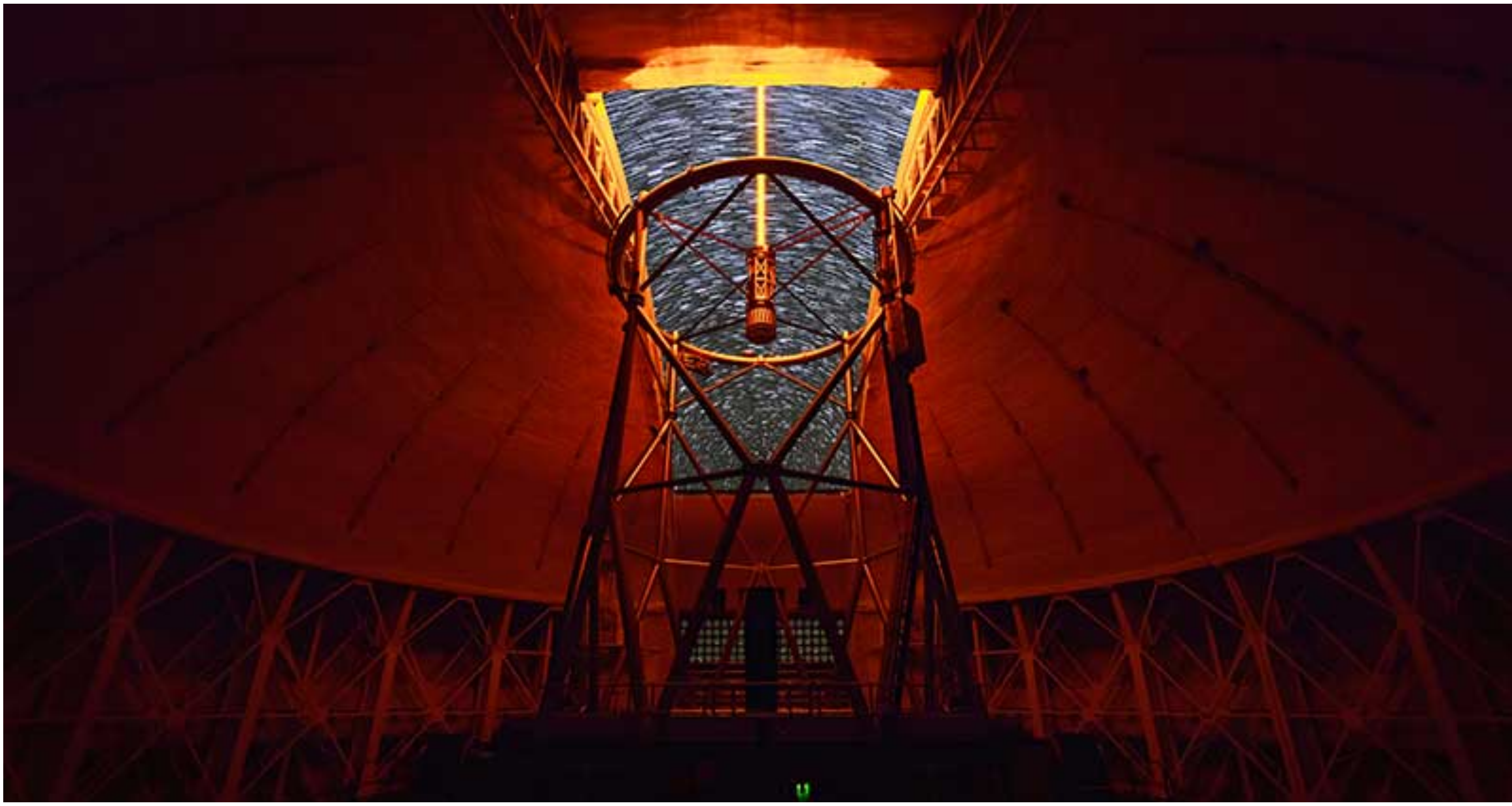

Gemini in the Era of Multi Messenger Astronomy

Gemini North Adaptive Optics System

NSF Quarterly Progress Report
For the period of Performance April 2019 – June 2019

Submitted by:
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Table of Contents

Introduction and Overview

The progress of the GEMMA Gemini North Adaptive Optics and the Real-time Computer (GNAO) project is described for the quarter April 1 to June 30, 2019. This report makes reference to the 24 May 2019 version of the GNAO Project Execution Plan.

The project has completed 9 months of the 60-month effort. During this period, GNAO successfully completed intermediate milestones advancing the project in the conceptual design phase on track for review September 26th and 27th 2019. To date, the Project budgeted $1,303,772 and has incurred approximately $381,835 in actual costs.

In May, a decision was made to change the governance structure of the GEMMA program. Due to the importance and size of the GEMMA Program and the need for GEMMA to pull resources from across nearly all areas of the Observatory, the Director appointed a GEMMA Executive Committee, chaired by the Deputy Director. The Director has the authority to set the membership of the Executive Committee and to make final decisions if necessary. Within the Observatory, the Executive Committee controls the resources necessary to the success of GEMMA and will resolve resource conflicts without escalation to the Director in most cases. The Executive Committee Chair keeps the Director informed about major issues and decisions. The decision was also made to combine the GNAO and RTC projects under a single project.

For the GNAO + RTC project, the project manager and principal investigator share management of the project. The PM is responsible for the day-to-day management of the project, and the PI is responsible for the alignment with the science requirements. The project manager and the principal investigator co-equally report to the Chair and the Executive Committee. Henry Roe will also act as the line manager for the GNAO+RTC PM.

Issues arising with GNAO+RTC will be escalated to the Chair, who will work with the GEMMA Program Manager, GNAO+RTC Project Manager, and Principal Investigator to ensure the Executive Committee is kept fully informed of developing issues. The Executive Committee will pull in additional expertise as needed from across GEMMA and Gemini.

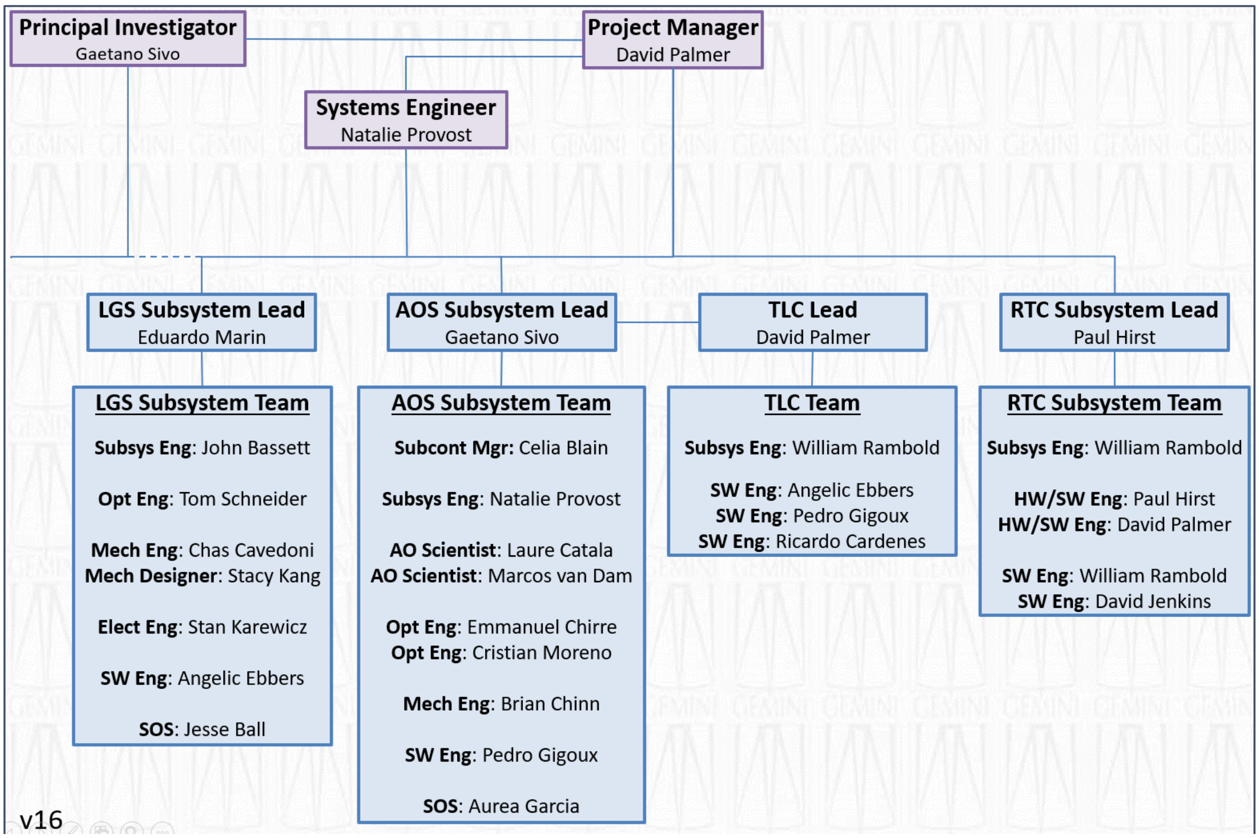
GEMMA Program Roles

GEC members: For each project in GEMMA there is a designated member of the GEC who holds responsibility for interfacing to the project and represents the GEC for the responsibilities listed below. For GNAO+RTC that member is Henry Roe.

GEMMA Executive Committee	
Name	**Title**
Henry Roe (Chair)	Deputy Director
John Blakeslee	Chief Scientist
Inger Jørgensen	Portfolio Manager
Scot Kleinman	Associate Director Development
Andy Adamson	Associate Director Hawai'i Operations
Rene Rutten	Associate Director Chile Operations
Catherine Blough (GEMMA Program Manager)	Senior Program and Project Coordinator

During this quarter staffing changes were also made. The GNAO PM transitioned from Stephen Goodsell to David Palmer and RTC PM transition from David Henderson to David Palmer was completed. GNAO/RTC labor needs for the project were assessed as part of the in-depth PEP revision and with continuous negotiation for in-house labor (made easier by the very high priority the observatory has given GNAO/RTC), labor needs are currently met.

The technical organizational structure was refined to better focus the work to be performed and the corresponding communication. This standard project organization empowers the subsystem leads to perform their jobs, along with their teams, reporting progress and problems up to the PI/PM.



Project Management

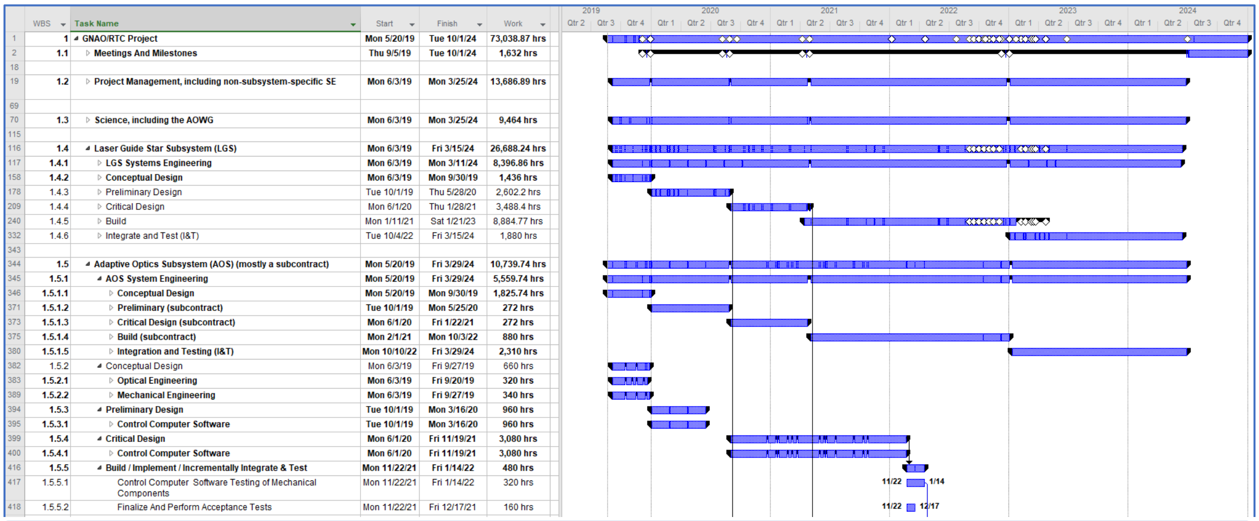
During the month of May, NSF requested that a revised PEP, including a resource-loaded WBS, be submitted by May 24th. A significant amount of project team effort was utilized to develop the WBS and develop the basis of estimates for procurements. This activity served to bring together the team and develop a common understanding of the project scope, schedule, milestones, work packages, cost and tasks.

The GNAO scope, from its planning stage through a first-light astronomical image, concluding at completion of Integration and Testing and the completion of a commissioning plan as part of the current funding, is unchanged and the end-of-project deliverables are identified in the following list:

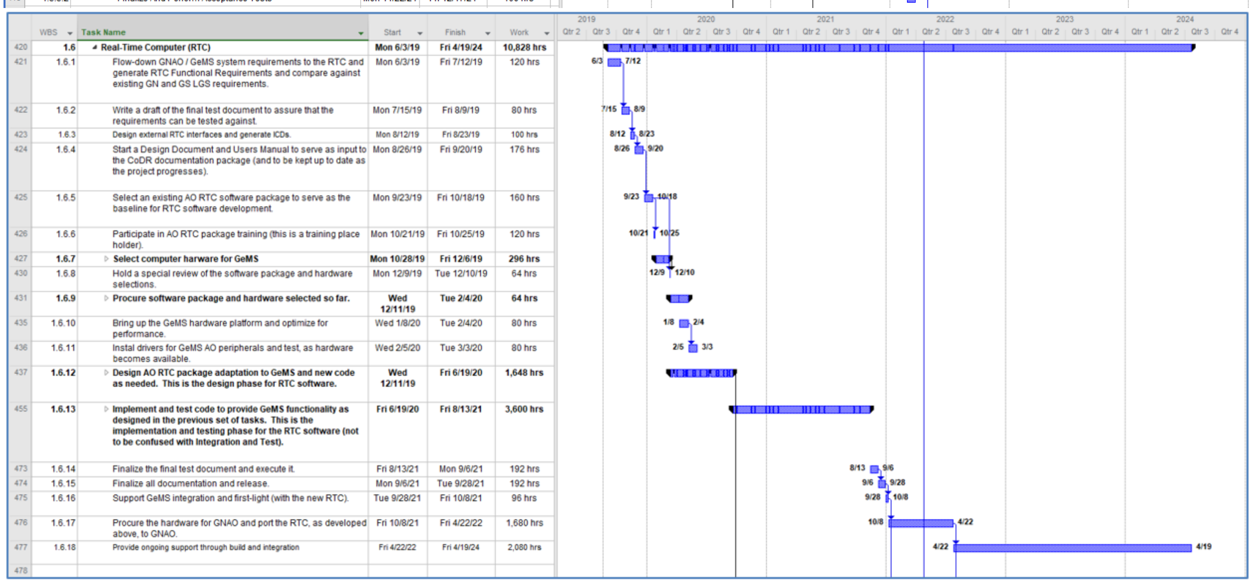
- GNAO/RTC Facility
- GNAO/RTC Documentation Set
- GNAO/RTC Facility Associated Hardware
- GNAO/RTC Facility Associated Software

- Relevant Observatory Infrastructure Upgrades
- Relevant Observatory Control System Upgrades
- Staff GNAO/RTC Training

The GNAO/RTC schedule (high level rollup shown below) has not changed in this quarter and is still on track to meet the first milestone, the CoDR review in September. Significant work continues as described in the list of WBS tasks in the next section.



	WBS	Task Name	Start	Finish	Work
1	**1**	**GNAO/RTC Project**	**Mon 5/20/19**	**Tue 10/1/24**	**73,038.87 hrs**
2	**1.1**	**Meetings And Milestones**	**Thu 9/5/19**	**Tue 10/1/24**	**1,632 hrs**
18					
19	**1.2**	**Project Management, including non-subsystem-specific SE**	**Mon 6/3/19**	**Mon 3/25/24**	**13,686.89 hrs**
69					
70	**1.3**	**Science, including the AOWG**	**Mon 6/3/19**	**Mon 3/25/24**	**9,464 hrs**
115					
116	**1.4**	**Laser Guide Star Subsystem (LGS)**	**Mon 6/3/19**	**Fri 3/15/24**	**26,688.24 hrs**
117	**1.4.1**	**LGS Systems Engineering**	**Mon 6/3/19**	**Mon 3/11/24**	**8,396.86 hrs**
158	**1.4.2**	**Conceptual Design**	**Mon 6/3/19**	**Mon 9/30/19**	**1,436 hrs**
178	1.4.3	Preliminary Design	Tue 10/1/19	Thu 5/28/20	2,602.2 hrs
209	1.4.4	Critical Design	Mon 6/1/20	Thu 1/28/21	3,488.4 hrs
240	1.4.5	Build	Mon 1/11/21	Sat 1/21/23	8,884.77 hrs
332	1.4.6	Integrate and Test (I&T)	Tue 10/4/22	Fri 3/15/24	1,880 hrs
343					
344	**1.5**	**Adaptive Optics Subsystem (AOS) (mostly a subcontract)**	**Mon 5/20/19**	**Fri 3/29/24**	**10,739.74 hrs**
345	**1.5.1**	**AOS System Engineering**	**Mon 5/20/19**	**Fri 3/29/24**	**5,559.74 hrs**
346	**1.5.1.1**	**Conceptual Design**	**Mon 5/20/19**	**Mon 9/30/19**	**1,825.74 hrs**
371	**1.5.1.2**	**Preliminary (subcontract)**	**Tue 10/1/19**	**Mon 5/25/20**	**272 hrs**
373	**1.5.1.3**	**Critical Design (subcontract)**	**Mon 6/1/20**	**Fri 1/22/21**	**272 hrs**
375	**1.5.1.4**	**Build (subcontract)**	**Mon 2/1/21**	**Mon 10/3/22**	**880 hrs**
380	**1.5.1.5**	**Integration and Testing (I&T)**	**Mon 10/10/22**	**Fri 3/29/24**	**2,310 hrs**
382	1.5.2	Conceptual Design	Mon 6/3/19	Fri 9/27/19	660 hrs
383	**1.5.2.1**	**Optical Engineering**	**Mon 6/3/19**	**Fri 9/20/19**	**320 hrs**
389	**1.5.2.2**	**Mechanical Engineering**	**Mon 6/3/19**	**Fri 9/27/19**	**340 hrs**
394	**1.5.3**	**Preliminary Design**	**Tue 10/1/19**	**Mon 3/16/20**	**960 hrs**
395	**1.5.3.1**	**Control Computer Software**	**Tue 10/1/19**	**Mon 3/16/20**	**960 hrs**
399	**1.5.4**	**Critical Design**	**Mon 6/1/20**	**Fri 11/19/21**	**3,080 hrs**
400	**1.5.4.1**	**Control Computer Software**	**Mon 6/1/20**	**Fri 11/19/21**	**3,080 hrs**
416	**1.5.5**	**Build / Implement / Incrementally Integrate & Test**	**Mon 11/22/21**	**Fri 1/14/22**	**480 hrs**
417	1.5.5.1	Control Computer Software Testing of Mechanical Components	Mon 11/22/21	Fri 1/14/22	320 hrs
418	1.5.5.2	Finalize And Perform Acceptance Tests	Mon 11/22/21	Fri 12/17/21	160 hrs



	WBS	Task Name	Start	Finish	Work
420	**1.6**	**Real-Time Computer (RTC)**	**Mon 6/3/19**	**Fri 4/19/24**	**10,828 hrs**
421	1.6.1	Flow-down GNAO / GeMS system requirements to the RTC and generate RTC Functional Requirements and compare against existing GN and GS LGS requirements.	Mon 6/3/19	Fri 7/12/19	120 hrs
422	1.6.2	Write a draft of the final test document to assure that the requirements can be tested against.	Mon 7/15/19	Fri 8/9/19	80 hrs
423	1.6.3	Design external RTC interfaces and generate ICDs.	Mon 8/12/19	Fri 8/23/19	100 hrs
424	1.6.4	Start a Design Document and Users Manual to serve as input to the CoDR documentation package (and to be kept up to date as the project progresses).	Mon 8/26/19	Fri 9/20/19	176 hrs
425	1.6.5	Select an existing AO RTC software package to serve as the baseline for RTC software development.	Mon 9/23/19	Fri 10/18/19	160 hrs
426	1.6.6	Participate in AO RTC package training (this is a training place holder).	Mon 10/21/19	Fri 10/25/19	120 hrs
427	**1.6.7**	**Select computer harware for GeMS**	**Mon 10/28/19**	**Fri 12/6/19**	**296 hrs**
430	1.6.8	Hold a special review of the software package and hardware selections.	Mon 12/9/19	Tue 12/10/19	64 hrs
431	**1.6.9**	**Procure software package and hardware selected so far.**	**Wed 12/11/19**	**Tue 2/4/20**	**64 hrs**
435	1.6.10	Bring up the GeMS hardware platform and optimize for performance.	Wed 1/8/20	Tue 2/4/20	80 hrs
436	1.6.11	Instal drivers for GeMS AO peripherals and test, as hardware becomes available.	Wed 2/5/20	Tue 3/3/20	80 hrs
437	**1.6.12**	**Design AO RTC package adaptation to GeMS and new code as needed. This is the design phase for RTC software.**	**Wed 12/11/19**	**Fri 6/19/20**	**1,648 hrs**
455	**1.6.13**	**Implement and test code to provide GeMS functionality as designed in the previous set of tasks. This is the implementation and testing phase for the RTC software (not to be confused with Integration and Test).**	**Fri 6/19/20**	**Fri 8/13/21**	**3,600 hrs**
473	1.6.14	Finalize the final test document and execute it.	Fri 8/13/21	Mon 9/6/21	192 hrs
474	1.6.15	Finalize all documentation and release.	Mon 9/6/21	Tue 9/28/21	192 hrs
475	1.6.16	Support GeMS integration and first-light (with the new RTC).	Tue 9/28/21	Fri 10/8/21	96 hrs
476	1.6.17	Procure the hardware for GNAO and port the RTC, as developed above, to GNAO.	Fri 10/8/21	Fri 4/22/22	1,680 hrs
477	1.6.18	Provide ongoing support through build and integration	Fri 4/22/22	Fri 4/19/24	2,080 hrs
478					

The project has continued to "ramp up" staff effort, shown in the corresponding increase in labor costs. The table below shows the approved budget and expenses for the quarter ending June 30th 2019 and the year-to-date expenses.

GNAO	Approved Budget	3rd Qtr Expense	Total Expense YTD	Current Open Commitments	Spend Remaining
TOTAL WAGE & BENEFITS	659,553	178,361	281,112		456,003
TOTAL TRAVEL	56,492	12,009	12,009	7,494	36,988
TOTAL OTHER DIRECT COSTS	341,798	9,828	26,022	282,000	33,776
TOTAL EXPENSE	1,057,843	200,199	319,143	289,494	526,768
GRAND TOTAL	1,057,843	200,199	319,143	289,494	526,768
RTC	**Approved Budget**	**3rd Qtr Expense**	**Total Expense YTD**	**Current Open Commitments**	**Spend Remaining**
TOTAL WAGE & BENEFITS	65,929	28,281	56,729		37,631
TOTAL TRAVEL		-5,661			
TOTAL OTHER DIRECT COSTS	180,000	5,813	5,963	5,288	168,750
TOTAL EXPENSE	245,929	28,433	62,692	5,288	206,381
GRAND TOTAL	245,929	28,433	62,692	5,288	206,381

The project Risk Register is included as appendix A. There are identified high risks; however, when mitigated by Existing Controls, these end up as low to medium risks. In this quarter, no significant risks are identified.

WBS Progress

WBS 1.2.2 Systems Engineering

1.2.2 Conceptual Design

Configuration Management

Change Control Plan

- All changes to the project Configuration Items (CIs) will be managed using the Change Request system implemented in Jira.
- A change control board (CCB) has been formed consisting of the PM, PI, and SE.
- Exceeding the budget by greater than $200k or schedule threshold by greater than one month need Executive Committee Chair concurrence.
- All changes will be reported to the Executive Committee Chair, regardless of size.

Documentation Control Plan

- Baselined project documents are CIs. Therefore, they will go under change control as listed in the next slide: “*GNAO/RTC Documentation Set With CC Indicated”*.
- Once under change control, the same CCB described above will need to approve changes.
- To control the content and structure of project documents, we will use Gemini’s Document Management Tool (DMT), Docushare from Xerox.

Technical Management and Coordination

Technical Management and Coordination are executed applying tailored Systems Engineering (SE) Technical Management processes. These processes are cross cutting and applied to the Design and Realization Process (Implementation, Integration, V&V, and Transition to Operations) during the life cycle of the development of the project. These processes are:

- Technical Planning Process - in place since the creation of the PEP, and are detailed in the System Engineering Management Plan (SEMP).
- Technical Control Processes:
    - Requirements Management - implemented using DOORS.
    - Interface Management - implemented by functional decomposition of the functional architecture of the system design and by refining the physical architecture. Functional decomposition, using the functional flow block diagram (FFBD) technique and the generated N-Squared, support the definition of external and internal interfaces to later design and implement them. The design of the interfaces are documented in ICDs for configuration control.
    - Technical Risk Management - supported by the PMO risk management strategy.
    - Configuration Management - implementation explained in the preceding section.
    - Technical Data Management is used to capture trade studies, cost estimates, technical analyses, reports, and other important documents not necessary under formal configuration control. They are stored in Docushare.
- Technical Assessment Process - used mainly to monitor technical progress through internal and external reviews. Also, it is used to assess key performance Parameters (KPM) and Technical Performance Metrics (TPM) of the design (namely Error Budget), and provide status information to support the assessment of the design, future implementation and Integration, and technical management decisions.
- Technical Decision Analysis at the CoD phase - used to analyze designs and implementation (Buy, Re-Use, Build) alternatives.

All the above processes will be described in further detail in the SEMP. They are core components of the Systems Engineering Engine that drives the development of GNAO/RTC.

Top level systems architecture definition and Conceptual Design Iteration

The system architectures are progressing as part of the iterative and recursive process of the architecture definition of the conceptual design. The architecture definition is developed by function decomposition, using the FFBD technique and iteratively bidirectionally assessed against the physical architecture represented by the Project Breakdown Structure (PBS).

WBS 1.3.1 Science

1.3.1.1 Conceptual Design

The GNAO science team (consisting of experts internal and external to Gemini) has defined science cases and linked each science case to a list of scientific requirements. The final collection of science cases covers a wide range of research areas including solar system, Galactic, and extragalactic topics. An overview of the GNAO science cases was presented at the AO4ELT6 conference held June 9-14 in Quebec, Canada. The CoDR Science Case Document with a detailed description of each science case is nearing completion.

The science cases were reviewed to extract the driving science cases and isolate the primary scientific requirements for GNAO. These have been flowed-down into technical requirements in discussion with the system engineer, the management team, and subsystem leads and implemented into the conceptual design.

The concept of operations has been derived in close collaboration between the science team, subsystem leads, and system engineering. The definition of operational concepts is largely finalized. An advanced draft for the Concept of Operations document is available. Comments from the wider GNAO team will be considered until September 3 before freezing the CoDR documents for submission to the review committee.

The GNAO project scientist visited Gemini South together with the project manager in June. The visit was used to participate in a GeMS observing run at Cerro Pachon and to liaise with the Gemini South based science and project team members.

A splinter meeting highlighting the GNAO science cases is planned for the AAS meeting, 4-8 January 2020, in Honolulu. The meeting will feature talks on GNAO and the science cases and will present the scientific potential of GNAO to the wider user community.

WBS 1.3.2 AO Working Group

1.3.2.1 Conceptual Design

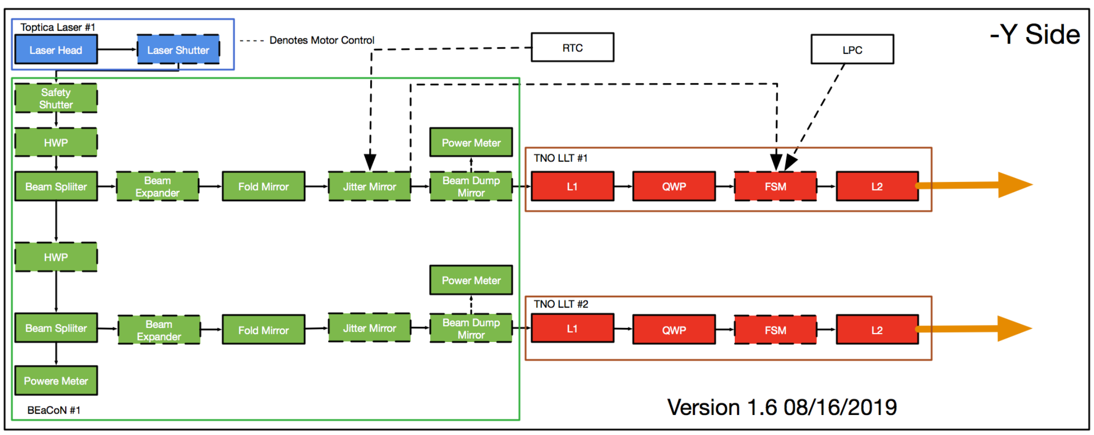
During this quarterly period, the AO working group has been interacting with the GNAO technical team to review and comment on the development of the CoD study. The design has changed significantly since the last report as a result of the trade-offs that were identified in the previous report. The AOS bench is designed to support five LGS WFS even if only 4 laser guide stars will be created on-sky, responding to the requirements derived from several science cases that require a more narrow field of view, yet better performance on-axis. Optimizing the reconstructor of the AO correction and steering one of the lasers on axis to feed an on-axis LGS WFS fulfill this performance requirement. The results obtained in simulations are very promising.

The AOWG met in person for a full afternoon during the AO4ELT6 conference in Quebec City. Taking advantage of the annual meeting in adaptive optics, we met together to discuss status and advancements to our conceptual design. The GNAO team prepared a list of work packages for discussion identifying the path forward and critical points to be studied.
The AOWG is keen to meet once a month for a status report and updates on trade studies. We plan to continue the monthly meetings until the end of the CoD stage.

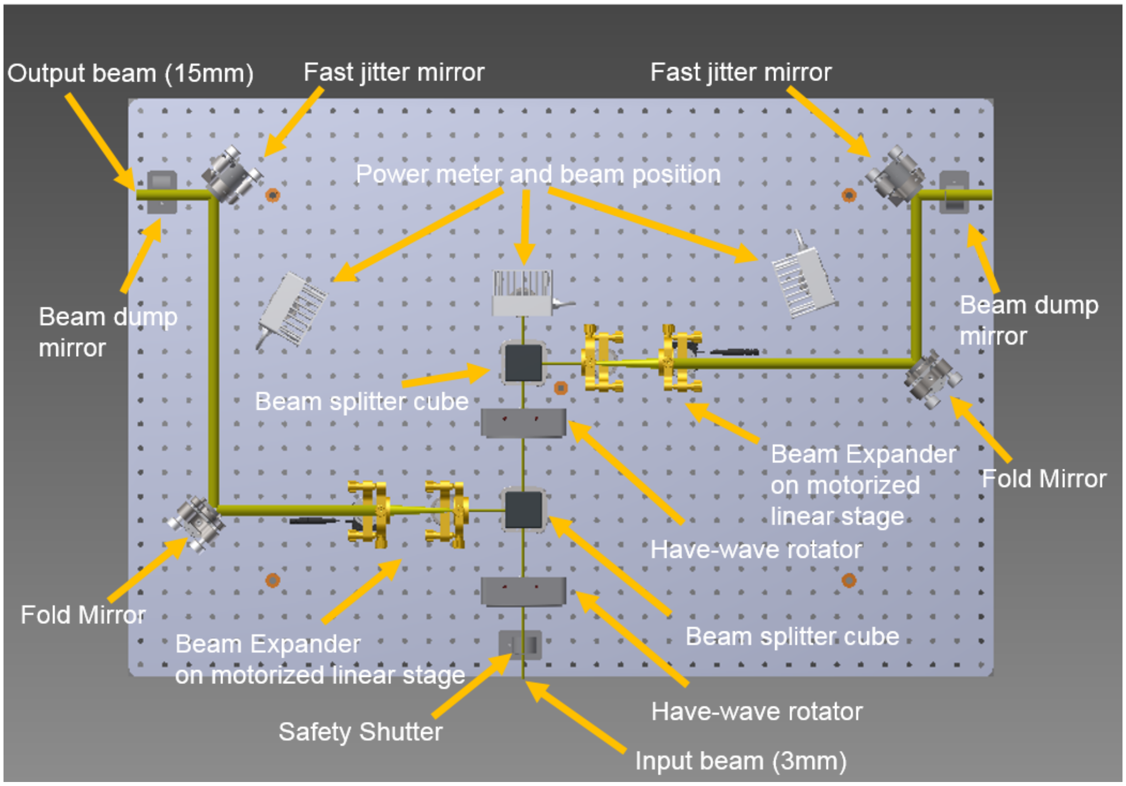
WBS 1.4.1 Laser Guide Star Subsystem Engineering

1.4.1.1 Conceptual Design

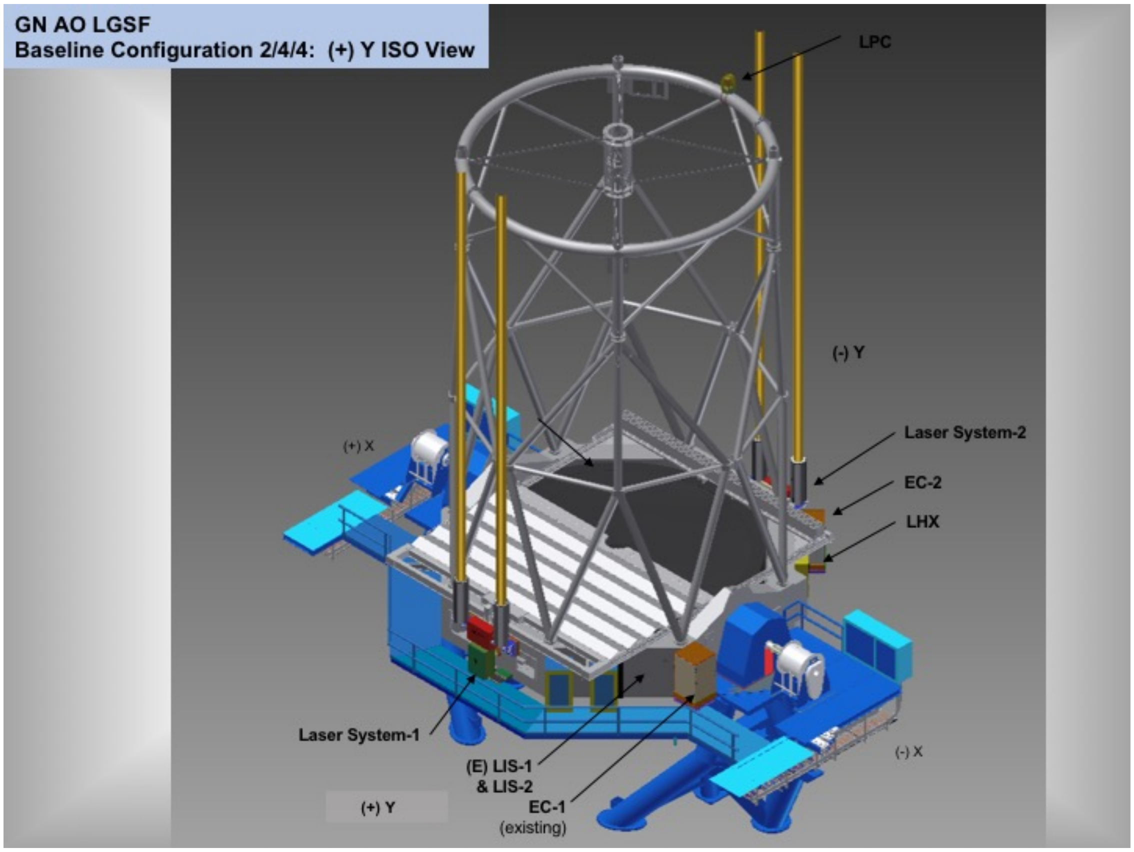
During this period the Laser Guide Star Facility (LGSF) for the GNAO system has seen a large change from initial concept to a first draft of the design. This includes identifying the major systems of the LGSF, identifying if they will be built in house or purchased, and beginning the work to integrate all the subsystems in the package. During the period it was decided GNAO will use two Toptica lasers, four side-launched Laser Launch Telescopes (LLT) and two Beam Expander and Conditioning Nodes (BEaCoN). Additionally a new Laser Heat Exchanger (LHX) will also be needed to supply the cooling to the additional laser systems. An overview of the LGSF was presented at the Laser for Adaptive Optics workshop in Quebec city. The figure below is a block diagram of the elements of the LGSF at the end of the period.



The Toptica lasers are readily available, well known to the observatory from our current use of these lasers at both sites, and procuring an additional one poses the least risk to the observatory. We have baselined to use the same LLTs as those that are used at the ESO VLT. For the BEaCoN module, the decision was made to make this component in house. This is based on the experience Gemini has with designing, building, and maintaining the current Beam Transfer Optics (BTO) at both Gemini North and Gemini South, and also the design and build of two new Beam Injection Modules (BIM) for the recent Toptica laser upgrades at both Gemini North and South. The below figure shows the design of the BEaCoN.



During this period the integration of the systems on the telescope were studied, specifically, the mechanical mounting of the lasers, BEaCoNs, LLTs and the LHX. We have studied how to mount the systems and maintain the proper telescope balance. The figure below shows the mounting of the full GNAO LGSF on the telescope.



We are currently working on the LGSF system requirements, how they flow down from the GNAO top level requirements along with functional flows of the LGSF system based off the GNAO concept of operations. This work is ongoing and is done in parallel with the broader ConOps and functional flow for the entire GNAO system.

WBS 1.5.1 AOS Subsystem

1.5.1.1 Conceptual Design

The AOS subsystem has advanced significantly this quarter. The science cases have been developed and key science cases have been identified and the requirements matrix has been produced. This has helped the AOS team to flow down the Top level requirements for the AO system itself. Trade studies have been identified and strong end-to-end AO simulations have been conducted in order to understand the performance that the AO system will deliver. We are currently flowing down the requirements at the component level in order to feed our conceptual design with potential hardware candidates.

The conceptual design document, the requirements document and the Concept of Operations document are all fully drafted and are undergoing additional revision. Full performance assessment and science sky coverage estimation have been performed.

WBS 1.5.2 Optical Engineering

1.5.2.1 Conceptual Design

Engineering development of the conceptual design advanced in both the optical and mechanical. We have a full end-to-end optical design from the telescope entrance pupil to the science focal plane at f/32 on the science detector. The optical layout fits within the envelope constraint we have, and each module of the AO subsystem is conceptually developed. Estimation of throughput, emissivity, and distortions were performed and compared to the science requirements. A summary of the work included in the conceptual design document is listed below:

- A depiction of the general layout of the optical components. (COMPLETED).
- A summary of optical elements contained and coatings that could be used. (COMPLETED).
- A description of optical mounting schemes, including the general approach used to mount and align major optical components. (ONGOING).
- A description of the throughput budgets and estimated throughput. (COMPLETED).
- A description of key risks associated with the optical design, e.g., long-term stability of optical alignment, manufacturability, coating reliability, expected lifetimes, etc. (ONGOING).

- An overview of the facility's mechanical design. (COMPLETED).
- An overview of the facility's subassemblies in the mechanical layout. (~70% COMPLETED).
- Ongoing items: Volume for SFS defined but no design, early design concepts for LGSWFS and TTWFS are completed, and CAL needs development of requirements before advancing design.
- Designs (3D models / drawings) for all subassemblies are ongoing**.** Models are all working versions. (50% COMPLETED).
- A description of the design elements that are common to multiple assemblies. (90% COMPLETED. The optical mechanical mount is the principal remaining item.

WBS 1.6 Real Time Computer

1.6.1 RTC Systems Engineering

During this quarter the work focused on deriving RTC functional and performance requirements from the evolving System, Science, and ConOPS requirements. GeMS and ALTAIR requirements were used to help guide the requirement definition process.

A conceptual design was prepared, including a functional analysis, based on these requirements.

Work was started on the RTC foundation documents, which will evolve throughout the design process:

- Design Document
- User Manual
- Test and Verification Document

These documents will also serve as inputs to the CoDR documentation package.

1.6.2 Software Selection

Two open source RTC packages were investigated as possible baselines for the GNAO RTC AO package. Adaptations required to support GeMS were investigated as well.

Conceptual Design Review Planning Update

The Conceptual Design Review is scheduled for September 26th and 27th, 2019 at Gemini north. The review panel has been identified, a charge prepared and an agenda is under review. The CoDR documentation set will be available for review to the panel 10 days prior to the review dates. Work will continue through Quarter 4 on the documentation set and planning for the review.

Appendix A

GNAO Risk Register D- GNAO - 003																
Part I. Risk Identification						Part II. Risk Analysis for Existing Controls			Part III. Risk Response							
Name	**Project Risk Category**	**Risk Description (ignoring controls) [use: if, because, then]**	**Impact 1-5 (ignoring controls)**	**Likelihood 1-5 (ignoring controls)**	**Total Risk Score** Low = 1 - 8 Med = 9 - 16 High = 17 - 25	**What Controls (if any) are currently in place?**	**Control Effectiveness 1-5**	**Residual Risk Score** Low = 1 - 8 Med = 9 - 16 High = 17 - 25	**Control or Risk Mitigation Strategy**	**Control effectiveness based on mitigation strategy 1-5**	**Residual Mitigated Risk** Low = 1 - 8 Med = 9 - 16 High = 17 - 25	**Contingency Plan**	**Cost of contingency plan**	**Owner**	**Review Due Date**	**Status**
Internal resource shortage	Resources	If the current team is allocated to other projects then the project may fall behind schedule	4	5	20	The project has been made the highest priority at the Observatory (even above operations); we are leaving "Control Effectiveness" set to 3 until we see the practical effect of this highest priority mandate	3	10	More assertively enforce highest priority mandate. More aggressively hire and train replacements for GNAO/RTC team members. Assign a dedicated team or firmly dedicated percentages of team members.							
Late GNAOI interface / integration requirements (since it is outside the scope GNAO)	Technical	If the requirements are not developed and the interfaces cannot be completed in a timely manner the project completion will not be met.	3	3	9	The GNAOI is in process.	2	2	Bring GSAOI up from south to use in place of GNAOI temporarily							
Procurements	Schedule	If procurements are not comleted in a timely manner the schedule will slip.	5	4	20	A phased procurement strategy has been developed, in conversation with long-lead-time vendors, and will be implemented as we conclude CoD; this is still a relatively likely risk, none-the-less, given the time frame of the project	3	10	Explore ways to expedite the procurement process and possible alternate vendors							
Vendor Delays	Technical	If the strategy to procure major (non off-the-shelf) subassemblies from different vendors is delayed, then this may impact schedule and budget.	3	3	9	We have been in conversation with potential vendors; this is still a relatively likely risk, none-the-less, given the time frame of the project	3	5								
AOS subcontract	Schedule	If we cannot get an AOS subcontract in place very quickly due to everyting that goes into letting such a contract, inlcuding approvals, we may not receive the AOS in time to complete our project on schedule.	5	4	20	Perform all or part of the Preliminary Design in-house, supplementing with external resources, until a contract is in place and then work collaboratively with subcontractor for the remainder of PD.	4	15	Request quick turn-around for NSF approvals. Request that we be able to use one or more time and materials contracts.							
Legacy hardware interfaces for GeMS RTC	Schedule	If there is insufficient information on legacy hardware to implement interfaces to the new RTC, then the schedule may be impacted.	4	4	16	Begin evaluating interfaces early	3	8								
Tight design phase schedule and resources precluding following system engineering processes	Quality	If the design processes outlined in the GNAO SEMP are skipped or minimized because of resource and/or schedule constraints, then the quality of the deliverable could be compromised.	4	3	12	Identify and apply additional SE resources	4	9								
RTC Resources	Resources	If the RTC is designed in-house because of budget constraints, then the RTC could be delivered behind schedule due to insufficient in-house resources.	4	3	12	Pursue a trade study and RFP to evaluate external options.										
Number of Lasers	Technical	If only 2 Lasers are available because of budget constraints, then the top level performance requirements may not be met.	3	2	6	Ensure upscope options for additional LGS are accounted for in design. Escalate risk to observatory	2	2								
M2 Print-Through	Technical	If the existing GN M2 print-through limitation is not addressed, then the performance requirements may not be met over the elevation range.	4	4	16	Analyze limitations of print-through impact on performance. Escalate risk to observatory.										