Keck Adaptive Optics Note 473

Keck Next Generation Adaptive Optics System Design Phase Project Report #2

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1. Narrative

This report provides an update to Project Report #1 that was submitted to the Observatory Directors on Jan. 19, 2007. The next project report will be submitted in June.

1.1 Summary

The emphasis during the last two months has continued to be on understanding the major design drivers through a process of iteratively developing the science case requirements and the performance budgets to meet these requirements. In parallel with this effort, work has continued on a number of trade studies in support of the performance budgets and the design choices that will need to be made.

In the last project report we reported that progress had been slower (and costs have therefore been lower) than anticipated in the SEMP due to delays in ramping up personnel and processes on this project and that this ramp up was nearing completion. Overall the system design phase efforts continue to be behind schedule although good progress is being made and overall we are now at reasonable staffing levels versus the plan. We are in the midst of a scheduled mid-year replan that we intend to use as one tool in addressing the schedule slip. Our intention continues to be to deliver the system design within budget and schedule

1.2 Technical Status

The technical status reported below is organized according to the major WBS elements in the SEMP. Only the currently scheduled WBS elements are included.

1.2.1 System Design Phase Management (WBS 1)

The NGAO Twiki site (http://www.oir.caltech.edu/twiki_oir/bin/view.cgi/Keck/NGAO/WebHome) continues to be heavily utilized to manage and document the project.

Two team meetings have been held since the last report and our next team meeting will occur in April.

The scheduled mid-year replan has recently begun. We will be looking for ways to better focus our efforts and to regain our schedule loss (primarily due to a slower than planned ramp up of personnel).

1.2.2 System Requirements (WBS 2)

The product of this WBS is a System Requirements Document (SRD), including both science and observatory requirements, which will be used to guide the NGAO design. The first releases of the Science Case Requirements Document (SCRD) and the SRD have been completed since the last report.
Science Cases (WBS 2.1.1 to 2.1.3) and Science Case Requirements Document (WBS 2.1.4). Release 1 of the SCRD is complete. An NGAO science meeting was held at the CfAO on March 28 which will

provide good input to Release 2 of the SCRD. The presentations are posted at http://lao.ucolick.org/twiki/bin/view/CfAO/NGAOScienceAgenda and included discussions of asteroid shape and multiplicity, planets around low mass stars, Galactic Center astrometry and high redshift galaxies. Le Mignant has assumed the lead on documenting the observing scenarios using an observing scenarios spreadsheet template. He has started this process by working with Marchis on documenting the solar system observing scenarios.

Observatory Requirements (WBS 2.2) and System Requirements Document (WBS 2.3). Release 1 of the SRD is complete. Some initial input for version 2 has been received. Reviewing these requirements will be a topic for team meeting 6.

1.2.3 Performance Budgets (WBS 3.1.1)

Investigations of the underlying key performance drivers for NGAO continue. The performance budget research phase is largely ending and the performance budget technical reports are in the process of being produced.

The progress and status of each of the performance budget elements is summarized below.

Model Assumptions (WBS 3.1.1.1). The telescope dynamic and static wavefront error conclusions are currently being documented in a KAON which will be completed shortly. The sodium return versus laser format comparison has been completed as a web page for the LGS community.

Model/Tool Validation (WBS 3.1.1.2). Good progress has been made at the LAO in getting an operational tomography laboratory experiment.

Transmission and Background Budgets (WBS 3.1.1.3 & 3.1.1.4). The framework for a detailed transmission and background flux modeling has been completed, allowing the investigation of background flux impact for a realistic NGAO system at different spectral resolutions. This model has been validated against observed NIRC2 backgrounds. This tool will allow rapid evaluation of different optical design choices, as they impact transmission and background flux.

Wavefront Error and Encircled Energy Budgets (WBS 3.1.1.5 & 3.1.1.6). The detailed wavefront error budget tool is continuing to be refined. The latest version has been used by Wizinowich to recreate the performance seen for Keck LGS AO and to predict the relative benefit of several potential upgrades to Keck I AO. Dekany has also incorporated a detailed Ensquared Energy model to this tool, estimating in a simple way the residual spatial frequency power spectrum of each wavefront error term. Using a four-bin model of residual error spectrum, we can now make reasonably accurate and fast iterations on IFU signal-to-noise performance metrics.

Photometric Precision Error Budget (WBS 3.1.1.7). A technical report on photometric performance considerations for NGAO has been developed and written by the photometric performance team. Including a detailed review of recent research on photometry in adaptive optics, it lists and discusses a number of considerations that are unique to conducting photometry with adaptive optics systems, and includes a case study on photometry of stellar populations in nearby galaxies. The latest draft of this technical report has been posted at: http://eraserhead.caltech.edu/keck/ngao/photometry/drafts/

Astrometric Accuracy Error Budget (WBS 3.1.1.8). The astrometric perfomance team has established the primary error terms that arise in AO systems. These error terms are the differential chromatic refraction, static or quasistatic distortion that arises in the adaptive optics system and instrumentation, and the effects of differential atmospheric tilt jitter. The team has examined the effects of these error terms in the context of two different applications: narrow field observations of the Galactic Center and wide field observations of sparsely populated clusters. This performance team is in the process of generating a draft report summarizing these findings, some of which are themselves leading edge research in understanding the current limitations to real data being collected with Keck LGS AO.

Polarimetric Accuracy (WBS 3.1.1.9). Seeking an additional scientist to assist Ireland (Caltech) with the development of a polarimetric accuracy technical report. To date, inquiries have been made, but no scientist commitment beyond Mike's has been received.

High-contrast Error Budget (WBS 3.1.1.10). A spreadsheet contrast tool previously developed by Macintosh for GPI was adapted to NGAO, and a first working version delivered to the NGAO high-contrast team (1/22/07). Typical NGAO wavefront error budgets were reproduced using this tool, and initial contrast budgets produced, however lacking proper modeling of some crucial Keck-specific error sources, in particular static and dynamic segment aberrations. In addition the tool does not model a coronograph. To complement the shortcomings of this tool, numerical simulations were employed, using Monte Carlo methods and physical optics models that accurately modeled segment figures and vibrations, and a simple diffraction suppression apodizer acting as a pseudo-coronograph. A first draft of the contrast performance budget report, collecting results from both the spreadsheet tool and the numerical simulations, was produced in March. The current focus of this study is to continue and expand the numerical simulations to cover the critical parts of the parameter space (actuator density, tomography and LGS errors etc), and to implement a proper coronograph model (standard/apodized Lyot).

Observing Efficiency Performance Budget (WBS 3.1.1.11). Progress being made.

System Uptime Performance Budget (WBS 3.1.1.12). No progress.

1.2.4 Trade Studies (WBS 3.1.2)

A series of trade studies were initiated at the start of the Keck NGAO System Design phase in order to help solidify system requirements and to give us a perspective on the feasible system architectures. The progress and status of these trade studies is described below.

MOAO versus MCAO (WBS 3.1.2.1.1). Status: nearly complete as KAON 452. This study was reported as nearly complete in the last progress report. Additional work has gone into this report, especially in the area of fleshing out the hybrid approach options.

NGAO versus Keck AO Upgrades (WBS 3.1.2.1.2). Status: Complete as KAONs 461 and 462. KAON 461 anchors the NGAO wavefront error budget tool to current Keck AO performance. The tool is then used to evaluate the performance improvements from various upgrades. KAON 462 evaluates the upgrade approach from the perspective of the various performance budgets. A very rough cost and schedule assessment is also included. The conclusion is that the option of upgrading the existing system should continue to be evaluated as an option. Potential benefits include delivering incremental performance improvements earlier and lower cost. The main downside is that this approach is unlikely to achieve the same ultimate performance as a new NGAO system.

Keck Interferometer Support (WBS 3.1.2.1.5). Status: Near completion. Several options for supporting interfereometry with NGAO have been defined. Each methods technical aspects as well as rough cost estimates were developed and presented at team meeting #5 for comment. A KAON documenting the study is in progress.

GLAO for non-NGAO Instruments (WBS 3.1.2.1.7). Status: Complete as KAON 472. Focusing on the performance benefits of having a ground-layer AO capability rather than proposing solutions to all the technical issues associated with its implementation, this report shows that GLAO on Keck could offer significant performance and efficiency benefits to most existing and future non-NGAO instruments. The underlying assumptions of the study was that at least 5 LGS that can be positioned in a large asterism (up to 6 arc minutes) were available for wavefront sensing, and an adaptive secondary mirror (ASM) of relatively high order (modeled as 32x32 actuators across the telescope pupil). The WFS implementation was left unspecified, but it seems most likely that new WFS modules would need to be built for using the ASM with non-NGAO instruments, rather than trying to reuse the WFS inside of NGAO. A wide range of observation

scenarios were investigated, including varying seeing conditions, turbulence distribution, field of view and observing wavelength, and all scenarios were constrained so as to correspond to a relatively large sky coverage (50% at 30 degrees galactic latitude). Results showed that performance gains for FWHM and encircled energy ranged between a factor of 1.2 to 4 for all conditions and wavelengths between 0.5 to 2.2 microns, indicating a gain of modest to substantial whenever GLAO would be used. While no direct showstoppers were identified in implementing GLAO for non-NGAO instruments, several technical issues remain to be solved, most notably the particular WFS implementation.

Science Instrument Re-use (WBS 3.1.2.1.8). Status: In process. Updates provided at meetings 3 and 4.

Telescope Wavefront Error (WBS 3.1.2.1.9). Status: Complete, with the exception of the KAON which is in process. The unique design of the Keck telescopes provides some challenges for NGAO. Flicker and Neyman using previous studies and in consultation with experts from the Keck, TMT, JPL, UC and Caltech communities have compiled information on telescope wavefront errors from segment figures and phasing. In addition dynamic information on telescope tracking and individual segment motion has also been compiled. This information has been used in combination with computer simulation of NGAO to determine specifications for the telescope environment and NGAO. Preliminary results were presents at team meeting #4.

Optical Relay (WBS 3.1.2.2.2) & Field Rotation Strategy (WBS 3.1.2.2.2.3). Status: In process.

Rayleigh Rejection (WBS 3.1.2.2.5). Status: KAON in process. Focus on addressing questions raised during Team Meeting #3 and coming up to speed with a fratricide modeling tool developed by Gavel for the Gemini MCAO program.

LGS Wavefront Sensor Type (WBS 3.1.2.2.6) & LGS Wavefront Sensor Number of Subapertures (WBS 3.1.2.2.7). Status: Nearly complete as KAON 465. An update was provided at NGAO team meeting #4.

Low Order Wavefront Sensor Architecture (WBS 3.1.2.2.9). Status: In process.

Number and Type of Low Order Wavefront Sensors (WBS 3.1.2.2.10). Status: Complete as KAON 465. This trade study concludes that (1) near IR sensing is preferable to visible for the NGS WFS. In particular, a combination of J+H bands gives the best performance. (2) Multiple TT stars can significantly improve the tilt estimate. A further improvement can be achieved if one of the NGS WFS also measures focus, which aids in estimating the combinations of quadratic null modes. (3) A 2 arc min diameter patrol field for finding NGS is sufficient, there is little benefit to making the field larger due to the reduced partial correction and tilt anisoplanatism from being so far off-axis. (4) The radius of the LGS asterism affects the partial correction of the NGS and hence the sky coverage. The LGS asterism radius needs to be optimized as a function of a weighted sum of the tomography error over the science field and the residual TT error from the partially corrected NGS.

Fast Tip/Tilt Implementation Options (WBS 3.1.2.2.13). Status: In process. No progress since last report.

LGS Asterism and Geometry (WBS 3.1.2.3.3). Status: Complete as KAON 429, as reported in Progress Report #1.

Variable versus Fixed Laser Asterism (WBS 3.1.2.3.4). Status: Complete as KAON 427, as reported in Progress Report #1.

1.2.5 Science Instrument (WBS 3.5)

The NGAO instruments working group has focused on examining the instrumentation requirements identified in the science case and interacting with the science team to clarify and bound key parameters that

will lead to the development of more complete requirements that can be used to derive an initial set of technical performance requirements for instrumentation. Applications for near-IR integral field spectroscopy and deployable imaging are being considered, along with concepts for imaging slicing and possible visible imager and visible IFU configurations. The group now has six members (Sean Adkins, Steve Eikenberry, James Larkin, Claire Max, David Le Mignant, Anna Moore) and holds weekly telecons. We are planning to hold an instrumentation workshop session when schedules permit

1.2.6 Keck Adaptive Optics Notes

The following KAONs have been produced since the last report:
- 461 Wavefront error budget predictions & measured performance for current & upgraded Keck AO
- 462 NGAO Trade Study: Keck AO Upgrade
- 463 Lessons learned on LGS operations: weather impact, efficiency & science operations model
- 465 NGAO LGS wavefront sensor: type and number of subapertures trade study
- 466 Computer simulations of AO PSFs for NGAO
- 468 An Algorithm for reconstruction of Keck Telescope segment figures
- 469 Effect of Keck segment figure errors on Keck AO performance
- 470 Keck NGAO sky coverage modeling
- 472 GLAO for non-NGAO instruments

1.3 Schedule and Budget Status

1.3.1 Milestones

The SEMP milestones through June are shown in the table below along with their status. Milestones 3 and 4 have been completed since the last report.

#	MILESTONE	DATE	DESCRIPTION	STATUS
1	SD SEMP Approved	10/9/06	Approval of this plan by the Directors. Initial SEMP version released to Directors for comment on 9/12 & final version on 9/29/06.	**Verbal approval received** from individual Directors. Written approval requested.
2	SD phase contracts in place	10/27/06	Contracts issued to Caltech & UCSC for the system design phase.	**Complete**
3	Science Case Requirements Summary v1.0 Release	10/27/06	Initial Release of the Science Requirements as input to trade studies and performance budgeting	**Complete**
4	System Requirements Document (SRD) v1.0 Release	12/8/06	Initial release of System Requirements with emphasis on the science requirements	**Complete**
5	Performance Budgets Summary v1.0 Release	2/27/07	First round of all performance budgets complete & documented	Good progress
6	SRD v2.0 Release	3/22/07	Second release of System Requirements Document	Just started
7	Trade Studies Complete	5/25/07	All trade studies complete & documented (as a series of Keck Adaptive Optics Notes)	Good progress

1.3.2 Schedule

The following discussion focuses on the WBS elements for which major work should have occurred through mid-March. Overall we are behind schedule.

SD Phase Management (WBS 1). We are generally on track with the management items. The planning and contracting is complete to date and meetings are being held on schedule. The mid-year replan will likely be completed about one month behind schedule.

System Requirements (WBS 2). The first versions of the science case and systems requirements documents are complete. However this category is behind the original schedule. By not having these sufficiently defined we assume more risk that the performance budgets and the AO system and science instrument decisions may need to change.

Performance Budgets (WBS 3.1). The performance budgets are behind schedule. The switch from understanding the budgets to documenting the budgets should help in bringing these budgets to closure.

Trade Studies (WBS 3.2). Five of the 21 trade studies planned for completion through the end of March are complete; and three additional studies have begun. Nine of the incomplete studies are 50% or more complete. The focus is now on completing the trade studies that have been started as opposed to starting new studies.

Science Instruments (WBS 3.5). This effort is behind schedule. As of the past month weekly meetings of the Instrument Working Group are being held which should allow for an improvement in schedule.

1.3.3 Budget

As mentioned in Progress Report #1 the plan was to re-evaluate the Observatory contingency to determine if additional funds could be shifted to NGAO in order to meet the FY07 SEMP budget request. The requested additional amount of $46k has recently been released to the project. This represents a total FY07 budget of $818k.

The total budget spent through February, 2007 is $234k. This represents 29% of the FY07 budget and 20% of the total System Design Phase budget.

The contract limits for COO and UCO were increased in March from $50k each to $200k for COO and $130k for UCO.

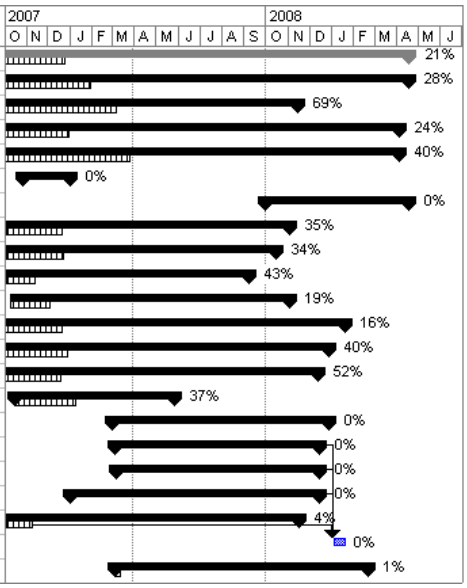
1.4 Anticipated Accomplishments in Next Period

The next project report will be distributed prior to the June 20 SSC meeting. During this period we will need to complete the science requirements, performance budgets and the scheduled trade studies. We anticipate all project milestones through milestone 7 (see Milestone table in section 1.3.1) to be complete by the next report. The mid-year replan will be completed shortly and we will also report on the results of this activity.

2. Schedule

A high level snapshot of the tracked schedule is shown below through mid-March. The percent complete values refer to the percent complete of the task. Overall the system design phase plan is 21% complete. The tracked schedule in both MS Project and Excel format can be found at http://www.oir.caltech.edu/twiki_oir/bin/view.cgi/Keck/NGAO/SystemDesignPhasePlanning.

ID	WBS	Task Name	Lead	Work
0	0	NGAO System Design Phase Schedule		16,725 hrs
1	1	SD Phase Management	PW	2,175 hrs
2	1.1	Planning and Contracting	PW	230 hrs
11	1.2	Project Meetings		1,352 hrs
28	1.3	Tracking and Reporting	PW	120 hrs
39	1.4	Proposals & Fundraising		0 hrs
42	1.5	System Design Report & Review	SA	473 hrs
52	2	System Requirements	PW	3,524 hrs
53	2.1	Science Requirements	CM	3,090 hrs
116	2.2	Observatory Requirements	CN	224 hrs
123	2.3	System Requirements Document		210 hrs
134	3	System Design	PW	9,826 hrs
135	3.1	Systems Engineering	RD	5,256 hrs
136	3.1.1	Performance Budgets	RD	2,346 hrs
173	3.1.2	Trade Studies	RD	1,790 hrs
206	3.1.3	System Architecture	RD	1,120 hrs
221	3.2	AO System	DG	1,780 hrs
249	3.3	Laser Facility		750 hrs
263	3.4	Science Operations	DLM	670 hrs
293	3.5	Science Instruments	SA	1,290 hrs
302	3.6	System Design Manual	PW	80 hrs
303	4	Systems Engineering Management Plan (SEMP)	PW	1,200 hrs



3. Financial Summary

The schedule shows 21% of the system design phase activities complete through March. The budget shows 20% of the budget spent through February. The predicted budget spent through March (scaling an average of the Jan. and Feb. actuals) results in a total expenditure through March of $298k or 26% of the budget. We therefore appear to be slightly behind in terms of earned value.

The average number of FTEs working on the NGAO system design tasks at our three institutions was 4.3 in the first three months of FY07 versus the ~ 6 FTE level in the SEMP. This average has increased to 6.3 FTEs in the last two months. The total expenditure through the end of Feb. is $234k. This represents 32% of the requested budget for FY07 versus the ~ 42% level planned in the SEMP.

WMKO Report: The following table lists the WMKO FTEs and total costs through February, along with the year to date (YTD) total and the FY plan from the SEMP. The WMKO labor has ramped up.

Category	Oct	Nov	Dec	Jan	Feb	YTD	FY Plan	% Spent
Personnel (FTEs)	2.1	2.5	1.4	3.2	3.7	1.1	2.8	39%
Personnel ($k)	13.4	23.9	10.4	30.2	24.9	102.8	305.5	34%
Travel, phone ($k)	0.1	2.5	0.1	0.6	0.1	3.4	13.3	25%
Total ($k)	13.4	26.4	10.5	30.8	25.0	106.2	318.8	33%

COO Report: The following table lists the COO FTEs and total personnel costs through Feb.

Category	Oct	Nov	Dec	Jan	Feb	YTD	FY Plan	% Spent
Personnel (FTEs)	0.3	1.1	0.7	1.3	1.8	0.4	1.6	27%
Personnel ($k)	6.9	14.9	11.3	22.1	26.2	81.5	232.5	35%
Travel, phone ($k)	0.0	0.0	0.1	1.2	4.2	5.5	13.3	41%
Total ($k)	6.9	14.9	11.4	23.2	30.5	87.0	245.8	35%

UCO/Lick Report: The following table lists the UCO/Lick FTEs and total personnel costs through Feb. The FTEs exceed the plan because of extra work in the LAO lab which is not paid for by NGAO.

Category	Oct	Nov	Dec	Jan	Feb	YTD	FY Plan	% Spent
Personnel (FTEs)	1.7	1.7	1.3	1.2	1.4	0.6	1.7	36%
Personnel ($k)	7.0	8.0	6.9	8.0	8.0	37.9	162.6	23%
Travel, phone ($k)	0.0	0.4	0.0	2.3	0.4	3.0	13.3	22%
Total ($k)	7.0	8.4	6.9	10.3	8.4	40.8	175.9	23%

A postdoc is included in the UCO budget. An offer has been made to a candidate for this position.

Science Case Requirements Report: The SEMP does include 1850 hours ($57k) for graduate students to support the science case development. None of these funds have been spent or committed to date. Project scientist and science community participation, which is "free" to the project, is not currently tracked.