Keck Adaptive Optics Note 593

Next Generation Adaptive Optics: Response to NGAO SDR Panel Recommendations

P. Wizinowich, R. Dekany, C. Max, D. Gavel
May 5, 2008

We thank the Review Panel for applying their expertise, experience and time to reviewing the NGAO system design. We intend to utilize the Panel's recommendations (KAON 588) to further develop and strengthen the NGAO program during the Preliminary Design.

In addition to the recommendations, we appreciate the committee's positive affirmation of our approach in a number of areas including the following quotes from the Executive Summary:

- "Keck Observatory has assembled an NGAO team with the necessary past experience … needed to develop the Next Generation Adaptive Optics Facility"
- "It is a sound, though aggressive, strategy to be among the first observatories to develop and depend on advanced laser guide star AO systems as a means to maintain Keck's leadership in ground-based observational astronomy for the immediate future"
- "NGAO is an important pathfinder for the 2nd generation of AO based instruments for future Extremely Large Telescopes"
- "The NGAO Science cases are mature, well developed and provide enough confidence that the science … will be unique within the current landscape"
- "The science requirements are comprehensive, and sufficiently analyzed to properly flow-down technical requirements."
- "The predicted Sky Coverage for NGAO is essential and should remain a top requirement"
- "The error budget is sufficiently developed at this stage of the project and meets the science requirements."
- "The system technical requirements are clear, complete and well documented."
- "The performance predicted for the conceptual design meets the scientific and technical requirements."
- "The project's approach to management and decision making for the system design phase was appropriate and cost effective. The System Design deliverables are complete. For the preliminary design phase, the NGAO proposed management structure seems appropriate."
- "These design drivers are well justified by the key science cases which themselves fit well into the scientific landscape."
- "The project has adequately defined the objectives and task plan for the next design phase."

- "The review panel recommends proceeding with the Preliminary Design phase because of the appealing science cases of NGAO and time constraints for the competition."

The remainder of this document summarizes the Review Committee's recommendations and our initial response to how we would endeavor to utilize these recommendations during the Preliminary Design.

We have divided the recommendations into the following twelve categories related to science requirements (1,2&3), systems engineering (4,5&6), science instruments (7&8), risk (9), planning (10&11) and management structure (12).

Each of the bullets (a, b, c, etc.) below is a direct quote from the Committee Report. The bullets proceeded by a "Q" correspond to the reviewer's response to specific questions in the charge to the reviewers. The other bullets come from the executive summary. The recommendations are followed by the NGAO management team's responses.

1. Complete the science cases.
   a. Q1: For the PDR, those which are less complete should be brought up to achieve a uniformly high level. Two areas which are apparently omitted and might deserve some development were crowded field stellar populations and AGN, specifically the accretion disk, obscuring torus and inner jets.

   Response: We agree. This work is scheduled in the MS project plan that was presented at the SDR.

2. Requirements development.
   a. The IFU spaxel size and Ensquared Energy requirements should be confirmed using a representative set of High-Z galaxies: the review panel recommends considering the potential scientific advantage of having several spaxel sizes.
   b. Q1: To take full advantage of the angular resolution gain over JWST it will be necessary to offer a spaxel scale that Nyquist samples the point spread function.
   c. The PSF knowledge accuracy needs to be carefully specified from both the astronomical and technical view point.
   d. Q2: Among the open technical requirements that will be important to understand soon are the Point Spread Function (PSF) requirements.
   e. The requirements and analysis at the subsystem level … need additional work.

   Response: We agree. The d-IFU requirements will be further evaluated as part of the NGAO science requirements and the development of the d-IFU science instrument concept. The PSF requirements and related design work are scheduled in the MS project plan that was presented at the SDR.

3. Consider L' imaging.
   a. Q2: There may be significant scientific gains for science programs involving anything that is dusty, young or old from considering L' imaging, as the AO

performance should be improved at these longer wavelengths and a cooled AO system will trump all the work that has been done with existing AO systems. Due to choices of dichroics, it has been designed out of the first generation TMT system and therefore would expand the uniqueness of the NGAO system.

Response: The science evaluation performed for the NGAO proposal ranked L- and M-band imaging as the fifth priority for single object instruments. L' was also given a lower priority partly because JWST will have much higher sensitivity at this wavelength. Given this ranking we did not spend time on further evaluating this science during the system design, however we did make sure that the system design did not preclude future implementation of this capability. Given this recommendation we will work with the community during the preliminary design to determine if L'-imaging should be given a higher priority.

4. More performance modeling and validation.
   a. the detailed design will require even more attention to maintain an accurate and reliable error budget during the next phases of the project. In particular, the panel believes special attention is needed in the areas of real-world laser power requirements and minimizing implementation errors associated with the Multi Object AO system's open-loop control of MEMs deformable mirrors. The panel recommends increasing emphasis on simulations and validations with independently developed codes.
   b. The expected performance of MOAO should be confirmed to the accuracy level required by NGAO, for instance, using the Villages on-sky experiments.
   c. Q2: development of a comprehensive simulation tool to fully evaluate system performance vs. critical system parameters for each science area. This tool should include the expected instrument sensitivities and uniformity, the expected PSF and Strehl, and very importantly – the inclusion of time variable effects such as jitter and seeing.

Response: We will look at what additional performance modeling, evaluation and anchoring of assumptions should be included during the preliminary design. We will in particular focus on those topics that will reduce risk.
We would like to compare the NFIRAOS and NGAO error budgets, and the extent to which they have been anchored with simulations or data, in order to understand where additional simulations or improved parametric tools would benefit NGAO.
We will continue to learn from both the planned Villages and LAO experiments.

5. Component performance assumptions.
   a. the sodium photon return, the LGS wavefront sensor performance and possibly the low order wavefront sensor performance assumed seems optimistic and will require careful analysis during preliminary design.
   b. Q2: More work is needed to (a) assess the expected photon return vs. laser power at zenith for a range of different sodium column densities, and (b) double-check the existing results on the relationship between photon return and the LGS WFS measurement error due to noise.

c. Q3: more work is needed to validate these results and obtain similar levels of performance from reliable, observatory-class components. Some of the requirements in this category include:
   - take a careful look at what is realistic in terms of the return signal. Compare Keck NGAO estimates with what TMT has done recently (they are now using ~one-half of the original return values).
   - … relies critically on LGS wavefront sensor and near-IR tip tilt sensors … These sensors need to have been tested to the required performance by the end of the PD phase.
   - The performance assumes that the open loop operation of the MOAO MEMs mirrors can achieve the assumed residual errors. This is a high risk area since these elements need to be calibrated for non-common path aberrations … corrected for non-linear response and gain effects … possibility of registration errors
   - 32x32 and 64x64 MEMS with large (4 micron) stroke, calibration errors on the order of 30 nm and few or no dead actuators.

d. Q3: the expected performance of these components should be sufficiently well known at the end of the preliminary design phase … to allow long lead items to be purchased. … breakpoints exist where simpler and cheaper design concepts become the preferred approach because they will perform at least as well for less cost and at less risk.

e. Q3: main concerns …: 6 channels of MOAO using 32x32 MEMs devices operating in open loop, adequate signal from the sodium layer for 64x64 wavefront sensing, low noise performance of the detector arrays for both LGS wavefront sensing and TT sensing in the near IR. While preliminary open loop control of MEMS on the sky are encouraging … needs to be followed full scale lab and on-sky demonstrations to measure residual errors.

f. Q3: designs and performance characteristics of the critical AO hardware components should be known by the end of the Preliminary Design Phase to enable long lead procurement to begin.

Response: We will refine our assumptions based on our best understanding of the type of laser and the corresponding sodium return on Mauna Kea. We plan to evaluate several proven LGS WFS detector options during the PD and will assess the system implications and performance based on this choice. We plan to further demonstrate and document the candidate LOWFS detector performance (in collaboration with the Caltech SNAP team) and utilize these results in our performance modeling. We will also perform further work to understand the performance dependence on these assumptions. We will be following the MEMS demonstration and characterization work at the LAO. We agree that it is important to be in a position to place long lead procurements by the PDR and believe that our PD plan supports this.

6. More systems engineering.

a. More emphasis should be given to Systems Engineering activities and a comprehensive Assembly Integration and Testing plan

b. The review committee recommends appointing a full-time System Engineer for the Preliminary design phase.
c. Q7: Systems engineering activities to accurately overview the design of the Adaptive Optics, multi-laser guide star facility and the interfacing/operation with the focal plane instruments should be increased. It is recommended to dedicate a full time system engineer already for the preliminary design phase.
d. Q7: Detailed plan for the Assembly, Integration, Testing and Commissioning of the NGAO facility is essential to ensure that the NGAO design is compatible with the system testing approach and the list of tasks and amount of work to be performed is clearly identified.
e. Q7: The planned human resources dedicated to AIT and commissioning plan activities during the preliminary design phase is underestimated.

Response: We will examine whether other activities can potentially be reduced to increase the systems engineering activities during PD phase. We had consciously moved the further development of the Assembly Integration and Testing Plan from PD to DD phase due to funding availability. We will reconsider this decision in light of the reviewer recommendation. We would very much like to have a full-time System Engineer and plan to implement such a person by the time of the PDR, and preferably earlier.

7. Re-evaluate benefit/cost of d-IFS.
   a. the review panel believes that the actual cost/complexity to science benefits of the required IFS multiplex factor of 6 should be reassessed.
   b. One descope option not affecting dramatically the science (at the expense of telescope time) seems to be the reduction of IFU channels. We believe this will significantly reduce cost and complexity.
   c. Q1: if the inclusion of multiple deployable IFUs become a major difficulty in cost, schedule, complexity and uncertainty for the NGAO project, this incremental efficiency gain from multiple IFUs needs to more thoroughly justified.

   Response: We agree that the scientific case for the d-IFS needs to be carefully evaluated versus the cost and complexity. At minimum we will re-evaluate the science case, including potential trades between the number of IFUs and a single (or fewer) more sensitive IFU(s).

8. Perform science instrument conceptual designs.
   a. an estimate of the instrumentation and associated run-out cost and schedule in addition to the NGAO project cost and schedule must be included to assess funding shortage risks, schedule and human resources conflicts and scientific priorities.
   b. Q7: We recommend starting the conceptual design activities of the instrument and defining interfaces between NGAO and the focal plane instrument early in the NGAO preliminary design phase.

Response: We agree that the instrument conceptual designs need to be developed in order to more fully understand the science cases, requirements, interfaces, costs and schedules. Our current plan includes some work on the science cases, requirements and interfaces, but the required level of design integration will require additional funding for the instrument designs. This is an issue that needs further discussion with our Directors.

9. Complete the risk register and develop a risk mitigation plan.
   a. develop a more detailed risk mitigation plan – beyond that shown in the technical and programmatic risk matrices including decision trees and sublevels.
   b. reassess the concept choices with a goal to reduce the complexity and risk of NGAO keeping the key science objectives. In particular, the potential decrease of complexity brought by the reduction of IFU numbers (if scientifically acceptable) and the possibility to have only one (or two with NGS) AO optical paths for all focal plane instruments might be considered.
   c. Q3: The NGAO project needs to coordinate very closely with all of these external activities to avoid being surprised by schedule slips or performance shortfalls. It should obtain "ownership" of its top 1-2 technology development requirements if at all possible.
   d. Q3: We would recommend a more pro-active stance in the development of subsystem components (especially detectors and lasers) during the preliminary design phase of the project.
   e. Q3: cannot find MOAO performance listed as a risk … The open loop control issues in MOAO include the correction of non-common path errors and the maintenance of DM-to-WFS pupil registration, not just the linearity of the DM and the WFS themselves. Current demonstrations with 12x12 MEMS need to be scaled up to order 32x32 to demonstrate that MOAO calibration errors still remain in the 50-60 nm RMS range. We also recommend a careful examination of the error budget associated with details of the NGAO MOAO design concept, and a risk mitigation plan that demonstrates required performance in the lab of a prototype channel of the MOAO design.
   f. Q3: We recommend developing a detailed risk mitigation plan (that builds on the mitigation column in KAON 510 and 566) to show in a waterfall fashion the expected reduction of risk with time to an acceptable level at each major milestone.
   g. Q7: the project should be more proactive in controlling technical risk by funding development for the highest risk items. There appears to be no budget for this purpose. We also feel that in some areas (laser development for instance) it would be useful to collaborate with other organizations (e.g. TMT) to develop a common set of requirements.

Response: We will develop the recommended more detailed risk mitigation plan (as opposed to the presented list of risks and mitigation strategies) during the preliminary design. We also intend to look for additional opportunities to jointly work with other groups to reduce risk. The expected funding profile makes it difficult for us to obtain sole "ownership" of technology development requirements. However we do intend to collaborate or participate in consortia to take a pro-active stance in the development of such items as lasers, detectors and MEMS. Where funding limitations preclude our directly buying down risk, we will further develop alternative technologies and understand their implications to system performance.

With respect to the MOAO performance risk: We broke the MOAO risks into the areas of inadequate tomographic reconstruction (technical risk item 5) and inadequate MEMS performance (technical risk item 17). We did not include wavefront sensor calibration and pupil registration in the risk table (although these items are included in the error budget) since we ranked their likelihood and consequence to be relatively low. We will further address these risks through experiments and opto-mechanical design.

10. Produce a staged implementation and descopes plan.
    a. it is essential that the NGAO team develop a fall back plan and/or a staged implementation plan in case of funding shortage. In particular, the risk associated with the availability of the laser, sodium photon return flux, practical implementation of MOAO, point spread function accuracy and estimate, detector readout noise, and interface/requirements of the focal plane instrumentation need further analysis and a detailed, phased mitigation plan.
    b. Staged implementation might not be very cost effective but should be carefully investigated during the preliminary design phase.
    c. Summary & Q7: we recommend using the first 6 months of the Preliminary Design phase to investigate descope possibilities and phased implementation aiming at reducing NGAO complexity, cost and risk to an affordable level possibly validated by an internal delta review.
    d. Q3: Fallback options should also be further developed as part of the plans for addressing possible deficiencies. Are there intermediate designs … that could be implemented if the current laser, detector, MEMS, or MOAO requirements cannot be met within the desired schedule or available budget?
    e. Q3: Detailing the implementation of a MCAO option is one recommended fallback option
    f. Q3: a fallback option for high Strehl … may be more challenging. But reducing the number of … laser guide stars to a minimum and driving the 64x64 MEMS in closed loop … may be one possible approach. Other 64x64 wavefront correctors with a modestly larger inter-actuator pitch could be considered in this case
    g. Q6: We strongly advise that a more predictable, phased implementation approach be developed and adopted in the Preliminary Design phase.
    h. Q6: An alternate approach would be a phased development and implementation - to spread out the implementation and testing. This longer period of procurement could provide more efficient use of key technical personnel. In addition, the staged approach would provide continuous upgrade capability to WMKO providing more immediate science return. One example of this is the cooled AO enclosure which would immediately benefit the current capabilities – assuming the existing AO is made to operate in the cooled environment. A second example is the high power lasers – these devices have major procurement/vendor uncertainties which could be usefully explored with an early implementation

strategy and if success is achieved early, one of the lasers could greatly benefit the existing system.

Response: We agree that staged implementation plans need to be developed in detail during the first six months of the preliminary design. We will work with our Directors to define two or three variations that we will then develop in detail.

11. Re-examine the cost and develop a schedule.
    a. Based on the cost and schedule of past and planned projects of lower or similar complexity, the review panel believes that the NGAO project cost and schedule are not reliable and may not be realistic. Contingencies are also too tight. In particular, the time of 18 months allocated for the manufacturing and assembly and 6 months for integration and test, is probably optimistic by a large amount.
    b. Q3: The project's schedule and AIT/commissioning plan should avoid attempting to implement too much, too quickly.
    c. Q4: The budget book showed some pages not complete or no estimates for the words in the tasks - a detailed review and audit should be conducted – unless this has already been done.
    d. Q4: during the PD phase both the cost estimate and schedule be further refined to more conservatively reflect the challenge of implementing the NGAO system.
    e. Q4: The contingency estimate is too lean and should be refined to fully reflect the technical and market risks inherent in the system.
    f. Q4: The schedule should be refined to more fully reflect the numerous procurement, technical, integration and commissioning risks in such a challenging system:
        - 22 months to complete a preliminary design is realistic
        - +24 months to complete the detailed design is realistic
        - +18 months for Subsystem development and testing – the laser system needs more time than this and needs to be started much earlier
        - + ~3 months of lab integration and testing – is too short a time before the system is moved to the telescope
        - + 6 months of telescope integration – is too short by as much as a factor of two.
    g. Q4: The contingency for the laser system development at 18% is probably not adequate. Based on guidelines from TMT's process and the state of development for what is assumed about the laser return, this number should be of the order of 30% or even more.

Response: We will develop another level of cost estimation during the preliminary design. During system design, we considered project costs composed of hundreds of tasks and specific procurements. During PD, we will revise the basis of estimate to move more items from engineering judgment and analogy estimates to direct vendor quote basis. It would be very helpful to obtain the next level of cost information for the TMT NFIRAOS project in order to better understand the reasons for the differences in our cost estimates.

With respect to item “c” we believe that the budget sheets are complete; our choice to produce cost sheets for each WBS in each of the four project phases resulted in a number of blank sheets (for example the subsystems become part of the system during the FSD phase resulting in no subsystem work during the DC phase).
We will develop an implementation schedule during the preliminary design taking into account the complexity of the system and the implementation challenges.
With respect to item “f”, we somehow mis-communicated the lab and telescope I&T times to the reviewers. The lab and telescope I&T durations are currently 6 and 18 months, respectively; we will produce a more detailed plan to determine the required durations. We agree that there are long lead procurements, such as the laser, that need to begin during the detailed design phase.
We will re-evaluate the contingency (currently 22% overall) during the preliminary design. The laser cost estimate and contingency will be part of this process.

12. Implement management structure changes.
    a. The role and authority of the Project Manager, Project Scientist, System Engineer and Configuration Control Board should be clearly described and agreed upon in the management plan.
    b. Q7: We recommend reviewing the WBS and schedule associated with each element to make a more consistent picture.
    c. for the Detailed Design phase and beyond we suggest that the WBS, organization and management approach be fully oriented to deliverables and to responsible managers for each deliverable as opposed to the current focus on institutional setting and project phase.
    d. Q5: The WBS should be organized strictly along the lines of deliverables with the DD phase and subsequent phases accommodated under these deliverables. Thus the level 2 WBS elements should be Project Management (with System Engineering under PL as a Level 3 element), each of the subsystems (AO, Laser, etc. taken through Lab Integration, System Integration, Transition to Operations.
        - System Engineering is a technical staff function reporting to the PM who holds system responsibility.
        - The organization chart should have managers responsible for each of these Level 2 and then Level 3 elements.
        - There should be a single Project Manager to whom all Level 2 managers report and who chairs the CCB (which is advisory to the PM).
        - The CCB process should be defined into hierarchies of decision levels corresponding to WBS levels, and budget and schedule changes as well as interface changes. This hierarchy should define decision authorities.

Response: We will clearly identify roles as recommended in item a.
We will make use of this input in developing the management structure for the post-preliminary design phases of this project. Organization of the CCB process is already an identified PD phase task (WBS 1.3.3.7).