Keck Adaptive Optics Note 574

NEXT GENERATION ADAPTIVE OPTICS: SYSTEMS ENGINEERING MANAGEMENT PLAN

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Author List

Name	Function
Peter Wizinowich	**NGAO Executive Committee (EC) Chair**
Richard Dekany	**EC Member**
Don Gavel	**EC Member**
Claire Max	**EC Member & NGAO Science Team Chair**

Contributors: .Sean Adkins, Erik Johansson, Elizabeth McGrath, David Le Mignant, Chris Neyman, Viswa Velur

Approval Control

Control	Name	Function
Revised by:		
Approved by:		
Authorized by:		

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1 INTRODUCTION

A Systems Engineering Management Plan (SEMP) is a standard part of the project documentation for W.M. Keck Observatory (WMKO) development efforts. This SEMP represents a key deliverable from the system design phase for the WMKO Next Generation Adaptive Optics (NGAO) project. This document will be updated as a product of the NGAO preliminary and detailed design phases.

The following sections document the proposed management process, schedules and budgets for the remainder of the NGAO project.

2 PROJECT PLAN

2.1 Organization Structure

The System Design phase management structure setup by the Observatory Directors (i.e., Armandroff, Bolte, Kulkarni and Lewis) consisted of a four member Executive Committee (EC) with one person identified as EC Chair and another as Project Scientist. The participants represented the three institutions collaborating on the NGAO System Design. The members of the EC worked well together and the structure also supported good involvement of the three institutions.

For the Preliminary Design phase we propose a revised management structure. The Chair of the EC, Peter Wizinowich, will become the overall Project Manager. The two other EC technical leads, Rich Dekany and Don Gavel, will become Project Managers responsible for the work at their respective institution. This will allow us to have a leaner and less complex project structure, so that we can focus on management and technical leadership of specific parts of the Preliminary Design.

The proposed organization structure including other senior leadership roles is shown in Figure 1. All items highlighted in yellow represent part of the NGAO preliminary design phase project for which this SEMP is written. The NGAO project continues to be led by the EC members but now in more defined roles. The NGAO Project Scientist will be assisted by an NGAO Science Advisory Team. The NGAO senior management group (Wizinowich, Dekany, Gavel and Max) will provide project management with the cleaner lines of authority necessary for successful completion of the Preliminary Design.

NGAO science instruments are separately managed under the direction of the WMKO Instrument Program Manager (IPM), Sean Adkins. The dashed links between the science instruments and the Project Manager, Project Scientist and Systems Engineering reflect the need for close collaboration in the design and development of these systems. The requirements for both the AO facility and science instruments flow down from the NGAO science case requirements. These requirements and the interface definitions between systems are maintained by the NGAO Systems Engineering team.

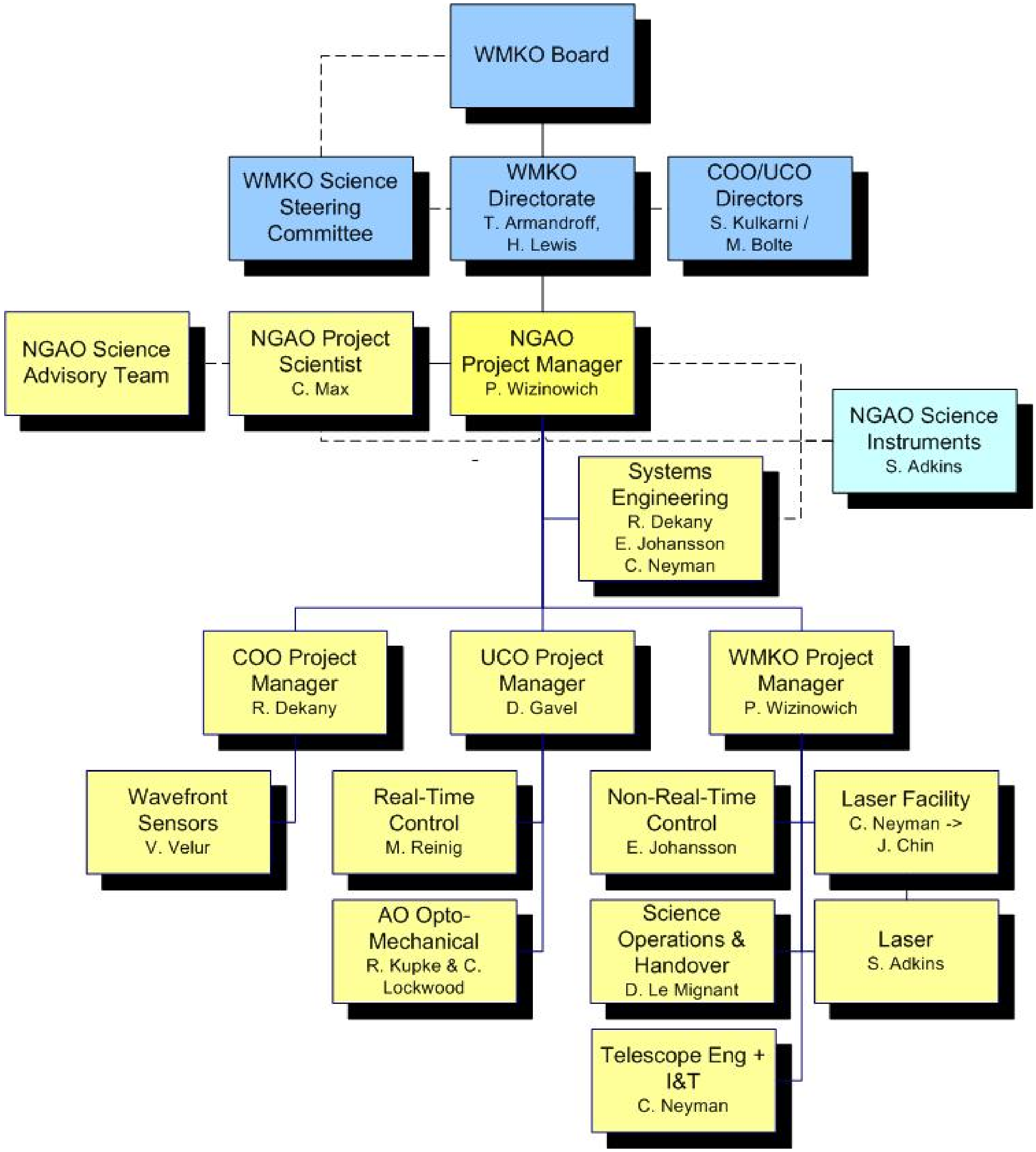

Figure 1. NGAO Preliminary Design Phase Management Structure.
Solid lines are direct reports. Dashed lines are advisory or collaborative.

WMKO's top-level management structure is highlighted in blue in Figure 1. The NGAO Project Manager reports directly to the WMKO Director, Taft Armandroff, and Deputy Director, Hilton Lewis. They in turn report to the WMKO Board. There is a close collaboration between the WMKO Directorate and the Director of the University of California Observatories (UCO), Mike Bolte, and the Director of the Caltech Optical Observatories (COO), Shri Kulkarni. A similar collaboration exists with the WMKO Science Steering Committee co-chaired by Jean Brodie and Tom Soifer.

Due to the collaborative inter-Observatory nature of the NGAO project and the EC System Design phase mandate, the EC provided regular reports to the Observatory Directors during the System Design phase and looked to them for guidance. In order to ensure clear direction during the Preliminary Design the NGAO Project Manager will meet regularly with the WMKO Directorate (at least bi-weekly) and the NGAO senior management (Dekany, Gavel, Max and Wizinowich) will have four scheduled telecoms with the Directors.

The NGAO EC provided updates at each of the SSC meetings during the NGAO System Design. The Project Manager and Project Scientist will plan to provide updates at each SSC meeting during the Preliminary Design. The NGAO project looks for the community science input primarily through the NGAO Project Scientist. The Project Scientist seeks guidance from the NGAO Science Advisory Team and the SSC.

The NGAO Preliminary Design is partially funded by the NSF's Telescope Systems and Instrumentation Program (TSIP). The WMKO IPM has been responsible for interactions with and reporting to this program for other TSIP funded projects. The NGAO Project Manager will collaborate with the WMKO IPM to provide monthly updates to the TSIP.

This organization structure will need to be modified as we move from Preliminary to Detailed Design phase. The amount of activity will increase dramatically and we will need additional dedicated project management and systems engineering resources. Personnel will be identified or hired for these roles.

As noted in Figure 1 the laser facility management will be transitioning from Chris Neyman to Jason Chin during the preliminary design as Jason frees up from the Keck I LGS AO implementation project management role.

2.2 WMKO Design Phase and Deliverables

WMKO's standard development process is shown in Figure 2. This document is being written as a product of the NGAO System Design and presents the SEMP for the remaining development phases starting with the Preliminary Design and ending with the transition of NGAO into Facility Class Operation. Table 1 lists the standard deliverables for each of the development phases.

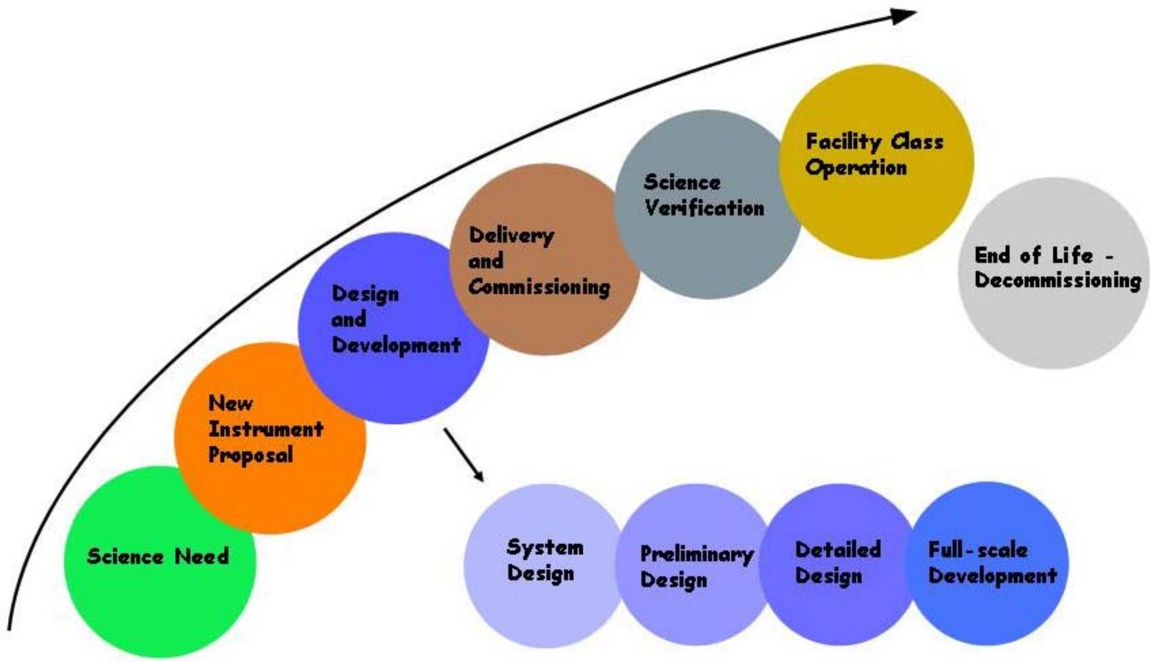

Figure 2. The WMKO Development Process.

The deliverables for the AO portion of the NGAO project consist of documentation and the actual AO Facility, Laser Facility and related interfaces. Major documentation items include:

Table 1. WMKO Development Process Deliverables.

System Design:
- Science Case Requirements Document
- System Requirements Document
- System Design Manual
- Systems Engineering Management Plan
- System Design Report

Preliminary Design:
- Requirements Documents for Key Subsystems
- Operations Concept Document
- Preliminary Technical Specifications
- Interface Control Documents
- Preliminary Design Report

Detailed Design:
- Detailed Design Drawings and Bills of Material
- Final Technical Specifications
- Acceptance Test Plans

Detailed Design Report

Full Scale Development:
- Hardware and Software Manuals and Maintenance Documentation
- Pre-ship Review Reports

Installation/Commissioning:
- Acceptance, Operational Readiness and Science Verification Review Reports

2.3 Work Breakdown Structure

The NGAO Project Work Breakdown Structure (WBS) is shown schematically in Figure 3. The top level structure reflects the transition from Design (1.0) through Full Scale Development (4.0 to 7.0) to Delivery and Commissioning (8.0 and 9.0). WBS 8.0 includes Science Verification and WBS 9.0 covers the handover to Facility Class Operation. Management (2.0) and Systems Engineering (3.0) are ongoing items through both Full Scale Development (FSD) and Delivery and Commissioning (DC).

Each of the top level WBS elements is briefly described in the following section. A full WBS dictionary can be found in KAON 583.

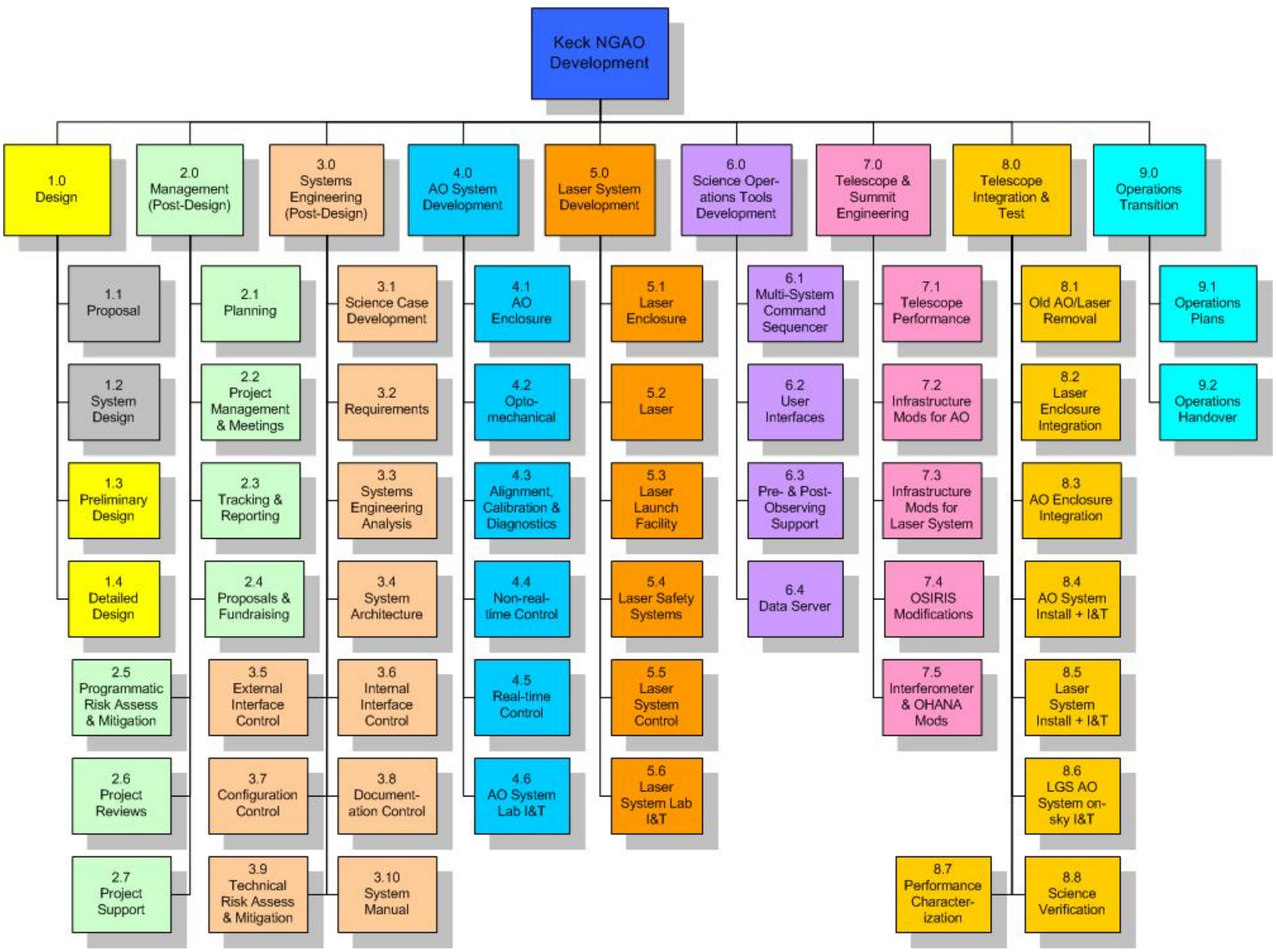

Figure 3. NGAO Work Breakdown Structure.

2.3.1 Design WBS

The two gray highlighted boxes in Figure 2 represent the project phases completed prior to the start of the Preliminary Design. There are two remaining design phases, Preliminary Design and Detailed Design. In order to simplify the creation of separate project plans and budgets for each design phase a WBS numbering plan is used within each design phase WBS (1.3 and 1.4) that reflects the overall WBS numbering for each of the major elements shown in Figure 3. For example, the overall WBS contains an element number 4.0, named “AO System Development”. An identically named WBS element appears in each of the Preliminary Design and Detailed Design WBS outlines, but these elements are numbered 1.3.4 and 1.4.4 respectively.

2.3.2 Management WBS

The management WBS has seven major elements:

1. Planning. This WBS includes the normal adjustments to the plan during a development phase, supporting the Observatory’s fiscal year planning process and preparing the Systems Engineering Management Plan (SEMP). The SEMP, the document you are currently reading, will be updated during the Preliminary and Detailed Design phases.
2. Project Management and Meetings. This category includes management telecoms and team meetings and telecoms. During the preliminary design phase for example management teleconferences will occur weekly and team teleconferences monthly with four face-to-face team meetings.
3. Tracking and Reporting. Monthly status reports will be provided throughout the project and regular reporting will be made quarterly at WMKO SSC meetings. During the Preliminary Design phase the monthly reports will be provided to the TSIP and the Observatory Directors and monthly telecoms will be held with the TSIP representatives.
4. Proposals. The NGAO team will need to write proposals and support fundraising. This is primarily a schedule item here since the WMKO labor for these activities is covered outside the NGAO budget. Some COO and UCO labor is covered here.
5. Programmatic Risk Assessment and Mitigation. This WBS covers analysis of the programmatic risks and some mitigation activities. Some mitigation activities are covered under the appropriate development WBS.
6. Project Reviews. Project reviews corresponding to major milestones are covered under this WBS. These include:
    a. Preliminary Design Review.
    b. Detailed Design Reviews.
    c. An intermediate Full Scale Development Review as a checkpoint during development (we may revisit the need for this review).
    d. A Pre-lab I&T Review to determine that the subsystems are ready for lab I&T.
    e. A Pre-ship Review to determine that the system and telescope infrastructure are ready for telescope I&T.
    f. An Operability Review to determine that NGAO is ready for shared-risk science.

   g. An Operations Readiness Review to determine that NGAO and the operations team are ready for Facility Class Operation.
7. Project Support. This category includes administrative and contract support, the procurement of shared infrastructure for development and/or testing purposes, and research time for postdocs and scientists working on the NGAO project.

2.3.3 Systems Engineering WBS

The Systems Engineering WBS has ten major elements:

1. Science Case Development. This WBS is the primary home for the Project Scientist and Science Advisory Team activities. These include science case and requirements development, science observing planning, science performance input to the performance budgets, science operations tools and Operations Concept Document, understanding and updating the case for NGAO's science competitiveness and liaising with the science community. This will continue to be an active area during the Preliminary Design and should move to more of a supporting role until we reach the telescope I&T and science verification phase.
2. Requirements. This category includes the development and maintenance of the Operations Concept Document, System Requirements Document, Functional Requirements database, and the software and component standards that we select for NGAO. The System and Functional Requirements were developed during the System Design phase and will require updating during the remaining design phases. The initial Operations Concept and Standards Documents will be developed during the Preliminary Design.
3. Systems Engineering Analysis. This is where all the performance budgets and the modeling and analysis tools are developed and maintained. There is a close connection with the Science Case Development WBS activities.
4. System Architecture. Four high level architectural views are developed and maintained in this WBS: system hardware, software, control systems and operations sequences. These architectures are the high level views that reach across the various subsystem (i.e., they reach across WBS 4.0 to 7.0). The system hardware architecture is the cascaded relay architecture developed during the System Design.
5. External Interface Control. This WBS covers the development and maintenance of the interface definitions to the Observatory and to the NGAO science instruments. One or more Interface Control Documents will be produced.
6. Internal Interface Control. This WBS covers the development and maintenance of the interface definitions between NGAO subsystems. One or more Interface Control Documents will be produced.
7. Configuration Control. Initially this will cover the definition of the configuration control process and subsequently the configuration control activity.
8. Documentation Control. Initially this will cover the definition of the document control process and subsequently the document control activity.
9. Technical Risk Assessment and Mitigation. This WBS covers analysis of the technical risks and some mitigation activities. Most mitigation activities are covered under the appropriate development WBS.

10. Design Manual. A System Design Manual was produced during the System Design phase. This Manual will be updated during the Preliminary and Detailed Design phases. It will ultimately be further updated to reflect the as-built system in order to provide the operations team with a complete design reference.

2.3.4 AO System WBS

WBS 4.0 includes all of the elements related to the AO system itself. One of the larger WBS elements, WBS 4.2 is shown at another level of detail in Figure 4, and one of its component elements, WBS 4.2.7 Low Order Wavefront Sensor Assembly, is shown at a further level of detail.

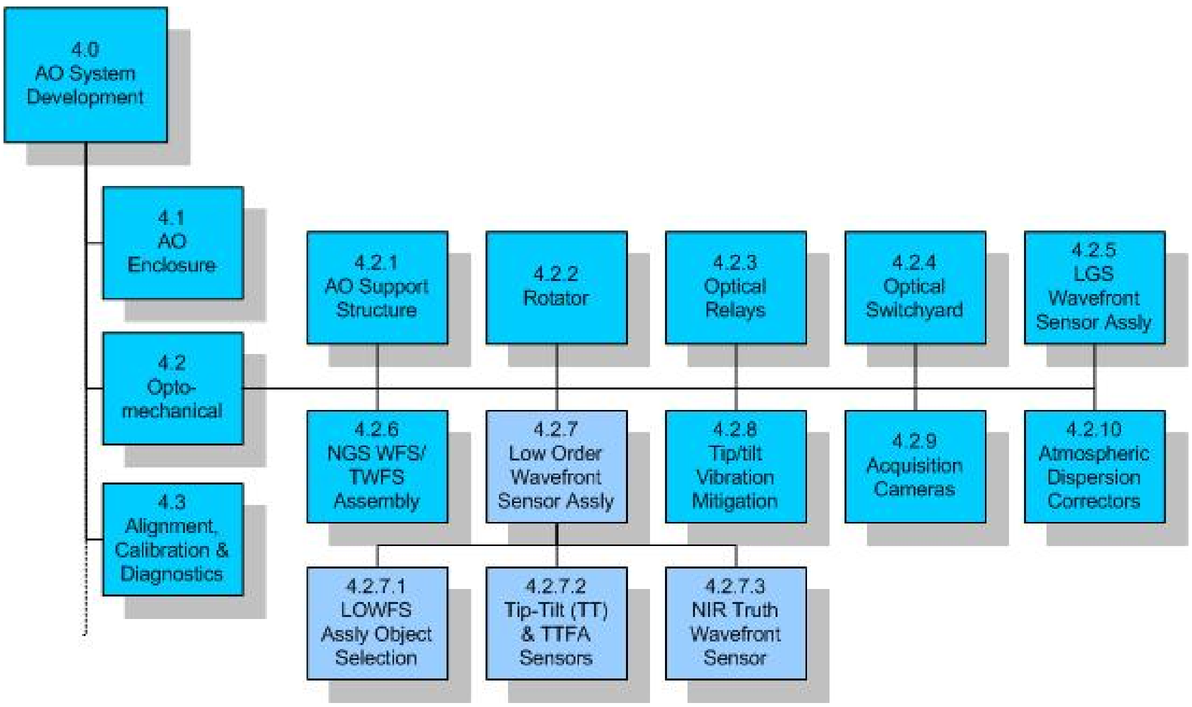

Figure 4. NGAO AO System Opto-Mechanical Work Breakdown Structure.

All of the subsystems are expected to be completed, including testing and demonstration of compliance at the subsystem level, within their WBS element. These subsystems, as well as the subsystems from WBS 6.0, are then delivered to WBS 4.6 AO system lab I&T. The output of WBS 4.6 is an AO system demonstrated to be ready for telescope I&T.

2.3.5 Laser System WBS

WBS 5.0 includes all of the elements related to the laser facility itself. All of the subsystems are expected to be completed, including testing and demonstration of compliance at the subsystem level, within their WBS element. These subsystems, as well as appropriate elements of WBS 6.0, are then delivered to WBS 5.6 laser system lab I&T. The output of WBS 5.6 is a laser system demonstrated to be ready for telescope I&T.

2.3.6 Science Operations Tools WBS

The science operations tools provide the high level coordination between the AO system, laser system, telescope and science instruments. These are the tools used to operate the NGAO system for science. The user interfaces provide the operator and astronomer interfaces to NGAO and the multi-system command sequencer provides the high level coordination. The pre- and post-observing tools are intended to support optimal observation planning and the generation of the data needed by the astronomer to make their observations scientifically useful. The data server collects and temporarily stores the required data.

2.3.7 Telescope and Summit Engineering WBS

This WBS covers the modifications needed to the telescope and summit facilities, and some existing science instruments, needed to integrate with NGAO. Currently there is no effort in the area of telescope performance, but we have left WBS 7.1 as a placeholder in case we find that it would be more cost effective to implement some changes to the telescopes performance than to achieve some performance aspect with NGAO.

2.3.8 Telescope Integration and Test WBS

This WBS covers all NGAO activities at the summit, from installation through performance characterization and science verification.

2.3.9 Operations Transition WBS

This WBS covers the development of operations plans and training of operations personnel. These activities will overlap in time with elements of other WBS elements, especially integration and test. The cost of operations personnel to be trained is covered by the Observatory.

2.4 Product Structure

A partial view of the Product Structure is provided in Figure 5. MS Project was chosen as the tool to maintain the product structure since it allows easy roll-up of the structure. The view shown in Figure 5 allows you to see the lowest product structure level for the rotator. This product structure was developed in parallel with the WBS.

ID	PBS#	Component or Assembly	Assemble	Align	Test
1	1	AO System			
2	1.1	AO Enclosure			
5	1.2	Opto-Mechanical System			
6	1.2.1	AO Support Structure			
15	1.2.2	Rotator	Y	Y	Y
16	1.2.2.1	Mirror Box	Y	Y	
17	1.2.2.1.1	Mirror Housing			
21	1.2.2.1.2	M1	Y		Y
22	1.2.2.1.2.1	Mirror			
23	1.2.2.1.2.1.1	Polished Substrate			Y
24	1.2.2.1.2.1.2	Coating			Y
25	1.2.2.1.2.2	Mount			
26	1.2.2.1.2.2.1	Fabricated Parts			
27	1.2.2.1.2.2.2	OTS Hardware			
28	1.2.2.1.3	M2	Y		Y
35	1.2.2.1.4	M3	Y		Y
42	1.2.2.2	Rotation Assembly	Y		
50	1.2.2.3	Rotator Support	Y		
60	1.2.2.4	Specialized Tools			
62	1.2.2.5	Documentation			
66	1.2.3	Optical Relays			
134	1.2.4	Optical Switchyard			
313	1.2.5	LGS Wavefront Sensor Assembly			
361	1.2.6	NGS Wavefront Sensors			
396	1.2.7	Low Order Wavefront Sensor Assembly			
454	1.2.8	Tip/Tilt Vibration Mitigation			
455	1.2.9	Acquisition Camera			
468	1.2.10	Atmospheric Dispersion Correctors			
474	1.2.11	Custom instrument interfaces			
477	1.3	Alignment, Calibration, and Diagnostics			
508	1.4	Non-Real-Time Controls			
547	1.5	Real-time Control System			
688	2	Laser System			
689	2.1	Laser Enclosure			
690	2.2	Laser			
717	2.3	Laser Launch Facility			
748	2.4	Laser Safety System			
751	2.5	Laser System Control			
790	3	Science Operations Tools			

Figure 5. Partial view of the NGAO Product Structure.

2.5 Project Milestones and Schedule

The major project milestones are shown in Table 2. Our ability to meet these milestones will strongly depend on the availability and consistency of funding. It will also depend on advance knowledge of when funding will become available since it takes time to ramp up personnel and to set up contracts.

The 22 month Preliminary Design, as discussed in section 3.4, is driven by the availability of funding. The 24 month Detailed Design phase is driven by the need to allow time to significantly increase the number of personnel at the start of the Detailed Design phase. The 18 months between the end of the Detailed Design and the start of lab I&T will only be adequate if long lead procurements can be placed during the Detailed Design. The laser procurement in particular will likely need to be placed during the Preliminary Design.

Table 2. NGAO Project milestones.

Year	Month	NGAO Project Milestone
2008	April	System Design Review
2010	February	Preliminary Design Review
2012	February	Detailed Design Review
2013	February	Full Scale Development Intermediate Review
2013	August	Pre-Lab I&T Readiness Review
2014	February	Pre-Ship Readiness Review
2014	May	NGS First Light
2014	July	LGS First Light
2014	August	15A Shared-Risk Science Availability Review
2014	December	Operational Readiness Review

Although a single date is shown for the pre-lab I&T and pre-ship readiness reviews there will likely be good reasons to have a separate earlier review for the laser system. In order to meet the aggressive summit installation schedule it would be ideal to be able to have the laser in place and tested on the sky prior to shipping the AO system to the summit.

WMKO's observing time is scheduled in six month increments beginning in February and August. Generally speaking WMKO notifies the Time Allocation Committees (TACs) of instrument availability at least five months prior to the next observing semester. The NGAO summit integration effort needs to be coordinated with this process. The successful completion of the later NGAO project milestones would therefore result in notifications of AO science availability, shown in Table 3, being sent to the TACs. For example, the project milestone of a pre-lab I&T readiness review in August, 2013 would be the milestone at which we would notify the TACs that the Keck II AO system would not be available for science in semester 14A. We would be performing science verification science in semester 14B, but no AO system would be available on Keck II for TAC-allocated science for a full year in this scenario. The Keck I AO system would be available for science during this period but the Keck Interferometer would not be able to be used for a year, except for some limited science verification in semester 14B.

Table 3. TAC notifications associated with NGAO milestones.

Date	Milestone	TAC Notification for Semester
Aug, 2013	Pre-lab I&T Readiness Review	AO system unavailable for 14A
Feb, 2014	Pre-Ship Readiness Review	AO system unavailable for 14B
Aug, 2014	Shared-Risk Science Availability Review	NGAO available for shared-risk for 15A
Dec, 2014	Operational Readiness Review	NGAO available for science for 15B

2.6 Cost Estimate

2.6.1 Introduction

The NGAO SD Phase Cost Estimate was developed through a controlled process over a period of 10 weeks following, but somewhat overlapping the AO System Design work package element. Approximately 36 work-weeks of effort went into the generation of the SD phase cost estimate, including generation of the full project WBS Dictionary, labor, non-labor, and travel estimation, science/technical performance iterations, and consistency verification. The estimate was conducted by a dozen estimators who are all technical experts and in most cases are expected to be involved in the execution of the NGAO project plan. Approximately half of the estimators have had extensive prior cost estimation experience on complex opto-electro-mechanical instrumentation projects. A full description of both the estimation process and estimator guidelines for our System Design phase cost estimate is provided in KAON 546.

2.6.2 Project Scope

The NGAO project includes a new Nasmyth-based adaptive optics instrument, comprised of a K-mirror-fed, wide-field optical relay followed by a laser guide star wavefront sensor assembly, a narrow-field science optical relay and high order NGS wavefront sensor, and a low-order natural guide star wavefront sensor assembly for use on an interim basis until the delivery of the dIFS instrument (not included within NGAO scope). NGAO also includes a a thermally-controlled AO instrument enclosure, an AO instrument diagnostics and calibration unit, and two “truth” wavefront sensors necessary to maintain precision wavefront control.

NGAO includes a new laser guide star launch facility, consisting of a baseline 100W of CW sodium D_2-line laser power providing an assumed total of ~10 photons/cm^2/millisecond returning to the telescope aperture from a median abundance sodium layer, divided into six laser guide stars. This laser asterism and power are sufficient for all NGAO narrow-field science goals. In addition, the NGAO system includes a laser projection and wavefront sensing system that supports expansion to 150W total laser power and nine laser guide star beacons and wavefront sensors, sufficient to support wide-field d-IFS science. The cost estimate presented here includes the entire projection capability and wavefront sensing for all nine laser beacons, but does not include the purchase of the incremental 50W of laser power required only by the d-IFS instrument.

Regarding instrumentation, the NGAO SD phase cost estimate does not include delivery of any new back-end science instruments *per se*, as these will be developed as separate WMKO projects. However, we do include all modifications to OSIRIS and the Keck Interferometer (KI) necessary to enable their use with NGAO.

2.6.3 Cost Estimation Process

2.6.3.1 Objectives

The primary objective of the SD phase cost estimation effort was set out to develop a comprehensive estimate of the total NGAO project cost, excluding science instruments. This includes the costs for engineering, design, analysis, procurement, fabrication, assembly, inspection, administration, installation, and commissioning of the telescope, instrumentation, and support facilities.

The cost estimates were prepared by responsible technical experts who are experienced in the various fields required to design, build, and commission the NGAO system. Vendor quotations, engineering calculations, analogies based on prior telescope programs, and parametric cost estimates were collected according the lowest level of full-project Work Breakdown Structure and by project phase. Approximately 300 BOE's were generated by ~12 estimators and organized into the NGAO SD Phase Cost Book. This documentation will include the basic configuration information and list all critical assumptions used during the estimating process. Two sample cost estimation sheets can be found in the Appendices in Sections 6 and 7.

Large, complex, and challenging projects entail uncertainty and cost risk. A contingency to cover anticipated costs resulting from this uncertainty has been developed using standardized risk analyses as established in the cost estimating plan. Contingencies have been developed at the same level of the WBS used to prepare the cost estimates.

NGAO costs will be monitored and controlled over the life of the project. The cost estimate has been integrated with the project schedule to establish a time phased budget baseline. This time-phased budget has been developed in detail for the Preliminary Design phase and at an annual cost level for the full NGAO project. A more formal project management control system will be established in the PD phase to compare actual costs with the project's budget baseline and the work accomplished.

The NGAO SD phase cost estimate is a detailed bottom-up estimate performed at the lowest reasonable level within available time. The estimate is based on the project Work Breakdown Structure (WBS), a product-oriented hierarchy that identifies all the elements of the NGAO project and their parent/child relationships. The scope of work for each WBS element will be described thoroughly in the NGAO WBS Dictionary. Each lowest-level WBS element has been estimated independently for each program phase including Preliminary Design, Detailed Design, Construction, and Commissioning. The cost estimate for each activity shall be based on the scope of work defined for the WBS element for each defined program phase. Where strong parametric relationships have been established for specific portions of the estimate, a Cost Estimating Relationship (CER) has been utilized and referenced in the BOE. All estimates are given in **Base Year (2008) dollars**.

2.6.3.2 Project Phases

For each BOE, the full cost-to-completion will be subdivided into four project phases as shown in Table 4.

NGAO Project Phase	Phase Code	Duration
Preliminary Design	PD	22 months
Detailed Design	DD	24 months
Full Scale Development	FSD	24 months
Delivery and Commissioning	DC	18 months

Table 4. NGAO Project phases and durations.

The durations are tentative for the purpose of the System Design phase cost estimation task and will be updated for future revisions of the project cost estimate. The majority of the work in the DC phase will be expended in the first 12 months, but the DC phase allows for an 18-month phase to fully complete transition to routine science operations.

For guidance on the level of maturity of design, we adopt for this costing exercise the WMKO Instrument Development Program Definitions of project phases (Adkins, S., "An Overview of the WMKO Development Phases", December 8, 2005). This is, in part, as follows:

Preliminary Design

> The preliminary design phase has two primary objectives. The first objective is to deliver documented designs for each system, sub-system and component, hardware or software, of sufficient detail to establish through inspection and analysis the feasibility of the proposed design, and the likelihood that the design will meet the requirements. The second objective is to present the project plan to completion, including a detailed schedule and budget.

Detailed Design

> The detailed design phase has two primary objectives. The first objective is to complete the design, fabrication and assembly documentation for the system and all components, hardware or software, and show that the final design complies with all specifications and applicable standards. The second objective is to present the project plan to completion, including a schedule and budget.

Full Scale Development

> The full-scale development phase builds the hardware, codes the software and integrates the complete system and performs laboratory testing culminating in the completion of an acceptance test plan followed by a pre-ship review.

Delivery and Commissioning

> The objective of the delivery and commissioning phase is to install the AO instrument on one of the Keck telescopes, verify the correct operation of all hardware and software, perform first light observations and gather the data needed to complete the Acceptance Test Plan.

2.6.3.3 Costing Methodology

Each WBS Estimator provided data for each activity within the WBS, categorized by specific labor category, non-labor category, or travel. Each item in the cost estimate was tagged with a descriptor that characterizes the method used to derive the estimate. The categories established for this project in decreasing order of general confidence, and the associated code for entry in the Cost Estimating Input Form, are shown in Table 5.

Estimating Methodology	Input Code
Direct Historical Data ("done before")	DH
Catalog Prices	CP
Vendor Quotes	VQ
Cost Estimating Relationship	CER
Engineering Estimate	EE

Table 5. Estimating Methodology

Each methodology is defined in the following fashion:

- Direct Historical Data - The use of costs demonstrated in immediate, applicable history for the same product or service.
- Catalog Prices - A known, advertised price from a potential supplier for a specific product or service.
- Vendor Quote - A quote from a potential supplier within the program estimate. Note: although useful to refining our current cost estimates, a balance must be found that satisfies project needs while not alienating vendors who often commit considerable resources for the generation of detailed price quotes.
- Cost Estimating Relationship – An estimate based on parametric relationships, analogy to another program, or by "Rule of Thumb."
  - Parametric Estimate – A statistical model based on characteristics and costs of multiple previous observations.
  - Estimate by Analogy - Scaling of costs demonstrated in previous observations using subjective or objective factors.
  - Rule of Thumb - General cost relationships demonstrated by informal studies of past programs.
- Engineering Estimate – An estimate based on the judgment of a recognized authority.

2.6.3.4 Resource Pricing

Labor, Non-Labor, and Travel costs have been based directly on information provided by the cost estimator. All Labor Resource estimates were provided in hours of direct effort required to complete the work package and/or perform the task; the cost of labor resource estimates was calculated within the cost estimating system utilizing the hours estimated. Non-Labor expenses such as materials, subcontracts, and non-travel direct costs were estimated based on the unit cost and number of units required. Travel costs were based on the number of trips, general trip location, and duration of the trip. A narrative rationale for each resource estimate was developed and included in the estimate BOE.

2.6.3.5 Labor Resources

Average NGAO labor rates for each labor category will be used when available for pricing direct labor. The labor categories used in the estimating process, the associated code for entry in the Cost Estimating Input Form, and comparable Salary Grade are provided in Table 6.

Resource	Input Code	Salary Grade
Technical Functions:		
Post Doc	PostDoc	**A**
Technician	Tech	**A**
Junior Scientist / Engineer	JunSci	**B**
Associate Scientist / Engineer	AssoSci	**C**
Information Tech. Specialist	IT	**C**
Senior Scientist / Engineer	SrSci	**D**
Lead Scientist / Engineer	LdSci	**E**
Free Labor	FL	**$0 / hr**
Business Functions:		
Administrative I	AsstAdmin	**A**
Administrative II	AssoAdmin	**B**
Management Functions:		
Subsystem Manager	SubMgr	**E**
Project Manager	ProjMgr	**E**

Table 6. Labor categories.

All estimates were provided in hours of productive effort required to accomplish the task. The rates used to price labor hours have been adjusted to include paid leave such as sick leave, vacations, holidays, etc. For estimating purposes, the typical 2,080 hour working year has been reduced to 1,800 hours to account for the expected annual productive hours. The hourly labor rates have been adjusted such that 1,800 productive hours is priced at a full year of salary. In addition, all fringe benefits and other indirect costs have been included and applied by the cost estimating system utilizing demonstrated burdening factors.

NGAO salary grades A-E were converted into quantitative labor rates using a blending of known WMKO, COO, and UCO/Lick salary rates, corresponding to specific individuals classified in these categories, and in approximately equal contribution among the NGAO partner institutions. Detailed salary figures are not included here in order to protect privileged personnel information however, we can report this summary labor rate information:

- The weighted-average salary of all labor on the NGAO project equals FY08 $92,700 per annum without benefits burden or FY08 $116,800 per annum including a 26% burden.

This corresponds to an equivalent rate of $116,800 / 1,800 = $65 / productive work hour. Excluding free labor the equivalent rate becomes $75 / productive work hour.

2.6.3.6 Non-Labor Expenses

All non-labor and non-travel expenses that will be directly charged to NGAO have been included as a non-labor expense estimate. This includes, but is not limited to, all subcontracts, materials and equipment, and shipping costs. All non-labor estimates have been placed into the appropriate category to identify the type of activity that will take place. The categories, and the associated code for entry in the Cost Estimating Input Form, are provided in Table 7.

Category	Input Code
Equipment	EQP
Material	MAT
Subcontract	SUB
Shipping	SHIP
Other Direct Cost	ODC

Table 7. Non-labor categories.

2.6.3.7 Travel

All travel in support of an activity has been included as part of the input sheet submitted for that item. Travel estimates were performed by determining the number of trips that will be required based on the general location and duration. Travel destinations and durations, and the associated codes for entry in the Cost Estimating Input Form, are shown in Table 8 and Table 9, respectively.

Destination	Input Code
Intra - California	CALIF
Hawaii - California	HAWAII
International (Origination/Destination unspecific)	INTER
Other locations not included in above list	OTHER

Table 8. Travel destination categories.

Duration	Input Code
Extended: More than three weeks.	EXT
Long: Greater than one week but less than 3 weeks.	LONG
Mid: Greater than 3 days but less than 1 week.	MID
Short: Three days or under	SHORT

Table 9. Travel duration categories.

Travel applicable to conferences, project-wide reviews, outreach, and funding source meetings has been included as costs in the NGAO Project Management WBS 2 element and not as part of the input sheets submitted for a particular item.

Estimators assumed that entire Level 3 WBS elements (e.g. WBS 4.4) will be executed entirely within a single partnership organization. (I&T elements, of course, will require multiple institution participation and are expected to require considerable travel.)

We have included the labor costs for travel itself (e.g. time 'sitting on a plane') in the travel section of our cost summarizes, depending on the duration of each flight. Estimators therefore included in their WBS element labor resource estimates only the actual work hours spent at the destination site, and not labor hours while traveling.

2.6.3.8 Shipping

Shipping for each element to its integration point, assumed to be WMKO headquarters facility in Kamuela, HI, has been included with the estimate for that cost element. The cost of shipping integrated elements from WMKO to the summit has been estimated as a cost for the Integration and Test element of the WBS. Insurance costs for all shipments between California and Hawaii have not been specifically included, as each of WMKO, COO, and UCO/Lick typically self-insures.

2.6.3.9 Sales Tax

We assume the NGAO project will incur sales / use taxes on some but not all purchases, depending on the organization making the purchase, the location of the vendor, and other factors. Out-of-state procurements are charged sales tax in California but not in Hawaii. Based on a cursory assessment of a plausible procurement division between the NGAO partners, we have currently adopted an 'effective' sales tax rate of 3.00% which we apply to all non-labor EQP and MAT cost categories.

2.6.4 Cost Estimates

2.6.4.1 Estimate to Completion

Our System Design phase full project Estimate to Completion (ETC) based upon the above described methodology is summarized as a function of WBS in Table 10 and by NGAO project phase in Table 11.

We note that labor and non-labor costs (which includes some labor costs as subcontracts) are comparable to one another. Compared with previously built AO systems, this ratio overweights project labor, reflecting our belief that NGAO will require significant systems engineering, software development, I&T, and telescope commissioning to ensure satisfaction of all flow-down requirements to ultimately meet performance goals.

WBS	WBS Title	Prelim. Design	Detailed Design	Full Scale Develop-ment	Delivery & Commiss.	Base Cost ($K, FY08)	Contin-gency	Total
2	Management	874	1,232	1,594	657	4,356	318	4,674
3	Systems Engineering	811	1,004	478	193	2,485	401	2,886
4	AO System Development	730	2,208	9,742	3	12,683	3,849	16,533
5	Laser System Development	285	1,947	6,619	128	8,980	1,935	10,915
6	Science Operations	166	756	646		1,568	233	1,801
7	Telescope & Summit Eng.	95	424	1,049	19	1,587	344	1,932
8	Telescope Integr. & Test	46	106	114	1,944	2,211	525	2,735
9	Operations Transition	14	20	555	70	660	91	750
	Sub-Totals ($K, FY08)	3,021	7,697	20,797	3,015	34,530	7,697	42,227

Table 10. NGAO cost estimate (in FY08 $k) by WBS

Phase	Labor (PY)	Cost Estimate (FY08 $k)						% of NGAO Budget
		Labor	Non-Labor	Travel	Sub-Total	Contin-gency	Total	
Preliminary Design	21.0	2,582	216	224	3,022	458	3,479	8%
Detailed Design	43.6	5,516	1,827	354	7,697	1,403	9,100	22%
Full Scale Develop	50.5	5,661	14,510	626	20,797	5,234	26,031	62%
Delivery/ Commission	22.4	2,287	250	478	3,015	602	3,617	9%
Total =	**138**	16,045	16,804	1,681	**34,531**	7,697	**42,227**	100%
% =		38%	40%	4%	82%	18%	100%	

Table 11. NGAO cost estimate (in FY08 $k) by project phase.

2.6.4.2 Cost Comparison

In order to provide ourselves with an external check of our ‘bottom-up’ cost estimation methodology, we have tabulated the known, expected, or budgeted costs of several comparable AO systems, which we present in Table 12. The notes associated with this Table can be found in Table 13.

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NGAO Cost Estimate Comparisons

All quantities are in thousands, FY$08

	NGWFC	Notes 11,12	PALM 3000	Notes 21	Keck II LGS AO	Notes 31,32	GPI	Notes 41,42	GEMS	Notes 51,52	NGAO	Notes 61	NFIRAOS	Notes 71
Sodium Laser Power	--		8W	22	14W	33	NGS		50W	53	100W	62	150W	72
Summary Costs														
Labor Costs	$ 1,217		$ 3,798		--		$10,673		$ 5,667	54, 55	$ 16,045		$ 3,873	73
Non-Labor Costs	$ 996	13,14	$ 1,623		--		$ 3,264		$14,771	55	$ 16,804		$ 58,135	74
Travel	$ 19		$ 67		--		$ 467	43	$ 439		$ 1,681	63	--	
Contingency	--		$ 1,572	23	--		$ 5,183	44	--	56	$ 7,697	64	$ 22,007	75
Total Costs	$ 2,232		$ 7,060		$ 15,206	34	$19,587	45	$22,000	57	$ 42,227	65	$ 90,871	76
Specific WBS Costs (w/ contingency)														
Management	--		$ 686		--		--		--		$ 4,674	WBS 2	$ 3,682	77
Systems Engineering	--		$ 296		--		--		--		$ 2,886	WBS 3	$ 2,695	78
AO System Development	--		$ 3,707		--		--		$ 6,201		$ 16,533	WBS 4	$ 45,896	79
Laser System Development	$ 0		$ 149	24	$ 1,515	35	$ 0		$ 5,190		$ 10,915	WBS 5	$ 35,395	80
AO System I&T	$ 293	15	$ 315	25	--		--		--		$ 2,735	WBS 8	--	
Science Ops Transition	--		$ 396		--		--		--		$ 750	WBS 9	$ 0	
RTC (total)	$ 805	13	$ 573	26,27	$ 1,245	36	--		$ 990		$ 2,241	WBS 4.5.1	--	
Adaptive Mirrors (total)	--	16	$ 935	28	$ 516	37	--		$ 1,367	58	$ 2,032	WBS 4.5.2	--	

-- = Data Not Available

Table 12. NGAO cost comparison to similarly complex AO systems.

Notes

11 Based on E. Johansson's 3/10/08 spreadsheet summarizing labor costs (only)
12 NGWFC project includes WFC upgrades to both Keck I and Keck II telescopes, and a 3rd 'lab development' system
13 Includes $720,000 FY05 subcontract to Microgate, with 3 years x 4% escalation
14 As an upgrade, reused existing infrastructure (racks, network switches, terminal servers, etc.)
15 includes I&T on both telescopes
16 There were no adaptive mirror costs for this wavefront controller upgrade

21 Based on A. Bouchez' 3/7/08 spreadsheet mapping PALM-3000 upgrade costs onto NGAO WBS.
22 The 8W Chicago Sum Frequency Laser was developed prior to PALM-3000 and its costs are not included here.
23 Corresonds to 29%. As of 3/17/08, contigency funding for PALM-3000 has not been fully secured.
24 Includes Laser Guide Star Facility maintenance only.
25 PALM-3000 is an upgrade of existing PALMAO LGS system, reusing many components with new optical layout, new HOWFS, new RTC, and some new non-RTC software.
26 RTC based upon parallel NVIDEA GPU architecture developed at JPL; includes a copy 'lab development' system
27 RTC supports 64^2 subap, 128^2 pixels quad-cell, 3717 total actuator full VMM reconstructor at 2kHz update rate and < 220 microsec RTC compute latency
28 Includes $800,000 Xinetics, Inc. 66^2 actuator DM (112mm diameter beam) and drive electronics

31 Based on P. Wizinowich actuals spreadsheet of 3/8/08
32 Includes assumed escalation for each actual year costs during 1993-2007 project costs
33 Keck II LGS utilizes a 14W short-pulse laser developed by LLNL
34 Includes some AO team operations and spotter costs; cost to milestone of 1st TAC-allocated science night
35 Original budget for laser contract; was exceeded by unknown amount
36 Original budget for wavefront controller; was exceeded by unknown amount
37 For single 349 actuator Xinetics DM (140 mm beam) including electronics

41 Based on input from D. Palmer, 3/23/08
42 The full GPI project includes a back-end IFS instrument not costed here (cost approx. $4.6M, including $250K for data analysis pipeline (est.))
43 Actual travel reported to be greater than this budget (D. Palmer, private communication).
44 Includes $1,183K project contingency and $4,000K of contingency held by Gemini Observatory for the GPI project
45 Includes Gemini-held contingency but not the back-end IFS instrument

51 Based on our understanding of M. Boccas figures presented 9/5/07. GEMS delivery includes many significant subcontracts so mapping into NGAO WBS is quite approximate.
52 Includes assummed escalation of 4% per annum from mid-point of 2000-2009 project, or 4% x 3 years ~ 12% escalation
53 GEMS uses a 50W LMCT laser being developed jointly with new a 20W LMCT laser for Keck Observatory
54 Project office and partial science support staff labor only; subcontract labor included in 'non-labor' total as procurements
55 GEMS labor costs do not include labor component of FY08$13,161,000 worth of industrial subcontracts
56 Budget estimate as of Sept 2007; project development in progress.
57 Approximate total cost to complete based on available data; uncertainty in our interpretation of project scope boundary estimated to be 5-15%
58 Includes three PZT stack DM's (17^2, 17^12, and 9^2 actuators, 80mm diameter beam)

61 Includes BTO and WFS suite ready for 9 LGS beacons, with initial projection of 6 beacons
62 NGAO assumes 2 x 50W SOR lasers equivalent return; actual laser selection has not occurred.
63 NGAO assumes 175/335/13 California/Hawaii/International trips
64 Corresponds to 22%
65 Approximately $1M in observatory infrastructure costs not included

71 Based on TMT Cost Book (June 2007); includes IR WFS subsystem for the IRIS instrument
72 NFIRAOS baseline is 3 x 50W LMCT lasers based on design developed for Keck I LGS / GEMS
73 Includes project office Management and Systems Engineering only; all NFIRAOS instrument and LGSF labor considered as subcontracts
74 Includes NFIRAOS, project office led component development, and IRIS IR low-order WFS's
75 Corresponds to 35.5%
76 Escalated FY06$ by (1.04)^2; after removing $2.6M attributable to future AO system development
77 Project office management only (e.g. does not include NFIRAOS or LGSF systems engineering)
78 Project office systems engineering only (e.g. does not include NFIRAOS or LGSF systems engineering)
79 Includes NFIRAOS, all AO system component development, IRIS IR WFS, AO system I&T, and 41% contingency
80 Includes laser enclosure, beam delivery and launch facility, 3 x 50W sodium lasers, and 26% contingency

Table 13. NGAO cost comparison notes.

Although we believe our bottoms-up estimate to be solid, we gain additional confidence in our cost estimates by comparison with independent costing of similar recent and proposed AO systems, as shown in Table 12. Compared to the original Keck II LGS system, for example, our NGAO estimate has significantly increased, as expected, reflecting the greater technical challenge of achieving better wavefront control. Much of the additional cost for NGAO arises from the need for ~ 10 photons/cm^2/millisecond returning from the sodium layer to the telescope aperture at zenith, more than 10 times that from the current Keck II LGS system. The approximately $27M greater cost for NGAO is roughly attributable to ~$9M more for lasers, ~$6M more for wavefront sensors, ~$3M more for the 2nd stage AO relay, approximately ~$5M more for increased labor due to greater systems engineering and I&T complexity, and ~$4M greater contingency.

Compared with Gemini GPI, which uses a similar MEMS DM to our baselined NGAO 2nd relay DM, our bottom-up NGAO cost estimate, excluding the laser system (WBS 5) for a fairer comparison with the NGS GPI system, is somewhat higher, reflecting the multi-instrument and multi-functional nature of NGAO. The approximately $23M greater NGAO cost, relative to GPI, can be attributed as ~$13M to the 100W laser system (including contingency), ~$5M to wavefront sensors, and ~$6M to greater system complexity.

Compared to the Gemini South MCAO system, GEMS, the incremental cost of NGAO is also attributable in a self-consistent way. The approximately $20M additional cost for NGAO is attributable to approximately ~$4M for greater laser costs (100W v. 50W), ~$4M for wavefront sensors, ~$1M for real-time-computer, ~$3M for the 2nd stage AO relay, $4M for greater system complexity, and $4M for increased contingency (all relative to the GEMS baseline budget.)

Compared with the TMT NFIRAOS budget, our NGAO cost estimate is significantly less, reflecting we believe an overall lower technical and cost risk, incorporating our understanding of costs incurred on the original Keck II LGS AO system. From a component perspective, NGAO saves cost on the laser guide star facility, less expensive piezostack DM(s) (requiring less stroke), less expensive LGS WFS detectors (offset by our need for nine vs. six sensor channels), less expensive LGS WFS optics and mechanics, and less expensive instrument structure and enclosure. We also project lower RTC costs relative to NFIRAOS, in part due to improved computing components and architecture, and in part due to a different development model. Moreover, the use of existing components[1] in nearly all NGAO subsystems eliminates the need for component development. Finally, we have elected an approach to laser procurement that carries some risk, namely a collaborative laser development, as opposed to TMT's commercial procurement strategy. Resolving this major project risk is a key goal for the preliminary design phase.

2.6.4.3 Preliminary Design Phase Cost Estimate

A more detailed breakdown of costs during the preliminary design phase is shown in Table 14. This table shows the WBS level at which the cost estimate was prepared. Similar tables for the other three project phases, and the overall total cost, are provided in the Appendices in Sections 8 to 11.

Our division of effort in the Preliminary Design phase emphasizes systems engineering (including further refinement of the science case and flow down requirements, such as astrometric requirements), AO system development, and laser system development. WBS 2, Management, includes project-wide support, including items such as software licenses that are shared resources not directly attributable to specific NGAO subsystems.

[1] The notable exception is the 64x64 MEMS DM, but this is a critical development for GPI and expected by 2009.

		Labor					$k			% of WBS in this	
		hrs	PY	Trips	Labor	Non-labor	Travel	Conting	Total	Phase	
2	**Management**										**926**
2.1	Planning	1570	0.9	0	158	0	0	8	166	36%	
2.2	Project Management & Meetings	2170	1.2	22	199	0	66	13	278	26%	
2.3	Tracking & Reporting	829	0.5	7	94	0	14	5	113	16%	
2.4	Proposals & Fundraising	40	0.0	0	5	0	0	0	5	50%	
2.5	Programmatic Risk Assessment & Mitigation	180	0.1	0	21	0	0	2	23	33%	
2.6	Project Reviews	456	0.3	13	48	0	33	4	85	10%	
2.7	Project Support	3361	1.9	4	166	59	12	19	255	16%	
3	**Systems Engineering**										**909**
3.1	Science Case Development										
3.1.1	Science Requirements	2260	1.3	5	108	2	5	8	123	65%	
3.1.2	Science Observing Planning and Execution	420	0.2	0	22	0	0	2	24	20%	
3.1.3	Science Input to Other WBS Elements Affecting Sc	130	0.1	7	5	0	11	3	20	28%	
3.1.4	Science Competitiveness	104	0.1	4	4	0	22	2	28	33%	
3.1.5	User Community Liason	70	0.0	2	3	0	2	0	5	25%	
3.1.6	Science Advisory Team Meetings	160	0.1	8	8	0	7	1	16	25%	
3.2	Requirements	1094	0.6	0	84	0	0	7	90	29%	
3.3	Systems Engineering Analysis										
3.3.1	Performance Budgets	748	0.4	4	82	0	4	17	103	28%	
3.3.2	Modeling & Analysis	880	0.5	4	81	0	9	18	107	38%	
3.3.3	PSF Calibration	0	0.0	2	0	0	5	0	5	3%	
3.4	System Architecture										
3.4.1	System Hardware Architecture	264	0.1	0	25	0	0	7	32	26%	
3.4.2	Motion Control / Electronics Architecture	80	0.0	0	8	0	0	2	10	26%	
3.4.3	System Software Architecture	304	0.2	0	30	0	0	7	36	37%	
3.4.4	Operations Sequences Architecture	224	0.1	1	18	0	3	4	25	26%	
3.5	External Interface Control	284	0.2	0	25	0	0	1	26	53%	
3.6	Internal Interface Control	280	0.2	4	23	0	9	4	36	18%	
3.7	Configuration Management	218	0.1	0	12	0	0	5	16	34%	
3.8	Documentation Control	20	0.0	0	2	0	0	0	2	15%	
3.9	Technical Risk Assessment & Mitigation	700	0.4	0	71	108	0	9	188	38%	
3.10	System Manual	120	0.1	0	14	0	0	1	15	36%	

4	**AO System Development**										**939**
4.1	AO Enclosure	300	0.2	0	22	0	0	3	25	3%	
4.2	Optomechanical										
4.2.1	AO Support Structure	160	0.1	0	12	0	0	3	15	5%	
4.2.2	Rotator	120	0.1	0	9	0	0	2	11	10%	
4.2.3	Optical Relays	533	0.3	0	39	0	0	12	50	6%	
4.2.4	Optical Switchyard	400	0.2	0	29	0	0	9	38	5%	
4.2.5	LGS Wavefront Sensor Assembly	1520	0.8	0	111	0	0	39	150	5%	
4.2.6	NGS WFS / TWFS Assembly	628	0.3	0	35	0	0	7	42	8%	
4.2.7	Low Order Wavefront Sensor Assembly	1596	0.9	2	108	0	2	43	153	7%	
4.2.8	Tip/Tilt Vibration Mitigation	80	0.0	0	6	0	0	1	6	2%	
4.2.9	Acquisition Cameras	128	0.1	0	9	0	0	1	10	8%	
4.2.10	Atmospheric Dispersion Correctors	240	0.1	0	17	0	0	5	22	10%	
4.3	Alignment, Calibration, and Diagnostics										
4.3.1	Simulator	250	0.1	0	19	0	0	3	22	7%	
4.3.2	System Alignment Tools	255	0.1	0	20	0	0	3	23	14%	
4.3.3	Atmospheric Profiler	0	0.0	0	0	0	0	0	0	0%	
4.4	Non-real-time Control										
4.4.1	AO Controls Infrastructure	0	0.0	0	0	0	0	0	0	0%	
4.4.2	AO Sequencer	140	0.1	0	12	0	0	4	15	15%	
4.4.3	Motion Control SW	230	0.1	0	19	0	0	7	26	7%	
4.4.4	Device Control SW	240	0.1	0	20	0	0	8	27	9%	
4.4.5	Motion Control Electronics	60	0.0	0	5	0	0	2	7	2%	
4.4.6	Non-RTC Electronics	160	0.1	0	13	0	0	4	18	12%	
4.4.7	Lab I&T System	0	0.0	0	0	0	0	0	0	0%	
4.4.8	Acquisition, Guiding, and Offloading Control	160	0.1	0	13	0	0	4	17	21%	
4.5	Real-time Control										
4.5.1	Real-time Control Processor	3037	1.7	0	147	16	0	46	208	9%	
4.5.2	DM's and Tip/Tilt Stages	320	0.2	1	25	0	3	3	31	2%	
4.6	AO System Lab I&T	200	0.1	0	20	0	0	1	21	2%	
5	**Laser System Development**										**339**
5.1	Laser Enclosure	160	0.1	0	12	0	0	3	14	9%	
5.2	Laser	820	0.5	4	86	0	15	10	111	2%	
5.3	Laser Launch Facility	856	0.5	0	61	20	0	26	106	5%	
5.4	Laser Safety Systems	170	0.1	0	13	0	0	2	15	8%	
5.5	Laser System Control	910	0.5	0	75	0	0	12	87	11%	
5.6	Laser System Lab I&T	48	0.0	0	4	0	0	1	5	1%	
6	**Science Operations**										**185**
6.1	Multi-System Command Sequencer										
6.1.1	Sequencer Infrastructure	180	0.1	0	18	0	0	2	20	10%	
6.1.2	Setup Sequences: Configurations & Calibrations	100	0.1	0	10	0	0	1	11	11%	
6.1.3	Observing Sequences	240	0.1	0	24	0	0	3	26	11%	
6.1.4	System Health and Troubleshooting	100	0.1	0	10	0	0	1	11	9%	
6.2	User Interfaces										
6.2.1	User Interface Infrastructure	180	0.1	0	18	0	0	2	19	18%	
6.2.2	Setup Operations: Configuration, Calibrations	80	0.0	0	8	0	0	1	9	12%	
6.2.3	Observations User Interfaces for operator, observe	240	0.1	0	24	0	0	2	26	15%	
6.3	Pre- & Post-Observing Support										
6.3.1	Users' Documentation	20	0.0	0	2	0	0	0	2	8%	
6.3.2	Planning Tools	340	0.2	0	30	0	0	3	33	10%	
6.3.3	Data Products	250	0.1	0	18	0	0	3	21	7%	
6.4	Data Server	70	0.0	0	6	0	0	2	8	7%	
7	**Telescope & Summit Engineering**										**116**
7.1	Telescope Performance	0	0.0	0	0	0	0	0	0	0%	
7.2	Infrastructure Mods for AO	660	0.4	1	45	5	4	14	68	7%	
7.3	Infrastructure Mods for Laser	280	0.2	0	22	0	0	5	27	4%	
7.4	OSIRIS Modifications	100	0.1	0	8	0	0	1	9	6%	
7.5	Interferometer and OHANA Mods	61	0.0	0	5	6	0	1	12	10%	
8	**Telescope Integration & Test**										**50**
8.1	Old AO/Laser Removal	120	0.1	0	8	0	0	1	8	3%	
8.2	Laser Enclosure Integration	0	0.0	0	0	0	0	0	0	0%	
8.3	AO Enclosure Integration	0	0.0	0	0	0	0	0	0	0%	
8.4	AO System Install + I&T	170	0.1	0	11	0	0	1	12	2%	
8.5	Laser System Install + I&T	212	0.1	0	16	0	0	1	18	6%	
8.6	LGS AO System On-sky I&T	40	0.0	0	3	0	0	0	4	1%	
8.7	Performance Characterization	0	0.0	0	0	0	0	0	0	0%	
8.8	Science Verification	80	0.0	0	8	0	0	1	9	4%	
9	**Operations Transition**										**15**
9.1	Operations Plans	96	0.1	0	7	0	0	0	7	1%	
9.2	Operations Handover										
9.2.1	Operations Personnel Training	50	0.0	0	5	0	0	1	6	7%	
9.2.2	Documentation & Spares Transition	20	0.0	0	2	0	0	0	2	9%	
	Total =	34375	19	95	2582	216	224	458	3479	8%	**3479**

Table 14. Preliminary Design phase cost estimate (FY08 $).

2.6.4.4 Key Cost Risks

The single largest known component cost uncertainty is associated with the NGAO sodium guide star lasers. Our strategy for procurement of appropriate guide star lasers relies on early negotiation and establishment of the principle of technology transfer from the StarFire Optical Range (SOR) in Albuquerque, New Mexico. In the event that access to SOR technology is precluded for whatever reason, increased costs for sodium guide star laser procurement may be incurred. Depending on commercial vs. academic options, this outcome could increase NGAO laser costs by several million dollars.

NGAO programmatic risk also causes us to incur financial risk. The NGAO project is structured to rely on successful raising of private instrument funding, as it is not expected to be feasible within the envelope of Keck Observatory operations and TSIP-generated instrumentation funds alone. In particular, the proposed $3.4 million preliminary design phase expenditure represents a significant outlay risk to the Observatory. If private funding is not successful and the NGAO project suspended at or before PDR, a significant fraction of this investment will be lost. Offsetting this, the NGAO management team has identified the following durable benefits to WMKO to be achieved by NGAO PDR:

- Installation of a MASS/DIMM atmospheric profilometer at Keck Observatory, enabling improved on- and off-axis PSF calibration with the existing Keck AO systems.
- Demonstration of ‘single laser’ tomography algorithms that are expected to reduce focal anisoplanatism error, the dominant wavefront error source for the center-projected Keck I LGS AO system.
- Prototyping work of infrared LOWFS subsystems in the NGAO PD phase will result in hardware that could be used as part of a single-channel near-IR tip/tilt sensor for Keck I or Keck II AO. Implementation of such a sensor would require a separately funded WMKO project, but the NGAO investment is estimated to be > 50% reallocatable.
- Improved designs for atmospheric dispersion correctors could benefit the Keck LGS AO systems, even if NGAO did not proceed beyond PDR.

2.6.4.5 Potential Cost Savings

During the Preliminary Design phase, we intend to explore a number of specific issues that we believe have the potential for significant cost savings. Each of the following questions will be answered within the first six months of the PD phase:

- Is the cost/benefit ratio of ‘Point and Shoot’ TT and TTFA star sharpening justified by a detailed analysis?
- Is LGS HOWFS barrel rotation, selected in the SD Phase on the basis of wanting one-to-one subaperture to DM actuator registration, necessary, or can sufficient performance be achieved by developing reconstructors that encode the variable (but known) pupil rotation geometry. We will engage with ESO and/or TMT to seek mutual benefit from such investigations.

- Can uplink AO sharpening of our sodium beacon be cost-effectively implemented to reduce the total NGAO sodium laser power requirement?
- Can one or more Rayleigh beacons be cost-effectively implemented to either 1) reduce the number of NGS IR LOWFS stars from three to one (potentially saving ~$1M) and/or 2) reduce the total sodium laser power requirement (by augmenting expensive sodium photons with low-cost Rayleigh photons)?

In addition, we will actively monitor other activities underway around the world that may lead to component cost savings, such as better understanding of sodium return as a function of laser spectral content and pulse format, and advances in fast frame rate, low noise CCD development.

2.6.4.6 Estimate Refinement

In developing the next iteration of the cost estimate during PD phase, we will refine the estimate to include a more fulsome development of the lowest level WBS available. We will increase our direct communications with vendors and move a larger fraction of cost estimates into the Vendor Quote (VQ) category. We will also refine our labor rates to reflect actual rates of specific individuals identified as assigned to each WBS element and/or cost account. Finally, we expect to refine the bases of estimate to replace a substantial fraction of estimates classified as Engineering Estimate (EE) to our increasingly higher fidelity bases: Cost Estimating Relationship (CER), Direct Historical (DH), and Vendor Quote (VQ) respectively.

2.7 Risk Assessment and Management

A programmatic risk assessment was performed and documented in KAON 566 along with proposed mitigation efforts. A technical risk assessment and mitigation plan was similarly documented in KAON 510. Both KAONs use the JPL risk management approach of ranking risks by likelihood and consequences.

2.8 Configuration and Documentation Management

There are a number of configuration items that will need to be managed. These include requirements, interface definitions, designs, plans, spares inventory, etc.

Documentation management is expected to be performed with the following tools:

- All technical and programmatic notes to continue to be given a Keck Adaptive Optics Note (KAON) number. These documents will be maintained on the NGAO Twiki site and also on the more protected Keck Docushare site.
- Requirements to continue to be maintained in the Contour database (see section 2.9).
- Interface definitions to be input and maintained in the Contour database.
- SolidWorks mechanical models to be maintained in a shared repository. Mechanical drawings to ultimately be maintained within the Keck Mechanical group database using assigned numbers.

- Electronics drawings to be maintained within the Keck Electronics group database using assigned numbers.
- Spares inventory to be integrated within the Keck Electronics group spares inventory.
- Preventative maintenance tasks to be integrated within the Keck Facilities group preventative maintenance program database.

An NGAO Configuration Control Board (CCB) will be formed to review and approve changes to the requirements, interfaces, designs and drawings. The CCB will use similar tools and procedures as used by existing Keck CCBs (for example the AO CCB and the Interferometer CCB). Keck's existing Engineering Change Request (ECR) and Field Change Notices (FCN) will be used to request approval for changes.

The requirements and interface definitions will fall under CCB responsibility during the Preliminary Design phase. Design changes will fall under CCB responsibility during the Detailed Design.

CCB responsibilities will be handed over to a Keck operation's CCB at the time of the Operability Review.

2.9 Interface Definition

Both external and internal interfaces will be defined during the Preliminary Design phase. An N-squared diagram will be developed for interfaces between NGAO subsystems.

2.10 Requirements Management and Compliance

KAON 573 describes our approach to requirements development and management. All requirements from the Science Case Requirements (KAON 455) and System Requirements (KAON 456) Documents, as well as the Functional Requirements, are maintained in a requirements management software database (e.g., the Contour tool by JAMA software). This database is web accessible from each of our three institutions.

Compliance testing versus requirements will be performed at the subsystem, system and science levels, corresponding to the functional, systems and science requirements, respectively as shown in Figure 6.

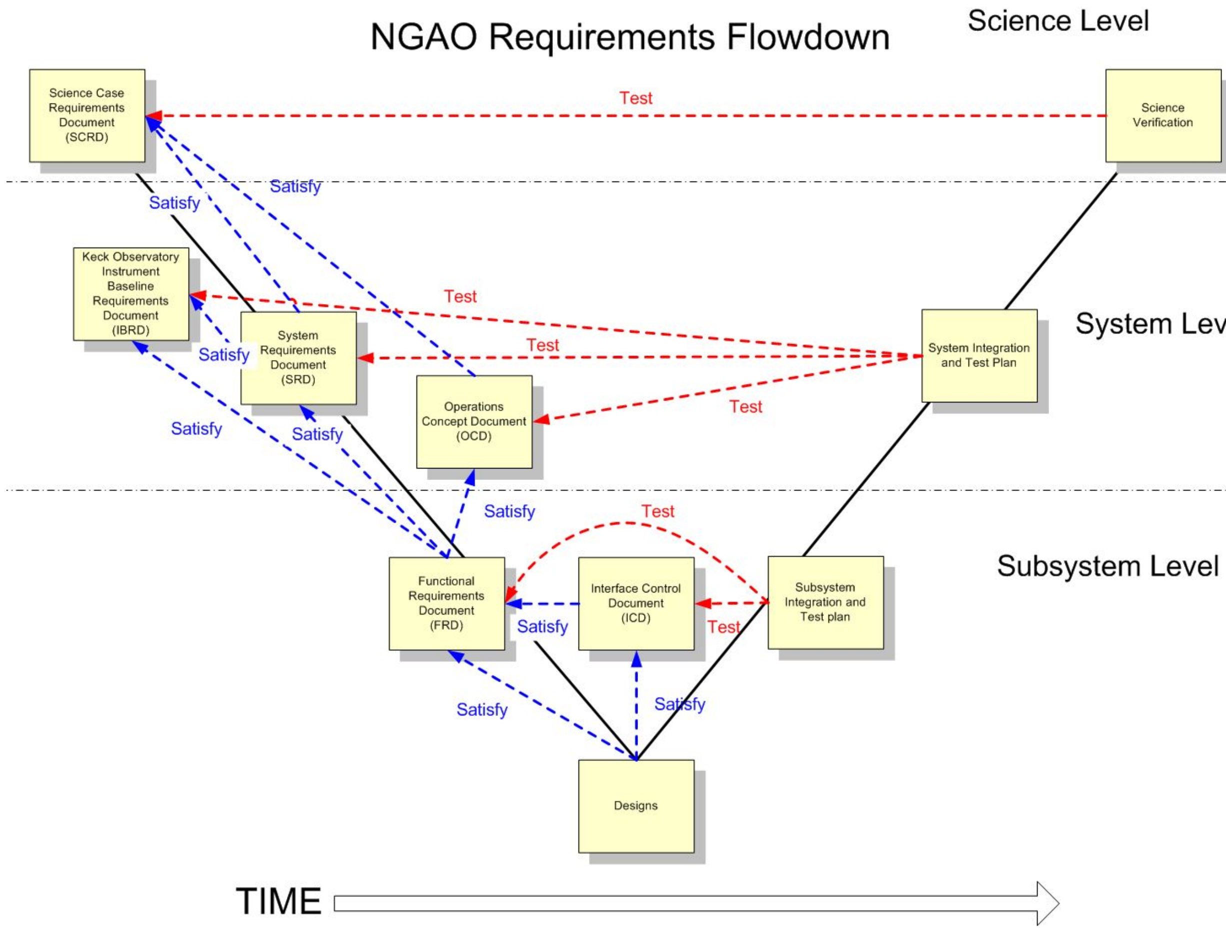


Figure 6. Modified V-diagram shown the requirements flowdown and relationship to testing.

2.11 Integration and Test

Our approach to integration and test is documented in KAON 581 and is shown schematically in Figure 7, along with the WBS numbers for each activity. This Figure is divided into subsystem development, lab I&T, summit preparation and telescope I&T sections. A philosophy that will be followed throughout this process is for subsystems and systems to be complete, including testing versus requirements, prior to transitioning to the next phase. This will be ensured by appropriate Reviews.

The subsystem development (WBS 4.0 to 6.0) and summit preparation (WBS 7.0) phase begins with the successful completion of the Detailed Design Review. These subsystems are intended to be complete and fully tested at the subsystem level prior to system lab I&T. Their readiness, as well as the readiness of the lab facilities, will be evaluated at a pre-lab I&T Readiness Review. The AO and laser systems undergo separate lab I&T efforts since they can largely be treated independently.

Readiness of the AO and laser systems, as well as the summit infrastructure to proceed to telescope I&T will be evaluated at a pre-ship review. Successful completion of this review will result in installation at the telescope followed by a sequence of I&T activities.

The pre-lab and pre-ship I&T Readiness Reviews will likely be separate events for the laser and AO system. Ideally the laser would have been implemented on the telescope prior to the AO system pre-ship review in order to minimize the time between decommissioning the existing AO system and implementing NGAO.

The Operability Review is a milestone intended to mark the point where the system and operations are ready to support shared-risk science observations. The system will continue to be characterized and optimized prior to the final handover to operations and regular science operations which will be marked by the Operations Readiness Review.

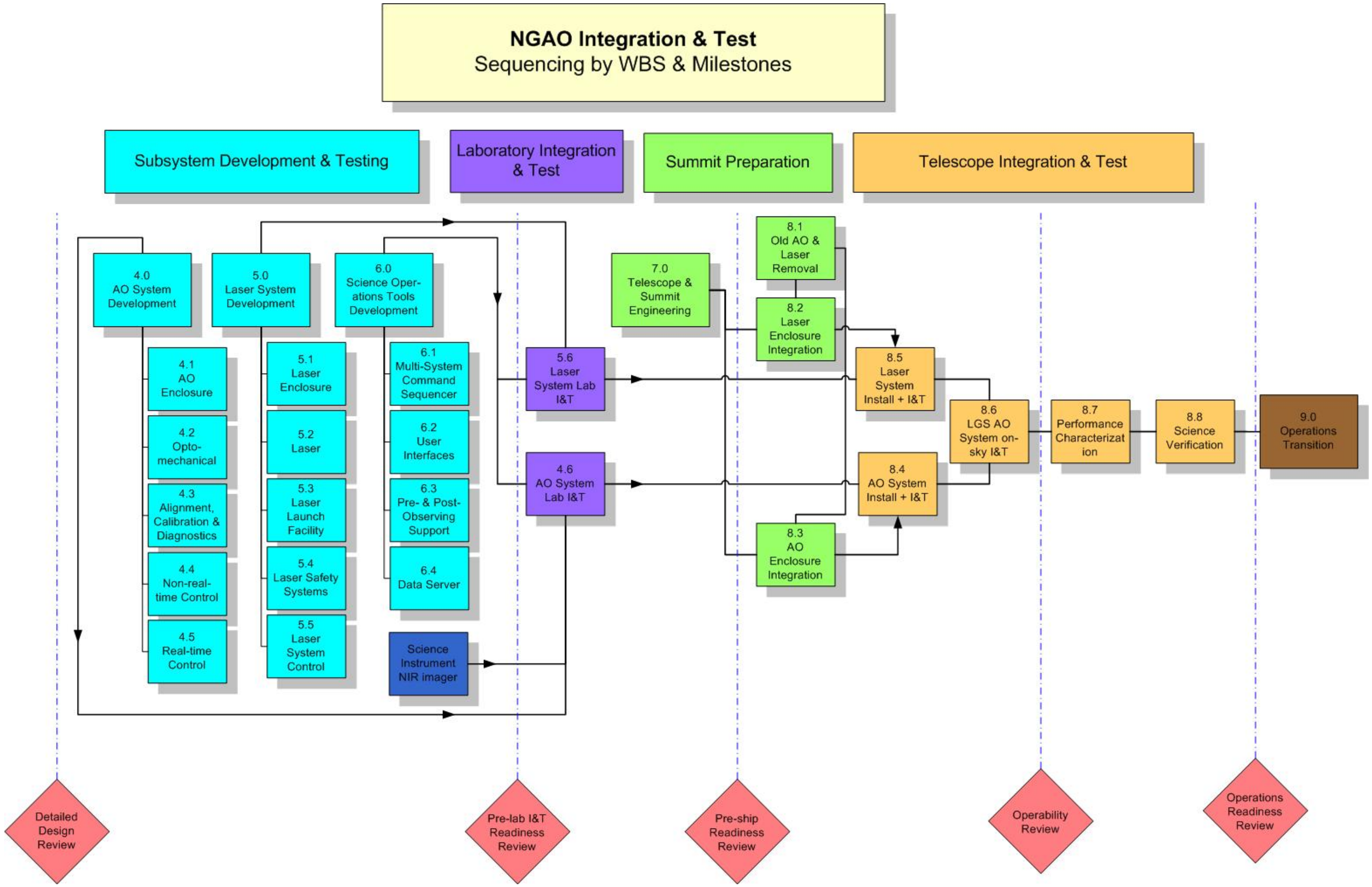


Figure 7. NGAO Integration and Test Approach.

2.12 Component Failure and Spares Approach

Two component failure issues need to be addressed: failures during development and failures during operations. The impact of failures during development and operations are different. Spares are one way to address failures and need to be considered in this context. Highly reliable components should be the standard.

The impact of a component failure depends on the development phase, its criticality to the subsystem and overall system, and the required time to troubleshoot, repair or replace the component. The failure of a key component during subsystem development could potentially result in the late delivery of a subsystem and the delay of system integration and test. The failure of a key component during lab or telescope integration and test could result in significant cost and schedule impacts.

A component failure during a science night must be addressed immediately, preferably by having a back-up mode of the instrument that does not require this component. It is important to have good tools and procedures for quickly identifying and repairing or replacing the failed component. The failed component should be able to be replaced or repaired prior to the next night or in the worst case before the next observing run.

A preventative maintenance program is required during operations to minimize the chance of component failures and to ensure the early detection of components that are starting to fail.

Failures can be addressed by a combination of troubleshooting and repair procedures, good component documentation, proper sparing, team expertise and vendor support (potentially including maintenance contracts).

Some component failures are more likely to happen during development than operations. Infant mortality is most likely during subsystem development, where more time is potentially available to replace it. An optic is more likely to be broken as it is being shipped or integrated during subsystem, lab or telescope integration.

For cost reasons not everything can be spared. We must therefore focus on the most critical components and the limited lifetime components. The likelihood and impact of a failure needs to be considered.

A partial list of key components and their recommended sparing was developed during the SD phase and was incorporated in the cost estimate. This list will be further defined during the remaining design phases. The sparing recommendation needs to include the number of units in the system, and some analysis of the consequence and likelihood of failure during both development and operations. This list could be integrated into the Product Structure MS Project tool.

3 PRELIMINARY DESIGN PHASE PLAN

3.1 PD Phase Management

The Preliminary Design (PD) Phase management structure was shown in Figure 1.

Leadership responsibilities for specific parts of the preliminary design are indicated in the MS Project Plan in section 3.5.

3.2 PD Phase Overview and Deliverables

The PD phase is the second design phase for WMKO development projects. This phase follows the system design and precedes the detailed design phase.

In the Observatory's development program, the preliminary design phase has two primary objectives. The first objective is to deliver documented designs for each system, subsystem and component, hardware or software, of sufficient detail to establish through inspection and analysis the feasibility of the proposed design, and the likelihood that the design will meet the requirements. The second objective is to present the project plan to completion, including a detailed schedule and budget.

The principal activities of the preliminary design phase are design, prototyping, simulation and analysis. The key deliverables are preliminary technical specifications, requirements for subsystems, a preliminary Operations Concept Document, Interface Design document(s), and a Preliminary Design report.

3.3 PD Phase Work Breakdown Structure

The WBS structure for the Preliminary Design is identical to this WBS numbering in Figure 3 except that each WBS element number is preceded by "1.3" and there is no WBS 1.3.1. For example, WBS 1.3.2 is the Preliminary Design Phase Management and WBS 1.3.4.1 is the preliminary design of the AO enclosure. This approach to the design phase WBS numbering was chosen to allow a separate budget and plan for the design phases.

3.4 PD Phase Planning Assumptions

The following assumptions were used in producing the preliminary design phase plan:

- The collaboration between WMKO, COO and UCO would continue in the PD phase.
- The NGAO Preliminary Design is funded by the NSF TSIP at $2M.
- The remainder of the NGAO Preliminary Design is funded by WMKO.
- The available funding profile is $455k in FY08 (starting May 1) and $2000k in FY09.
- Since the PD phase cost estimate is $3479k the remaining $1024k is required in FY10.

The estimated PD phase cost when combined with the above funding profile resulted in a 22 month PD schedule, with a Preliminary Design Review date of February 22, 2010, as shown in the next section. This assumes that we can ramp up from an average spending rate of $167k/month in FY09 to a rate of $205k/month in FY10.

3.5 PD Phase Schedule

The level three version of the PD schedule (ignoring the initial "1.3") is shown in Figure 8 through Figure 15. The complete PD schedule can be found in section 12. The schedule includes WBS numbers, task names, initials of the task lead, number of work hours and start and end dates.

The approach to developing this schedule was to: 1) develop the WBS and product structure, 2) incorporate this structure into an MS project plan, 3) apply the work hours from the cost estimation work sheets, 4) apply resources to the MS project plan, 5) iterate to produce a realistic schedule and 6) iterate to produce a realistic budget. Links have only been used sparingly so far in this schedule due to their tendency to move tasks in unusual ways. Some non-PD phase tasks are included with zero hours in order to maintain WBS numbering for future phases.

We will track performance versus this baseline schedule. We will also update this schedule, with the original baseline maintained, as needed during the PD phase to ensure we achieve the PD goals within schedule and budget. Three potential replanning windows are included in the plan to address new information about the design or such issues as changing personnel availability or external constraints. Replanning activities not required will be returned to the contingency pool.

ID	WBS	Task Name	Lead	Work
4	**1.3**	**Preliminary Design**		**36,131 hrs**
5	1.3.1	Reserved		0 hrs
6	**1.3.2**	**PD Phase Management**	PW	**9,306 hrs**
7	**1.3.2.1**	**Planning**	PW	**1,640 hrs**
8	**1.3.2.1.1**	**Replans (PD phase)**		**190 hrs**
12	**1.3.2.1.2**	**WMKO FY Plans**		**40 hrs**
15	**1.3.2.1.3**	**Systems Engineering Management Plan**	PW	**1,410 hrs**
25	**1.3.2.2**	**Project Management & Meetings**	PW	**2,270 hrs**
26	**1.3.2.2.1**	**Executive Committee**	PW	**600 hrs**
29	**1.3.2.2.2**	**Team Meetings**	PW	**1,670 hrs**
52	**1.3.2.2.3**	**Director Telecons**	PW	**0 hrs**
57	**1.3.2.3**	**Tracking & Reporting**	PW	**869 hrs**
58	**1.3.2.3.1**	**Monthly Status Reports**	PW	**546 hrs**
62	**1.3.2.3.2**	**SSC Meetings**	PW	**91 hrs**
71	**1.3.2.3.3**	**Other Presentations**	PW	**232 hrs**
77	**1.3.2.4**	**Proposals**	PW	**480 hrs**
78	1.3.2.4.1	Advancement Support		80 hrs
79	1.3.2.4.2	TSIP Proposal for DDR		240 hrs
80	1.3.2.4.3	Other Proposal		160 hrs
81	**1.3.2.5**	**Programmatic Risk Assessment & Mitigation**	PW	**180 hrs**
82	**1.3.2.5.1**	**Risk Assessment**	PW	**60 hrs**
85	**1.3.2.5.2**	**Risk Mitigation**	PW	**120 hrs**
89	**1.3.2.6**	**Preliminary Design Review**	PW	**506 hrs**
90	1.3.2.6.1	Define Success Criteria for all Reviews		60 hrs
91	1.3.2.6.2	Review Setup (Date, Participants, Charter)		16 hrs
92	1.3.2.6.3	Preliminary Design Report		100 hrs
93	1.3.2.6.4	Review Package Distributed		6 hrs
94	1.3.2.6.5	Reviewer Comments Received		0 hrs
95	1.3.2.6.6	Reviewer Comments Addressed		80 hrs
96	1.3.2.6.7	PDR Presentation Preparation		68 hrs
97	1.3.2.6.8	Preliminary Design Review		128 hrs
98	1.3.2.6.9	Reviewer Report Received		0 hrs
99	1.3.2.6.10	Response to Reviewer Report		48 hrs
100	**1.3.2.7**	**Project Support**	PW	**3,361 hrs**
101	1.3.2.7.1	Administrative/Contract Support		765 hrs
102	1.3.2.7.2	Shared Infrastructure		200 hrs
103	1.3.2.7.3	Research Time		2,396 hrs

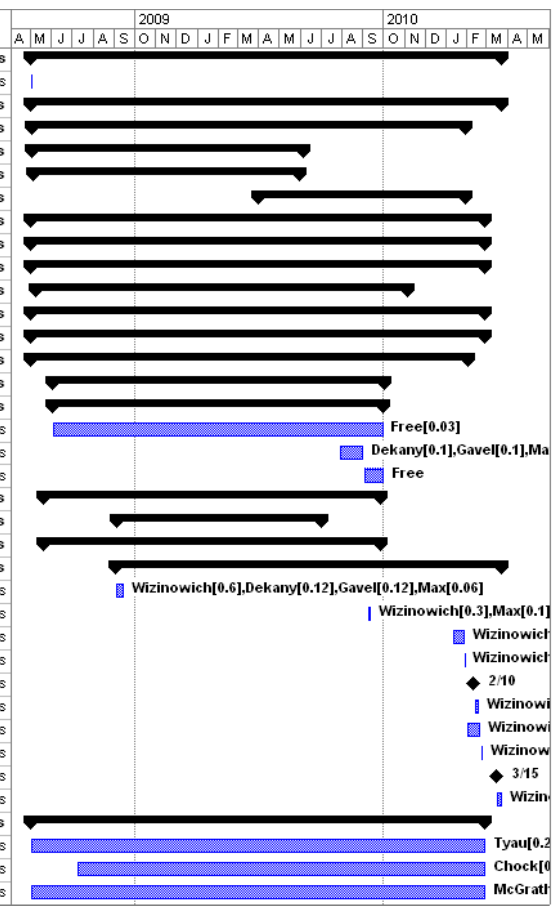


Figure 8. PD phase Management schedule (WBS2).

The WBS dictionary definitions and deliverables for the PD phase elements can be found in KAON 583. The design approach for the real-time controller (WBS 1.3.4.5.1) is somewhat atypical and therefore is described in more detail in section 13.

ID	WBS	Task Name	Lead	Work
104	**1.3.3**	**Systems Engineering**	**RD**	**9,415 hrs**
105	**1.3.3.1**	**Science Case Requirements**	**CM**	**4,005 hrs**
151	**1.3.3.2**	**Requirements**	**EJ**	**970 hrs**
152	**1.3.3.2.1**	**Operations Concept Document (OCD)**	**DLM**	**480 hrs**
156	**1.3.3.2.2**	**System Requirements (SRD)**	**EJ**	**80 hrs**
159	**1.3.3.2.3**	**Functional Requirements (FRD)**	**EJ**	**250 hrs**
163	1.3.3.2.4	Software Standards (Define & Document)	EJ	80 hrs
164	1.3.3.2.5	Component Standards (Define & Document)	EJ	80 hrs
165	**1.3.3.3**	**Systems Engineering Analysis**	**RD**	**1,788 hrs**
166	**1.3.3.3.1**	**Performance Budgets**	**RD**	**828 hrs**
189	**1.3.3.3.2**	**Modeling & Analysis**	**RD**	**880 hrs**
194	1.3.3.3.3	PSF Calibration	DLM	80 hrs
195	**1.3.3.4**	**System Architecture**	**RD**	**1,070 hrs**
196	**1.3.3.4.1**	**System Hardware Architecture**	**RD**	**264 hrs**
200	**1.3.3.4.2**	**Software Architecture**	**EJ**	**162 hrs**
204	**1.3.3.4.3**	**Control Systems Architecture**	**EJ**	**420 hrs**
210	**1.3.3.4.4**	**Operations Sequences Architecture**	**DLM**	**224 hrs**
215	**1.3.3.5**	**External Interface Control**	**CN**	**244 hrs**
216	**1.3.3.5.1**	**Observatory Interfaces**	**CN**	**120 hrs**
220	**1.3.3.5.2**	**Science Instrument Interfaces to NGAO**	**SA**	**124 hrs**
228	**1.3.3.6**	**Internal Interface Control**	**CN**	**280 hrs**
229	1.3.3.6.1	Diagram & Document Draft Outline	CN	50 hrs
230	1.3.3.6.2	Interface N-Squared Diagram	CN	100 hrs
231	1.3.3.6.3	Interface Definition Document	CN	130 hrs
232	**1.3.3.7**	**Configuration Control**	**EJ**	**218 hrs**
233	1.3.3.7.1	Change Control Guidelines & Tools Definition	EJ	218 hrs
234	**1.3.3.8**	**Documentation Control**	**EJ**	**20 hrs**
235	1.3.3.8.1	Document Control Guidelines & Tools Definition	EJ	20 hrs
236	**1.3.3.9**	**Technical Risk Assessment & Mitigation**	**PW**	**700 hrs**
237	**1.3.3.9.1**	**Risk Assessment**	**PW**	**100 hrs**
240	**1.3.3.9.2**	**Risk Mitigation Efforts**	**PW**	**600 hrs**
245	1.3.3.10	Preliminary Design Manual	PW	120 hrs

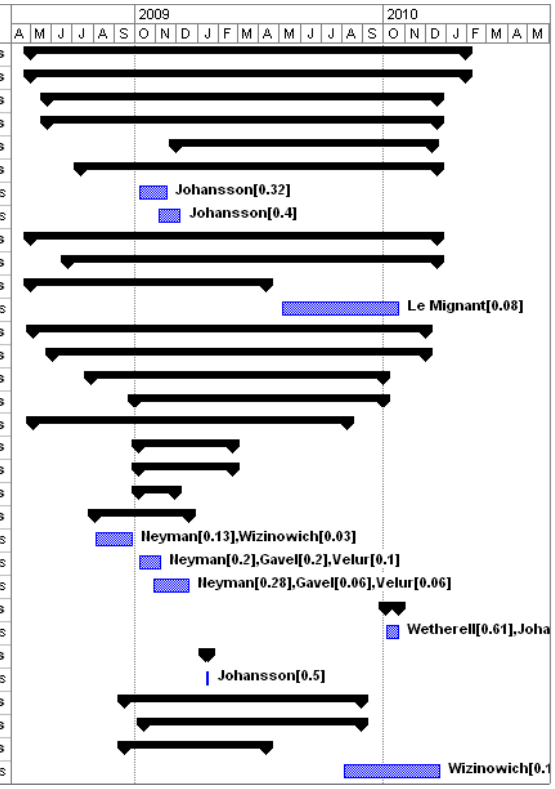


Figure 9. PD phase Systems Engineering schedule (WBS3).

ID	WBS	Task Name	Lead	Work
246	**1.3.4**	**AO System Design**	**DG**	**10,757 hrs**
247	1.3.4.1	AO Enclosure	JB	300 hrs
248	**1.3.4.2**	**Opto-Mechanical**	**DG**	**5,405 hrs**
249	1.3.4.2.1	AO Support Structure	CL	160 hrs
250	1.3.4.2.2	Rotator	CL	120 hrs
251	1.3.4.2.3	Optical Relays	RK	533 hrs
252	1.3.4.2.4	Optical Switchyard	RK	400 hrs
253	**1.3.4.2.5**	**LGS Wavefront Sensor Assembly**	**VV**	**1,520 hrs**
264	**1.3.4.2.6**	**NGS WFS/TWFS Assembly**	**VV**	**628 hrs**
273	**1.3.4.2.7**	**Low Order Wavefront Sensor Assembly**	**VV**	**1,596 hrs**
286	**1.3.4.2.8**	**Tip/Tilt Vibration Mitigation**	**CN**	**80 hrs**
288	**1.3.4.2.9**	**Acquisition Cameras**	**CN**	**128 hrs**
291	**1.3.4.2.10**	**Atmospheric Dispersion Correctors**	**RK**	**240 hrs**
295	**1.3.4.3**	**Alignment, Calibration & Diagnostics**	**CN**	**505 hrs**
296	**1.3.4.3.1**	**Simulator**	**CN**	**250 hrs**
302	**1.3.4.3.2**	**System Alignment Tools**	**CN**	**255 hrs**
308	**1.3.4.4**	**Non-real-time Control**	**EJ**	**990 hrs**
309	1.3.4.4.1	AO Controls Infrastructure		0 hrs
310	**1.3.4.4.2**	**AO Sequencer**	**EJ**	**140 hrs**
319	**1.3.4.4.3**	**AO Motion Control Software**	**EJ**	**230 hrs**
328	**1.3.4.4.4**	**AO Device Control Software**	**DM**	**240 hrs**
337	**1.3.4.4.5**	**AO Motion Control Electronics**	**EW**	**60 hrs**
339	**1.3.4.4.6**	**Non-RTC Electronics**	**EW**	**160 hrs**
345	**1.3.4.4.7**	**Non-RTC Lab System Integration & Test**		**0 hrs**
350	**1.3.4.4.8**	**Acquisition, Guiding & Offload (AGO) Control**	**EJ**	**160 hrs**
359	**1.3.4.5**	**Real-time Control**	**DG**	**3,357 hrs**
360	**1.3.4.5.1**	**RTC Processor**	**DG**	**3,037 hrs**
379	**1.3.4.5.2**	**DMs & Tip/Tilt Stages**	**DG**	**320 hrs**
397	**1.3.4.6**	**AO System Lab I&T**	**CN**	**200 hrs**
398	1.3.4.6.1	AO System Lab I&T Scope Definition	PW	16 hrs
399	1.3.4.6.2	AO System Lab Facility Plan	CN	24 hrs
400	1.3.4.6.3	AO System Lab Integration Plan	CN	80 hrs
401	1.3.4.6.4	AO System Lab Test Plan	CN	80 hrs

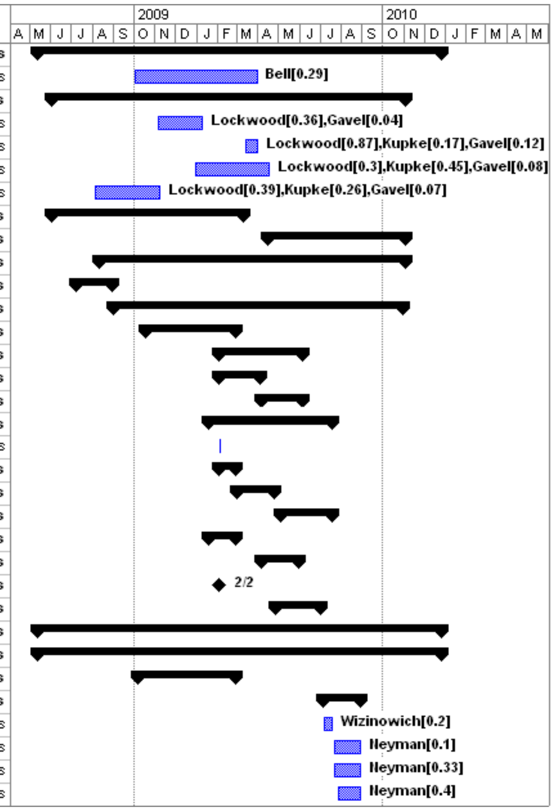


Figure 10. PD phase AO System schedule (WBS4).

ID	WBS	Task Name	Lead	Work
402	**1.3.5**	**Laser System Design**	**CN**	**2,964 hrs**
403	**1.3.5.1**	**Laser Enclosure (LE)**	**JC**	**160 hrs**
404	1.3.5.1.1	LE Requirements & Interfaces	JC	40 hrs
405	1.3.5.1.2	LE Mechanical Design	DM	50 hrs
406	1.3.5.1.3	LE Environmental Control Design	CN	50 hrs
407	1.3.5.1.4	LE Assembly & Test Plans	JC	20 hrs
408	**1.3.5.2**	**Laser**	**SA**	**820 hrs**
409	1.3.5.2.1	Laser Project Management	SA	300 hrs
410	**5.2.3.1**	**Laser Requirements**	**SA**	**160 hrs**
415	**5.2.3.2**	**Laser Preliminary ICD**	**SA**	**40 hrs**
417	**5.2.3.3**	**Laser Request for Proposals (RFP)**	**SA**	**120 hrs**
421	**5.2.3.4**	**Laser RFP Response Report**	**SA**	**120 hrs**
425	**5.2.3.5**	**Laser Contract**	**SA**	**80 hrs**
428	**1.3.5.3**	**Laser Launch Facility (LLF)**	**CN**	**856 hrs**
429	1.3.5.3.1	LLF Requirements & Interfaces		100 hrs
430	1.3.5.3.2	LLF Optical Design		260 hrs
431	1.3.5.3.3	LLF Launch Telescope Preliminary Design Contract		96 hrs
432	1.3.5.3.4	LLF Mechanical Design		220 hrs
433	1.3.5.3.5	LLF Electrical Design		120 hrs
434	1.3.5.3.6	LLF Assembly, Alignment & Test Plans		60 hrs
435	**1.3.5.4**	**Laser Safety Systems**	**JC**	**170 hrs**
436	**1.3.5.4.1**	**Personnel & Equipment Safety System**	**JC**	**130 hrs**
443	**1.3.5.4.2**	**Laser Traffic Control System (LTCS) Modification**	**DS**	**40 hrs**
449	**1.3.5.5**	**Laser System Control (LSC)**	**EJ**	**910 hrs**
450	**1.3.5.5.1**	**LSC Software**	**EJ**	**600 hrs**
455	**1.3.5.5.2**	**LSC Hardware**	**EW**	**310 hrs**
459	1.3.5.6	Laser System Lab I&T Plan	CN	48 hrs

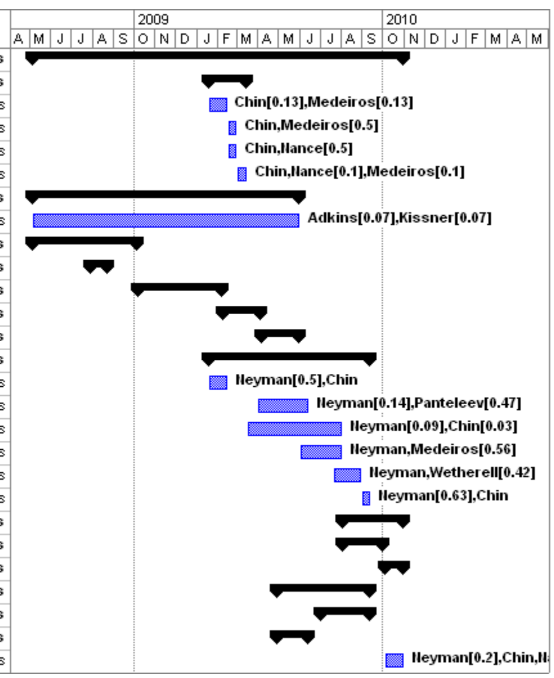


Figure 11. PD phase Laser System schedule (WBS5).

ID	WBS	Task Name	Lead	Work	2009 / 2010
460	**1.3.6**	**Science Operations Tools Design**	**DLM**	**1,800 hrs**	
461	**1.3.6.1**	**Multi-Systems Command Sequencer (MCS)**	**EJ**	**620 hrs**	
462	**1.3.6.1.1**	**MCS Infrastructure**		**180 hrs**	
477	**1.3.6.1.2**	**Setup Sequences: Configuration & Calibration**		**100 hrs**	
488	**1.3.6.1.3**	**Observing Sequences**		**240 hrs**	
505	**1.3.6.1.4**	**Alarm Handler & Troubleshooting Sequences**		**100 hrs**	
516	**1.3.6.2**	**User Interfaces**	**DLM**	**500 hrs**	
517	**1.3.6.2.1**	**User Interface (UI) Infrastructure**		**180 hrs**	
529	**1.3.6.2.2**	**Setup User Interfaces**		**80 hrs**	
540	**1.3.6.2.3**	**Observations User Interfaces**		**240 hrs**	
560	**1.3.6.3**	**Pre- & Post-Observing Science Support Tools**	**DLM**	**610 hrs**	
561	**1.3.6.3.1**	**User Documentation**		**20 hrs**	
564	**1.3.6.3.2**	**Science Observations Planning Tools**		**340 hrs**	
585	**1.3.6.3.3**	**Data Products**		**250 hrs**	
604	**1.3.6.4**	**Data Server**	**EJ**	**70 hrs**	
605	1.3.6.4.1	Data Server: Architecture		40 hrs	Johansson[0.03]
606	1.3.6.4.2	Data Server: HW & SW Specification & Selection		20 hrs	Johansson[0.01]
607	1.3.6.4.3	Data Server: Software Design		0 hrs	2/2
608	1.3.6.4.4	Data Server: Compliance Matrix		0 hrs	2/2
609	1.3.6.4.5	Data Server: Test Plan		0 hrs	2/2
610	1.3.6.4.6	Data Server: Summary Report		10 hrs	Johansson[0.01]

Figure 12. PD phase Science Operations Tools schedule (WBS6).

ID	WBS	Task Name	Lead	Work	2009 / 2010
611	**1.3.7**	**Telescope & Summit Engineering Design**	**CN**	**1,101 hrs**	
612	1.3.7.1	Telescope Performance		0 hrs	
613	**1.3.7.2**	**Infrastructure Modifications for AO**	**JB**	**660 hrs**	
614	1.3.7.2.1	Infrastructure Requirements & Interfaces	JB	90 hrs	Bell[0.38],Wetherell,Wizinowich[0.6
615	1.3.7.2.2	Infrastructure Mechanical Modifications	DM	160 hrs	Bell,Medeiros[0.33],Mogens
616	1.3.7.2.3	Infrastructure Electrical Modifications	CN	120 hrs	Nance[0.33]
617	1.3.7.2.4	Infrastructure Glycol Cooling Modifications	CN	140 hrs	Nance[0.39]
618	1.3.7.2.5	Infrastructure CCR Modifications	CN	40 hrs	Nance[0.11]
619	1.3.7.2.6	Infrastructure Implementation & Test Plans	JB	110 hrs	Bell[0.25],Medeiros,Na
620	**1.3.7.3**	**Infrastructure modifications for Laser System**	**JB**	**280 hrs**	
621	1.3.7.3.1	Infrastructure Requirements & Interfaces	JB	70 hrs	Bell[0.25],Chin,Nance
622	1.3.7.3.2	Infrastructure Mechanical Modifications	DM	50 hrs	Medeiros[0.14]
623	1.3.7.3.3	Infrastructure Electrical Modifications	CN	40 hrs	Nance[0.11]
624	1.3.7.3.4	Infrastructure Glycol Cooling Modifications	CN	50 hrs	Nance[0.14]
625	1.3.7.3.5	Infrastructure Implementation & Test Plans	JB	70 hrs	Bell[0.2],Chin,Medeiro
626	1.3.7.4	OSIRIS Modifications	SA	100 hrs	Adkins[0.17],Wetherell[0.33],Medeiros[0.33]
627	**1.3.7.5**	**Interferometer Modifications**	**PW**	**61 hrs**	
628	1.3.7.5.1	Optical Design of Post Field Selector Optics	PW	45 hrs	Wizinowich[0.08],Kupke[0.06]
629	1.3.7.5.2	Evaluation of Optical Design Impact on Interferometer	PW	16 hrs	Wizinowich[0.05]

Figure 13. PD phase Telescope and Summit Engineering schedule (WBS7).

ID	WBS	Task Name	Lead	Work
630	**1.3.8**	**Telescope Integration & Test**	**CN**	**622 hrs**
631	**1.3.8.1**	**Old AO/Laser Removal**	**JB**	**120 hrs**
632	1.3.8.1.1	AO Removal Plan	JB	60 hrs
633	1.3.8.1.2	Laser Removal Plan	DM	60 hrs
634	1.3.8.2	Laser Enclosure Integration		0 hrs
635	1.3.8.3	AO Enclosure Integration		0 hrs
636	**1.3.8.4**	**AO System Install + I&T**	**CN**	**170 hrs**
637	1.3.8.4.1	Opto-Mechanical Integration Plan	CN	60 hrs
638	1.3.8.4.2	Electronics Integration Plan	EW	40 hrs
639	1.3.8.4.3	Computer Integration Plan	JC	20 hrs
640	1.3.8.4.4	AO System Integration Plan	CN	40 hrs
641	1.3.8.4.5	AO System Test Plan	CN	10 hrs
642	**1.3.8.5**	**Laser System Install + I&T**	**JC**	**212 hrs**
643	1.3.8.5.1	Laser System Installation & Integration Plan	JC	148 hrs
644	1.3.8.5.2	Laser System Test Plan	CN	64 hrs
645	1.3.8.6	LGS AO System On-sky I&T Plan	DLM	40 hrs
646	1.3.8.7	Performance Characterization		0 hrs
647	1.3.8.8	Science Verification Plan	DLM	80 hrs

Figure 14. PD phase Telescope Integration and Test schedule (WBS8).

ID	WBS	Task Name	Lead	Work
648	**1.3.9**	**Operations Transition**	**DLM**	**166 hrs**
649	**1.3.9.1**	**Operations Plans**	**DLM**	**96 hrs**
650	1.3.9.1.1	Operations Support Plan	DLM	40 hrs
651	1.3.9.1.2	Operations Maintenance & Spares Plan Template	EW	56 hrs
652	**1.3.9.2**	**Operations Handover**	**DLM**	**70 hrs**
653	1.3.9.2.1	Operations Personnel Training Plan	DLM	50 hrs
654	1.3.9.2.2	Documentation Transition Plan	DLM	20 hrs

Figure 15. PD phase Operations Transition schedule (WBS9).

3.6 PD Phase Milestones

Major milestones for the NGAO PD phase are shown below in Table 15. These milestones are consistent with the PD phase schedule discussed in section 3.5.

Table 15: Milestones

Year	Month	NGAO Project Milestone
2008	May	Preliminary Design phase begins
2008	October	Functional Requirements PD Release 1
2009	March	Operations Concept Document Release 1
2009	April	External Interface Document Release 1
2009	February	Internal Interface Document Release 1
2009	May	Software & Controls Architectures PD complete
2009	May	LGS WFS Assembly PD complete
2009	June	Laser vendor identified & contract ready
2009	June	Optical relay/switchyard PD complete
2009	September	RTC Processing Requirements complete
2009	November	Laser Launch Facility PD complete
2009	December	LOWFS Assembly PD complete
2010	February	Preliminary Design Review

3.7 PD Phase Personnel and Core Team

Table 16 was used as a modified output of the MS Project Plan to help balance individuals and the hours per fiscal year. This table lists the names of all of the PD phase personnel. The work hours do not include any contingency time. Some cases of over assigning work to an individual are in italics. These will be addressed by a combination of transferring work to others and/or moving work into another FY.

Table 16. PD phase personnel assignments versus Fiscal Year (FY).

Name	Work (hrs) by FY			Work	Work %			
	FY08	FY09	FY10	PY	FY08	FY09	FY10	Total
Adkins	292	524	45	0.48	39%	29%	6%	26%
Bell		608	143	0.42	0%	34%	19%	23%
Bouchez		80		0.04	0%	4%	0%	2%
Britton	230	525	23	0.43	31%	29%	3%	24%
Brown			40	0.02	0%	0%	5%	1%
Chin		238	80	0.18	0%	13%	11%	10%
Chock	29	121	70	0.12	4%	7%	9%	7%
Contract Administrator	18	44	18	0.04	2%	2%	2%	2%
Dekany	392	841	467	0.94	52%	47%	62%	52%
Doyle			16	0.01	0%	0%	2%	0%
EE / Programmer	407	1820	347	1.43	54%	*101%*	46%	78%
Free (WMKO)	20	400		0.23	3%	22%	0%	13%
Gavel	250	613	364	0.68	33%	34%	49%	37%
Grace			16	0.01	0%	0%	2%	0%
Hale	47	525	55	0.35	6%	29%	7%	19%
Johansson	432	2070	422	1.63	58%	*115%*	56%	89%
Kissner	57	141		0.11	8%	8%	0%	6%
Kupke	95	675	56	0.46	13%	37%	7%	25%
Le Mignant	603	1841	638	1.71	80%	*102%*	85%	93%
Lockwood	139	924	118	0.66	18%	51%	16%	36%
Macintosh		160		0.09	0%	9%	0%	5%
Max (free)	272	668	203	0.63	36%	37%	27%	35%
McGrath	728	1950	622	1.83	97%	*108%*	83%	100%
Medeiros		508	40	0.30	0%	28%	5%	17%
Mogensen		30		0.02	0%	2%	0%	1%
Morrison	55	760		0.45	7%	42%	0%	25%
Nance		488	77	0.31	0%	27%	10%	17%
Neyman	609	1763	403	1.54	81%	98%	54%	84%
Panteleev		200	16	0.12	0%	11%	2%	7%
Reinig	100	265	168	0.30	13%	15%	22%	16%
Student/Postdoc	227	933		0.64	30%	52%	0%	35%
Summers			40	0.02	0%	0%	5%	1%
Tyau	69	430	176	0.38	9%	24%	23%	20%
Velur	217	1426	269	1.06	29%	79%	36%	58%
Wetherell		935	196	0.63	0%	52%	26%	34%

Wizinowich	376	933	633	1.08	50%	52%	*84%*	59%
Zolkower	229	963	73	0.70	31%	53%	10%	38%
Total (hrs) =	5895	24401	5835					
Total (PY) =	3.3	13.6	3.2	20.1				

Table lists the 18 core team members and their roles during the PD phase. These include all individuals assigned to the plan at a level ≥ 20%. In most cases the percentages for these core personnel are significantly higher in FY09. These core team members bring a great deal of relevant experience to the project. Overall they represent 83% of the PD phase labor. We consider the UCO EE / Programmer, Johansson, Le Mignant, McGrath and Neyman to be full-time on this project, and will look at transferring some COO work to allow Velur to become full-time as well.

Table 17. Core PD phase team members.

Name	Inst	Role	%
Adkins, Sean	WMKO	Laser procurement, instrument interfaces	26
Bell, Jim	WMKO	AO enclosure & infrastructure	23
Britton, Matthew	COO	Wavefront sensor design, performance budgets	24
Dekany, Rich	COO	COO project management, systems engineering	52
EE / Programmer (tbd)	UCO	Real-time control	78
Gavel, Don	UCO	UCO project management, technical overview	37
Johansson, Erik	WMKO	Non-real time controls & software, systems engineering	89
Kupke, Renate	UCO	AO optical design	25
Le Mignant, David	WMKO	Science operations tools, operations concept	93
Lockwood, Chris	UCO	AO mechanical design	36
Max, Claire	UCO	Project Scientist, science requirements development	35
McGrath, Elizabeth	UCO	Postdoc for Project Scientist, science development	100
Morrison, Doug	WMKO	Non-real time control software	25
Neyman, Chris	WMKO	Systems engineering, laser & AO facility design	84
Velur, Viswa	COO	Wavefront sensor design	58
Wetherell, Ed	WMKO	Non-real time control electronics	34
Wizinowich, Peter	WMKO	PI and project manager, technical overview	59
Zolkower, Jeff	COO	Wavefront sensor design	28

3.8 PD Phase Budget and Contingency

The PD phase budget estimate is $3479k in FY08 dollars as previously shown in Table 14. The dollars by fiscal year are summarized in Table 18. This Table also shows the breakdown of work (hours) and personnel costs by Institution. The hours are from the MS Project Plan shown in Section 3.5. The last row compares the cost estimate to the available budget. The costs and available budget have been made to just match in FY08. We will have to adjust the schedule to shift some hours from FY09 to FY10 to stay within the available FY09 budget.

Institution	Work (hours)				Cost ($k)			
	FY08	FY09	FY10	Total	FY08	FY09	FY10	Total
COO	1116	4360	927	6403	107	419	88	614
UCO	1719	6407	1675	9801	113	444	118	675
WMKO	2542	11633	3030	17204	196	841	228	1264
Free (Max + WMKO)	292	1068	203	1563	0	0	0	0
Student/Postdoc	227	933	0	1160	9	37	0	46
Labor Total =	5895	24401	5835	36131	425	1741	434	2600
Procurements ($k)					2	164	50	216
Travel ($k)					28	125	61	214
Labor & Non-Labor Total ($k) =					30	289	111	430
Contingency ($k)					0	0	449	449
Total ($k) =					**455**	**2030**	**994**	**3479**
Available ($k) =					455	2000	1024	3479
Available - Total ($k) =					0	-30	30	0

Table 18. PD phase work distributed by Institution.

As can be seen from Table 18 all of the contingency dollars are in FY10 and as can be seen from the FY10 column of Table 16 we also have people available to use these contingency dollars on in FY10. To the extent that contingency is not needed we may therefore be able to complete the Preliminary Design ahead of the current schedule. To the extent that contingency is required we have the people to perform the work. In FY08 and 09 are only available contingency is to reprioritize tasks in order to provide additional resources and to allow some items to slip in schedule (eventually into FY10).

3.9 PD Phase Risk Assessment and Risk Management

A PD phase risk is that work will be shifted into the Detailed Design (DD) phase. Although some of the PD phase deliverables are clearly defined, the state of the design acceptable for a preliminary design can be open to interpretation thereby potentially leaving more work for the DD phase. The definition of the Detailed Design on the other hand is clear cut. We will attempt to mitigate this risk and to keep the tasks well focused by using the work planning sheets we used during the SD phase. The required information includes the WBS dictionary definition, the required inputs, the products, the methodology that will be taken to obtain the products and an effort estimate. Much of the information required to fill in these sheets is already in the cost estimation work sheets. These sheets will require approval from the appropriate Institutional Project Manager and the NGAO Project Manager. The advantage of using these sheets is that the team starts a task with all the relevant information compiled and with a consensus between the team and project management.

The cost risks for the PD phase were tabulated in the PD phase cost worksheets. Overall we have identified 15% contingency for the PD phase. The estimated work is scheduled toward the beginning of the PD phase leaving contingency dollars at the end of the phase to cover work slippage. Problems will be handled as they arise but we will have funded schedule contingency at the end of the phase to ensure that the work is completed. We have also made sure that key personnel have some available time in the last few months of the project to be able to use these contingency dollars. To the extent that we can leave the contingency untouched we can also pull in the Preliminary Design Review date.

3.10 PD Phase Management

NGAO management will be responsible for maintaining the PD phase budget and schedule for the PD phase.

Cost accounting and other financial and administrative matters will be done by WMKO. WMKO will be issuing contracts to CIT and UC to fund personnel at these institutions to participate in the PD phase, as was done for the SD phase. COO and UCO will provide monthly financial reports to WMKO by the 15^{th} of the following month. The PD phase actual expenditures will be tracked at the 1.3.X level of the WBS (i.e., 1.3.2 Management through 1.3.9 Operations Transition).

A monthly written project report will be provided to the Observatory Directors and the TSIP. The same or similar format to the MOSFIRE monthly reports to TSIP will be used. The project leads will be expected to provide monthly status reports for inclusion in the monthly report. This input will also be used to give quarterly updates at the WMKO SSC meetings. The management team will meet with the Observatory Directors four times during the PD phase to ensure

In order to ensure clear direction during the Preliminary Design the NGAO PI will meet regularly with the WMKO Directorate (at least bi-weekly) and the NGAO senior management (Dekany, Gavel, Max and Wizinowich) will have four scheduled teleconferences with the Directors.

The team will have monthly teleconferences throughout the PD phase and four face-to-face multi-day meetings. The NGAO senior management will alternate between weekly and bi-weekly telecoms depending on the issues that need to be addressed.

Email will be used as a primary means of intra-project communications. Working documents will continue to be posted on the NGAO Twiki site:

http://www.oir.caltech.edu/twiki_oir/bin/view/Keck/NGAO/WebHome,

which proved to be a very productive shared work environment during the SD phase. Documents will continue to be archived as Keck Adaptive Optics Notes on the KeckShare site at:

http://keckshare.keck.hawaii.edu/dsweb/View/Collection-218.

A Preliminary Design Review (PDR) will be held as the culmination of this design phase. This review will be conducted in accordance with WMKO standards. To the extent practical we are expecting the same reviewers as for the System Design Review.

4 PHASED IMPLEMENTATION AND DESCOPE OPTIONS

This section was not identified as a System Design phase deliverable. Although the Directors and SSC have expressed interest in these topics we all agreed that this issue would have to wait until after the System Design Review. That being said we have had some initial thoughts on this subject especially during the development of the system architecture. These initial thoughts are provided below.

The following notes are the result of an NGAO Executive Committee discussion on program structure during the July, 2007 system architecture meeting. The purpose of this discussion was to determine whether particular architectures were favored (or not favored) because they allowed the implementation to be structured in an advantageous (or non-advantageous) way. For example, an architecture could have a significant advantage if it allowed for incremental funding and/or a useful system even in the absence of full funding.

In the event of having to descope, the approach to system design can take one of the following paths:

Preferred: Complete the DDR to fully implement the AO system.

Option: Complete the PDR to fully implement the AO system and the selected option, & the DDR for the initial phases.

Preferred Design Option and Approach

The preferred approach is to have full funding for the preferred system architecture and five science instruments. The science instruments include d-IFS, NIR & visible imagers, and NIR & visible spectrographs. d-IFS would have five or more patrolling IFU heads feeding a moderate resolution cyrogenic spectrograph(s) and an imager scoring capability.

- Complete NGAO design
- Development sequence (in parallel)
    - Component development
    - Subsystem development & lab I&T
    - Entire AO system + imager science camera demonstrated in lab
    - Lasers demonstrated in lab with fibers & projector telescope
- Telescope implementation sequence (in series)
    - Lasers with fibers & projector telescope implemented on telescope & test/demo with old AO system & use for science
    - Remove old AO system
    - Take AO system & imager science camera to telescope & implement as science facility
    - Add on science instruments at telescope
- Risk mitigations

- Some initial risk mitigations to occur during design phase and potentially others during development phase. Potential examples, include tomography experiments, vibration reduction, PSF reconstruction, CCID-56 testing and a LOWFS demonstration.
- Keck AO upgrades. It may be desirable to implement some upgrades to the existing AO systems in support of risk mitigation and also to maintain mid-term scientific competitiveness (which might also help with schedule risk).

Descope Options

If insufficient funds are available for the above preferred option then a number of descopes could be taken. The following list of potential descopes starts with first item to be descoped and then the second, etc. The idea would be to add these items back as additional funds became available. We would need to move down this descope list until we fit into the available funds.

Descope options (in order of preferred descope):

1. Visible spectrograph
2. NIR spectrograph
3. Visible imager
4. AO system partially meets requirements initially, but designed for full requirements. There are a series of potential options here. To list just a couple likely candidates:
   - Less laser power (probably in 50W increments)
   - Fewer LGS wavefront sensors
5. Reduce number of d-IFS heads to two or three, but upgradeable to more.
6. d-IFS.
7. NIR imager.

Keck AO Upgrade Option

This option could be followed in the event of very limited initial funding for NGAO.

A base approach would be to continue to upgrade Keck I AO to keep Keck AO scientifically competitive in the mid-term. In parallel with this development we would either amass adequate funding to start on NGAO or use this money as it becomes available to start building up NGAO subsystems. These subsystems could either be used as part of the Keck AO upgrade path or as part of a new NGAO system should more funding become available.

A more decisive approach, in the limited funds scenario, would be to adopt the Keck AO upgrade approach earlier and proceed along this path to NGAO capabilities. This would have the advantage of directly designing and planning for the upgrade approach as opposed to designing and planning to maintain two options (both the new NGAO and upgrade options).

5 SYSTEM DESIGN PHASE SUMMARY

A SEMP was produced for the system design phase (KAON 414). The purpose of this section is to provide a brief overview of the schedule and budget actuals versus the plan in KAON 414.

The original schedule had the System Design Review on March 31, 2008. This review will actually be held three weeks later on April 21, 2008.

Table 19 lists the System Design phase actual dollars spent versus the plan presented in KAON 414. The original plan was in FY07 dollars. The numbers reported in Table 19 are in actual year dollars. The bottom line is that by the end of April, 2008, which is expected to represent the end of the System Design phase, we anticipate spending $50k more than the $1170k plan. The plan numbers are $26.8k higher than those listed in KAON 414 due to two factors: the first occurred prior to the start of the System Design phase and was due to an increase of $10k in WMKO labor rates as part of the normal cost adjustment that occurs in the annual WMKO budgeting process. The second was a $16.7k adjustment to the FY08 numbers for inflation. The $50k overrun was anticipated several months ago and the WMKO Directorate has agreed to cover this from Observatory contingency.

Institution	FY07	FY08 (to 2/29)	FY08 Remain	Total	Plan	Plan - Total
COO	261.6	72.1	20.9	354.6	314.9	-39.7
UCO	144.0	92.6	11.9	248.5	238.1	-10.4
WMKO	327.1	195.3	80.9	603.3	438.6	-164.7
Students	6.2	7.0	0.0	13.2	57.4	44.2
Contingency					103.9	
Inflation					16.7	
Total ($k) =	738.9	367.0	113.7	1219.6	1169.6	-50.0
Plan ($k) =	818	351.6		1169.6		
Plan - Total =	79.1	-129.2		-50.0		

Table 19. System Design phase actual $k versus plan.

Table 20 lists the System Design phase actual hours used versus the plan presented in KAON 414 (free hours such as those provided by the Project Scientist and some LAO personnel are not included). Personnel billing was provided in fractions of an FTE for each month and these were converted to actual worked hours assuming 1800 hrs/year. There is good agreement between the actual and plan hours at each Institution through February, 2008.

Institution	Plan (hours)	Actuals (to 2/29/08)	Actual - Plan	Actual Avg. Rate ($/hr)	Plan Rate ($/hr)
COO	3369	3581	212	85.29	87.56
UCO	3154	2651	-503	88.10	69.11
WMKO	7276	7539	263	65.80	56.21
Total (hrs) =	13799	13771	-28		

Table 20. System Design phase actual hours versus plan.

From the calculated hours and the associated billed personnel dollars we can calculate the average dollar rate per hour shown in the second last column of Table 20 and compare it to the planned rate in the last column. The difference in the actual versus planned rate when multiplied by the planned hours at each Institution results in a $122k increase. This factor is responsible for using up our $104k contingency.

The actual travel used through February, 2008, was $44.2k versus the budget of $60k. The remainder of this budget, and a little more, will be used for the System Design Review. Utilities and computing services which we had not budgeted for totaled $5k through February, 2008. The procurement of two Contour database licenses at a cost of $6k was unplanned but will easily save more than this in personnel time to maintain the NGAO requirements.

The System Design phase plan was broken into the following major phases that represented a sequential flow but necessarily overlapped at some level:

- Requirements development.
- Performance budget development and trade studies.
- System architecture development.
- Subsystem design.
- Costing and planning.

Since the initial plan had been very much top-down and because we were entering a new collaboration we recognized that we would likely need to replan during the System Design phase. Two replans were therefore scheduled for the SD phase. These replans proved to be necessary and were documented in KAONs 481 and 516. The first replan addressed slow ramp-up of project personnel, an effect that also caused the need to overlap the first three phases (shown in the previous paragraph) more than initially intended. The second replan was motivated by an identified variance between planned and realized earned value. This was primarily because people were taking longer to perform tasks than originally planned due partly to our initial top-down plan, partly to part-time personnel inefficiency, and occasionally to people who had difficulty documenting their work. We have addressed these in the Preliminary Design plan by producing bottoms-up estimates, switching to more full-time personnel and making sure that we utilize people who can document the work.

We ultimately completed less work than we had planned as shown in Figure 16 and Figure 17. By the end of March, 2008, 88% of the work we planned to complete had been completed; we estimate 91% by the time of the System Design Review. Several areas were not completed to the initially intended level including: the science cases and requirements; the science operations functional requirements, conceptual design and test plans; the science instruments functional requirements, feasibility design and test plans; the overall project schedule; and a configuration management plan. The incomplete portions of these items, with the exception of the science instruments, have been included in the Preliminary Design phase plan. In addition, several originally planned trade studies were cancelled during the System Design since they would no longer provide timely input to the architectural or design decisions, and some more relevant trade studies were performed instead.

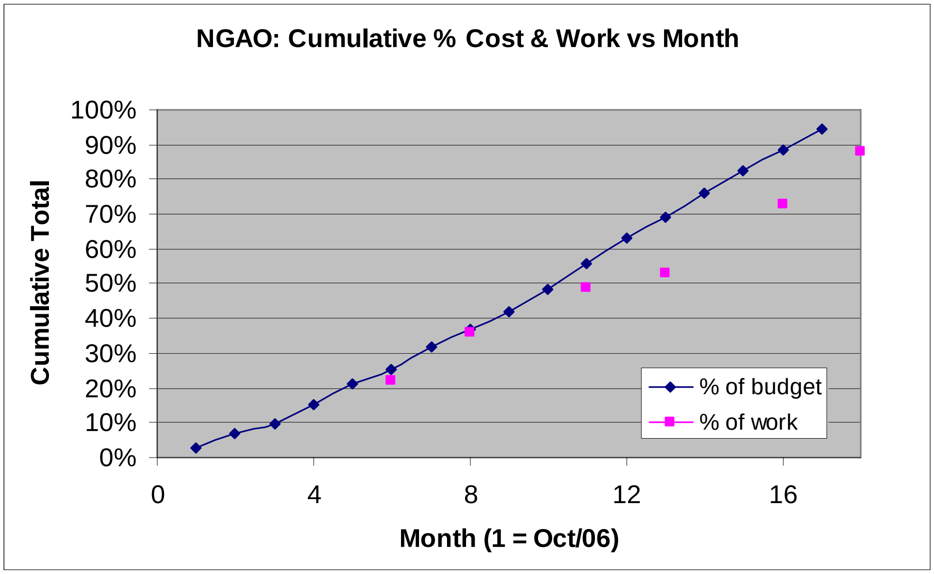


Figure 16. System Design cumulative percent complete for budget and work.

ID	WBS	Task Name	Lead	% Work Co	Work
0	0	NGAO System Design Phase Schedule		88%	11,390.2 hrs
1	1	SD Phase Management	PW	81%	2,108 hrs
2	1.1	Planning and Contracting	PW	100%	230 hrs
11	1.2	Project Meetings		97%	1,352 hrs
27	1.3	Tracking and Reporting	PW	94%	120 hrs
38	1.4	Proposals & Fundraising		0%	0 hrs
41	1.5	System Design Report & Review	SA	15%	406 hrs
51	2	System Requirements	PW	81%	959.2 hrs
52	2.1	Science Requirements	CM	82%	705.2 hrs
140	2.2	Observatory Requirements	CN	80%	174 hrs
145	2.3	System Requirements Document		72%	80 hrs
153	3	System Design	PW	91%	7,337 hrs
154	3.1	Systems Engineering	RD	95%	4,585 hrs
241	3.2	AO System	DG	94%	1,269 hrs
273	3.3	Laser Facility	CN	100%	465 hrs
287	3.4	Science Operations	DLM	32%	390 hrs
318	3.5	Science Instruments	SA	81%	488 hrs
362	3.6	System Design Manual (SDM)	PW	100%	140 hrs
365	4	Systems Engineering Management Plan (SE	PW	88%	986 hrs
366	4.1	Project Plan	PW	82%	410 hrs
371	4.2	Risk Assessment & Management Plan	DG	100%	40 hrs
372	4.3	Preliminary Design Phase Plan	PW	100%	192 hrs
376	4.4	Integration and Test Plans	CN	84%	154 hrs
383	4.5	Configuration Management Plan	EJ	25%	30 hrs
384	4.6	Project Management Plan	PW	100%	80 hrs
385	4.7	SEMP Document	PW	100%	80 hrs

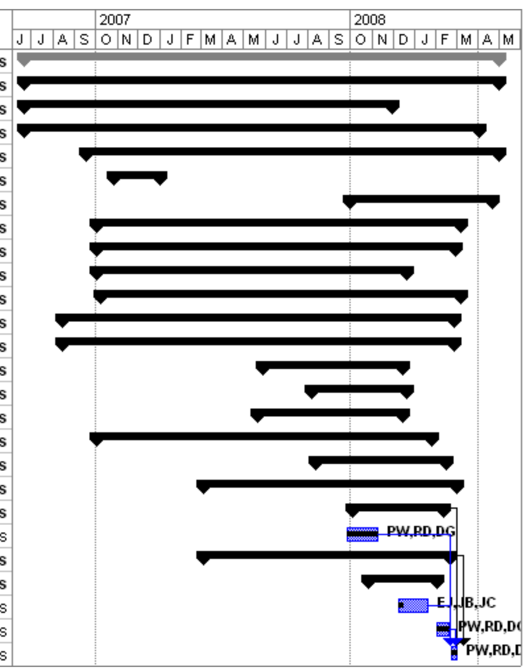


Figure 17. System Design work completed versus plan.

Dedicated personnel in the Preliminary Design phase will be very important. We found that the personnel working on the System Design phase fluctuated significantly as shown in Figure 18 (note that the number of pay periods in a month can also introduce fluctuations). This was partly due to people cycling on to perform a specific task and partly due to conflicts for their time.

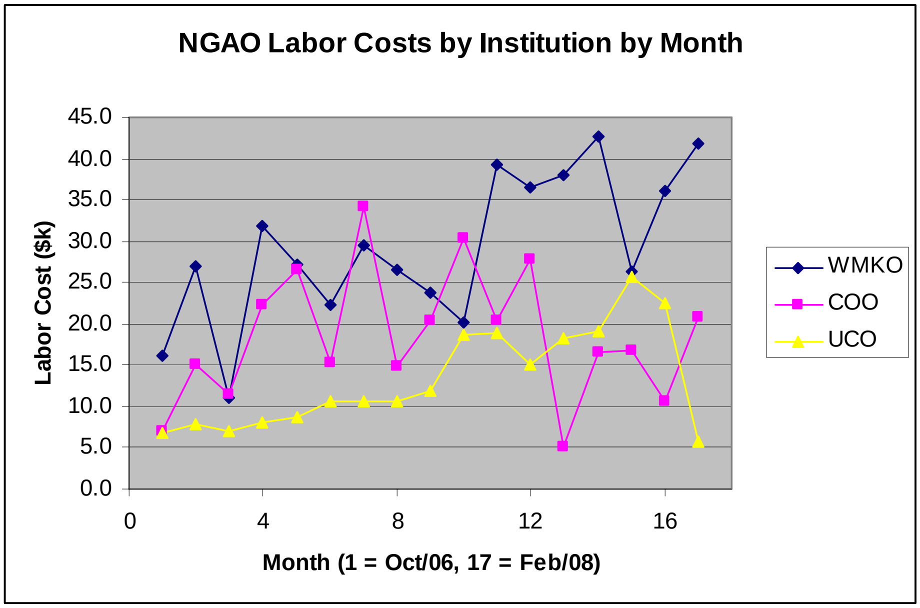


Figure 18. System Design actual labor costs by Institution and month.

We also encountered inefficiencies during the System Design phase due to our new multi-institution collaboration. As pointed out earlier we did benefit from the Executive Committee structure however it also added to the management overhead. There were also inefficiencies due to work being spread across multiple institutions during the System Design phase, which was required to come to joint conclusions on systems engineering issues. We have produced a Preliminary Design plan that has work packages primarily assigned to individual institutions in order to reduce the inter-institution inefficiencies.

Quarterly project reports were provided to the Directors prior to each Keck Science Steering Committee meeting throughout the System Design Phase (KAONs 459, 473, 494, 512, 514 and 557). These reports provide additional information on the progress and issues over the course of the System Design phase.

6 APPENDIX: COST ESTIMATION WORKSHEET EXAMPLE (WBS 3.3.3 DD PHASE)

NGAO Cost Estimating Worksheet

WBS*: 3.3.3
WBS Title*: PSF Calibration
Phase*: DD
Responsible Estimator*: Richard Dekany
Estimators*:

Estimate Date*: 3/17/08

Links:
Cost Estimating Plan
Input Cheat Sheet

* - Required Fields

Element Scope / WBS Dictionary Entry*:

This element includes the effort to develop, test and verify on-axis, telemetry-based (RTC + Cn2(h,t) data) PSF reconstruction software as a prototype for planned facility-delivered telemetry-based PSF reconstruction software implemented in WBS 6.3. We assume here that the objectives of the FY2008 CfAO-funded research effort on PSF reconstruction successfully meets all their stated objectives.

In addition, this element includes the effort test and verify off-axis, anisoplantic PSF software as a prototype for planned facility-delivered anisoplanatic PSF estimation software implemented in WBS 6.3. The premise is that Cn2(h,t) information is available, and is used to estimate the PSF across the NGAO FoR, using either a measured reference PSF or an RTC+Cn2(h,t) telemetry derived PSF.

This estimate assumes the availability of an atmospheric profiler at the Keck ridge site.

No general-use Keck AO system PSF reconstruction tool is produced in this work package.

Deliverables*:

Prototype on-axis PSF estimation software with best effort PSF prediction performance
A technical report describing the performance of the prototype software on simulated Keck AO system data
A technical report describing the performance of the prototype on-axis PSF software on measured Keck AO system data
A technical report describing the performance of the prototype off-axis PSF software on measured Keck AO system data, extrapolating from a telemetry-based on-axis PSF (extrapolation from a measured on-axis PSF is assumed to be verified by M. Britton's FY08 CfAO research program).

Labor

BOE*:

Software development building on CfAO result 12 wk-weeks = 480 hrs (80 hrs SrSci + 400 hrs AssocSci)
Generation of simulated Keck AO system telemetry 120 hrs (120 AssocSci)
Technical report (writing and content) 4 wk-weeks = 160 hrs (40 SrSci + 120 AssocSci)
Conducting on-sky tests at Keck observatory 80 hr (40 SrSci + 40 AssocSci)
Data analysis and exercise of on-axis PSF reconstruction routines 320 hr (80 SrSci + 240 AssocSci)
Data analysis and exercise of off-axis PSF reconstruction routines 240 hr (60 SrSci + 180 AssocSci)

	Resource	Estimate Type	Hours
1	SrSci	EE	300
2	AssocSci	EE	1100
3			
+			

WBS Total Hours: 1400 WBS Labor Costs: $109,288

WBS Total Hours: 1400 WBS Labor Costs: $109,288

Non-Labor

BOE*:

None.

	Expense Item	Description	Category	Estimate Type	Unit Cost	Number of units
1						
2						

WBS Effective Tax: $0 WBS Non-Labor Costs: $0

Travel

BOE*:

One two-person trip to Hawaii to conduct a sky test

	Trip Type	Duration	Number of Trips
1	CALIF	SHORT	0
2	HAWAII	SHORT	2

WBS Travel Costs: $6,683

Risk Factors

	Factor	%	Basis*:
Technical*:	8	2%	These algorithms for Shack-Hartmann sensors advance the state-of-the-art, but there is little implementation risk as similar scale software has been previously developed by our team
Cost*:	8	1%	Our estimates for labor hours here are very uncertain, given the lack of documented software requirements (at this early project stage)
Schedule*:	4		The failure of this workpackage to maintain its schedule could delay completion of the pre- and post-observing support WBS 6.3
TOTAL:	**28%**		
Override:			

WBS Budgeted Cost:	$115,972
WBS Contingency:	$32,472
WBS TOTAL:	$148,444

Misc Comments:

3/5/08 - reclassified labor to weight AssocSci more strongly (~3 to 1 with SrSci)
Reduced duration of HAWAII trips to SHORT
3/11/08 - added scope deferred from PD phase
3/17/08 - RGD added remaining scope from PD phase; lowered Risk Factors to reflect balance of all work now in DD phase.

Scoping Options:

NGAO_SD_Cost_Estimate_Richard_Dekany_Penulto.xls, 3.3.3 DD, Last updated: 3/31/08

7 Appendix: Cost Estimation Worksheet Example (WBS 4.2.4 FSD Phase)

NGAO Cost Estimating Worksheet

WBS*: 4.2.4
WBS Title*: Optical Switchyard
Phase*: FSD
Responsible Estimator*: Don Gavel
Estimators*:

Estimate Date*: 2/14/08

Links:
Cost Estimating Plan
Input Cheat Sheet

* - Required Fields

Element Scope / WBS Dictionary Entry*:

Fabricate and / or receive parts and assemble the optical switchyard on the AO optical bench. Align and test for functional compliance and interface with the rest of the system. Complete a plan for on-telescope commissioning.

Deliverables*:

Completed working subsystem.
Report on test results.
Final version of on-telescope commissioning plan.

Labor

BOE*:

Refer to KAON 549. Assumes Optics and Dichroics are out-sourced, switcher stages are partially custom, partially commercial parts. Includes detent-position switches but not cabling, which is under non-RT control.

	Resource	Estimate Type	Hours
1	Tech	CER	1920
2	AssocSci	CER	320
+			

WBS Total Hours: 2240 WBS Labor Costs: $103,443

Non-Labor

BOE*:

	Expense Item	Description	Category	Estimate Type	Unit Cost	Number of units
1	Dichroic	LGS dichroic splitter	EQP	CER	$10,000.00	1
2	InOutMech	LGS dichroic switcher mechanism	MAT	CER	$4,000.00	1
3	Mirror	LGS acquisition fold	EQP	CER	$1,000.00	1
4	Dichroic	Dichroic: post-relay 1	EQP	CER	$20,000.00	6
5	Mirror	Mirror: post-relay 1	EQP	CER	$2,000.00	1
6	Dichroic	Interferometer dichroic	EQP	CER	$10,000.00	1
7	Mirror	Interferometer selection mirror	EQP	CER	$2,000.00	1
8	Mirror	NGS acquisition fold	EQP	CER	$2,000.00	1
9	InOutMech	LGS acquisition switcher mechanism	MAT	CER	$4,000.00	1
10	Decker	Post-relay dichroic switcher	MAT	CER	$30,000.00	1
11	SwitcherMech	3 way dirchoic switcher mechanism for Interferometer fold	MAT	CER	$15,000.00	1
12	InOutMech	NGS acquisition switcher	MAT	CER	$4,000.00	1
13	Dichroic	NGS WFS dichroic	EQP	CER	$10,000.00	2
14	SwitcherMech	3 way dirchoic switcher mechanism for NGS WFS	MAT	CER	$15,000.00	1
15	Dichroic	Dichroic: visible imager	EQP	CER	$10,000.00	1
16	SwitcherMech	3 way dichroic switcher mechanism for visible imager	EQP	CER	$7,000.00	1
17	Mirror	OSIRIS selection mirror	EQP	CER	$1,000.00	1
18	InOutMech	OSIRIS selection mechanism	MAT	CER	$2,000.00	1
19	Mirror	NGS field steering mirrors	EQP	CER	$1,000.00	2
20	Mount	NGS field steering mounts	EQP	CER	$1,500.00	2
+						

WBS Effective Tax $7,920 WBS Non-Labor Costs: $264,000

Travel

BOE*:

None necessary.

	Trip Type	Duration	Number of Trips
1			
2			
+			

WBS Travel Costs: $0

Risk Factors

	Factor	%	Basis*:
Technical*:	6	2%	all custom
Cost*:	10	1%	
Schedule*:	8		
TOTAL:	**30%**		
Override:			

WBS Budgeted Cost:	$375,363
WBS Contingency:	$112,609
WBS TOTAL:	$487,972

Misc Comments:

Scoping Options:

NGAO_SD_Cost_Estimate_Don_Gavel_Penult6-1.xls 4.2.4 FSD Last updated: 3/31/08

8 APPENDIX: NGAO COST ESTIMATE SUMMARY (IN FY08 $K)

		Labor hrs	PY	Trips	Labor	Non-labor	$k Travel	Conting	Total	% of NGAO	
2	**Management**									11%	**4674**
2.1	Planning	4390	2.4	5	421	0	19	22	461		
2.2	Project Management & Meetings	8358	4.6	85	766	0	232	57	1055		
2.3	Tracking & Reporting	5412	3.0	49	535	0	122	38	695		
2.4	Proposals & Fundraising	80	0.0	0	10	0	0	1	11		
2.5	Programmatic Risk Assessment & Mitigation	460	0.3	2	53	0	8	8	69		
2.6	Project Reviews	3544	2.0	104	376	0	383	69	828		
2.7	Project Support	20066	11.1	23	1010	354	67	123	1554		
3	**Systems Engineering**									7%	**2886**
3.1	Science Case Development										
3.1.1	Science Requirements	3460	1.9	17	159	2	16	12	189		
3.1.2	Science Observing Planning and Execution	1800	1.0	0	101	0	0	19	120		
3.1.3	Science Input to Other WBS Elements Affecting S	670	0.4	22	28	0	32	11	71		
3.1.4	Science Competitiveness	312	0.2	12	13	0	66	5	83		
3.1.5	User Community Liason	280	0.2	8	12	0	7	1	20		
3.1.6	Science Advisory Team Meetings	640	0.4	32	32	0	29	4	65		
3.2	Requirements	3699	2.1	0	286	0	0	23	309		
3.3	Systems Engineering Analysis										
3.3.1	Performance Budgets	2800	1.6	13	284	0	12	66	363		
3.3.2	Modeling & Analysis	2000	1.1	14	187	0	25	67	279		
3.3.3	PSF Calibration	1440	0.8	4	112	0	12	34	158		
3.4	System Architecture										
3.4.1	System Hardware Architecture	1016	0.6	0	95	0	0	28	123		
3.4.2	Motion Control / Electronics Architecture	310	0.2	0	30	0	0	9	40		
3.4.3	System Software Architecture	830	0.5	0	102	0	0	22	124		
3.4.4	Operations Sequences Architecture	776	0.4	4	67	0	13	14	95		
3.5	External Interface Control	524	0.3	0	45	0	0	3	48		
3.6	Internal Interface Control	1672	0.9	14	141	0	28	31	200		
3.7	Configuration Management	684	0.4	0	34	0	0	14	48		
3.8	Documentation Control	253	0.1	0	13	0	0	2	15		
3.9	Technical Risk Assessment & Mitigation	2000	1.1	1	197	263	4	32	496		
3.10	System Manual	340	0.2	0	39	0	0	2	41		
4	**AO System Development**									39%	**16533**
4.1	AO Enclosure	520	0.3	0	35	618	0	116	769		
4.2	Optomechanical										
4.2.1	AO Support Structure	1920	1.1	0	105	113	0	65	284		
4.2.2	Rotator	740	0.4	0	44	45	0	23	113		
4.2.3	Optical Relays	6720	3.7	0	399	266	0	199	864		
4.2.4	Optical Switchyard	4640	2.6	0	278	272	0	165	714		
4.2.5	LGS Wavefront Sensor Assembly	7450	4.1	3	495	1618	4	905	3022		
4.2.6	NGS WFS / TWFS Assembly	3384	1.9	0	194	237	0	96	527		
4.2.7	Low Order Wavefront Sensor Assembly	9520	5.3	5	592	1007	5	687	2290		
4.2.8	Tip/Tilt Vibration Mitigation	3180	1.8	0	210	52	0	58	319		
4.2.9	Acquisition Cameras	578	0.3	0	38	69	0	17	124		
4.2.10	Atmospheric Dispersion Correctors	2240	1.2	0	128	41	0	44	213		
4.3	Alignment, Calibration, and Diagnostics										
4.3.1	Simulator	1865	1.0	2	138	135	10	42	325		
4.3.2	System Alignment Tools	1695	0.9	2	125	1	10	20	156		
4.3.3	Atmospheric Profiler	0	0.0	0	0	0	0	0	0		
4.4	Non-real-time Control										
4.4.1	AO Controls Infrastructure	180	0.1	0	16	0	0	5	21		
4.4.2	AO Sequencer	980	0.5	0	78	0	0	25	103		
4.4.3	Motion Control SW	4560	2.5	0	266	0	0	101	366		
4.4.4	Device Control SW	3755	2.1	0	223	0	0	85	308		
4.4.5	Motion Control Electronics	760	0.4	0	57	180	0	87	325		
4.4.6	Non-RTC Electronics	760	0.4	0	57	49	0	38	144		
4.4.7	Lab I&T System	320	0.2	0	25	53	0	28	106		
4.4.8	Acquisition, Guiding, and Offloading Control	760	0.4	0	61	0	0	19	80		
4.5	Real-time Control										
4.5.1	Real-time Control Processor	13779	7.7	5	667	1067	16	490	2241		
4.5.2	DM's and Tip/Tilt Stages	3040	1.7	2	212	1483	6	332	2032		
4.6	AO System Lab I&T	8480	4.7	12	690	113	83	201	1086		

4.6	AO System Lab I&T	8480	4.7	12	690	113	83	201	1086		
5	**Laser System Development**									26%	**10915**
5.1	Laser Enclosure	1224	0.7	0	81	51	0	29	162		
5.2	Laser	3440	1.9	29	329	5691	109	1160	7289		
5.3	Laser Launch Facility	3900	2.2	2	266	1340	7	516	2130		
5.4	Laser Safety Systems	1812	1.0	0	133	36	0	27	196		
5.5	Laser System Control	8105	4.5	0	543	126	0	107	777		
5.6	Laser System Lab I&T	3126	1.7	0	193	72	0	95	360		
6	**Science Operations**									4%	**1801**
6.1	Multi-System Command Sequencer										
6.1.1	Sequencer Infrastructure	2120	1.2	0	182	0	0	24	206		
6.1.2	Setup Sequences: Configurations & Calibrations	980	0.5	0	84	0	0	11	95		
6.1.3	Observing Sequences	2520	1.4	0	212	0	0	28	240		
6.1.4	System Health and Troubleshooting	1230	0.7	0	105	0	0	17	123		
6.2	User Interfaces										
6.2.1	User Interface Infrastructure	1110	0.6	0	97	0	0	11	107		
6.2.2	Setup Operations: Configuration, Calibrations	750	0.4	0	64	0	0	7	72		
6.2.3	Observations User Interfaces for operator, observe	1790	1.0	0	152	0	0	17	170		
6.3	Pre- & Post-Observing Support										
6.3.1	Users' Documentation	300	0.2	0	25	0	0	1	26		
6.3.2	Planning Tools	3475	1.9	5	288	0	19	35	342		
6.3.3	Data Products	3340	1.9	0	249	0	0	52	301		
6.4	Data Server	680	0.4	0	51	39	0	29	119		
7	**Telescope & Summit Engineering**									5%	**1932**
7.1	Telescope Performance	0	0.0	0	0	0	0	0	0		
7.2	Infrastructure Mods for AO	6270	3.5	3	381	351	12	182	926		
7.3	Infrastructure Mods for Laser	4423	2.5	0	248	354	0	132	734		
7.4	OSIRIS Modifications	1200	0.7	0	90	46	0	17	153		
7.5	Interferometer and OHANA Mods	1024	0.6	0	75	31	0	13	118		
8	**Telescope Integration & Test**									6%	**2735**
8.1	Old AO/Laser Removal	4040	2.2	0	220	21	0	85	326		
8.2	Laser Enclosure Integration	1040	0.6	0	47	40	0	17	104		
8.3	AO Enclosure Integration	1100	0.6	0	52	41	0	24	117		
8.4	AO System Install + I&T	6850	3.8	4	443	10	28	93	574		
8.5	Laser System Install + I&T	3798	2.1	0	231	0	0	59	289		
8.6	LGS AO System On-sky I&T	5030	2.8	12	401	0	50	90	540		
8.7	Performance Characterization	3760	2.1	27	265	0	148	124	537		
8.8	Science Verification	2420	1.3	17	150	0	64	33	248		
9	**Operations Transition**									2%	**750**
9.1	Operations Plans	636	0.4	0	43	515	0	81	639		
9.2	Operations Handover										
9.2.1	Operations Personnel Training	520	0.3	10	42	0	38	8	88		
9.2.2	Documentation & Spares Transition	290	0.2	0	22	0	0	2	24		
	Total =	231944	129	549	16045	16804	1681	7697	42227	**100%**	**42227**

9 APPENDIX: NGAO DETAILED DESIGN COST ESTIMATE SUMMARY (IN FY08 $K)

		Labor			$k					% of WBS in this Phase	
		hrs	PY	Trips	Labor	Non-labor	Travel	Conting	Total		
2	**Management**										**1311**
2.1	Planning	1900	1.1	1	186	0	4	9	199	43%	
2.2	Project Management & Meetings	3300	1.8	37	309	0	108	21	438	42%	
2.3	Tracking & Reporting	1339	0.7	11	135	0	22	8	165	24%	
2.4	Proposals & Fundraising	40	0.0	0	5	0	0	0	5	50%	
2.5	Programmatic Risk Assessment & Mitigation	180	0.1	2	21	0	8	6	34	49%	
2.6	Project Reviews	548	0.3	16	58	0	64	10	132	16%	
2.7	Project Support	3990	2.2	5	192	106	15	25	337	22%	
3	**Systems Engineering**										**1186**
3.1	Science Case Development										
3.1.1	Science Requirements	680	0.4	6	28	0	6	2	36	19%	
3.1.2	Science Observing Planning and Execution	920	0.5	0	50	0	0	11	62	51%	
3.1.3	Science Input to Other WBS Elements Affecting Sc	180	0.1	8	8	0	12	4	23	33%	
3.1.4	Science Competitiveness	104	0.1	4	4	0	22	2	28	33%	
3.1.5	User Community Liason	70	0.0	2	3	0	2	0	5	25%	
3.1.6	Science Advisory Team Meetings	160	0.1	8	8	0	7	1	16	25%	
3.2	Requirements	990	0.6	0	76	0	0	6	82	26%	
3.3	Systems Engineering Analysis										
3.3.1	Performance Budgets	1120	0.6	4	109	0	4	28	141	39%	
3.3.2	Modeling & Analysis	760	0.4	5	74	0	7	32	113	41%	
3.3.3	PSF Calibration	1400	0.8	2	109	0	7	32	148	94%	
3.4	System Architecture										
3.4.1	System Hardware Architecture	304	0.2	0	28	0	0	8	36	29%	
3.4.2	Motion Control / Electronics Architecture	200	0.1	0	20	0	0	6	26	65%	
3.4.3	System Software Architecture	320	0.2	0	31	0	0	7	38	38%	
3.4.4	Operations Sequences Architecture	360	0.2	1	30	0	3	6	40	42%	
3.5	External Interface Control	140	0.1	0	12	0	0	1	13	26%	
3.6	Internal Interface Control	832	0.5	4	71	0	6	11	88	44%	
3.7	Configuration Management	180	0.1	0	9	0	0	4	12	25%	
3.8	Documentation Control	90	0.1	0	4	0	0	1	5	33%	
3.9	Technical Risk Assessment & Mitigation	800	0.4	1	84	155	4	19	261	53%	
3.10	System Manual	100	0.1	0	11	0	0	1	12	29%	
4	**AO System Development**										**2820**
4.1	AO Enclosure	120	0.1	0	9	0	0	1	10	1%	
4.2	Optomechanical										
4.2.1	AO Support Structure	480	0.3	0	35	0	0	10	45	16%	
4.2.2	Rotator	270	0.2	0	20	0	0	5	25	22%	
4.2.3	Optical Relays	2827	1.6	0	205	0	0	62	267	31%	
4.2.4	Optical Switchyard	2000	1.1	0	145	0	0	44	189	26%	
4.2.5	LGS Wavefront Sensor Assembly	2480	1.4	3	174	0	4	62	241	8%	
4.2.6	NGS WFS / TWFS Assembly	1812	1.0	0	105	0	0	19	124	24%	
4.2.7	Low Order Wavefront Sensor Assembly	4220	2.3	3	270	0	3	106	379	17%	
4.2.8	Tip/Tilt Vibration Mitigation	1100	0.6	0	74	0	0	12	86	27%	
4.2.9	Acquisition Cameras	188	0.1	0	13	0	0	2	15	12%	
4.2.10	Atmospheric Dispersion Correctors	720	0.4	0	52	0	0	14	66	31%	
4.3	Alignment, Calibration, and Diagnostics										
4.3.1	Simulator	870	0.5	0	65	0	0	10	74	23%	
4.3.2	System Alignment Tools	850	0.5	0	64	0	0	10	73	47%	
4.3.3	Atmospheric Profiler	0	0.0	0	0	0	0	0	0	0%	
4.4	Non-real-time Control										
4.4.1	AO Controls Infrastructure	140	0.1	0	13	0	0	4	17	79%	
4.4.2	AO Sequencer	420	0.2	0	33	0	0	11	44	43%	
4.4.3	Motion Control SW	650	0.4	0	51	0	0	20	71	19%	
4.4.4	Device Control SW	495	0.3	0	36	0	0	14	50	16%	
4.4.5	Motion Control Electronics	500	0.3	0	41	0	0	13	54	17%	
4.4.6	Non-RTC Electronics	400	0.2	0	32	0	0	10	42	29%	
4.4.7	Lab I&T System	280	0.2	0	23	0	0	7	31	29%	
4.4.8	Acquisition, Guiding, and Offloading Control	480	0.3	0	39	0	0	13	52	65%	
4.5	Real-time Control										
4.5.1	Real-time Control Processor	10154	5.6	1	485	29	3	145	661	30%	
4.5.2	DM's and Tip/Tilt Stages	960	0.5	1	76	0	3	9	88	4%	
4.6	AO System Lab I&T	1200	0.7	0	107	0	0	11	118	11%	

4.5.2	DM's and Tip/Tilt Stages	960	0.5	1	76	0	3	9	88	4%	
4.6	AO System Lab I&T	1200	0.7	0	107	0	0	11	118	11%	
5	**Laser System Development**										**2292**
5.1	Laser Enclosure	544	0.3	0	39	0	0	9	48	30%	
5.2	Laser	998	0.6	6	98	1438	23	265	1823	25%	
5.3	Laser Launch Facility	1220	0.7	0	88	0	0	28	116	5%	
5.4	Laser Safety Systems	647	0.4	0	49	0	0	8	57	29%	
5.5	Laser System Control	2610	1.5	0	208	0	0	33	242	31%	
5.6	Laser System Lab I&T	48	0.0	0	4	0	0	1	5	1%	
6	**Science Operations**										**850**
6.1	Multi-System Command Sequencer										
6.1.1	Sequencer Infrastructure	1120	0.6	0	102	0	0	11	113	55%	
6.1.2	Setup Sequences: Configurations & Calibrations	470	0.3	0	42	0	0	5	47	49%	
6.1.3	Observing Sequences	1340	0.7	0	117	0	0	13	130	54%	
6.1.4	System Health and Troubleshooting	600	0.3	0	55	0	0	9	64	52%	
6.2	User Interfaces										
6.2.1	User Interface Infrastructure	520	0.3	0	47	0	0	4	51	48%	
6.2.2	Setup Operations: Configuration, Calibrations	310	0.2	0	28	0	0	3	31	43%	
6.2.3	Observations User Interfaces for operator, observe	770	0.4	0	69	0	0	6	75	44%	
6.3	Pre- & Post-Observing Support										
6.3.1	Users' Documentation	100	0.1	0	8	0	0	0	9	33%	
6.3.2	Planning Tools	1570	0.9	3	138	0	11	13	162	47%	
6.3.3	Data Products	1390	0.8	0	109	0	0	20	129	43%	
6.4	Data Server	370	0.2	0	30	0	0	10	39	33%	
7	**Telescope & Summit Engineering**										**505**
7.1	Telescope Performance	0	0.0	0	0	0	0	0	0	0%	
7.2	Infrastructure Mods for AO	2450	1.4	0	165	30	1	39	235	25%	
7.3	Infrastructure Mods for Laser	1136	0.6	0	78	70	0	33	181	25%	
7.4	OSIRIS Modifications	380	0.2	0	33	0	0	3	36	24%	
7.5	Interferometer and OHANA Mods	619	0.3	0	48	0	0	6	53	45%	
8	**Telescope Integration & Test**										**115**
8.1	Old AO/Laser Removal	480	0.3	0	27	0	0	3	29	9%	
8.2	Laser Enclosure Integration	0	0.0	0	0	0	0	0	0	0%	
8.3	AO Enclosure Integration	0	0.0	0	0	0	0	0	0	0%	
8.4	AO System Install + I&T	100	0.1	0	7	0	0	1	7	1%	
8.5	Laser System Install + I&T	176	0.1	0	13	0	0	1	14	5%	
8.6	LGS AO System On-sky I&T	200	0.1	0	19	0	0	2	20	4%	
8.7	Performance Characterization	40	0.0	0	2	0	0	0	2	0%	
8.8	Science Verification	460	0.3	2	31	0	8	2	41	17%	
9	**Operations Transition**										**22**
9.1	Operations Plans	108	0.1	0	8	0	0	0	8	1%	
9.2	Operations Handover										
9.2.1	Operations Personnel Training	90	0.1	0	9	0	0	1	10	11%	
9.2.2	Documentation & Spares Transition	40	0.0	0	3	0	0	0	4	15%	
	Total =	75529	42	136	5516	1827	354	1403	9100	22%	**9100**

10 APPENDIX: NGAO FULL SCALE DEVELOPMENT COST ESTIMATE SUMMARY (IN FY08 $K)

		Labor					$k			% of WBS in this	
		hrs	PY	Trips	Labor	Non-labor	Travel	Conting	Total	Phase	
2	**Management**										**1739**
2.1	Planning	760	0.4	4	62	0	15	4	81	17%	
2.2	Project Management & Meetings	2414	1.3	26	207	0	58	21	286	27%	
2.3	Tracking & Reporting	1890	1.1	18	174	0	51	18	242	35%	
2.4	Proposals & Fundraising	0	0.0	0	0	0	0	0	0	0%	
2.5	Programmatic Risk Assessment & Mitigation	60	0.0	0	7	0	0	0	7	11%	
2.6	Project Reviews	1524	0.8	43	162	0	158	32	352	43%	
2.7	Project Support	9250	5.1	12	483	182	35	70	770	50%	
3	**Systems Engineering**										**554**
3.1	Science Case Development										
3.1.1	Science Requirements	520	0.3	6	22	0	6	2	29	15%	
3.1.2	Science Observing Planning and Execution	300	0.2	0	21	0	0	5	26	22%	
3.1.3	Science Input to Other WBS Elements Affecting S	220	0.1	7	9	0	9	3	21	30%	
3.1.4	Science Competitiveness	104	0.1	4	4	0	22	2	28	33%	
3.1.5	User Community Liason	70	0.0	2	3	0	2	0	5	25%	
3.1.6	Science Advisory Team Meetings	160	0.1	8	8	0	7	1	16	25%	
3.2	Requirements	1135	0.6	0	90	0	0	7	97	31%	
3.3	Systems Engineering Analysis										
3.3.1	Performance Budgets	620	0.3	2	63	0	2	8	72	20%	
3.3.2	Modeling & Analysis	240	0.1	3	21	0	5	10	36	13%	
3.3.3	PSF Calibration	40	0.0	0	3	0	0	1	4	3%	
3.4	System Architecture										
3.4.1	System Hardware Architecture	304	0.2	0	28	0	0	8	36	29%	
3.4.2	Motion Control / Electronics Architecture	30	0.0	0	3	0	0	1	4	10%	
3.4.3	System Software Architecture	240	0.1	0	24	0	0	5	29	29%	
3.4.4	Operations Sequences Architecture	96	0.1	1	9	0	3	2	15	16%	
3.5	External Interface Control	80	0.0	0	7	0	0	1	8	17%	
3.6	Internal Interface Control	416	0.2	4	36	0	6	11	53	26%	
3.7	Configuration Management	208	0.1	0	10	0	0	4	14	29%	
3.8	Documentation Control	104	0.1	0	5	0	0	1	6	38%	
3.9	Technical Risk Assessment & Mitigation	500	0.3	0	42	0	0	4	46	9%	
3.10	System Manual	80	0.0	0	9	0	0	0	9	23%	
4	**AO System Development**										**12770**
4.1	AO Enclosure	100	0.1	0	4	618	0	112	734	95%	
4.2	Optomechanical										
4.2.1	AO Support Structure	1280	0.7	0	58	113	0	52	223	79%	
4.2.2	Rotator	350	0.2	0	16	45	0	16	78	69%	
4.2.3	Optical Relays	3360	1.9	0	155	266	0	126	547	63%	
4.2.4	Optical Switchyard	2240	1.2	0	103	272	0	113	488	68%	
4.2.5	LGS Wavefront Sensor Assembly	3450	1.9	0	209	1618	0	804	2632	87%	
4.2.6	NGS WFS / TWFS Assembly	944	0.5	0	53	237	0	70	360	68%	
4.2.7	Low Order Wavefront Sensor Assembly	3704	2.1	0	214	1007	0	537	1759	77%	
4.2.8	Tip/Tilt Vibration Mitigation	2000	1.1	0	130	52	0	45	227	71%	
4.2.9	Acquisition Cameras	263	0.1	0	16	69	0	14	99	80%	
4.2.10	Atmospheric Dispersion Correctors	1280	0.7	0	58	41	0	26	126	59%	
4.3	Alignment, Calibration, and Diagnostics										
4.3.1	Simulator	745	0.4	2	54	135	10	30	228	70%	
4.3.2	System Alignment Tools	590	0.3	2	42	1	10	8	60	39%	
4.3.3	Atmospheric Profiler	0	0.0	0	0	0	0	0	0	0%	
4.4	Non-real-time Control										
4.4.1	AO Controls Infrastructure	40	0.0	0	3	0	0	1	5	21%	
4.4.2	AO Sequencer	420	0.2	0	33	0	0	11	44	42%	
4.4.3	Motion Control SW	3680	2.0	0	196	0	0	74	270	74%	
4.4.4	Device Control SW	3020	1.7	0	167	0	0	64	231	75%	
4.4.5	Motion Control Electronics	200	0.1	0	12	180	0	73	264	81%	
4.4.6	Non-RTC Electronics	200	0.1	0	12	49	0	23	84	59%	
4.4.7	Lab I&T System	40	0.0	0	2	53	0	21	75	71%	
4.4.8	Acquisition, Guiding, and Offloading Control	120	0.1	0	8	0	0	3	11	14%	
4.5	Real-time Control										
4.5.1	Real-time Control Processor	588	0.3	4	36	1023	13	300	1371	61%	
4.5.2	DM's and Tip/Tilt Stages	1760	1.0	0	110	1483	0	319	1912	94%	
4.6	AO System Lab I&T	7000	3.9	12	559	113	83	189	943	87%	
5	**Laser System Development**										**8139**

5	**Laser System Development**										**8139**
5.1	Laser Enclosure	520	0.3	0	30	51	0	18	100	62%	
5.2	Laser	1562	0.9	19	138	4132	72	868	5210	71%	
5.3	Laser Launch Facility	1824	1.0	2	117	1320	7	462	1907	90%	
5.4	Laser Safety Systems	995	0.6	0	71	36	0	17	124	63%	
5.5	Laser System Control	4585	2.5	0	260	126	0	62	448	58%	
5.6	Laser System Lab I&T	3030	1.7	0	186	72	0	93	350	97%	
6	**Science Operations**										**766**
6.1	Multi-System Command Sequencer										
6.1.1	Sequencer Infrastructure	820	0.5	0	63	0	0	11	74	36%	
6.1.2	Setup Sequences: Configurations & Calibrations	410	0.2	0	32	0	0	5	38	39%	
6.1.3	Observing Sequences	940	0.5	0	72	0	0	12	84	35%	
6.1.4	System Health and Troubleshooting	530	0.3	0	41	0	0	7	48	39%	
6.2	User Interfaces										
6.2.1	User Interface Infrastructure	410	0.2	0	32	0	0	5	37	34%	
6.2.2	Setup Operations: Configuration, Calibrations	360	0.2	0	28	0	0	4	32	45%	
6.2.3	Observations User Interfaces for operator, observe	780	0.4	0	60	0	0	9	69	41%	
6.3	Pre- & Post-Observing Support										
6.3.1	Users' Documentation	180	0.1	0	15	0	0	1	15	59%	
6.3.2	Planning Tools	1565	0.9	2	120	0	8	19	147	43%	
6.3.3	Data Products	1700	0.9	0	122	0	0	29	151	50%	
6.4	Data Server	240	0.1	0	15	39	0	17	72	60%	
7	**Telescope & Summit Engineering**										**1290**
7.1	Telescope Performance	0	0.0	0	0	0	0	0	0	0%	
7.2	Infrastructure Mods for AO	3160	1.8	2	171	316	8	129	623	67%	
7.3	Infrastructure Mods for Laser	3007	1.7	0	148	284	0	95	527	72%	
7.4	OSIRIS Modifications	520	0.3	0	30	46	0	11	88	57%	
7.5	Interferometer and OHANA Mods	344	0.2	0	22	25	0	6	53	45%	
8	**Telescope Integration & Test**										**136**
8.1	Old AO/Laser Removal	40	0.0	0	2	0	0	0	2	1%	
8.2	Laser Enclosure Integration	0	0.0	0	0	0	0	0	0	0%	
8.3	AO Enclosure Integration	0	0.0	0	0	0	0	0	0	0%	
8.4	AO System Install + I&T	180	0.1	0	11	0	0	1	12	2%	
8.5	Laser System Install + I&T	0	0.0	0	0	0	0	0	0	0%	
8.6	LGS AO System On-sky I&T	590	0.3	0	46	0	0	11	57	11%	
8.7	Performance Characterization	0	0.0	0	0	0	0	0	0	0%	
8.8	Science Verification	600	0.3	5	36	0	19	10	65	26%	
9	**Operations Transition**										**636**
9.1	Operations Plans	216	0.1	0	15	505	0	78	597	94%	
9.2	Operations Handover										
9.2.1	Operations Personnel Training	180	0.1	5	13	0	19	3	35	40%	
9.2.2	Documentation & Spares Transition	50	0.0	0	4	0	0	0	4	16%	
	Total =	88077	49	195	5661	14510	626	5234	26031	62%	**26031**

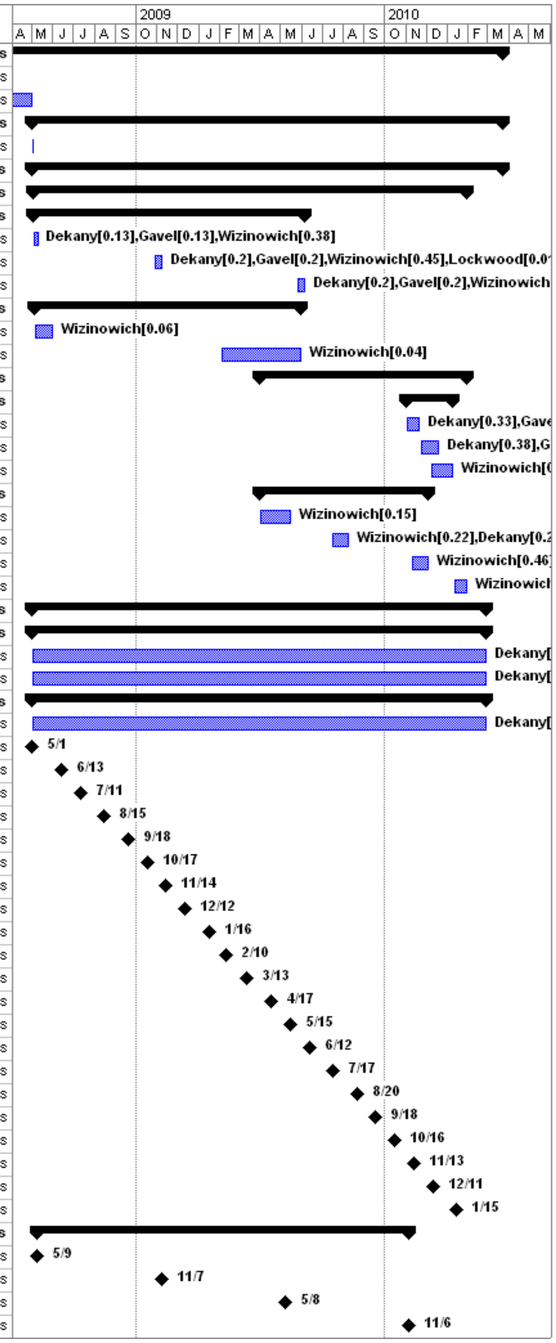
11 Appendix: NGAO Delivery and Commissioning Cost Estimate Summary (in FY08 $K)

WBS	Element	Labor hrs	PY	Trips	Labor	Non-labor	$k Travel	Conting	Total	% of WBS in this Phase	
2	**Management**										**699**
2.1	Planning	160	0.1	0	15	0	0	1	16	3%	
2.2	Project Management & Meetings	474	0.3	0	51	0	0	2	52	5%	
2.3	Tracking & Reporting	1354	0.8	13	133	0	35	7	175	25%	
2.4	Proposals & Fundraising	0	0.0	0	0	0	0	0	0	0%	
2.5	Programmatic Risk Assessment & Mitigation	40	0.0	0	5	0	0	0	5	7%	
2.6	Project Reviews	1016	0.6	32	108	0	128	24	259	31%	
2.7	Project Support	3465	1.9	2	170	7	6	9	192	12%	
3	**Systems Engineering**										**237**
3.1	Science Case Development										
3.1.1	Science Requirements	0	0.0	0	0	0	0	0	0	0%	
3.1.2	Science Observing Planning and Execution	160	0.1	0	7	0	0	1	8	7%	
3.1.3	Science Input to Other WBS Elements Affecting Sc	140	0.1	0	6	0	0	1	7	9%	
3.1.4	Science Competitiveness	0	0.0	0	0	0	0	0	0	0%	
3.1.5	User Community Liason	70	0.0	2	3	0	2	0	5	25%	
3.1.6	Science Advisory Team Meetings	160	0.1	8	8	0	7	1	16	25%	
3.2	Requirements	480	0.3	0	37	0	0	3	40	13%	
3.3	Systems Engineering Analysis										
3.3.1	Performance Budgets	312	0.2	3	31	0	3	13	47	13%	
3.3.2	Modeling & Analysis	120	0.1	2	12	0	4	6	23	8%	
3.3.3	PSF Calibration	0	0.0	0	0	0	0	0	0	0%	
3.4	System Architecture										
3.4.1	System Hardware Architecture	144	0.1	0	14	0	0	4	18	15%	
3.4.2	Motion Control / Electronics Architecture	0	0.0	0	0	0	0	0	0	0%	
3.4.3	System Software Architecture	176	0.1	0	17	0	0	4	21	21%	
3.4.4	Operations Sequences Architecture	96	0.1	1	9	0	3	2	15	16%	
3.5	External Interface Control	20	0.0	0	2	0	0	0	2	4%	
3.6	Internal Interface Control	144	0.1	2	10	0	8	5	23	12%	
3.7	Configuration Management	78	0.0	0	4	0	0	2	5	11%	
3.8	Documentation Control	39	0.0	0	2	0	0	0	2	14%	
3.9	Technical Risk Assessment & Mitigation	0	0.0	0	0	0	0	0	0	0%	
3.10	System Manual	40	0.0	0	4	0	0	0	5	12%	
4	**AO System Development**										**4**
4.1	AO Enclosure	0	0.0	0	0	0	0	0	0	0%	
4.2	Optomechanical										
4.2.1	AO Support Structure	0	0.0	0	0	0	0	0	0	0%	
4.2.2	Rotator	0	0.0	0	0	0	0	0	0	0%	
4.2.3	Optical Relays	0	0.0	0	0	0	0	0	0	0%	
4.2.4	Optical Switchyard	0	0.0	0	0	0	0	0	0	0%	
4.2.5	LGS Wavefront Sensor Assembly	0	0.0	0	0	0	0	0	0	0%	
4.2.6	NGS WFS / TWFS Assembly	0	0.0	0	0	0	0	0	0	0%	
4.2.7	Low Order Wavefront Sensor Assembly	0	0.0	0	0	0	0	0	0	0%	
4.2.8	Tip/Tilt Vibration Mitigation	0	0.0	0	0	0	0	0	0	0%	
4.2.9	Acquisition Cameras	0	0.0	0	0	0	0	0	0	0%	
4.2.10	Atmospheric Dispersion Correctors	0	0.0	0	0	0	0	0	0	0%	
4.3	Alignment, Calibration, and Diagnostics										
4.3.1	Simulator	0	0.0	0	0	0	0	0	0	0%	
4.3.2	System Alignment Tools	0	0.0	0	0	0	0	0	0	0%	
4.3.3	Atmospheric Profiler	0	0.0	0	0	0	0	0	0	0%	
4.4	Non-real-time Control										
4.4.1	AO Controls Infrastructure	0	0.0	0	0	0	0	0	0	0%	
4.4.2	AO Sequencer	0	0.0	0	0	0	0	0	0	0%	
4.4.3	Motion Control SW	0	0.0	0	0	0	0	0	0	0%	
4.4.4	Device Control SW	0	0.0	0	0	0	0	0	0	0%	
4.4.5	Motion Control Electronics	0	0.0	0	0	0	0	0	0	0%	
4.4.6	Non-RTC Electronics	0	0.0	0	0	0	0	0	0	0%	
4.4.7	Lab I&T System	0	0.0	0	0	0	0	0	0	0%	
4.4.8	Acquisition, Guiding, and Offloading Control	0	0.0	0	0	0	0	0	0	0%	
4.5	Real-time Control										
4.5.1	Real-time Control Processor	0	0.0	0	0	0	0	0	0	0%	
4.5.2	DM's and Tip/Tilt Stages	0	0.0	0	0	0	0	0	0	0%	
4.6	AO System Lab I&T	80	0.0	0	3	0	0	0	4	0%	
5	**Laser System Development**										**145**

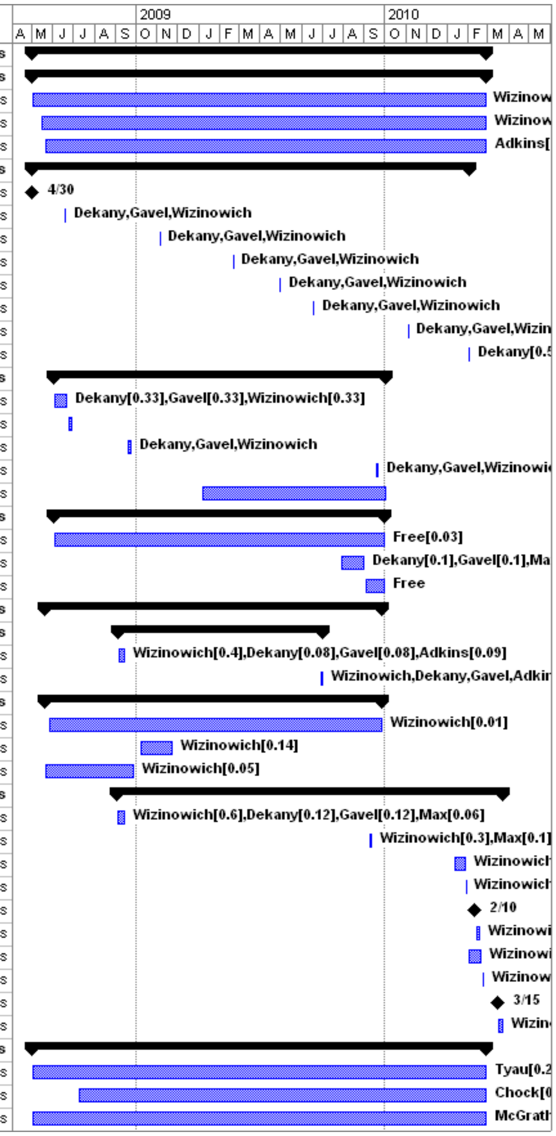
5	**Laser System Development**										**145**
5.1	Laser Enclosure	0	0.0	0	0	0	0	0	0	0%	
5.2	Laser	60	0.0	0	7	121	0	17	145	2%	
5.3	Laser Launch Facility	0	0.0	0	0	0	0	0	0	0%	
5.4	Laser Safety Systems	0	0.0	0	0	0	0	0	0	0%	
5.5	Laser System Control	0	0.0	0	0	0	0	0	0	0%	
5.6	Laser System Lab I&T	0	0.0	0	0	0	0	0	0	0%	
6	**Science Operations**										**0**
6.1	Multi-System Command Sequencer										
6.1.1	Sequencer Infrastructure	0	0.0	0	0	0	0	0	0	0%	
6.1.2	Setup Sequences: Configurations & Calibrations	0	0.0	0	0	0	0	0	0	0%	
6.1.3	Observing Sequences	0	0.0	0	0	0	0	0	0	0%	
6.1.4	System Health and Troubleshooting	0	0.0	0	0	0	0	0	0	0%	
6.2	User Interfaces										
6.2.1	User Interface Infrastructure	0	0.0	0	0	0	0	0	0	0%	
6.2.2	Setup Operations: Configuration, Calibrations	0	0.0	0	0	0	0	0	0	0%	
6.2.3	Observations User Interfaces for operator, observe	0	0.0	0	0	0	0	0	0	0%	
6.3	Pre- & Post-Observing Support										
6.3.1	Users' Documentation	0	0.0	0	0	0	0	0	0	0%	
6.3.2	Planning Tools	0	0.0	0	0	0	0	0	0	0%	
6.3.3	Data Products	0	0.0	0	0	0	0	0	0	0%	
6.4	Data Server	0	0.0	0	0	0	0	0	0	0%	
7	**Telescope & Summit Engineering**										**21**
7.1	Telescope Performance	0	0.0	0	0	0	0	0	0	0%	
7.2	Infrastructure Mods for AO	0	0.0	0	0	0	0	0	0	0%	
7.3	Infrastructure Mods for Laser	0	0.0	0	0	0	0	0	0	0%	
7.4	OSIRIS Modifications	200	0.1	0	19	0	0	2	21	13%	
7.5	Interferometer and OHANA Mods	0	0.0	0	0	0	0	0	0	0%	
8	**Telescope Integration & Test**										**2434**
8.1	Old AO/Laser Removal	3400	1.9	0	184	21	0	82	286	88%	
8.2	Laser Enclosure Integration	1040	0.6	0	47	40	0	17	104	100%	
8.3	AO Enclosure Integration	1100	0.6	0	52	41	0	24	117	100%	
8.4	AO System Install + I&T	6400	3.6	4	415	10	28	91	543	95%	
8.5	Laser System Install + I&T	3410	1.9	0	201	0	0	56	258	89%	
8.6	LGS AO System On-sky I&T	4200	2.3	12	333	0	50	76	459	85%	
8.7	Performance Characterization	3720	2.1	27	264	0	148	123	535	100%	
8.8	Science Verification	1280	0.7	10	75	0	38	20	133	54%	
9	**Operations Transition**										**77**
9.1	Operations Plans	216	0.1	0	13	10	0	2	26	4%	
9.2	Operations Handover										
9.2.1	Operations Personnel Training	200	0.1	5	15	0	19	3	37	42%	
9.2.2	Documentation & Spares Transition	180	0.1	0	13	0	0	1	14	59%	
	Total =	34174	19	123	2287	250	478	602	3617	9%	**3617**

12 Appendix: Full NGAO Preliminary Design Phase Schedule

ID	WBS	Task Name	Lead	Work
1	1	**NGAO Design**		**36,131 hrs**
2	1.1	Proposal		0 hrs
3	1.2	System Design		0 hrs
4	**1.3**	**Preliminary Design**		**36,131 hrs**
5	1.3.1	Reserved		0 hrs
6	**1.3.2**	**PD Phase Management**	**PW**	**9,306 hrs**
7	**1.3.2.1**	**Planning**	**PW**	**1,640 hrs**
8	**1.3.2.1.1**	**Replans (PD phase)**		**190 hrs**
9	1.3.2.1.1.1	Replan based on SDR		30 hrs
10	1.3.2.1.1.2	Replan 1		80 hrs
11	1.3.2.1.1.3	Replan 2		80 hrs
12	**1.3.2.1.2**	**WMKO FY Plans**		**40 hrs**
13	1.3.2.1.2.1	Support WMKO FY09 Planning		10 hrs
14	1.3.2.1.2.2	Support WMKO FY10 Planning		30 hrs
15	**1.3.2.1.3**	**Systems Engineering Management Plan**	**PW**	**1,410 hrs**
16	**1.3.2.1.3.1**	**Project Plan**		**1,010 hrs**
17	1.3.2.1.3.1.1	PBS, WBS & Task Definition	PW	260 hrs
18	1.3.2.1.3.1.2	Cost Estimation	RD	480 hrs
19	1.3.2.1.3.1.3	Full Schedule (MS Project Plan)	PW	270 hrs
20	**1.3.2.1.3.2**	**Detailed Design Phase Plan**	**PW**	**320 hrs**
21	1.3.2.1.3.2.1	Detailed Design Plan v1 (FY10 planning)	PW	40 hrs
22	1.3.2.1.3.2.2	Detailed Design Plan v2 (TSIP proposal)	PW	40 hrs
23	1.3.2.1.3.2.3	Detailed Design Plan Final Version	PW	240 hrs
24	1.3.2.1.3.3	SEMP Document	PW	80 hrs
25	**1.3.2.2**	**Project Management & Meetings**	**PW**	**2,270 hrs**
26	**1.3.2.2.1**	**Executive Committee**	**PW**	**600 hrs**
27	1.3.2.2.1.1	Executive Committee Management Activities		300 hrs
28	1.3.2.2.1.2	Executive Committee Telecons		300 hrs
29	**1.3.2.2.2**	**Team Meetings**	**PW**	**1,670 hrs**
30	1.3.2.2.2.1	Meeting Participation		1,670 hrs
31	1.3.2.2.2.2	Team Meeting #1 (CIT - 1 day)		0 hrs
32	1.3.2.2.2.3	Team Meeting #2 (telecon)		0 hrs
33	1.3.2.2.2.4	Team Meeting #3 (telecon)		0 hrs
34	1.3.2.2.2.5	Team Meeting #4 (telecon)		0 hrs
35	1.3.2.2.2.6	Team Meeting #5 (UC - 3 days)		0 hrs
36	1.3.2.2.2.7	Team Meeting #6 (telecon)		0 hrs
37	1.3.2.2.2.8	Team Meeting #7 (telecon)		0 hrs
38	1.3.2.2.2.9	Team Meeting #8 (telecon)		0 hrs
39	1.3.2.2.2.10	Team Meeting #9 (telecon)		0 hrs
40	1.3.2.2.2.11	Team Meeting #10 (WMKO - 4 days)		0 hrs
41	1.3.2.2.2.12	Team Meeting #11 (telecon)		0 hrs
42	1.3.2.2.2.13	Team Meeting #12 (telecon)		0 hrs
43	1.3.2.2.2.14	Team Meeting #13 (telecon)		0 hrs
44	1.3.2.2.2.15	Team Meeting #14 (telecon)		0 hrs
45	1.3.2.2.2.16	Team Meeting #15 (telecon)		0 hrs
46	1.3.2.2.2.17	Team Meeting #16 (CIT - 3 days))		0 hrs
47	1.3.2.2.2.18	Team Meeting #17 (telecon)		0 hrs
48	1.3.2.2.2.19	Team Meeting #18 (telecon)		0 hrs
49	1.3.2.2.2.20	Team Meeting #19 (telecon)		0 hrs
50	1.3.2.2.2.21	Team Meeting #20 (telecon)		0 hrs
51	1.3.2.2.2.22	Team Meeting #21 (telecon)		0 hrs
52	**1.3.2.2.3**	**Director Telecons**	**PW**	**0 hrs**
53	1.3.2.2.3.1	Director Telecon #1		0 hrs
54	1.3.2.2.3.2	Director Telecon #2		0 hrs
55	1.3.2.2.3.3	Director Telecon #3		0 hrs
56	1.3.2.2.3.4	Director Telecon #4		0 hrs

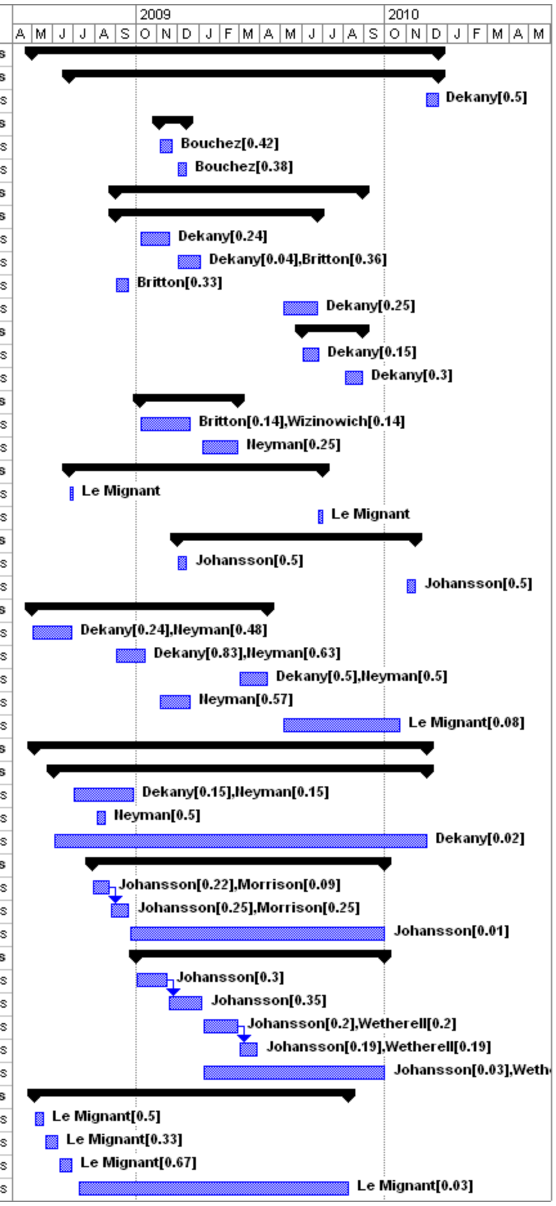


ID	WBS	Task Name	Lead	Work
57	**1.3.2.3**	**Tracking & Reporting**	**PW**	**869 hrs**
58	**1.3.2.3.1**	**Monthly Status Reports**	**PW**	**546 hrs**
59	1.3.2.3.1.1	Monthly Team Status Reports		340 hrs
60	1.3.2.3.1.2	Monthly Project Reports (TSIP, Directors)		170 hrs
61	1.3.2.3.1.3	TSIP Project Report Telecons		36 hrs
62	**1.3.2.3.2**	**SSC Meetings**	**PW**	**91 hrs**
63	1.3.2.3.2.1	SSC Meeting (CIT) - SDR report		0 hrs
64	1.3.2.3.2.2	SSC Meeting (Keck)		13 hrs
65	1.3.2.3.2.3	SSC Meeting (UCSC)		13 hrs
66	1.3.2.3.2.4	SSC Meeting (Keck)		13 hrs
67	1.3.2.3.2.5	SSC Meeting (CIT)		13 hrs
68	1.3.2.3.2.6	SSC Meeting (Keck)		13 hrs
69	1.3.2.3.2.7	SSC Meeting (UCSC)		13 hrs
70	1.3.2.3.2.8	SSC Meeting (Keck)		13 hrs
71	**1.3.2.3.3**	**Other Presentations**	**PW**	**232 hrs**
72	1.3.2.3.3.1	SPIE AO Conference Presentations/Papers		120 hrs
73	1.3.2.3.3.2	SPIE AO Conference (Marseille)		0 hrs
74	1.3.2.3.3.3	Keck Science Meeting 08		56 hrs
75	1.3.2.3.3.4	Keck Science Meeting 09		56 hrs
76	1.3.2.3.3.5	Other		0 hrs
77	**1.3.2.4**	**Proposals**	**PW**	**480 hrs**
78	1.3.2.4.1	Advancement Support		80 hrs
79	1.3.2.4.2	TSIP Proposal for DDR		240 hrs
80	1.3.2.4.3	Other Proposal		160 hrs
81	**1.3.2.5**	**Programmatic Risk Assessment & Mitigation**	**PW**	**180 hrs**
82	**1.3.2.5.1**	**Risk Assessment**	**PW**	**60 hrs**
83	1.3.2.5.1.1	Programmatic Risk Assessment v1		32 hrs
84	1.3.2.5.1.2	Programmatic Risk Assessment v2		28 hrs
85	**1.3.2.5.2**	**Risk Mitigation**	**PW**	**120 hrs**
86	1.3.2.5.2.1	Laser Procurement		40 hrs
87	1.3.2.5.2.2	Science Instruments		40 hrs
88	1.3.2.5.2.3	Funding		40 hrs
89	**1.3.2.6**	**Preliminary Design Review**	**PW**	**506 hrs**
90	1.3.2.6.1	Define Success Criteria for all Reviews		60 hrs
91	1.3.2.6.2	Review Setup (Date, Participants, Charter)		16 hrs
92	1.3.2.6.3	Preliminary Design Report		100 hrs
93	1.3.2.6.4	Review Package Distributed		6 hrs
94	1.3.2.6.5	Reviewer Comments Received		0 hrs
95	1.3.2.6.6	Reviewer Comments Addressed		80 hrs
96	1.3.2.6.7	PDR Presentation Preparation		68 hrs
97	1.3.2.6.8	Preliminary Design Review		128 hrs
98	1.3.2.6.9	Reviewer Report Received		0 hrs
99	1.3.2.6.10	Response to Reviewer Report		48 hrs
100	**1.3.2.7**	**Project Support**	**PW**	**3,361 hrs**
101	1.3.2.7.1	Administrative/Contract Support		765 hrs
102	1.3.2.7.2	Shared Infrastructure		200 hrs
103	1.3.2.7.3	Research Time		2,396 hrs

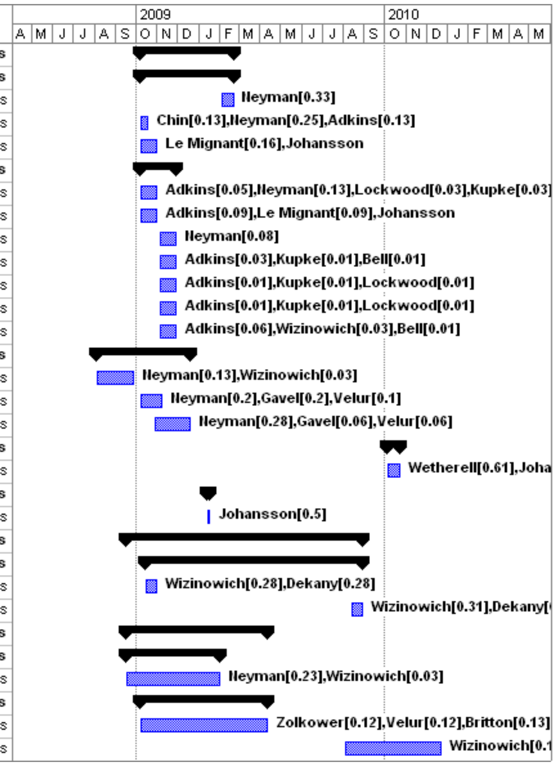


ID	WBS	Task Name	Lead	Work	2009–2010 (A M J J A S O N D J F M A M J J A S O N D J F M A M)
104	**1.3.3**	**Systems Engineering**	**RD**	**9,415 hrs**	
105	**1.3.3.1**	**Science Case Requirements**	**CM**	**4,005 hrs**	
106	**1.3.3.1.1**	**Science Case Requirements**	**CM**	**2,701 hrs**	
107	**1.3.3.1.1.1**	**Requirements for new Science Drivers**		**440 hrs**	
108	1.3.3.1.1.1.1	Astrometry Science in Sparse Fields		140 hrs	McGrath[0.07],Student[0.14],Max[0.04]
109	1.3.3.1.1.1.2	Resolved Stellar Populations in Crowded Field:		160 hrs	Student[0.25],Max[0.08]
110	1.3.3.1.1.1.3	Debris Disks & Young Stellar Objects		80 hrs	McGrath[0.08],Max[0.08]
111	1.3.3.1.1.1.4	QSO Host Galaxies		60 hrs	McGrath[0.1],Max[0.05]
112	**1.3.3.1.1.2**	**Extend SCRD Discussion of Science Drivers**		**601 hrs**	
113	1.3.3.1.1.2.1	Nearby AGNs		30 hrs	McGrath[0.05],Max[0.02]
114	1.3.3.1.1.2.2	Gravitational Lensing		44 hrs	McGrath[0.1],Max[0.01]
115	1.3.3.1.1.2.3	Backup Science		44 hrs	McGrath[0.05],Max[0.01],Le Mignant[0.05]
116	1.3.3.1.1.2.4	Ice Giant Planets		10 hrs	McGrath[0.02]
117	1.3.3.1.1.2.5	GR at Galactic Center		95 hrs	Student[0.16],Max[0.03]
118	1.3.3.1.1.2.6	Extrasolar Planets		140 hrs	McGrath[0.1],Macintosh[0.19],Max[0.05]
119	1.3.3.1.1.2.7	Asteroids		68 hrs	Student[0.1],Le Mignant[0.05],Max[0.02]
120	1.3.3.1.1.2.8	QSO Host Galaxies		80 hrs	McGrath[0.06],Max[0.02]
121	1.3.3.1.1.2.9	Backup Science - NGS & Acquisition Camera		90 hrs	McGrath[0.04],Le Mignant[0.06],Neyman[0.04],Max[0.04]
122	**1.3.3.1.1.3**	**Characterize PSF Stability, Knowledge & Subt**		**1,340 hrs**	
123	1.3.3.1.1.3.1	Nearby AGNs		580 hrs	McGrath[0.09],Student[0.2],
124	1.3.3.1.1.3.2	Galactic Center Astrometry		190 hrs	Student[0.21],Max[0.04]
125	1.3.3.1.1.3.3	Extrasolar Planets		260 hrs	McGrath[0.05],Student[0.16],Macint
126	1.3.3.1.1.3.4	Minor Planet Multiplicity		90 hrs	Student[0.28],Max[0.03]
127	1.3.3.1.1.3.5	QSO Host Galaxies		220 hrs	McGrath[0.06],Student[0.19],Max[0.09]
128	1.3.3.1.1.4	Characterize Sensitivity & Background Requiremen		160 hrs	McGrath[0.16],Max[0.05]
129	1.3.3.1.1.5	Science Requirements Summary Matrix		100 hrs	McGrath[0.06
130	1.3.3.1.1.6	SEMP Input		60 hrs	McGrath[0.0
131	**1.3.3.1.2**	**Science Observing Planning & Execution**	**CM**	**480 hrs**	
132	1.3.3.1.2.1	Key Science Driver Observing Scenarios		240 hrs	McGrath[0.14],Le Mignant[0.08],Max[0.03]
133	1.3.3.1.2.2	Design Reference Missions		240 hrs	McGrath[0.1
134	**1.3.3.1.3**	**Science Performance Input**	**CM**	**180 hrs**	
135	1.3.3.1.3.1	Define Science Driver Parameters for Performance		20 hrs	McGrath[0.1],Max[0.1]
136	1.3.3.1.3.2	Input to User Interfaces, Planning & Observing Tool		80 hrs	McGrath[0.03]
137	1.3.3.1.3.3	Input to Preliminary Operations Concept Document		80 hrs	McGrath[0.02],I
138	**1.3.3.1.4**	**Science Competitiveness**	**CM**	**144 hrs**	
139	1.3.3.1.4.1	Update List of Science Goals for Other Facilities		64 hrs	McGrath[0.01],I
140	1.3.3.1.4.2	Evaluate NGAO Potential to Compliment Other Facili		50 hrs	McGrath[0.01],I
141	1.3.3.1.4.3	Define NGAO Uniqueness Space		30 hrs	McGrath[0.01],I
142	**1.3.3.1.5**	**User Community Liaison**	**CM**	**220 hrs**	
143	1.3.3.1.5.1	Enlist People to work on new NGAO Science Aspe		60 hrs	Max[0.01],McGrath[0.01
144	**1.3.3.1.5.2**	**SSC & Keck Science Meeting**		**160 hrs**	
145	1.3.3.1.5.2.1	Prepare & Give Presentations		110 hrs	Max[0.02],I
146	1.3.3.1.5.2.2	Obtain & Document Feedback		50 hrs	Max[0.01],I
147	**1.3.3.1.6**	**Science Advisory Team Meetings**	**CM**	**280 hrs**	
148	1.3.3.1.6.1	Prepare Minutes, Presentations & KAONs		180 hrs	Max[0.03],McGrat
149	1.3.3.1.6.2	Refine Science Requirements		20 hrs	Le Mignant[0.01]
150	1.3.3.1.6.3	Evaluate Science Impact of Proposed Changes		80 hrs	Max[0.01],McGrat
151	**1.3.3.2**	**Requirements**	**EJ**	**970 hrs**	
152	**1.3.3.2.1**	**Operations Concept Document (OCD)**	**DLM**	**480 hrs**	
153	1.3.3.2.1.1	OCD Outline	DLM	40 hrs	Le Mignant[0.4],Wizinowich[0.1]
154	1.3.3.2.1.2	OCD Release 1	DLM	200 hrs	Le Mignant[0.33],Neyman[0.14],Wizinowich[0.0
155	1.3.3.2.1.3	OCD Release 2	DLM	240 hrs	Le Mignant[0.3
156	**1.3.3.2.2**	**System Requirements (SRD)**	**EJ**	**80 hrs**	
157	1.3.3.2.2.1	SRD Release I	EJ	50 hrs	Johansson[0.63]
158	1.3.3.2.2.2	SRD Release 2	EJ	30 hrs	Johansson[0.38
159	**1.3.3.2.3**	**Functional Requirements (FRD)**	**EJ**	**250 hrs**	
160	1.3.3.2.3.1	FRD Release 1	EJ	120 hrs	Johansson[0.14],Dekany[0.11],Wizinowich[0.07],Gavel[0.11]
161	1.3.3.2.3.2	FRD Release 2	EJ	70 hrs	Johansson[0.1
162	1.3.3.2.3.3	Compliance Matrix	EJ	60 hrs	Johansson[0.38]
163	1.3.3.2.4	Software Standards (Define & Document)	EJ	80 hrs	Johansson[0.32]
164	1.3.3.2.5	Component Standards (Define & Document)	EJ	80 hrs	Johansson[0.4]

ID	WBS	Task Name	Lead	Work
165	**1.3.3.3**	**Systems Engineering Analysis**	**RD**	**1,788 hrs**
166	**1.3.3.3.1**	**Performance Budgets**	**RD**	**828 hrs**
167	1.3.3.3.1.1	Requirements Flowdown Report	RD	60 hrs
168	**1.3.3.3.1.2**	**Throughput & Background Budget**	**AB**	**80 hrs**
169	1.3.3.3.1.2.1	Thermal Background Analysis Software with I		50 hrs
170	1.3.3.3.1.2.2	Thermal Analysis		30 hrs
171	**1.3.3.3.1.3**	**Wavefront & Encircled Energy**	**RD**	**328 hrs**
172	**1.3.3.3.1.3.1**	**WFE/EE Budget Tool**	**RD**	**256 hrs**
173	3.3.3.1.3.1.1	NGS TT & TTFA Sharpening Budgets		60 hrs
174	3.3.3.1.3.1.2	Improved Bandwidth Model		80 hrs
175	3.3.3.1.3.1.3	Improved Atmospheric Dispersion Model		40 hrs
176	3.3.3.1.3.1.4	Other		76 hrs
177	**1.3.3.3.1.3.2**	**WFE/EE Performance Analysis**	**RD**	**72 hrs**
178	3.3.3.1.3.2.1	Key Science Cases Analysis		24 hrs
179	3.3.3.1.3.2.2	Additional Science Case Analysis		48 hrs
180	**1.3.3.3.1.4**	**Astrometric Precision**	**PW**	**200 hrs**
181	1.3.3.3.1.4.1	Develop Astrometric Budget Tool		120 hrs
182	1.3.3.3.1.4.2	Galactic Center Astrometric Analysis		80 hrs
183	**1.3.3.3.1.5**	**Observing Efficiency**	**DLM**	**80 hrs**
184	1.3.3.3.1.5.1	Observing Efficiency Tool		40 hrs
185	1.3.3.3.1.5.2	Observing Efficiency Analysis		40 hrs
186	**1.3.3.3.1.6**	**Observing Uptime**	**EJ**	**80 hrs**
187	1.3.3.3.1.6.1	Observing Uptime Tool		40 hrs
188	1.3.3.3.1.6.2	Observing Uptime Analysis		40 hrs
189	**1.3.3.3.2**	**Modeling & Analysis**	**RD**	**880 hrs**
190	1.3.3.3.2.1	T/T Sharpening Study Report		240 hrs
191	1.3.3.3.2.2	Performance vs T/T NGS Report		240 hrs
192	1.3.3.3.2.3	Galactic Center Performance Report		240 hrs
193	1.3.3.3.2.4	PSF Libraries		160 hrs
194	1.3.3.3.3	PSF Calibration	DLM	80 hrs
195	**1.3.3.4**	**System Architecture**	**RD**	**1,070 hrs**
196	**1.3.3.4.1**	**System Hardware Architecture**	**RD**	**264 hrs**
197	1.3.3.4.1.1	Hybrid Rayleigh / Sodium Trade Study		160 hrs
198	1.3.3.4.1.2	Degraded Laser Power Trade Study		40 hrs
199	1.3.3.4.1.3	System Architecture: Evaluate & Document Change		64 hrs
200	**1.3.3.4.2**	**Software Architecture**	**EJ**	**162 hrs**
201	1.3.3.4.2.1	Evaluate Software Architecture Options	EJ	50 hrs
202	1.3.3.4.2.2	Determine/Document Software Arch Approach	EJ	80 hrs
203	1.3.3.4.2.3	Software Architecture: Evaluate & Document Chan	EJ	32 hrs
204	**1.3.3.4.3**	**Control Systems Architecture**	**EJ**	**420 hrs**
205	1.3.3.4.3.1	Evaluate Control Systems Arch Options	EJ	80 hrs
206	1.3.3.4.3.2	Determine/Document Control Systems Arch	EJ	100 hrs
207	1.3.3.4.3.3	Evaluate Motion Control Arch Options	EJ	120 hrs
208	1.3.3.4.3.4	Determine/Document Motion Control Arch	EJ	60 hrs
209	1.3.3.4.3.5	Control Systems Architecture: Evaluate & Documer	EJ	60 hrs
210	**1.3.3.4.4**	**Operations Sequences Architecture**	**DLM**	**224 hrs**
211	1.3.3.4.4.1	Define Required System Level Sequences		40 hrs
212	1.3.3.4.4.2	Develop System Level Sequences Approach		40 hrs
213	1.3.3.4.4.3	Sequences Definition Document		80 hrs
214	1.3.3.4.4.4	Sequences: Evaluate & Document Changes		64 hrs



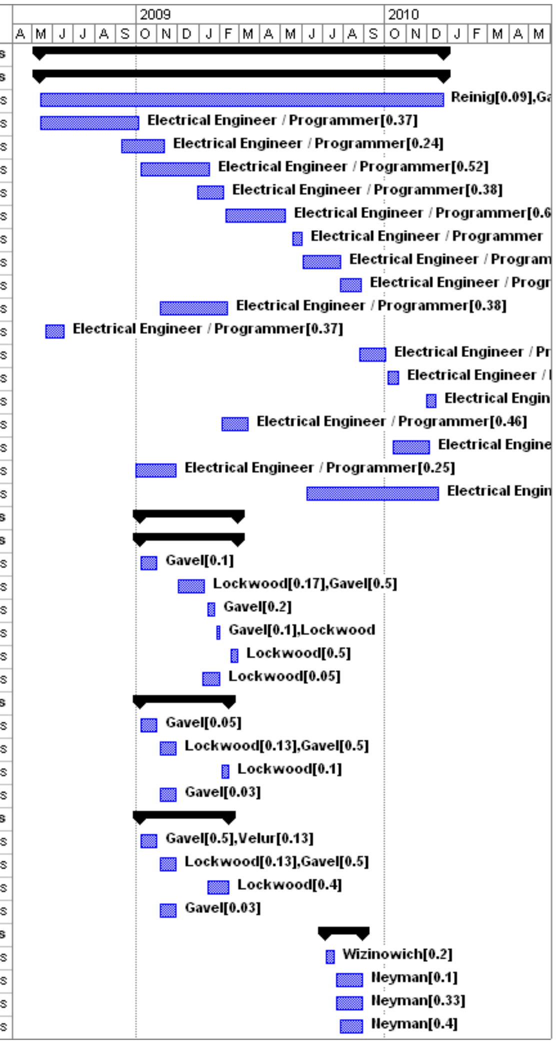
ID	WBS	Task Name	Lead	Work
215	**1.3.3.5**	**External Interface Control**	**CN**	**244 hrs**
216	**1.3.3.5.1**	**Observatory Interfaces**	**CN**	**120 hrs**
217	1.3.3.5.1.1	AO System ICD	CN	40 hrs
218	1.3.3.5.1.2	Laser System ICD	CN	40 hrs
219	1.3.3.5.1.3	Science Tools ICD	DLM	40 hrs
220	**1.3.3.5.2**	**Science Instrument Interfaces to NGAO**	**SA**	**124 hrs**
221	1.3.3.5.2.1	Generic Science Instrument ICD to AO	CN	40 hrs
222	1.3.3.5.2.2	Generic Science Instrument ICD to NGAO Science '	DLM	40 hrs
223	1.3.3.5.2.3	Interferometer Specific ICD	CN	12 hrs
224	1.3.3.5.2.4	OSIRIS Specific ICD	SA	8 hrs
225	1.3.3.5.2.5	NIR Camera Specific ICD	SA	4 hrs
226	1.3.3.5.2.6	Visible Camera Specific ICD	SA	4 hrs
227	1.3.3.5.2.7	d-IFS Specific ICD	SA	16 hrs
228	**1.3.3.6**	**Internal Interface Control**	**CN**	**280 hrs**
229	1.3.3.6.1	Diagram & Document Draft Outline	CN	50 hrs
230	1.3.3.6.2	Interface N-Squared Diagram	CN	100 hrs
231	1.3.3.6.3	Interface Definition Document	CN	130 hrs
232	**1.3.3.7**	**Configuration Control**	**EJ**	**218 hrs**
233	1.3.3.7.1	Change Control Guidelines & Tools Definition	EJ	218 hrs
234	**1.3.3.8**	**Documentation Control**	**EJ**	**20 hrs**
235	1.3.3.8.1	Document Control Guidelines & Tools Definition	EJ	20 hrs
236	**1.3.3.9**	**Technical Risk Assessment & Mitigation**	**PW**	**700 hrs**
237	**1.3.3.9.1**	**Risk Assessment**	**PW**	**100 hrs**
238	1.3.3.9.1.1	Risk Assessment v1	PW	50 hrs
239	1.3.3.9.1.2	Risk Assessment v2	PW	50 hrs
240	**1.3.3.9.2**	**Risk Mitigation Efforts**	**PW**	**600 hrs**
241	**1.3.3.9.2.1**	**PSF Calibration**		**200 hrs**
242	1.3.3.9.2.1.1	Support/Monitor Profiler Implementation	CN	200 hrs
243	**1.3.3.9.2.2**	**Sky Coverage**		**400 hrs**
244	1.3.3.9.2.2.1	Prototype NIR Tip/tilt Sensor	VV	400 hrs
245	1.3.3.10	Preliminary Design Manual	PW	120 hrs



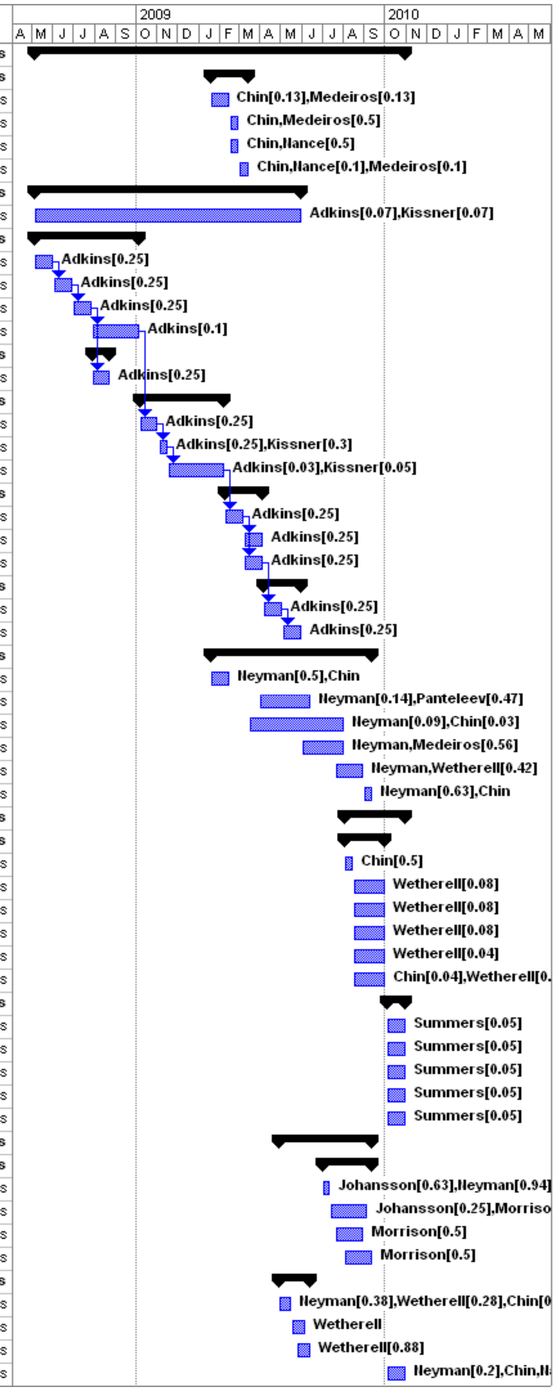
ID	WBS	Task Name	Lead	Work	2009 / 2010
246	**1.3.4**	**AO System Design**	**DG**	**10,757 hrs**	
247	1.3.4.1	AO Enclosure	JB	300 hrs	Bell[0.29]
248	**1.3.4.2**	**Opto-Mechanical**	**DG**	**5,405 hrs**	
249	1.3.4.2.1	AO Support Structure	CL	160 hrs	Lockwood[0.36],Gavel[0.04]
250	1.3.4.2.2	Rotator	CL	120 hrs	Lockwood[0.87],Kupke[0.17],Gavel[0.12]
251	1.3.4.2.3	Optical Relays	RK	533 hrs	Lockwood[0.3],Kupke[0.45],Gavel[0.08]
252	1.3.4.2.4	Optical Switchyard	RK	400 hrs	Lockwood[0.39],Kupke[0.26],Gavel[0.07]
253	**1.3.4.2.5**	**LGS Wavefront Sensor Assembly**	**VV**	**1,520 hrs**	
254	1.3.4.2.5.1	Review concept design for LGS WFS assembly (in		120 hrs	Zolkower[0.25],Britton[0.25],Velur[0.25]
255	1.3.4.2.5.2	Develop to preliminary design level the opto-mecha		420 hrs	Zolkower[0.25],Velur[0.25],Britton[0.25]
256	1.3.4.2.5.3	Identify the issues with uplink TTM, asterism gener		100 hrs	Velur[0.19],Britton[0.5]
257	1.3.4.2.5.4	Develop to preliminary design level the opto-mecha		40 hrs	Zolkower[0.25],Velur[0.25]
258	1.3.4.2.5.5	Package and model the assembly.		200 hrs	Zolkower[0.5],Velur[0.75]
259	1.3.4.2.5.6	Develop background model and work out stray LGS		80 hrs	Britton[0.75]
260	1.3.4.2.5.7	Identify the motion control needs and specify soluti		240 hrs	Johansson[0.5],Hale[0.5],Velur[0.5]
261	1.3.4.2.5.8	Identify design risks and mitigation of the identified		80 hrs	Zolkower[0.75],Britton[0.75],Velur[0.75]
262	1.3.4.2.5.9	Develop a preliminary integration plan for the asser		80 hrs	Britton[0.34],Zolkower[0.34],Velur[0.41]
263	1.3.4.2.5.10	LGS WFS Assembly Documentation		160 hrs	Zolkower[0.5],Velur[0.5]
264	**1.3.4.2.6**	**NGS WFS/TWFS Assembly**	**VV**	**628 hrs**	
265	1.3.4.2.6.1	Review concept design for NGS WFS and TWFS; ju		40 hrs	Zolkower[0.25],Britton[0.25]
266	1.3.4.2.6.2	Develop to preliminary design level the opto-mecha		200 hrs	Zolkower[0.45],Velur[0.45]
267	1.3.4.2.6.3	Check compliance of design with the design of the		100 hrs	Velur[0.45],Zolkower[0.45]
268	1.3.4.2.6.4	Package and model the NGS WFS assembly.		116 hrs	Zolkower[0.4],Velur[0.4]
269	1.3.4.2.6.5	Identify the motion control needs and specify soluti		56 hrs	Hale[0.5],Johansson[0.5]
270	1.3.4.2.6.6	Identify design risks and mitigation of the identified		28 hrs	Velur[0.75]
271	1.3.4.2.6.7	Check compliance with alignment plan for the NGS		32 hrs	Zolkower[0.41],Velur[0.
272	1.3.4.2.6.8	NGS WFS Assembly Documentation		56 hrs	Velur[0.5],Zolkowe
273	**1.3.4.2.7**	**Low Order Wavefront Sensor Assembly**	**VV**	**1,596 hrs**	
274	1.3.4.2.7.1	Review concept design for LOWFS assembly.		64 hrs	Zolkower[0.15],Hale[0.15]
275	1.3.4.2.7.2	Investigate optimum method of dithering based on r		112 hrs	Hale[0.18],Dekany[0.18],Britton[0.2]
276	1.3.4.2.7.3	Develop to preliminary design level the opto-mecha		240 hrs	Hale[0.5],Zolkower[0.5],Dekany[0.25]
277	1.3.4.2.7.4	Develop to preliminary design level the opto-mecha		240 hrs	Hale[0.75],Zolkower[0.75],Velur[0.75]
278	1.3.4.2.7.5	Make sure that the design doesn't preclude the incl		20 hrs	Velur[0.75]
279	1.3.4.2.7.6	Package and model the assembly.		160 hrs	Zolkower[0.75],Velur[0.75]
280	1.3.4.2.7.7	Develop thermal model and work emissivity details		40 hrs	Zolkower[0.5]
281	1.3.4.2.7.8	Identify the motion control needs and specify soluti		360 hrs	Johansson[0.25],Hale[0.25],Velu
282	1.3.4.2.7.9	Identify design risks and mitigation of the identified		80 hrs	Hale[0.5],Velur[0.5]
283	1.3.4.2.7.10	Develop a preliminary integration plan for the asser		80 hrs	Velur[0.75]
284	1.3.4.2.7.11	Develop a test plan based on the design to test per		120 hrs	Hale[0.75],Velur[0.75]
285	1.3.4.2.7.12	LOWFS Assembly Documentation		80 hrs	Hale[0.75],Velur[0.7
286	**1.3.4.2.8**	**Tip/Tilt Vibration Mitigation**	**CN**	**80 hrs**	
287	1.3.4.2.8.1	TT Vibration Mitigation Analysis		80 hrs	Neyman[0.25]
288	**1.3.4.2.9**	**Acquisition Cameras**	**CN**	**128 hrs**	
289	1.3.4.2.9.1	Implementation Issues		40 hrs	Neyman[0.13],Le Mignant[0.13]
290	1.3.4.2.9.2	Opto-Mechanical Design		88 hrs	Neyman[0.35],Pante
291	**1.3.4.2.10**	**Atmospheric Dispersion Correctors**	**RK**	**240 hrs**	
292	1.3.4.2.10.1	LOWFS ADCs		140 hrs	Kupke,Lockwood[0.75]
293	1.3.4.2.10.2	NIR Science ADC		50 hrs	Kupke,Lockwood[0.25]
294	1.3.4.2.10.3	Visible Science & NGS WFS ADC		50 hrs	Kupke,Lockwood[0.25]
295	**1.3.4.3**	**Alignment, Calibration & Diagnostics**	**CN**	**505 hrs**	
296	**1.3.4.3.1**	**Simulator**	**CN**	**250 hrs**	
297	1.3.4.3.1.1	Simulator Requirements & Interfaces		50 hrs	Neyman[0.5],Wizinowich[0.13]
298	1.3.4.3.1.2	Simulator Optical Design		50 hrs	Neyman[0.13],Wizinowich[0.5]
299	1.3.4.3.1.3	Simulator Mechanical Design		60 hrs	Neyman[0.13],Bell[0.63]
300	1.3.4.3.1.4	Simulator Electrical Design		50 hrs	Neyman[0.25],Wetherell[0.38]
301	1.3.4.3.1.5	Simulator Assembly, Alignment & Test Plans		40 hrs	Neyman[0.5]
302	**1.3.4.3.2**	**System Alignment Tools**	**CN**	**255 hrs**	
303	1.3.4.3.2.1	Alignment Requirements & Interfaces		60 hrs	Neyman[0.5],Kupke[0.13],Wizinowich[0.
304	1.3.4.3.2.2	Alignment Optical Design		50 hrs	Neyman[0.13],Kupke[0.5]
305	1.3.4.3.2.3	Alignment Mechanical Design		50 hrs	Neyman[0.13],Lockwood[0.5]
306	1.3.4.3.2.4	Alignment Electrical Design		35 hrs	Neyman[0.25],Wetherell[0.19]
307	1.3.4.3.2.5	Alignment Assembly, Alignment & Test Plans		60 hrs	Neyman[0.5],Kupke[0.13],Wizinowi

ID	WBS	Task Name	Lead	Work	2009–2010
308	**1.3.4.4**	**Non-real-time Control**	**EJ**	**990 hrs**	
309	1.3.4.4.1	AO Controls Infrastructure		0 hrs	
310	**1.3.4.4.2**	**AO Sequencer**	**EJ**	**140 hrs**	
311	1.3.4.4.2.1	AO Sequencer: Architecture		80 hrs	Johansson[0.5]
312	1.3.4.4.2.2	AO Sequencer: Interface Control Document		20 hrs	Johansson[0.13]
313	1.3.4.4.2.3	AO Sequencer: Software Module Design		30 hrs	Johansson[0.19]
314	1.3.4.4.2.4	AO Sequencer: User Interface Design		0 hrs	2/2
315	1.3.4.4.2.5	AO Sequencer: Technical Specifications		0 hrs	2/2
316	1.3.4.4.2.6	AO Sequencer: Compliance Matrix		0 hrs	2/2
317	1.3.4.4.2.7	AO Sequencer: Test Plan		0 hrs	2/2
318	1.3.4.4.2.8	AO Sequencer: Summary Report		10 hrs	Johansson[0.06]
319	**1.3.4.4.3**	**AO Motion Control Software**	**EJ**	**230 hrs**	
320	1.3.4.4.3.1	Motion Control SW: Architecture		80 hrs	Johansson[0.16],Morrison[0.09]
321	1.3.4.4.3.2	Motion Control SW: ICD		40 hrs	Johansson[0.06],Morrison[0.06]
322	1.3.4.4.3.3	Motion Control SW: Module Design		90 hrs	Johansson[0.06],Morrison[0.22]
323	1.3.4.4.3.4	Motion Control SW: User Interface Design		0 hrs	3/2
324	1.3.4.4.3.5	Motion Control SW: Technical Specifications		0 hrs	3/2
325	1.3.4.4.3.6	Motion Control SW: Compliance Matrix		0 hrs	3/2
326	1.3.4.4.3.7	Motion Control SW: Test Plan		0 hrs	3/2
327	1.3.4.4.3.8	Motion Control SW: Summary Report		20 hrs	Johansson[0.06]
328	**1.3.4.4.4**	**AO Device Control Software**	**DM**	**240 hrs**	
329	1.3.4.4.4.1	Device Control: Software Architecture		80 hrs	Morrison[0.5]
330	1.3.4.4.4.2	Device Control: Interface Control Document		40 hrs	Morrison[0.33]
331	1.3.4.4.4.3	Device Control: Software Module Design		100 hrs	Morrison[0.5]
332	1.3.4.4.4.4	Device Control: User Interface Design		0 hrs	6/15
333	1.3.4.4.4.5	Device Control: Technical Specifications		0 hrs	6/15
334	1.3.4.4.4.6	Device Control: Compliance Matrix		0 hrs	6/15
335	1.3.4.4.4.7	Device Control: Test Plan		0 hrs	6/15
336	1.3.4.4.4.8	Device Control: Summary Report		20 hrs	Morrison[0.1]
337	**1.3.4.4.5**	**AO Motion Control Electronics**	**EW**	**60 hrs**	
338	1.3.4.4.5.1	Motion Control HW: Spreadsheet		60 hrs	Wetherell[0.25]
339	**1.3.4.4.6**	**Non-RTC Electronics**	**EW**	**160 hrs**	
340	1.3.4.4.6.1	Non-RTC Electronics: Architecture		80 hrs	Wetherell[0.25]
341	1.3.4.4.6.2	Non-RTC Electronics: Selection/Specification		60 hrs	Wetherell[0.19]
342	1.3.4.4.6.3	Non-RTC Electronics: Compliance Matrix		0 hrs	
343	1.3.4.4.6.4	Non-RTC Electronics: Test Plan		0 hrs	
344	1.3.4.4.6.5	Non-RTC Electronics: Documentation		20 hrs	Wetherell[0.06]
345	**1.3.4.4.7**	**Non-RTC Lab System Integration & Test**		**0 hrs**	2/2
346	1.3.4.4.7.1	Non-RTC I&T: Architecture		0 hrs	2/2
347	1.3.4.4.7.2	Non-RTC I&T: Electronics Specification & Selection		0 hrs	2/2
348	1.3.4.4.7.3	Non-RTC I&T: Test Plan		0 hrs	2/2
349	1.3.4.4.7.4	Non-RTC I&T: Summary Report		0 hrs	2/2
350	**1.3.4.4.8**	**Acquisition, Guiding & Offload (AGO) Control**	**EJ**	**160 hrs**	
351	1.3.4.4.8.1	AGO: Architecture		80 hrs	Johansson[0.16],Le Mignant
352	1.3.4.4.8.2	AGO: ICD		40 hrs	Johansson[0.11]
353	1.3.4.4.8.3	AGO: Software Module Design		20 hrs	Johansson[0.05]
354	1.3.4.4.8.4	AGO: User Interface		0 hrs	4/27
355	1.3.4.4.8.5	AGO: Technical Specification		0 hrs	4/27
356	1.3.4.4.8.6	AGO: Compliance Matrix		0 hrs	4/27
357	1.3.4.4.8.7	AGO: Test Plan		0 hrs	4/27
358	1.3.4.4.8.8	AGO: Summary Report		20 hrs	Johansson[0.05]

ID	WBS	Task Name	Lead	Work
359	**1.3.4.5**	**Real-time Control**	**DG**	**3,357 hrs**
360	**1.3.4.5.1**	**RTC Processor**	**DG**	**3,037 hrs**
361	1.3.4.5.1.1	RTC Technical Management	MR	463 hrs
362	1.3.4.5.1.2	Centroid/Wavefront Reconstruction Processing Re		314 hrs
363	1.3.4.5.1.3	Centroid/Wavefront Reconstruction Test Definition		90 hrs
364	1.3.4.5.1.4	Preconditioning & Scaling Processing Requirements		310 hrs
365	1.3.4.5.1.5	Preconditioning & Scaling Processing Test Definitio		90 hrs
366	1.3.4.5.1.6	Low Order WFS Processing Requirements		310 hrs
367	1.3.4.5.1.7	Low Order WFS Processing Test Definition		90 hrs
368	1.3.4.5.1.8	Layer Combining & DM Processing Requirements		310 hrs
369	1.3.4.5.1.9	Camera Data Transfer Issues		90 hrs
370	1.3.4.5.1.10	Radial versus Rectilinear Voxels Trade Study		220 hrs
371	1.3.4.5.1.11	Define Required Bit Resolution		65 hrs
372	1.3.4.5.1.12	Characterize Single Event Upset		65 hrs
373	1.3.4.5.1.13	Power Characterization and Parameter Estimation		90 hrs
374	1.3.4.5.1.14	Voxel Communication Parameters		90 hrs
375	1.3.4.5.1.15	Diagnostic Control & I/O Requirements		110 hrs
376	1.3.4.5.1.16	Monitoring Control & I/O Requirements		110 hrs
377	1.3.4.5.1.17	Define Testing Procedures		90 hrs
378	1.3.4.5.1.18	Documentation		130 hrs
379	**1.3.4.5.2**	**DMs & Tip/Tilt Stages**	**DG**	**320 hrs**
380	**1.3.4.5.2.1**	**Woofer DM/TT**	**DG**	**132 hrs**
381	1.3.4.5.2.1.1	Define Requirements		16 hrs
382	1.3.4.5.2.1.2	Evaluate Tip/Tilt Mount Options		44 hrs
383	1.3.4.5.2.1.3	Evaluate Combined DM & Tip/Tilt Performance		16 hrs
384	1.3.4.5.2.1.4	Select Tip/Tilt Mount		8 hrs
385	1.3.4.5.2.1.5	Design Mechanical Package		40 hrs
386	1.3.4.5.2.1.6	Obtain Quotes		8 hrs
387	**1.3.4.5.2.2**	**Tweeter DM/TT**	**DG**	**48 hrs**
388	1.3.4.5.2.2.1	Define Requirements		8 hrs
389	1.3.4.5.2.2.2	Evaluate Options & Select Tip/Tilt Mount		28 hrs
390	1.3.4.5.2.2.3	Design Mechanical Package		8 hrs
391	1.3.4.5.2.2.4	Obtain Quotes		4 hrs
392	**1.3.4.5.2.3**	**LOWFS DM/TT**	**DG**	**140 hrs**
393	1.3.4.5.2.3.1	Define Requirements including LOWFS Interfac		28 hrs
394	1.3.4.5.2.3.2	Evaluate Options & Select Tip/Tilt Mount		28 hrs
395	1.3.4.5.2.3.3	Design Mechanical Package		80 hrs
396	1.3.4.5.2.3.4	Obtain Quotes		4 hrs
397	**1.3.4.6**	**AO System Lab I&T**	**CN**	**200 hrs**
398	1.3.4.6.1	AO System Lab I&T Scope Definition	PW	16 hrs
399	1.3.4.6.2	AO System Lab Facility Plan	CN	24 hrs
400	1.3.4.6.3	AO System Lab Integration Plan	CN	80 hrs
401	1.3.4.6.4	AO System Lab Test Plan	CN	80 hrs



ID	WBS	Task Name	Lead	Work
402	**1.3.5**	**Laser System Design**	**CN**	**2,964 hrs**
403	**1.3.5.1**	**Laser Enclosure (LE)**	**JC**	**160 hrs**
404	1.3.5.1.1	LE Requirements & Interfaces	JC	40 hrs
405	1.3.5.1.2	LE Mechanical Design	DM	50 hrs
406	1.3.5.1.3	LE Environmental Control Design	CN	50 hrs
407	1.3.5.1.4	LE Assembly & Test Plans	JC	20 hrs
408	**1.3.5.2**	**Laser**	**SA**	**820 hrs**
409	1.3.5.2.1	Laser Project Management	SA	300 hrs
410	**5.2.3.1**	**Laser Requirements**	**SA**	**160 hrs**
411	5.2.3.1.1	Laser Performance Analysis		40 hrs
412	5.2.3.1.2	Laser Requirements Analysis		40 hrs
413	5.2.3.1.3	Laser Requirements Development		40 hrs
414	5.2.3.1.4	Laser Requirements Drafting and Revisions		40 hrs
415	**5.2.3.2**	**Laser Preliminary ICD**	**SA**	**40 hrs**
416	5.2.3.2.1	Laser ICD Drafting and Revisions		40 hrs
417	**5.2.3.3**	**Laser Request for Proposals (RFP)**	**SA**	**120 hrs**
418	5.2.3.3.1	Laser Proposal Drafting		40 hrs
419	5.2.3.3.2	Laser Proposal Release		40 hrs
420	5.2.3.3.3	Laser Proposal Response Period		40 hrs
421	**5.2.3.4**	**Laser RFP Response Report**	**SA**	**120 hrs**
422	5.2.3.4.1	Laser Proposal Evaluation		40 hrs
423	5.2.3.4.2	Laser Response Discussions		40 hrs
424	5.2.3.4.3	Laser Report Drafting and Revisions		40 hrs
425	**5.2.3.5**	**Laser Contract**	**SA**	**80 hrs**
426	5.2.3.5.1	Laser Contract Drafting and Revisions		40 hrs
427	5.2.3.5.2	Laser Contract Negotiations		40 hrs
428	**1.3.5.3**	**Laser Launch Facility (LLF)**	**CN**	**856 hrs**
429	1.3.5.3.1	LLF Requirements & Interfaces		100 hrs
430	1.3.5.3.2	LLF Optical Design		260 hrs
431	1.3.5.3.3	LLF Launch Telescope Preliminary Design Contract		96 hrs
432	1.3.5.3.4	LLF Mechanical Design		220 hrs
433	1.3.5.3.5	LLF Electrical Design		120 hrs
434	1.3.5.3.6	LLF Assembly, Alignment & Test Plans		60 hrs
435	**1.3.5.4**	**Laser Safety Systems**	**JC**	**170 hrs**
436	**1.3.5.4.1**	**Personnel & Equipment Safety System**	**JC**	**130 hrs**
437	1.3.5.4.1.1	Safety Requirements & Interfaces		40 hrs
438	1.3.5.4.1.2	Safety Algorithms, Diagrams & Dataflow		20 hrs
439	1.3.5.4.1.3	Safety Communication Protocols & Methods		20 hrs
440	1.3.5.4.1.4	Safety Performance Estimate		20 hrs
441	1.3.5.4.1.5	Safety Electronics, Shutter & Interlocks		10 hrs
442	1.3.5.4.1.6	Safety Test Plans		20 hrs
443	**1.3.5.4.2**	**Laser Traffic Control System (LTCS) Modification**	**DS**	**40 hrs**
444	1.3.5.4.2.1	LTCS Requirements & Interfaces		8 hrs
445	1.3.5.4.2.2	LTCS Algorithms, Diagrams & Dataflow		8 hrs
446	1.3.5.4.2.3	LTCS Communication Protocols & Methods		8 hrs
447	1.3.5.4.2.4	LTCS Performance Estimate		8 hrs
448	1.3.5.4.2.5	LTCS Test Plans		8 hrs
449	**1.3.5.5**	**Laser System Control (LSC)**	**EJ**	**910 hrs**
450	**1.3.5.5.1**	**LSC Software**	**EJ**	**600 hrs**
451	1.3.5.5.1.1	LSC Software Requirements & Interfaces	EJ	120 hrs
452	1.3.5.5.1.2	LSC Sequencer Software	EJ	240 hrs
453	1.3.5.5.1.3	LSC Motion Control Software	EJ	120 hrs
454	1.3.5.5.1.4	LSC Device Control Software		120 hrs
455	**1.3.5.5.2**	**LSC Hardware**	**EW**	**310 hrs**
456	1.3.5.5.2.1	LSC Hardware Requirements & Interfaces	EW	90 hrs
457	1.3.5.5.2.2	LSC Motion Control Hardware	EW	120 hrs
458	1.3.5.5.2.3	LSC Device Control Hardware	EW	100 hrs
459	1.3.5.6	Laser System Lab I&T Plan	CN	48 hrs

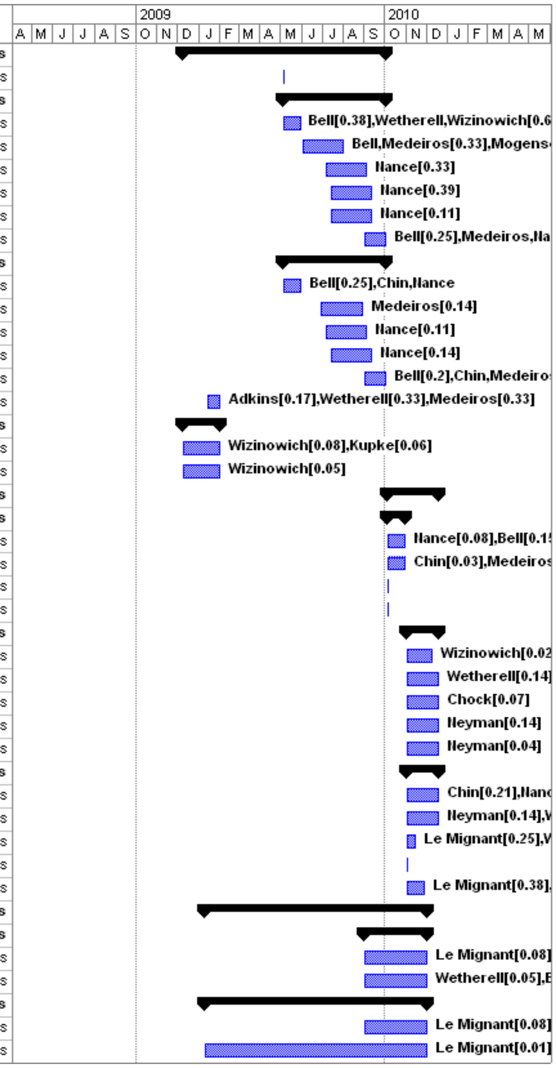


ID	WBS	Task Name	Lead	Work	2009 / 2010: A M J J A S O N D J F M A M J J A S O N D J F M A M
460	**1.3.6**	**Science Operations Tools Design**	**DLM**	**1,800 hrs**	
461	**1.3.6.1**	**Multi-Systems Command Sequencer (MCS)**	**EJ**	**620 hrs**	
462	**1.3.6.1.1**	**MCS Infrastructure**		**180 hrs**	
463	**1.3.6.1.1.1**	**MCS Infrastructure Architecture**		**140 hrs**	
464	1.3.6.1.1.1.1	MCS Architecture		40 hrs	Johansson[0.05],Le Mignant
465	1.3.6.1.1.1.2	MCS Operations Concept Document		40 hrs	Johansson[0.06]
466	1.3.6.1.1.1.3	MCS Software Requirements		40 hrs	Johansson[0.06]
467	1.3.6.1.1.1.4	MCS Module Definitions		20 hrs	Johansson[0.03]
468	**1.3.6.1.1.2**	**Coordination Sequence Support Library**		**20 hrs**	
469	1.3.6.1.1.2.1	Functional Requirements		20 hrs	Johansson[0.03]
470	1.3.6.1.1.2.2	Interface Definitions		0 hrs	
471	**1.3.6.1.1.3**	**Command Interface**		**10 hrs**	
472	1.3.6.1.1.3.1	Functional Requirements		10 hrs	Johansson[0.02]
473	1.3.6.1.1.3.2	Interface Definitions		0 hrs	
474	**1.3.6.1.1.4**	**System Health**		**10 hrs**	
475	1.3.6.1.1.4.1	Functional Requirements		10 hrs	Johansson[0.02]
476	1.3.6.1.1.4.2	Interface Definitions		0 hrs	
477	**1.3.6.1.2**	**Setup Sequences: Configuration & Calibration**		**100 hrs**	
478	**1.3.6.1.2.1**	**Setup Sequences Common Structure**		**60 hrs**	
479	1.3.6.1.2.1.1	Setup Sequences Operations Concept Docum		20 hrs	Johansson[0.03]
480	1.3.6.1.2.1.2	Setup Sequences Software Requirements		20 hrs	Johansson[0.03]
481	1.3.6.1.2.1.3	Setup Sequences Module Definitions		20 hrs	Johansson[0.03]
482	**1.3.6.1.2.2**	**Configuration Sequences**		**20 hrs**	
483	1.3.6.1.2.2.1	Functional Requirements		20 hrs	Le Mignant[0.03]
484	1.3.6.1.2.2.2	Interface Definitions		0 hrs	
485	**1.3.6.1.2.3**	**Calibration Sequences**		**20 hrs**	
486	1.3.6.1.2.3.1	Functional Requirements		20 hrs	Le Mignant[0.03]
487	1.3.6.1.2.3.2	Interface Definitions		0 hrs	
488	**1.3.6.1.3**	**Observing Sequences**		**240 hrs**	
489	**1.3.6.1.3.1**	**Observing Sequences Common Structure**		**120 hrs**	
490	1.3.6.1.3.1.1	Observing Sequences Operations Concept Dc		40 hrs	Le Mignant[0.04],Johansson[0.01]
491	1.3.6.1.3.1.2	Observing Sequences Software Requirement:		40 hrs	Johansson[0.06]
492	1.3.6.1.3.1.3	Observing Sequences Module Definitions		40 hrs	Johansson[0.03],Le Mignant[0.03]
493	**1.3.6.1.3.2**	**Acquisition Sequences**		**60 hrs**	
494	1.3.6.1.3.2.1	Functional Requirements		40 hrs	Le Mignant[0.04],Johansson[0.01]
495	1.3.6.1.3.2.2	Interface Definitions		20 hrs	Johansson[0.03]
496	**1.3.6.1.3.3**	**Observing Sequences**		**20 hrs**	
497	1.3.6.1.3.3.1	Functional Requirements		20 hrs	Le Mignant[0.03]
498	1.3.6.1.3.3.2	Interface Definitions		0 hrs	
499	**1.3.6.1.3.4**	**Quality Monitoring Sequences**		**20 hrs**	
500	1.3.6.1.3.4.1	Functional Requirements		20 hrs	Le Mignant[0.03]
501	1.3.6.1.3.4.2	Interface Definitions		0 hrs	
502	**1.3.6.1.3.5**	**Optimization Sequences**		**20 hrs**	
503	1.3.6.1.3.5.1	Functional Requirements		20 hrs	Le Mignant[0.03]
504	1.3.6.1.3.5.2	Interface Definitions		0 hrs	
505	**1.3.6.1.4**	**Alarm Handler & Troubleshooting Sequences**		**100 hrs**	
506	**1.3.6.1.4.1**	**Alarm Handler & Troubleshooting Common $**		**100 hrs**	
507	1.3.6.1.4.1.1	Alarm & Troubleshooting Operations Concept I		40 hrs	Le Mignant[0.04],Johansson[0.01]
508	1.3.6.1.4.1.2	Alarm & Troubleshooting Software Requireme		20 hrs	Johansson[0.03]
509	1.3.6.1.4.1.3	Alarm & Troubleshooting Module Definitions		40 hrs	Johansson[0.03],Le Mignant[0.03]
510	**1.3.6.1.4.2**	**Alarm Handler Sequences**		**0 hrs**	
511	1.3.6.1.4.2.1	Functional Requirements		0 hrs	
512	1.3.6.1.4.2.2	Interface Definitions		0 hrs	
513	**1.3.6.1.4.3**	**Troubleshooting Sequences**		**0 hrs**	
514	1.3.6.1.4.3.1	Functional Requirements		0 hrs	
515	1.3.6.1.4.3.2	Interface Definitions		0 hrs	

ID	WBS	Task Name	Lead	Work	Resources
516	**1.3.6.2**	**User Interfaces**	**DLM**	**500 hrs**	
517	**1.3.6.2.1**	**User Interface (UI) Infrastructure**		**180 hrs**	
518	**1.3.6.2.1.1**	**UI Infrastructure Architecture**		**120 hrs**	
519	1.3.6.2.1.1.1	UI Architecture		40 hrs	Johansson[0.05],Le Mignant
520	1.3.6.2.1.1.2	UI Operations Concept Document		40 hrs	Le Mignant[0.03],Johansson[0.03]
521	1.3.6.2.1.1.3	UI Software Requirements		20 hrs	Johansson[0.03]
522	1.3.6.2.1.1.4	UI Module Definitions		20 hrs	Johansson[0.03]
523	**1.3.6.2.1.2**	**UI Command Interface to MCS**		**40 hrs**	
524	1.3.6.2.1.2.1	Functional Requirements		20 hrs	Johansson[0.03]
525	1.3.6.2.1.2.2	Interface Definitions		20 hrs	Johansson[0.03]
526	**1.3.6.2.1.3**	**UI Command Interface to Pre- & Post-Observ**		**20 hrs**	
527	1.3.6.2.1.3.1	Functional Requirements		20 hrs	Johansson[0.03]
528	1.3.6.2.1.3.2	Interface Definitions		0 hrs	
529	**1.3.6.2.2**	**Setup User Interfaces**		**80 hrs**	
530	**1.3.6.2.2.1**	**Setup UI Common Structure**		**50 hrs**	
531	1.3.6.2.2.1.1	Setup UI Operations Concept Document		20 hrs	Le Mignant[0.02]
532	1.3.6.2.2.1.2	Setup UI Software Requirements		10 hrs	Johansson[0.01]
533	1.3.6.2.2.1.3	Setup UI Module Definitions		20 hrs	Johansson[0.02]
534	**1.3.6.2.2.2**	**Setup UI Configurations**		**15 hrs**	
535	1.3.6.2.2.2.1	Functional Requirements		15 hrs	Le Mignant[0.01]
536	1.3.6.2.2.2.2	Interface Definitions		0 hrs	
537	**1.3.6.2.2.3**	**Setup UI Calibrations**		**15 hrs**	
538	1.3.6.2.2.3.1	Functional Requirements		15 hrs	Le Mignant[0.01]
539	1.3.6.2.2.3.2	Interface Definitions		0 hrs	
540	**1.3.6.2.3**	**Observations User Interfaces**		**240 hrs**	
541	**1.3.6.2.3.1**	**Observations UI Common Structure**		**130 hrs**	
542	1.3.6.2.3.1.1	Observations UI Operations Concept Documer		40 hrs	Le Mignant[0.02],Johansson
543	1.3.6.2.3.1.2	Observations UI Software Requirements		10 hrs	Johansson[0.01]
544	1.3.6.2.3.1.3	Observations UI Module Definitions		80 hrs	Johansson[0.03],Le Mignant[0.03]
545	**1.3.6.2.3.2**	**Acquisition & AO Control UI**		**30 hrs**	
546	1.3.6.2.3.2.1	Functional Requirements		20 hrs	Le Mignant[0.01]
547	1.3.6.2.3.2.2	Interface Definitions		10 hrs	Johansson[0.01]
548	**1.3.6.2.3.3**	**Observing Sequences UI**		**20 hrs**	
549	1.3.6.2.3.3.1	Functional Requirements		20 hrs	Le Mignant[0.01]
550	1.3.6.2.3.3.2	Interface Definitions		0 hrs	
551	**1.3.6.2.3.4**	**Status & Graph UI**		**20 hrs**	
552	1.3.6.2.3.4.1	Functional Requirements		20 hrs	Le Mignant[0.01]
553	1.3.6.2.3.4.2	Interface Definitions		0 hrs	
554	**1.3.6.2.3.5**	**Advanced Monitoring UI**		**20 hrs**	
555	1.3.6.2.3.5.1	Functional Requirements		20 hrs	Le Mignant[0.01]
556	1.3.6.2.3.5.2	Interface Definitions		0 hrs	
557	**1.3.6.2.3.6**	**Optimization & Troubleshooting UI**		**20 hrs**	
558	1.3.6.2.3.6.1	Functional Requirements		20 hrs	Le Mignant[0.01]
559	1.3.6.2.3.6.2	Interface Definitions		0 hrs	

ID	WBS	Task Name	Lead	Work	
560	**1.3.6.3**	**Pre- & Post-Observing Science Support Tools**	**DLM**	**610 hrs**	
561	**1.3.6.3.1**	**User Documentation**		**20 hrs**	
562	1.3.6.3.1.1	User Documentation Operations Concept		10 hrs	Le Mignant[0.01]
563	1.3.6.3.1.2	User Documentation Functional Requirements		10 hrs	Le Mignant[0.01]
564	**1.3.6.3.2**	**Science Observations Planning Tools**		**340 hrs**	
565	**1.3.6.3.2.1**	**NGS Star Finder**		**60 hrs**	
566	1.3.6.3.2.1.1	Operations Concept		20 hrs	Le Mignant[0.02]
567	1.3.6.3.2.1.2	Functional Requirements & Use Case Definitior		40 hrs	Le Mignant[0.03]
568	1.3.6.3.2.1.3	Interface Definitions		0 hrs	
569	1.3.6.3.2.1.4	Module Definitions		0 hrs	
570	**1.3.6.3.2.2**	**Performance Prediction Tool**		**140 hrs**	
571	1.3.6.3.2.2.1	Operations Concept		40 hrs	Le Mignant[0.03]
572	1.3.6.3.2.2.2	Functional Requirements & Use Case Definitior		40 hrs	Le Mignant[0.03]
573	1.3.6.3.2.2.3	Interface Definitions		20 hrs	Johansson[0.02]
574	1.3.6.3.2.2.4	Module Definitions		40 hrs	Johansson[0.02],Le Mignant
575	**1.3.6.3.2.3**	**Observation Planning & Efficiency Tool**		**140 hrs**	
576	1.3.6.3.2.3.1	Operations Concept		40 hrs	Le Mignant[0.03]
577	1.3.6.3.2.3.2	Functional Requirements & Use Case Definitior		40 hrs	Le Mignant[0.03]
578	1.3.6.3.2.3.3	Interface Definitions		20 hrs	Johansson[0.02]
579	1.3.6.3.2.3.4	Module Definitions		40 hrs	Johansson[0.02],Le Mignant
580	**1.3.6.3.2.4**	**Laser Clearinghouse Coordination Tool**		**0 hrs**	
581	1.3.6.3.2.4.1	Operations Concept		0 hrs	
582	1.3.6.3.2.4.2	Functional Requirements & Use Case Definitior		0 hrs	
583	1.3.6.3.2.4.3	Interface Definitions		0 hrs	
584	1.3.6.3.2.4.4	Module Definitions		0 hrs	
585	**1.3.6.3.3**	**Data Products**		**250 hrs**	
586	**1.3.6.3.3.1**	**Generic Data Products**		**80 hrs**	
587	1.3.6.3.3.1.1	Operations Concept		20 hrs	Le Mignant[0.02]
588	1.3.6.3.3.1.2	Functional Requirements & Use Case Definitior		40 hrs	Le Mignant[0.03]
589	1.3.6.3.3.1.3	Interface Definitions		20 hrs	Johansson[0.02]
590	**1.3.6.3.3.2**	**Science Data Quality Assessment**		**160 hrs**	
591	**1.3.6.3.3.2.1**	**Quality Metrics & Logged Information**		**80 hrs**	
592	3.6.3.3.2.1.1	Operations Concept		40 hrs	Le Mignant[0.03]
593	3.6.3.3.2.1.2	Functional Requirements & Use Case Def		40 hrs	Le Mignant[0.03]
594	3.6.3.3.2.1.3	Interface Definitions		0 hrs	
595	**1.3.6.3.3.2.2**	**PSF Calibration**		**80 hrs**	
596	3.6.3.3.2.2.1	Operations Concept		40 hrs	Le Mignant[0.03]
597	3.6.3.3.2.2.2	Functional Requirements & Use Case Def		40 hrs	Le Mignant[0.03]
598	3.6.3.3.2.2.3	Interface Definitions		0 hrs	
599	3.6.3.3.2.2.4	Module Definitions		0 hrs	
600	**1.3.6.3.3.3**	**Science Data Archiving**		**10 hrs**	
601	1.3.6.3.3.3.1	Operations Concept		10 hrs	Le Mignant[0.01]
602	1.3.6.3.3.3.2	Functional Requirements & Use Case Definitior		0 hrs	
603	1.3.6.3.3.3.3	Interface Definitions		0 hrs	
604	**1.3.6.4**	**Data Server**	**EJ**	**70 hrs**	
605	1.3.6.4.1	Data Server: Architecture		40 hrs	Johansson[0.03]
606	1.3.6.4.2	Data Server: HW & SW Specification & Selection		20 hrs	Johansson[0.01]
607	1.3.6.4.3	Data Server: Software Design		0 hrs	2/2
608	1.3.6.4.4	Data Server: Compliance Matrix		0 hrs	2/2
609	1.3.6.4.5	Data Server: Test Plan		0 hrs	2/2
610	1.3.6.4.6	Data Server: Summary Report		10 hrs	Johansson[0.01]

ID	WBS	Task Name	Lead	Work
611	**1.3.7**	**Telescope & Summit Engineering Design**	**CN**	**1,101 hrs**
612	1.3.7.1	Telescope Performance		0 hrs
613	**1.3.7.2**	**Infrastructure Modifications for AO**	**JB**	**660 hrs**
614	1.3.7.2.1	Infrastructure Requirements & Interfaces	JB	90 hrs
615	1.3.7.2.2	Infrastructure Mechanical Modifications	DM	160 hrs
616	1.3.7.2.3	Infrastructure Electrical Modifications	CN	120 hrs
617	1.3.7.2.4	Infrastructure Glycol Cooling Modifications	CN	140 hrs
618	1.3.7.2.5	Infrastructure CCR Modifications	CN	40 hrs
619	1.3.7.2.6	Infrastructure Implementation & Test Plans	JB	110 hrs
620	**1.3.7.3**	**Infrastructure modifications for Laser System**	**JB**	**280 hrs**
621	1.3.7.3.1	Infrastructure Requirements & Interfaces	JB	70 hrs
622	1.3.7.3.2	Infrastructure Mechanical Modifications	DM	50 hrs
623	1.3.7.3.3	Infrastructure Electrical Modifications	CN	40 hrs
624	1.3.7.3.4	Infrastructure Glycol Cooling Modifications	CN	50 hrs
625	1.3.7.3.5	Infrastructure Implementation & Test Plans	JB	70 hrs
626	1.3.7.4	OSIRIS Modifications	SA	100 hrs
627	**1.3.7.5**	**Interferometer Modifications**	**PW**	**61 hrs**
628	1.3.7.5.1	Optical Design of Post Field Selector Optics	PW	45 hrs
629	1.3.7.5.2	Evaluation of Optical Design Impact on Interferometer	PW	16 hrs
630	**1.3.8**	**Telescope Integration & Test**	**CN**	**622 hrs**
631	**1.3.8.1**	**Old AO/Laser Removal**	**JB**	**120 hrs**
632	1.3.8.1.1	AO Removal Plan	JB	60 hrs
633	1.3.8.1.2	Laser Removal Plan	DM	60 hrs
634	1.3.8.2	Laser Enclosure Integration		0 hrs
635	1.3.8.3	AO Enclosure Integration		0 hrs
636	**1.3.8.4**	**AO System Install + I&T**	**CN**	**170 hrs**
637	1.3.8.4.1	Opto-Mechanical Integration Plan	CN	60 hrs
638	1.3.8.4.2	Electronics Integration Plan	EW	40 hrs
639	1.3.8.4.3	Computer Integration Plan	JC	20 hrs
640	1.3.8.4.4	AO System Integration Plan	CN	40 hrs
641	1.3.8.4.5	AO System Test Plan	CN	10 hrs
642	**1.3.8.5**	**Laser System Install + I&T**	**JC**	**212 hrs**
643	1.3.8.5.1	Laser System Installation & Integration Plan	JC	148 hrs
644	1.3.8.5.2	Laser System Test Plan	CN	64 hrs
645	1.3.8.6	LGS AO System On-sky I&T Plan	DLM	40 hrs
646	1.3.8.7	Performance Characterization		0 hrs
647	1.3.8.8	Science Verification Plan	DLM	80 hrs
648	**1.3.9**	**Operations Transition**	**DLM**	**166 hrs**
649	**1.3.9.1**	**Operations Plans**	**DLM**	**96 hrs**
650	1.3.9.1.1	Operations Support Plan	DLM	40 hrs
651	1.3.9.1.2	Operations Maintenance & Spares Plan Template	EW	56 hrs
652	**1.3.9.2**	**Operations Handover**	**DLM**	**70 hrs**
653	1.3.9.2.1	Operations Personnel Training Plan	DLM	50 hrs
654	1.3.9.2.2	Documentation Transition Plan	DLM	20 hrs



13 Appendix: Management Approach to Real-Time Controller Design

Don Gavel and Marc Reinig, March, 2008

The proposed real-time controller (RTC) for Keck NGAO is an atypical design compared to AO real-time controllers built in the past. Because of the extremely demanding compute speed and data communication requirements for real-time tomography, we have proposed a massively parallel processing architecture. “Programming” these systems is not like programming a standard (Von Neuman architecture) computer, but is instead one of simultaneously designing the processors themselves along with specifying the data handling and communication tasks each of the processors will do.

From an engineering management perspective, we adopt an approach that more closely resembles that of managing the AO system’s mechanical or electrical subsystems design, rather than managing a software project. In Preliminary Design (PD) and Detailed Design (DD) phases, the mechanical engineers, for example, specify and design the mechanical components and systems, ending up with full set of specifications and full set of drawings ready to hand off to fabrication. On the other hand, a typical software system is “designed” in time for the Detailed Design Review (DDR), but is not yet “coded.” The software coding is traditionally done in the Full Scale Development (FSD) phase. However, for the proposed Keck NGAO RTC architecture, we will be treating the system and its units as items to be fully designed by the end of DD phase and ready to be handed off for fabrication in FSD phase, just as a mechanical design would be. In FSD phase, actual construction and populating of circuit boards, and burning in of the RTC processing tasks (the “code”) into the chips on those boards, will occur.

The elemental subsystems within the RTC product structure are reflected to some extent in the RTC’s work breakdown structure (WBS) for PD phase. Each of the identified subsystems of the architecture can be viewed as a piece of electronic hardware to be designed to meet a specific set of requirements. During PD phase, these requirements are themselves being fully developed, but some progress will be made, to the PDR level, on specifying the subsystem elements themselves, just as they would in a mechanical hardware system design. A few of the RTC WBS tasks are design trade studies intended to support a design decision prior to PDR.

Finally, since there are a number of RTC subsystems that must work together as a whole, there is an element of system engineering that needs to take place. This is reflected in a number of compliance “testing” tasks affiliated with each subsystem and the overall system engineering tasks to be performed by the senior engineer responsible for the RTC.

A preliminary dictionary for the tasks in PD phase is given below. These are in the WBS for PD phase at level 1.3.4.5.1.x

1. Technical Management. Coordinate the overall design and systems engineering for the RTC. Develop a simulator that will prove the system design prior to build (Full Scale Development)

phase. Coordinate the requirements specification process and development of compliance matrices and use these to assure the RTC design will meet performance requirements in conjunction with the overall NGAO system engineering effort.

2. Centroider/Wavefront Reconstructor Requirements Specification and Design. Design a subsystem that takes digital inputs coming from the wavefront sensor camera controllers and produces reconstructed wavefronts (phase in nanometers) and transmits these to the tomography engine in real time, conforming to an overall error and timing budget. This system will also provide telemetry and monitoring (diagnostic) data streams to the supervisory (non-RTC) system.

3. Centroider/Wavefront Reconstructor Testing Plan and Compliance Plan Development. Develop a compliance matrix and testing plan for the Centroider/Wavefront Reconstructor, including a plan to prove the system design in an overall RTC system simulator prior to build (Full Scale Development) phase.

4. Preconditioning and Scaling Requirements Specification and Design. Specify and design the real-time tomography engine. This unit accepts wavefront phase data from the centroider/wavefront reconstructors and low order wavefront sensors and produces estimates of the delta-index variations in the atmosphere volume above the telescope. The process must adhere to an overall error and timing budget. This system will also provide telemetry and monitoring (diagnostic) data streams to the supervisory system.

5. Preconditioning and Scaling Testing Plan and Compliance Plan Development. Develop a compliance matrix and testing plan for the tomography engine, including a plan to prove the system design in an overall RTC system simulator prior to Full Scale Development phase.

6. Low Order WFS Processor Requirements Specification and Design. Specify and design a subsystem that takes digital inputs coming from the low order wavefront sensor controllers and produces an estimate of the low-order invisible modes in the atmosphere volume above the telescope, and sends this information into the tomography engine. This subsystem must conform to overall error and timing budgets. This system will also provide telemetry and monitoring (diagnostic) data streams to the supervisory (non-RTC) system.

7. Low Order WFS Testing Plan and Compliance Plan Development. Develop a compliance matrix ant testing plan for the low order WFS processor, including a plan to prove the system design in an overall RTC system simulator prior to Full Scale Development phase.

8. Layer Combining and DM Processor Requirements Specification and Design. Specify and design a set of subsystems that will 1) accept volume delta-index information from the tomography engine and produce projected estimates for wavefronts in directions of on-axis

science, IFU science, low order WFS, and PSF monitors (i.e., every DM field position in the system), and 2) calculate the required mirror voltage commands needed to bring each DM to the indicated wavefront. This subsystem must conform to overall error and timing budgets. This system will also provide telemetry and monitoring (diagnostic) data streams to the supervisory (non-RTC) system.

9. Assess Data Communications Issues: Centroider Distance from Camera Head. Perform an engineering trade study to determine whether bit rate x distance will drive the centroider units to be located physically close to the wavefront sensor camera heads. Consider options and costs therein, given any solution will need to conform to overall error budget and timing budgets.

10. Assess Tomography Engine Size Issue: Voxel Sample Size vs Altitude. Perform an engineering trade study to decide whether to adopt an altitude scaling of voxel sample size in order to reduce number of voxels / processor boards at the cost of a more complex algorithm. Consider options and costs therein, given any solution will need to conform to overall error budget and timing budgets.

11. Determine Required Data Resolution. Perform an engineering study to determine the minimum data representation size ("bit width") required of data within the various stages of processing, assuming bit width will drive complexity and cost but that a minimum is required to meet the overall error and timing budgets.

12. Characterize the Effects of Single Event Upsets (SEUs). Predict, given the processor system design, the rate of "single event upsets" – cosmic ray or other events that corrupt data in processing elements, and determine the requirements for redundancy and error correction coding, in light of the need to meet overall error and timing budgets.

13. Determine Parameters for Optimization of Power Consumption. Perform a design trade study that addresses methods of minimizing total RTC power consumption, and assures that the overall power required will be within limits imposed by the telescope and Naysmyth platform infrastructure while still conforming to overall RTC error and timing budgets.

14. Voxel, Chip, and Board Communications Infrastructure Requirements and Design. Develop options for the layout, communication paths, and data communication protocols for on-chip, chip-to-chip, and board-to-board communications within the centroider, tomography engine, and DM processing subsystems. Perform engineering design trade studies to determine a parametric model for characterizing cost and complexity vs communication approaches while adhering to overall RTC system error and timing budgets. Provide an initial specifications for a selected communications model.

15. Telemetry Control and I/O Requirements and Design. Specify and design the RTC-side I/O support for the high speed gathering, transport, and recording of telemetry data.

16. Monitoring Control and I/O Requirements and Design. Specify and design the RTC-side I/O support for the low speed gathering, transport, and display of system monitoring information.

17. Define Testing Procedures. Develop a compliance matrix and testing plan for the overall RTC. Develop a system engineering test plan to prove the RTC system design with a simulator prior to the full scale development phase.

18. Documentation. Write a set of documents for the RTC. These include the requirements documents, the preliminary design documents and related materials, and trade study reports from PD phase.