# THE CHARACTERIZATION OF A SEGMENTED DEFORMABLE MIRROR USING THE TECHNIQUE OF PHASE-DIVERSITY

Robert M. Albarrán, University of Hawaii-Hilo at Subaru Telescope (NAOJ)
Mentor: Frantz Martinache, Advisors: Lucio Ramos & Olivier Guyon
Collaborator: Yosef Razin

## ABSTRACT

Density variations in the Earth's atmosphere, due to atmospheric convection and turbulence, yield astronomical images with poor spatial resolution, preventing large telescopes from achieving their ideal diffraction-limited high resolution. Today, large optical and infrared ground-based observatories use a technique known as Adaptive Optics (AO) to correct for the distortion of light induced by our atmosphere, thereby producing diffraction-limited images. Deformable Mirrors (DM) and wavefront control devices are critical AO components, from which more and more is being demanded. During my internship at Subaru Telescope, I have designed and assembled an optical bench to characterize the surface quality of one such DM with 37 segments, each of which may be driven in piston and tip-tilt. I characterized the DM by using the technique of phase-diversity: by programming a CCD camera to take a series of images, in and out of focus, of the reflected light of the DM, an algorithm developed at Subaru may then be used to drive the DM. This DM optical configuration will serve as a test-bed for advanced wavefront control techniques in part of the extreme-AO system currently being assembled at Subaru. Future implications of segmented mirror technology may extend to projects such as the Thirty Meter Telescope and the James Webb Space Telescope.

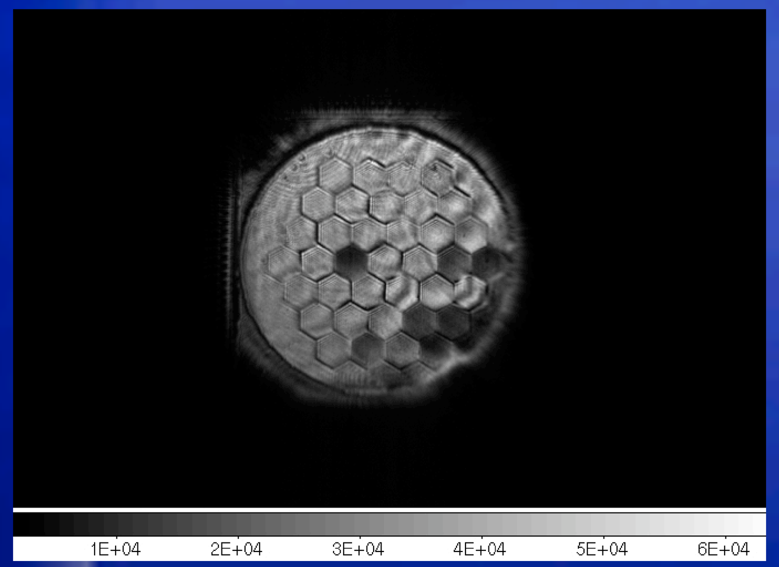



Figure 1: A sample of the sequence of images taken during the Foucault Knife-Edge Test. Seven of the 37 individual segments are imaged as off-axis. (See the Foucault Knife-Edge Test).

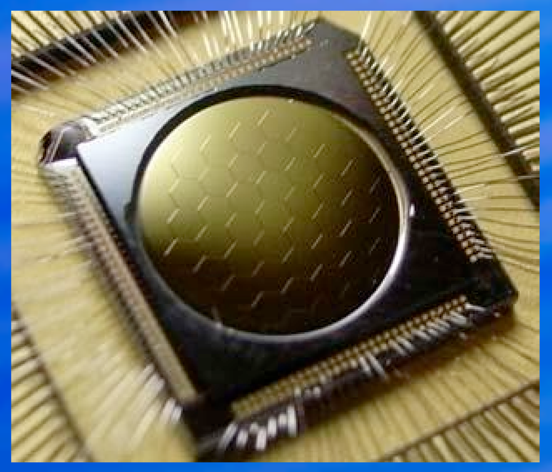
## GOALS FOR PROJECT

The four goals of my project are to:

1. Design and assemble an optical bench with a segmented Deformable Mirror (DM).
2. Use this configuration to establish a baseline map of the DM surface quality by using the two following tests:
   - The Foucault knife-edge test
   - The phase-diversity technique
3. Compare the results to accurately identify the DM segment surface quality.
4. Efficiently enable the optical configuration for precise wavefront control.

## DEFORMABLE MIRROR

Figure 2: The Iris AO S37-8 Deformable Mirror (DM) with 37 hexagonal segments.



The 37 segments of a pristine and rapidly controlled MEMS based Deformable Mirror (DM) are ready to be sophisticatedly studied and carefully characterized. Each hexagonal segment spans 700 microns and sits on a temperature insensitive flexure that supports an electrode driven actuator platform. With an inscribed aperture of 3.5 mm, the S37-8 Iris AO deformable mirror requires an extensive mapping to assist in high-precision atmospheric wavefront correction. To do so, experiments are to proceed with various mirror surface quality characterization techniques on an effectively designed optical assembly.

## THE OPTICAL DESIGN

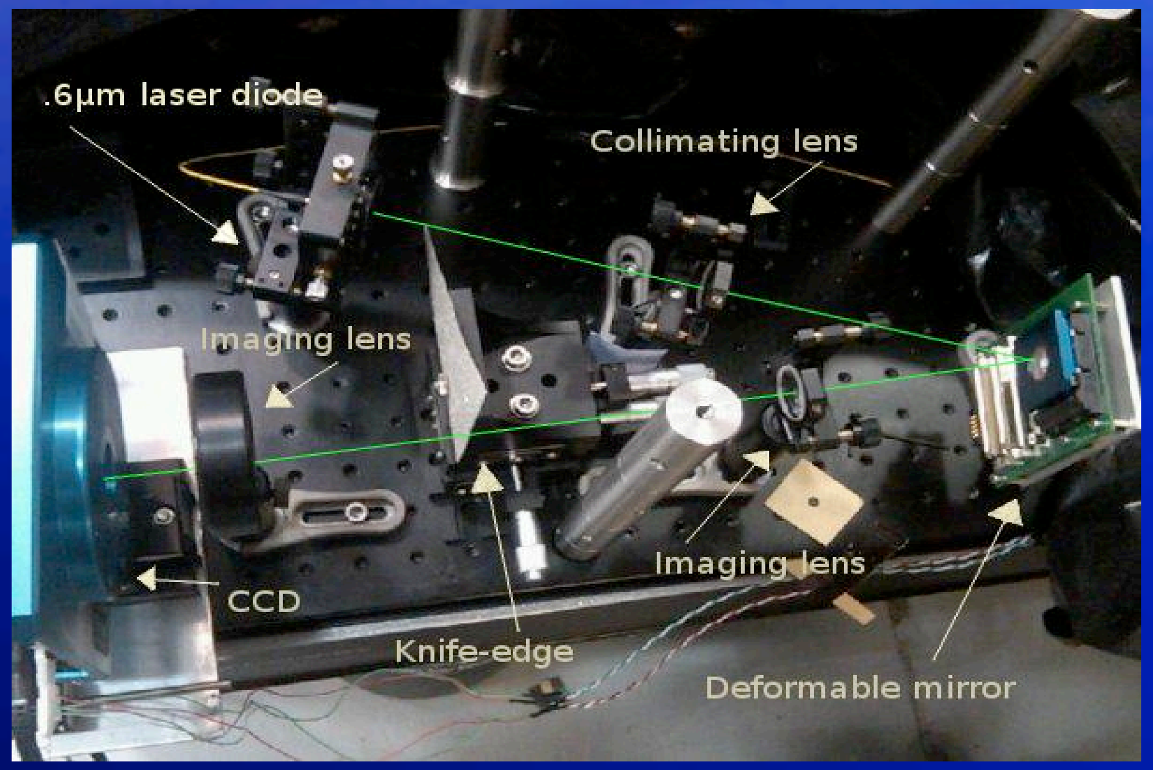



Figure 3: The light path from the laser diode to the CCD camera. This design is optimized for the visible range of the electromagnetic spectrum.

My optical assembly includes a 635 nm laser diode that propagates through a 25 mm diameter collimating lens, which is 150 mm in focal length, residing upstream from the DM. Downstream from the DM the beam propagates through a pupil mask (blue circle in Figure 2) attached to a 25 mm diameter imaging lens, with a 125 mm focal length. Following, the Foucault knife-edge is mounted on a spatial-filter interchangeable post (red circle in Figure 2) prior to a 50 mm diameter imaging lens, with a 50 mm focal length. An Apogee Charged-Coupled Device (CCD) camera on a sliding track will then electronically take a sequence of images of the DM between the image plane and pupil plane. Tests are conducted to precisely align these active optics and provide data to work with.

## THE FOUCAULT KNIFE-EDGE TEST

The purpose of the pupil mask is to exclude the DM mount and frame in the image. After a testing process, the pupil mask is effectively placed on the first of the two imaging lenses. By testing different spatial filters at the focal plane of the first imaging lens we may identify the individual off-tilt segments of the mirror. We accomplish this by using a Foucault knife-edge to distinguish the off-tilt segments seen in Figure 1. As found, there are select segments that are off-tilt by a certain degree.

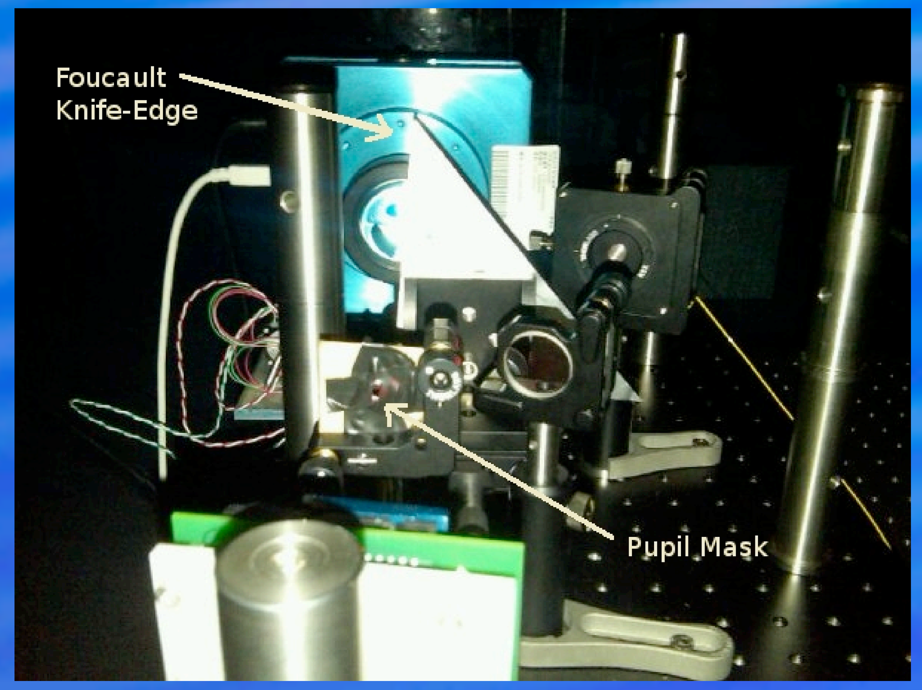



Figure 4: The pupil mask conjugate to the first imaging lens on bottom. The Foucault knife-edge on top.

## THE PHASE-DIVERSITY TECHNIQUE

To further explore the surface character of a small segmented mirror, one may manipulate constant values, such as the laser diode wavelength and the flatness of the DM, in an equation to compute the phase of the light reflected from the mirror. In order to do so, the actual flatness of the DM must be found. This is done with a computer code developed at Subaru Telescope that produces simulation images of the DM (see Figure 5). As fair representations of the actual images, the simulation images illustrate a surface flatness of 30 nm. Subsequently, the phase of the analyzed region of the DM was found to be .29 radians or 30 nm.

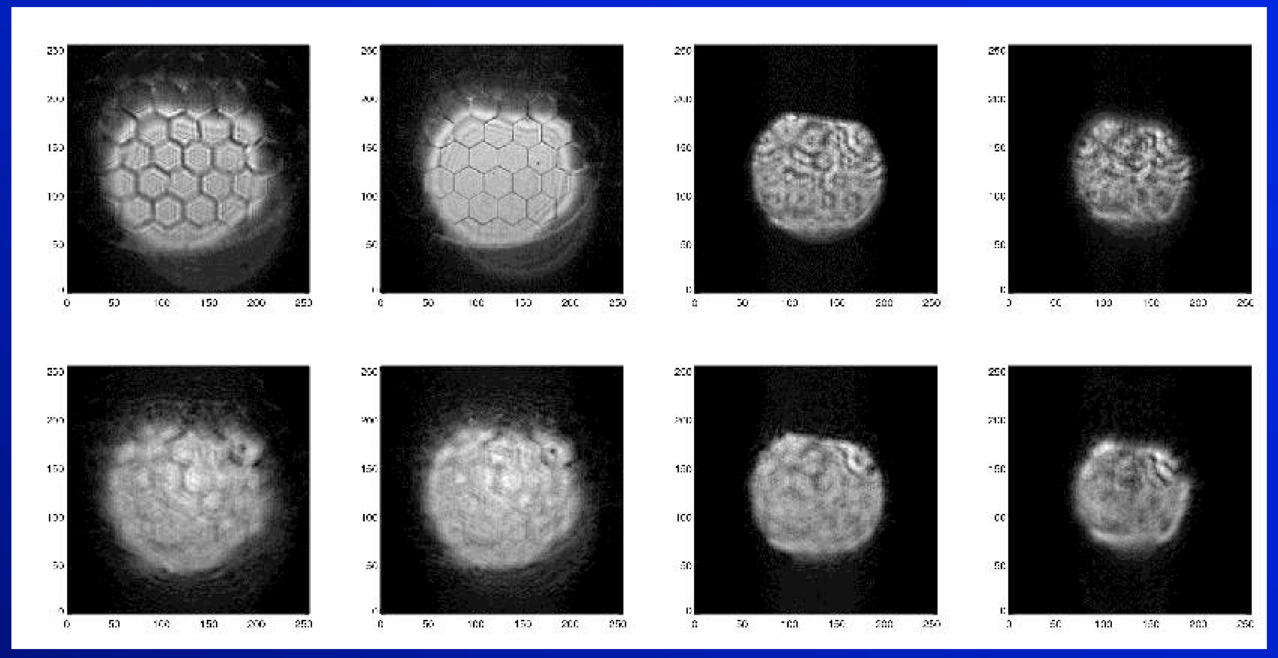


Figure 5: Comparison between the actual images of the deformable mirror (DM) in and out of focus (top row) and the simulation images of the sequence developed at Subaru Telescope (bottom row).

## THE RESULTS

After painstaking hardship, this astronomical instrument has determined the surface character of a small segmented deformable mirror (DM) and is now ready for high-precision wavefront control. This bench serves as an optical extension to the infrared-optimized instrument currently being assembled at Subaru Telescope; the Subaru Coronagraphic Extreme Adaptive Optics (SCEXAO). Now that I successfully accomplished the goals set prior to the experiment, I understand the experimental results at an more intimate level. The experimental technology and scientific methods applied in this project provided much insight into the future of AO for the 8-10 meter class telescope.

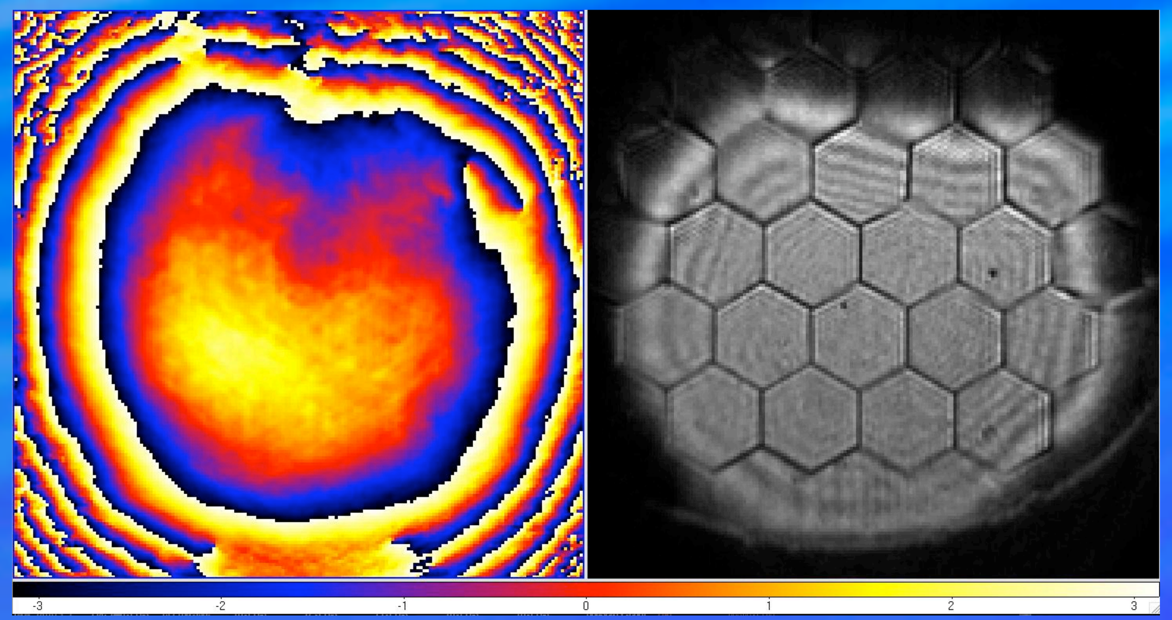


Figure 6: The reconstructed phase of the center region of the DM shows a surface error of 30 nm (on left). The optical intensity of the region of the DM not occulted by the pupil mask (on right).

## CONCLUSION

Today, large ground-based observatories, operating in the optical and infrared wavelengths, pose an enormous progress towards the finding of life in the universe. The SCEXAO module along with the currently operating High-Contrast Imaging AO (HiCIAO) camera and 188-actuator Adaptive Optics system (AO-188) is in the context of the Subaru Strategic Exploration of Exoplanets and Disks (SEEDS). This collection of aggressive astronomical instruments will enable the Subaru Telescope to directly image extra-solar planets four times closer to their host stars than ever previously seen by astronomers. Other astronomical applications of segmented mirror technology include the European Extremely Large Telescope (E-ELT), the Giant Magellan Telescope (GMT), the Thirty Meter Telescope (TMT) and the James Webb Space Telescope (JWST).

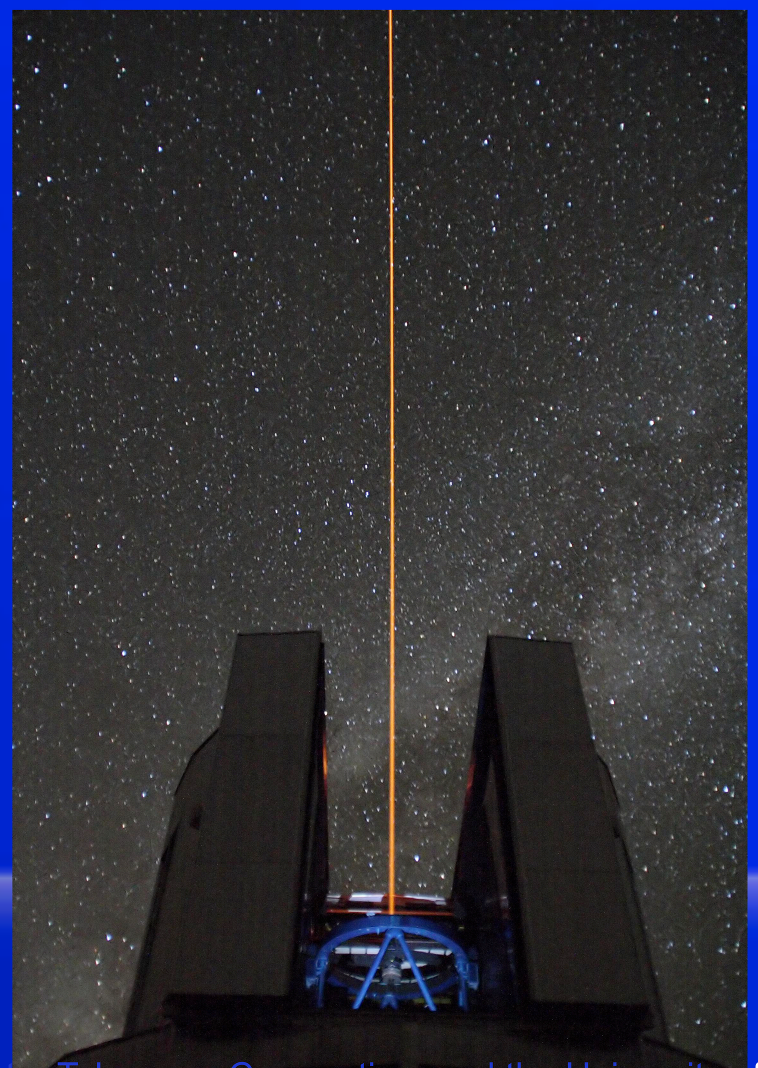


Figure 7: The 8.3m primary mirror Subaru Telescope with the Laser Guide Star (LGS) located on the 13,796 summit of Maunakea, Big Island Hawai'i. thehttp://subarutelescope.org/

The 2009 Hawaii Island Akamai Internship Program is funded by the National Science Foundation Center for Adaptive Optics (NSF #AST - 9876783), the Thirty Meter Telescope Corporation, and the University of Hawaii.