W.M. Keck Observatory Next Generation AO System Build-to-Cost Review
Committee Report
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Committee

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1. Introduction and Summary

Following the System Design Review for the W. M. Keck Observatory (WMKO) Next Generation AO (NGAO) System, a group consisting of the UCO Director, COO Director, WMKO Directorate and SSC Co-Chairs directed the project team to conduct a "Build-to-Cost" study and determine whether the original NGAO System Concept could be reconfigured within an overall cost cap of $60M (in "then-year," or as-spent, dollars), while remaining scientifically competitive and technically viable. The cost cap is to include suitable science instruments for NGAO as well as the AO system. The NGAO team was to report the results of this study no later than the April 2009 SSC meeting. The Review Success Criteria were then defined by the team, and approved by the Board, as follows:

1. The revised science cases & requirements continue to provide a compelling case for building NGAO
2. We have a credible technical approach to producing an NGAO facility within the cost cap and in a timely fashion
3. We have reserved contingency consistent with the level of programmatic & technical risk

This report documents the findings of the external Review Committee for the Build-to-Cost review which presented and discussed the results of the resulting study. The review was held on March 18th, 2009, at the LAX Westin Hotel in Los Angeles, California.

The Committee strongly congratulates the NGAO team for a concise, convincing presentation which demonstrates that the above criteria for further development of the system have been very effectively met. We recommend that the project is now ready to proceed with the Preliminary Design Phase to continue the development of the updated system concept, with no further changes in overall scope or basic architecture either necessary or desirable.

The Committee's more detailed comment upon each of the above success criteria are summarized in the three sections below.

2. Science Case

The revised NGAO system concept developed for the B2C review eliminates the separate optical path for a wide-field science instrument, and preserves the narrow-field optical path for high-resolution and high-contrast science at visible and near infra-red wavelengths. Sky coverage is also (to first order) fully maintained. The preserved science cases seem very compelling. The Committee finds the elimination of the wide-field d-IFU capability tolerable, particularly as the on-axis IFU will still enable the same observations to be made (although without the multiplex gain in observing efficiency that would be provided by the d-IFU). We are unable to identify any other design change to bring NGAO within the cost cap with such a modest impact upon overall scientific capability.

NGAO in Relation to TMT and JWST

The B2C Review material included a comparison of the scientific capabilities of NGAO, JWST, and early-light Narrow Field IR AO System (NFIRAOS) for TMT. The committee found the comparison of NGAO with JWST very compelling, particularly with regards to sensitivity in J and H bands (between the OH lines) and spatial resolution at all wavelengths. The comparison with TMT is less conclusive, given TMT's larger aperture diameter and the fact that the current estimates for the image quality to be provided by NGAO and NFIRAOS (expressed in terms of either RMS wavefront error or Strehl ratio) are fairly similar. In spite of this, there remain a variety of valuable synergies between TMT and NGAO which should be highlighted and explored further.

NGAO will provide unique science at least until the advent of TMT and NFIRAOS, a window of three years according to current (and hardly infallible) program schedules. It is consequently very desirable that the current development schedule for NGAO be maintained, or even accelerated if possible. Regardless of schedule details, NGAO will also provide a good learning platform for AO techniques that will be needed and used by TMT and provide significant risk reduction learning advantages (tomographic wavefront reconstruction, laser hardware, laser fratricide, “sharpening” of tip-tilt stars, etc.).

NGAO will also serve as an essential high angular resolution "feeder" telescope for TMT. For instance, AO survey programs with NGAO could observe many objects in the near-IR and far-red (e.g. Y and J bands) at roughly three times the resolution of JWST, and with more telescope time available than may be possible with either TMT or JWST. The most appealing objects would then be natural targets to follow up with TMT, e.g., at higher resolution or with TMT AO-fed spectroscopy (of targets studied with NGAO only by imaging).

Work to compare and reconcile the NGAO and NFIRAOS wavefront error budgets should continue. Keck is 10m, while TMT is 30m. For many components of the AO system, it should be possible to obtain better performance at Keck than at TMT for a given effort. For example, a 64x64 DM gives much better wavefront sampling on a 10m than a 30m. Some error terms will scale differently, such as the wavefront error due to LGS wavefront sensor measurement noise, and characteristics of the local wavefront disturbances introduced by the two observatories may be different as well. To the Committee, it still seems very possible that NGAO may out perform NFIRAOS with respect to some performance metrics under some conditions (e.g., enclosed energy in a 20 milliarcsecond pixel at 800 nm under conditions of good seeing and high sodium column

density). Such cases may provide NGAO with an "observing niche" well beyond the construction and commissioning of TMT, and identify possible directions for future AO system upgrades for improved performance at shorter wavelengths.

3. Technical Approach

The overall technical approach for NGAO presented at the B2C review is a sound simplification of original SDR concept. In particular, the elimination of the wide field science channel has enabled a variety of further technical simplifications which reduce both risk and cost. Some of these simplifications include:

- A simplified laser guide star asterism with reduced laser power;
- Size reductions for some important optical elements;
- Smaller computation and memory requirement for the real-time control system (thanks to the reduced field-of-view); and
- A reduced number of mechanisms to implement and control.

Several independently derived changes have also helped to reduce costs, including:

- Mounting the lasers on the telescope elevation structure;
- Eliminating the requirement to interface NGAO with OSIRIS;
- Reducing the number of lenslet arrays and beamsplitter arrays, at the expense of slightly reduced performance in natural guide star (NGS) AO mode; and
- Eliminating the Truth WFS located in the narrow-field optical path[1].

The Committee concurs with all of these changes, which bring the estimated cost of the adaptive optics component of NGAO to $47M in then-year dollars (including contingency). The $13M remaining within the overall $60M cost cap is available for the associated science instrument.

The Committee recommends that these science instruments now deserve increased attention during the Preliminary Design Phase. Beyond overall development of the instrument concept, the committee recommends:

- A more detailed cost trade-off between combined and separate instruments for the imaging and integral field spectrograph observing modes;
- More detailed study of imaging capabilities and requirements, particularly the current choice of a single plate scale;
- The options and costs of implementing a fixed pupil mode for high-contrast applications.

The option for adding multiple instrument ports at a later time should definitely be maintained as the overall system design progresses. Future design upgrades to enable improved performance at shorter wavelengths below 800 nm should also not be precluded.

4. Contingency

The NGAO team has developed their contingency using a comprehensive, bottoms-up approach to assessing the cost risk in each NGAO subsystem and component. The

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1This last simplification has also led to the introduction of an important new subsystem concept, the "One Truth Wavefront Sensor" (see slide 59 of the B2C presentation). This is in contrast with TMT, where a multiplicity of Truths is still permitted.

Committee believes that the overall contingency included within the total $60M cost cap should be sufficient for a well-managed program based upon a build-to-cost philosophy, but we also recognize some persistent uncertainties which are difficult to characterize and manage solely in budgetary terms. Many of the AO components to be implemented in NGAO will appreciably advance the current state-of-the-art, including (at least):

- High power sodium guide star laser operating in a variable gravity environment
- Order 64x64 MEMS with relatively large stroke, very high repeatability, and very high actuator reliability.
- A real-time controller based upon novel processing hardware and control algorithms.

The Committee recommends that functional contingency options should be developed for (at least) these components, where a budgetary contingency may not fully describe the risks involved. The NGAO risk register should be augmented to identify decision points and criteria for addressing these risks. For example, what is the latest point at which the laser location can be moved back to the Nasmyth platform if laser performance with a variable gravity vector remains unacceptable? Would it be possible to begin operations using a 32x32 MEMS if the final 64x64 device is not yet available? The status of the highest-impact risks should be presented and discussed at each review.

The committee also recommends that an explicit schedule contingency should be defined as the NGAO schedule is developed. The Committee was concerned that the six months allocated for lab integration and test of the system may not be adequate to address unexpected surprises or required rework.

5. General Remarks

As part of the Preliminary Design Review process, the Committee encourages the project to consider a phased implementation schedule in order to maximize the probability of achieving an initial deployment of NGAO by 2015, if not somewhat sooner. Some of the options that could be considered include the phased introduction of lasers and/or the low-order wavefront sensors (and their associated point-and-shoot MOAO subsystems). For example, high sky coverage is an important science requirement for NGAO, but phasing this capability over several years might be a compromise worth considering.

Finally, a few specific comments from the committee members are summarized below:

- Double-check that all zenith angle effects have been correctly accounted for when estimating NGAO performance for observations of the Galactic Center
- Consider whether less costly DM options may be sufficient for “sharpening” NGS images for the low-order wavefront sensors.
- Why is the imager FoV so much larger than required for the various science cases, and also much larger than the field corrected by single-conjugate Laser Tomography AO?