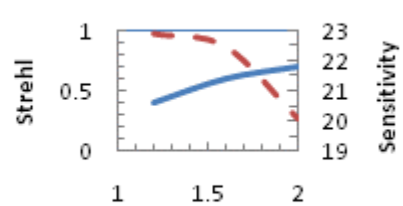
## Research and Education Activities & Summary of Findings

The main activities for the first year of this project have included working with the science user community to establishing the system performance goals, evaluating the operations requirements with input from Lick instrument specialists, and developing a preliminary design for the engineered system. The new instrument consists of three main components: 1) the optical relays for the AO system and their associated optomechanics, 2) the adaptive optics control system including deformable mirror and real-time control computer, and 3) the infrared science camera.

The instrument's science data-gathering performance expectations, originally outlined in the proposal, have now been refined and flowed down to the engineering phase. Basic system parameters and Strehl and throughput performance models were presented at a recent meeting of the SPIE. The figure below summarizes our results[1].

| | Old System | New System |
|---|---|---|
| Deformable Mirror | 61 actuator piezo-electric driven glass face-sheet, 72 mm beam | 1024-actuator MEMS deformable mirror, 10 mm beam |
| Wavefront Sensor | Shack-Hartmann, 42 cm subaperture. | Shack-Hartmann, selectable 10 cm (30 across aperture) or 20 cm (16 across aperture) subapertures<br>Lincoln Labs CCID-66 detector technology |
| Laser Guidestar | 11 Watt 589 nm dye laser. 100 ns pulse at 11 kHz.<br>Beacon flux return signal is ~5 ph/s/cm2/Watt. | 10 Watt 589 nm sodium beacon. 30 μs CW pulse (Rayleigh-blank format)<br>LLNL-design fiber laser,1583 nm + 938 nm lasers combined in sum-frequency crystal<br>Expect ~50 ph/s/cm2/Watt flux return |
| Science Detector | PICNIC 256x256 array, 76 milli-arc-second sampling. 1.2 μm to 2 μm. Diffraction-limited only in K band (2μm) | Hi2RG 2k x 2k detector (using single 1k x 1k quadrant). 38 milli-arc-second sampling. 0.8 μm to 2 μm. Diffraction-limited from 1 μm to 2 μm. |
| Performance vs wavelength<br><br>Strehl -----<br>Sensit - - - |   |   |

The optical engineering has achieved a level where we know the beam paths and overall size, and have identified the optical elements needed to complete the system. The layout is shown in the figure below.

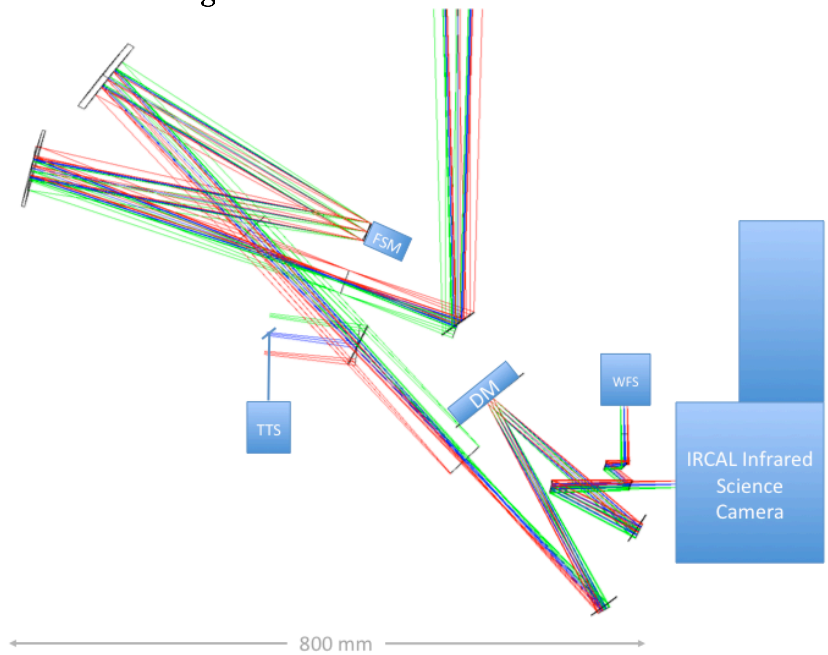



**Figure 1.** Optical configuration of the new Shane Adaptive Optics system and science camera. Incoming starlight from the telescope enters the system from the top.

Legend:

FSM-Fast steering mirror
TTS-Tip/Tilt sensor
DM-Deformable Mirror
WFS-Wavefront Sensor

The optical system provides for two pupil locations at which are placed the two stages of wavefront correction: a tip/tilt/low-order corrector mirror and high-order deformable mirror. Locating both these correctors at pupil conjugates minimizes field-dependent aberration and anisoplanatic errors. The output beam is at a high f/number to match the AO diffraction-limted spatial resolution to the science detector pixel size. In laser guidestar operations, there must be accommodation for a tip/tilt guidestar over a wider field of regard and this is provided through a splitter and field selection mirrors at the output of the first relay.

We are currently working with the mechanical engineers to develop the instrument-supporting mechanical structure.  The Cassegrain focus of the telescope is subject to varying gravity vector as it tracks stars, so the instrument mechanical structure must be designed for predictable flexure characteristics to keep it aligned to diffraction-limited performance.

Main components of the adaptive optics system, including the deformable mirror and the wavefront sensor camera, have been identified and some procured. The Boston Micromachines 32x32 actuator array deformable mirror and drive electronics have been delivered. The wavefront sensor camera, based on a 160x160 pixel CCID 66 array from Lincoln Laboratories, is in final assembly at SciMeasure Analytical Systems and is due to be delivered shortly.

Several options for the real-time control system computer have been analyzed. The core real-time operation, that of reconstructing the wavefront phase given the Hartmann sensor image data, has been demonstrated with a high-speed graphics processing engine using software developed in our laboratory. The full system specification with the required data bus and I/O units, is now work in progress.

The sodium guidestar fiber laser has completed its system tests at Lawrence Livermore National Laboratory and is due to be delivered to UC Observatories Laboratory for Adaptive Optics this summer. The system has demonstrated its goal of output power in excess of 10 Watts in the laboratory. While at UC LAO it will undergo engineering hardening for operations at the mountain and will be installed at the telescope in year 3 of this project.

We have determined that upgrading the infrared science instrument as described in the proposal will require minimal modification of the dewar for the existing IRCAL instrument. We have researched our options for the detector, and have decided to purchase an EG-A grade Hawaii-2RG detector. This guarantees science-grade performance over a 1k x 1k area at a reduced price compared to that for a full science-grade detector. That 1k squared area is the size we need to cover the available field from the AO system while still realizing the gain from the smaller pixel size to Nyquist sample the AO PSF in the J and H bands. The EG-A grade also provides all the gains of the Hawawii-2RG detectors over previous generation IR detectors. We intend to use the SIDECAR ASIC electronics package from Teledyne to run the HAWAII-2RG detectors. That has the advantage of allowing us to drawn on the extensive experience of the UCLA Infrared Laboratory with running these HAWAII-2RG detectors with the ASIC in the OSIRIS instrument for Keck and the soon-to-be delivered Keck MOSFIRE and Gemini Planet Imager. We will also be able to use the UCLA group's instrument software for those instruments as the basis for the new IRCAL detector software on the instrument computer side, reducing the cost, risk and time to completion for that part of the project.

On the mechanical side, we have integrated the as-built optical design of IRCAL with a new CADD model in order to determine whether and how the larger detector will fit in the existing instrument. The good news is that we will be able to use the existing cryostat unaltered, with only minor changes to the mounting plate needed to secure the new detector package in place. We have also developed a design for improving the accuracy and repeatability of the mechanical couplings that move the aperture, grating/filter wheels to enable use of IRCALs spectroscopic mode as well as improve operational reliability. We will conduct an internal review of that design once we finalize the details of the detector mount. The review will include input from the team who originally built IRCAL.

[1] Gavel, D.T., "Progress update on the visible light laser guidestar experiments at Lick Observatory," MEMS Adaptive Optics IV, Proceedings of the SPIE, Vol 7595 (2010).