Keck Adaptive Optics Technical Overview White Paper – Initial Release

In support of Keck 2035 Science Strategic Planning

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1. Introduction

This is an initial release of a companion report to the Keck Adaptive Optics White Paper (12/1/21) submitted by the Keck AO future study group (FSG) to the Keck 2035 Science Strategic Planning process. The white paper and presentation (12/8/21) at the Keck 2035 Science Strategic Planning meeting were well received at that meeting and the recommendations were substantially endorsed. The purpose of this report is to provide definitions of the AO systems envisioned by the FSG and a potential roadmap to achieve these capabilities. This document will be updated and refined in further FSG discussions, and we welcome questions and feedback from the strategic planning process.

2. AO System Definitions

Three types of AO systems are envisioned. One to enhance the seeing and two to provide diffraction-limited science. All three are intended to provide correction from short optical wavelengths into the near-infrared. These systems may, and should, overlap in technology and implementation but would be designed for the specific types of science to be performed. All three systems should be capable of supporting the rapid instrument switches needed for targets of opportunity or time domain astronomy. The following text is intended to provide more specific definitions for each of these systems. *All performance metrics are notional at this time (and will be studied and refined as a next step).*

The enhanced seeing AO system(s). An Adaptive Secondary Mirror (ASM) would be implemented on one or both Keck telescopes. All sky, high throughput, enhanced seeing is the primary driver for an ASM and is achieved by sensing and correcting the ground layer turbulence. On the 2035 timeframe at least one science instrument should be designed and implemented along with an ASM to take full advantage of the ground layer AO (GLAO) correction. Wavefront sensors would be implemented at the ports where science instruments are located that could take advantage of GLAO. The GLAO system would deliver an image resolution close to the free-atmosphere seeing, typically 0.3” in median seeing at 500 nm over a 10’ diameter field of view. The system would provide performance improvements from the U to K-band. Other requirements on the ASM include maintaining a stable “flat” surface in the absence of wavefront sensor control while provide focus correction, the capability to be used by a higher order AO system, and not excluding the implementation of a prime focus instrument on the same telescope. Note that an ASM would not be required if only narrow field enhanced seeing was needed since the AO correction could be provided by a MEMS deformable mirror in the science instrument path.

The high contrast AO system. The high contrast AO system should be designed and integrated with the high contrast science instruments it will feed, since the combination of capabilities and performance play a key role in the final achievable contrast. The science instruments should include a high contrast instrument and an extreme precision radial velocity (EPRV) spectrograph. The AO system should be capable of injecting science light into a fiber or fiber lantern to feed the EPRV instrument or other high-contrast fiber-fed instrumentation. The high contrast AO system should be a natural guide star (NGS) AO system capable of doing laser tomography AO (LTAO) for fainter targets. It shall be designed to support science from B to K-band over a 1” diameter corrected field. In the NGS mode the system shall deliver an on-axis residual wavefront error with a spatial power spectrum of 80 nm rms from 2 to 10 cycles across the pupil when using an on-axis $H \leq 11$ magnitude NGS (equivalent to a Strehl ratio of 0.36 at 500 nm). It will be critical for this high contrast AO system to be designed and implemented to support technology development to help advance the field while delivering cutting edge science return.

The high sky coverage, diffraction-limited AO system. The current Keck AO systems and science instruments (NIRC2 and OSIRIS) have been delivering high sky coverage, diffraction-limited science in the near-infrared. KAPA combined with Liger will provide critical improvements in these capabilities. The 2035 version will be designed and implemented to provide much higher performance over wider corrected fields, with higher sky coverage and science at visible wavelengths. New science instruments will need to be designed and implemented in concert with the AO system to take advantage of the AO system's performance, especially a visible imager and integral field spectrograph (and in the nearer term Liger to shorter wavelengths). This AO system should support science from U to N-bands and provide a corrected field of ≥ 1' diameter. Some notional initial performance requirements include: ≥ 40% sky coverage with encircled energy EE50 diameter <= 20 mas at V for 2" off-axis; ≥ 20% sky coverage with Strehl ratio ≥ 0.3 at V for 10" off-axis; and ≥ 75% sky coverage with Strehl ratio ≥ 0.1 at V for 10" off-axis. The system will likely need to provide an LTAO mode for higher performance narrow science fields and a multi-conjugate AO (MCAO) mode for the 1' diameter science fields.

3. Science Drivers

The drivers for the above definitions came from connecting the science cases developed in the AO workshops (organized by the FSG in October 2021) to the technology requirements as summarized in the following table (DL = Diffraction-limited; ES = Enhanced Seeing).

#	Science Case	FoV (dia.)	Image Quality	Sky Coverage	λ	AO Flavor
1	Extragalactic					
1a	Single Object	30"	DL	All sky	U-K	MCAO
1b	Large Sample	20'	ES	All sky	U-K	GLAO
2	Stellar Populations	1'	DL (ES if not)	All sky	B-K	MCAO
3	Solar System					
3a	Large Bodies	1'	DL (ES if not)	All sky	U-N	MCAO
3b	Small Bodies	2"	DL	All sky	U-N	LTAO + wide GS
4	Exoplanets					
4a	High Contrast (tech dev)	1"	DL, SR~1	NGS	V-K	90% NGS
4b	EPRV	1"	DL, SR~1	NGS	B,V-K	10% LTAO
5	Explosive Transient Phenomena (known single object)	< 1"	DL to ES	All sky	U-K (or H?)	LTAO + wide GS or GLAO or SIGHT-style + high throughput

4. Roadmap

The following table provides one possible roadmap for the implementation of the recommended 2035 AO science strategic plan. Further iteration on this starting roadmap will occur based on feedback and additional information, including funding realities. This roadmap assumes implementation of (1) an ASM for science with FOBOS, LRIS-2 and MCAO-fed instruments on Keck I, (2) an LTAO/MCAO system for science with Liger (R to K-band) and a visible IFS/imager (U to I-bands) on Keck I using the ASM as the ground-conjugated deformable mirror, and (3) a high contrast NGS/LT AO system on Keck II for technology development and for science with NIRC2, NIRSPAO (initially only; reconsider after SCALES moves to NIRC2 location), SCALES, HISPEC and a narrow-field visible imager. Both AO systems would provide a fiber feed for a visible EPRV instrument and other fiber-fed instruments. An ASM on Keck II could also be considered if driven by appropriate science instrumentation.

CY	Keck I (enhanced seeing)	Keck I (high sky coverage)	Keck II (high contrast)
2022	TNO study & UH ASM demo	KAPA commissioning	DM ordered, HAKA SDR
			Vis lucky imaging camera demoed
			KPIC Phase II operational
			LFC operational
2023	GLAO SDR	KAPA LTAO operational	NIRC2 electronics upg. complete
		Visible IFS/imager SDR	PCU & polarimeter installation
			PSF-R operational for NIRC2
			Vis lucky imaging mode operational
			High contrast testbed SDR
2024	ASM design/fab contract placed	Visible MCAO System SDR	Low order PyWFS mode for LGS AO
	GLAO PDR	KAPA PSF-R operational	Post-dawn observing operational
		Visible IFS/imager PDR	High contrast testbed PDR
2025	FOBOS + GLAO WFS PDR	Visible MCAO System PDR	HAKA high-order DM operational
	GLAO RTC contract placed		SCALES commissioned
			HISPEC commissioned
2026	LRIS2 + GLAO WFS PDR	Visible MCAO System DDR	Visible science imaging operational
			NIRSPAO modes decommissioned
	GLAO DDR		High contrast prototypes/demos
2027	Spare top end modified for ASM	Liger commissioned	Visible EPRV instrument PDR
			High contrast testbed implemented
2028	ASM factory acceptance	MCAO LGS facility installation	High contrast prototypes/demos
			Move SCALES to NIRC2 location
2029	ASM I&T off telescope	OSIRIS removal	Visible EPRV instrument DDR
	ASM commissioning w/ AO WFS		High contrast prototypes/demos
2030	ASM commissioning for non-AO	AO bench removal	High contrast prototypes/demos
	HIRES removal	MCAO AO system installation	
		LTAO system comm with Liger	
2031	FOBOS commissioned at RNAS	MCAO comm w/ ASM & Liger	Vis EPRV fiber feed commissioned
		Visible IFS/imager commissioned	
2032	FOBOS commissioned with ASM		Vis EPRV instrument commissioned
	LRIS de-commissioned		
2033	LRIS2 commissioned	Vis EPRV fiber feed commissioned	
2034	LRIS2 commissioned with ASM		
2035			