Keck Adaptive Optics Note 459

Keck Next Generation Adaptive Optics
System Design Phase Project Report #1

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1. Narrative

In July, 2006, the Observatory Directors established the Next Generation Adaptive Optics (NGAO) Executive Committee (EC) to manage the system design phase of the NGAO project. The EC subsequently submitted a Systems Engineering Management Plan (SEMP) for the NGAO system design phase to the Observatory Directors on Sept. 29, 2006. The SEMP included project reports to the Observatory Directors prior to each SSC meeting. This document represents the first of these project reports.

1.1 Summary

Good progress has been made on initiating the NGAO system design phase and on building up an effective team. The emphasis during the first half of FY07 has been, as planned, 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 begun on a number of trade studies in support of the performance budgets and the design choices that will need to be made.

Overall progress has 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. This ramp up is nearing completion and we expect the rate of progress to be much closer to the plan through the next reporting period.

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 bulk of the management work has centered on setting up the people, tools and procedures to manage the project and on organizing the team meetings. A major management tool that has been evolved is the NGAO Twiki site at http://www.oir.caltech.edu/twiki_oir/bin/view.cgi/Keck/NGAO/WebHome. This provides a location for all NGAO documentation as well as a tool for managing the work packages. In particular, we have instituted work scope planning sheets which are required to be filled out and approved prior to starting significant work on WBS elements. The subcontracts to COO and UCO/Lick were slow to get in place, but did not slow progress due to our agreement to make the contracts effective as of Oct. 1, 2006. Team meetings with well defined goals are held approximately every 6 weeks. To date three of these meetings have been held and a fourth is scheduled for Jan. 22. The action items from the team meetings and the EC weekly meetings are posted on the Twiki site.

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. Four releases of these Requirements are planned for the system design phase. Release 1 of the Science Case Requirements Document (KAON 455), which is used as input to the SRD, and version 1 of the SRD (KAON 456) are both close to completion and will be completed by the end of January.

Work to date on the Science Case Requirements is described below. The specific topics listed below were selected because they could have major impact on specific design specifications of NGAO and its instruments. In the next reporting period we will iterate on these science cases, and will add the following: Moons of the Giant Planets, Galactic Center Nature of Sgr A*, Debris Disks, Protostellar Envelopes & Outflows: Contrast and Polarimetry, Nearby AGNs, and Gravitational Lensing.

Solar System Science Case Requirements (WBS 2.1.1). Franck Marchis and Claire Max are currently updating the requirements for "Multiplicity, Size, and Shape of Minor Planets" based on the discussion in the NGAO Proposal. Since rocky solar system bodies are seen in reflected light, this is one of the key science cases that speak to the NGAO performance requirements at visible wavelengths. Marchis' simulations show that with a wavefront error of 140 nm, detection rates for as-yet-undiscovered moons of main-belt asteroids in R-band are very high (approaching 100%), and for close-in moons NGAO detection rates at H band greatly exceeds those of NIRC2 with current AO. Marchis estimates that between 1000-4000 binary asteroids could be discovered with NGAO (140 nm wavefront error), and that an accurate shape estimate for ~300 of them (1 order of magnitude more than the current known shapes for asteroids) will be attainable. Simulations are under way to determine expected detection rates for 170 nm and 200 nm wavefront error. It is highly desirable to minimize the observing efficiency. Discovery efficiency suffers in direct proportion to the time it takes to switch from one target to the next, particularly when the observing time per target is relatively short. This is an important constraint for this science case, since numerous targets must be observed per night. The observing efficiency requirement will be quantified in ongoing simulations.

Imaging and characterization of extrasolar planets around nearby stars (WBS 2.1.2.4). The Gemini and ESO specialized planet-finding AO systems will have extremely high contrast for direct imaging of young planets. However the design of these "extreme AO" systems restricts them to searches around bright, solar-type stars (I=8 to 9 mag). The LGS capabilities and high performance of NGAO will allow imaging and characterization of companions to low-mass stars and brown dwarfs for which the primary mass is a half solar mass or lower. In addition, direct imaging of substellar companions is substantially easier around lower mass primaries, since the required contrast ratios are smaller for a given companion mass. Simulations with 140 nm of NGAO wavefront error indicate that a young one-Jupiter-mass planet can be detected in orbit around a half-solar-mass star for angular separations greater than 0.5 arc sec. Simulations will be repeated for 170 and 200 nm wavefront error. This science case requires a coronagraph; future work will delineate the coronagraph specifications and will investigate the implications for IFU specifications. Contributors: Mike Liu and Claire Max.

Measurement of General Relativistic Effects in the Galactic Center (WBS 2.1.2.1 and 2.1.2.2). Current orbital reconstructions for the stars closest to Sgr A* are consistent with pure Keplerian motion. The improved astrometric and radial velocity precision provided by NGAO open the prospect of detecting deviations from pure Keplerian motion due to General Relativity and other effects. Andrea Ghez and Nevin Weinberg have outlined the performance requirements for detecting General Relativistic effects. Ghez, Jessica Lu, and Max are investigating the implications for NGAO system design. In order to detect General Relativistic effects using the most promising star (S0-2), astrometric precision of 100 micro-arc sec and radial velocity precision of 10 km/sec are required. Current Keck II AO performance with NIRC2, in the best cases, is approximately 250 micro-arc sec and 20 km/sec. Work is ongoing to understand quantitatively what is limiting the current performance, and to predict NGAO's tip-tilt accuracy based upon a list of the brighter infrared tip-tilt stars that will be accessible to NGAO. Current understanding of the astrometric accuracy attainable with MCAO systems suggests that MCAO is strongly disfavored for this science case.

Resolved Stellar Populations in Nearby Galaxies (WBS 2.1.3.1). The basic understanding of the star formation, chemical evolution, and accretion history of the Galaxy was developed based on color-magnitude diagram studies, abundances of elements in stars from different Galactic populations, and the relations between stellar kinematics, ages and metallicities. In the past decade, using the Hubble Space Telescope and 4m – 10m ground-based telescopes, studies based on resolved stellar populations have been extended to the Galaxy's dwarf galaxy complement and to the exterior regions of M31. NGAO will allow the study of resolved stellar populations in crowded fields throughout the Local Group and to groups within 10-20 Mpc. Mike Rich, David Reitzel, and Max are investigating key issues related to this science case: What is the leverage in using R and I bands instead of V bands in color-magnitude diagrams, since NGAO photometric performance in the traditionally-used V band will not be as accurate as in R and I bands? What are the relative advantages of MCAO (larger contiguous field but lower average Strehl) and MOAO (multiple smaller fields but higher Strehl)? Initial results suggest that higher and more stable Strehl ratios, even if over a smaller field, are preferred since the confusion limit is the key limitation to photometric performance.

High-z Galaxy Assembly and Star Formation History (WBS 2.1.3.2). Chuck Steidel, David Law, and Claire Max have continued their investigation of NGAO capabilities and requirements for the study of high-z galaxies. The study of high-redshift galaxies is a powerful driver for multiplexed observations, for example via deployable integral field unit (IFU) spectrographs. In order to take best advantage of the high areal densities of targets, it is desirable to be able to deploy of order 6-12 IFUs over a given 5 square arc minute field of regard. At redshift $z = 0.5$-3, major rest-frame optical emission lines such as Hα, [N II], and [O III] fall in the observed frame near-IR, and in order to study the evolution of galaxies across this range of cosmic times it is important to have wavelength coverage extending from 1 to 2.5 microns. Hα line emission from the well-studied redshift $z \sim 2$-3 galaxy sample falls in the K band, emphasizing the importance of optimizing observations at these wavelengths by reducing backgrounds and increasing throughput as much as possible. This science case places the strongest emphasis on achieving K-band backgrounds that are much lower than those for the current Keck II AO system with OSIRIS. Using the Gemini model of the Mauna Kea near-IR sky background coupled with a mathematical model of the thermal contributions from warm optical surfaces in the light path, Law et al. (2006) demonstrated that the current K-band performance of AO-fed instruments is limited primarily by thermal emission from the warm AO system. Using a combination of high-throughput optical components and AO system cooling, it is desirable that thermal radiation from the NGAO system will contributes less than 10-20% to the total K-band background. Future sensitivity studies will assess science performance for K-band backgrounds ranging from these values to their current, much higher values. Given the typical size of the target galaxies (less than or of order an arc sec), the field of view of each IFU should be suitably large to permit accurate sky subtraction (via on-IFU dithering) while sampling the target on the smallest scales permitted by detector noise characteristics. That is, each IFU should have a field of view measuring at least 3 x 1 arcseconds in order to avoid costly dedicated sky exposures.

Science Case Requirements Document (WBS 2.1.4). Release 1 of this document is expected to be completed in January. Contributors, July/06 through Jan/06, have included Andrea Ghez, David Law, Mike Liu, Jessica Lu, Franck Marchis, Claire Max, David Reitzel, Mike Rich and Chuck Steidel.

Observatory Requirements (WBS 2.2) and System Requirements Document (WBS 2.3). Release 1 of the SRD is expected to be completed in January. This document includes the requirements resulting from the science case requirements document and the observatory requirements. A separate baseline requirements document applicable to all new instrumentation capabilities is also in preparation that will be used as a reference. The interferometer specific requirements for NGAO were developed in KAON 428.

1.2.3 Performance Budgets (WBS 3.1.1)

The NGAO team has concentrated on early development of a comprehensive suite of performance budget studies (and related systems engineering tool development, including validating assumptions and tools) to allow efficient iteration and understanding of the impact of design choices scheduled to be made during the summer of 2007. The status of each of the performance budget elements is summarized below.

Model Assumptions (WBS 3.1.1.1). Ralf Flicker and Chris Neyman are mining available data sources to update atmospheric models for inclusion in the next round of NGAO performance predictions. In collaboration with Mauna Kea Weather Center and TMT personnel a new atmospheric model for Mauna Kea has been developed. The model is based on TMT 13 North (MASS/DIMM), CFHT (Megacam), UH(DIMM) and Subaru (DIMM) data sets. (KAON 415 & 420). Neyman is updating input on telescope static and dynamic errors in consultation with Mitch Troy and Sergey Panteleev. Don Gavel has collected experimental sodium return measurements from Lick , SOR and other LGS facilities. Neyman has compared the Keck laser return with sodium layer statistics from the LIDAR experiments on Maui. (KAONs 419, 416 & 417).

Model/Tool Validation (WBS 3.1.1.2). Ralf Flicker and Chris Neyman have compared Flicker's LGS tomography code with the TMT standard tomography code (Ellerbroek and Gilles, LAOS). The codes were found to give essentially the same tomography error with the same inputs. Gavel and Dekany compared sky coverage estimation algorithms and found them to be in agreement when the same star density models were used. Flicker, Viswa Velur and Dekany estimated the tomography experimentally at Palomar Observatory with the MGSU experiment (SPIE 6272). The tomography error was contaminated by other instrumental effects making it difficult to anchor simulations and analysis to this result. Gavel and UCSC LAO personnel are progressing with a lab setup to support tomography experiments. Clare and van Dam are collaborating with Ellerbroek and Gilles of the TMT (LAOS) to model the Keck II LGS system with simulations developed for the TMT.

Transmission and Background Budgets (WBS 3.1.1.3 & 3.1.1.4). Antonin Bouchez is developing detailed transmission and background budgets in consultation with Claire Max, David Law, and Chuck Steidel. The issue of allowable K-band background is a key architectural driver for the NGAO program.

Wavefront Error and Encircled Energy Budgets (WBS 3.1.1.5 & 3.1.1.6). Richard Dekany, Don Gavel, Chris Neyman and Ralf Flicker are developing tools to support requirements flowdown and architecture trade studies for NGAO. Documentation of the wavefront error budget tool developed by Dekany has begun, as has development of a new encircled energy calculation tool by Gavel. Assumptions and implementations in these tools have undergone a full-day review (held on 1/16/07 at Caltech) and documentation of an initial set of wavefront error budgets for several key observing scenarios (TNO multiples, the Galactic Center, field galaxies, and Io volcanism) is underway.

Photometric Precision Error Budget (WBS 3.1.1.7). Matthew Britton, Richard Dekany, Ralf Flicker, and Knut Olsen (NOAO) have begun development of a performance budget identifying and quantifying the primary limitations to higher precision photometry using adaptive optics. The team is considering both confusion-limited and sparser stellar fields to compare the relative advantage of different levels of NGAO system Strehl ratio, corrected field of view, auxiliary information to aid PSF estimation, and other factors.

Astrometric Accuracy Error Budget (WBS 3.1.1.8). Brian Cameron, Andrea Ghez, Jessica Lu, Matt Britton, and Richard Dekany are developing a similar performance budget identifying and quantifying the limitations to improved astrometric precision in both the Galactic Center and for sparsely populated fields. The team is considering the limitations imposed by crowding, uncalibratible high-order anisoplanatism, tilt anisoplanatism, and other factors.

Polarimetric Accuracy (WBS 3.1.1.9). Mike Ireland is leading the effort to quantify the polarimetric performance budget, beginning with identifying and quantifying the terms with the largest impact on this budget.

High-contrast Error Budget (WBS 3.1.1.10). Ralf Flicker, Bruce Macintosh, Michael Liu, Chris Neyman, and Richard Dekany are developing a high-contrast performance budget based primarily on the models previously developed by Macintosh for the Gemini Planet Imager (GPI). The team is considering the unique issues faced by NGAO, including residual Keck segment aberrations, dynamical behavior of the Keck primary mirror(s), and the sharper diffraction-limited afforded by the 10m aperture. The majority of effort is being directed toward understanding the high-contrast performance budget for LGS observations, an area where Keck NGAO will have unique capabilities with respect to Gemini's GPI, VLT's planet imager, and Palomar's PALM-3000. This is being undertaken in consideration of both the study of diffuse debris disks and the search and characterization for compact companions to young stars.

Observing Efficiency Performance Budget (WBS 3.1.1.11). David Le Mignant, Randy Campbell, Jason Chin, Jim Lyke, Marshall Perrin, Ellie Gates, and Erik Johansson are developing detailed observing efficiency budgets based upon careful studies of the existing Keck LGS systems efficiency. In conjunction with trade studies investigating the system operations architecture, strong emphasis is being placed on maximizing efficiency through appropriate automation of routine operations, including improved calibration and dithering architectures. Input on typically observing scenarios for NGAO has been solicited from throughout the Keck community, providing an initial database with which to investigate efficiency trades from deep field spectroscopy to large target count surveys.

System Uptime Performance Budget (WBS 3.1.1.12). Erik Johansson and Jason Chin are performing a more detailed development of the system uptime budget, concentrating on system failure sources with the existing Keck AO system. Crafting an appropriate perspective on the acceptable reliability of the NGAO system, with an eye toward minimizing initial and life-cycle costs, this engineering-focused performance budget will be important input to the systems engineering requirements flow down.

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.

We have completed or nearly completed the following trade studies: Multi-Object (MOAO) and Multi-Conjugate (MCAO) architectures, methods of mitigating laser Rayleigh backscatter, laser guide star asterism and geometry and variable versus fixed laser asterism on the sky. Trade studies that are currently underway include LGS wavefront sensor type and number of subapertures, instrument reuse, low-order wavefront sensor architecture, number and type, and fast tip/tilt steering opto-mechanical implementation options.

Trade studies that are scheduled to commence in the next two months include the following topics: NGAO versus Keck AO upgrades, Keck Interferometer support, K & L-band optimization, instrument balance, observing models, AO enclosure temperature, optical relay, field rotation, dichroics, DM stroke requirements, focus compensation, laser pulse format and free space versus fiber laser transport. The correcting fast tip/tilt with the DM trade study was cancelled since we have assumed this as part of our baseline.

MOAO versus MCAO (WBS 3.1.2.1.1). Status: Complete, except for document revisions. Don Gavel has provided an analysis of the options, benefits, and drawbacks of the possible wavefront control opto-mechanical architectures. MCAO offers a contiguous field of view, suitable for a wide field camera or spectrograph, but at the cost of considerable anisoplanatic error due to the deformable mirrors in series that act to correct layers of atmosphere. The MOAO arrangement greatly reduces anisoplanatic error but offers several discontiguous patches of correction. These are more suitable for deployable integral field spectrographs. An important consideration is the maturity of micro-electro-mechanical-system (MEMS) deformable mirrors, which is the only practical and cost-effective way of implementing MOAO. We are also considering a unique "hybrid" MCAO/MOAO architecture that could take advantage of the best features of each. This later study is still in progress. The report draft is KAON 452.

Rayleigh Rejection (WBS 3.1.2.2.5). Status: In process. Viswa Velur has evaluated the intensity of the Rayleigh, as well as aerosol and cirrus backscatter, as seen at the Keck focal plane and done a brief study of the available lasers and pulse formats and methods of blocking Rayleigh. The best choice for background rejection would be an appropriately pulsed laser which can have a gated return so that almost no Rayleigh background is encountered. However the most powerful and most promising laser in terms of sodium return per Watt, are CW. Viswa summarized his initial results in a presentation given at NGAO team meeting #3.

LGS Wavefront Sensor Type (WBS 3.1.2.2.6) & LGS Wavefront Sensor Number of Subapertures (WBS 3.1.2.2.7). Status: In process. Viswa Velur has begun trade studies of the optimal wavefront sensor type, especially the comparison of Shack-Hartman and Pyramid wavefront sensors, and number of subapertures. An update will be provided at NGAO team meeting #4.

Instrument Reuse (WBS 3.1.2.1.8). Status: In process. An initial assessment of the reuse of NIRC2 as the thermal near-IR imager was provided at meeting #3.

Low Order Wavefront Sensor Architecture (WBS 3.1.2.2.9) & Number and Type of Low Order Wavefront Sensors (WBS 3.1.2.2.10). Status: In process. Richard Clare, Ralf Flicker, Stephan Kellner and Chris Neyman have begun a study that will evaluate natural guide star tip/tilt/focus/astigmatism sensors and their sky-coverage performance. These sensors are needed to measure the Zernike wavefront modes to which the laser guide star wavefront sensor is blind, and since they need natural guide stars, have a severe impact on fractional sky coverage for observing. The team will evaluate both Hartmann and Pyramid wavefront sensors for sensitivity, signal-to-noise, and consequent sky coverage. Initial results will be presented at NGAO meeting #4.

Fast Tip/Tilt Implementation Options (WBS 3.1.2.2.13). Status: In process. Brian Bauman is midway through a study of how to implement fast tip/tilt with a minimum of complexity and impact on AO relay design. An attractive option is to put one of the deformable mirrors on a fast tip/tilt stage, a sort of two-in-one solution that eliminates a reflection. Other options include steering one of the powered mirrors, or simply using a flat at an intermediate plane with the possible consequence that a second tip/tilt flat will be needed to keep the pupil steady. A preliminary report was given by Brian at NGAO team meeting #3.

LGS Asterism and Geometry (WBS 3.1.2.3.3). Status: Complete. Ralf Flicker did a study of many possible arrangements, numbers, and fields of view of laser guide stars in order to fully explore the tomography error component of the NGAO system error budget in various operating modes and conditions. The arrangement spoken of in the proposal, a “quincunx” of 5 LGS, was studied, along with constellations having more (7-9) LGS, the later offering considerable better performance. It was recommended that an 8 LGS asterism be considered as the baseline, especially to cover the 25 to 30 arcsec radius field that is called for in the extragalactic science cases. Details are in KAON 429.

Variable versus Fixed Laser Asterism (WBS 3.1.2.3.4). Status: Complete. Viswa Velur did this quick study to consider the cost and complexity of a variable asterism, i.e. making the LGS asterism reconfigurable on the sky depending on the science observing scenario. With any given number of guide stars, tucking them in to a smaller asterism results in smaller tomography error, at the expense of field of view. Viswa concluded that the extra cost was marginal and complexity issues were worth the benefit of having this observing flexibility. Details are given in KAON 427.

1.2.5 Keck Adaptive Optics Notes

The following KAONs have been produced to date:

- 415 MK turbulence statistics from the TMT MASS/DIMM & weather station at 13N (restricted access)
- 416 Atmospheric sodium density from Keck LGS photometry
- 417 Sodium abundance data from MAUI Mesosphere
- 419 Simple models for the prediction of Na LGS brightness & comparison to measured returns from the Gemini and Keck lasers
- 420 Accessing the MK TMT seeing & weather data
- 427 Variable versus fixed LGS asterism
- 428 Implications & Requirements for Interferometry with NGAO
- 429 LGS asterism geometry & size
- 452 MOAO versus MCAO trade study report

– 455 NGAO Science case requirements document
– 456 NGAO System Requirements document

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.

#	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.	$50k initial contracts (pending budget resolution) issued on 12/19 & 12/21
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	V1.0 to be completed in Jan/07
4	System Requirements Document (SRD) v1.0 Release	12/8/06	Initial release of System Requirements with emphasis on the science requirements	V1.0 to be completed in Jan/07
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	Not started yet
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 in the first quarter of FY07. Overall we are behind schedule primarily due to delays in ramping up the team. This ramp up, although not yet complete, is nearing completion and the pace of progress is expected to significantly increase over the second quarter.

SD Phase Management (WBS 1). We are largely on track. The planning and contracting is complete to date and meetings are being held on schedule.

System Requirements (WBS 2). The first versions of the science case and systems requirements documents are nearly complete. However this category is behind the original schedule and could become a pacing item for the performance budgets.

Performance Budgets (WBS 3.1). Excellent starts have been made on all of the performance budgets as well as the model assumptions and validation. The individual WBS elements range between 25 and 50% complete. Seven of the performance budget WBS elements should have been completed by the end of January and won’t be. On the other hand four of the performance budgets are ahead of schedule. All of the teams are now in place however and the rate of progress has increased.

Trade Studies (WBS 3.2). Two of the seven trade studies planned for completion in the first quarter are complete. Nine additional trade studies are in process. One trade study has been cancelled due to its lower priority and the need to reshuffle personnel.

Science Instruments (WBS 3.5). This effort, which had been planned to start in the first quarter, is only recently gaining some momentum.

1.3.3 Budget

The FY07 SEMP budget request was $808k, including $10k in contingency. We were recently informed that the Observatory's 5-year plan includes $772k for NGAO. This includes $326k for WMKO personnel (a $20k increase from the SEMP assumed value) per Finance Department calculations and does not include the $10k of contingency since all contingency is hold within the Observatory's FY07 contingency. This leads to a total discrepancy between the proposed and actual budgets of $26k, but a larger problem of $46k less available for the CIT and UCO contracts than was proposed in the SEMP. For the moment we have decided to proceed with the SEMP plan and to take this information into account when we do the NGAO mid-year replan in March. The plan is to re-evaluate the Observatory contingency by April 30 to determine if additional funds could be shifted to NGAO.

Contracts were issued to COO and UCSC in December, covering work since Oct. 1, 2006, with a temporary limit of $50k each. These contract limits will need to be increased now that we better understand the available budget.

The total budget spent through the first quarter of FY07 is $110k or 14% of the available FY07 budget. The low spending rate is due to a slower ramp up of labor than planned.

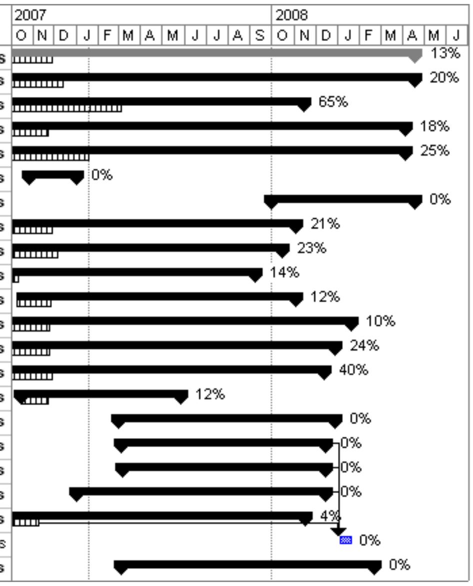
1.4 Anticipated Accomplishments in Next Period

The next project report will be distributed prior to the April 3 SSC meeting. During this period our emphasis will remain on developing the science requirements and performance budgets, and on completing the scheduled trade studies. We anticipate all project milestones through milestone 5 (see Milestone table in section 1.3.1) to be complete by the next report, with the potential delay of milestone 6.

2. Schedule

A high level snapshot of the tracked schedule is shown below through mid-January. The percent complete values refer to the percent complete of the task. As a reminder, WBS 4 is the SEMP for the post-system design phases of the project. 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

Through the first quarter an average of 4.3 FTEs have been working on the NGAO system design tasks at our three institutions (excluding Science Team members, who are not paid by NGAO) versus the ~ 6 FTE annual level in the SEMP (excluding students). The total expenditure through this period is $110k. This represents 16% of the requested personnel budget for FY07 versus the ~ 25% level planned in the SEMP.

WMKO Report: The following table lists the WMKO FTEs and total costs through December, along with the year to date (YTD) total and the FY plan from the SEMP. On average 2.0 WMKO personnel have been working on NGAO over this period (88% of this effort is from Flicker, Neyman and Wizinowich and 10% is from Adkins, Johansson and Le Mignant). WMKO labor is planned to ramp up in the next few months, per the SEMP, as we move into the system and subsystem design phase (WBS 3.2 to 3.5).

Category	Oct	Nov	Dec	YTD	FY Plan	% Spent
Personnel (FTEs)	2.1	2.5	1.4	2.0	2.8	18%
Personnel ($k)	13.4	23.9	10.4	47.7	305.5	16%
Travel, phone ($k)	0.1	2.5	0.1	2.6	13.3	20%
Total ($k)	13.4	26.4	10.5	50.3	318.8	16%

COO Report: The following table lists the COO FTEs and total personnel costs through Jan. 7. Dekany has been working at close to the expected 33% level, but Velur and Moore have been slower to ramp up. The COO team is believed to be at the FY plan rate in January.

Category	Oct	Nov	Dec	YTD	FY Plan	% Spent
Personnel (FTEs)	0.3	1.4	0.8	0.8	1.6	13%
Personnel ($k)				36.6	232.5	16%
Travel, phone ($k)					13.3	
Total ($k)					245.8	

UCO/Lick Report: The following table lists the UCO/Lick FTEs and total personnel costs through December (estimated). Gavel has been working at roughly the 33% level. Bauman was slow to start up but is now at the expected level. Ammons and Kupke are up to full speed on the “anchor to lab experiments” task (this task uses considerable LAO matching support).

A postdoc is included in the UCO budget. This position is being advertised and was not assumed to be filled in the SEMP until Feb/07.

Category	Oct	Nov	Dec	YTD	FY Plan	% Spent
Personnel (FTEs)	1.7	1.7	1.2	1.5	1.7	23%
Personnel ($k)				21.6	162.6	13%
Travel, phone ($k)				1.0	13.3	8%
Total ($k)				22.6	175.9	13%

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.