Keck Adaptive Optics Note 583

Keck Next Generation Adaptive Optics
Work Breakdown Structure Dictionary

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The NGAO Work Breakdown Structure is maintained in the Contour database. This KAON is a report of the current definitions and deliverables from the database. It is formatted so that each WBS element begins at the top of a new page; the first entry begins on the next page. The report is quite long (100+ pages), which should be kept in mind before printing.

WBS	Level	ID	Name
2	2	WBS-407	Management
Phase	**WBS Element**		**Deliverable**
PD			
DD			
FSD			
DC			

WBS	Level	ID	Name
2.1	3	WBS-408	Planning
Phase	**WBS Element**		**Deliverable**
PD	Replanning for the current phase and planning for the future phases. A plan for the current phase will have been generated during the previous phase. Multiple replans will be performed during the phase to ensure successful completion of the phase. The Systems Engineering Management Plan will be updated for completion of the project. This will include the updated project plan and cost estimates, and a detailed plan for the next phase, and may include changes to the management structure/approach.		COO and UCO contracts. Updated versions of the preliminary design phase MS Project plan. Systems Engineering Management Plan (SEMP) for the DD phase and beyond.
DD	Replanning for the current phase and planning for the future phases. A plan for the current phase will have been generated during the previous phase. Multiple replans will be performed during the phase to ensure successful completion of the phase. The Systems Engineering Management Plan will be updated for completion of the project. This will include the updated project plan and cost estimates, and a detailed plan for the next phase, and may include changes to the management structure/approach.		Updated versions of the detailed design phase MS Project plan. Systems Engineering Management Plan (SEMP) for the FSD phase and beyond.
FSD	Replanning for the current phase and planning for the future phases. A plan for the current phase will have been generated during the previous phase. Multiple replans will be performed during the phase to ensure successful completion of the phase.		Updated MS Project plans. Detailed plan for the delivery and commissioning phase.
DC	Replanning for the current phase. A plan for the current phase will have been generated during the previous phase. Multiple replans will be performed during the phase to ensure successful completion of the phase.		Updated MS project plan.

WBS	Level	ID	Name
2.2	3	WBS-409	Project Management & Meetings
Phase	**WBS Element**		**Deliverable**
PD	Executive Committee management time not explicitly covered elsewhere will be covered under this WBS, including the EC telecons. Personnel time and travel and meeting costs for team meetings will be covered under this WBS.		Regular EC and Team meetings.
DD	Executive Committee management time not explicitly covered elsewhere will be covered under this WBS, including the EC telecons. Personnel time and travel and meeting costs for team meetings will be covered under this WBS.		Regular EC and Team meetings.
FSD	The bulk of the routine project management costs will be covered under this WBS with the exception of project management tasks explicitly called out under other Management WBS elements. Team meeting costs are included under this WBS.		Regular EC and Team meetings.
DC	The bulk of the routine project management costs will be covered under this WBS with the exception of project management tasks explicitly called out under other Management WBS elements. Team meeting costs are included under this WBS.		Regular EC & team meetings.

WBS	Level	ID	Name
2.3	3	WBS-410	Tracking & Reporting

Phase	WBS Element	Deliverable
PD	This WBS will cover the development (including budget and schedule tracking) of the following reports: monthly TSIP reports, reports to the Directors (the TSIP reports may meet this need) and SSC and Keck science meeting presentations, as well as external reports by the NGAO project.	Tracked versions of the budget and schedule. Monthly TSIP reports. SSC and Keck Science Meeting presentations. External reports.
DD	This WBS will cover the development (including budget and schedule tracking) of the following reports: monthly TSIP reports, reports to the Directors (the TSIP reports may meet this need) and SSC and Keck science meeting presentations, as well as external reports by the NGAO project.	Tracked versions of the budget and schedule. Monthly TSIP reports. SSC and Keck Science Meeting presentations. External reports.
FSD	This WBS will cover the development (including budget and schedule tracking) and presentation of the required project reports to the relevant funding source, Observatory management and the WMKO science community, as well as some additional external reports.	Tracked versions of the budget and schedule. Monthly TSIP reports. SSC and Keck Science Meeting presentations. External reports.
DC	This WBS will cover the development (including budget and schedule tracking) and presentation of the required project reports to the relevant funding source, Observatory management and the WMKO science community, as well as some additional external reports.	Tracked versions of the budget and schedule. Monthly TSIP reports. SSC and Keck Science Meeting presentations. External reports.

WBS	Level	ID	Name
2.4	3	WBS-411	Proposals & Fundraising
Phase	**WBS Element**		**Deliverable**
PD	NGAO will be seeking funding from public and private sources. This WBS covers the development of public funding proposals and supporting Advancement in obtaining private funding.		Funding proposals.
DD	NGAO will be seeking funding from public and private sources. This WBS covers the development of public funding proposals and supporting Advancement in obtaining private funding.		Funding proposals.
FSD	NGAO will be seeking funding from public and private sources. This WBS covers the development of public funding proposals and supporting Advancement in obtaining private funding.		Funding proposals.
DC	NGAO will be seeking funding from public and private sources. This WBS covers the development of public funding proposals and supporting Advancement in obtaining private funding.		Funding proposals.

WBS	Level	ID	Name
2.5	3	WBS-412	Programmatic Risk Assessment & Mitigation
Phase	**WBS Element**		**Deliverable**
PD	Effort and costs associated with assessing and mitigating programmatic risks during the PD phase.		Documentation of the programmatic risk assessment and the results of programmatic risk mitigation efforts.
DD	Effort and costs associated with assessing and mitigating programmatic risks during the DD phase.		Documentation of the programmatic risk assessment and the results of programmatic risk mitigation efforts.
FSD	Effort and costs associated with assessing and mitigating programmatic risks during the FSD phase.		Documentation of the programmatic risk assessment and the results of programmatic risk mitigation efforts.
DC	Effort and costs associated with assessing and mitigating programmatic risks during the DC phase.		Documentation of the programmatic risk assessment and the results of programmatic risk mitigation efforts.

WBS	Level	ID	Name
2.6	3	WBS-413	Project Reviews
Phase	**WBS Element**		**Deliverable**
PD	The effort and costs associated with each Project Review during this phase including setting up the review, producing the report, addressing reviewer questions, holding the review and responding to the reviewer report. The Project Reviews during this phase will include the Preliminary Design Review. It will also include the effort to clarify and document the success criteria for each Project Review.		Success criteria for each project review. PDR report. Response to Reviewer report.
DD	The effort and costs associated with each Project Review during this phase including setting up the review, producing the report, addressing reviewer questions, holding the review and responding to the reviewer report. The Project Reviews during this phase will include a Detailed Design Review.		DDR report. Response to Reviewer report.
FSD	The effort and costs associated with each Project Review during this phase including setting up the review, producing the report, addressing reviewer questions, holding the review and responding to the reviewer report. The Project Reviews during this phase will include a Full Scale Development Intermediate Review, a Pre-Lab I&T Readiness Review and a Pre-Ship Readiness Review.		Project Reports. Response to Reviewer report.
DC	The effort and costs associated with each Project Review during this phase including setting up the review, producing the report, addressing reviewer questions, holding the review and responding to the reviewer report. The Project Reviews during this phase will include an Operability Review (readiness for shared-risk science & partial handover to operations) and an Operations Readiness Review (acceptance review and final handover to operations).		Project reports. Response to Reviewer reports.

WBS	Level	ID	Name
2.7	3	WBS-414	Project Support
Phase	**WBS Element**		**Deliverable**
PD	2.7.1 Administrative support & associated costs for contracting, procurements, audits & hiring. Admin assistant (secretarial) support. Project Manager support for contracts. 2.7.2 Procurement of shared infrastructure such as computers and software licences, as well as maintenance fees. IT support. 2.7.3 Professional development. Research time for postdocs & scientists (proportional to their time on NGAO). Professional development costs for WMKO NGAO staff.		COO and UCO contracts. Shared infrastructure procurement.
DD	2.7.1 Administrative support & associated costs for contracting, procurements, audits & hiring. Admin assistant (secretarial) support. Project Manager support for contracts. 2.7.2 Procurement of shared infrastructure such as computers and software licences, as well as maintenance fees. IT support. 2.7.3 Professional development. Research time for postdocs & scientists (proportional to their time on NGAO). Professional development costs for WMKO NGAO staff.		COO and UCO contracts. Shared infrastructure procurement.
FSD	2.7.1 Administrative support & associated costs for contracting, procurements, audits & hiring. Admin assistant (secretarial) support. Project Manager support for contracts. 2.7.2 Procurement of shared infrastructure such as computers and software licences, as well as maintenance fees. IT support. 2.7.3 Professional development. Research time for postdocs & scientists (proportional to their time on NGAO). Professional development costs for WMKO NGAO staff.		COO and UCO contracts. Shared infrastructure procurement.
DC	2.7.1 Administrative support & associated costs for contracting, procurements, audits & hiring. Admin assistant (secretarial) support. Project Manager support for contracts. 2.7.2 Procurement of shared infrastructure such as computers and software licences, as well as maintenance fees. IT support. 2.7.3 Professional development. Research time for postdocs & scientists (proportional to their time on NGAO). Professional development costs for WMKO NGAO staff.		COO and UCO contracts. Shared infrastructure procurement.

WBS	Level	ID	Name
3	2	WBS-415	Systems Engineering
Phase	**WBS Element**		**Deliverable**
PD			
DD			
FSD			
DC			

WBS	Level	ID	Name
3.1	3	WBS-416	Science Case Development
Phase	**WBS Element**		**Deliverable**
PD			
DD			
FSD			
DC			

WBS	Level	ID	Name
3.1.1	4	WBS-417	Science Requirements

Phase	WBS Element	Deliverable
PD	Specifications for each Key Science Driver and each Science Driver developed by the Science Advisory Team will detail the scientific performance needed in order to achieve the stated science goals. Where appropriate, these scientific performance requirements will be flowed down to AO and instrument requirements needed to achieve these specifications. Key science drivers are: Galaxy Assembly and Star Formation History; Nearby Active Galactic Nuclei; Precision Astrometry for Measurement of General Relativistic Effects in the Galactic Center; Imaging and Characterization of Extrasolar Planets Around Nearby Stars; Multiplicity of Minor Planets. Science Drivers are: QSO Host Galaxies; Gravitational Lensing; Astrometry Science in Sparse Fields; Resolved Stellar Populations in Crowded Fields; Debris Disks and Young Stellar Objects; Size Shape and Composition of Minor Planets; Characterization of Gas Giant Planets; Characterization of Ice Giant Planets; Backup Science. For each Key Science Driver and each Science Driver, the following will be analyzed and documented: Scientific Background; Specific Goals for NGAO Science; Target Description; Simulations of Astronomical Performance. From the above will be derived the set of Science Requirements for each Science Driver, as well as the flow-down to AO and instrument requirements where appropriate. All the various science requirements will be summarized in a Science Requirement Summary Matrix that collapses individual science requirements across all the science cases, to develop rolled-up requirements in each category. This will be a more specific version of the Rainbow Chart. (Feeds into WBS elements 3.2 Requirements Maintenance, 3.3.1 Performance Budgets, 3.3.2 Modeling and Analysis, and 3.3.3 PSF Calibration)	New writeups of the following science drivers for the SCRD: Astrometry Science in Sparse Fields, Resolved Stellar Populations in Crowded Fields, Debris Disks and Young Stellar Objects, QSO Host Galaxies. Extending the SCRD discussion of existing key science drivers and science drivers through analysis, simulations, and modeling. Finalized science requirements for each science driver. Develop quantitative understanding of PSF requirements and capabilities, in conjunction with WBS elements 3.3.1, 3.3.2, 3.3.3, 3.10, 4.3.3, 4.3.4, 6.3.2, 6.3.3. Produce Science Requirements Summary Matrix. Input to Systems Engineering Management Plan.
DD	Specifications for each Key Science Driver and each Science Driver developed by the Science Advisory Team will detail the scientific performance needed in order to achieve the stated science goals. In this phase the Science Advisory Team will assess proposed changes in AO and instrument requirements raised by the AO and instrument design teams. Where appropriate, these scientific performance requirements will be flowed down to AO and instrument requirements needed to achieve these specifications. Key science drivers are: Galaxy Assembly and Star Formation History; Nearby Active Galactic Nuclei; Precision Astrometry for Measurement of General Relativistic Effects in the Galactic Center; Imaging and Characterization of Extrasolar Planets Around Nearby Stars; Multiplicity of Minor Planets. Science Drivers are: QSO Host Galaxies; Gravitational Lensing; Astrometry Science in Sparse Fields; Resolved Stellar Populations in Crowded Fields; Debris Disks and Young Stellar Objects; Size Shape and Composition of Minor Planets; Characterization of Gas Giant Planets; Characterization of Ice Giant Planets; Backup Science.	Full-scale simulations of observations and science performance for most Science Drivers (key and otherwise), using results from 3.3.1, 3.3.2, and 3.3.3. KAONs evaluating proposed changes to Science Requirements as Detailed Design proceeds. Input to Systems Engineering Management Plan.

FSD	Specifications for each Key Science Driver and each Science Driver developed by the Science Advisory Team will detail the scientific performance needed in order to achieve the stated science goals. In this phase the Science Advisory Team will assess proposed changes in AO and instrument requirements raised by the AO and instrument design teams. Where appropriate, these scientific performance requirements will be flowed down to AO and instrument requirements needed to achieve these specifications. Key science drivers are: Galaxy Assembly and Star Formation History; Nearby Active Galactic Nuclei; Precision Astrometry for Measurement of General Relativistic Effects in the Galactic Center; Imaging and Characterization of Extrasolar Planets Around Nearby Stars; Multiplicity of Minor Planets. Science Drivers are: QSO Host Galaxies; Gravitational Lensing; Astrometry Science in Sparse Fields; Resolved Stellar Populations in Crowded Fields; Debris Disks and Young Stellar Objects; Size Shape and Composition of Minor Planets; Characterization of Gas Giant Planets; Characterization of Ice Giant Planets; Backup Science.	Input to Science Verification Plan Release 1. Science evaluation of new science cases as they arise from the community, based upon existing NGAO system design and architecture.
DC	This element focuses on deepening our understanding of NGAO science cases, understanding how the design as implemented will impact NGAO science, evaluating any proposed changes to the science requirements from the point of view of their scientific impact, helping the science instrument teams as the design and development process for the instruments proceeds, and providing significant input to the Final Operations Concept Document. It utilizes a Science Advisory Team: a network of astronomers throughout the UCO, COO, UH, and WMKO observing communities who detail the scientific background and goals of individual science cases.	

WBS	Level	ID	Name
3.1.2	4	WBS-418	Science Observing Planning and Execution
Phase	**WBS Element**		**Deliverable**
PD	The goal of this WBS element is to develop Observing Scenarios for all of the Key Science Drivers, and to develop a Design Reference Mission for at least two Key Science Drivers. Both tasks will integrate the outputs of WBS 3.1 and 6, to develop an understanding of end-to-end science operations and data products.		The Observing Scenarios developed in the System Design phase will be elaborated upon and completed. As of the end of the System Design phase 4 Observing Scenarios have been completed. In PD phase Observing Scenarios for the remaining Key Science Driver cases will be developed. These will provide input to the Preliminary Operations Concept Document.
DD	The goal of this WBS element is to develop Observing Scenarios for all of the Key Science Drivers, and to develop a Design Reference Mission for at least two Key Science Drivers. Both tasks will integrate the outputs of WBS 3.1 and 6, to develop an understanding of end-to-end science operations and data products.		Development of a Design Reference Mission for two Key Science Drivers will begin with a set of observing proposals and Observing Scenarios developed by members of the Science Advisory Team in conjunction with technical members of the NGAO team. Prototype observation planning tools are used during proposal development. In order to assess the feasibility of the proposed observations, simulated data will be generated based on the best available assumptions about the telescope, AO and instrument characteristics. This process will help assure that the required observing modes are available in the NGAO system. Scientific input for the simulations (such as expected source densities, magnitudes etc) will be provided by the scientists responsible for the proposal. The simulated data will then be passed back to the scientists for analysis using prototype NGAO post-observing tools in order to assess the extent to which the goals of the observations have been met and to evaluate the prototype tools. As understanding of the telescope, AO, and instrument parameters evolves, and as the pre- and post-observing tools mature, the science cases and simulations will be updated. This exercise will provide important input to the Operations Concept Document and the Science Verification Plan.
FSD	The goal of this WBS element is to develop Observing Scenarios for all of the Key Science Drivers, and to develop a Design Reference Mission for at least two Key Science Drivers. Both tasks will integrate the outputs of WBS 3.1 and 6, to develop an understanding of end-to-end science operations and data products.		Further refinement of the Design Reference Mission for at least two Key Science Drivers.
DC	The goal of this WBS element is to develop Observing Scenarios for all of the Key Science Drivers, and to develop a Design Reference Mission for at least two Key Science Drivers. Both tasks will integrate the outputs of WBS 3.1 and 6, to develop an understanding of end-to-end science operations and data products.		Results from previous phases will provide important input to the Science Verification Plan.

WBS	Level	ID	Name
3.1.3	4	WBS-419	Science Input to Other WBS Elements Affecting Science Performance
Phase	**WBS Element**		**Deliverable**
PD	This element provides a means for coordination with other WBS elements, necessary to ensure that the details of the observing scenarios, science operations, and science planning, modeling and analysis tools, PSF tasks, Error Budget tasks, etc. make use of input from the Science Advisory Team in their final deliverables, and that meet the science specifications sufficiently. The areas of particular interest are 3.3.1 Performance Budget Developement and Maintenance, 3.3.2 Modeling and Analysis, 3.3.3 PSF Calibration, 6.0 Science Operations, 6.1.3 Observing Sequences, 6.3.2 Science Observations Planning Tools, Operations Concepts Documents, and 8.8 Science Verification Planning. It is anticipated that members of the Science Advisory Team will be doing analysis, modeling, and simulation work that bridges between the science driver cases and these other WBS elements. Meetings between groups responsible for these tasks and the Science Team will serve to further the understanding of all affected parties. As details of each of these sub-components are developed, adjustments to final design and science requirements may need to be made.		KAONs describing the following, for example: 1) PSF information, stability, and accuracy required by each Key Science Driver and Science Driver. 2) Input specifications for each Key Science Driver, for use as input to Wavefront Error Budget tool, Photometric Error Budget, Astrometric Error Budget, Ensquared Energy and Contrast Error Budgets , Background requirements. Input to Preliminary Specifications document. Input to the Preliminary Operations Concept Document. Input to Preliminary Design Report. Input to Systems Engineering Management Plan. Evaluation and input for 6.2 User Interfaces, 6.3 Pre- & Post-observing Science Support Tools.
DD	This element provides a means for coordination with other WBS elements, necessary to ensure that the details of the observing scenarios, science operations, and science planning, modeling and analysis tools, PSF tasks, Error Budget tasks, etc. make use of input from the Science Advisory Team in their final deliverables, and that meet the science specifications sufficiently. The areas of particular interest are 3.3.1 Performance Budget Developement and Maintenance, 3.3.2 Modeling and Analysis, 3.3.3 PSF Calibration, 6.0 Science Operations, 6.1.3 Observing Sequences, 6.3.2 Science Observations Planning Tools, Operations Concepts Documents, and 8.8 Science Verification Planning. It is anticipated that members of the Science Advisory Team will be doing analysis, modeling, and simulation work that bridges between the science driver cases and these other WBS elements. Meetings between groups responsible for these tasks and the Science Team will serve to further the understanding of all affected parties. As details of each of these sub-components are developed, adjustments to final design and science requirements may need to be made.		Input to Final Specifications document. Input to the Final Operations Concept Document. Input to Design Reports. Input to Systems Engineering Management Plan. Evaluation and input for 6.2 User Interfaces, 6.3 Pre- & Post-observing Science Support Tools.
FSD	This element provides a means for coordination with other WBS elements, necessary to ensure that the details of the observing scenarios, science operations, and science planning, modeling and analysis tools, PSF tasks, Error Budget tasks, etc. make use of input from the Science Advisory Team in their final deliverables, and that meet the science specifications sufficiently. The areas of particular interest are 3.3.1 Performance Budget Developement and Maintenance, 3.3.2 Modeling and Analysis, 3.3.3 PSF Calibration, 6.0 Science Operations, 6.1.3 Observing Sequences, 6.3.2 Science Observations Planning Tools, Operations Concepts Documents, and 8.8 Science Verification Planning. It is anticipated that members of the Science Advisory Team will be doing analysis, modeling, and simulation work that bridges between the science driver cases and these other WBS elements. Meetings between groups responsible for these tasks and the Science Team will serve to further the understanding of all affected parties. As details of each of these sub-components are developed, adjustments to final design and science requirements may need to be made.		Input into Science Verification Plan, Acceptance Test Plan, evaluation and input for 6.2 User Interfaces, 6.3 Pre- & Post-observing Science Support Tools.

DC	This element provides a means for coordination with other WBS elements, necessary to ensure that the details of the observing scenarios, science operations, and science planning, modeling and analysis tools, PSF tasks, Error Budget tasks, etc. make use of input from the Science Advisory Team in their final deliverables, and that meet the science specifications sufficiently. The areas of particular interest are 3.3.1 Performance Budget Developement and Maintenance, 3.3.2 Modeling and Analysis, 3.3.3 PSF Calibration, 6.0 Science Operations, 6.1.3 Observing Sequences, 6.3.2 Science Observations Planning Tools, Operations Concepts Documents, and 8.8 Science Verification Planning. It is anticipated that members of the Science Advisory Team will be doing analysis, modeling, and simulation work that bridges between the science driver cases and these other WBS elements. Meetings between groups responsible for these tasks and the Science Team will serve to further the understanding of all affected parties. As details of each of these sub-components are developed, adjustments to final design and science requirements may need to be made.	Evaluation of final versions of 6.2 User Interfaces, 6.3 Pre- & Post-observing Science Support Tools as part of Acceptance Testing. Participation in Science Verification if the latter falls within the DC phase.

WBS	Level	ID	Name
3.1.4	4	WBS-420	Science Competitiveness
Phase	**WBS Element**		**Deliverable**
PD	In order to ensure the competitiveness of scientific results from NGAO, the Science Advisory Team will need to keep current on the capabilities of planned and concurrent facilities including other ground-based telescopes with AO , JWST, and ALMA, as well as future missions and facilities. The Science Advisory Team will provide feedback regarding NGAO science opportunities that complement other facilities and take advantage of the uniqueness space provided by NGAO at Keck.		KAONs describing implications of concurrent projects elsewhere on NGAO science opportunities.
DD	In order to ensure the competitiveness of scientific results from NGAO, the Science Advisory Team will need to keep current on the capabilities of planned and concurrent facilities including other ground-based telescopes with AO , JWST, and ALMA, as well as future missions and facilities. The Science Advisory Team will provide feedback regarding NGAO science opportunities that complement other facilities and take advantage of the uniqueness space provided by NGAO at Keck.		KAONs describing implications of concurrent projects elsewhere on NGAO science opportunities.
FSD	In order to ensure the competitiveness of scientific results from NGAO, the Science Advisory Team will need to keep current on the capabilities of planned and concurrent facilities including other ground-based telescopes with AO , JWST, and ALMA, as well as future missions and facilities. The Science Advisory Team will provide feedback regarding NGAO science opportunities that complement other facilities and take advantage of the uniqueness space provided by NGAO at Keck.		KAONs describing implications of concurrent projects elsewhere on NGAO science opportunities.
DC	In order to ensure the competitiveness of scientific results from NGAO, the Science Advisory Team will need to keep current on the capabilities of planned and concurrent facilities including other ground-based telescopes with AO , JWST, and ALMA, as well as future missions and facilities. The Science Advisory Team will provide feedback regarding NGAO science opportunities that complement other facilities and take advantage of the uniqueness space provided by NGAO at Keck.		KAONs if significant unexpected changes in external programs take place during this time period.

WBS	Level	ID	Name
3.1.5	4	WBS-421	User Community Liason
Phase	**WBS Element**		**Deliverable**
PD	Feedback from the Science Advisory Team and the observing community at large will be solicited and documented, to ensure that the requirements from the science cases developed to date remain consistent and up-to-date with changing methodology, advancing AO system design, and maturing instrument concepts. Input from observers with experience using current AO systems at Keck and elsewhere will be solicited to determine where improvements can be made in observing practices and observing support. (Feeds in to WBS sub-element 3.1.3 which will feed into WBS 6 and its sub-elements.)		KAONs describing user input and evaluation for WBS element 6 and its sub-elements. KAONs describing user input on Science Requirements.
DD	Feedback from the Science Advisory Team and the observing community at large will be solicited and documented, to ensure that the requirements from the science cases developed to date remain consistent and up-to-date with changing methodology, advancing AO system design, and maturing instrument concepts. Input from observers with experience using current AO systems at Keck and elsewhere will be solicited to determine where improvements can be made in observing practices and observing support. (Feeds in to WBS sub-element 3.1.3 which will feed into WBS 6 and its sub-elements.)		KAONs describing user input and evaluation for WBS element 6 and its sub-elements. KAONs describing user input on Science Requirements should the latter need to be modified.
FSD	Feedback from the Science Advisory Team and the observing community at large will be solicited and documented, to ensure that the requirements from the science cases developed to date remain consistent and up-to-date with changing methodology, advancing AO system design, and maturing instrument concepts. Input from observers with experience using current AO systems at Keck and elsewhere will be solicited to determine where improvements can be made in observing practices and observing support. (Feeds in to WBS sub-element 3.1.3 which will feed into WBS 6 and its sub-elements.)		KAONs describing user input and evaluation for WBS element 6 and its sub-elements. KAONs describing user input on Science Requirements should the latter need to be modified.
DC	Feedback from the Science Advisory Team and the observing community at large will be solicited and documented, to ensure that the requirements from the science cases developed to date remain consistent and up-to-date with construction realities, changing methodology, changes in AO system design, and final instrument concepts. Input from observers with experience using current AO systems at Keck and elsewhere will be solicited to determine where improvements can be made in observing practices and observing support. (Feeds in to WBS sub-element 3.1.3 which will feed into WBS 6 and its sub-elements.)		Community user input on developmental user planning tools, user interfaces, and data reduction tools (WBS element 6.) Participation in Science Verification if the latter falls within the DC phase.

WBS	Level	ID	Name
3.1.6	4	WBS-422	Science Advisory Team Meetings
Phase	**WBS Element**		**Deliverable**
PD	Meetings of the Science Advisory Team and its sub-groups will provide feedback on individual science requirements and goals for each Key Science Driver and each Science Driver, and on observing scenarios and sequences, observing planning tools, and science support tools (feeds in to WBS sub-element 3.1.3 which will feed into WBS 6 and its sub-elements), as well as on science-related impacts of technical design decisions.		Minutes of meetings, PowerPoint presentations, KAONs as appropriate.
DD	Meetings of the Science Advisory Team and its sub-groups will provide feedback on individual science requirements and goals for each Key Science Driver and each Science Driver, and on observing scenarios and sequences, observing planning tools, and science support tools (feeds in to WBS sub-element 3.1.3 which will feed into WBS 6 and its sub-elements), as well as on science-related impacts of technical design decisions.		Minutes of meetings, PowerPoint presentations, KAONs as appropriate.
FSD	Meetings of the Science Advisory Team and its sub-groups will provide feedback on individual science requirements and goals for each Key Science Driver and each Science Driver, and on observing scenarios and sequences, observing planning tools, and science support tools (feeds in to WBS sub-element 3.1.3 which will feed into WBS 6 and its sub-elements), as well as on science-related impacts of technical design decisions.		Minutes of meetings, PowerPoint presentations, KAONs as appropriate.
DC	Meetings of the Science Advisory Team and its sub-groups will provide feedback on individual science requirements and goals for each Key Science Driver and each Science Driver, and on observing scenarios and sequences, observing planning tools, and science support tools (feeds in to WBS sub-element 3.1.3 which will feed into WBS 6 and its sub-elements), as well as on science-related impacts of technical design decisions.		Minutes of meetings, PowerPoint presentations, KAONs as appropriate.

WBS	Level	ID	Name
3.2	3	WBS-423	Requirements

Phase	WBS Element	Deliverable
PD	Revise and update requirements as design and performance budgets mature. Verify requirements traceability. Work closely with the design and systems engineering teams to keep requirements current. Cost of design team members developing new requirements or updating existing requirements is covered under systems engineering 3.1, 3.4, 3.5 or WBS 4,5,6	1) Finalize requirements management standards and procedures for preliminary design, detailed design, full scale development, delivery and commissioning phases of NGAO product 2) Updates of requirements in database 3) Traceability matrices 4) Compliance matrices 5) Preliminary design requirement document 6) Operations concept document 7) IT maintenance 8) Software Standards Document (Coding standards to be followed by NGAO team developers (may or may not apply to subcontracts)) 9) Component Standards Document (Design / operations choices we will make for commonality across subsystems (e.g. recommended motors, stages, power supplies, etc.)
DD	Revise and update requirements as design and performance budgets mature. Produce various reports for traceability, compliance etc.. Work closely with the design and systems engineering teams to keep requirements updated. Document final system specifications. Cost of design team members developing new requirements or updating existing requirements is covered under Systems engineering 3.1, 3.4, 3.5 or WBS 4,5,6	1) Updates of requirements in database 2) Traceability matrices 3) Compliance matrices 4) Final specifications for all systems (requirements) 5) IT maintenance 6) Operations concept document
FSD	Produce various reports that document compliance with requirements during acceptance testing. Work closely with the design teams and contractors to document subsystem compliance. The requirements maintenance task is limited to making sure that the results of these compliance matrix tasks are reflected in the requirements database and to produce summary reports. Cost of design team members performing or supporting subsystems acceptance testing is covered under each I&T WBS is covered under WBS 4.6,5.6	1) Document compliance during acceptance testing of subsystems at factory and when delivered to Keck Observatory (or other integration laboratory) 2) Subsystem compliance matrices 3) IT maintenance of database
DC	Produce various reports that document compliance with requirements during acceptance testing. Work closely with the design teams and contractors to document system compliance. The requirements maintenance task is limited to making sure that the results of these compliance matrix tasks are reflected in the requirements database and to produce summary reports. Cost of design team members performing or supporting systems acceptance testing is covered under each I&T WBS is covered under WBS 8.4, 8.5, 8.6, 8.7, 8.8	1) Document compliance during acceptance testing of full NGAO system (AO, laser and integrated system) 2) IT maintenance of database

WBS	Level	ID	Name
3.3	3	WBS-424	Systems Engineering Analysis
Phase	**WBS Element**		**Deliverable**
PD			
DD			
FSD			
DC			

WBS	Level	ID	Name
3.3.1	4	WBS-425	Performance Budgets
Phase	**WBS Element**		**Deliverable**
PD	This element includes the effort to develop and maintain science path performance budgets including wavefront error, ensquared energy, background/transmission, high-contrast, photometric accuracy, and astrometric precision budgets. It also includes development and maintenance of wavefront error and ensquared energy budgets for the sharpening of NGS TT and TTFA guide stars and the Truth WFS guide stars, as refinements to the science wavefront error budget. It includes effort to maintain up-to-date performance predications of Key Science cases for use by the science advisory team operating under WBS 3.1, as well as technical supporting materials for the the requirements effort in WBS 3.2 and the technical risk assessment & mitigation effort in WBS 3.10. This element does not include development of operational efficiency budgets, which are included in WBS 6 "Operational Tools". This effort also includes development of a performance prediction software module to be delivered as a callable routine for the Science Operations WBS 6. During PD, the requirements for this module will be defined and the module architecture developed, but for now we assume the routine will return estimates for Strehl ratio and/or Ensquared Energy, based on a number of arguments that define the observing configuration, atmospheric conditions, and other parameters.	Thermal background analysis software w/ documentation Wavefront Error Budget Tool w/ documentation (includes WFE, EE, NGS TT and TTFA Sharpening Budgets) Photometric Accuracy Budget Tool w/ documentation [3/11/08 THIS ITEM HAS BEEN OMITTED from this WBS Scope] Astrometric Precision Budget Tool w/ documentaiton Technical Report describing flowdown of key functional requirements to their respective error budgets (alternatively, could be documented in Contour) Two iterations of the Key Science Case wavefront / EE performance budget summary (includes new Ensquared Energy performance budgets for "Galaxy Assembly and Star Formation History", "General Relativity Effect in the Galactic Center", "Nearby Active Galactic Nuclei", "QSO Host Galaxies" science cases.)
DD	This element includes the effort to develop and maintain science path performance budgets including wavefront error, ensquared energy, background/transmission, high-contrast, photometric accuracy, and astrometric precision budgets. It also includes development and maintenance of wavefront error and ensquared energy budgets for the sharpening of NGS TT and TTFA guide stars and the Truth WFS guide stars, as refinements to the science wavefront error budget. It includes effort to maintain up-to-date performance predications of Key Science cases for use by the science advisory team operating under WBS 3.1, as well as technical supporting materials for the the requirements effort in WBS 3.2 and the technical risk assessment & mitigation effort in WBS 3.10. This element does not include development of operational efficiency budgets, which are included in WBS 6 "Operational Tools". This effort also includes development of a performance prediction software module to be delivered as a callable routine for the Science Operations WBS 6. During DD the tool will be written and tested against the detailed WFE budget spreadsheet developed by Dekany.	New versions of: Thermal background analysis software w/ documentation Wavefront Error Budget Tool w/ documentation (includes WFE, EE, NGS TT and TTFA Sharpening Budgets) Photometric Accuracy Budget Tool w/ documentation Astrometric Precision Budget Tool w/ documentaiton Documentation for revisions to the Functional Requirements Flowdown Two iterations of the Key Science Case wavefront / EE performance budget summary Performance prediction tool requirements document and architecture document. Initial version of callable C-routine for performance prediction, along with test code to allow verification of the routine.
FSD	This element includes the effort to develop and maintain science path performance budgets including wavefront error, ensquared energy, background/transmission, high-contrast, photometric accuracy, and astrometric precision budgets. It also includes development and maintenance of wavefront error and ensquared energy budgets for the sharpening of NGS TT and TTFA guide stars and the Truth WFS guide stars, as refinements to the science wavefront error budget. It includes effort to maintain up-to-date performance predications of Key Science cases for use by the science advisory team operating under WBS 3.1, as well as technical supporting materials for the the requirements effort in WBS 3.2 and the technical risk assessment & mitigation effort in WBS 3.10. This element does not include development of operational efficiency budgets, which are included in WBS 6 "Operational Tools".	New versions of: Thermal background analysis software w/ documentation Wavefront Error Budget Tool w/ documentation (includes WFE, EE, NGS TT and TTFA Sharpening Budgets) Photometric Accuracy Budget Tool w/ documentation Astrometric Precision Budget Tool w/ documentaiton Documentation for revisions to the Functional Requirements Flowdown Two iterations of the Key Science Case wavefront / EE performance budget summary

DC	This element includes the effort to update science path performance budgets including wavefront error, ensquared energy, background/transmission, high-contrast, photometric accuracy, and astrometric precision budgets, but only to the extent that new phenomena are identified as important to understanding on-sky performance. Most performance budget effort in this phase is shifted to WBS 8.7 Performance Characterization.	Updates to one or more performance budget tools, as needed for WBS 8.7. One or more technical documents describing the physics modeled in the budget update(s).

WBS	Level	ID	Name
3.3.2	4	WBS-426	Modeling & Analysis
Phase	**WBS Element**		**Deliverable**
PD	This element includes the effort to conduct analytical and computational studies in support of WBS 3.3 "System Architecture" and potentially other WBS elements, particularly where the implications of design decisions cannot be adequated addressed by the tools developed under WBS 3.5 "Error and Performance Budget Maintenance". It includes development and exercise of covariance codes, detailed wave optics Monte Carlo simulations, with the following specific goals: 1) Develop a high fidelity tip-tilt performance model, to understand details of expected PSF 2) Understand performance with only one or two TT guide star(s) 3) Understand the role of minor solar system bodies as TT guide objects 4) Provide best estimate PSF's to the science team for further refinement of the key science drivers and performance budgets 5) Simulated science data to help the science team address specific science-case-generated questions 6) Trade study comparing the cost/benefit of alternative approaches to laser distribution for tip/tilt sharpening (e.g. Point and Shoot vs. Uniformly Distributed Asterism). This effort also includes continuous and discrete time controls system modelling of both the high-order and tip/tilt system plant function and disturbance rejection. It does not include development of wavefront reconstructors for use in the real-time-control system, which is included under WBS 4.5. The explicit flowdown of science requirements to functional requirements is part of WBS 3.5 Performance Budgets. Background and transmission budgets are also in WBS 3.5, but not development of exposure time calculators (assumed to be in WBS 3.1)		Technical Report on performance vs. TT star brightness, configuration, number, and source extent and contrast (e.g. AGN) Technical Report on specific performance using know LOWFS stars at the Galactice Center One updated release of polychromatic and field-dependent PSF's for use by the Science Advisory Team Technical Report on alternative approaches to tip/tilt sharpening (e.g. 'Point-n-Shoot)
DD	This element includes the effort to conduct analytical and computational studies in support of WBS 3.1 "Science Case", WBS 3.3 "System Architecture", and potentially other WBS elements, particularly where the implications of design decisions cannot be adequated addressed by the tools developed under WBS 3.5 "Error and Performance Budget Maintenance". It includes development and exercise of covariance codes, detailed wave optics Monte Carlo simulations. It also includes continuous and discrete time controls system modelling of both the high-order and tip/tilt system plant function and disturbance rejection. It does not include development of wavefront reconstructors for use in the real-time-control system, which is included under WBS 4.5.		Two unspecified technical reports requested by the Science Advisory Team Two updated releases of either the polychromatic, or other, PSF library Techincal Report and library of PSF's as a function of sky coverage for dIFU requirements refinement
FSD	This element includes the effort to conduct analytical and computational studies in support of WBS 3.1 "Science Case", WBS 3.3 "System Architecture", and potentially other WBS elements, particularly where the implications of design decisions cannot be adequated addressed by the tools developed under WBS 3.5 "Error and Performance Budget Maintenance". It includes development and exercise of covariance codes, detailed wave optics Monte Carlo simulations. It also includes continuous and discrete time controls system modelling of both the high-order and tip/tilt system plant function and disturbance rejection. It does not include development of wavefront reconstructors for use in the real-time-control system, which is included under WBS 4.5.		Two unspecified technical reports requested by the Science Advisory Team One updated release of either the polychromatic, or other, PSF library

DC	This element includes the effort to conduct analytical and computational studies in support of WBS 3.1 "Science Case", WBS 3.3 "System Architecture", and potentially other WBS elements, particularly where the implications of design decisions cannot be adequated addressed by the tools developed under WBS 3.5 "Error and Performance Budget Maintenance". It includes development and exercise of covariance codes, detailed wave optics Monte Carlo simulations. It also includes continuous and discrete time controls system modelling of both the high-order and tip/tilt system plant function and disturbance rejection. It does not include development of wavefront reconstructors for use in the real-time-control system, which is included under WBS 4.5.	Two unspecified technical reports requested by the Science Advisory Team Two updated releases of either the polychromatic, or other, PSF library

WBS	Level	ID	Name
3.3.3	4	WBS-427	PSF Calibration
Phase	**WBS Element**		**Deliverable**
PD	This work element has been postponed to the DD phase (RGD 3/17/08)		None in this phase.
DD	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.		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).
FSD	This element includes the effort to transfer the prototype software algorithms to the WBS 6.3 implementers. No new development of algorithms not already in hand at the end of the DD phase is assumed. This effort is only advisory.		Algorithm documentation for on- and off-axis PSF estimation algorithms
DC	There is no effort in this work element in the DC phase. The efficacy of the PSF calibration implementation will be evaluated in the WBS 8.8 Science Verification element.		None.

WBS	Level	ID	Name
3.4	3	WBS-428	System Architecture
Phase	**WBS Element**		**Deliverable**
PD			
DD			
FSD			
DC			

WBS	Level	ID	Name
3.4.1	4	WBS-429	System Hardware Architecture
Phase	**WBS Element**		**Deliverable**
PD	This element includes effort to refine and maintain the overall system hardware architecture, including several particular trade studies identified as potentially reducing NGAO total project cost. This effort also includes the effort of the NGAO Systems Engineer for understanding the impact of changes proposed via the WBS 3.8 Change Control Process. This element does not include rebalancing of performance requirements in light of new information, which is done in WBS 3.5 with updates to the requirements database through WBS 3.2).		Technical assessments of proposed system change orders. Contingency trade study to look at Degraded Laser Power options Trade study to evaluate potential cost savings via hybrid Rayleigh / sodium LGS systems Background analysis leading to Change Requests for re-allocation of functional requirements flowdown among subsysems
DD	This element includes effort to refine and maintain the overall system hardware architecture. This effort includes the effort of the NGAO Systems Engineer for understanding the impact of changes proposed via the WBS 3.8 Change Control Process.		One detailed functional allocation trade study (to be defined later)
FSD	This element includes effort to refine and maintain the overall system hardware architecture. This effort includes the effort of the NGAO Systems Engineer for understanding the impact of changes proposed via the WBS 3.8 Change Control Process.		One detailed functional allocation trade study (to be defined)
DC	This element includes effort to refine and maintain the overall system hardware architecture. This effort includes the effort of the NGAO Systems Engineer for understanding the impact of changes proposed via the WBS 3.8 Change Control Process.		One trade study responding to future science opportunity (for example in support of an instrument proposal that might have internal AO functionality (e.g. MOAO))

WBS	Level	ID	Name
3.4.2	4	WBS-430	Motion Control / Electronics Architecture
Phase	**WBS Element**		**Deliverable**
PD	This element includes effort to evaluate alternative architecture options and adopt an overall motion control / electronics architecture. This effort also includes labor for the Systems Engineer to evaluate overall implications of the motion control / electronics architecture, including iterations with the operations WBS 6 and the science case WBS 3.1		Motion control / Electronics architecture context diagram Motion control / Electonnics architecture preliminary design report
DD	This element includes effort to refine and maintain the overall motion control / electronics architecture. This effort also includes labor for the Systems Engineer to evaluate overall implications of the motion control / electronics architecture, including iterations with the operations WBS 6 and the science case WBS 3.1		Detailed NGAO electronics functional flow diagram Detailed cabling diagram Updated motion control / electronics architecture document
FSD	This element includes effort to refine and maintain the overall motion control / electronics architecture. This effort also includes labor for the Systems Engineer to evaluate overall implications of the motion control / electronics architecture, including iterations with the operations WBS 6 and the science case WBS 3.1		Updated MC/Electronics architecture document
DC	This element includes effort to refine and maintain the overall motion control / electronics architecture. This effort also includes labor for the Systems Engineer to evaluate overall implications of the motion control / electronics architecture, including iterations with the operations WBS 6 and the science case WBS 3.1		None.

WBS	Level	ID	Name
3.4.3	4	WBS-431	System Software Architecture
Phase	**WBS Element**		**Deliverable**
PD	This element includes effort to define the overall system software architecture. This effort includes the effort of the NGAO Systems Engineer for understanding the impact of changes proposed via the WBS 3.8 Change Control Process.		NGAO Software Architecture Document, contain descriptions of all software layers (e.g. component controller, subsystem sequencer, multisystem sequencer, user interfaces, etc.) This document should also contain object model for the system, capturing the static structure of the system, including relationships between objects along with their attributes and characteristic operations.
DD	This element includes effort to maintain the overall system software architecture. This effort includes the effort of the NGAO Systems Engineer for understanding the impact of changes proposed via the WBS 3.8 Change Control Process.		Updated revision of the Software Architecture Document.
FSD	This element includes effort to maintain the overall system software architecture. This effort includes the effort of the NGAO Systems Engineer for understanding the impact of changes proposed via the WBS 3.8 Change Control Process.		Updated revision of the Software Architecture Document.
DC	This element includes effort to maintain the overall system software architecture. This effort includes the effort of the NGAO Systems Engineer for understanding the impact of changes proposed via the WBS 3.8 Change Control Process.		Updated revision of the Software Architecture Document.

WBS	Level	ID	Name
3.4.4	4	WBS-432	Operations Sequences Architecture
Phase	**WBS Element**		**Deliverable**
PD	This element includes effort to define at a system level all of the configuration, procedures, and sequences that the operational system will need. These are implemented under WBS 6 and supported under WBS 4 and 5 as required. The set of common procedures to be defined will include, but not be limited to: Acquire LGS into WFS Acquire NGS into WFS (for various WFS's) Obtain WFS Skies Science Object Dither Register HOWFS's to DM's Measure Telescope Figure, and Image Sharpen This effort includes the effort of the NGAO Systems Engineer for understanding the impact of changes proposed via the WBS 3.8 Change Control Process.		NGAO Sequence Definition Document, including configuration definitions, state-space diagrams, functional flow diagrams (showing the timing of system configuration changes).
DD	This element includes effort to refine and maintain at a system level all of the configuration, procedures, and sequences that the operational system will need. These are implemented under WBS 6 and supported under WBS 4 and 5 as required. The set of common procedures to be defined will include, but not be limited to: Acquire LGS into WFS Acquire NGS into WFS (for various WFS's) Obtain WFS Skies Science Object Dither Register HOWFS's to DM's Measure Telescope Figure, and Image Sharpen This effort includes the effort of the NGAO Systems Engineer for understanding the impact of changes proposed via the WBS 3.8 Change Control Process.		Update to the NGAO Sequence Definition Document, including configuration definitions, state-space diagrams, functional flow diagrams (showing the timing of system configuration changes).
FSD	This element includes effort to maintain at a system level all of the configuration, procedures, and sequences that the operational system will need. During FSD, nearly all of this effort has shifted into implementation in WBS 6. This element retains some small labor for the Systems Engineer to remain in contact with the implementation team.		None.
DC	This element includes effort to maintain at a system level all of the configuration, procedures, and sequences that the operational system will need. During FSD, nearly all of this effort has shifted into implementation in WBS 6. This element retains some small labor for the Systems Engineer to remain in contact with the implementation team.		None.

WBS	Level	ID	Name
3.5	3	WBS-433	External Interface Control
Phase	**WBS Element**		**Deliverable**
PD	Includes interfaces between each of the NGAO Systems (AO, laser & science operations) and the telescope and Observatory, and between the NGAO Systems and the science instruments. A generic interface control document (ICD) will be made for science instruments. Instrument specific ICDs will also be generated for each science instrument (OSIRIS, Interferometer, OHANA, NIR imager, visible imager & the deployable IFS).		Preliminary NGAO to Observatory Interface Control Document (ICD). Preliminary NGAO to Science Instrument ICD documents.
DD	Includes interfaces between each of the NGAO Systems (AO, laser & science operations) and the telescope and Observatory, and between the NGAO Systems and the science instruments. A generic interface control document (ICD) will be made for science instruments. Instrument specific ICDs will also be generated for each science instrument (OSIRIS, Interferometer, OHANA, NIR imager, visible imager & the deployable IFS).		Detailed Design (DD) level NGAO to Observatory Interface Control Document (ICD). DD-level NGAO to Science Instrument ICD documents.
FSD	Includes interfaces between each of the NGAO Systems (AO, laser & science operations) and the telescope and Observatory, and between the NGAO Systems and the science instruments. A generic interface control document (ICD) will be made for science instruments. Instrument specific ICDs will also be generated for each science instrument (OSIRIS, Interferometer, OHANA, NIR imager, visible imager & the deployable IFS).		Revisions to the ICDs as needed.
DC	Includes interfaces between each of the NGAO Systems (AO, laser & science operations) and the telescope and Observatory, and between the NGAO Systems and the science instruments. A generic interface control document (ICD) will be made for science instruments. Instrument specific ICDs will also be generated for each science instrument (OSIRIS, Interferometer, OHANA, NIR imager, visible imager & the deployable IFS).		Revisions to the ICDs as needed.

WBS	Level	ID	Name
3.6	3	WBS-434	Internal Interface Control
Phase	**WBS Element**		**Deliverable**
PD	This element includes the effort to establish and maintain through documentation the design of the optical, mechanical, electronic, thermal, and hardware-driver-level software interfaces between internal NGAO subsystems. It specifically also includes definition of the interfaces between the Multi-System Command Sequencer (WBS 6.1) and AO Sequencer (WBS 4.4) and all interfaces to the Data Server (WBS 6.4). The scope of this task is defined by the content of the project N-squared diagram, which identifies the key internal subsystem interfaces. This element does not include the software design for the intermediate and high-level software layers, which is conducted in WBS 6 "Operations Tools". It does not include interface control between NGAO and its science instruments, the Keck telescope, or handing and support equipment, which is included in WBS 3.6 "External Interface Control".		System N-squared Diagram Estimate of approximately 50 distinct internal interface control documents (based on GPI and GS MCAO experience)
DD	This element includes the effort to refine and maintain through documentation the design of the optical, mechanical, electronic, thermal, and hardware-driver-level software interfaces between internal NGAO subsystems. It specifically also includes definition of the interfaces between the Multi-System Command Sequencer (WBS 6.1) and AO Sequencer (WBS 4.4) and all interfaces to the Data Server (WBS 6.4). The scope of this task is defined by the content of the project N-squared diagram, which identifies the key internal subsystem interfaces. This element does not include the software design for the intermediate and high-level software layers, which is conducted in WBS 6 "Operations Tools". It does not include interface control between NGAO and its science instruments, the Keck telescope, or handing and support equipment, which is included in WBS 3.6 "External Interface Control".		Two minor updates to the System N-squared Diagram Updates to all internal interface control documents
FSD	This element includes the effort to maintain through documentation the design of the optical, mechanical, electronic, thermal, and hardware-driver-level software interfaces between internal NGAO subsystems. It specifically also includes definition of the interfaces between the Multi-System Command Sequencer (WBS 6.1) and AO Sequencer (WBS 4.4) and all interfaces to the Data Server (WBS 6.4). The scope of this task is defined by the content of the project N-squared diagram, which identifies the key internal subsystem interfaces. This element does not include the software design for the intermediate and high-level software layers, which is conducted in WBS 6 "Operations Tools". It does not include interface control between NGAO and its science instruments, the Keck telescope, or handing and support equipment, which is included in WBS 3.6 "External Interface Control".		Two minor updates to the System N-squared Diagram Updates to some internal interface control documents, as issues are identified during I&T

DC	This element includes the effort to maintain through documentation the design of the optical, mechanical, electronic, thermal, and hardware-driver-level software interfaces between internal NGAO subsystems. It specifically also includes maintenance of the interfaces between the Multi-System Command Sequencer (WBS 6.1) and AO Sequencer (WBS 4.4) and all interfaces to the Data Server (WBS 6.4). The scope of this task is defined by the content of the project N-squared diagram, which identifies the key internal subsystem interfaces. This element does not include the software design for the intermediate and high-level software layers, which is conducted in WBS 6 "Operations Tools". It does not include interface control between NGAO and its science instruments, the Keck telescope, or handing and support equipment, which is included in WBS 3.6 "External Interface Control".	Updates to some internal interface control documents, as issues are identified during I&T

WBS	Level	ID	Name
3.7	3	WBS-435	Configuration Management
Phase	**WBS Element**		**Deliverable**
PD	This element includes the effort to establish and maintain a formal Change Control Process, providing appropriate levels of review and authorization for change requests affecting System Architecture (WBS 3.3), performance budget flow-down allocations (WBS 3.5), system and subsystem performance requirements (WBS 3.2), and the External (WBS 3.6) and Internal (WBS 3.7) Interfaces. It provides a focal point for project staff seeking to make performance or scope changes. This element includes effort to define the "baseline" system configuration, to define classes of changes, to establish change process controls, and to develop and disseminate configuration control policies and procedures. This element also includes the establishment and maintenance of a system software version control archival repository, but does not include the integration and testing of new software builds, which is conducted as part of WBS 4.4, 4.5, and 6. This element supports only the long-term maintenance of ' official' software builds, which are checked into the software configuration control system at discrete times corresponding to new functional releases. This effort does not include the "understanding the impact of changes" on the system, which is described in WBS 3.3 System Architecture.		Initial Change Control Policy and Guidelines Document Change Communication System Initial Detailed Product Breakdown Structure Initial Software Version Control System [assumed to be provided by Keck Observatory w/o cost to NGAO project]
DD	"This element includes the effort to establish and maintain a formal Change Control Process, providing appropriate levels of review and authorization for change requests affecting System Architecture (WBS 3.3), performance budget flow-down allocations (WBS 3.5), system and subsystem performance requirements (WBS 3.2), and the External (WBS 3.6) and Internal (WBS 3.7) Interfaces. It provides a focal point for project staff seeking to make performance or scope changes. This element includes effort to define the ""baseline"" system configuration, to define classes of changes, to establish change process controls, and to develop and disseminate configuration control policies and procedures. This element also includes the establishment and maintenance of a system software version control archival repository, but does not include the integration and testing of new software builds, which is conducted as part of WBS 4.4, 4.5, and 6. This element supports only the long-term maintenance of ' official' software builds, which are checked into the software configuration control system at discrete times corresponding to new functional releases. This effort does not include the ""understanding the impact of changes"" on the system, which is described in WBS 3.3 System Architecture."		Processed Change Request Authorizations

FSD	"This element includes the effort to establish and maintain a formal Change Control Process, providing appropriate levels of review and authorization for change requests affecting System Architecture (WBS 3.3), performance budget flow-down allocations (WBS 3.5), system and subsystem performance requirements (WBS 3.2), and the External (WBS 3.6) and Internal (WBS 3.7) Interfaces. It provides a focal point for project staff seeking to make performance or scope changes. This element includes effort to define the ""baseline"" system configuration, to define classes of changes, to establish change process controls, and to develop and disseminate configuration control policies and procedures. This element also includes the establishment and maintenance of a system software version control archival repository, but does not include the integration and testing of new software builds, which is conducted as part of WBS 4.4, 4.5, and 6. This element supports only the long-term maintenance of ' official' software builds, which are checked into the software configuration control system at discrete times corresponding to new functional releases. This effort does not include the ""understanding the impact of changes"" on the system, which is described in WBS 3.3 System Architecture."	Processed Change Request Authorizations
DC	"This element includes the effort to establish and maintain a formal Change Control Process, providing appropriate levels of review and authorization for change requests affecting System Architecture (WBS 3.3), performance budget flow-down allocations (WBS 3.5), system and subsystem performance requirements (WBS 3.2), and the External (WBS 3.6) and Internal (WBS 3.7) Interfaces. It provides a focal point for project staff seeking to make performance or scope changes. This element includes effort to define the ""baseline"" system configuration, to define classes of changes, to establish change process controls, and to develop and disseminate configuration control policies and procedures. This element also includes the establishment and maintenance of a system software version control archival repository, but does not include the integration and testing of new software builds, which is conducted as part of WBS 4.4, 4.5, and 6. This element supports only the long-term maintenance of ' official' software builds, which are checked into the software configuration control system at discrete times corresponding to new functional releases. This effort does not include the ""understanding the impact of changes"" on the system, which is described in WBS 3.3 System Architecture."	Processed Change Request Authorizations

WBS	Level	ID	Name
3.8	3	WBS-436	Documentation Control
Phase	**WBS Element**		**Deliverable**
PD	This element includes the effort to establish and maintain an archival document repository for technical design documents, such as optical design files, mechanical solid models and drawings, electrical design drawings, software functional flow diagrams, timing diagrams, and state space diagrams. It includes archival control of trade study and technical reports, and maintains the official versions of all performance budgets. It includes storage of but not maintaining the content of, the Functional Requirements database (WBS 3.2), or the External (WBS 3.6) or Internal (3.7) Interface Controls. The Contour database is included in WBS 2.7. Basically, much of the document control is already costed elsewhere in the NGAO WBS.		A document control plan describing project document control protocols assumes use of Keck Document Control infrastructure for design mechanical, electrical, software, and optical design documents
DD	This element includes the effort to maintain an archival document repository for technical design documents, such as optical design files, mechanical solid models and drawings, electrical design drawings, software functional flow diagrams, timing diagrams, and state space diagrams. It includes archival control of trade study and technical reports, and maintains the official versions of all performance budgets. It includes storage of but not maintaining the content of, the Functional Requirements database (WBS 3.2), or the External (WBS 3.6) or Internal (3.7) Interface Controls. Contour databased is included under WBS 2.7. Basically, much of the document control is already costed elsewhere in the NGAO WBS.		Updated Contour database Updated Data file 'vault' or other system for design mechanical, electrical, software, and optical design documents
FSD	This element includes the effort to maintain an archival document repository for technical design documents, such as optical design files, mechanical solid models and drawings, electrical design drawings, software functional flow diagrams, timing diagrams, and state space diagrams. It includes archival control of trade study and technical reports, and maintains the official versions of all performance budgets. It includes storage of but not maintaining the content of, the Functional Requirements database (WBS 3.2), or the External (WBS 3.6) or Internal (3.7) Interface Controls. Contour maintenance is in WBS 2.7. Basically, much of the document control is already costed elsewhere in the NGAO WBS.		Updated Contour database Updated Data file 'vault' or similar system for design mechanical, electrical, software, and optical design documents
DC	This element includes the effort to maintain an archival document repository for technical design documents, such as optical design files, mechanical solid models and drawings, electrical design drawings, software functional flow diagrams, timing diagrams, and state space diagrams. It includes archival control of trade study and technical reports, and maintains the official versions of all performance budgets. It includes storage of but not maintaining the content of, the Functional Requirements database (WBS 3.2), or the External (WBS 3.6) or Internal (3.7) Interface Controls. Contour maintenance is in WBS 2.7. Basically, much of the document control is already costed elsewhere in the NGAO WBS.		Updated Contour database Updated Data file 'vault' or similar system for design mechanical, electrical, software, and optical design documents

WBS	Level	ID	Name
3.9	3	WBS-437	Technical Risk Assessment & Mitigation
Phase	**WBS Element**		**Deliverable**
PD	Effort and costs associated with assessing and mitigating technical risks during the PD phase.		Documentation of the technical risk assessment and the results of technical risk mitigation efforts. The risk reduction activities listed below need review.
DD	Effort and costs associated with assessing and mitigating technical risks during the DD phase.		Documentation of the technical risk assessment and the results of technical risk mitigation efforts.
FSD	Effort and costs associated with assessing and mitigating technical risks during the FSD phase.		Documentation of the technical risk assessment and the results of technical risk mitigation efforts.
DC	Effort and costs associated with assessing and mitigating technical risks during the DC phase.		None

WBS	Level	ID	Name
3.1	3	WBS-438	System Manual
Phase	**WBS Element**		**Deliverable**
PD	Production of a manual documenting the NGAO system design.		Preliminary Design Manual (update to System Design Manual).
DD	Production of a manual documenting the NGAO system design.		Detailed Design Manual (update to Preliminary Design Manual).
FSD	Production of a manual documenting the NGAO system design.		Updated Detailed Design Manual based on changes during the FSD phase.
DC	Production of a manual documenting the NGAO system design.		Updated Detailed Design Manual based on changes during the DC phase.

WBS	Level	ID	Name
4	2	WBS-439	AO System Development
Phase	**WBS Element**		**Deliverable**
PD			
DD			
FSD			
DC			

WBS	Level	ID	Name
4.1	3	WBS-440	AO Enclosure
Phase	**WBS Element**		**Deliverable**
PD	Design the enclosure system for the AO system and Instruments. The enclosure should meet requirements for maintaining internal temperature, controlling dust, and controlling air flow. The enclosure should account for internal heat loads from the AO system and instruments, allow for pass-through of electronics cables, allow for human access for servicing, and allow a window for telescope optical feed. The cooling system should be sized to provide reasonable cool-down times while meeting power constraints of the observatory infrastructure.		A preliminary design for the system enclosure. A set of vendors for all key parts. A plan for completion of the final design in the design-development phase. A preliminary testing plan and compliance matrix.
DD	Complete the final mechanical design of the AO and instrument enclosure system.		Final design drawings ready to send to fabrication. A complete list of vendors and parts to be purchased. A final testing plan and compliance matrix
FSD	Fabricate and / or receive parts and assemble the AO and instrument enclosure system.		Completed enclosure, assembled on the Nasmyth platform
DC	Commission the AO and instrument enclosure system on the Nasmyth platform. Test to meet compliance matrix as driven by system requirements, such as temperature stability, air flow, dust control, etc.		Completed and commissioned enclosure system. Documentation of system tests.

WBS	Level	ID	Name
4.2	3	WBS-441	Optomechanical
Phase	**WBS Element**		**Deliverable**
PD			
DD			
FSD			
DC			

WBS	Level	ID	Name
4.2.1	4	WBS-442	AO Support Structure
Phase	**WBS Element**		**Deliverable**
PD	Given functional requirements and the conceptual design, complete a preliminary but detailed design of the AO support structure. Complete a tolerance analysis including effects of manufacturering variability, flexure, and temperature variation. Write a preliminary testing, assembly, and alignment plan and a preliminary compliance matrix		Preliminary optical prescription for the AO support structure Report on tolerance analysis. Components list including selected vendors. Preliminary testing and assembly plan. Preliminary compliance matrix.
DD	Complete a detailed design for the AO support structure. Complete a comprehensive assembly and testing plan. Comple a compliance martix. Note: some substantial portions of the AO support structure can only be assembled at the the telescope, so a plan must be generated that allows AO system integration in the laboratory and provides for the infrastructure necessary at the telescope for final mounting		Design drawings at a level sufficient for fabricatiobn. Identifacation of all components along with vendor sources. Acceptance plan for components. Final assembly, subsystem testing, and alignment plan. Final compliance matrix for subsystem acceptance. Plans for assembly of a support structure for laboratory system testing, and for assembly of a structure at the telescope.
FSD	Fabricate and / or receive parts and assemble the AO support structure. Mount and align the subsystem. Complete the subsystem acceptance test plan and verify concurrance with the compliance matrix.		Completed support structure for laboratory integration and test. Report on subsystem tests.
DC			

WBS	Level	ID	Name
4.2.2	4	WBS-443	Rotator
Phase	**WBS Element**		**Deliverable**
PD	Given functional design requirements, design the opto-mechanical system that will function as a front-end K-mirror image derotator. Write a preliminary testing plan and compliance matrix.		Preliminary design drawings that specify the construction of the derotator . Detailed specifications of the optics in the derotator (exact dimensions) and the method of mounting them. Preliminary testing plan and compliance matrix.
DD	Complete the final design of the image derotator system. Complete the final testing plan and compliance matrix.		Final design drawings ready for fabrication. Specification of components and vendor sources. Final testing plan and compliance matrix.
FSD	Fabricate the image derotator system. Assemble on optical bench and run through a series of tests according to the test plan.		Completed derotator, assembled and mounted to the AO optical bench. Report on completed subsystem test.
DC	Deliver the image derotator system to the AO optical bench at start of integration and test phase.		Delived system with documentation and report of testing results.

WBS	Level	ID	Name
4.2.3	4	WBS-444	Optical Relays
Phase	**WBS Element**		**Deliverable**
PD	Given functional requirements and the conceptual design, complete a preliminary but detailed design of the AO optical relays. Complete a tolerance analysis including effects of manufacturer's optics variability, flexure, and temperature variation. Write a preliminary testing, assembly, and alignment plan and a preliminary compliance matrix.		Preliminary optical prescription for the AO relays. Report on tolerance analysis. Components list including selected vendors. Preliminary testing , assembly, and alignment plan. Preliminary compliance matrix.
DD	Complete a detailed design for the AO optical relays. Complete a comprehensive assembly, testing, and alignment plan. Comple a compliance martix. Complete a preliminary delivery and commissioning plan.		Optical relay prescriptions to the detailed level. Identifacation of all components for optics and mounts along with vendor sources. Complete set of mechanical drawings. Acceptance plan for components. Final assembly, subsystem testing, and alignment plan. Final compliance matrix for subsystem acceptance. Preliminary delivery and commissioning plan.
FSD	Fabricate and / or receive parts and assemble the AO optical relays. Mount and align the subsystem. Complete the subsystem acceptance test plan and verify concurrance with the compliance matrix. Complete the delivery and commissioning plan.		Completed working subsystem. Acceptance test report. Completed compliance matrix. Final delivery and commissioning plan.
DC			

WBS	Level	ID	Name
4.2.4	4	WBS-445	Optical Switchyard
Phase	**WBS Element**		**Deliverable**
PD	Given functional requirements and the conceptual design, complete a preliminary design for the "optical switchyard, " which consists of the dicroics and other elements used for system configuration into various science observing modes. Write the preliminary acceptance and test plans.		Preliminary design for switchable elements system including dichroic changers, flip mirrors, etc. Specifications for the dichroics sufficient to get preliminary vendor quotes. Preliminary testing/acceptance test plan, and a compliance matrix.
DD	Complete a final design for the optical switchyard. Complete the final acceptance and test plans.		Final drawings of all optical and mechanical elements, including motion-controlled mounts. Components list and vendors. Final acceptance and test plan.
FSD	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.		Completed working subsystem. Report on test results. Final version of on -telescope commissioning plan.
DC			

WBS	Level	ID	Name
4.2.5	4	WBS-446	LGS Wavefront Sensor Assembly
Phase	**WBS Element**		**Deliverable**
PD	Perform preliminary design for the laser guide star wavefront sensor assembly. The laser guide star WFS assembly consists of an eight probe arm Object Selection Mechanism (OSM) and nine identical LGS WFS units. Inputs: 1. Functional requirements document 2. System design manual (in particular uplink TTM information and asterism generator design). 3. Relevant KAONs. 4. NGAO error budget spreadsheet. 5. Dithering KAON What this WBS will not cover: This element does not include centroiding algorithm development nor wavefront reconstruction from the LGS WFS (WBS 4.5). It does not include programming of spot-tracking-on-chip readout modes of the CCD camera and controller. The final acquisition Operations Tools developed under WBS 6.0.		1. Review concept design for LGS WFS assembly (includes OSM) 2. Develop to preliminary design level the opto-mechanical design for the LGS wavefront sensor unit. 3. Identify the issues with uplink TTM, asterism generation and OSM concepts to ensure it conforms to the dithering requirements. This is important when the LGSs have to move with the source 4. Develop to preliminary design level the opto-mechanical design for the LGS OSM. (overlaps with TT(FA) OSMs; hence costed there) 5. Package and model the assembly. 6. Develop background model and work out stray LGS light problems. 7. Identify the motion control needs and specify solutions. 8. Identify design risks and mitigation of the identified risks. 9. Write an alignment plan for each of the units in the assembly [3/11/08 - RGD deferred to DD phase] 10. Write an alignment plan for the LGS OSM. (overlaps with LOWFS; hence costed there) [3/11/08 - RGD deferred to DD phase] 11. Develop a preliminary integration plan for the assembly. 12. Develop a test plan based on the design to test performance.[3/11/08 - RGD deferred to DD phase] 13. Build a compliance matrix to test for conformance to requirements.[3/20/08 - RGD deferred to DD phase] 14. Document the above.
DD	Perform detailed design for the laser guide star wavefront sensor assembly. The laser guide star WFS assembly consists of an eight probe arm Object Selection Mechanism (OSM) and nine identical LGS WFS units. Inputs: 1. Preliminary design 2. OSM prototyping results 3 . Functional requirements document 4. Relevant KAONs. 5. Understand dither mechanisms 6. NGAO error budget spreadsheet. What this WBS will not cover: This element does not include centroiding algorithm development nor wavefront reconstruction from the LGS WFS (WBS 4.5). It does not include programming of spot-tracking-on-chip readout modes of the CCD camera and controller. The final acquisition Operations Tools developed under WBS 6.0.		1. Detailed design of the individual LGS WFS wavefront sensor units 2. Detailed design of the LGS OSM 3. Perform tolerance analysis for each of the units and the entire assembly. 4. Package and model the assembly.(incl. FEA analysis) 5. Specify remaining needs and get quotes for all motion control units. 6. Specify and get quotes for optics, mounts, stages and detectors. 7. Get shop drawings out for all components with bill of materials. 8. Specify interfaces (optical, mechanical and electronics) 9. Define cabling plan. 10. Reconcile the performance of detailed design with error budget. 11. Write a detailed alignment plan for the assembly 12. Develop a detailed I&T plan for the assembly. 13. Build a complete compliance matrix to test for conformance to requirements. 14. Document the above.
FSD	Perform full-scale development of the laser guide star wavefront sensor assembly. The laser guide star WFS assembly consists of an eight probe arm Object Selection Mechanism (OSM) and nine identical LGS WFS units. Inputs: 1. Detailed design 2. OSM prototyping results 3. Functional requirements document 4. Relevant KAONs. 5. NGAO error budget spreadsheet. What this WBS will not cover: This element does not include centroiding algorithm development nor wavefront reconstruction from the LGS WFS (WBS 4.5). It does not include programming of spot-tracking-on-chip readout modes of the CCD camera and controller. The final acquisition Operations Tools developed under WBS 6.0.		TASKS: 1. Send out Purchase Orders for all components. 2. Send out shop drawings for manufacture 3. Develop software needed to test the LGS WFSs (check wavefronts from each WFS, check centroids, check basic motion control, charecterize performance of individual unit) 4. Understand lead time and co-ordinate scheduling. 5. Build necessary fixtures to align sensors (sources alignment jigs etc.) 6. Build LGS OSM. 7. Build LGS WFS channels 8. Build structural unit and test for flexure 9. Test each channel individually 10. Integrate the WFSs channels into assembly. 11. Test the entire assembly as an integral unit (including OSM) 12. Check and resolve interface and cable management issues. 13. Test the whole unit at operating conditions to facilitate I&T for lab and telescope tests. 14. Check for conformance to requirements and fill out compliance matrix. 15. Document the whole process 16. Deliver user and maintenance manuals. 17. Refine alignment plan as per built unit. 18. Hawaii lab (I & T) Ð Pack (after dismantling, if need be) to ship to HI 19 . Ship to HI 20. Unpack and assemble in HI 21. Perform system check out 22. Integrate in lab in HI 23. Calibrate using NGAO telescope simulator and calibration unit 24. Run in closed loop and evaluate performance. 25. Update compliance matrix.
DC	Integrate and test the LGS WFS on the telescope with at least one science instrument - This is work is part of WBS 8.1 and 8.2		Please see WBS 8.1 and 8.2

WBS	Level	ID	Name
4.2.6	4	WBS-447	NGS WFS / TWFS Assembly
Phase	**WBS Element**		**Deliverable**
PD	Perform preliminary design for the narrow field natural guide star wavefront sensor assembly. The natural guide star WFS assembly consists of the NGS HOWFS and the NGS narrow field TWFS. Inputs: 1. Functional requirements document 2. System design manual 3. Relevant KAONs. 4. NGAO error budget spreadsheet. 5. Dithering KAON What this WBS will not cover: This element does not include centroiding algorithm development nor wavefront reconstruction from the LGS WFS (WBS 4.5). The final acquisition Operations Tools developed under WBS 6.0. The field steering mirrors are costed as part of the opto-mechanical relay for this phase of the project.	1. Review concept design for NGS WFS and TWFS; jointly called NGS WFS assembly. 2. Develop to preliminary design level the opto-mechanical design for the NGS wavefront sensor assembly. 3. Check compliance of design with the design of the field steering mirror assembly. 4. Package and model the NGS WFS assembly. 5. Develop a preliminary design for a dynamic aperture field spot Ð overlaps with all WFSs work is costed here. [Deferred 3/11/08] 6. Identify the motion control needs and specify solutions. 7. Identify design risks and mitigation of the identified risks. 8. Write an alignment plan.[3/11/08 - RGD deferred to DD phase] 9. Check compliance with alignment plan for the NGS OSM (written as part of opto-mechanical relay sub-system design effort). 10. Develop a preliminary integration plan for the assembly. [3/11/08 - 112 hrs AssocSci deferred to DD phase] 11. Develop a test plan based on the design to test performance.[3/11/08 - 112 hrs AssocSci deferred to DD phase] 12. Build a compliance matrix to test for conformance to requirements.[3/24/08 - RGD deferred to DD phase] 13. Document the above.
DD	"Perform detailed design for the narrow field natural guide star wavefront sensor assembly. The natural guide star WFS assembly consists of the NGS HOWFS and the NGS narrow field TWFS. Inputs: 1. Preliminary design 2. Functional requirements document 3. Relevant KAONs. 4. NGAO error budget spreadsheet. This WBS will not cover: This element does not include centroiding algorithm development nor wavefront reconstruction from the LGS WFS (WBS 4.5). The final acquisition Operations Tools developed under WBS 6.0. The field steering mirrors are appraised as part of the opto-mechanical relay for this phase of the project.	"1. Detailed design of the NGS WFS wavefront sensor assembly (includes TWFS) 2. Check compliance with the detailed design of the NGS/TWFS field-steering mirror mechanism. 3. Perform detailed tolerance analysis for each of the units and the entire assembly. 4. Package and model the assembly (incl. FEA analysis) 5. Specify and get quotes for optics, mounts, stages and detectors 6. Get shop drawings out for all components with bill of materials. 7. Specify interfaces (optical, mechanical and electronics) 8. Define cabling plan. 9. Reconcile the performance of detailed design with error budget. 10. Write a detailed alignment plan for the assembly 11. Develop a detailed I&T plan for the assembly. 12. Build a complete compliance matrix to test for conformance to requirements. 13. Document the above.
FSD	Perform full-scale development of the narrow field natural guide star wavefront sensor assembly. The natural guide star WFS assembly consists of the NGS HOWFS and the NGS narrow field TWFS. Inputs: 1. Detailed design 2. Functional requirements document 3. Relevant KAONs. 4. NGAO error budget spreadsheet. This WBS will not cover: This element does not include centroiding algorithm development nor wavefront reconstruction from the LGS WFS (WBS 4.5). The final acquisition Operations Tools developed under WBS 6.0. The field steering mirrors are appraised as part of the opto-mechanical relay for this phase of the project	1. Send out Purchase Orders for all components. 2. Send out shop drawings for manufacture 3. Develop software needed to test the WFS. 4. Understand lead time and co-ordinate scheduling. 5. Build necessary fixtures to align sensors (sources alignment jigs etc.) 6. Integrate with field steering mechanism for test 7. Build NGS WFS and TWFS separately 8. Build structural unit and test for flexure 9. Check and resolve interface and cable management issues. 10. Check for conformance to requirements and fill out compliance matrix. 11. Document the whole process 12. Deliver user and maintenance manuals. 13. Refine alignment plan as per built unit. 14. Hawaii lab (I & T) Ð Pack (after dismantling, if need be) to ship to HI 15. Ship to HI 16. Unpack and assemble in HI 17. Perform system check out 18. Integrate in lab in HI 19. Calibrate using NGAO telescope simulator and calibration unit 20. Run in closed loop and evaluate performance. 21. Update compliance matrix
DC	Integrate and test the NGS WFS on the telescope with at least one science instrument - This is work is part of WBS 8.1 and 8.2	Please see WBS 8.1 and 8.2

WBS	Level	ID	Name
4.2.7	4	WBS-448	Low Order Wavefront Sensor Assembly

Phase	WBS Element	Deliverable
PD	Perform preliminary design for the infrared low-order (tip/tilt and tip/tilt/focus/astigmatism) natural guide star wavefront sensor assembly. The LOWFS assembly consists of a four probe arm Object Selection Mechanism (OSM), the 2 tip-tilt wavefront sensor units, PSF monitor unit and 1 TTFA-TWFS wavefront sensor unit. Inputs: 1. Functional requirements document 2. System design manual. 3. Relevant KAONs. 4. NGAO error budget spreadsheet. 5. ADC location and prescription This element does not include centroiding algorithm development nor wavefront reconstruction from the TTFA (WBS 4.5.1). It does not include programming of an associated component controller (WBS 4.4.4) or motion control (WBS 4.4.3). The final acquisition Operations Tools will be developed under WBS 6.0.	1. Review concept design for LOWFS assembly. 2. Investigate optimum method of dithering based on requirements. 3. Develop to preliminary design level the opto-mechanical design for the tip-tilt and the TTFA-WF TWFS wavefront sensor units. [3/11/08 - RGD defer 160 hrs to DD; accept less detailed design] 4. Develop to preliminary design level the opto-mechanical design for the LOWFS OSM. [3/11/08 - RGD defer 60 hrs to DD; accept less detailed design] 5. Make sure that the design doesn't preclude the inclusion of a PSF monitor later 6. Package and model the assembly. 7. Develop thermal model and work emissivity details of the LOWFS assembly and feed into the overall emissivity budget 8. Identify the motion control needs and specify solutions. 9. Identify design risks and mitigation of the identified risks. 10. Write an alignment plan for each of the units in the assembly [3/11/08 - RGD - deferred to DD phase] 11. Write an alignment plan fort the LOWFS OSM.[3/11/08 - RGD - deferred to DD phase] 12. Develop a preliminary integration plan for the assembly. 13. Develop a test plan based on the design to test performance. 14. Build a compliance matrix to test for conformance to requirements.[3/20/08 - RGD - deferred to DD phase] 15 . Document the above.
DD	Perform detailed design for the infrared low-order (tip/tilt and tip/tilt/focus/astigmatism) natural guide star wavefront sensor assembly. The LOWFS assembly consists of a three probe arm Object Selection Mechanism (OSM), the 2 tip-tilt wavefront sensor units, PSF monitor unit and 1 TTFA-TWFS wavefront sensor unit. Inputs: 1. Preliminary design 2. OSM prototyping results 3. LOWFS noise and centroiding algorithm know-how. 4. Functional requirements document 5. Relevant KAONs. 6. NGAO error budget spreadsheet. This element does not include centroiding algorithm development nor wavefront reconstruction from the TTFA (WBS 4.5.1). It does not include programming of an associated component controller (WBS 4.4.4) or motion control (WBS 4.4.3). The final acquisition Operations Tools will be developed under WBS 6.0.	1. Detailed design of the TT wavefront sensor units 2. Detailed design of the TTFA-TWFS wavefront sensor unit 3. Ensure that the detailed design accomodates inclusion of a PSF monitor later. 4. Detailed design of the LOWFS OSM 5. Perform tolerance analysis for each of the units and the entire assembly. 6. Package and model the assembly. 7. Specify and get quotes for the motion control units. 8. Specify and get quotes for optics, Dewar flasks and detectors 9. Get shop drawings out for all components with bill of materials. 10. Specify detailed interfaces (optical, mechanical and electronics) 11. Develop cabling plan. 12. Model sensor performance based on detailed design; reconcile with error budget. 13. Write detailed alignment plan for the assembly 14. Develop a detailed I& T plan for the assembly. 15. Build a complete compliance matrix to test for conformance to requirements.[3/20/08 - RGD - reduced hours from 320 to 100] 16. Document the above.
FSD	Perform full scale development of the infrared low-order (tip/tilt and tip/tilt/focus/astigmatism) natural guide star wavefront sensor assembly. The LOWFS assembly consists of a three probe arm Object Selection Mechanism (OSM), the 2 tip-tilt wavefront sensor units, and 1 TTFA-TWFS wavefront sensor unit. This element includes shipping and lab testing of the unit in HI. Inputs: 1. Detailed design 2. OSM prototyping results 3. Functional requirements document 4. Relevant KAONs. 5. NGAO error budget spreadsheet. What this WBS will not cover: This element does not include centroiding algorithm development nor wavefront reconstruction from the TTFA (WBS 4.5). It does not include programming of Pixels Of Interest (POI) readout modes of the infrared camera controller nor noise evaluation and system characterization (WBS 4.5). The final acquisition Operations Tools developed under WBS 6.0.	Note, this task list will be turned into deliverables in a subsequent iteration: 1. Send out Purchase Orders for all components. 2. Send out shop drawings for manufacture 3. Develop software needed to test the WFS. 4. Understand lead time and co-ordinate scheduling. 5. Build necessary fixtures to align sensors (sources alignment jigs etc.) 6. Build OSM. 7. Build TT WFS channels 8. No task (PSF channel not being built as part of this task). 9. Build TTFA-WF TWFS WFS channel (w/ provision for the truth WFS channel). 10. Build structural unit 11. Test each channel individually 12. Integrate the WFSs and PSF camera channels into assembly. 13. Test the entire unit as an integral unit (including OSM) 14. Check and resolve interface and cable management issues. 15. Test the whole unit at operating conditions to facilitate I&T for lab and telescope tests. 16. Check for conformance to requirements and fill out compliance matrix. 17. Document the whole process 18. Deliver user and maintenance manuals. 19. Refine alignment plan as per built unit. 20. Hawaii lab (I & T) Ð Pack (after dismantling, if need be) to ship to HI 21. Ship to HI 22. Unpack and assemble in HI 23. Perform system check out 24. Integrate in lab in HI 25. Calibrate using NGAO telescope simulator and calibration unit 26. Run in closed loop and evaluate performance. 27. Update compliance matrix.
DC	Integrate and test the Low Order WFS on the telescope with at least one science instrument - This is work is part of WBS 8.1 and 8.2	Please see WBS 8.1 and 8.2

WBS	Level	ID	Name
4.2.8	4	WBS-449	Tip/Tilt Vibration Mitigation
Phase	**WBS Element**		**Deliverable**
PD	The detailed design of an approach for mitigating the telescope tip/tilt vibrations to the level needed to achieve the required NGAO tip/tilt performance.		Tip/tilt vibration mitigation preliminary design.
DD	The detailed design of an approach for mitigating the telescope tip/tilt vibrations to the level needed to achieve the required NGAO tip/tilt performance.		Tip/tilt vibration mitigation detailed design.
FSD	All of the tasks (procurement, fabrication, assembly, alignment, testing, documentation, etc.) associated with the post-design development of the tip/tilt vibration mitigation subsystem. This includes the opto-mechanical side of I&T with the required non-real-time control elements. All unit testing should be complete and the subsystem should be fully ready for AO lab I&T..		A functional and fully unit tested tip/tilt vibration mitigation subsystem ready for AO lab I&T.
DC	NA		

WBS	Level	ID	Name
4.2.9	4	WBS-450	Acquisition Cameras
Phase	**WBS Element**		**Deliverable**
PD	Perform preliminary design of acquisition cameras required to acquire stars for the wavefront sensors and the science instruments. Baseline design assumes: 1. 1Kx1K CCD LGS acq. camera (175 mas/pixel over 175") This WBS element involves the mechanical, optical, electrical/ electronics for the acquisition cameras. Inputs: 1. Functional requirements document 2. System design manual 3. Relevant KAONs. 4. NGAO error budget spreadsheet.		1. Preliminary opto-mechanical acquisition camera designs 2. Document the design process. 3. Define operating overheads. 4. Write a preliminary test plan 5. Preliminary compliance matrix 6. Identify risks and find mitigation schemes.
DD	Perform detailed design of acquisition cameras required to acquire stars for the wavefront sensors and the science instruments. Baseline design assumes: 1. H1RG acq camera in front of the LOWFS (150 mas/pixel over 150") [3/11/08 - Omitted by design iteration RGD] 2. 1Kx1K CCD LGS acq. camera (175 mas/pixel over 175") This WBS element involves the mechanical, optical, electrical/ electronics for the acquisition cameras. Inputs: 1. Preliminary design 2. Functional requirements document 3 . Relevant KAONs. 4. NGAO error budget spreadsheet.		1. Detailed opto-mechanical acquisition camera designs (including interface to the AO system) 2. Quotes for all components. 3. Document the design process. 4. Define final operating overheads. 5. Write a detailed test plan 6. Final compliance matrix 7. Identify risks and find mitigation schemes.
FSD	Perform full scale development of acquisition cameras required to acquire stars for the wavefront sensors and the science instruments. Baseline design assumes a 1Kx1K CCD LGS acq. camera (175 mas/pixel over 175") This WBS element involves the mechanical, optical, electrical/ electronics for the acquisition cameras. Inputs: 1. Detailed design 2. Functional requirements document 3. Relevant KAONs. 4. NGAO error budget spreadsheet.		1. Procure components send out shop drawings for manufacture. 2. Build acquisition cameras and fixture. 3. Write low level software to characterize detector. 4. Test performance (sensitivity, RON, DC, QE, read out speed etc) for each camera 5. Refine detailed test plan as per built unit 6. Final compliance matrix 7. Pack & ship to HI 8. Integrate in lab at HI.
DC	Commission the acquisition cameras as part of the NGAO system on the telescope Ð done as part of WBS elements 8.1 and 8.2.		Please see WBS 8.1 and 8.2

WBS	Level	ID	Name
4.2.10	4	WBS-451	Atmospheric Dispersion Correctors
Phase	**WBS Element**		**Deliverable**
PD	Given functional requirements and the conceptual design, complete a preliminary design for all of the atmospheric dispersion correctors Demonstrate by analysis that the design complies with functional requirements. Complete a tolerance analysis including effects of manufacturer's optics variability, flexure, and temperature variation. Write a preliminary testing, assembly, and alignment plan and a preliminary compliance matrix.		Preliminary optical prescription for the ADCs. Report on functional compliance and tolerance analysis. Components list including selected vendors. Preliminary testing, assembly, and alignment plan. Preliminary compliance matrix.
DD	Complete a detailed design for the atmospheric dispersion correctors. Complete a comprehensive assembly, testing, and alignment plan. Comple a compliance martix.		Optical relay prescriptions to the detailed level. Identifacation of all components for optics and mounts along with vendor sources. Complete set of mechanical drawings. Acceptance plan for components. Final assembly, subsystem testing, and alignment plan. Final compliance matrix for subsystem acceptance.
FSD	Fabricate and / or receive parts and assemble the atmospheric dispersion correctors. Mount optics, align, and test the ADC subsystems. Integrate the ADCs into the AO optical system and run through an integrated acceptance test plan to verify concurrance with functional performance requirements.		Completed working ADCs. Acceptance test report. Completed compliance matrix.
DC			

WBS	Level	ID	Name
4.3	3	WBS-452	Alignment, Calibration, and Diagnostics
Phase	**WBS Element**		**Deliverable**
PD			
DD			
FSD			
DC			

WBS	Level	ID	Name
4.3.1	4	WBS-453	Simulator
Phase	**WBS Element**		**Deliverable**
PD	Produce a preliminary design for a telescope simulator with multiple NGS and LGS sources and a means of simulating dynamic turbulence. The system should also include arc lamps, both flat field (white light) and spectral (line) sources, for science instrument calibration. Control software (mechanisms, lamp control, etc.) is part of non real-time AO control system (WBS 4.4) The use of source simulator for AO calibration is part of real-time AO control (WBS 4.5) and Automation and Optimization (WBS 6.6)		1) Optical design of source simulator including a complete ray trace design, preliminary tolerances, and a preliminary alignment plan. 2) Mechanical design of source simulator including mounts for optics, mechanical drawings, structural analysis, mechanisms designs, and motion control. 3) Electrical design of source simulator including motion control for mechanisms, control of turbulence simulator, intensity control of lamps and point sources 4) Interfaces (internal to NGAO) 5) Verify compliance, update requirements matrices and updated requirements (preliminary specifications) 6) Assembly, alignment, and test plans 7) Document Design
DD	Produce a detailed design needed to fabricate a telescope simulator with multiple NGS and LGS sources and a means of simulating turbulence. The system should also include arc lamps, both flat field (white light) and spectral (line) sources, for science instrument calibration. Control software (mechanisms, lamps, etc.) is part of non real-time AO control system (WBS 4.4) The use of source simulator for AO calibration is part of real-time AO control (WBS 4.5) and Automation and Optimization (WBS 6.6)		1) Final optical design of source simulator including a ray trace design, design tolerances, and alignment plan 2) Final mechanical design of source simulator (fabrication drawings, structural analysis, mechanisms designs, motion control 3) Final electrical design for motion control, turbulence simulator, lamps and point sources 4) Assembly, alignment and test plans 5) Vendor quotes 6) Verify compliance, compliance matrices and final specifications (requirements) 7) Document design
FSD	Construct or procure a telescope simulator based on previous developed design (see detailed design phase 4.3.1) Delivery of AO simulator to AO integration lab (Waimea , CIT or UCSC, TBD). Test delivered system as a unit before installation into AO systems		1) Simulator 2) Factory acceptance test results 3) "As built" optical, mechanical, electrical documentation 4) Alignment/installation plan 5) List of critical spare parts 6) Simulator packaged and shipped to AO integration lab 7) On site acceptance test results at integration lab 8) Compliance matrices and readiness evaluation
DC	Does not include integration of simulator into main AO optomechanical system (WBS 4.2) and verification of functionality with AO system see WBS 4.6 (AO lab I &T)		N/A

WBS	Level	ID	Name
4.3.2	4	WBS-454	System Alignment Tools
Phase	**WBS Element**		**Deliverable**
PD	Produce a preliminary design for a set of alignment tools to be used on a regular basis and installed permanently inside the NGAO system. This could include an end to end metrology system (if needed). The system would also facility end to end optical measurements of the AO system including non-common path aberrations and registration between the various sensors and correctors inside the AO system. Measurement technique could utilize interferometry, wavefront sensing or image based phase recovery. Tooling needed to achieve installation and proper alignment of the AO bench that are not permanent are part of wbs 4.2 (AO optomechanical) Control software (mechanisms, etc.) is part of non real-time AO control system (WBS 4.4) The use of alignment tools for AO calibration is part of real-time AO control (WBS 4.5) and Automation and Optimization (WBS 6.6) Cost estimation and schedule for alignment tools is part of preliminary design (WBS 1.3) Risk reduction effort are part of preliminary design (WBS 1.3)		1)Optical design of alignment tools including a complete ray trace design , preliminary tolerances, and a preliminary alignment plan 2) Mechanical design of alignment tools, including mechanical drawings, structural analysis, mechanisms designs, and motion control. 3) Electrical design of source simulator including motion control for mechanisms, control of turbulence simulator, intensity control of lamps and point sources 4) Interfaces (internal to NGAO) 5) Assembly, alignment and test plans 6) Verify compliance, update requirements matrices and updated requirements (preliminary specifications) 7) Document design
DD	Produce a detailed design for a set of alignment tools to be used on a regular basis and installed permanently inside the NGAO system. Tooling needed to achieve installation and proper alignment of the AO optomechanical systems that are not permanent are part of wbs 4.2 (AO optomechanical) Control software (mechanisms, etc.) is part of non real-time AO control system (WBS 4.4) The use of alignment tools for AO calibration is part of real-time AO control (WBS 4.5) and Automation and Optimization (WBS 6.6) Cost estimation and schedule for alignment tools is part of detailed design (WBS 1.4) Risk reduction effort are part of detailed design (WBS 1.4)		1) Final optical design of alignment tools including a ray trace design, design tolerances, and alignment plan 2) Final mechanical design of alignment tools (fabrication drawings, structural analysis, mechanisms designs, motion control) 3) Final electrical design for motion control, sensor readouts, etc. 4) Assembly, alignment, and test plans 5) Vendor quotes 6) Verify compliance, update requirements matrices and updated final specification (requirements) 7) Document design
FSD	Construct or procure the alignment tools based on previously developed design (see 4.3.2. DD)		1) Alignment tools 2) Factory acceptance test results 3) "As built" optical , mechanical, electrical documentation 4) Alignment/installation plan 5) List of critical spare parts 7) Alignment tools deliver to AO integration lab 8) On site acceptance test results at integration lab
DC	Does not include integration of alignment tools into main AO optomechanical system (WBS 4.2) and verification of functionality with AO system see WBS 4.6 (AO lab I &T)		N/A

WBS	Level	ID	Name
4.3.3	4	WBS-455	Atmospheric Profiler
Phase	**WBS Element**		**Deliverable**
PD	This element includes the effort to maintain a complete atmospheric profiler to provide near-real-time measurements of the vertical distribution of optical turbulence in the Earth's atmosphere in the vicinity of Keck Observatory. (The procurement and installation of this profiler is assumed to be part of WBS 3.10 Technical Risk Assess & Mitigation.) It includes the establishment of an independent data archive for turbulence profile information, as well as the software interface to provide the same information to the NGAO system when the NGAO system is in use. This element does not include operational software related to observation scheduling or sequencing nor software pertaining to PSF calibration or near-real-time optimization of NGAO system performance (through generation of optimal reconstructors or otherwise, WBS 4.5 and WBS 6.) This element does not include installation of the atmospheric profiler at Keck Observatory (WBS 8.4), but does include preliminary profiler operational checkout and data cross-validation with AO system SLODAR measurements.		On-going stream of Cn2(h,t) data (to be provided under Observatory auspices - no NGAO project deliverable)
DD	This element includes the effort to maintain a complete atmospheric profiler to provide near-real-time measurements of the vertical distribution of optical turbulence in the Earth's atmosphere in the vicinity of Keck Observatory. (The procurement and installation of this profiler is assumed to be part of WBS 3.10 Technical Risk Assess & Mitigation.) This element does not include operational software related to observation scheduling or sequencing nor software pertaining to PSF calibration or near-real-time optimization of NGAO system performance (through generation of optimal reconstructors or otherwise, WBS 4.5 and WBS 6.) This element does not include installation of the atmospheric profiler at Keck Observatory (WBS 8.4), but does include preliminary profiler operational checkout and data cross-validation with AO system SLODAR measurements.		On-going stream of Cn2(h,t) data (to be provided under Observatory auspices)
FSD	This element includes the effort to maintain a complete atmospheric profiler to provide near-real-time measurements of the vertical distribution of optical turbulence in the Earth's atmosphere in the vicinity of Keck Observatory. (The procurement and installation of this profiler is assumed to be part of WBS 3.10 Technical Risk Assess & Mitigation.) This element does not include operational software related to observation scheduling or sequencing nor software pertaining to PSF calibration or near-real-time optimization of NGAO system performance (through generation of optimal reconstructors or otherwise, WBS 4.5 and WBS 6.) This element does not include installation of the atmospheric profiler at Keck Observatory (WBS 8.4), but does include preliminary profiler operational checkout and data cross-validation with AO system SLODAR measurements.		On-going stream of Cn2(h,t) data (to be provided under Observatory auspices)

DC	This element includes the effort to maintain a complete atmospheric profiler to provide near-real-time measurements of the vertical distribution of optical turbulence in the Earth's atmosphere in the vicinity of Keck Observatory. (The procurement and installation of this profiler is assumed to be part of WBS 3.10 Technical Risk Assess & Mitigation.) This element does not include operational software related to observation scheduling or sequencing nor software pertaining to PSF calibration or near-real-time optimization of NGAO system performance (through generation of optimal reconstructors or otherwise, WBS 4.5 and WBS 6.) This element does not include installation of the atmospheric profiler at Keck Observatory (WBS 8.4), but does include preliminary profiler operational checkout and data cross-validation with AO system SLODAR measurements.	On-going stream of Cn2(h,t) data (to be provided under Observatory auspices)

WBS	Level	ID	Name
4.4	3	WBS-456	Non-real-time Control
Phase	**WBS Element**		**Deliverable**
PD			
DD			
FSD			
DC			

WBS	Level	ID	Name
4.4.1	4	WBS-457	AO Controls Infrastructure
Phase	**WBS Element**		**Deliverable**
PD	A preliminary design for the AO controls infrastructure. The infrastructure consists of the overall distributed control system architecture, including the distributed control system design and data communications paradigm, the component control computers, and the system configuration management process.		"1. A preliminary design of the distributed controls architecture to be used for AO control, including CPU types, operating systems, low-level data communications (e.g., Ethernet, Fibre Channel, etc.), high-level data communications (e.g., keywords, EPICS), bandwidth and data storage requirements. 2. A preliminary selection of all the computers, both real-time (VxWorks) and non-real-time (Unix) required to support the AO controls architecture. 3. An Interface Control Document describing all the subsystem interfaces. 4. A document describing the SW and HW configuration management process. 5. A report summarizing the design."
DD	A detailed design for the AO controls infrastructure.		"1. A final design of the distributed controls architecture to be used for AO control, including CPU types, operating systems, low-level data communications (e.g., Ethernet, Fibre Channel, etc.), high-level data communications (e.g., keywords, EPICS), bandwidth and data storage requirements. 2. A final selection of all the computers, both real-time (VxWorks) and non-real-time (Unix) required to support the AO controls architecture, including vendor quotes. 3. An Interface Control Document describing all the subsystem interfaces. 4. A document describing the SW and HW configuration management process. 5. A report summarizing the design."
FSD	Integration and testing of all the AO non-RT control system component pieces. Testing with NGAO the muli-system sequencer.		"1. The integrated AO non-RT controls system. 2. Final test documentation."
DC	Final I&T of AO non-RT controls system on telecsope.		Completed AO non-RT controls system, ready for on-sky I&T.

WBS	Level	ID	Name
4.4.2	4	WBS-458	AO Sequencer
Phase	**WBS Element**		**Deliverable**
PD	A preliminary design for the top-level AO Sequencer. The sequencer consists of a command interface to support data access (keywords) for the entire AO system, a set of high-level coordination sequences that control the execution of multiple complex tasks in the lower level AO control system, a data interface that supports posting of telemetry and status data for use by the other systems, and a system health monitor that monitors a number of important AO parameters and reports failures to the other systems and sets alarms, as appropriate.		"1. A description and block diagram of the SW architecture. 2. An Interface Control Document describing all the SW interfaces. 3. A description of the major component SW modules. 4. A preliminary user interface design. 5. A preliminary technical specification. 6. A preliminary compliance matrix. 7. A preliminary test plan. 8. A report summarizing the design."
DD	A detailed design for the top-level AO Sequencer.		"1. A description and block diagram of the SW architecture. 2. An Interface Control Document describing all the SW interfaces. 3. A description of the major component SW modules. 4. A final user interface design. 5. A final technical specification. 6. A final compliance matrix. 7. A final test plan. 8. A report summarizing the design."
FSD	Implementation and testing of the top-level AO sequencer. Testing will require coordination with other AO Control subsystems, the laser subsystem, and the multi-system sequencer.		"1. The final AO sequencer codes. 2. Final test documentation"
DC	Final I&T of AO sequencer on telescope.		Completed AO sequencer, ready for on-sky I&T.

WBS	Level	ID	Name
4.4.3	4	WBS-459	Motion Control SW
Phase	**WBS Element**		**Deliverable**
PD	"A preliminary design of the motion control SW to include: 1. A command driver interface (e.g., EPICS driver) 2. A low-level generic ""N-DOF"" device sequence 3. High-level device sequences for complex devices requiring coordinated moves or multiple stage moves 4. User interfaces"		"1. A description and block diagram of the SW architecture. 2. An Interface Control Document describing all the SW interfaces. 3. A description of the major component SW modules. 4. A preliminary user interface design. 5. A preliminary technical specification. 6. A preliminary compliance matrix 7. A preliminary test plan. 8. A report summarizing the design."
DD	"A detailed design of the motion control SW to include: 1. A command driver interface (e.g., EPICS driver) 2. A low-level generic ""N-DOF"" device sequence 3. High-level device sequences for complex devices requiring coordinated moves or multiple stage moves 4. User interfaces"		"1. Detailed description and diagrams of the SW architecture. 2. An Interface Control Document describing all the SW interfaces. 3. A detailed description of the major component SW modules. 4. A detailed user interface design. 5. A detailed technical specification. 6. A detailed compliance matrix 7. A detailed test plan. 8. A report summarizing the design."
FSD	Implementation and testing of the motion control SW. This will be done using the lab I&T test system and test devices, followed by I&T of actual devices. Also includes detailed performance testing and documentation of all the motion controlled devices in the system.		"1. The final motion control SW. 2. Final test documentation."
DC	Final I&T of motion control SW on telescope.		Compete motion control system SW, ready for on-sky I&T.

WBS	Level	ID	Name
4.4.4	4	WBS-460	Device Control SW
Phase	**WBS Element**		**Deliverable**
PD	"A preliminary design of the device control SW, to include 1. Camera control 2. DM/TT mirror control 3. RTC control 4. Environmental control 5. User interfaces Note: this may include the design of device drivers in each case, depending on the device."		"1. A description and block diagram of the SW architecture. 2. An Interface Control Document describing all the SW interfaces. 3. A description of the major component SW modules. 4. A preliminary user interface design. 5. A preliminary technical specification. 6. A preliminary compliance matrix 7. A preliminary test plan. 8. A report summarizing the design."
DD	"A detailed design of the device control SW, to include 1. Camera control 2. DM/TT mirror control 3. RTC control 4 . Environmental control 5. User interfaces Note: this may include the design of device drivers in each case, depending on the device."		"1. Detailed description and diagrams of the SW architecture. 2. An Interface Control Document describing all the SW interfaces. 3. A detailed description of the major component SW modules. 4. A detailed user interface design. 5. A detailed technical specification. 6. A detailed compliance matrix 7. A detailed test plan. 8. A report summarizing the design."
FSD	Implementation and testing of the device control SW. This will be done using the lab I&T test system and test devices, followed by I&T of actual devices.		"1. The final device control SW. 2. Final test documentation."
DC	Final I&T of device control SW on telescope.		Complete device control system, ready for on-sky I&T.

WBS	Level	ID	Name
4.4.5	4	WBS-461	Motion Control Electronics
Phase	**WBS Element**		**Deliverable**
PD	"A preliminary design of the motion control electronics, including: 1. A trade study to determine the system motion control architecture and philosophy (distributed vs centralized). 2. Specification and selection of the type of motion control system to be used along with its component devices. 3. Selection of all the component devices required to support the NGAO motion control, with headroom for incorporation of additional devices."		"1. Results of the motion control trade study. A description of the motion control architecture and philosophy. 2. A preliminary selection and specification of the motion control electronics. 3. A preliminary motion control spreadsheet detailing accuracy/repeatability, range, and bearing runout for each device. 4. A preliminary compliance matrix. 5. A preliminary test plan. 6. A report documenting the design."
DD	"A detailed design of the motion control electronics, including: 1. Definition of the system motion control philosophy 2. Specification and selection of the type of motion control system to be used along with its component devices. 3. Selection of all the component devices required to support the NGAO motion control, with headroom for incorporation of additional devices."		"1. A detailed description of the motion control architecture and philosophy. 2. A final selection and specification of the motion control electronics, including vendor quotes. 3. A final motion control spreadsheet detailing accuracy/repeatability, range, and bearing runout for each device. 4. A final compliance matrix. 5. A final test plan. 6. A report documenting the design."
FSD	Procurement of all motion control electronics. Implementation, testing and calibration of the motion contol electronics. Initial testing will be done using the lab I&T system, followed by a buildup of the complete system.		"1. The completed motion control electronics system. 2. Final test documentation."
DC	Final I&T of motion control system on telescope.		Complete motion control system, ready for on-sky I&T.

WBS	Level	ID	Name
4.4.6	4	WBS-462	Non-RTC Electronics
Phase	**WBS Element**		**Deliverable**
PD	"A preliminary design of the non RTC electronics, including: 1. The high-level support CPUS (Unix servers). 2. The low-level support CPUs (VxWorks). 3. The power control electronics. 4. The Environmental control electronics. 5. Miscellaneous electronics."		"1. A description of the non RTC electronics architecture. 2. A preliminary selection and specification of the non-RTC electronics. 3. A preliminary compliance matrix. 4. A preliminary test plan. 5. A report documenting the design."
DD	"A detailed design of the non RTC electronics, including: 1. The high-level support CPUS (Unix servers). 2. The low-level support CPUs (VxWorks). 3. The power control electronics. 4. The Environmental control electronics. 5. Miscellaneous electronics."		"1. Detailed description and drawings of the non RTC electronics architecture. 2. A final selection and specification of the non-RTC electronics, including vendor quotes. 3. A preliminary compliance matrix . 4. A preliminary test plan. 5. A report documenting the design."
FSD	Procurements of all electronics for the non-RT control systems (not including motion control electronics, which are already covered). Implementation and testing of the electronics infrastructure for the AO control system. Initial testing will be done in the using the lab I&T system, followed by a buildup of the complete system.		"1. The completed AO control system electronics (heavy overlap here with other 4.4 WBS entries). 2. Final test documentation."
DC	Final I&T of non-RTC electronics on telescope.		Complete non-RTC electronics, ready for on-sky I&T.

WBS	Level	ID	Name
4.4.7	4	WBS-463	Lab I&T System
Phase	**WBS Element**		**Deliverable**
PD	Preliminary design of a lab I&T system suitable for testing all the devices which interface to the non RTC systems. The testing will occur during the FSD phase in preparation for the full system lab I&T that occurs later in that phase. The design will include a specification and selection of the component electronics and computer support HW and SW.		"1. A description of the lab I&T architecture. 2. A preliminary test plan showing how the system will be used to test the various components. 3. A report documenting the design."
DD	Detailed design of a lab I&T system suitable for testing all the devices which interface to the non RTC systems. The testing will occur during the FSD phase in preparation for the full system lab I&T that occurs later in that phase. The design will include a specification and selection of the component electronics and computer support HW and SW .		"1. Detailed description and drawings of the lab I&T architecture, including vendor quotes. 2. A final test plan showing how the system will be used to test the various components. 3. A report documenting the design."
FSD	Implementation and testing of the lab I&T system.		The completed lab I&T system to be used for testing many of the AO control devices, HW, and SW.
DC	Lab I&T system used for testing and debug to support telescope I&T of overall system.		None.

WBS	Level	ID	Name
4.4.8	4	WBS-464	Acquisition, Guiding, and Offloading Control
Phase	**WBS Element**		**Deliverable**
PD	Preliminary design of the acquisition, guiding, and offload functions and interfaces between the AO system and the telescope.		"1. A description and block diagram of the SW architecture. 2. An Interface Control Document describing all the interfaces. 3. A description of the major component SW modules. 4. A preliminary user interface design. 5. A preliminary technical specification. 6. A preliminary compliance matrix. 7. A preliminary test plan. 8. A report summarizing the design."
DD	Detailed design of the acquisition, guiding, and offload functions and interfaces between the AO system and the telescope.		"1. Detailed description and diagrams of the SW architecture. 2. An Interface Control Document describing all the SW interfaces. 3. A detailed description of the major component SW modules. 4. A detailed user interface design. 5. A detailed technical specification. 6. A detailed compliance matrix 7. A detailed test plan. 8. A report summarizing the design."
FSD	Implementation and testing using a telescope simulator.		The completed acquisition, guiding, and offload control SW ready to be tested on the telescope.
DC	Telescope I&T of the acquisition, guiding, and offloading SW. Some daytime testing with the telescope, but most testing must be at night on the sky.		Complete acquisition, guiding, and offloading SW.

WBS	Level	ID	Name
4.5	3	WBS-465	Real-time Control
Phase	**WBS Element**		**Deliverable**
PD			
DD			
FSD			
DC			

WBS	Level	ID	Name
4.5.1	4	WBS-466	Real-time Control Processor
Phase	**WBS Element**		**Deliverable**
PD	Given functional requirements and the conceptual design, complete a preliminary but detailed design of the AO real-time control system. Complete an analysis showing that the design meets minimal performance requirements. Write a preliminary assembly and testing plan and a preliminary compliance matrix.		Preliminary design for the AO real-time control system. Design document describing both hardware and software structure. Report on performance analysis. Components list including selected vendors. Preliminary manufacturing, assembly, and testing plan. Preliminary compliance matrix.
DD	Complete a detailed design for the AO real-time control system. Complete a final design document with details of hardware and software systems. Write a preliminary software user and maintenance manual. Write an assembly , testing, and alignment plan. Comple a compliance martix .		Design document with details of the harware and software systems. Purchasing, fabrication, assembly and test plan. Compliance matrix. Preliminary version of a software user and maintenance manual.
FSD	Fabricate and / or receive parts and assemble the AO real-time control system. Mount in electronics racks and cable to the AO system real-time components such as DMs, Tip/ Tilt stages, WFS cameras etc. Complete all real-time software programming. Complete the subsystem acceptance test plan and verify concurrance with the compliance matrix. Complete a series of full system integration tests including on-bench tests with a turbulence source and telescope simulator. Verify that the system meets its functional performance requirements. This effort does not include the WFS detectors (WBS 4.2.7, 4.2.8, 4.2.9) nor the DM's (WBS 4.5.2), but it does include the interface boards for conversion of camera signals to the RTC and output board converting RTC to DM driver commands.		Completed working AO real-time control system. Acceptance test report. Completed compliance matrix.
DC	None.		None.

WBS	Level	ID	Name
4.5.2	4	WBS-467	DM's and Tip/Tilt Stages
Phase	**WBS Element**		**Deliverable**
PD	Given functional requirements and the conceptual design, complete a preliminary esign of the DM and Tip/Tilt stages. Complete a tolerance analysis including effects of manufacturer's optics variability, flexure, and temperature variation. Write a preliminary testing, assembly, and alignment plan and a preliminary compliance matrix.		Preliminary design for the DM and Tip/Tilt stages. Report on tolerance analysis. Components list including selected vendors. Preliminary testing , assembly, and alignment plan. Preliminary compliance matrix.
DD	Complete a detailed design for the DM and Tip/Tilt stages . Complete a comprehensive assembly, testing, and alignment plan. Comple a compliance martix.		Final mechanical drawinggs sufficient to start fabrication. Identification of all components for optics and mounts along with vendor sources. Acceptance plan for components. Final assembly, subsystem testing, and alignment plan. Final compliance matrix for subsystem acceptance.
FSD	Fabricate and / or receive parts and assemble the DM and Tip/Tilt stages. Mount DMs and TT mirrors and align the system acooridingly. Complete the acceptance test plan and verify concurrance with the compliance matrix		Completed working systems. Acceptance test report. Completed compliance matrix.
DC			

WBS	Level	ID	Name
4.6	3	WBS-468	AO System Lab I&T
Phase	**WBS Element**		**Deliverable**
PD	This WBS covers the lab integration of the AO subsystems into a single AO system and the testing of this system with a science instrument.		Preliminary plan for AO system lab I&T.
DD	This WBS covers the lab integration of the AO subsystems into a single AO system and the testing of this system with a science instrument.		Detailed plan for AO system lab I&T.
FSD	This WBS covers the lab integration of the AO subsystems into a single AO system and the testing of this system with a science instrument.		A temporary lab facility, preferably using the AO enclosure cold room, in which to perform AO system lab I&T and to support delivery and commissioning, including required tools and equipment in support of integration. A permanent lab facility for long-term operations & NGAO development support. A fully functional and characterized AO system demonstrated to meet all of the lab testable requirements. Documentation : Lab-specific vendor documentation, integration procedures, test procedures and results, and requirements compliance.
DC	This WBS covers the lab integration of the AO subsystems into a single AO system and the testing of this system with a science instrument. The DC phase includes lab support for the summit I&T efforts and cleanup of the lab facilities prior to project completion.		Temporary lab I&T facilities removed. Technical support for telescope I &T. Lab facility to support operations.

WBS	Level	ID	Name
5	2	WBS-469	Laser System Development
Phase	**WBS Element**		**Deliverable**
PD			
DD			
FSD			
DC			

WBS	Level	ID	Name
5.1	3	WBS-470	Laser Enclosure
Phase	**WBS Element**		**Deliverable**
PD	Develop a preliminary design for an enclosure to house the laser and its electronics and to control air flow, temperature, humidity, etc. as required. Control of laser, environmental monitors and supporting optomechanical system is part of laser system control (WBS 5.5) Optical mechanical system that couples lasers to launch telescope are part of laser launch facility (WBS 5.3) Software control of safety shutters and interlock part of laser Safety System (WBS 5.4)		1) Mechanical design of laser enclosure 2) Electrical design of environmental control (temp, airflow, humidity, etc.) 3) Interfaces (internal to NGAO) 4) Assemble and test plans 5) Verify compliance, update requirements matrices and updated requirements (preliminary specifications) 6) Document design
DD	Produce a final design at a level needed to fabricate an enclosure to house the laser and its electronics and to control air flow, temperature, humidity, etc. as required. Software control laser and supporting optomechanical system is part of laser system control (WBS 5.5) Optical mechanical system that couples lasers to launch telescope are part of laser launch facility (WBS 5.3) Software control of safety shutters and interlock part of laser Safety System (WBS 5.4)		1) Final mechanical design of laser enclosure 2) Final electrical design of environmental control (temp, airflow, humidity, etc.) 3) Assemble, alignment and test plans 4) Vendor quotes 5) Verify compliance, compliance matrices, and final specification (requirements) 6) Document design
FSD	Construct or procure a laser system enclosure based on previous developed design		1) Construct Laser enclosure at telescope (Mauna Kea), Use Waimea facilities for laser I&T 2) Acceptance test results 3) "As built" mechanical, electrical documentation 4) List of critical spare parts 5) Compliance matrices and readiness evaluation
DC	Likely laser enclosure will be installed directly on telescope and not assembled at some "integration" lab. Installation of lasers, optics, etc. on telescope is covered under (WBS 8.2) Laser System Installation I&T		N/A

WBS	Level	ID	Name
5.2	3	WBS-471	Laser
Phase	**WBS Element**		**Deliverable**
PD	This WBS will deliver a set of laser requirements consistent with the laser performance required for NGAO. The WBS will also determine options for laser procurement, recommend the best option, and after funding is secured, negotiate a contract for the development of the recommended laser systems. This WBS carries out these tasks only for the actual lasers which are expected to consist of one or more laser units providing the required 589 nm power with supervisory control, diagnostic, power and safety systems. Not included are the overall environmental enclosure, beam transport system, cooling water supply, or infrastructure to support these items.		See Adkins' supporting materials.
DD	This WBS element will deliver the NRE required for the laser system procurement contract. This includes a detailed design for the laser systems, a detailed design review for the laser systems, an acceptance test plan for the laser systems, and an interface control document covering the interface requirements for the laser systems to the NGAO system.		See Adkins' supporting material.
FSD	This WBS element will procure the laser systems based on the results of the detailed design phase NRE activities. This WBS element includes shipping to Hawaii, but does not include placing lasers in the telescope enclosure for subsequent post verification testing during the DC phase.		See Adkins' supporting materials. 3/11/08 - RGD - invoked scoping option of initial subcontract for 50W x 2 lasers = 100W of laser power.
DC	This WBS element will carry out a post delivery verification of performance, and provide the support services needed for installation, training, spares procurement and establish a preventative maintenance program for the lasers		Lasers performance verification report.

WBS	Level	ID	Name
5.3	3	WBS-472	Laser Launch Facility
Phase	**WBS Element**		**Deliverable**
PD	Develop a preliminary design for the systems required for delivering the laser power from the laser to the sky. This includes: 1) Laser Beam Transport: Develop preliminary design for delivering the laser power from the laser to the launch telescope. 2) Laser Pointing and Diagnostics: Develop preliminary design for determining and controlling the alignment and pointing of the laser beams. Develop preliminary design for regularly monitoring the beam quality, laser power, and health of the laser launch system. 3) Laser Launch Telescope: Develop the preliminary design for the telescope needed to launch multiple laser beacons Does not include: Software control of these systems is part of laser system control (WBS 5.5) Software control of safety shutters and interlocks is part of laser safety system (WBS 5.4)		1. Preliminary optical design for optics located in laser enclosure (beam transport, laser pointing, diagnostics) including ray trace design, preliminary tolerances, and preliminary alignment plan 2. Preliminary optical design for launch telescope 3. Preliminary optical design for optics located along telescope tube and behind secondary (beam transport , laser pointing, and diagnostics) 4. Mechanical design for mechanical elements located in laser enclosure (beam transport, laser pointing, diagnostics) including mechanical drawings, mechanism for motion control, optic mounts 5. Mechanical design for laser launch telescope and mechanical supports 6. Mechanical design for mechanical elements located along telescope tube and behind secondary 7. Electrical design for beam transport, laser pointing, diagnostics and launch telescope including electrical system for motion control, monitoring 8. Interfaces (internal to NGAO) 9. Assembly, alignment, and test plans 10. Verify compliance, update requirements matrices and updated requirements (preliminary specifications) 11. Document design
DD	Develop a final design for the systems required for delivering the laser power from the laser to the sky. This includes: 1) Laser Beam Transport: Develop final design for delivering the laser power from the laser to the launch telescope. 2) Laser Pointing and Diagnostics: Develop final design for determining and controlling the alignment and pointing of the laser beams. Develop final design for regularly monitoring the beam quality, laser power, and health of the laser launch system. 3) Laser Launch Telescope: Develop the final design for the telescope needed to launch multiple laser beacons Does not include: Software control of these systems is part of laser system control (WBS 5.5) Software control of safety shutters and interlocks is part of laser safety system (WBS 5.4)		1. Final optical design for optics located in laser enclosure (beam transport, laser pointing, diagnostics) including ray trace design, tolerances, and alignment plan 2. Final optical design for launch telescope 3. Final optical design for optics located along telescope tube and behind secondary (beam transport, laser pointing, and diagnostics) 4. Final mechanical design for mechanical elements located in laser enclosure (beam transport, laser pointing, diagnostics) including fabrications drawings 5. Final mechanical design for laser launch telescope and mechanical supports 6. Mechanical design for mechanical elements located along telescope tube and behind secondary 7. Final electrical design for beam transport, laser pointing, diagnostics and launch telescope including electrical system for motion control, monitoring 8. Assembly, alignment, and test plans 9. Vendor quotes 10. Verify compliance, compliance matrices and final specifications (requirements) 11. Document design
FSD	Construct or procure the systems for delivering the laser power from the laser to the sky. This includes: 1) Laser Beam Transport: delivering the laser power from the laser to the launch telescope. 2) Laser Pointing and Diagnostics: determining and controlling the alignment and pointing of the laser beams. In addition regularly monitoring the beam quality, laser power, and health of the laser launch system. 3) Laser Launch Telescope: the telescope needed to launch multiple laser beacon Software to control these system is included under laser system control (WBS 5.5)		1. Construction of laser Launch Telescope 2. Construction of laser enclosure electro-optical system 3. Construction of coude + secondary electro-optical system 4. Factory acceptance test results 5. "As built" optical, mechanical, electrical documentation 6. Installation plan 7. List of critical spare parts 8. Compliance matrices and readiness evaluation 9. Systems packed and shipped to Laser Integration Lab (Waimea)
DC	Receive laser launch facility system at "Integration" lab. Is part of Laser lab I&T see WBS 5.6		N/A

WBS	Level	ID	Name
5.4	3	WBS-473	Laser Safety Systems
Phase	**WBS Element**		**Deliverable**
PD	This is mainly a software and control task, hardware costs included in other WBS elements, with the exception of computer equipment to host these software systems. Develope a preliminary design for safety systems for the laser to protect aircraft, satellites, personnel and equipment. Personnel and equipment safety systems: Develope preliminary design for the required safety interlock systems. Aircraft, Satellite & Laser Traffic Control Safety Systems: Develop a preliminary designs for the safety systems needed to protect aircraft pilots (eye safety) and spacecraft from the laser beacons. All telescopes on Mauna Kea are currently required to participate in the laser traffic control system. Assumes that intelocks, shutters and other hardward (including electronics) used by safety system are part of WBS 5.1, 5.2, 5.3 Cameras for detecting airplanes is part of Mauna Kea facility (ASCAM) and not costed here		1. Preliminary design of personnel and equipment safety system software a) Define algorithms, diagrams, dataflow b) Select communication protocols and methods c) Estimate performance 2. Preliminary design of laser traffic control system software a) Define algorithms, diagrams, dataflow b) Select communication protocols and methods c) Estimate performance 3. Electronics, shutter and interlock for safety system (see WBS 5.1, 5.3, 5.5) 4. Interfaces (internal to NGAO) 5. Software test plans 6. Verify compliance, update requirements matrices and updated requirements (preliminary specifications) 7. Document design
DD	This is mainly a software and control task, hardware costs included in other WBS elements, with the exception of computer equipment to host this software. Develop a detailed design for safety systems for the laser to protect aircraft, satellites, personnel and equipment. Personnel and equipment safety systems: finalize means of protecting equipment from inadvertent damage during operation. Aircraft, Satellite & Laser Traffic Control Safety Systems: Develop final designs for the safety systems needed to protect aircraft pilots (eye safety) and spacecraft from the laser beacons. All telescopes on Mauna Kea are currently required to participate in the laser traffic control system. Assumes that interlocks, shutters and other hardware (including electronics) used by safety system are part of WBS 5.1, 5.2, 5.3 Cameras for detecting airplanes is part of Mauna Kea facility (ASCAM) and not costed		1. Final software design of personnel and equipment safety system software a) Define software to the subroutine level b) Prototype high risk sections of software c) verify performance 2. Final software design of laser traffic control system a) Define software to the subroutine level b) Prototype high risk sections of software c) verify performance 3. Test plans 4. Vendor quotes 5. Verify compliance, compliance matrices and final specifications (requirements) 6. Document design
FSD	Personnel and equipment safety systems: develop the required safety systems and software. Aircraft, Satellite & Laser Traffic Control Safety Systems: Develop the safety systems needed to protect aircraft pilots (eye safety) and spacecraft from the laser beacons.		1) Personnel and equipment safety system (final code and computer systems) 2) Aircraft, satellite & laser traffic control safety system 3) Acceptance test results 4) software documentation 5) Integration/ Installation plan 6) configuration management (part of WBS 3.6??)
DC	Receive laser safety system at "integration" lab and perform on site testing of subsystem part of Laser Lab I& T WBS 5.6		N/A

WBS	Level	ID	Name
5.5	3	WBS-474	Laser System Control
Phase	**WBS Element**		**Deliverable**
PD	Develop a preliminary design for a laser system control, design the architecture for the laser system control and diagnostics software, including laser, beam transport, and launch system. Software must be integrated with the laser safety system, AO system, observing tools, science instruments, and the telescope operating system. Specify and develop the preliminary design for the electronics systems needed to provide laser control and diagnostics functions. The motion control software is part of this WBS . The laser and other electronic to support control functions are costed under WBS 5.1, 5.2, 5.3		1. Preliminary design of laser facility control system software a) Laser sequencer b) Motion Control Software c) Device Control Software d) Motion Control Electronics e) Laser Control Electronics (external to LMCT/SOR laser) 2. Interfaces (internal to NGAO) 3. Software test plans 4. Verify compliance, update requirements matrices and updated requirements (preliminary specifications) 5. Document design
DD	Develop final design for a laser system control, design the architecture for the laser system control and diagnostics software, including laser, beam transport, and launch system. Software must be integrated with the laser safety system, AO system, observing tools, science instruments, and the telescope operating system. Specify the final design for the electronics systems needed to provide laser control and diagnostics functions. The laser and other electronic to support control functions are costed under WBS 5.1, 5.2, 5.3, The motion control software is part of this WBS.		1. Final software design of laser facility control system software a) Laser sequencer b) Motion Control Software c) Device Control Software d) Motion Control Electronics e) Laser Control Electronics (external to LMCTI/SOR laser) 2. Interface control document 3. Technical specification 4. Compliance matrix. 5. Test plan. 6. Summary report 7. Vendor quotes
FSD	Develop final software for a laser facility control system. Construct or procure the final electronics systems needed to provide laser control and diagnostics functions. The laser and other electronic to support control functions are costed under WBS 5.1, 5.2, 5.3, The motion control software is part of this WBS.		1. Laser facility control system (final code and computer systems) a) Laser sequencer b) Motion Control Software c) Device Control Software d) Motion Control Electronics e) Laser Control Electronics 2. Factory acceptance test results 3. "As built" software documentation 4. Installation and configuration management plan (partial overlap with WBS 3.6 probably not) 5. List of critical spare parts 6. Compliance matrices and readiness evaluation 7. IT support on installation 8. Systems shipped to Laser Integration Lab (Waimea)
DC	N/A		N/A

WBS	Level	ID	Name
5.6	3	WBS-475	Laser System Lab I&T
Phase	**WBS Element**		**Deliverable**
PD	Preliminary design level plan for lab integration and testing for all aspects of the laser system, including verification of laser performance, beam transfer efficiency , safety systems, diagnostics, and active systems such as high-speed pointing control		Preliminary testing and integration plan for laser system
DD	Final lab integration and testing plan for all aspects of the laser system, including verification of laser performance, beam transfer efficiency, safety systems, diagnostics, and active systems such as high-speed pointing control		Final laser system integration and testing plans
FSD	Integration of laser system in laboratory environment. It is likely that a full scale integration of the laser system (unlike the AO system) is not practical anywhere but at the summit (see WBS 8.2). But to the extent possible connect and test various laser subsystems at integration lab: laser, laser transport, laser control, laser safety systems.		1. Lab Infrastructure modifications (Waimea) a) power modifications b) cooling system modifications 2. Installation and assemble of laser facility components (see below) a) Laser b) Beam transport (AO enclosure) c) Launch Telescope d) Control software e) Safety systems software 3. Integration lab acceptance test results a) Laser b) Beam transport (AO enclosure) c) Launch Telescope d) Control software e) Safety systems software 4. "As built" optical, mechanical, electrical documentation 5. Installation plan 6. Compliance matrices and readiness evaluation 7. Package for shipment to Mauna Kea 8. Systems shipped to WMKO (Mauna Kea)
DC	Cost of installing laser facility at telescope is costed under laser Install I&T (WBS 8.2)		N/A see WBS 8.2

WBS	Level	ID	Name
6	2	WBS-476	Science Operations
Phase	**WBS Element**		**Deliverable**
PD			
DD			
FSD			
DC			

WBS	Level	ID	Name
6.1	3	WBS-477	Multi-System Command Sequencer
Phase	**WBS Element**		**Deliverable**
PD			
DD			
FSD			
DC			

WBS	Level	ID	Name
6.1.1	4	WBS-478	Sequencer Infrastructure
Phase	**WBS Element**		**Deliverable**
PD	Produce a preliminary design based on SD requirements, including definitions, communication protocols and standards, system interfaces (hardware and software), and documentation required for interfacing command to and coordinating the NGAO sub-systems and with the instrument sequencer. The infrastructure for this WBS needs to be consistent and coordinated with the infrastructure for the AO subsystem (WBS 4.4) and NGAO subsystems overall (WBS 3.6 and 3.7).		1) Detailed design document for the coordination sequencer, command interface, data interface and system health. 2) Functional requirements for the software 3) Preliminary Operation Concept Document 3) Develop Modules Definitions 4) Detailed design document for the hardware
DD	Produce a detailed design for the MCS infrastructure that is consistent and tested to work with the other subsystems.		1) Final functional requirements for the software. 2) Final design document for the hardware 3) Test plan for the MCS infrastructure 4) Module Level Design, Description and Specifications 5) Final OCD
FSD	Procure, build the MCS. Perform unit testing for the MCS. Document results.		1) Procure and assemble hardware 2) Software modules written and tested internally 3) MCS Manual 4) Acceptane test plan at the telescope
DC	The effort for the DC phase has now been added to Lab I &T and Telescope I&T.		See support material on twiki

WBS	Level	ID	Name
6.1.2	4	WBS-479	Setup Sequences: Configurations & Calibrations
Phase	**WBS Element**		**Deliverable**
PD	Produce a preliminary design based on SD requirements and the updated observing scenarios for the various sequences to configure and calibrate the NGAO system and the science instruments. The infrastructure for this WBS needs to be consistent and coordinated with the AO sequencer (WBS 4.4) and the diagnostic tools (WBS 4.3).		1) Functional requirements for the software modules 2) Preliminary Operation Concept Document 3) Modules definitions 4) Prototype for some of the calibration modules (e.g, img sharpening)
DD	Based on PD phase for this WBS and the deliverables from the System Architecture, produce a detailed design document and a test plan for the setup sequences.		1) Final functional requirements for the software modules. 2) Final design document for the hardware (if necessary) 3) Test plan for the sequences 4) Module Level Design, Description and Specifications
FSD	Procure, build the setup sequences and integrate with the subsystem sequencers (AO) in the lab.		1) Software modules written and tested internally 2) Setup Sequences Manual 3) Full integrated tests with AO sequencer 4) Acceptane test plan at the telescope and with other subsystems
DC	The effort for the DC phase has now been added to Lab I &T and Telescope I&T.		See support material on Twiki

WBS	Level	ID	Name
6.1.3	4	WBS-480	Observing Sequences
Phase	**WBS Element**		**Deliverable**
PD	Produce a preliminary design based on SD requirements and the updated observing scenarios for the three following classes of observing sequences: 1) Acquisition sequences, 2) Observing Sequences, and 3) Performance Monitoring and Optimization for the NGAO system science operations. The design for these sequences needs to be consistent and coordinated with all other (sub) sequencer (AO, telescope and acquisition, laser, adn instrument).		1) Functional requirements for the software modules 2) Preliminary Operation Concept Document 3) Command interface and status simulator for the subsequencers 4) Built and tested prototype for the software modules
DD	Detailed design for the Observing Sequences (1) Acquisition sequences, 2) Observing Sequences, and 3) Performance Monitoring and Optimization). This effort required a coordinated effort with the subsystem sequencers.		1) Test report with prototype using the subsequencer simulator or/and the subsequencers when possible 2) Final functional requirements for the software modules. 3) Final design document for the hardware (if necessary) 4) Test plan for the observing sequences (lab, daytime, on-sky) 5) Configuration Control Plan for the observing sequences 6) Final OCD
FSD	Procure, build the observing sequences (1) Acquisition sequences, 2) Observing Sequences, and 3) Performance Monitoring and Optimization) per DD phase reports and integrate with the subsystem sequencers in the lab.		1) Software modules written and tested internally and with simulator 2) Sequences Manual for 1) Acquisition sequences, 2) Observing Sequences , and 3) Performance Monitoring and Optimization 3) Full integrated tests with other subsequencer (this could be sequential tests with one subsystem at a time) 4) Acceptane test plan at the telescope and with other subsystems
DC	The effort for the DC phase has now been added to Lab I &T and Telescope I&T.		

WBS	Level	ID	Name
6.1.4	5	WBS-481	System Health and Troubleshooting
Phase	**WBS Element**		**Deliverable**
PD	Produce a preliminary design based on SD functional requirements, the system design report and the updated observing scenarios for 1) System Health sequences, and 2) Troubleshooting sequences for the NGAO system during science operations. The design for these sequences needs to be consistent and coordinated with all other (sub) sequencer (AO, telescope and acquisition, laser, and instrument).		1) Functional requirements for the software modules 2) Preliminary Operation Concept Document 3) System health and status simulator for the subsequencers 4) Built and tested prototype for the software modules
DD	Detailed design for the MCS for System Health and Troubleshooting. This effort required a coordinated effort with the subsystem sequencers.		1) Test report with prototype using the subsequencer simulator or/and the subsequencers when possible 2) Final functional requirements for the software modules. 3) Final design document for the hardware (if necessary) 4) Test plan for the observing sequences (lab, daytime, on-sky) 5) Configuration Control Plan for the sequences 6) Final OCD
FSD	Procure, build the System Health and Troubleshooting per DD phase reports and integrate with the subsystem sequencers in the lab.		1) Software modules written and tested internally and with simulator 2) System Health and Troubleshooting Sequences Manual 3) Full integrated tests with other subsequencer (this could be sequential tests with one subsystem at a time) 4) Acceptane test plan at the telescope and with other subsystems
DC	The effort for the DC phase has now been added to Lab I &T and Telescope I&T.		See material on Twiki

WBS	Level	ID	Name
6.2	3	WBS-482	User Interfaces
Phase	**WBS Element**		**Deliverable**
PD			
DD			
FSD			
DC			

WBS	Level	ID	Name
6.2.1	4	WBS-483	User Interface Infrastructure
Phase	**WBS Element**		**Deliverable**
PD	Produce a preliminary design for the User Interfaces Infrastructure based on SD requirements, including definitions, communication protocols and standards, system interfaces (hardware and software), and documentation required for interfacing the user (operator, specialist, observer) and the commands. The infrastructure for this WBS needs to be consistent and coordinated with the infrastructure for the MCS and the Planning Tools (WBS 6).		1) Detailed design document for the User Interfaces 2) Functional requirements for the software 3) Preliminary Operation Concept Document 3) Modules Definitions 4) Detailed design document for the hardware
DD	Detailed Design for the User Interface Infrastructure		1) Final functional requirements for the software. 2) Final design document for the hardware 3) Test plan for the infrastructure 4) Configuration Control Plan for the GUI and other modules 5) Final OCD
FSD			1) Procure and assemble hardware 2) Software modules written and tested internally 3)User Interfaces Manual 4) Full integrated tests with MCS and planning tools 5) Acceptane test plan at the telescope
DC	The effort for the DC phase has now been added to Lab I &T and Telescope I&T.		

WBS	Level	ID	Name
6.2.2	4	WBS-484	Setup Operations: Configuration, Calibrations
Phase	**WBS Element**		**Deliverable**
PD	Based on SD requirements and the updated observing scenarios, produce a preliminary design for the Users' Tools to configure and calibrate the NGAO system and the science instruments. The infrastructure for this WBS needs to be consistent and coordinated with the MCS PD (WBS 6.1.2), the AO and instrument sequencers PD (WBS 4.4 and instruments) and the software for the diagnostic tools (WBS 4.3).		1) Functional requirements for the Configuration and Calibration Setup module from the User Interfaces 2) Preliminary Operation Concept Document 3) Simulation sofware for the MCS and the subsequencer (some prototype for MCS may exist) 4) Modules Definitions for the User Interface modules: configurations and calibrations
DD	Produce a detailed design for User Interfaces for the Configuration and Calibrations based on the PD report and the test results on the prototype.		1) Final functional requirements for the software modules. 2) Test plan for the User Interfaces 3) Report on Module Level Design, Description and Specifications 4) Final OCD
FSD	Build and Code the User Interface software. Integrate with the other tools and subsystems sequencers. Write the manual.		1) Software for User Interfaces written and tested internally 2) User Interface Manual for Operation Setup 3) Full integrated tests with AO sequencer (and instruments) and Pre-observing tools 4) Acceptane test plan at the telescope and with other subsystems
DC	The effort for the DC phase has now been added to Lab I &T and Telescope I&T.		

WBS	Level	ID	Name
6.2.3	4	WBS-485	Observations User Interfaces for operator, observer, specialist
Phase	**WBS Element**		**Deliverable**
PD	Based on the SD functional requirements and the updated observing scenarios, produce a preliminary design for the User Interface tools to operate the system for the three types of users: operator, specialist and observer. The UI to develop are: - Observations UI: Acquisitions and AO controls - Observations UI : Observing sequences execution UI - Observations UI: NGAO status and graph UI - Observations UI: Advanced Monitoring (stats, and alarm handler display) - Observations UI: Optimization and Troubleshooting Execution UI The preliminary design for this WBS needs to be consistent and coordinated with the MCS, the Planning Tools (WBS 6) and the instrument user interface.		1) Functional requirements for the User Interfaces, depending on the user 2) Preliminary Operation Concept Document 3) User Interface modules definitions
DD	Based on functional requirements and PD report on the test, develop final functional requirements for DD report.		1) Final functional requirements for the software modules. 2) Test plan for the User Interfaces 3) Report on Module Level Design, Description and Specifications 4) Final OCD
FSD	Code, build and integrate all User Interfaces with MCS annd Observation Planning Software.		1) Software for User Interfaces written and tested internally 2) User Interface Manual for User Interface for Operator, Specialist and Observer 3) Full integrated tests with MCS and Pre-observing tools 4) Acceptane test plan at the telescope and with other subsystems
DC	The effort for the DC phase has now been added to Lab I &T and Telescope I&T.		

WBS	Level	ID	Name
6.3	3	WBS-486	Pre- & Post-Observing Support
Phase	**WBS Element**		**Deliverable**
PD			
DD			
FSD			
DC			

WBS	Level	ID	Name
6.3.1	4	WBS-487	Users' Documentation
Phase	**WBS Element**		**Deliverable**
PD	For the preliminary design phase, provide a list of NGAO UsersÕ Documentation (electronic and paper) for the astronomer and estimate the WMKO support effort to keep the documentation up-to-date.		1) Preliminary Documentation Concept Document
DD	Provide a detailed plan for documentation list and management.		1) Final Requirements for Documentation 2) Draft documentation
FSD	Release 1 for documentation and build infrastructure to manage it..		1) Release 1 documentation for NGAO Observations and Operations 2) Documentation Control Management
DC	The effort for the DC phase has now been added to Lab I &T and Telescope I&T.		

WBS	Level	ID	Name
6.3.2	4	WBS-488	Planning Tools
Phase	**WBS Element**		**Deliverable**
PD	Based on the SD functional requirements and the updated observing scenarios, produce a preliminary design for the pre-observing tools: 1) NGS Finder Tool, 2) Performance Prediction Tool, 3) Observing Scenarios and Efficiency Tool and 4) Laser Clearinghouse Coordination Tool. The design for these tools needs to be consistent and coordinated with the User Interface tools for Operator, Observer and Specialist (WBS 6.2).		1) Functional requirements for the four tools and Use Case Definitions 2) Architecture and Interface Definitions 3) Preliminary Operation Concept Document 3) Modules Definitions
DD	Based on the PD functional requirements, complete final design for the pre-observing tools: 1) NGS Finder Tool, 2) Performance Prediction Tool, 3) Observing Scenarios and Efficiency Tool and 4) Laser Clearinghouse Coordination Tool. The design for these tools needs to be consistent and coordinated with the User Interface tools for Operator, Observer and Specialist (WBS 6.2).		1) Final functional requirements for the software modules. 2) Test plan for the Planning Tools 3) Report on Module Level Design, Description and Specifications 4) Final OCD
FSD	Procure, build the planning tools per DD phase reports and integrate with the User Interface and other subsystems in the lab.		1) Software modules written and tested internally, with the GUIs and the subsystem in lab 2) Tools shared with the observers participating in commisioning and VS phase 3) Planning Tools Manuals 4) Full integrated and remote tests 5) Acceptane test plan at the telescope and with other subsystems
DC	The effort for the DC phase has now been added to Lab I &T and Telescope I&T.		

WBS	Level	ID	Name
6.3.3	4	WBS-489	Data Products
Phase	**WBS Element**		**Deliverable**
PD	Based on the SD functional requirement and the SD report , produce the preliminary design requirements for the method & interfaces required to manage the data after the observations, for optimal science return. This WBS addresses three main aspects: 1) Generic Data Product: From the science cases and the observing scenarios, produce the PD for the data products for the science, data organization and data storage. 2) Science Data Quality Assessment: Produce the PD for the method, software tools, documentation, interfaces and WMKO support for a -posteriori quality metric estimate from the recorded data, including the implementation of PSF reconstruction. 3) Science Data Archiving: Produce the PD for method, software tools, documentation, interfaces and WMKO support required to archive the data. Particularly, explore options for flexible and expandable data archiving (including data retrieval) depending on the science requirements. Many aspects of this WBS needs to be coordinated with WBS 6.4 (data server) and the work fron the science teams (TBD) This WBS does not include the development of the algorithm for PSF reconstruction. This has been moved to WBS 3.4 and 3.5.		For each of - Generic Data Products, - Science Data Quality Assessment and - the Science Data Archiving Deliver: 1) Functional requirements 2) Preliminary Operation Concept Document 3) Modules Definitions
DD	Based on the PD functional requirements and the PD report, produce the detailed design requirements to manage the data after the observations, for optimal science return. There are 3 areas: 1) Generic Data Product: Produce a detailed design for the data products for the science, data organization and data storage. 2) Science Data Quality Assessment: Based on the PD studies and test results, produce the DD for the method and tools. The implementation of the method should be fully validated either at the telescope when possible or at the lab. 3) Science Data Archiving: Based on the PD report, the DD shoudl produce the final plans and report for for managing and planning for data archives.		1) Final functional requirements for the software modules. 2) Test plan for the User Interfaces 3) Report on Module Level Design, Description and Specifications 4) Final OCD
FSD	The FSD phase produces the tools for managing: code, build and integrate all tools and user interfaces with the subsystem, test and document.		1) Software modules written and tested internally with the data server (WBS 6.4) 2) Tools shared with the observers participating in commisioning and VS phase 3) Data Products Manuals 4) Full integrated and remote tests 5) Acceptane test plan at the telescope and with other subsystems
DC	The effort for the DC phase has now been added to Lab I &T and Telescope I&T.		

WBS	Level	ID	Name
6.4	3	WBS-490	Data Server
Phase	**WBS Element**		**Deliverable**
PD	Preliminary design of the NGAO data server system.		"1. A description and block diagram of the data server architecture. 2. A preliminary selection and specification of the data server COTS HW and SW components. 3. A preliminary design of custom data server SW. 4. A preliminary compliance matrix. 5. A preliminary test plan. 6. A report documenting the design."
DD	Detailed design of the NGAO data server system.		"1. A detailed description and diagram of the data server architecture. 2. A final selection and specification of the data server COTS HW and SW components. 3. Final design of custom data server SW. 4. A final compliance matrix. 5. A final test plan. 6. A report documenting the design."
FSD	Implementation and testing of the NGAO data server system.		The completed data server, tested and ready for telescope I&T.
DC	Telescope I&T of the data server system.		The complete data server system integrated into the NGAO system on the summit.

WBS	Level	ID	Name
7	2	WBS-491	Telescope & Summit Engineering
Phase	**WBS Element**		**Deliverable**
PD			
DD			
FSD			
DC			

WBS	Level	ID	Name
7.1	3	WBS-492	Telescope Performance
Phase	**WBS Element**		**Deliverable**
PD	This WBS covers any improvements or changes to the telescope performance required to support NGAO.		Preliminary design for telescope performance improvements, including requirements. Includes a trade study/investigation of what telescope improvements would have a significant impact on NGAO performance versus alternate approaches to achieving the performance requirements.
DD	his WBS covers any improvements or changes to the telescope performance required to support NGAO.		Detailed design for telescope performance improvements.
FSD	his WBS covers any improvements or changes to the telescope performance required to support NGAO.		Implemented, tested and documented telescope performance improvements at the telescope satisfying the requirements.
DC	NA		

WBS	Level	ID	Name
7.2	3	WBS-493	Infrastructure Mods for AO
Phase	**WBS Element**		**Deliverable**
PD	Produce preliminary design for needed infrastructure modifications for installation of AO system. This WBS does not consider software modifications such as telescope drive control system (DCS), upgrades to EPICS, etc. for example Plan for anticipated needs of new instruments (cooling,LN2, power, etc.), coordinate with instrument development		1. Preliminary mechanical design for modifications to Nasmyth deck and support structure 2. Preliminary design for electrical power modifications to support AO cooled enclosure 3. Preliminary electrical power design to support AO electrical power needs 4. Preliminary design for piping for waste heat removal from Keck "meet locker" enclosure to outside of dome (see 4.1 AO enclosure) 5. Preliminary design for modification to facility glycol system (if needed) 6. Preliminary design for azimuth wrap, cables trays, conduits, run from Nasmyth deck to other areas of the observatory 7. Preliminary design of modification to systems for cooling (AO detectors IR WFS and new Instruments d-IFS, OSIRIS, Vis Imager, NIR Imager) 8. Interfaces (internal to NGAO) 9. Assembly and test plans 10. Verify compliance, update requirements matrices and updated requirements (preliminary specifications) 11. Document design
DD	Produce final design for needed infrastructure mods for installation of AO system. This WBS does not consider software infrastructure changes such as the telescope drive control system software (DCS), upgrades to EPICS, etc. for example. Plan for anticipated needs of new instruments (LN2, power, etc.), coordinate with instrument development		1. Final mechanical design for modifications to Nasmyth deck and support structure 2. Final design for electrical power modifications to support AO cooled enclosure 3. Final electrical power design to support AO electrical power needs 4. Final design for piping for waste heat removal from Keck "meet locker" enclosure to outside of dome (Part of AO enclosure estimate) 5. Final design for modification to facility glycol system (if needed) 6. Final design for cable trays, conduits, etc. run from Nasmyth deck to other areas of the observatory 7. Final design of modification to system for cooling (AO detectors IR WFS and new Instruments d-IFS, OSIRIS, Vis Imager, NIR Imager) 8. Installation plan and test plans 9. Engineering change requests (ECR) approved 10. Vendor quotes 11. Verify compliance, compliance matrices and final specifications (requirements) 12. Document design
FSD	Perform needed modifications to the Keck facility		1. Mechanical modifications to Nasmyth deck and support structure 2. Electrical power modifications to support AO cooled enclosure 3. Electrical power modification to support AO electrical power needs 4. Construct duct work for waste heat removal from AO enclosure to area outside of Keck dome 5. Perform modifications to facility glycol system (if needed) 6. Add or modify cable trays, conduits, etc. run from Nasmyth deck to other areas of the observatory 7. Modification to LN2 system for cooling (AO detectors IR WFS and new Instruments d-IFS, OSIRIS, Vis Imager, NIR Imager) 8. Regression testing of WMKO modifications 9. Update observatory documentation, "As built" electrical and mechanical documentation
DC	Facility modification are done "in place" during FSD phase. Results of needed "regression" testing after modification to Keck facility see FSD phase 7.2		N/A

WBS	Level	ID	Name
7.3	3	WBS-494	Infrastructure Mods for Laser
Phase	**WBS Element**		**Deliverable**
PD	Produce preliminary design for needed infrastructure mods for installation of laser system. This WBS does not consider software modifications such as existing laser safety system for example		1. Preliminary mechanical design for modifications to telescope elevation ring, secondary support, Nasmyth deck structures 2. Preliminary design for telescope modifications to support beam transport system 3. Preliminary electrical power design to support laser electrical power needs 4. Preliminary design for modification to facility glycol system 5. Preliminary design for azimuth wrap, cables trays, conduits, etc. run from laser enclosure, telescope secondary to other areas of the observatory 6. Interfaces (internal to NGAO) 7. Assembly, and test plans 8. Verify compliance, update requirements matrices and updated requirements (preliminary specifications) 9. Document design
DD	Produce final design for needed infrastructure mods for installation of laser system		1. Design of platform to support laser enclosure 2. Final mechanical design for modifications to telescope elevation ring, secondary support, Nasmyth deck structures 3. Final design for modification to telescope structure to support beam transport system 4. Final electrical power design to support laser electrical power needs 5. Final design for modification to facility glycol system 6. Final design for cables, trays, conduits, run from laser enclosure, telescope secondary to other areas of the observatory 7. Installation plan 8. Engineering change requests (ECR) approved 9. Vendor quotes 10. Verify compliance, compliance matrices and final specifications (requirements) 11. Document design
FSD	Perform needed modifications to the Keck facility.		1. Mechanical modification to telescope structure 2. Mechanical modification for laser platform 3. Electrical power modifications to support laser electrical power needs 4. Modifications to facility glycol system 5. Conduits, hangers and cable trays installed 6. Regression testing of telescope and other observatory systems (test results) 7. Updates to observatory documentation ("As built" optical, mechanical, electrical) 8. List of critical spare parts
DC	Facility modification are done "in place" during FSD phase.		N/A

WBS	Level	ID	Name
7.4	3	WBS-495	OSIRIS Modifications
Phase	**WBS Element**		**Deliverable**
PD	This WBS element will determine the modifications required to allow OSIRIS to be used with NGAO. The scope of this effort assumes that no optical or performance changes will be required for OSIRIS, and it assumes that NGAO will provide the required optical interface and calibration sources for OSIRIS. This element also assumes that a fixed position frame with dewar lid lift will be designed and built as part of the Keck I LGS project's move of OSIRIS from Keck II to Keck I. This element will develop a preliminary design for the required mechanical and electrical/electronic modifications. This element will also develop a revised ICD for OSIRIS including a preliminary set of requirements for the software interface between OSIRIS and the AO system.		Preliminary design package for mechanical and electrical/electronic modifications. Revised OSIRIS ICD for NGAO.
DD	This element will develop a detailed design for the required mechanical and electrical/electronic modifications to allow OSIRIS to be used with the AO system. This element will update the revised ICD for OSIRIS developed in the PD phase, including final requirements for the software interface between OSIRIS and the AO system. This element will also produce a draft ATP for the OSIRIS modifications.		Detailed design package for mechanical and electrical/electronic modifications. Final OSIRIS ICD for NGAO. Draft ATP for OSIRIS modifications.
FSD	This element will implement the required mechanical and electrical/electronic modifications to allow OSIRIS to be used with the AO system. This element will also perform an ATP for the OSIRIS modifications.		OSIRIS modifications per detailed design. ATP report for the modifications.
DC	This element will install the modified OSIRIS on the AO system and perform the required commissioning tests.		OSIRIS ready to go with NGAO.

WBS	Level	ID	Name
7.5	3	WBS-496	Interferometer and OHANA Mods
Phase	**WBS Element**		**Deliverable**
PD	Preliminary design work for NGAO support of Keck Interferometer, OHANA and ASTRA. Design work specific to support of interferometry at Keck Some of this work may overlap with design work for NGAO optical bench, motion control, non-real-time control, real-time control		1. Polarization study 2. Optical design of NGAO interferometer interface including a complete ray trace design, preliminary tolerances, and a preliminary alignment plan. 3. Mechanical design for interferometer including mounts for optics, mechanical drawings, structural analysis, mechanisms designs, and motion control. 4. Electrical design of interferometer interface including motion control for mechanisms 5. Interfaces (internal to NGAO) 6. Assembly, alignment, and test plans 7. Verify compliance, update requirements matrices and updated requirements (preliminary specifications) 8. Document design
DD	Detailed design work for NGAO support of Keck Interferometer, OHANA and ASTRA. Design work specific to support of interferometry at Keck. Verify that design provides required performance. Some of this work may overlap with detailed design work for NGAO optical bench, motion control, non-real-time control, real-time control		1. Final optical design of interferometer interface including a ray trace design, design tolerances, and alignment plan 2. Final mechanical design of interferometer interface (fabrication drawings, structural analysis, mechanisms designs, motion control 3. Final electrical design for motion control and other interface electrical systems 4. Assembly, alignment, and test plans 5. Vendor quotes 6. Verify compliance, compliance matrices and final specifications (requirements) 7. Document design
FSD	Construct modification needed for NGAO to support interferometry observations including KI, ASTRA and OHANA		1. Interferometer interface (assemble) 2. Factory acceptance test results 3 . "As built" optical, mechanical, electrical documentation 4. List of critical spare parts 5. Compliance matrices and readiness evaluation 6. Delivery of interferometry interface to AO integration lab 7. Test delivered system as a unit before installation into AO systems
DC	N/A		N/A

WBS	Level	ID	Name
8	2	WBS-497	Telescope Integration & Test
Phase	**WBS Element**		**Deliverable**
PD			
DD			
FSD			
DC			

WBS	Level	ID	Name
8.1	3	WBS-498	Old AO/Laser Removal
Phase	**WBS Element**		**Deliverable**
PD	Removal of the existing AO and laser systems from the NGAO telescope and summit, and appropriate distribution or disposal of this equipment.		Preliminary plan for AO and laser system removal, in enough detail to use to make a reasonable cost estimate.
DD	Removal of the existing AO and laser systems from the NGAO telescope and summit, and appropriate distribution or disposal of this equipment.		Detailed plan for AO and laser system removal. Should include inventory of everything requiring removal, which items need to be kept & how each item will be stored or disposed.
FSD	Removal of the existing AO and laser systems from the NGAO telescope and summit, and appropriate distribution or disposal of this equipment.		Review plans for AO and laser system removal & update as appropriate. Should include inventory of everything requiring removal, which items need to be kept & how each item will be stored or disposed.
DC	Removal of the existing AO and laser systems from the NGAO telescope and summit, and appropriate distribution or disposal of this equipment.		AO and laser systems removed from the telescope and summit.

WBS	Level	ID	Name
8.2	3	WBS-499	Laser Enclosure Integration
Phase	**WBS Element**		**Deliverable**
PD	N/A see laser enclosure design elements PD phase WBS 5.1		
DD	N/A see laser enclosure design elements DD phase WBS 5.1		
FSD	N/A see laser enclosure elements FSD phase WBS 5.1		N/A
DC	Installation of support systems inside laser enclosure including electrical, thermal management, environmental control (temp, humidity, particle count, etc.) Testing of installed laser enclosure systems, part of laser system installation, integration and testing 8.2		1. Infrastructure installation 2. Safety interlocks wire up 3. Electrical connections, "wall power" for laser 4. Network connections

WBS	Level	ID	Name
8.3	3	WBS-500	AO Enclosure Integration
Phase	**WBS Element**		**Deliverable**
PD	N/A see AO enclosure design elements PD phase WBS 4.1		
DD	N/A see AO enclosure design elements DD phase WBS 4.1		
FSD	N/A see AO enclosure infrastructure instatallation FSD phase WBS 8.3		
DC	Installation of support systems inside AO enclosure including electrical, cooling/thermal management, environmental control (temp, humidity, particle count, etc.) Testing of installed AO enclosure systems, part of AO system installation, integration and testing 8.1		1. Install electrical connections 2. Install Infrastructure (HEPA Filter, interlocks, env. sensors and monitors) 3. AO bench mounts 4. Network connections

WBS	Level	ID	Name
8.4	3	WBS-501	AO System Install + I&T
Phase	**WBS Element**		**Deliverable**
PD	Packing and shipping of the AO lab system to the summit. Installation of the AO system in the AO and electronics enclosures, along with the lab science instrument. Integration and test at the level demonstrated during AO system lab I&T. NGS AO I&T on the sky with the first science instrument. I&T with the following science instruments is included: NIR imager, OSIRIS and interferometer. I&T with the visible camera and the d-IFS will happen as these instruments are available; install of these instruments will be covered by the instrument projects and only the AO part of their I&T is covered here.		Preliminary design for AO system install and I&T.
DD	Packing and shipping of the AO lab system to the summit. Installation of the AO system in the AO and electronics enclosures, along with the lab science instrument. Integration and test at the level demonstrated during AO system lab I&T. NGS AO I&T on the sky with the first science instrument. I&T with the following science instruments is included: NIR imager, OSIRIS and interferometer. I&T with the visible camera and the d-IFS will happen as these instruments are available; install of these instruments will be covered by the instrument projects and only the AO part of their I&T is covered here.		Detailed design for AO system install and I&T.
FSD	Packing and shipping of the AO lab system to the summit. Installation of the AO system in the AO and electronics enclosures, along with the lab science instrument. Integration and test at the level demonstrated during AO system lab I&T. NGS AO I&T on the sky with the first science instrument. I&T with the following science instruments is included: NIR imager, OSIRIS and interferometer. I&T with the visible camera and the d-IFS will happen as these instruments are available; install of these instruments will be covered by the instrument projects and only the AO part of their I&T is covered here.		Final install and I&T plans, updated based on FSD phase.
DC	Packing and shipping of the AO lab system to the summit. Installation of the AO system in the AO and electronics enclosures, along with the lab science instrument. Integration and test at the level demonstrated during AO system lab I&T. NGS AO I&T on the sky with the first science instrument. I&T with the following science instruments is included: NIR imager, OSIRIS and interferometer. I&T with the visible camera and the d-IFS will happen as these instruments are available; install of these instruments will be covered by the instrument projects and only the AO part of their I&T is covered here.		Fully functional AO system on telescope. Telescope off-sky I&T report. NGS AO I&T report for each science instrument.

WBS	Level	ID	Name
8.5	3	WBS-502	Laser System Install + I&T
Phase	**WBS Element**		**Deliverable**
PD	Preliminary design level plan for telescope installation, integration and testing for all aspects of the laser system		1. Preliminary design level plan for installation, integration of laser facility 2. Preliminary design level testing plan for laser system
DD	Final plan for telescope installation, integration and testing for all aspects of the laser system		1. Final laser system installation and integration plan 2. Final testing plan
FSD	See WBS 8.5 DC phase		
DC	Integration of laser system at telescope. Test various laser subsystems on telescope: laser, laser transport, laser control, laser safety systems. System level testing of laser facility including testing of laser system on the sky without AO system. Final testing of laser system on sky (without AO). Testing with AO system is part of WBS 8.3, 8.4, 8.5		1. Installation of laser facility subsystems on telescope a) Laser b) Beam transport (AO enclosure+Coude) c) Launch Telescope d) Control software e) Safety systems software 2. Test results for parts of laser facility that can only be practically tested when full system is integrated on telescope 3. Test results of laser facility on-sky testing 4. Acceptance (i.e. formal review) of laser facility 5. Final documentation

WBS	Level	ID	Name
8.6	3	WBS-503	LGS AO System On-sky I&T
Phase	**WBS Element**		**Deliverable**
PD	During the PD phase, the team will produce a design report, based on previous on-sky comissioning experience at Keck and elsewhere. A preliminary design will be provided for the tools required for the on-sky I&T.		1) Preliminary Design LGS AO system On-sky I&T: plan and tools
DD	During the DD phase, the team produces release 1 for the plan for the LGS AO System On-sky I&T. All tests must be coordinated with WBS 8.1 and 8.2.		1) Test report with prototype methods and tools, some of them tested and implemented with current LGS system and in the lab 2) Release 1 for the LGS AO System On-sky I&T plan
FSD	During the Full Scale Development phase, the team delivers a Final version for the LGS AO system on-sky I&T. The tools required for the I&T are being built. The scientists are exercising the tools in the lab or current LGS system. The plan includes the management of the engineering data.		1) Release 2 for the LGS AO System On-sky I&T plan 2) Final Test-Level Design, Description and Data Reduction Plan 3) Test validation using Lab or on-sky K1 LGSAO
DC	The LGS AO System On-sky I&T is one of the main phase during the DC phase. This element includes the effort required for LGS AO System On-sky I&T for the purpose of validating the AO system performance budgets in LGS-AO mode. It does include validation of the science operations tools and characterization of the observational efficiency performance.		1) Reports describing the operations and performance of individual subsystems on-sky (LOWFS, HOWFS, etc) 2) Report characterizing the performance in operations of the integrated system (accuracy and efficiency for dither sequences, tracking & guiding, Na layer tracking, etc) 3) Report describing the overall AO system performance budget (TT and LO WF error, HO error including tomographic error, calibration errors, etc) as a function of the atmospheric turbulence profile. 4) Report describing the evaluation of the science operations tools (including Observing Sequences) for LGS AO operations. 5) Report describing the observing efficiency budget for several key observing modes.

WBS	Level	ID	Name
8.7	3	WBS-504	Performance Characterization
Phase	**WBS Element**		**Deliverable**
PD	Not applicable. No performance characterization is planned for this phase.		
DD	This effort includes development of a draft performance characterization plan to inform the design process. It should include enough detail to understand the steps that will be required for performance characterization work in the DC phase.		Draft performance characterization plan.
FSD	Not applicable. No performance characterization is planned for this phase.		
DC	This element includes the effort required for initial NGAO system performance characterization for the purpose of producing information for observers to assist in their planning of observations. It does not include validation of all AO system performance budgets, which will be done under WBS 8.4, 8.5, and 8.6. It also does not include characterization of the observational efficiency performance (WBS 6).		Report describing Strehl and/or FWHM and/or Ensquared Energy vs. r0, vs. NGS HO star brightness, off-axis NGS HO distance, laser guide star return, sky fraction (for various galactic latitudes), laser guide star asterism, LOWFS source brightness, LOWFS source geometry, LOWFS source extent, HO WFS pupil sampling, turbulence-weighted wind speed , lunation and distance from the moon. Report describing photometric and astrometric precision and Strehl stability under various conditions Report describing high-contrast performance vs. guide star brightness

WBS	Level	ID	Name
8.8	3	WBS-505	Science Verification
Phase	**WBS Element**		**Deliverable**
PD	During the Prelimanry Design phase, the team produces a plan for conducting the Science Verification (SV) phase. This phase takes place during the NGAO comissioning and before the handover to the observing support team.		1) Preliminary plan for SV phase
DD	During the detailed design, the team produces a detailed plan for the SV phase. Type of science, instruments, participating teams, data policy, etc		1) Release 1 for the SV plan 2) Preliminary SV Case Level Design, Description and Data Reduction Plan
FSD	During the FSD, the SV team develop a Release 2 for the SV plan. This plan includes the type of observations and instruments, science team selection , methodology with particular emphasis with expected return for the NGAO team (tool validation, etc). Some of the science team may need to start working on simulation, analysis tool that will be needed when the SV data is released.		1) Release 2 for the SV phase, including inputs and preparation from the science teams
DC	The SV phase takes place during the commissioning of the instruments. The SV observations are conducted, the data posted and shared(?). The scientists use the available NGAO tools for data quality analysis. Following the scientific analysis of the data, a report is handed over to the NGAO SV team. This report is a quality metric for the science efficiency of the NGAO + instruments, prior to the operation handover.		1) Scientific papers 2) VS report and recommendations

WBS	Level	ID	Name
9	2	WBS-506	Operations Transition
Phase	**WBS Element**		**Deliverable**
PD			
DD			
FSD			
DC			

WBS	Level	ID	Name
9.1	3	WBS-507	Operations Plans
Phase	**WBS Element**		**Deliverable**
PD	Development of operations plans, including an observing support plan, and an operations maintenance and spares plan, and a spares inventory. Although some initial design documentation can be prepared the bulk of this document will need to be prepared as we gain more experience with the system during the FSD and DC phases.		1) Preliminary observing support plan. 2) Preliminary operations maintenance & spares plan. May largely be a template to be filled in during the FSD phase. Should include all the major maintenance categories and a spreadsheet template for the spares. Should look at similar documents and the spares required for the existing Keck AO systems.
DD	Development of operations plans, including an observing support plan, and an operations maintenance and spares plan, and a spares inventory. Although some initial design documentation can be prepared the bulk of this document will need to be prepared as we gain more experience with the system during the FSD and DC phases.		Minor revision of the preliminary operations plans.
FSD	Development of operations plans, including an observing support plan, and an operations maintenance and spares plan, and a spares inventory. Although some initial design documentation can be prepared the bulk of this document will need to be prepared as we gain more experience with the system during the FSD and DC phases.		1) Operations observing support plan based on the development of the system, especially the science operations tools. 2) Operations maintenance & spares plan based on subsystem fabrication & lab I&T results. Spares inventory. Need to understand from each subsystem lead what maintenance & spares are required.
DC	Development of operations plans, including an observing support plan, and an operations maintenance and spares plan, and a spares inventory. Although some initial design documentation can be prepared the bulk of this document will need to be prepared as we gain more experience with the system during the FSD and DC phases.		1) Final operations observing support plan based on the telescope I&T experience. 2) Final operations maintenance & spares plan based on telescope I&T results. Final spares inventory, with additional required spares procured for operations.

WBS	Level	ID	Name
9.2	3	WBS-508	Operations Handover
Phase	**WBS Element**		**Deliverable**
PD			
DD			
FSD			
DC			

WBS	Level	ID	Name
9.2.1	4	WBS-509	Operations Personnel Training
Phase	**WBS Element**		**Deliverable**
PD	This element includes a plan for operations personnel training. During the PD, an early version for this plan will be released, focusing on the topics for the training and a preliminary agenda and targets for implementing the training.		1) Preliminary Design for the Operations Personel Training (Observing support, EE, ME, SE, etc..)
DD	This element includes a plan for operations personnel training. During the DD, a Release 1 plan is developed between the NGAO, the Observatory scientists and engineers, and WMKO Group Leads.		1) Release 1 for the Operations Personnel Training (Observing support, EE, ME, SE, etc..)
FSD	The Operations Personnel Training starts during this phase for some of the key personnels and the key training issues . A Release 2 for the plan is produced. This WBS needs to be coordinated with the WBS 9.3.		1) Release 2 for the plan co-authored by some Observatory Scientists and Engineers, and WMKO Group Leads 2) Operations Personnel Training Matrix in place 3) Start active Training and manage matrix
DC	During this phase, the Observatory personel assist the NGAO teams, and are in the main phase of their active training. The training plan is being executing. A training matrix is used to monitor the training needs and status. Again, this is to be coordinated with the operation handover process.		1) Training Matrix and Training Report

WBS	Level	ID	Name
9.2.2	4	WBS-510	Documentation & Spares Transition
Phase	**WBS Element**		**Deliverable**
PD	This element includes the design for the plan to transition the documentation and the spares management. During the PD, an early version for this plan will be released.		1) PD plan for documentation and spreas management transition
DD	This element includes a plan for transitioning the documentation and the spares management. During the DD, a Release 1 plan is developed between the NGAO, the Observatory scientists and engineers, and WMKO Group Leads.		1) Release 1 for the plan to transition document and spares management
FSD	A Release 2 for the plan to transition the documentation and the spare management is produced. WMKO personnel start actively reviewing the available information. This WBS needs to be coordinated with the WBS 9.3.		1) Release 2 for the plan co-authored by some Observatory Scientists and Engineers, and WMKO Group Leads 2) Start active Documentation and Spare list review
DC	During this phase, the Observatory personel assist the NGAO teams, and are in the main phase of their active training. The personnel review the documentation and the lists of spares as they become more familiar with NGAO. The management for the documentation and the spare is transition from the development team to the operations team.		