An Adaptive Secondary Mirror for WMKO

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We describe the current plans for developing an adaptive secondary mirror (ASM) adaptive optics (AO) system for WMKO. Such a system has the potential for enhancing a broad range of science objectives, improving the performance of existing WMKO instrumentation, and providing improved performance for future instrumentation. A concept study was carried out between August 2020 - June 2021 to outline the initial design and science motivations for an ASM. The project is currently starting a Phase A study, supported by the SSC and WMKO.

1 Background and Status of Technology

Adaptive Optics (AO) is an important capability of ground-based telescopes that enables higher spatial resolution and more sensitive observations. Integrating the AO system into the telescope optics (via an adaptive secondary mirror) can significantly improve sensitivity for both diffraction-limited AO (especially at 2-5 μm) and seeing-limited instruments that employ ground-layer adaptive optics (GLAO). Current generation adaptive secondary mirrors (ASM's) have been implemented at several telescopes, including the MMT, LBT, Magellan, and VLT using Lorentz force (commonly called voice-coil) actuators and thin glass shells to replace the telescope's static secondary mirrors. These actuators apply force via a current carrying wire coil acting on a permanent magnet attached to a thin curved facesheet. The advantage of this design is the high stroke and linearity achieved. However, the low-power efficiency of the actuators results in designs that require active cooling, high-speed position control, and thin (and consequently fragile) facesheets, increasing the complexity of the assembly.

The Netherlands Organization (TNO) has developed a technology with efficiencies approximately 75 times that of similarly sized voice-coil actuators (1). The actuators utilize the efficiency gains of enclosing the magnetic field path that drives the actuator in a ferromagnetic material, thus reducing the current needed to apply a particular force. This larger force allows for building in an internal stiffness to each actuator and rigid connections to the facesheet. The resulting assembly has very high structural resonant frequencies, compared to voice coil designs, allowing for a simple control approach. Further, the power required to correct turbulent wavefronts can be dramatically lower, allowing for simpler, passive cooling approaches to the system. Finally, the additional efficiency can be traded against the facesheet thickness to provide a sturdier deformable facesheet. A thicker facesheet reduces fabrication and maintenance risk and complexity. The resulting system has the potential to be more robust and simpler than currently deployed ASM's.

2 Science Justification

The value of integrating an ASM into a telescope facility primarily lies in the potential for broader use of AO by any instrument that can benefit from the improved image quality. We review several areas where an ASM-based AO system can be advantageous.

2.1 Enhanced Seeing Observations:

AO systems can provide "enhanced seeing" observations by correcting the ground layer of turbulence, typically referred to as ground-layer adaptive optics system (GLAO). The limitation on this performance is the upper layer turbulence and the height of the ground layer turbulence. For Maunakea, the ground-layer is dominated by a thin surface layer of $\sim$30 meters (2), (3) with mild upper-layer turbulence. Seeing improvements of a factor of ~ 2 (FWHM) over fields of view of 18 arcmin have been demonstrated on Maunakea (4).

The development of enhanced seeing technology will dramatically improve the capabilities of existing Keck seeing-limited spectrographs such as LRIS, DEIMOS, and MOSFIRE, if these systems can be upgraded for improved image quality. With JWST (2021), Roman (2026), and ELTs (2026) revolutionizing our understanding of galaxies at the epoch of reionization (EoR), enhanced seeing ensures that Keck will make key contributions to the study of the EoR based on the rest-frame ultraviolet spectroscopic followup. For example, studies of faint Lya and rest-ultraviolet metal lines (e.g., CIII], CIV, HeII, MgII) will be essential and within reach of MOSFIRE ($\sim 10^{-18}$ erg/s/cm^2) with GLAO. At the same time, wide-field AO opens new and unique scientific territory. Multiplexed, GLAO-resolved spectroscopy with FOBOS IFUs is the only viable path to probe the internal physics of large galaxy samples at $z \sim 1$, and at $z \sim 1$–3 with a future IR-FOBOS. Meanwhile, GLAO opens up important but crowded regions for study, such as the Milky Way's Central Molecular Zone and the M31 disk.

2.2 Improved Thermal Infrared Observations:

An ASM-based AO system can improve the performance of diffraction-limited observations by allowing for optical systems that have fewer warm optical elements. Such a system, when compared to a post-focal plane AO system, can yield higher throughput. For observations at wavelengths greater than 2 microns, background emission from the warm optics can also be reduced. The increase in signal-to-noise can improve the required observing times by factors greater than 2 at wavelengths where thermal emission contributes background radiation (typically $> 2\ \mu$m wavelength) and the sky background is low. IGNIS, when coupled with an ASM could provide high spatial and spectral resolution data with dramatically improved sensitivity compared to the current NIRSPEC/AO bench.

SCALES will directly image exoplanet at 2-5 μm where the planet is comparatively less faint compared to the star. This advantage improves for cooler (< 800 K) planets. However, the dominant source of noise for these observations is typically the background from the warm optics. Observations of cooler planets will thus be enabled by a lower background system, allowing us to study in detail the atmospheric composition of planets that are more similar to those in our own solar system.

2.3 Diffraction-limited AO improvements

An ASM is still a valuable addition to the existing AO bench as it would have 5x as many actuators as the current deformable mirror. The ASM would replace the current DM; but the AO bench would still provide wavefront sensing and field rotation for the diffraction-limited instrument suite (NIRC2, OSIRIS, SCALES, and Liger in the future). This will be particularly useful for high-contrast imaging applications such as for exoplanets and the Galactic Center.

The ASM opens up the exciting possibility of upgrading the rest of the AO bench to a multi-conjugate AO (MCAO) system, delivering diffraction-limited resolution over a 0.5-2' field of view at both optical to infrared wavelengths. MCAO systems require multiple deformable mirrors and the ASM would act as the first. The same actuator technology may be feasible for a second, high-actuator count DM on the AO bench.

2.4 Facility improvements

The current secondary mirror assemblies for both telescopes provides piston movement for focus correction and tip-tilt adjustment for coma removal. The focus correction routines (MIRA and autofoc) are time intensive (5-10 minutes) and thus used less frequently than would be helpful. Lookup tables for elevation and temperature are only moderately helpful, due to instrument specific effects, according to recent discussions with Luke Gers and Randy Campbell at WMKO.

A new secondary mirror assembly can help this situation in several ways. First, a more reliable static adjustment mechanism with precision reference positions, would allow for better characterization of focus drifts. Also, for wide-field performance, centration of the secondary will be important to remove binodal astigmatism that can be introduced by correcting on-axis coma with tilt changes only. A more agile secondary mirror assembly coupled with focus sensors at instrument ports also provides the capability for fast and transparent focus correction.

3 Status of the Keck ASM Concept Study

Over the past year, the Keck ASM instrument team has studied the viability of an ASM design for WMKO. Some top level findings from the study are:

- An ASM concept could utilize one of the spare top end assemblies (which originally housed the f/25 secondary mirrors) and incorporate existing infrastructure from the f/15 top end into the assembly.
- Mirror concepts from 1000-4000 total actuators were studied and found to be viable approaches. A 2000 actuator concept has been preliminarily chosen for further study as the best tradeoff between performance and system complexity.
- The finite element modeling of the assembly predict minor wavefront changes due to gravity deflection and low order (mostly focus) changes with temperature.
- The assembly would produce low enough thermal power at the top end that a passively cooled system is a consideration.

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