Technology Maturation for High-Contrast Exoplanet Science at W. M. Keck Observatory[1]

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Introduction: One of the most technically challenging US-ELT science goals is articulated in Astro2020: "to detect, image, and characterize temperate rocky planets around low-mass stars, [and] measure their atmospheric compositions including searches for oxygen." The arrival of 30-m-class telescopes alone will not enable this science — a gulf of several orders of magnitude separates the performance of modern high contrast imaging systems from the performance required for temperate planet imaging and spectroscopy with the ELTs. As the home of two precursor TMT exoplanet science instruments (HISPEC and SCALES), and the only segmented 10-m class telescope with an adaptive optics system, Keck is uniquely positioned for end-to-end demonstrations of the high contrast technologies required for habitable-zone exoplanet science with the ELTs.

In this whitepaper, we describe a three-part infrastructure plan for high-contrast technology maturation at WMKO, summarized below. Because each component of the proposed plan involves the expertise and engagement of the Keck AO team, the foundation of this work is an expansion of that team's personnel and resources.

Proposed Infrastructure	**Community Impact**
An open-source, sky-validated simulation of the Keck AO system and high-contrast instrument suite	The Keck community will be able to chart a credible technological course for achieving specific contrast ratio milestones.
A dedicated high-contrast technology maturation instrument that can operate simultaneously with science instruments	The Keck community will have a platform for rapidly developing new technologies on sky, while balancing the needs of science instruments.
A high-contrast technology focused WMKO mini-grant program that supports Keck AO personnel time and on-sky time	The WMKO and university-based Keck communities will have frequent opportunities to partner for on-sky technology development efforts.

Proposed Infrastructure #1: Simulation Capabilities

The first step in any Keck AO upgrade proposal is to refer to the error budget spreadsheet that is maintained by the AO team to understand how the proposed upgrade will impact the final Strehl ratio and FWHM. Currently, this approach has two limitations: 1) the values in the error budget are still in the process of being validated, and 2) the spreadsheet refers to the Strehl ratios and FWHM achieved by the Shack-Hartmann wavefront sensor, and has not yet been expanded to include new wavefront sensing capabilities at Keck II or to output contrast estimations. We propose to evolve today's error budget spreadsheet into an open-source simulation tool that will allow the community to predict the impact of new AO and high contrast

[1] This whitepaper addresses all five of the questions posed in the whitepaper call.

technologies on the system's contrast performance. The first step in this effort will be to construct an error budget in which each term has been validated via daytime and/or on-sky experiments. Next, the error budget will be applied to an optical-propagation-based simulation tool that can reproduce the total wavefront error (WFE) and WFE power spectral density distributions observed on sky. Then, the simulation will be upgraded to also reproduce the raw and post-processed contrast ratios achieved by the observatory's high contrast science instruments on-sky. These steps should be pursued as a collaboration between observatory staff and university partners. Finally, the observatory would allocate personnel and bench/sky time to maintain the simulation tool as an on-going resource for the community.

Proposed Infrastructure #2: A High-Contrast Technology Development Instrument
We propose that the community develop a new Keck II AO-fed instrument that is dedicated to supporting rapid technology maturation for high contrast imaging. This instrument should include both visible and near-IR wavelength subsystems — this flexibility is required for supporting exoplanet imaging in different wavelength regimes as well as allowing the instrument to operate simultaneously with upcoming high contrast science instruments such as HISPEC and SCALES. Each of these subsystems would be equipped with two high speed, low noise detectors, one at a pupil plane and one at an image plane. Each subsystem would have space for testing new apodizer, focal plane, and Lyot plane masks, polarimetric masks, as well as open space for visiting sub-systems such as new wavefront sensors or new detectors. The instrument would be equipped with its own deformable mirror to support "second-stage" AO corrections and its own set of atmospheric dispersion correctors (unless these are installed upstream as an upgrade to the Keck II AO system). Proposals for daytime and sky access to this instrument would not be handled through the standard institutional TAC process. Rather, they would be separately allocated as part of a dedicated high contrast mini-grant program (see below).

Proposed Infrastructure #3: An Expanded, Focused Mini-Grant Program: Current Keck mini-grants are "for efforts and equipment costs for either new tools and techniques to improve the observatory scientific productivity or minor hardware capability enhancements." Inspired by this existing program, we propose a new mini-grant category that focuses on high-contrast technology maturation. There would be two classifications of submissions to this program: 1) proposals to collect data using the high contrast technology development instrument in an existing configuration during the day or on sky (e.g. to characterize speckle statistics), and 2) proposals that request time from WMKO staff members and sky time with the high contrast technology development instrument to implement new software or hardware. The proposers would fund the hardware and university personnel time, while the mini-grant program would fund the WMKO personnel time and make sky time available. The mini-grant program would have its own dedicated pool of nights and would be administered either by its own TAC or by a subset of existing TACs. Ideally the sky time and the TAC would draw on the resources of the full collaboration, rather than just one institution. The program would foster on-going collaborations between the Keck community and the WMKO staff in achieving the community's shared science goals for next-generation facilities.