GEMMA
Gemini North Adaptive Optics and Real Time Computer Project Execution Plan

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C-GNAO-003

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Change Log

The purpose of this log is to describe updates to the material and to improve the clarity and legibility of the Project Execution Plan. A summary of the changes for this revision is given below.

Changes between PEP submitted in December 2018 and May 2019:

1. Inserted Change Log as new material to reflect edited sections, moved material, deleted material and updated material
2. Sub plans included in the PEP
3. Inserted List of Figures and Tables
4. Updated list of Acronyms to merge RTC and GNAO PEP
5. Updated all project references from GNAO to GNAO/RTC, unless referring to a particular component of the project in which case one designation or the other may be used.
6. 1. Introduction, updated to include RTC
7. 1.1 Scientific Objectives, updated to include Scientific Objectives for RTC
8. 1.1 Scientific Objectives, updated to include Scientific Objectives for RTC
9. 1.2 Scientific Requirements, inserted 'Top-tier GNAO/RTC Science Cases with some parameters' as Table 1, updated 'Summary of Nearly-Final GNAO/RTC Science Requirements' to include RTC Requirements. This is now Table 2. Removed 'AO Requirements table' (previously Table 2), see GNAO Comment #2 in Appendix B. Inserted Table 3 'Gemini's ICDs and Specification Documents that GNAO/RTC will comply with'
10. 1.3 Facility/Infrastructure, updated to include Facility/Infrastructure for RTC
11. 2.1 Internal Governance & Organization, updated Figure 1 'GNAO/RTC Project Organizational Structure', removed Table 3 'GNAO CoDS Roles', updated text to reflect changes in staffing
12. 2.2 External Organization, inserted Figure 2 'GEMMA Organizational Structure', inserted Table 4 'Gemini Executive Committee' for the GEMMA Program, removed reference to Public Information and Outreach communication, inserted project escalation path
13. 2.3 Partnerships*, u*pdated to include Partnerships for RTC
14. 2.4 Roles and Responsibilities, inserted project role description for Project Manager, Principal Investigator, Project Scientist, Systems Engineer and Project Coordinator
15. 2.6 Inserted Community Relations and Outreach as detailed in GEMMA PEP
16. 3.0 Design Overview, inserted section on Design and Overview of GNAO subsystems; LGS, AOS and RTC
17. 3.1.0 Detailed Bottom-Up Project Plan, inserted this as a new sub-section in 3.1 Project Plan which details the Bottom-Up Project Plan which has been developed. This details where cost estimates are derived from for: In-house work, AOS and RTC subcontracts, procurements and the result of our planning for LGS option selection
18. 3.1.1 GNAO/RTC Scope, updated to include RTC in the scope of the project
19. 3.1.2.1 GNAO/RTC Facility, updated to include LGS, AOS, and RTC subsystems, a new block diagram of the LGS subsystems has been included as Figure 7 ' Conceptual block diagram of the LGS subsystems', Figure 2 'Block Diagram of the Laser Launch Subsystems' has been updated and is now Figure 8 'Conceptual block diagram of the AOS subsystems'. The detailed explanation of the previous Figure 2 'Block Diagram of the Laser Launch Subsystems' has thus been removed.
20. 3.1.2.2 GNAO/RTC Documentation Set, deliverable documents GNAO-33 and GNAO-34 have been removed and the descriptions thereof
21. 3.1.2.3 GNAO/RTC Facility Associated Hardware, removed set of GNAO facility spares.
22. 3.1.2.4 GNAO/RTC Facility Associated Software, inserted brief description of plan
23. 3.1.3 GNAO/RTC Project Structure Figure 4 is now Figure 9 'GNAO/RTC Project Phases and Stages' due to the additional Figures in the PEP
24. 3.1.3.3 Telescope Integration and Commissioning Phase, updated Telescope Integration Stage description, noted that Commissioning and Science Verification Stage is not covered by our current CSA or most of this document

25. 3.1.4 GNAO/RTC Project Kick Off Meetings and Design Reviews, updated who decides on when to schedule a project review from accordance of 'GNAO Project Manager and NSF Program Officer' to 'GNAO/RTC project management team', inserted GNAO/RTC reviews schedule as Table 6.
26. 3.2 Development Budget and Funding Sources, updated to include Development Budget and Funding Sources for RTC . Included new subsections: 3.2.1 GNAO/RTC Labor by Fiscal Year, 3.2.2 GNAO/RTC Budget by Fiscal Year, 3.2.3 GNAO/RTC Budget by WBS Element, 3.2.3 GNAO/RTC Phased Procurements and inserted associate tables to display the budget information
27. 3.3 Project Development Schedule (previously GNAO Development Schedule), Figure 6 'Project Phases and Stages start and end dates' is now Figure 10 'Project phases showing phased completions for subsystems', removed external project dependency of RTC
28. 4.1 Summary of Total Project Definition, updated to include RTC as major component, removed subsection 4.1.1 MCAO Adaptive Optics Bench, 4.1.2 New laser guide star facility
29. 4.2 Work Breakdown Structure (WBS), updated Table 5 'Work Breakdown Structure (level 4)', this is now Table 8 'Work Breakdown Structure' and also includes RTC, removed Table 6 'Work Breakdown Structure (level 5 and 6) for the GNAO Facility'
30. 4.3 WBS Dictionary, updated and also includes RTC
31. 4.5 Cost Estimating Plan, Cost Reports and Baseline Budget, updated to note that his will be refined as we continue through CoD
32. 4.6 Complexity Factor, updated that we have lowered the complexity to 22%.
33. Removed 4.7 Cost Book, Cost Model Data Set and Basis of Estimate
34. 4.7 Funding Profile, updated that GNAO/RTC's funding profile is as per the GEMMA CSA and removed Table 7 'Project Cost Summary [M$]'
35. 4.8 Baseline Schedule Estimating Plan and Integrated Schedule, inserted details that the schedule will be refined as we continue through CoD
36. 4.9 Schedule Contingency, added that we have not allocated explicit budget contingency to go along with schedule contingency
37. 5.1 Staffing Plan has been updated to reflect new hires and consolidate GNAO and RTC resources, updated Figure 8 'The Current GNAO Resource Assignment Matrix' with Table 10 'GNAO/RTC labor needs in FTE-fractions per FY (assuming 1720 hours per year)'
38. 5.2 Hiring and Staff Transition Plan, removed sub sections 5.2.1-5.2.4, listed new staff hires
39. 7.1 Systems Engineering Plan, updated that SEMP will be submitted at CoDR
40. 7.2 Systems Engineering Requirements, removed
41. 7.3 Interface Management Plan, removed that this document will be the basis for specifying interface requirements, documented in an IRD and manage external and internal interface via ICDs.
42. 7.6 Deleted Facility Divestment Plan as neither the GNAO or RTC project are large facility projects
43. 9.1 Acquisition Plans, removed reference to the Project Management Plan, details acquisition of required subcontracts as stated in section 3
44. 10.2 Earned Value Analysis (EVA), changed name from Earned Value Management System (EVMS) to Earned Value Analysis (EVA), inserted details as detailed in GEMMA PEP
45. 10.3 Financial and Business Controls, inserted Financial and Business Controls as detailed in GEMMA PEP
46. 11. Site and Environment, deleted section as neither the GNAO or RTC project are large facility projects
47. 11 Cyber Infrastructure, updated details of 11.1 Cyber-Security Plan and 11.2 Code Development Plan
48. 12.1 Environmental Safety and Health Plans, updated that we will identify and adapt an existing Gemini ES&H plan to its needs during the Conceptual Design Stage.
49. 14.1 Updated to include Integration and Commissioning Plan for RTC
50. 14.2 Updated to include Acceptance / Operational Readiness Plan for RTC
51. Appendix A Inserted Brief GNAO/RTC Team Bios
52. Appendix B Inserted GNAO and RTC questions from NSF with responses

53. Made many additional changes to continue to merge the GNAO and RTC PEPs and to incorporate the in-depth project plan that we have completed

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List of Names and Acronyms

Acronym	Definition
A&G	Acquisition and Guider unit
AIS	Advanced Image Slicer
AIV	Assembly, Integration and Verification
ANTARES	Arizona-NOAO Temporal Analysis and Response to Events System
Altair	ALTitude conjugate Adaptive optics for the InfraRed
ALeRCE	Automatic Learning for the Rapid Classification of Events
AO	Adaptive Optics
AOB	Adaptive Optics Bench
ARC	Astronomical Research Cameras (A detector controller vendor)
ASM	Adaptive Secondary Mirror
AURA	Association of Universities for Research in Astronomy
BTO	Beam Transfer Optics
CANARY	The on-sky pathfinder for Multi-Object Adaptive Optics
CCD	Charge Coupled Device (detector)
CDR	Critical Design Review
CoDR	Conceptual Design Review
ConOps	Concept of Operations
CP	Cerro Pachón (the site of the Gemini South telescope)
CPU	Central Processing Unit
CSA	Cooperative Support Agreement
DM	Deformable Mirror
DM0	Deformable Mirror of GeMS conjugated to 0m. Others are DM4.5 and DM9.
DMT	Document Management Tool
DR	Data Reduction
DRS	Data Reduction Software
DSP	Digital Signal Processor
ELT	Extremely Large Telescope
EM	Electromagnetic
EMCCD	Electron Multiplying Charge Coupled Device
ESA	European Space Agency
ESO	European Southern Observatory
FoV	Field of View
FTE	Full-Time Equivalent
FWHM	Full-Width Half Maximum
GeMS	Gemini Multi-Conjugate Adaptive Optics System
GHOST	Gemini High-resolution Optical SpecTrograph
GIRMOS	Gemini InfraRed Multi-Object Spectrograph
GLAO	Ground Layer Adaptive Optics
GMOS	Gemini Multi-Object Spectrograph (-S located at Gemini South, -N at Gemini North)

GMT	Giant Magellan Telescope
GN	Gemini North
GNAO	Gemini North Adaptive Optics system (a generic name for the proposed new AO system)
GNAOI	Gemini North Adaptive Optics Imager
GNIRS	Gemini Near InfraRed Spectrograph
GPI	Gemini Planet Imager
GPOL	Gemini POLarimeter
GW	Gravitational-wave
GS	Gemini South
GSAOI	Gemini South Adaptive Optics Imager
HO	High Order
Hubble	Hubble Space Telescope
IRAF	Image Reduction and Analysis Facility
INTEGRAL	INTErnational Gamma-Ray Astrophysics Laboratory
ICD	Interface and Control Document
IDF	Instrument Development Fund
IQ	Image Quality
IR	InfraRed
ISS	Instrument Support Structure
JWST	James Webb Space Telescope
LBT	Large Binocular Telescope
KPP	Key Performance Parameter
KSR	Key Science Requirement
LCO	Las Campanas Observatory or Las Cumbres Observatory
LCGTN	Las Cumbres Global Telescope Network
LGS	Laser Guide Star
LGSF	Laser Guide Star Facility
LGSWFS	Laser Guide Star WaveFront Sensor
LIGO	Laser Interferometer Gravitational-Wave Observatory
LL	Laser Launch
LLT	Laser Launch Telescope
LPC	Laser Pointing Camera
LQG	Linear Quadratic Gaussian
LSST	Large Synoptic Survey Telescope
LTAO	Laser Tomographic Adaptive Optics
MCAO	Multi-Conjugate Adaptive Optics
MMT	Multi-Mirror Telescope
MOAO	Multi-Object Adaptive Optics
MUX	A readout multiplexer; can be used for testing controllers without the more expensive and sensitive light-sensing component of a complete detector
NACO	Nasmyth Adaptive Optics System (NAOS) – Near-Infrared Imager and Spectrograph (CONICA)
NASA	National Aeronautics and Space Administration
NCOA	National Center for Optical-Infrared Astronomy

NCPA	Non-Common Path Aberration
NFIRAOS	Narrow FIeld Infrared Adaptive Optics System TMT
NIFS	Near-Infrared Integral Field Spectrometer
NGS	Natural Guide Star
NGS2	Next Generation Sensor for Natural Guide Star
NGSWFS	Natural Guide Star WaveFront Sensor
NOAO	National Optical Astronomy Observatory
NIRCAM	Near Infrared Camera
NIR	Near InfraRed
NSF	National Science Foundation
NUMA	Non-Uniform Memory Access
O&M	Operations and Maintenance
OAP	Off-Axis Parabola
OCS	Observing Control System (Gemini operations software)
ODGW	On-Detector Guide Window
OIWFS	On-Instrument WaveFront Sensor
OIR	Optical and Infrared
PC	Personal Computer
PI	Principal Investigator
PM	Project Manager
PMB	Performance Measurement Baseline
PMKB	Project Management Knowledge Base (Gemini's Project Management Database)
PMO	Portfolio Management Office
POLC	Pseudo Open Loop Control
PSF	Point Spread Function
PWFS	Peripheral WaveFront Sensor (two located in the A&G system)
QAP	Quality Assurance Pipeline
RfP	Request for Proposals
RTC	Real-Time Computer
rToO	Rapid Target of Opportunity
SFS	Slow Focus Sensor
SH	Shack-Hartmann
SHWFS	Shack-Hartmann WaveFront Sensor
SCAO	Single Conjugate Adaptive Optics
SEMP	Systems Engineering Management Plan
SIMD	Single Instruction Multiple Data
SOAR	Southern Astrophysical Research Telescope
SF	Science Fold
SR	Strehl Ratio
SwRI	Southwest Research Institute
TDA	Time Domain Astronomy
TI	Telescope Integration
TMT	Thirty Meter Telescope
TOM	Target Observation Manager
ToO	Target of Opportunity

Toptica	Toptica Laser
TT	Tip-Tilt
TTM	Tip-Tilt Mirror
TFS	Transient follow-up system
VIS	Visible wavelength region
VLT	Very Large Telescope
WBS	Work Breakdown Structure
WFS	WaveFront Sensor
XAO	eXtreme Adaptive Optics
ZTF	Zwicky Transient Facility

1 Introduction

Until early May, 2019, the GEMMA Program contained 2 separate projects, namely the Gemini North Adaptive Optics (GNAO) project and the Real-Time Computer (RTC) project (plus 2 other projects, TDA and PIO). Due to considerable synergies between the GNAO and RTC projects and to improve management and execution efficiencies, Gemini has merged these two projects. The RTC will be a subsystem of GNAO and, therefore, has the same upper level requirements as GNAO and has been planned as part of GNAO.

This Project Execution Plan (PEP) describes how Gemini will execute the combined GNAO and RTC projects to deliver the new GNAO facility, including a modular RTC subsystem that will also be suitable to serve as the RTC foundation for other instruments. Taking advantage of that suitability, the project will also deliver a new RTC implementation for GeMS.

In the process of merging the 2 projects, the GNAO and RTC PEPs were merged by combining sections from each so that each merged section contains information pertaining to both projects. Text, graphics and, tables were updated as appropriate.

To aid in the transition to the combined project, this PEP will refer to the project as GNAO/RTC, unless referring to a particular component of the project in which case one designation or the other may be used. When the project delivers the next revision of the PEP, at the conclusion of the Conceptual Design, we expect to let 'GNAO' refer to the combined project.

1.1 Scientific Objectives

Although GNAO/RTC will be a facility that will feed instruments, rather than an instrument itself, there are still, of course, scientific objectives associated with it. We discuss these objectives in terms of GNAO/RTC's sister facility, the Gemini Multi-Conjugate Adaptive Optics System (GeMS) currently operating at Gemini South. Although it is beyond the scope of this project and hence this document, an imaging instrument, GNAOI, is beginning development to be used with GNAO/RTC. GNAOI will be similar to GSAOI discussed below.

One of Gemini's key strengths is an opto-mechanical design optimized for superb image quality. The Gemini Multi-Conjugate Adaptive Optics System (GeMS) system, the first laser assisted Multi Conjugate Adaptive Optics (MCAO), at Gemini South, coupled with the Gemini South AO Imager (GSAOI), takes advantage of this strength to deliver nearly diffraction-limited K-band images with typically 0.085″ resolution over a 1.4′ field of view.

Science results from GeMS/GSAOI include the deepest color-magnitude diagrams ever produced for obscured globular clusters within the bulge of the Milky Way (Saracino et al. 2016, ApJ, 832, 48) and are providing new age and mass estimates for these clusters. In combination with earlier *Hubble* imaging, GeMS has determined the proper motion of the distant halo globular cluster Pyxis, finding that it is likely of extragalactic origin and yielding a lower limit on the total mass of the Milky Way (Fritz et al. 2017, ApJ, 840, 30). Proper motions for high-velocity, sub-arcsecond-sized knots within the "molecular fingers" of the dense core of Orion measured with GeMS provide evidence for an explosive origin for the protostellar outflow (Bally et al. 2015, 579, A130).

A pilot GSAOI imaging survey of luminous infrared galaxies (LIRGs) discovered three core-collapse supernovae within dusty, crowded regions of intense star formation, indicating that the supernova rates within LIRGS are much higher than previously estimated, but most are missed as a result of dust obscuration and inadequate resolution (Kool et al. 2018, MNRAS, 473, 5641). GeMS was used to study the near-IR morphologies of distant galaxies at spatial resolutions surpassing what *Hubble* can achieve at such wavelengths (Lacy et al. 2018, ApJ, 864, L8).

While Maunakea is a better astronomical site for AO performance, Gemini North lacks any wide-field AO capability and its aging single-conjugate ALTAIR AO system falls well short of fully exploiting the site's outstanding characteristics. In fact, no comparable Multi-Conjugate Adaptive Optics (MCAO) system similar to GeMS exists in the northern hemisphere and there are no plans for one for another decade. The Thirty-Meter Telescope (TMT), with its NFIRAOS MCAO system, will provide diffraction-limited AO imaging in the IR over a 34" FoV on a 30m telescope, but it is unlikely to begin operations before the end of the 2020s.

Gemini's Science and Technology Advisory Committee has advocated in their recent reports for a world-class wide-field AO system for Gemini North building on our previous experience with GeMS. A more advanced and reliable GeMS-like Gemini North AO system will enable detailed investigations of stellar populations, supernova physics, proper motions, and galactic archaeology similar to the GeMS studies referenced above. In addition, with greater sky coverage from improved guide star sensor cameras, the proposed GNAO/RTC system will be capable of a great variety of other innovative science, such as:

- Monitoring Mira variables in galaxies as far as the Virgo cluster to constrain stellar lifetimes on the thermally pulsating asymptotic giant branch in diverse populations, an important consideration for understanding galaxy evolution while at the same time providing the basis for systematic checks on the Cepheid-supernova distance scale;
- Detailed studies at sub-kiloparsec scales in the rest-frame optical of galaxy morphology and interactions at "cosmic noon," the peak of star formation activity and galaxy assembly at $z\sim2$;
- High-resolution narrow-band imaging of Lyman-alpha emitters at redshifts $z>7$ selected to lie between the atmospheric OH lines to study the earliest stages of galaxy formation.

These science topics will also be investigated by JWST; however, because of JWST's L2 orbit and limited range of pointing angles, it can only observe most targets during limited periods each year. This limitation (as well as the expected highly competitive proposal pressure) provides an excellent opportunity for synergy between Gemini/GNAO/RTC and the JWST. GNAO/RTC will be the only system able to study and monitor high-priority northern targets with a similar spatial resolution and field of view (FoV) as the Near InfraRed Camera (NIRCAM) on JWST during months when those targets are not observable by JWST itself. This will be especially important for time-domain science including candidate lensed supernovae (SN) such as SN Refsdal (Kelly et al. 2015), for which additional lensed images are predicted to appear depending on the lens model when the target would be unobservable by JWST and when Hubble itself may no longer be operational. Another limitation for JWST will be the very limited access to Targets of Opportunity (ToOs). GNAO/RTC will be able to handle more of them because of longer windows of accessibility through the year, and ease of rapid response from the ground.

GNAO/RTC will also enable high-resolution investigation of high-priority targets identified by LSST visible from both hemispheres while they are being observed spectroscopically with SCORPIO at Gemini South. Combined with GeMS, the proposed GNAO/RTC system will allow Gemini to provide unique wide-field AO over the entire sky. The presence of the only such system in the northern hemisphere will establish a clear science mission for Gemini North in the coming decade that will see the launch of JWST in 2021 and the start of LSST science operations in 2023.

Finally, the design of GNAO/RTC will also enable the possibility to feed a multi-object spectroscopic instrument such as GIRMOS (a visiting instrument coming to Gemini in 2024) with higher spectral resolution than JWST (which peaks at R~2,700). By building an improved multi-conjugate AO system in support of Gemini North's science mission, Gemini will take full advantage of previous investment in GeMS and employ the latest technology for better performance and support of the next generation of laser AO-assisted instruments bound for Gemini North. The design and construction of an Adaptive Secondary Mirror is outside the scope of this agreement but its future inclusion will be considered when evolving science cases and performing facility trade studies.

During the Conceptual Design Stage of the project, the team will engage with our community to evolve the science cases prepared and gathered during our 2012 GNAO workshop[1] and to identify further science cases. Based on past experience, we shall form an initial core science team comprising of members internal and external to Gemini which will help us further refine a set of research objectives based on driving science cases resulting in a science cases document at the end of the Conceptual Design Stage.

1.2 GNAO/RTC Scientific Requirements

Several science cases are driving the GNAO/RTC science requirements. The top-tier science cases are given in Table 1, below, along with some pertinent parameters. Second-tier cases are also informing the science requirements, but are not shown.

[1] http://www.gemini.edu/science/public/gnao2012/Home.html

Science case	Spectral range	field of view	astro. acc	photo. acc
Extra-galactic and Cosmology				
High z galaxy dynamics	0.9-2.4 um	3" per object	<100mas	~10%
Galaxy metallicity maps	0.9-2.4 um	3" per object	<100mas	~10%
Nuclear star clusters & disks	0.9-2.5 um	20"x20"		
Central parsecs around AGN: AGN feedback, dual AGN candidates	0.9-2.5 um	<~ 10"x10"		~10%
Cosmological Constraints from Strongly Lensed, Multiple-source Systems	1.2 -2.5 um	30"	1 mas	~10%
Follow-up and Monitoring Gravitationally Lensed Transients	0.7-2.5 um	2'	10 mas	2%
Galactic and nearby extra-galactic				
Galactic young massive star clusters	1-2 um	>2'	<0.3mas	few %
Globular clusters	1.5-2.4 um	4" IFU and a patrol field of 2' or more	<10mas	<20%
Galactic nucleus	1-2.9(-5) um	>2'	<0.2 mas	few %
Galactic young massive star clusters (Arches, Quintuplet, central pc) in Galactic center	1-2.9 um	~0.5'		yes
Brown dwarfs, solar system				
Narrow-ish BD binaries (astrometric orbits & resolved spectra)	1-2.5 um	~1" | ~10'	n/a | ~1 mas	n/a
Giant Planet Atmospheres and their Disks	1-5 um	1'	<1mas	few %

Table 1 *Top-tier GNAO/RTC Science Cases with some parameters*

These science cases have, in turn, generated the following science requirements. These science requirements are in the process of being flowed down to the GNAO/RTC subsystems and may be iterated with the Science Team in the process.

REQ-ID	Metric	Requirement	Goal
	GNAO Top Level Science		
GNAO-001	**Corrected Field of View**	2' circular diameter	2.2' circular diameter
GNAO-002	**Strehl ratio**	30% uniform over the entire FoV under good conditions 50% uniform over the entire FoV under excellent conditions	50% uniform over the entire FoV under all conditions
GNAO-003	**PSF astrometry accuracy with 3 NGSs under median seeing conditions**	0.2 mas	0.1 mas
GNAO-004	**Seeing Limit for Operations**	Up to 1.2" @ 0.5 µm	1.5" @ 0.5µm
GNAO-005	**Sky coverage with 1 NGS**	60% at galactic pole	75% at galactic pole
GNAO-006	**Sky coverage with 3 NGSs**	20% at galactic pole	30% at galactic pole
GNAO-007	**Wavelength Coverage**	deliver a science corrected beam between 850nm < λ < 2.5µm	deliver a science corrected beam between 600nm < λ < 5µm
GNAO-009	**Focal Ratio**	F/32	
GNAO-011	**Spatial performance / PSF Quality (with 3, 2 1 NGS)**	The shape of the GNAO PSF shall vary less than 10% under the best observing conditions over (realistic) elevation variations (e.g. 0 degrees from Zenith to 45 degrees) . This covers spatial movement on the sky.	
GNAO-013	**Static Field Distortion (Less than x% from center to edge)**	The static field distortion shall be less than 2% from the center to the edge of the field of view. (TBR)	
GNAO-014	**Dynamic Field Distortion**	0.2 mas across the field	0.1 mas across the field
GNAO-020	**Throughput**	70% over the required wavelength range.	75% over the goal wavelength range.
GNAO-021	**Emmisivity**	For wavelength of 2.2 microns, emmisivity shall be <19%	For wavelength of 5 microns, emmisivity shall be <19%
GNAO-023	**Ghosts images**	The ghost image shall be at a level below 10E-4 from the parent image	
GNAO-024	**Zenith Angle**	meet performance up to 60 (TBR) degree zenith angle	
GNAO-025	**Scattered Light**	<2%	<1%

Table 2 *Summary of Nearly-Final GNAO/RTC Science Requirements*

In addition to requirements stemming from the Science Cases and Concept of Operations, GNAO/RTC shall comply with the relevant requirements, specifications and interfaces contained within Gemini's set of ICDs and Specification documents as listed in Table 3, below.

General Gemini Facility ICDs
● Gemini Observatory Facility Instrument Common Requirements and Standards Specification (version A)
● ICD 1.9/5.0 Science and Facility Instruments to Transport, Observatory and Operations Environments ICD (version C) – This includes environmental temperature ranges, etc.
● ICD 1.5.3/1.9 ISS to Science Instruments ICD (version D)
● ICD 1.9/3.6 Science and Facility Instruments to ISS System Services ICD (version F)
● ICD 1.9/2.7 Science Instruments to Facility Handling Equipment ICD (version E)
● ICD-G0014 Optomechanical Coordinate System (version B)
General Gemini Software Requirements, Standards, and ICDs

● GIAPI Builder Req-01302009 GIAPI Software Requirements for Instrument Builders (version 04) ICD 50	
● GIAPI C++ Language Glue API ICD (version 11)	
● GIAPI Use-08292006 GIAPI Design and Use (version 08)	
● GPSG-STD-102 Coding Standards and Guidelines for the Gemini Data Processing Software (in development)	
● Gemini Recipe System documentation (in development)	
Applicable Software ICDs	
● 1.1.13/1.9 Interlock System to Science Instruments ICD (version A)	
● ICD 10 EPICS Synchro Bus Driver (version 13 - Nov 1997)	
● ICD 20 Synchro Bus - Node/Page Specifications (version D)	
Applicable Telescope Subsystem ICDs	
● Telescope Control System (TCS) ICD	
● Secondary Control System (SCS) ICD	
● Acquisition and Guidance System (A&G) ICD	
● Observatory Control System (OCS) ICD	
● Data Handling System (DHS) ICD	
● Gemini Interlock System (GIS) ICD	

Table 3 *Gemini's ICDs and Specification Documents That GNAO/RTC Will Comply With*

1.3 Facility/Infrastructure

AURA and Gemini Observatory have the relevant institutional infrastructure, support departments and experience to execute a project of this size and nature. The GeMS project was similar in size and structure and the GPI project was similar in size. The Gemini North telescope has been operational for the best part of two decades and is well documented. Changes will be required to the existing physical infrastructure of the Gemini North observatory which is within the scope of the project and will be described as the design stages of the project progress. The organization will need to supplement its expertise in Adaptive Optics to include GNAO/RTC into its current portfolio of development projects and existing operational commitments.

1.4 Scientific & Broader Societal Impacts

Multi-messenger astrophysics (MMA) is one of NSF's Ten Big Ideas. MMA combines the results from some of the NSF's major astrophysics facilities in order to elucidate the nature of new and rare events. In response to the NSF-sponsored report by the National Research Council on

Optimizing the U.S. Ground-Based Optical and Infrared Astronomy System[2] and the NOAO/LSST report on Maximizing Science in the Era of LSST[3], NOAO initiated a project to establish a transient follow-up network based on the Las Cumbres Observatory design and incorporating multiple facilities that will be under the forthcoming umbrella of NSF's National Center for Optical-Infrared Astronomy (NCOA). The TDA project, part of GEMMA, will make both Gemini telescopes active and crucial participants in that network. The particular impact of incorporating Gemini into this network is that Gemini will provide by far the largest apertures in the initial network, thus enabling spectroscopy of the most distant transient events.

The addition of the wide-field AO-corrected capabilities of GNAO/RTC to its repertoire in the north is another important way in which Gemini Observatory is aligning itself with NSF priorities and is preparing to be a leader in exploring and discovering the nature of transient and time-variable sources. The Gemini Board's guidelines state that "Gemini will strive to be the best observatory in the world for the execution of flexible, innovative, and efficient science programs." Between physical location and hardware and software changes, Gemini will be well positioned in this new environment.

[2] https://www.nap.edu/catalog/21722/optimizing-the-us-ground-based-optical-and-infrared-astronomy-system

[3] https://www.noao.edu/meetings/lsst-oir-study/

2 Organization

2.1 Internal Governance, Organization, and Communication

The GNAO/RTC project is organized as shown in Figure 1, below. The GNAO/RTC Management Team consists of the Project Manager, Principal Investigator, System Engineer, and Project Scientist. The Project Management Team is supported by a Project Coordinator. Stephen Goodsell, the acting Project Manager, prior to the arrival of David Palmer, will serve as a Project Consultant so the project can continue to benefit from his significant knowledge and insights.

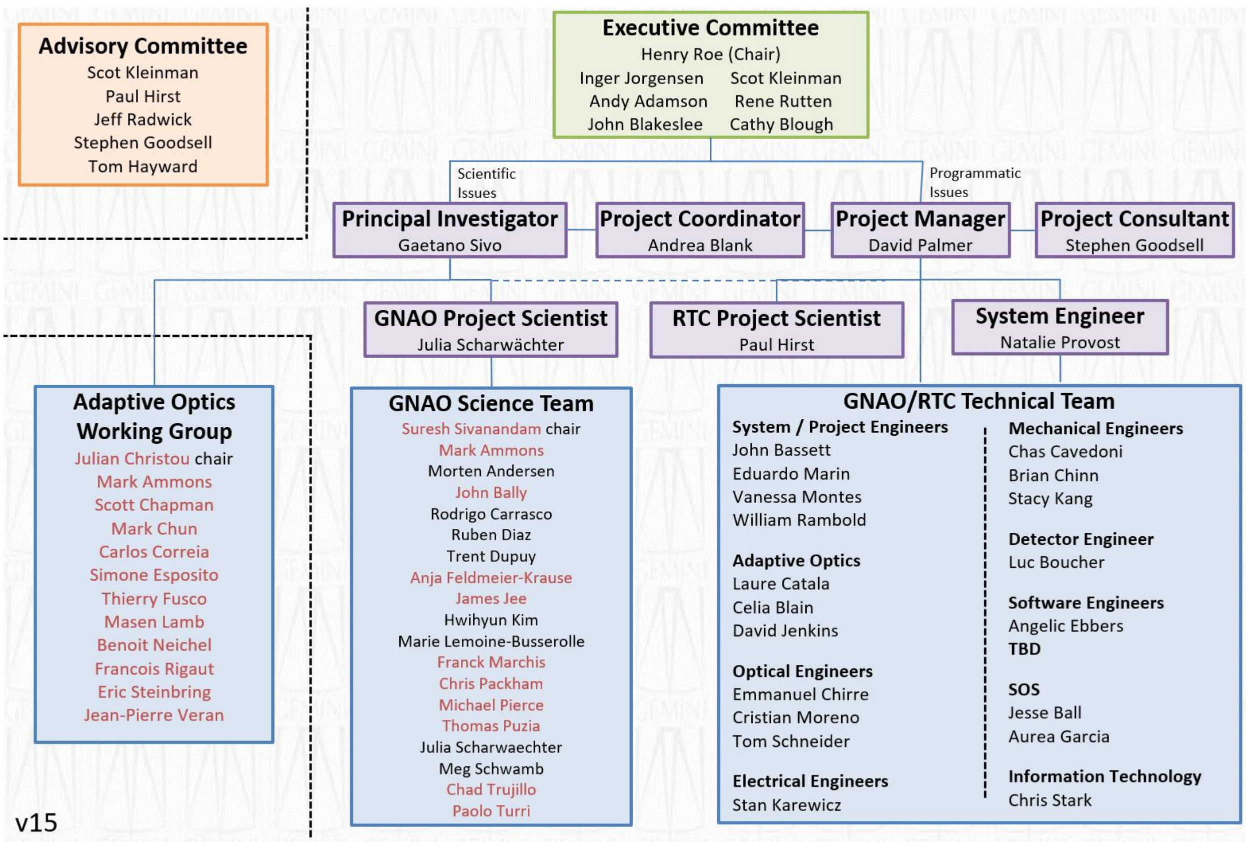

Figure 1 *GNAO/RTC Project Organizational Structure (red indicates external participants)*

The Project Manager (PM) and Principal Investigator (PI) share authority and responsibility for leading the project, the PM for programmatic issues and the PI for scientific issues. In practice they, and the whole management team, will function more as a team rather than as individuals. To help facilitate that, the management team will have almost daily tag-up meetings. The dashed line between the science and technical teams indicates that, although responsibility resides on either side of the dashed line, there will be encouraged interactions between the two. Although it is not indicated on the org chart, the technical team will report to the System Engineer (SE) for SE related issues and to the PM for programmatic related issues. In practice, this will be a team effort as well.

The PM and PI will report up to the Executive Committee as described in more detail in the External Organization subsection, below. Also, please see the Roles and Responsibilities subsection for additional information.

In addition to the management team tag-up just mentioned, communication will be managed by 3 project mailing lists: one for the project team, one for the science team, and one for the AO Working Group; and the project team will hold weekly meetings to interact and track the status of the project. Beyond that, impromptu conversations are encouraged, as needed, as long as any possible results get shared and agreed on by other pertinent people – again, we are a team.

Please see Appendix A for brief team bios.

2.2 External Organization

The GNAO/RTC project will follow the GEMMA organizational structure instituted by Gemini Management, as shown in Figure 2, below.

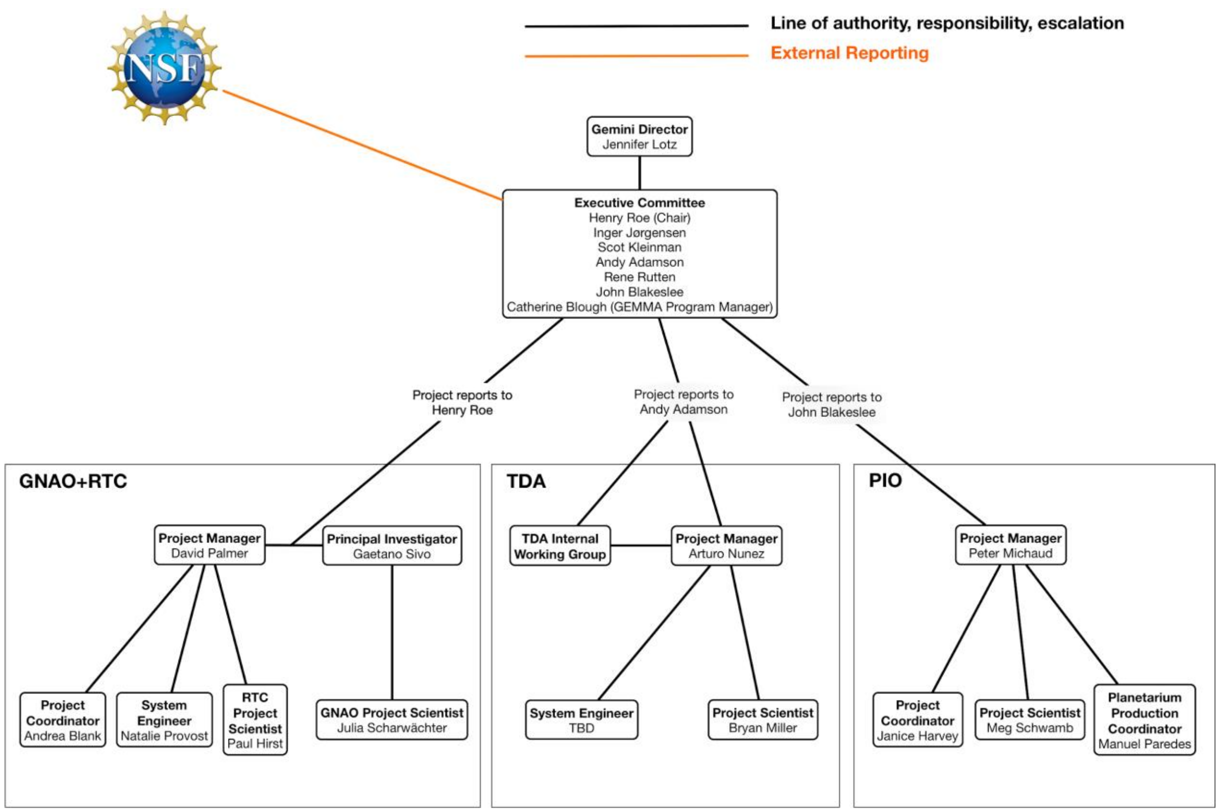

Figure 2 *GEMMA Organizational Structure*

In this structure, GNAO/RTC will report to and be overseen by a Gemini Executive Committee (please see Table 4, below) that will, in turn, report to and be overseen by the NSF and the Gemini Director. Specifically, authority flows downward from the Director to the Executive Committee to the Principal Investigator and Project Manager to the rest of the project team. Escalation flows upward along the reverse path. Escalations involving scientific issues may include the Chief Scientist. Escalations concerning program or portfolio issues may include the Program and

Portfolio Managers. Similarly, issues arising from the Portfolio and Program Managers should go from them to the Executive Committee.

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

Table 4 *Gemini Executive Committee*

The Executive Committee will be responsible for successful delivery of the GEMMA Program's objectives and benefits and will resolve conflicts, resource and otherwise. In all cases the Executive Committee will be consulted on major project decisions that have significant external impacts, such as design choices that impact future development options, major procurements, or major changes in deliverables by the projects. The Executive Committee will seek consensus decisions, but the Chair has final authority on decisions when consensus cannot be expeditiously found. Issues arising in GNAO/RTC will be escalated to Henry Roe as the Chair, who will work with the GEMMA Program Manager, GNAO/RTC Project Manager, and GNAO/RTC 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.

2.3 Partnerships

In developing GNAO/RTC, we are seeking to create broad partnerships within the Gemini community. One initiative is through the re-initiation of the Gemini Adaptive Optics Working Group (AOWG). Please see the bottom left of Figure 1 (section 2.1), "GNAO/RTC Project Organizational Structure".

The AOWG will provide guidance to Gemini and useful information and exploration for working group members. Previous versions of the AOWG have performed complex trade studies and analyses for past AO efforts at Gemini. We will initially focus the AOWG on helping form GNAO/RTC's top-level requirements. The AOWG charter sets member expectations to:

- Provide expertise regarding the Observatory's AO program including technical and design recommendations, community experience, and best practices.
- Bring lessons learned from other AO systems so new Gemini systems can build on previous work the observatory has not been directly involved in.
- Develop science cases for the observatory AO program that can be used to guide design decisions.
- Provide simulations, input parameters, and output results to help develop the AO program.

In addition, GNAO/RTC has invited several external scientists to join Science Team (again, please see Figure 1; external participants are shown in red).

Finally, the Gemini STAC and Board will, of course, also have insight and participation in these efforts.

2.4 Roles and Responsibilities

2.4.1 Project Manager

The Project Manager and Principal Investigator have delegated authority to deliver the project's products within the agreed upon tolerances and constraints that flows from the Executive Committee to them. The Project Manager is the ultimate arbiter between the other members of the project management team for programmatic issues and escalates, as needed, to the Executive Committee.

The Project Manager has delegated authority in conjunction with the Principal Investigator to drive the project with trades involving scope, cost, and schedule. The Project Manager plans, executes, and manages the project on a day-to-day basis within the agreed tolerances. The Project Manager is accountable for delivering the required products within the specified tolerances of time, cost, available resources, quality, scope, risk, and benefits.

The Project Manager:

- Plans, organizes, and leads the day to day project work in a manner consistent with
- Observatory standards.
- Provides monthly progress reports to the Program Manager and Portfolio Manager, reviewed by the Executive Committee and Principal Investigator. Identifies and engages stakeholders.
- Manages the project budget, schedule, scope, resources, and risks according to the corresponding management plans.
- Appropriately escalate decisions or issues based on agreed upon tolerances to the
- Executive Committee if needed.

The Project Manager escalates to the Executive Committee.

2.4.2 Principal Investigator

The Principal Investigator and Project Manager have delegated authority to deliver the project's products within the agreed upon tolerances and constraints that flows from the Executive Committee to them. The Principal Investigator is the ultimate arbiter between the other members of the project management team for scientific issues and escalates, as needed, to the Executive Committee.

The Principal Investigator and Project Manager provide the balance between science requirements (scope) and costs and schedule. The Principal Investigator and Project Manager decide on trades between these three areas, within agreed upon tolerances, as needed. The Principal Investigator understands the scientific, technical, and management aspects of the project.

The Principal Investigator:

- Motivates and technically leads the project team with a clear understanding of the instrument's design, capabilities, and science output.
- Serves as visible spokesperson for the project, building support within the entire range of project stakeholders.

The Principal Investigator escalates to the Executive Committee.

2.4.3 Project Scientist

The Project Scientist helps ensure that the project meets its scientific mandate. While the Chief Scientist is accountable for ensuring the project meets the needs of the Gemini scientific community, the Project Scientist is responsible for developing the project's science cases. The Chief Scientist ensures these science cases meet Gemini's needs. The Project Scientist is responsible for the day to day scientific aspects of the project. The Project Scientist leads the scientific requirement and testing flow from science cases to concepts of operations to science requirements and performance validation. The Project Scientist works closely with the Chief Scientist, Principal Investigator, Project Manager, Project Engineer, and Systems Engineer.

The Project Scientist:

- Leads the definition of project science requirements development, including those for data reduction and internal Gemini software changes. This work includes leading the initial science cases document and providing use cases to the Concept of Operations document.
- Identifies driving science cases and enabled science cases from the science case document, ensures the project satisfies driving science cases, and adjusts the enabled science cases as the project progresses.
- Provides scientific input and validation to project trades in collaboration with the Project Manager, Systems Engineer, and Project Engineer.
- Leads the validation of science requirements through the project's lifecycle. The Project Scientist is responsible for ensuring the project's products meet the scientific performance requirements.
- Collaborates with the Systems Engineer to produce key performance indicators, merit functions, performance models, or simulations to assist in trade studies, project tracking, and requirements validation.
- Leads the project's combined (internal and external) science team(s). May co-lead external teams with an external Project Scientist.
- Works with the Project Manager to provide scientifically relevant information and updates to stakeholders.
- Develops good relationships with project teams and collaborates with them in improving their plans, designs, methods, and deliverables.
- Supports the Project Manager on project monitoring, reviews, and oversight.

2.4.4 Systems Engineer

The Systems Engineer is accountable for ensuring the project meets its requirements. This work begins with ensuring the requirements are fit for purpose ("validation"), have a complete, traceable flow from high-level science and use cases to the lowest level ("definition"), and are testable and tested (“verification”). The Systems Engineer helps the project develop a complete design that balances the competing project constraints.

The Systems Engineer is responsible for managing the technical processes within the project, ensuring they are technically sound and suffice to produce this complete, balanced design that meets requirements. The System Engineer works closely with the Project Scientist on requirements flow and the Project Manager on technical process development and oversight. The Project Manager and Systems Engineer may agree to share and/or delegate some duties between themselves. The Systems Engineer escalates to the Project Manager.

The Systems Engineer:

- Leads the requirement definition, validation, and verification processes.
- Typically owns and operates the project’s risk and configuration management processes.
- Maintains a working knowledge both of best practice in Systems Engineering and the design, development and testing of astronomical projects.
- Provides observatory interfaces to and typically serves as the primary technical contact to external teams.
- Is accountable for developing and coordinating observatory interfaces and ensuring the consistency and ultimate compliance of the relevant system and subsystem interfaces.
- Helps the project maintain robust cross-discipline communications.

2.4.5 Project Coordinator

The Project Coordinator supports the Project Management Team with the following:

- Initiating, tracking, and managing documentation
- Creating and tracking project schedules
- Maintaining the issues log and decision tracker
- Managing action items and updating team members on their actions and the results
- Managing information flow within the team
- Assisting with reports on project schedule, risk, budget, issues

2.5 Community Relations and Outreach

During the execution of the GEMMA program, Gemini will maintain a public web page[4] to provide information on program status and updates. The GEMMA program page will be clearly accessible from Gemini’s public home page and science operations web page, and it will contain links for more detailed status information on each of the component projects. We will use the same channels for general information to our user base and the general, as used for other Gemini work: Gemini Focus, e-Newscasts, and social media postings.

Community relations and public outreach are central to the PIO project within the GEMMA program. In brief, the project contains components aimed at public outreach, education, and media training. NSF funding for multi-messenger astronomy will be spotlighted by the planned “MMA summit” that will develop a charter for public communication of the concepts and discoveries related to MMA and other science enabled by the GEMMA funding. The public outreach and educational aspects will include the production and distribution of a multimedia

[4] www.gemini.edu/gemma

planetarium program telling the story of multi-messenger astronomy, and the development of inquiry-based classroom educational materials and activities to inspire students to pursue STEM-related careers.

3 Design and Development

3.0 Design Overview

From knowledge of MCAO systems and from previous projects (GeMS, for example), we know that GNAO/RTC will be composed of 3 interrelated subsystems. These are discussed briefly below to aid in discussion of the project plan. The requirements for these subsystems are in the process of being flowed down from upper level requirements and will be provided for the GNAO/RTC CoDR.

3.0.1 The Laser Guide-Star Subsystem (LGS)

The LGS uses lasers to cause sodium in the upper atmosphere to fluoresce and, thereby, forms 'stars' that the AO subsystem (AOS) can use to correct atmospheric turbulence (instead of natural guide-stars that are only sparsely available with adequate brightness). Although our optimal number of laser spots (stars) is 6, using 3 lasers and 6 laser launch telescopes (LLTs), as shown in the middle of Figure 3, that would require 2 new lasers (we already have 1 used with existing systems) and 6 new LLTs – all of which are expensive. We are, therefore, considering other options, including 5 spots using 3 lasers and 4 LLTs (and using the existing center LLT; shown to the left in Figure 3) and 4 spots using 2 lasers and 4 LLTs (to the right in Figure 3). These 3 options are referred to as 3/6/6 (center), 3/5/5 (left), and 2/4/4 (right) respectively.

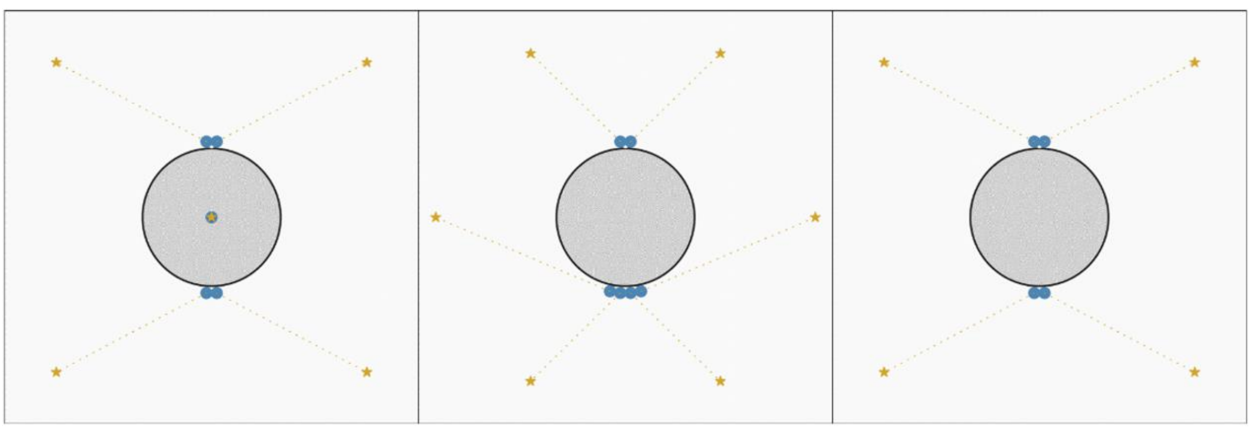

Figure 3 *Possible LLT / laser spot options –* ***left****: 5 spots using 3 lasers and 4 LLTs (and the existing center LLT);* ***center****: 6 spots using 3 lasers and 6 LLTs;* ***right****: 4 spots using 2 lasers and 4 LLTs*

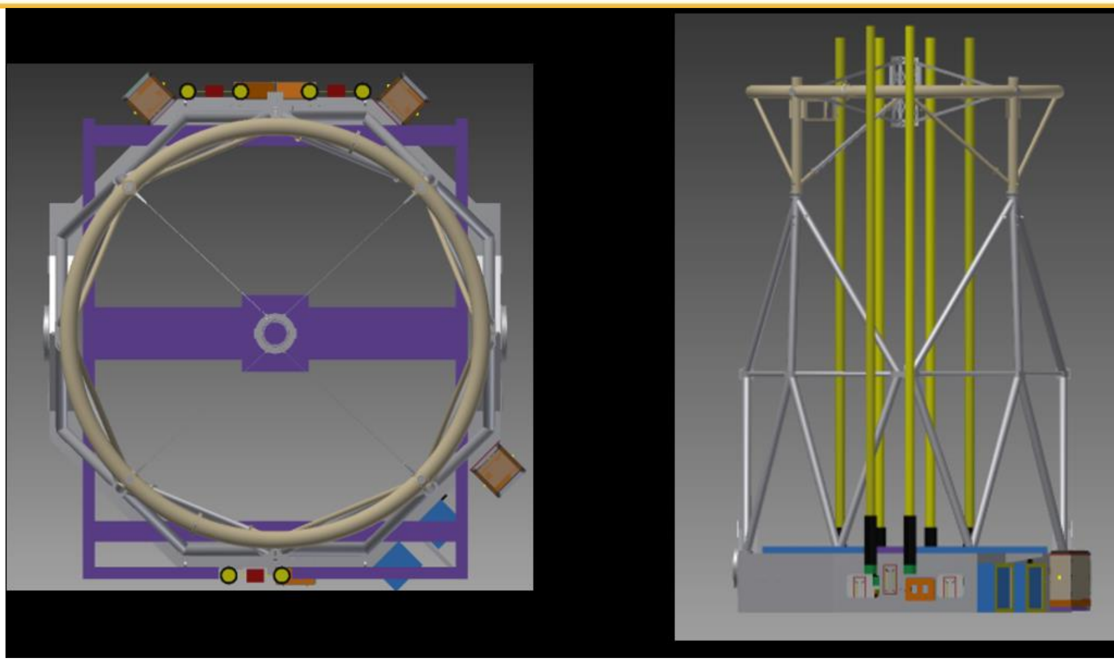

Figure 4 *Conceptual top and side views of the 3/6/6 option*

Also, please note that, even with the laser 'stars', between 1 and 3 natural guide-stars (NGSs) are also required to adequately measure tip/tilt and angular separations.

3.0.2 The Adaptive Optics Subsystem (AOS)

The Adaptive Optics Subsystem (AOS), sometimes also referred to as the AO Bench (AOB), will measure wavefront aberrations introduced mostly by the atmosphere and apply corrections for these aberrations. Since the AOS needs to handle multiple LGSs and NGSs, as in the previous subsection, the design and implementation of the AOS is very challenging, particularly within Gemini's volume and mass constraints. To help envision this, Figure 5 shows concepts of the optical path and mechanical mounting for the AOS. For reference, the ISS, the dark gray cube, is about 1.6m on a side.

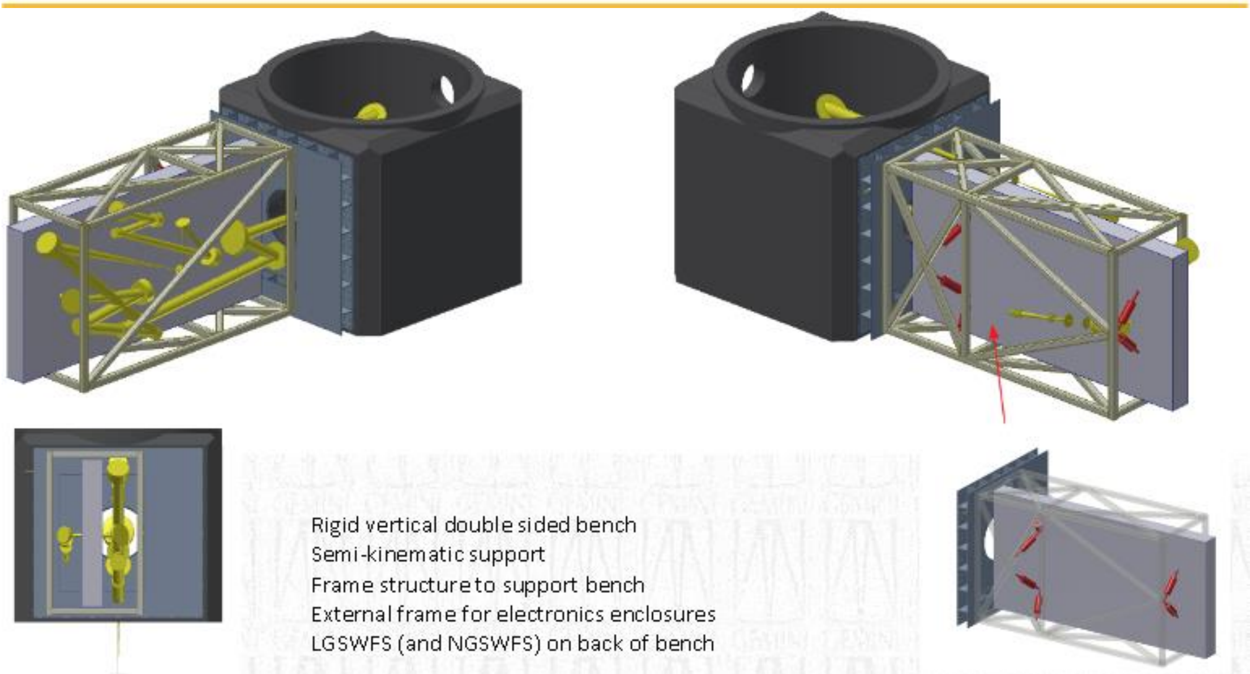

Figure 5 *Concepts of the optical path and mechanical mounting for the AOS*

In order to adequately correct the atmosphere over a wide field, as is the goal for MCAO, multiple deformable mirrors (DMs) are required. As shown in Figure 6, 3 DMs are planned, although 1 will be a flat mirror in anticipation of an Adaptive Secondary Mirror (ASM) as mentioned below.

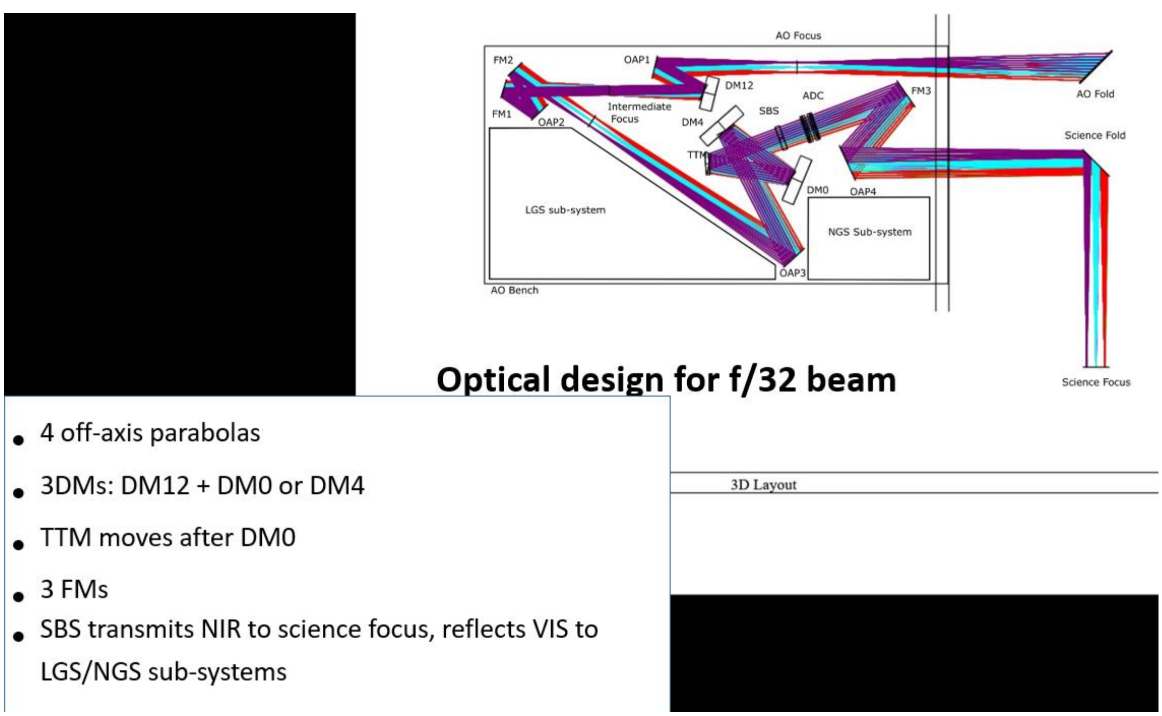

Figure 6 *Conceptual optical design for the AOS Science Path, showing 3 DMs*

3.0.3 The Real-Time Computer (RTC)

The Real-Time Computer (RTC) reads the wavefront sensor (WFS) data, calculates corrections, and outputs those corrections to the deformable mirrors (DMs) and tip/tilt (TT) mirror. That all needs to be done at 500 frames per second (fps) or faster. Given that frame rate, the number of WFSs, and the number of DMs, a huge amount of I/O (input/output) needs to occur and large numbers of calculations need to be done per second. In addition, other functions need to be performed, including interfacing with the outside world; providing streams of data for diagnostic, operations, and analysis purposes; and updating wavefront reconstruction matrices (that are used in calculating corrections).

In order to achieve this, we intend to use state-of-the-art interface hardware and computer servers. We will also make the RTC modular so that it will be suitable to serve as the RTC foundation for other instruments. Taking advantage of that suitability, we will also deliver a new RTC implementation for GeMS.

3.1 Project Plan

3.1.0 Detailed Bottom-Up Project Plan

In order to assure ourselves that we can complete the required work for the time and money provided in the GNAO/RTC's portion of the GEMMA CSA, we have developed a detailed bottom-up project plan. To develop this plan, we have adopted the following approach:

- Have Gemini serve as "prime contractor".
    - Do the LGS subsystem in-house – That means buying components (lasers, LLTs, etc.), but doing the design and implementation of the subsystem in-house.
    - Subcontract out the AO subsystem – This means subcontracting with a qualified external vendor, possibly basing their work on our internally-generated design.
    - Use a hybrid approach for the RTC – Which means utilizing an existing or nearly existing code package (examples may include but are not limited to: DARC, HEART, CACAO, and COSMIC, but specify and procure the hardware platform and tailor the software package to our needs in-house.

It is important to emphasize that this is a preliminary plan, meaning that it is being made early in the process and with some assumptions. We will be making the plan as correct as we can with what we know at this time, but it will be refined as we proceed through CoD (and then though the project). It is also important to note that we have made some selections for the sake of estimating that will be representative of our final system but won't necessarily be in our final system.

In order to develop as high a fidelity plan as possible, given what we know now, we did several things, as described in the following.

3.1.0.1 In-House Work

For the work to be performed in-house, we solicited estimates from the experts in Gemini who have performed similar work in the past, have been developing conceptual designs for GNAO/RTC, and who will perform the work for this project. So, in other words, mechanical engineers estimated mechanical engineering, software engineers estimated software engineering, etc. We then sanity checked each other and against other projects as possible.

We used all of the estimates to construct a fully resourced project plan for labor using MS Project – please see WBS__GNAO_RTC.final_2_4_4.mpp (or WBS__GNAO_RTC.final_2_4_4.pdf) for considerably more details. Please note that this project plan still needs refinement in terms of some additional resource leveling and a bit of additional scrubbing for duplicate work.

3.1.0.2 AO Adaptive Optics Subsystem (AOS) Subcontract

For the Adaptive Optics Subsystem (AOS), we requested Rough Order of Magnitude (ROM) estimates from 4 institutions skilled in the art of building AO systems and who may be prospective subcontractors for this work. To request the ROMs, we flowed-down top-level requirements to the AO subsystem in a preliminary sense and then sent a Documentation Package to the prospective institutions. The following was included in the ROM Request package:

1. "1 GNAO_AO_Subsystem_ROM_Request.pptx" (this document), which includes:
    a. The ROM request,
    b. An overview of the system,
    c. Example fast active components, and
    d. The nominal phasing for the project.
2. "2 GNAO_Requirements_ROUGH_DRAFT.xlsx" – includes draft GNAO requirements and corresponding AO subsystem requirements on which to base the subsystem being estimated. We're happy to discuss / iterate these.
3. "3 GNAO_AOB_Concept.pptx" – provides conceptual / feasibility designs for your consideration and guidance.
4. Documents for reference:
    a. "4 INST-REQ-0001 Science and Facility Common Requirements.docx"
    b. "5 ISS to AO System ICD 1.5.3 to 1.8_DRAFT.docx"
    c. "6 ICD 1.9 to 5.0 Science Instruments to Transport Storage Operational Environments Rev D.docx"

All of the institutions responded. Confidentiality prevents us from including details in this document (although they can be provided upon request). The summary is that, from the ROMs, we estimate that the AOS subcontract will cost approximately $4.36M. This does not include several of the expensive AOS components that Gemini would procure and provide to the subcontractor (the DMs, for example), Gemini labor to technically manage the subcontract and provide Systems Engineering, or complexity -- please see Table 7d for details.

3.1.0.3 RTC Subcontract

Above, we describe our 'hybrid' approach to developing the RTC, starting with an existing code package and adapting it to our needs in-house. Another option, however, would be to subcontract with another institution to develop all or most of the RTC for us. With that in mind, we requested Rough Order of Magnitude (ROM) estimates from 2 institutions experienced with RTC development. Both responded. Again, due to confidentiality, we cannot share the details here. But, the summary is that we estimate from the ROMs that an RTC subcontract would cost approximately $2.2M. This does not include complexity.

3.1.0.4 Procurements

For procurements, we estimated costs based on: previous quotes (adjusting for inflation), recent interactions with prospective vendors, web-quotes, and/or experience with previous projects for lower-cost items. We then sanity checked the items based on previous experience or actuals. A summary of this can be found in the "GNAO/RTC phased procurements" table in subsection 3.2, below. Additional details can be provided upon request.

3.1.0.5 Result of our planning for LGS option selection

As mentioned in subsection 3.0.1, above, we believe that the 3/6/6 lasers/LLTs/spots option is our optimal one for the LGS and that the 3/5/5 option is the next best. However, as a result of our current planning, we find that the option that fits in our funding envelope is the 2/4/4 option. Although we are continuing to evaluate, we believe that we can marginally meet our requirements with this configuration, but with no headroom. Between now and our CoDR, we will continue the evaluation and also look for other trades we can make to get to the 3/5/5 option. We will make the final decision as we conclude our CoD.

Further details of this plan are discussed in the next several subsections.

3.1.1 GNAO/RTC Scope

The GEMMA NSF CSA award will fund the GNAO/RTC project from its planning stage to the completion of first-light. First-light is defined as obtaining science results with GNAO/RTC and its planned first-light instrument, the Gemini North Adaptive Optics Imager (GNAOI). Normally, first-light would be the first part of the Commissioning phase. But, since it will be the ending point of the current GNAO/RTC funding, for planning purposes we are including it at the end of the Integration and Test (I&T) phase. In the following, we will refer to this part of the project as GNAO/RTC(CSA).

The GNAO/RTC project will continue beyond first-light, with other funding, to execute Commissioning and until GNAO/RTC is fully integrated into regular science operations. We will refer to the complete project (including GNAO/RTC(CSA)) as GNAO/RTC(All). In preparation for Commissioning, we will complete a Commissioning plan as part of GNAO/RTC(CSA).

Below are the defined bounds of the NSF CSA award in the areas of GNAOI, the Adaptive Secondary Mirror (ASM), and complete GNAO/RTC Commissioning and beyond.

- GNAOI:
    - The design, manufacture, integration, test and delivery of GNAOI is **outside** the scope of both GNAO/RTC(CSA) and GNAO/RTC(All).
    - GNAOI will be funded using Gemini the Instrumentation Development Fund.
    - Gemini plans to release a Request for Proposal (RfP) for GNAOI in Q3-2019 and place a contract with an external organization to design, manufacture, integrate, test and deliver the instrument.
    - We expect GNAOI to be delivered to Gemini North by Dec 2023.
    - The integration between GNAOI and GNAO/RTC is **inside** the scope of the GNAO/RTC(CSA).
    - Successful first-light science demonstration and a significant science result are **inside** the scope of the GNAO/RTC(CSA).
- Adaptive Secondary Mirror (ASM):

- A feasibility study, a post-conceptual design, and anything beyond, including placing any specific external contracts, are **outside** the scope of both GNAO/RTC(CSA) and GNAO/RTC(All).
- A GNAO/RTC conceptual design that is compatible with and takes advantage of a future ASM upgrade is **inside** the scope of GNAO/RTC(CSA).

- Complete GNAO/RTC Commissioning, Science Verification and Facility Optimization:
  - Complete GNAO/RTC commissioning which includes commissioning GNAO/RTC on-sky over its full parameter space is **outside** the scope of GNAO/RTC(CSA) but **inside** the scope of the GNAO/RTC(All).
  - Science Verification, which could include early science observations while on-sky optimization occurs is **outside** the scope of GNAO/RTC(CSA) but **inside** the scope of the GNAO/RTC(All).
  - Facility Optimization, which includes meeting facility FTE support requirements and base facility operations, is **outside** the scope of GNAO/RTC(CSA) but **inside** the scope of the GNAO/RTC(All).
  - GNAO/RTC(All) ends on completion of the facility optimization and successful handover from GNAO/RTC(All) to Gemini Science Operations.

This Project Execution Plan currently focuses on the scope within GNAO/RTC(CSA) but will be expanded in the future to include the remainder of GNAO/RTC(All).

3.1.2 GNAO/RTC End-of-project Deliverables

The end-of-project GNAO/RTC Deliverables currently include:

- GNAO/RTC Facility
- GNAO/RTC Documentation Set
- GNAO/RTC Facility Associated Hardware
- GNAO/RTC Facility Associated Software
- Observatory Infrastructure Upgrades
- Observatory Control System Upgrades
- Staff GNAO/RTC Training

3.1.2.1 GNAO/RTC Facility

The GNAO/RTC Facility includes all the operational hardware and software to meet the set of requirements and fulfill the set of identified science cases. This consists of the LGS, AOS, and RTC subsystems as described in the “Design Overview” subsection above. These are shown in block diagram form for the LGS and AOS in Figure 7 and Figure 8. The RTC will be a computer residing with the AOS.

Not shown on the block diagrams are an AOS top-level control computer (TLC) and an LGS control computer for each BTO bench.

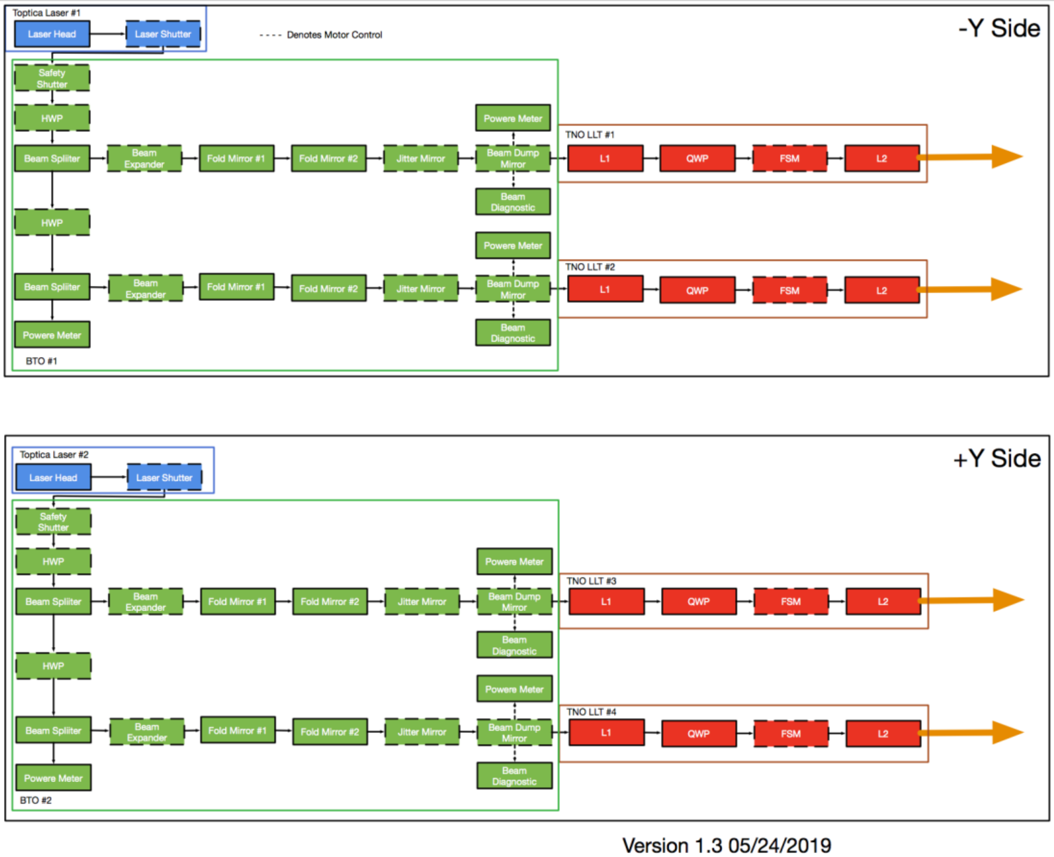

Figure 7 *Conceptual block diagram of the LGS subsystems*

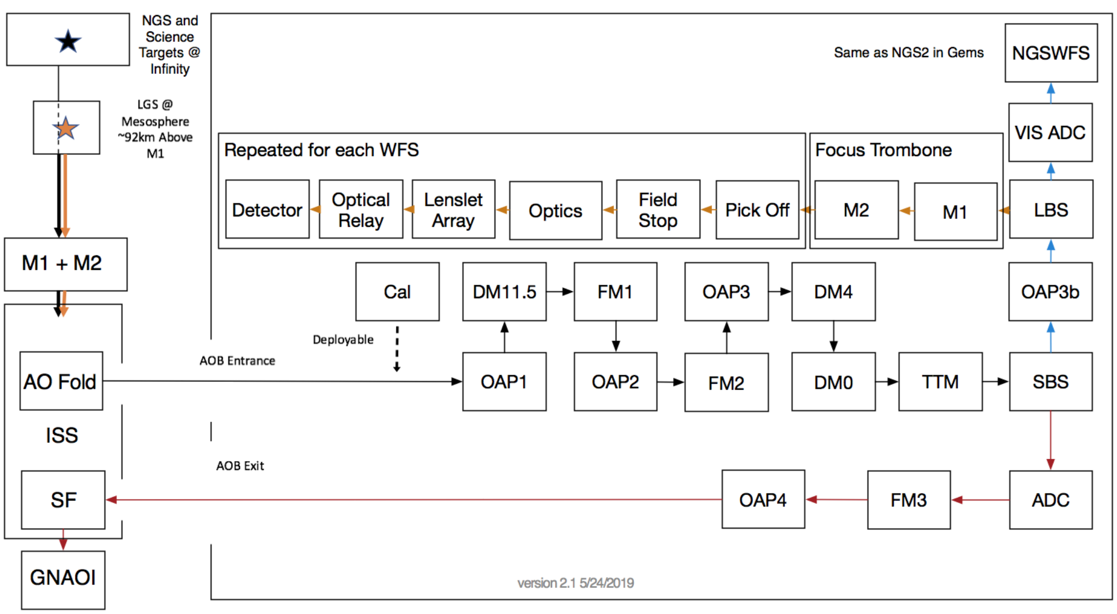

Figure 8 *Conceptual block diagram of the AOS subsystems*

3.1.2.2 GNAO/RTC Documentation Set

The initial GNAO/RTC Documentation Set is given below in Table 5. This set will be reviewed during the Conceptual Design Stage of the project. Please note that CSV-related documentation has been removed because the CSV is no longer within the work scope described in this document (please see subsection 3.1.1).

	Doc No.	Deliverable	Stage					
			CoD	PD	CD	AIV	TTI	~~CSV~~
Design	GNAO-01	Project Management Plan (PMP)	✓ cc	✓	✓	✓	✓	
	GNAO-02	System Engineering Management Plan (SEMP)	✓ cc	✓	✓	✓	✓	
	GNAO-03	Safety Management Plan (SMP)	✓ cc	✓	✓	✓	✓	
	GNAO-04	Science Cases	✓ cc	✓	✓	✓	✓	~~✓~~
	GNAO-05	Concept of Operations Document (ConOps)	✓ cc	✓	✓	✓	✓	~~✓~~
	GNAO-06	Requirements Document (RD)	✓	✓	✓	✓	✓	~~✓~~
	GNAO-07	Conceptual Design Document (CoDD)	✓					
	GNAO-08	CoD End Stage Report	✓					
	GNAO-10	Preliminary Design Document (PDD)		✓				
	GNAO-11	Facility Interface Control Documents (ICD)		✓ D	✓ cc	✓	✓	~~✓~~
	GNAO-12	Acceptance Test Plan (ATP)		✓ D	✓ cc			
	GNAO-13	PD End Stage Report		✓				
	GNAO-15	Critical Design Document (CDD)			✓			
	GNAO-16	Assembly, Integration and Verification Plan			✓			
	GNAO-17	CD End Stage Report			✓			
Build	GNAO-19	As-built records				✓ cc	✓	~~✓~~
	GNAO-20	Recommended Spares List				✓ cc	✓	~~✓~~
	GNAO-21	Pre-Integration Acceptance Test Report (pre-ATR)				✓		
	GNAO-22	Service and Maintenance Manual (S&MM)				✓ cc	✓	~~✓~~
	GNAO-23	User Manual (UM)				✓ cc	✓	~~✓~~
	GNAO-24	Technical Manual (TM)				✓ cc	✓	~~✓~~
	GNAO-25	Software Maintenance Manual (SMM)				✓ cc	✓	~~✓~~
	GNAO-26	Commissioning & Science Verification Plan (CSVP)				✓ D	✓ cc	
	GNAO-28	AIV End Stage Report				✓		
Telescope Int. & Comm.	GNAO-30	Post-Integration Acceptance Test Report (post-ATR)					✓	
	GNAO-31	TI End Stage Report					✓	
	GNAO-32	C&SV Stage Plan					✓	
	~~GNAO-33~~	~~Commissioning and Science Verification Report (CSVR)~~						~~✓~~
	~~GNAO-34~~	~~GNAO End Project Report~~						~~✓~~

[cc] Change Control [D] Draft

Table 5 *GNAO/RTC Documentation Set: Matrix listing end-of-stage documents*

The purpose of each document is provided below.

- **Project Management Plan [PMP]:** Communicates the project management approach, methodology, practices, processes, and tools that will apply through the lifetime of the project. The PMP shall also communicate the specifics related to the creation, monitoring, and control of management elements including budget, schedule, risk, work elements, resources, and communication.
- **System Engineering Management Plan [SEMP]:** Communicates the system engineering approach, methodology, practices, processes and tools it shall apply to the project during its duration.

- **Safety Management Plan [SMP]:** Communicates the project's approach to keeping personnel and the instrument safe during the project.
- **Science Cases:** Communicates the science cases for the facility and envisaged instruments.
- **Concept of Operations [ConOps]:** Communicates the instrument's operating modes and key operating scenarios.
- **Requirements Document [RD]**: Communicates the requirements associated with the project deliverables.
- **Design Document (Conceptual, Preliminary, Critical):** Communicates the current end-of-stage design of the GNAO/RTC Facility, the GNAO/RTC Associated Hardware, and the GNAO/RTC Associated Software at the end of each design stage.
- **End Stage Reports:** Reviews the progress of the project to date including how the stage performed against the original project and stage plan baseline. It shall discuss the major successes and challenges of the stage, suggest future actions based on lessons learned, and include requests related to deviations associated with the next stage.
- **Facility Interface Control Documentation Set:** Communicates the facility's internal interfaces.
- **Acceptance Test Plan [ATP]:** Communicates the test plan for the facility both pre- and post- telescope integration.
- **Assembly, Integration, and Verification Plan:** Provides staff with the technical procedures to assemble, integrate, and verify the GNAO/RTC Facility.
- **Service and Maintenance Manual [S&MM]:** Provides staff with the information necessary to service and maintain the instrument.
- **User Manual [UM]:** Provides a Gemini Instrument Scientist with an understanding of the facility and its operation. It shall provide information on the facility's configuration, modes of operation, user calibration procedures, and performance characteristics.
- **Technical Manual [TM]:** Provides staff with the necessary technical information to assemble, align, internally calibrate, cable, and place the facility into an operational state and also provide a technical understanding of the design and structure of the instrument.
- **Software Maintenance Manual [SMM]:** Provides staff with a description of the facility software at a level of detail that a programmer familiar with the Gemini software environment, but not initially familiar with the facility software, can maintain it properly.
- **As-built Records:** Provides staff with all the specifications, 3d models, 2d manufacturing drawings, wiring diagrams, and software code to successfully refabricate and acquire the components of the GNAO/RTC facility such that it could be duplicated.
- **Recommended Spares List:** Provides the observatory with a list of GNAO/RTC hardware components the project believes are important for Gemini to obtain. It shall include a list of GNAO/RTC Facility and GNAO/RTC Associated Hardware spares that shall be purchased by the project.
- **Pre-Integration Acceptance Test Report:** Documents the results of the requirement verifications performed on the GNAO/RTC Facility before it has been fully integrated with the telescope. Test may include those at the subsystem level.
- **Commissioning & Science Verification Plan:** Communicates the plan and procedures needed to systematically characterize the performance of the instrument in all of its modes and verify any remaining concept of operations requirements and science requirements. The plan for first-light commissioning will be a subset of this document.
- **Post-Integration Acceptance Test Report:** Communicates the results for the requirement verifications performed on the GNAO/RTC Facility after telescope integration.

3.1.2.3 GNAO/RTC Facility Associated Hardware

GNAO/RTC facility associated hardware includes deliverable hardware that are not part of the GNAO/RTC facility but are necessary for the successful operation and maintenance of the instrument. These items include any necessary non-commonly available hardware and tools used for alignment, assembly, calibration, handling, installation, maintenance, service, testing, and transportation (including shipping containers).

3.1.2.4 GNAO/RTC Facility Associated Software

GNAO/RTC facility associated software includes deliverable software items that are not part of the GNAO/RTC facility but are necessary for the successful operation and maintenance of the instrument. These items include any software required for alignment, calibration, maintenance, service, simulation, and testing.

3.1.2.5 Observatory Infrastructure Upgrades

Changes to Gemini existing infrastructure to successfully accommodate and maintain GNAO/RTC. This deliverable will be detailed during the Design Phase of the project.

3.1.2.6 Observatory Control System Upgrades

Changes to the existing Gemini software to operate and monitor GNAO/RTC. This deliverable will be detailed during the Design Phase of the project.

3.1.2.7 Staff GNAO/RTC Training

A defined set of knowledge and experience of Gemini staff responsible for operating and for maintaining the facility. This deliverable will be detailed during the Design Phase of the project.

3.1.3 GNAO/RTC Project Structure

The GNAO/RTC project shall be divided into 3 phases and 5 stages as shown in Figure 9 below.

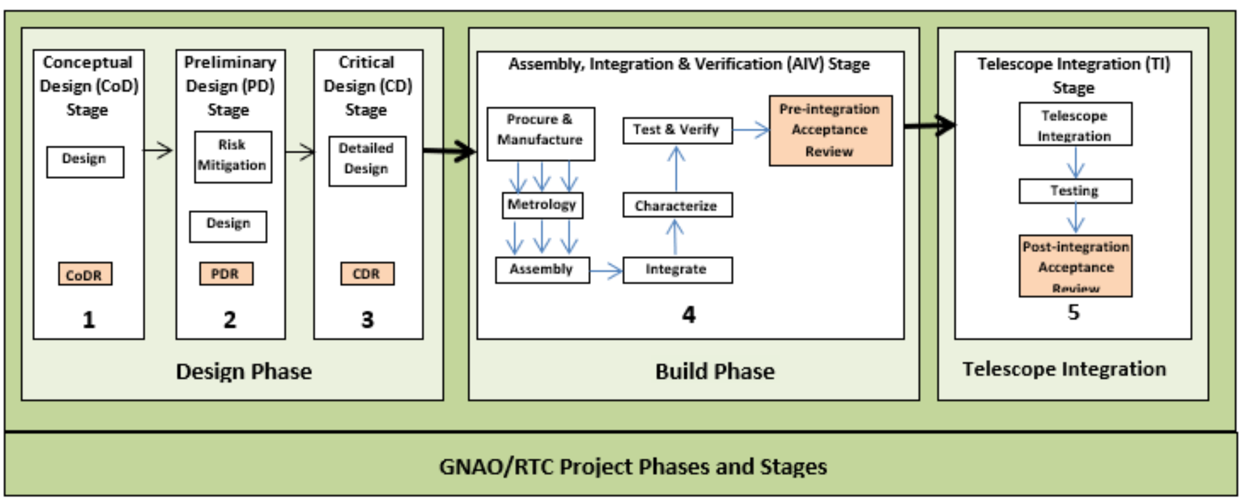

Figure 9 *GNAO/RTC Project Phases and Stages*

3.1.3.1 Design Phase

The Design Phase of the project is the phase in which Gemini develops the design of the GNAO/RTC Deliverables. It is divided into three stages:

- Conceptual Design Stage
- Preliminary Design Stage
- Critical Design Stage

The successful completion of the Critical Design Review (CDR) shall mark the closure of the project's Design Phase.

3.1.3.2 Build Phase

The Build Phase of the project is the phase in which Gemini manufactures, procures, creates, measures, assembles, integrates, characterizes, optimizes, tests, and verifies the GNAO/RTC deliverables. This phase consists of a single standalone stage:

- Assembly, Integration, and Verification (AIV) Stage

The integration includes the integration and verification of hardware and software within the observatory to the point of making changes to any live operational systems. Hence there should be no impact on Science Operations during this stage. The successful completion of the AIV Stage shall mark the closure of the project's Build Phase. Once the phase is completed, all hardware and software associated with the GNAO/RTC facility, the GNAO/RTC Associated Software, and the GNAO/RTC Associated Hardware should be in their final state and placed under change control.

3.1.3.3 Telescope Integration and Commissioning Phase

The Telescope Integration and Commissioning Phase of the project is the phase in which subcontractors transport, test, integrate, and commission their GNAO/RTC Contract Deliverables. This phase has been divided into two stages:

- Telescope Integration Stage – First Light will be included at the end of this stage, thus ending the portion of the project covered by our current CSA and this document
- Commissioning and Science Verification Stage – This stage is not covered by our current CSA or most of this document

The remaining integration and verification activities during this stage include making changes and verifying those changes to live operational systems such as the observatory control software and any required changes to the AO fold.

The successful completion of the Commissioning and Science Verification Stage shall mark the closure of the project, the formal acceptance of the project deliverables by regular operations.

3.1.4 GNAO/RTC Project Kick Off Meetings and Design Reviews

Each stage shall begin with a kickoff meeting and conclude with an end-of-stage review. In the interest of saving time and money, some kickoff meeting will likely be held by video. The kickoff meetings will occur within approximately 15 working days of the beginning of each stage.

At each kickoff meeting the GNAO/RTC project shall present any changes to the Project Plan (including the schedule, budget, and risks) requested as a result of the previous end-of-stage review. The meeting shall focus on the upcoming stage's scope of work, plan, and deliverables, including project deliverables.

All design stages will hold a formal end-of-stage review which will be held on or around the date contained in the project plan. The stage review acts as a project health check to demonstrate that the project is on-schedule and on-track to meet requirements, and ready to proceed to the next stage. The required state of the GNAO/RTC Deliverables at the end of each stage can be found in Table 5, GNAO/RTC Documentation Set: Matrix listing end-of-stage documents (section 3.1.2.2).

The review evaluation criteria shall be circulated to the GNAO/RTC project team prior to the submission of the review documentation before submission of the end-of-stage material to the External Review Committee.

Once the GNAO/RTC project management team is confident that the GNAO/RTC project will have all end-of-stage deliverables ready by a certain date, it shall confirm the date of the review. Gemini and the NSF shall schedule the Conceptual Design Review, the Preliminary Design Review and the Critical Design Review. Each review shall be held at the Gemini North Base Facility, Hilo, US.

Gemini shall select an external review committee chair and shall select the review committee members with the advice of the review committee chair, if so requested. Additional NSF personnel may elect to attend the review. The GNAO/RTC Project Manager may be tasked with making the logistical arrangements. The GNAO/RTC Project Team shall deliver the end-of-stage documentation to the review committee at least two weeks before the end-of-stage review. Gemini shall be responsible for all travel expenses and arrangements for Gemini staff and the review committee.

Within 10 working days after the review, the review committee shall produce and deliver an End-of-Stage Review Report to the NSF Program Officer and the GNAO/RTC Project Manager and the NSF Program Officer shall decide whether the GNAO/RTC project can proceed to the next design stage or whether to require additional work (including, possibly, an additional review) to correct identified shortcomings.

GNAO/RTC reviews are preliminarily scheduled as in the following (please note that we are in the process of scheduling our CoDR, with probable dates being 9/26/19 and 9/27/19 (as calendar conflicts are preventing us from using our preliminary dates in the week of 9/16/19)):

1	**GNAO/RTC Project**	**Mon 5/20/19**
1.1	**Meetings And Milestones**	**Thu 9/5/19**
1.1.1	Submit documentation for CoDR	Thu 9/5/19
1.1.2	CoDR	Tue 9/17/19
1.1.3	CoDR concludes, PD commences	Mon 9/30/19
1.1.4	Submit documentation for PDR	Wed 5/6/20
1.1.5	PDR	Mon 5/18/20
1.1.6	PDR concludes, CD commences	Fri 5/29/20
1.1.7	Submit documentation for CDR	Wed 1/6/21
1.1.8	CDR	Mon 1/18/21
1.1.9	CDR concludes, Build commences	Fri 1/29/21
1.1.10	Submit documents for Pre-I&T Review	Thu 9/8/22
1.1.11	Pre-I&T Review	Tue 9/20/22
1.1.12	Pre-I&T Review concludes, I&T commences	Mon 10/3/22
1.1.13	Final document review	Wed 3/27/24

Table 6 *Preliminary GNAO/RTC reviews schedule*

3.2 Development Budget and Funding Sources

The GNAO/RTC budget is shown in different tables below. The basis of estimate for the budget is described in the "3.1.0 Detailed Bottom-Up Project Plan" subsection, above.

3.2.1 GNAO/RTC Labor by Fiscal Year

LABOR COSTS	FY19	FY20	FY21	FY22	FY23	FY24	TOTAL
Engineering	$317,688	$448,756	$426,911	$249,615	$221,347	$119,255	**$1,783,572**
Management	$114,448	$353,645	$304,691	$259,560	$72,913	$57,577	**$1,162,834**
Postdocs	$21,887	$133,300	$92,879	$67,590	$44,984	$27,579	**$388,218**
Project Support	$7,515	$21,815	$22,469	$23,143	$23,069	$13,464	**$111,475**
Scientists	$98,747	$244,961	$191,815	$167,175	$84,529	$49,982	**$837,209**
Systems Engineering	$154,403	$428,828	$413,904	$284,717	$195,505	$107,078	**$1,584,436**
SOS	$2,294	$0	$0	$0	$0	$0	**$2,294**
Software Engineering	$45,994	$96,381	$102,638	$84,920	$49,982	$3,677	**$383,593**
Technicians	$0	$0	$120,499	$154,248	$0	$0	**$274,747**
Grand Total	**$762,976**	**$1,727,686**	**$1,675,806**	**$1,290,969**	**$692,329**	**$378,613**	**$6,528,378**

Table 7a *GNAO/RTC Labor by Fiscal Year (with 22% complexity included)*

3.2.2 GNAO/RTC Budget by Fiscal Year

WBS #	Labor	FY19	FY20	FY21	FY22	FY23	FY24	Total
1.1	Meetings And Milestones	$31,169	$31,169	$31,169	$31,169	$0	$31,169	**$155,846**
1.2	Project Management, including non-subsystem-specific SE	$139,054	$428,431	$350,360	$300,546	$109,246	$73,259	**$1,400,897**
1.3	Science, including the AOWG	$88,173	$217,988	$164,183	$153,604	$92,774	$47,428	**$764,149**
1.4	Laser Guide Star Subsystem (LGS)	$245,820	$541,645	$655,755	$500,656	$277,238	$109,197	**$2,330,311**
1.5	Adaptive Optics Subsystem (AOS)	$188,060	$245,788	$255,614	$132,791	$115,211	$64,451	**$1,001,914**
1.6	Real-Time Computer (RTC)	$70,699	$262,663	$218,726	$172,203	$97,860	$53,108	**$875,260**
	Non-Labor							
1.4	Laser Guide Star Subsystem (LGS)	$0	$372,026	$1,444,500	$2,185,661	$0	$0	**$4,002,187**
1.5	Adaptive Optics Subsystem (AOS)	$0	$826,546	$3,158,196	$0	$2,126,042	$1,594,532	**$7,705,316**
1.6	Real-Time Computer (RTC)	$0	$156,160	$0	$100,040	$0	$0	**$256,200**
	Other							
other	Spent to date	$288,574	$0	$0	$0	$0	$0	**$288,574**
other	Travel	$54,158	$102,096	$88,902	$52,797	$29,804	$53,732	**$381,489**
other	Supplies	$2,288	$6,863	$6,863	$6,863	$6,863	$6,863	**$36,600**
other	Freight	$0	$0	$0	$0	$48,800	$0	**$48,800**
	Totals	**$1,107,995**	**$3,191,376**	**$6,374,267**	**$3,636,329**	**$2,903,837**	**$2,033,739**	**$19,247,544**

Table 7b *GNAO/RTC Budget by Fiscal Year (with 22% complexity included as appropriate)*

	FY19	FY20	FY21	FY22	FY23	FY24	Total
Spent to date	$288,574	$0	$0	$0	$0	$0	**$288,574**
Labor	$762,976	$1,727,686	$1,675,806	$1,290,969	$692,329	$378,613	**$6,528,378**
Procurements	$0	$528,186	$3,805,430	$2,285,701	$0	$0	**$6,619,317**
Contracts	$0	$826,546	$797,266	$0	$2,126,042	$1,594,532	**$5,344,386**
Travel	$54,158	$102,096	$88,902	$52,797	$29,804	$53,732	**$381,489**
Supplies	$2,288	$6,863	$6,863	$6,863	$6,863	$6,863	**$36,600**
Freight	$0	$0	$0	$0	$48,800	$0	**$48,800**
Total	**$1,107,995**	**$3,191,376**	**$6,374,267**	**$3,636,329**	**$2,903,837**	**$2,033,739**	**$19,247,544**

Table 7c *GNAO/RTC Budget Summary by Fiscal Year (with 22% complexity included as appropriate)*

3.2.3 GNAO/RTC Budget by WBS Element

WBS #	Description	Total	Labor	Procures	Contracts	Travel, etc.	Notes
1.1	**Meetings And Milestones**	**$155,846**	$155,846				this is the labor to participate in review meetings, etc.
1.2	**Project Management, including non-subsystem-specific SE**	**$1,400,897**	$1,400,897				
1.3	**Science, including the AOWG**	**$764,149**	$764,149				
1.4	**Laser Guide Star Subsystem (LGS)**	**$6,332,498**	$2,330,311				this is the labor to do the LGS in-house with the the 2/4/4 option (2 lasers, 4 LLTs, 4 spots) in the 2-2-0 configuration
				$4,002,187			these are the procurements to support the 2/4/4 option (2 lasers, 4 LLTs, 4 spots) -- we already have 1 laser, so we need 1 more laser and 4 LLTs
1.5	**Adaptive Optics Subsystem (AOS)**	**$8,707,230**	$1,001,914				this is for Systems Engineering and Control Computer software development
				$2,360,931			this is for the fast active AO components that we said we would provide when requesting ROMs, to support the 2/4/4 option
					$29,280		small contracts with Flatwavefronts for AO simulations
					$5,315,106		this is the estimated cost of the AOS subcontract, as per the ROM estimates that we requested and received
1.6	**Real-Time Computer (RTC)**	**$1,131,460**	$875,260				this is for labor to develop the RTC in-house starting with an open-source AO software package
				$256,200			these are the prcurements to develop the RTC in-house
other	**Estimated spending to May 31, 2019**	**$288,574**				$288,574	based on actuals of $216,829.28 to early May; our in-depth plan starts on June 1, 2019
other	**Travel expenses**	**$381,489**				$381,489	
other	**Supplies**	**$36,600**				$36,600	
other	**Freight**	**$48,800**				$48,800	
	Total total	**$19,247,544**	**$6,528,378**	**$6,619,317**	**$5,344,386**	**$755,463**	

Table 7d *GNAO/RTC Budget by Subsystem (with 22% complexity included as appropriate)*

3.2.3 GNAO/RTC Phased Procurements (next page)

Please note that the phased procurements shown below will require ordering and partially paying for some items prior to the conclusion of our Design Phases, the laser and LLT's in particular. We will be requesting permission to do this at our CoDR.

		PD		CD			Build							I&T						First Light
	Phase starts	10/1/2019		6/1/2020			2/1/2021							10/3/2022						4/1/2024
	Calendar year:	CA19	CA20	CA20	CA20	CA20	CA21	CA21	CA21	CA21	CA22	CA22	CA22	CA22	CA23	CA23	CA23	CA23	CA24	CA24
	Fiscal year:	FY20	FY20	FY20	FY20	FY21	FY21	FY21	FY21	FY22	FY22	FY22	FY22	FY23	FY23	FY23	FY23	FY24	FY24	FY24
Item	**Need By**																			
lasers	11/2/2021	$372,026								$868,061										
4 LLTs	10/4/21, 12/20/21, 2/16/22, 3/2/22					$518,500	$518,500			$518,500	$518,500									
heat exchangers	2/8/2021						$109,800													
optical tables for BTOs	5/3/2021							$5,856												
optics for BTOs	5/3/2021							$15,860												
BTOs enclosure	5/3/2021							$85,400												
motors for BTOs	5/3/2021							$29,280												
FSMs for lasers	5/3/2021							$57,238												
motor controller for BTOs	5/3/2021							$26,840												
laser pointing camera	5/3/2021							$48,800												
beam diagnostic systems	5/3/2021							$15,860												
safety equipment	3/7/2022						$5,978													
telescope mounting hdw	3/7/2022										$146,400									
telescope demo, etc.	3/7/2022										$134,200									
Control computer	2/1/2021						$6,588													
DM0	1sr Q in build						$421,583													
drive electronics for DM0	1sr Q in build						$171,758													
DM1	1sr Q in build						$0													
drive electronics for DM1	1sr Q in build						$0													
DM2	1sr Q in build						$421,583													
drive electronics for DM2	1sr Q in build						$171,758													
TT stage/mirror	1sr Q in build						$89,378													
TT mirror	1sr Q in build						$173,237													
LGS WFS cameras	1sr Q in build						$837,884													
NGS WFS camera	1sr Q in build						$70,455													
Control computer	1sr Q in build						$3,294													
Flatwavefronts	PD and CD	$14,640		$14,640																
AOS Subcontract	PD through I&T			$797,266			$797,266							$2,126,042						$1,594,532
RTC computer		$112,240								$56,120										
AO interface electronics			$43,920							$43,920										
Total:		**$498,906**	**$43,920**	**$811,906**		**$518,500**	**$3,799,062**	**$285,134**		**$1,486,601**	**$799,100**			**$2,126,042**						**$1,594,532**

Table 7e *GNAO/RTC phased procurements (with 22% complexity applied)*

3.3 Project Development Schedule

Figure 10a shows the GNAO/RTC project phases along with phased completions for subsystems (schedule contingency is not shown at the end of the project).

Task Name	Start
Overall project Preliminary Design	Tue 10/1/19
Overall project Critical Design	Mon 6/1/20
Overall project Build	Mon 2/1/21
Overall project I&T	Tue 10/4/22
AOS Preliminary Design	Tue 10/1/19
LGS PD concludes	Thu 5/28/20
AOS Critical Design	Mon 6/1/20
RTC design complete	Fri 6/19/20
LGS CD concludes	Thu 1/28/21
RTC -- GeMS RTC deployed	Fri 10/8/21
AOS control computer ready for integration	Mon 1/17/22
RTC -- GNAO RTC ready for integration	Fri 4/22/22
LGS laser system 1 installed and commissioned	Fri 7/22/22
AOS Build	Mon 2/1/21
LGS laser system 2 installed and commissioned	Mon 10/24/22
LGS control computer tested and ready	Tue 3/28/23
AOS I&T	Tue 10/4/22
First Light	Mon 4/1/24

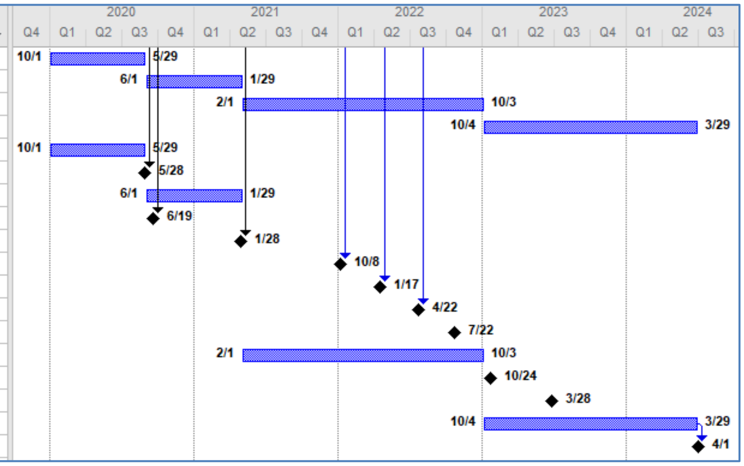

Figure 10a *Project phases showing phased completions for subsystems*

The project phases are shown in yellow and, not coincidentally, the AOS (to be subcontracted), follows those phases (the AOS is shown in blue). The other 2 subsystems are phased a bit differently so that they can be ready as needed. The RTC, for example, shown in green, will conclude its design phase toward the beginning of the project's CD phase so that it can be ready for integration with the AOS during the AOS's build phase. Similarly, the LGS subsystem, in orange, will be integrated onto the telescope and tested as its components are ready, to be prepared for the AOS integration early in I&T. With this approach, the bulk of the I&T phase will be dedicated to integrating the AOS and testing the system as a whole.

Figures 10b and 10c show a slightly unrolled view of the overall project plan. Please see WBS__GNAO_RTC.final_2_4_4.mpp (or WBS__GNAO_RTC.final_2_4_4.pdf) for considerably more details. Please note that this project plan still needs refinement in terms of some additional resource leveling and a bit of additional scrubbing for duplicate work.

	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

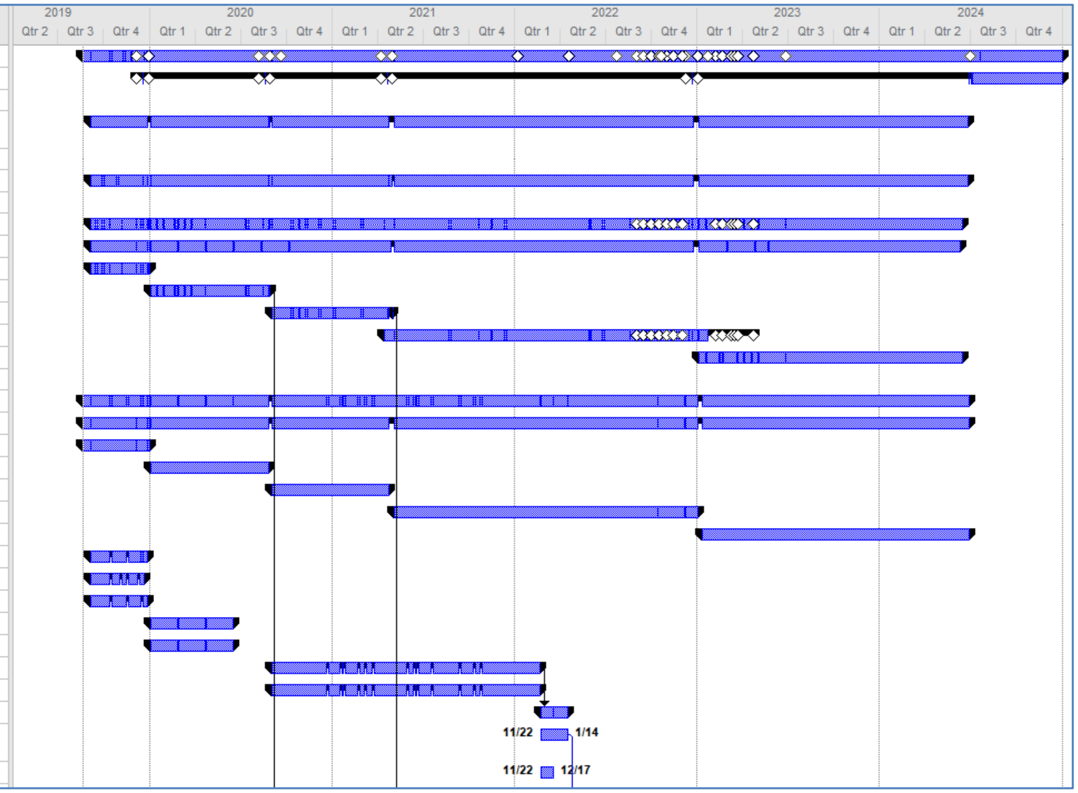

Figure 10b *GNAO/RTC project schedule, 1 of 2 (see WBS__GNAO_RTC.final_2_4_4 for detail)*

	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

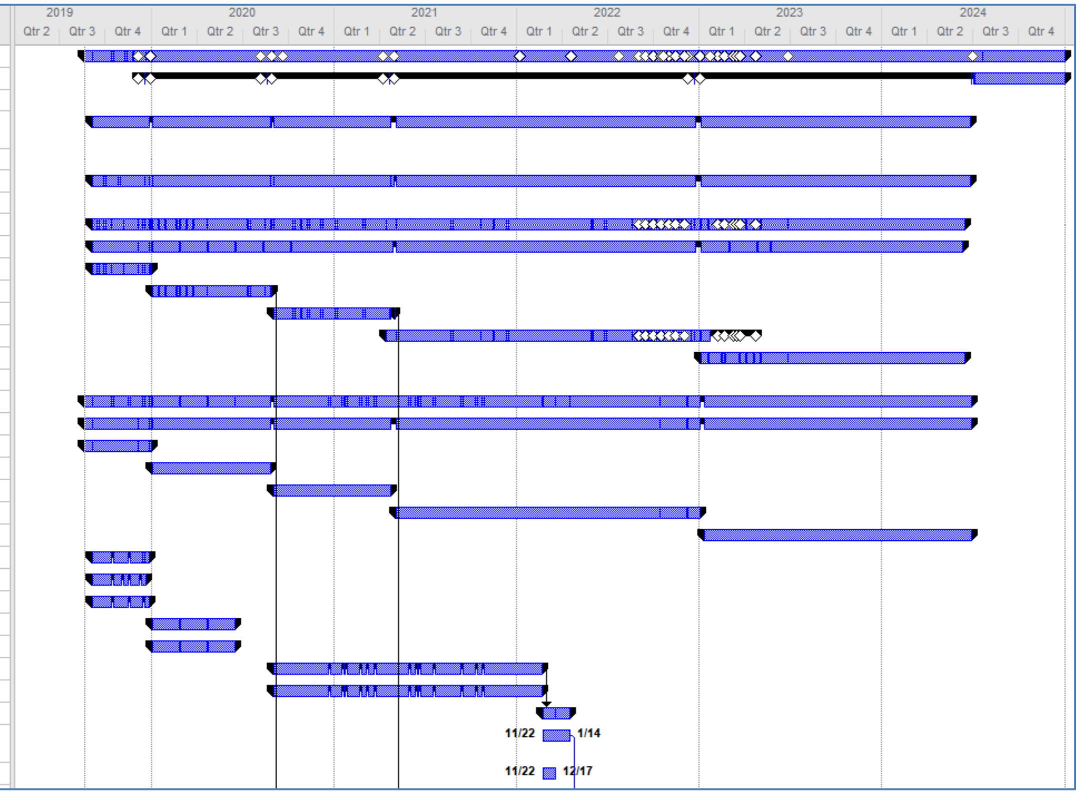

Figure 10c *GNAO/RTC project schedule, 2 of 2 (see WBS__GNAO_RTC.final_2_4_4 for detail)*

In addition to the above, there are other inter-project dependencies that we need to be mindful of. These include GNAOI, the first-light imaging science instrument we are developing externally to the GEMMA program; the adaptive secondary mirror we are also developing externally to the GEMMA program; and any additional instruments coming to Gemini for possible use behind GNAO/RTC -- such as IGRINS2 and GIRMOS. These are listed below.

a. GNAOI – this is the only one on this list that we are dependent on, although even for this we have a likely backup (bring GSAOI north for this purpose)
    i. **Provide** GNAO/RTC Specification
    ii. **Provide** GNAO/RTC Interfaces
    iii. **Receive** GNAOI Requirements
    iv. **Receive** GNAOI Pre-delivery Test Report
    v. **Receive** GNAOI (by 12/31/23)

b. ASM
    i. **Provide** GNAO/RTC Specification
    ii. **Provide** GNAO/RTC Interfaces
    iii. **Receive** Requirements from ASM
    iv. **Receive** ASM Interfaces
    v. **Provide** GNAO/RTC Test Report.

c. Other instruments (IGRINS2, GIRMOS, …)
    i. **Provide** GNAO/RTC Specification
    ii. **Provide** GNAO/RTC Interfaces
    iii. **Receive** Requirements from other instruments for our consideration (although, except for not precluding the use of these instruments with our design, the support of them is beyond the scope of this project)

We shall further consider these during the Design Phase of the project.

4 Construction Project Definition

4.1 Summary of Total Project Definition

The baseline design for GNAO/RTC will provide a Multi-Conjugate Adaptive Optics (MCAO) system that provides high angular resolution over a large field of view over a broad wavelength range with a near diffraction-limited correction to all instruments. The MCAO system will be designed as per current requirements and to allow for future upgrade paths. The GNAO/RTC facility will includes three major components as described elsewhere in this document:

- Laser Guide Star Subsystem (LGS).
- Adaptive Optics Subsystem (AOS).
- Real-Time Computer (RTC).

Related to the project are:

- Gemini North Adaptive Optics Imager (GNAOI): A new imaging camera we intend to develop with existing IDF funds.
- Adaptive Secondary Mirror (ASM): We plan to use IDF funds to incorporate an ASM into GNAO/RTC in the future.

This work will occur in collaboration with the GNAOI effort. We will design and build GNAO/RTC to be compatible with the ASM, but we do not expect to install and commission the ASM until after GNAO/RTC is operational. Top level requirements for the ASM will be considered to ensure that GNAO/RTC will not preclude the use of the ASM.

4.2 Work Breakdown Structure (WBS)

Please see WBS__GNAO_RTC.final_2_4_4.mpp for much more detail.

WBS #	WBS Title	Deliverable	Responsible Organization
1.1	Meetings and Milestones	reviews and other project meetings	Gemini
1.2	Project Management, including non-subsystem-specific SE	management and SE products	Gemini
1.3	Science, including the AOWG	Sciences cases, science requirements, and consultation	Gemini
1.4	Laser Guide Star Subsystem (LGS)	LGS subsystem	Gemini
1.5	Adaptive Optics Subsystem (AOS)	AOS subsystem	Gemini and a to-be-selected subcontractor
1.6	Real-Time Computer (RTC)	RTC subsystem	Gemini and possibly a to-be-selected subcontractor

Table 8 *Work Breakdown Structure*

4.3 WBS Dictionary

WBS#	Task Description
1	GNAO/RTC Project
1.1	Meetings and Milestones
1.2	Project Management, including non-subsystem-specific SE
1.2.1	Project Management (PM), including: project oversight; technical management; schedule, budget, and scope management; procurement and subcontract management; reporting and reviews; and other communications.
1.2.2	GNAO/RTC Systems Engineering
1.2.2.1	Conceptual Design ● Configuration Management ● Technical team management/coordination ● Risk Management ● Top level systems architecture definition and Conceptual Design Iteration ● External Interface definition and management ● Generate and manage error budget
1.2.2.2	Preliminary Design ● Configuration Management ● Technical team management/coordination ● Risk Management ● Top level systems architecture refinement ● External Interface refinement and management ● Refine and manage error budget
1.2.2.3	Critical Design ● Configuration Management ● Technical team management/coordination ● Risk Management ● Top level systems architecture refinement ● External Interface refinement and management ● Refine and manage error budget
1.2.2.4	Build / Implement ● Configuration Management ● Technical team management/coordination ● Risk Management ● Integration and Test (I&T) ● Configuration Management ● Technical team management/coordination ● Risk Management
1.3	Science, including the AOWG
1.3.1	Science
1.3.1.1	Conceptual Design ● Prepare science cases and derive scientific requirements ● Prepare Concept of Operations document together with technical team using flowed-down requirements from science team and AO working group. This includes initial strategies for commissioning and acceptance tests.

WBS#	Task Description
1.3.1.2	Preliminary Design ● Review/update science cases for PD ● Update concepts of operations for PD ● Participate in preparing acceptance test plan
1.3.1.3	Critical Design ● Review/update science cases for CD ● Update concepts of operations for CD ● Participate in updating acceptance test plan ● Participate in preparing commissioning plan
1.3.1.4	Build / Implement ● Participate in updating acceptance test plan ● Participate in updating commissioning plan
1.3.1.5	Integration and Test ● Participate in acceptance testing
1.3.2	AO Working Group
1.3.2.1	Conceptual Design ● Define trade off tasks based on science inputs
1.3.2.2	Preliminary Design ● Review Concept of Operations document together with technical team using flowed-down requirements from science team and AO working group. This includes initial strategies for commissioning and acceptance tests.
1.3.2.3	Critical Design ● Review/update AO top-level requirements based on science cases for CDR ● PI Support
1.3.2.4	Build / Implement ● PI Support
1.3.2.5	Integration and Test (I&T) ● Participate in bench performance verification
1.4	Laser Guide Star Subsystem (LGS)
1.4.1	LGS Systems Engineering
1.4.1.1	Conceptual Design ● LGS Subsystem requirements definition ● Generate LGS Interface requirements definition ● Generate LGS ConOps ● Lead and participate in design trades, particularly the # of LLTs, lasers, and configuration ● Review and provide input on LGS documentation package
1.4.1.2	Preliminary and Critical Design ● LGS Design Systems Engineering and Oversight
1.4.1.3	Build and Integration and Testing (I&T) ● LGS Fabrication Systems Engineering and Oversight, including change control, interface management, acceptance testing review and oversight, etc. ● LGS Verification ● Support LGS Integration and Test, including development of integration test plan, implementing plan, lead anomaly resolution, lead interface management, perform tests, review and document results

WBS#	Task Description
1.4.2	Conceptual Design
1.4.2.1	Provide CoD of BTO layout for competing LGSF options. Provide optical performance, pricing difference, and fabrication comparison for consideration. Demonstrate that different designs can meet the project performance requirements.
1.4.2.2	Prepare MEP (Mechanical, Electrical, and Plumbing) Deliverable for CoD including 3-d mechanical layouts, mechanical balancing plans, mechanical mounting plans, electrical power plans and plumbing service plans in sufficient detail to demonstrate concept meets functional requirements, cost and schedule constraints.
1.4.2.3	Control Computer Software ● Refine laser to LIS electronics interface ● Define LIS changes to support multiple lasers ● Define motor control options for BIM/BTO
1.4.3	Preliminary Design
1.4.3.1	Provide preliminary optical design concept for LGSF units that include Zemax optical design model of BTO, 3-D mechanical model layout of BTO, initial build and alignment plan, and cost analysis. Demonstrate that preliminary design can meet the project performance specification and be built within the allotted time and budget. Use feedback from Preliminary Design to finalize design decisions in Critical Design.
1.4.3.2	Prepare MEP Deliverable for PD including 3-d mechanical layouts, mechanical assembly drawings, mechanical balancing plans and balancing hardware assembly drawings, mechanical mounting assembly drawings, electrical power plans and plumbing service plans in sufficient detail to demonstrate preliminary design meets functional requirements, interface requirements, cost constraints and schedule constraints for the down selected LGSF option
1.4.3.3	Control Computer Software ● Analyze all I/O needs ● Choose Motor Control solution for BIM/BTO ● Define BTO control architecture and functions. ● Define interface/control functions for new heat exchanger ● Review current Toptica EPICS laser control solution ● Define fast steering mirror (FSM) control ● Define contents of consolidated Laser Control Console
1.4.4	Critical Design
1.4.4.1	Provide finalized optical design and analysis for LGSF units. Provide finalized 3-D mechanical model layout as well as schematic drawings for all necessary parts. Provide electrical diagram for all electronic parts. Provide parts list and final price for all opto-mechanical and opto-electronic parts. Demonstrate in detail that design meets all project requirements, and all issues have been addressed. Provide necessary procedures for build, integration, and testing of LGSF units.
1.4.4.2	Prepare MEP Deliverable for CD including 3-d mechanical layouts assembly drawings and fabrication drawings, mechanical balancing plans balancing hardware assembly and fabrication drawings, mechanical mounting plans, assembly drawings and fabrication drawings, electrical power plans installation drawings and plumbing service plans and installation drawings and specify all procured components in sufficient detail to demonstrate critical design meets functional requirements, interface requirements, cost constraints and schedule constraints.

WBS#	Task Description
1.4.4.3	Control Computer Software ● Design BTO software (produce detailed design doc) ● Design LIS changes (produce detailed design doc) ● Design interface changes (if needed) ● Design fast steering mirror (FSM) control ● Design Laser Control Console (produce detailed design doc) ● Design interface to new heat exchanger
1.4.5	Build
1.4.5.1	Order and receive optical parts and tools necessary to build and align LGSF units. Build BTO units in lab and order BTO enclosure from vendor after soliciting quotes. Integrate, align, and test BTO, Laser Head, and LLT in lab before attaching components to Telescope. Conduct optical alignment and system testing of each LGSF unit as it is integrated onto the telescope.
1.4.5.2	Receive, Build and Install MEP hardware and systems including all necessary alignment tools, mounting hardware and telescope balancing hardware for LGSF (Procurement, FAT & Site Acceptance and Verification of LLT, Laser, BTO and other Opto-mechanical Equipment excluded from MEP Scope)
1.4.5.3	Control Computer Software ● Implement LIS design in PLC (includes BTO door switches) ● Implement LIS design in EPICS (providing UI for PLC implementation) ● Implement LHX interface in PLC ● Implement LHX interface in EPICS (providing UI for PLC implementation) ● Implement changes to TLEI (if needed) ● Implement BTO ● Implement fast steering mirror (FSM) control ● Implement Laser Control Console
1.4.6	Integrate and Test (I&T)
1.4.6.1	Provide I&T support and Final Document Preparation
1.4.6.2	Control Computer Software ● Test LIS Interface for each Laser (Toptica EC to LIS PLC) ● Test LIS shuttering sequences with all lasers ● Test access door interlocks and bypasses. ● Test all BTO functionality (motors, loops, status, error handling) ● Test any new features ● Test LHX ● Test fast steering mirror (FSM) control ● Test Laser Control Console
1.5	Adaptive Optics Subsystem (AOS) (mostly a subcontract)
1.5.1	AOS System Engineering
1.5.1.1	Conceptual Design ● AOS Subsystem Requirements Definition ● Generate AOS Concept of Operations ● Lead and participate in design trades ● Generate, review, and provide input on AOS Package
1.5.1.2	Preliminary (subcontract) ● provide SE oversight

WBS#	Task Description
1.5.1.3	Critical Design (subcontract) ● provide SE oversight
1.5.1.4	Build (subcontract) ● provide SE oversight ● AOS Verification
1.5.1.5	Integration and Testing (I&T) ● Lead AOS Integration and Test in conjunction with the AOS subcontractor, including development of integration test plan, implementing plan, lead anomaly resolution, lead interface management, Perform tests, review and document results
1.5.2	Conceptual Design
1.5.2.1	Optical Engineering ● refine conceptual optical design including layout of the AOB, optical elements, and coatings ● perform preliminary tolerancing analysis ● perform preliminary throughput analysis ● assess risks in the conceptual optical design ● documentation preparation
1.5.2.2	Mechanical Engineering ● refine conceptual mechanical design including structural, science path, LGSWFS, and NGSWFS ● preliminary thermal and flexure studies ● preliminary optomechanical tolerancing analysis ● documentation preparation
1.5.3	Preliminary Design
1.5.3.1	Control Computer Software ● Adaptive Optics Subsystem Components Controller Design ● Instrument Sequencer Design ● Graphical User Interface Design
1.5.4	Critical Design
1.5.4.1	Control Computer Software ● Implement AOS Components Controller ● Implement Instrument Sequencer ● Implement Graphical User Interface ● Implement GIAPI interfaces ● Implement Safety Interlocks ● Telemetry storage and access control
1.5.5	Build / Implement / Incrementally Integrate & Test
1.5.5.1	Control Computer Software Testing of Mechanical Components
1.5.5.2	Finalize and Perform Acceptance Tests
1.6	Real-Time Computer (RTC)
1.6.1	RTC Systems Engineering
1.6.1.1	● flow-down GNAO / GeMS system requirements to the RTC and generate RTC Functional Requirements and compare against existing GN and GS LGS requirements.
1.6.1.2	● write a draft of the final test document to assure that the requirements can be tested against.

WBS#	Task Description
1.6.1.3	● design external RTC interfaces and generate ICDs.
1.6.1.4	● 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).
1.6.2	Select computer hardware (for GeMS) and a software package; then procure it and bring it up (this is to serve as development/test platform)
1.6.2.1	● select an existing AO RTC software package to serve as the baseline for RTC software development
1.6.2.2	● participate in AO RTC package training (this is a training place holder)
1.6.2.3	● analyze the requirements for and select AO peripheral interfaces for GeMS
1.6.2.4	● analyze the requirements for and select/configure a computer platform for GeMS, including OS
1.6.2.5	● hold a special review of the software package and hardware selections.
1.6.2.6	● procure software package, including support as required
1.6.2.7	● procure the AO peripheral interfaces for GeMS
1.6.2.8	● procure the computer platform for GeMS
1.6.2.9	● bring up the GeMS hardware platform and optimize for performance
1.6.2.10	● install drivers for GeMS AO peripherals and test, as hardware becomes available
1.6.3	Design the adaptation of the AO RTC package to GeMS and design new code as needed. This is the design phase for RTC software.
1.6.3.1	● adapt AO RTC package infrastructure to GeMS/GNAO needs
1.6.3.2	● TLC interface software
1.6.3.3	● NGS camera interface software (the 'Design' work for this is higher than normal, wrt 'Implementation', to accommodate GeMS legacy hardware)
1.6.3.4	● NGS tip/tilt computation
1.6.3.5	● TT interface software
1.6.3.6	● LGS cameras interface software (the 'Design' work for this is higher than normal, wrt 'Implementation', to accommodate GeMS legacy hardware)
1.6.3.7	● centroider
1.6.3.8	● reconstructor
1.6.3.9	● DMs interface software (the 'Design' work for this is higher than normal, wrt 'Implementation', to accommodate GeMS legacy hardware)
1.6.3.10	● slow focus detector software
1.6.3.11	● slow focus computation
1.6.3.12	● LGS zoom interface software (for slow focus) (the 'Design' work for this is higher than normal, wrt 'Implementation', to accommodate GeMS legacy hardware)
1.6.3.13	● telescope offload and LGS pointing control software
1.6.3.14	● telemetry date streaming/archiving software
1.6.3.15	● telemetry data display software
1.6.3.16	● investigate PSF reconstruction
1.6.3.17	● reconstructor matrix generation
1.6.4	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).
1.6.4.1	● adapt DARC infrastructure to GeMS/GNAO needs

WBS#	Task Description
1.6.4.2	● TLC interface software
1.6.4.3	● NGS camera interface software
1.6.4.4	● NGS tip/tilt computation
1.6.4.5	● TT interface software
1.6.4.6	● LGS cameras interface software
1.6.4.7	● centroider
1.6.4.8	● reconstructor
1.6.4.9	● DMs interface software
1.6.4.10	● slow focus detector software
1.6.4.11	● slow focus computation
1.6.4.12	● LGS zoom interface software (for slow focus)
1.6.4.13	● telescope offload and LGS pointing control software
1.6.4.14	● telemetry date streaming/archiving software
1.6.4.15	● telemetry data display software
1.6.4.16	● investigate PSF reconstruction
1.6.4.17	● reconstructor matrix generation
1.6.5	Perform final testing, integration, and first-light for new GeMS RTC
1.6.5.1	● finalize the final test document and execute it
1.6.5.2	● finalize all documentation and release
1.6.5.3	● support GeMS integration and first-light (with the new RTC)
1.6.6	Procure the hardware for GNAO and port the RTC, as developed above, to GNAO.
1.6.7	Provide ongoing support through build and integration

Table 9 *Work Breakdown Structure Dictionary*

4.4 Scope Management Plan and Scope Contingency

Scope Management will be documented in the Project Management Plan available at the Conceptual Design Review. The scope of the project at present is detailed in see section 3.1.1.

4.5 Cost Estimating Plan, Cost Reports and Baseline Budget

A detailed budget was one of the products of the in-depth project planning that we describe in subsection 3.1.0. This budget will be refined as we continue through CoD and will be baselined at the conclusion of the CoD phase.

4.6 Complexity Factor

We derived a complexity factor of 22% during the proposal phase to allow for increased costs based on project complexity. It is common for Gemini to contractually require Facility Class Instrument vendors to withhold at least an additional 15% of the baseline budget for risk mitigation purposes and then for Gemini to hold an additional 15% of the baseline budget, 30% in total. However, given that GNAO/RTC is being based on reasonably mature technology, some of which we have even had recent experience with (such as the Toptica lasers), and that there is a precursor to GNAO/RTC (GeMS), we have lowered the complexity to 22%.

4.7 Funding Profile

GNAO/RTC's funding profile is as per the GEMMA CSA.

4.8 Baseline Schedule Estimating Plan and Integrated Schedule

A detailed schedule was one of the products of the in-depth project planning that we describe in subsection 3.1.0. This schedule will be refined as we continue through CoD and will be baselined at the conclusion of the CoD phase.

4.9 Schedule Contingency

Gemini requires contractors to maintain a baseline schedule and include schedule contingency of a reasonable amount – generally at least 15% beyond the critical path. However, for the same reasons given for Complexity, above (mature technology and a precursor system), we have chosen to allocate approximately 8% (6 months) of schedule contingency. Note that we have not allocated explicit budget contingency to go along with schedule contingency. This is because we would expect to have to use schedule contingency due to inadequate resources during the project phases rather than because we have badly underestimated the work. If the second of these ends up being the case (or both), we would utilize our 22% budget contingency.

5 Staffing

5.1 Staffing Plan

Table 10 shows GNAO/RTC's labor needs in FTE-fractions per FY (assuming 1720 hours per year) by labor category. These were extracted from our in-depth project plan as previously described. "Software Engineer" is highlighted in yellow because that is our only pressing need at present, as discussed in the next subsection.

FTEs	FY19	FY20	FY21	FY22	FY23	FY24	TOTAL
Engineering	2.10	2.88	2.66	1.51	1.30	0.68	**11.13**
Management	0.53	1.59	1.33	1.10	0.30	0.23	**5.08**
Postdocs	0.23	1.36	0.92	0.65	0.42	0.25	**3.83**
Project Support	0.11	0.31	0.31	0.31	0.30	0.17	**1.51**
Scientists	0.71	1.71	1.30	1.10	0.54	0.31	**5.67**
Systems Engineering	1.12	3.02	2.83	1.89	1.26	0.67	**10.79**
SOS	0.02	0.00	0.00	0.00	0.00	0.00	**0.02**
Software Engineering	0.29	0.59	0.61	0.49	0.28	0.02	**2.28**
Technicians	0.00	0.00	0.98	1.22	0.00	0.00	**2.20**
Grand Total	**5.11**	**11.46**	**10.94**	**8.27**	**4.40**	**2.33**	**42.51**

Table 10 *GNAO/RTC labor needs in FTE-fractions per FY (assuming 1720 hours per year)*

5.2 Hiring and Staff Transition Plan

Significant progress has been made in staffing since the last version of the PEP:

- A Sr. Project Manager (PM) has been hired (David Palmer);
- A Principle Investigator has been designated (Gaetano Sivo);
- A Project Scientist has been designated (Julia Scharwächter);
- A Sr. System Engineer has been identified (William Rambold) – we are working on a long-term contract with him;
- A postdoc was hired (David Jenkins, starting in July); and
- A combination of people already involved with the project will serve as an AO Scientist (Gaetano Sivo, Celia Blain (starting in mid-July), Laure Catala (a postdoc), and Marcos van Dam (a contractor we have worked with frequently in the past)).

Please see Appendix A for brief bios for several of these people.

The one person we are still short on is a Software Engineer, as in the previous subsection. We plan to either have a person identified in-house by our CoDR or to more actively pursue an external person by then.

6 Risk and Opportunity Management

6.1 Risk Management Plan

The GNAO/RTC project complies with the Gemini PMO Risk Management Plan. It covers:

- Project Risk Process
- Other Roles and Responsibilities
- Budgeting
- Timing
- Risk Register Scoring and Interpretation, with Impact and Likelihood scoring
- Reporting Formats
- Tracking

6.2 Risk Register

The GNAO/RTC Risk Registers:

Part I - Risk Identification

1. Categorization & Description
2. Impact, Likelihood & Total risk scores

Part II - Existing controls, per risk:

1. Effectiveness
2. Residual risk score

Part III - Risk Response, per mitigation strategy:

1. Effectiveness
2. Residual risk score
3. Contingency Plan
    a. Cost
    b. Owner
    c. Review schedule
    d. Status.

6.3 Contingency Management Plan

The Contingency Management Plan will be developed during the Conceptual Design Stage of the project.

7 Systems Engineering

7.1 Systems Engineering Plan

An initial version of the combined GNAO/RTC Systems Engineering Management Plan (SEMP), to document the role of systems engineering throughout the GNAO/RTC life cycle has been developed. We will refine this plan in the Conceptual Design Phase and submit it for CoDR.

The primary systems engineering roles are to perform and/or lead the following activities:

- Concept of Operations Management
- Requirements Management
- System Design
- Interface Management
- System Integration
- Verification and Validation
- Quality Control Management

7.2 Interface Management Plan

The objective of the interface management is to achieve functional and physical compatibility among all interrelated system elements. Early in the Design Phase, we will refine external, internal, functional, and physical interfaces and revise and/or develop Interface Control Documents (ICDs) as needed.

7.3 Quality Assurance and Quality Control Plan

Quality Assurance (QA) provides an independent assessment to the project manager and systems engineer of the items produced and processes used during the project life cycle. The Project Manager and Systems Engineer will ensure that contractors implement a quality assurance program and ensure visibility into QA processes and risk mitigation. Internally, the Project Manager and Systems Engineer will manage quality risks and enforce adherence to procedures and specifications throughout the system development and system integration.

7.4 Concept of Operations Plan

The Concept of Operations (ConOps) is an important component in capturing stakeholder expectations, driving system requirements, and driving the architecture of a project. It will serve as the basis for subsequent definition documents such as the operations plan and operations handbook and provides the foundation for the long-range operational planning activities such as operational facilities and staffing. We are generating a ConOps document as we work through the Conceptual Design Stage.

8 Configuration Control

8.1 Configuration Control Plan

The Gemini Systems Engineering Group is working on a revised configuration management tool. GNAO/RTC will utilize that tool. More details will be available at our CoDR.

8.2 Change Control Plan

All changes to the project will be requested through a Change Request Form and submitted to the Project Manager. To review and approve changes, we will institute a change control board (CCB) consisting of at least the PM, PI, and SE; with others, such as the PS, available for consultation.

If the CCB decides that a requested change is warranted, but the change would cause budget or schedule impacts greater than set thresholds, the Executive Committee Chair would be consulted for concurrence. Those thresholds will be set at: greater than $200k for cost or greater than one month for schedule. In any case, regardless of the related cost or schedule impacts, all changes will be reported to the Executive Committee Chair.

8.3 Documentation Control Plan

Project documents will go under change control as listed in the "*GNAO/RTC Documentation Set: Matrix listing end-of-stage documents"* table in subsection 3.1.2.2. Once under change control, the same CCB described in the previous subsection will need to approve changes.

To physically control changes, we intend to utilize Gemini's Document Management Tool (DMT). The details of this will be worked out as be go through CoD and finalized by our CoDR.

9 Acquisitions

9.1 Acquisition Plans

As described in section 3, GNAO/RTC will require one, possibly two large subcontracts. To let these, GNAO/RTC will use Gemini's normal process beginning with Requests for Proposals (RFPs). We intend to be nearly ready to issue an RFP for the AOS shortly after our CoDR, with the optimistic hope of having a contract in place by early in CA20. We will continue to explore ways to expedite that as we progress our CoD. A similar approach will be used for the RTC, if we choose the subcontractor route for that subsystem.

Other procurements will be handled through Gemini's normal procurements process.

9.2 Acquisition Approval Process

Gemini follows the AURA CAS procurement policies that can be found here.

10 Project Management Controls

10.1 Project Management Control Plan

The overall management approach for GNAO/RTC is to create a simple organizational structure, with frequent communication channels, regular reporting and monitoring, and the utilization of established management and systems engineering practices and procedures, most of which are described in previous sections. In order to ensure that all hardware, documentation, and reports are delivered on time and on budget, the management team will continue to refine the WBS, and its associated cost and schedule, that we have developed, as described above.

These detailed efforts, coupled with formal monthly updates and monitoring, and continual informal monitoring will assist the PM in closely controlling schedule and cost.

In addition, Gemini has a Portfolio Management Office that provides guidance to the project management process by providing:

- Methodology for the Project Life Cycle, including:
  - Project Startup
  - Initiation
  - Execution
  - Closeout
- The System Development Life Cycle:
  - Analysis and Requirement
  - Design
  - Development
  - Validation and Verification
- Project Management and Systems Engineering Templates.
- Reporting and resource allocation tools
- Training
- Documentation describing
  - Monitor and Control
  - Change Management Process

This methodology will be used throughout this project as needed.

10.2 Earned Value Analysis (EVA)

Earned Value Analysis (EVA) will be used to track the project from both labor cost and schedule perspectives. The Cost Performance Index (CPI) and Schedule Performance Index (SPI) will be tracked down to the discipline level for each subsystem. So, for example, electro-mechanical engineering will be tracked for the LGS subsystem. When management, systems engineering, and science are included, this will result in approximately 12 elements that will be tracked. Labor will be tracked to these levels using a Gemini account number for each. Actual costs and % completes will be entered, to update and report CPI and SPI, on a monthly basis. The requirement to use EVA in this manner and at the same frequency (monthly) will be flowed down to our subcontractors.

10.3 Financial and Business Controls

AURA Central Administrative Services (CAS) provides AURA Operating Centers funded by NSF with business services. These services are aligned with federal and state laws and regulations, AURA policy and CAS procedures. CAS provides the following services:

- Procurement
- Sub-awards
- Property management
- Logistics
- Cash Management and Disbursement
- Accounting
- Payroll
- Financial and Compliance Audits
- Compliance
- Business IT

AURA CAS and Human Resources policies and procedures can be found here.

11 Cyber Infrastructure

11.1 Cyber-Security Plan

GNAO/RTC will comply with the Gemini Master Information Security Policy and Procedures document, and all other pertinent Information Security policies within the scope of the Gemini Cybersecurity Framework.

11.2 Code Development Plan

Gemini standards for writing, testing and verifying, deploying, and documenting software, including configuration control during the stages of development are maintained by the software group and are posted on the internal website and cover the following topics.

- Documenting the Code
- Coding Practices
- Coding Styles
- 5 EPICS Tools
- ADE Concepts
- Software Development using the ADE
- Managing External Software

11.3 Data Management Plan

GNAO/RTC will utilize the Gemini Data Management Plan.

12 Environmental Safety and Health

12.1 Environmental Safety and Health Plans

GNAO/RTC will identify and adapt an existing Gemini ES&H plan to its needs during the Conceptual Design Stage.

13 Review and Reporting

13.1 Reporting Requirements

Gemini is required by the CSA to provide quarterly financial reports and an annual report in September. The reports are to coincide with other observatory reports required for the governance committees and Board.

13.2 Audits and Reviews

The project's review process is described in subsection 3.1.4. Currently audits are not planned at the project level.

14 Integration and Commissioning

14.1 Integration and Commissioning Plan

Given the nature of the Gemini North facility and the structure of the project there will not be an Integration and Commissioning Plan. Instead there will be an Assembly, Integration and Verification Plan and a Commissioning and Science Verification Plan.

The Assembly, Integration and Verification Plan will be development during the Critical Design and Build Stages of the project. The Commissioning and Science Verification Plan will be developed during the Build Phase of the project (but, as mentioned previously, will not be executed in the work covered by this PEP).

See section 3 for additional details.

14.2 Acceptance / Operational Readiness Plan

Given the nature of the Gemini North facility and the structure of the project there will not be an Acceptance / Operational Readiness Plan. Instead an Acceptance Test Plan along with an end-of-project review will assess the readiness of the facility to transfer from the responsibility of the GNAO/RTC project to Gemini Science Operations. Based on experience the completeness of the GNAO/RTC Documentation Set will be important entrance criteria for calling the review.

See section 3 for additional details.

15 Project Close-out

15.1 Project Close-out Plan

Details of procedures and criteria for closing out the project, including procedures for closing out all acquisitions and financial accounting, will be contained in the Project Management Plan, due at the Conceptual Design Review.

15.2 Transition to Operations Plan

Gemini is an operating facility and special attention will be made on how to minimize the impact on operations during the GNAO/RTC Facility Integration and Commissioning. The GNAO/RTC project will work closely with Gemini Science Operations throughout the project to review plans to achieve this. No separate transition to operations plan is envisioned.

16 Appendix A: Brief GNAO/RTC Team Bios

David Palmer, Project Manager

Dave Palmer has approximately 25 years of project and people management experience. He has successfully managed projects of varying sizes, up to about the $10M per year level, in both the public and private sectors. One of those projects was the Gemini Planet Imager (GPI), giving him invaluable experience and insights for the management of GNAO/RTC. On GPI (and other AO systems) he also had technical responsibility for the design and development of the Adaptive Optics Computer (AOC). He is a Computer Scientist by degree, specializing in real-time control for many of the past 39 years.

Gaetano Sivo, Principal Investigator

Gaetano Sivo has a Ph.D. in adaptive optics and astronomy. He has 10 years of experience working on adaptive optics for astronomy and instrumentation development of various systems. One of these was the Canary wide-field AO demonstrator in which Gaetano has participated in the design and conducted successfully the first on-sky demonstration of using new smart AO controllers on multi-laser AO systems. The past 5 years he has been dedicating his time on the Gemini South multi conjugated AO GeMS serving as instrument scientist and project scientist of various upgrades on this system such as the new Toptica laser.

Natalie Provost, Lead Systems Engineer

Natalie is the Gemini South Lead Systems Engineer, where she has been working on AO projects since arriving in August 2018. Prior to that, she has had 18 years of aerospace and systems engineering experience on satellite systems. She joined Gemini from The Aerospace Corporation, where she was a key member of the commissioning team of the Joint Polar Satellite System (JPSS) at NASA; her role was as the Instrument Post Launch Test Lead and Instrument Systems Engineer for Flight Operations. Prior to that Natalie had significant System Engineering and Project Engineering positions at Northrop Grumman Aerospace Systems and Boeing Integrated Defense Systems.

Julia Scharwächter, GNAO Project Scientist

Julia Scharwächter has 14 years of work experience in observational astronomy, including 7 years at international observatories. Her main research interests include active galactic nuclei and the evolution of galaxies and their supermassive black holes with a focus on adaptive-optics-assisted observations and integral field spectroscopy. She holds a Ph.D. in astrophysics from the University of Cologne (Germany, 2005) and worked as an ESO Fellow at the European Southern Observatory in Chile and as a postdoctoral researcher at the Australian National University and at Paris Observatory in France. Julia joined Gemini Observatory as an Associate Scientist in 2016, where she has been the GMOS-N Instrument Scientist since July 2016 and the GNAO Project Scientist since April 2019.

Paul Hirst, RTC Project Scientist

Paul Hirst has a Ph.D. in astronomy and 20 years of experience of operations, infra-red instrumentation, data reduction pipelines, and data archiving at major astronomical observatories. As head of the Technology Development Department at Gemini, Paul contributes expertise from both the technological and the research astronomer viewpoint to leverage new and established software and hardware technologies to efficiently meet the challenges of modern observatory operations and development.

Stephen Goodsell, Project Consultant

Stephen Goodsell is the Gemini Head of Instrumentation. He has ~20 years of experience in astronomical instrumentation research and development which includes 15 years managing and overseeing programs and projects. Stephen's relevant qualifications include PhD (Adaptive optics real-time control optimization), MSc (Imaging and Image Processing), BSc (Physics), diploma in management, obtaining certification in PRINCE2 project management and practitioner certification in Management Successful Programs (MSP), Management of Portfolios (MoP) and Management of Risk (MoR). Stephen has achieved the following relevant professional status and accreditations: Fellow of the Institute of Leadership and Management (FInstLM), Fellow of the Royal Astronomical Society (FRAS), Member of the Institute of Physics (MInstP) and Charter Physicist (CPhys). Stephen's relevant experience includes holding management positions in the following astronomical adaptive optics projects/programs: Durham University Adaptive Optics Program Manager, ESO SPARTA RTC Work Package Manager, WHT GLAS work package manager, GPI Gemini project manager and technical representative and creation of the 2012 Gemini GLAO Workshop report. Stephen served as acting GEMMA GNAO PM (10-Dec-18 to 3-May-19).

Andrea Blank, Project Coordinator

Andrea Blank's background in Corporate Hospitality gives her 12 years of experience in project and operational management with a strong focus on stakeholder management and engagement. Andrea represents Gemini South in Gemini's Portfolio Management Office (PMO) and supports projects in the use of Gemini's project management methodology.

Eduardo Marin, Project Engineer, LGS WP Lead

Eduardo Marin has approximately 12 years of experience working at astronomical observatories. He is an expert in nighttime operations focusing on the "Big-Picture" of how systems are interconnected and work together. Since 2011 he has been part of the GeMS team at Gemini South specializing in maximizing the efficacy of laser-assisted AO operations. He was a key member of the LGSF upgrades at both Gemini South and North, working on the integration and leading the night time commissioning of the new laser systems. He has an undergraduate degree in Astronomy and is currently pursuing a master's degree in Optical Sciences.

Vanessa Montes, Project Engineer, AOS WP Lead

Vanessa Montes is the current GeMS Instrument Manager. She has had 10 years of experience in adaptive optics while working at Gemini, exposing her to different areas such as: engineering support for GeMS operations and commissioning, and, project management and systems engineering in GeMS related projects. She holds a degree in electronics engineering and has pursued training in the areas of: project management, systems engineering, motor control and adaptive optics.

Morten Andersen, Scientist

Morten Andersen is an assistant astronomer at Gemini South since 2015. He is the Gemini project scientist for SCORPIO, Gemini's next facility instrument. His scientific interests range from the low-mass content in massive star clusters, resolved stellar populations, supernova remnants interacting with molecular clouds and dust evolution in the interstellar medium. His scientific work has taken advantage of high spatial resolution imaging and spectroscopy both from space and from adaptive optics facilities on the ground.

John Bassett, Systems Engineer

John Bassett has over 35 years of experience in software development and systems integration. This work is on development, integration, and test of control systems on aircraft, rocket launch facilities, and instrumentation for astronomical telescopes. His degree is in aerospace engineering. Continuing training and experience have focused on software and systems engineering.

Chas Cavedoni, Mechanical Engineer

Chas Cavedoni has 21 years of mechanical engineering experience with Gemini Observatory starting as the first Gemini North operations hire in 1997 plus an additional 12 years of Maunakea observatory experience. He has led or participated in nearly all mechanical projects at Gemini North from construction thru nearly 20 years of operation. Projects including the original GN AO System, the follow-up GS AO system and the recent upgrade to the GN Toptica Laser system. Prior to that, Chas was the project manager of the United Kingdom Infrared Telescope Upgrades Project which included a fast steering secondary system, an active primary mirror support system, a primary mirror cooling system and a dome ventilation system. Prior to that Chas led the mechanical group at the University of Hawaii Institute for Astronomy providing engineering services for the development of numerous cryogenically cooled infrared instruments and adaptive secondary systems.

Emmanuel Chirre, Optical Engineer

Emmanuel Chirre is an Optical and Laser Engineer at the Gemini South Observatory. He holds a Ph.D. in Optical Engineering and Instrumentation, and an M.Sc. in Physics and Laser Technology. Emmanuel has over 8 years of experience in optics. His experience encompasses work with adaptive optics instruments, wavefront sensor devices and class IV lasers in the field of biomedicine and astronomy. During his Ph.D., Emmanuel developed Shack-Hartmann sensors for AO modules with applications in vision science. In astronomy, Emmanuel has been involved in many engineering projects, including the upgrade of the Gemini South Laser Guide Star Facility and the re-alignment of the Gemini multi-object spectrograph. The past years, he has been working on optical improvements for the Gemini Multi-Conjugate Adaptive Optics system (GeMS) and associated optomechanical sub-systems. He also has significant hands-on laboratory experience with a wide range of scientific instruments.

Angelic Ebbers, Software Engineer

Angelic Ebbers has been developing and maintaining control systems for Instrumentation and Observatory infrastructure for over 20 years. She was part of the Canadian team that built GMOS N/S and Altair for Gemini before moving to Hawaii. During the last 15 years working for Gemini Observatory, Angelic has been involved in all aspects of telescope operations as well as contributing to several large internal projects including: adding LGS capability to Altair, motion control for the BTO for GEMS at Gemini South and recently all aspects of interfacing for new Toptica Lasers, now commissioned at both GS and GN. Angelic's particular strengths are in the field of motion control including driver development, component sequencing, and beam steering.

William Rambold, Systems/Software Engineer

William Rambold has more than 35 years experience in the development and operational support of Astronomical Instruments at HAA, Gemini, CFHT, and as a private contractor. His areas of expertise include control systems, real-time software, electronics, detectors, systems engineering, project management, and system testing/verification. William has had significant involvement in many workhorse facility instruments, for example, developing the control system architecture for the Gemini GMOS spectrograph and providing project/systems engineering oversight for the CFHT MegaCam wide-field imager. He has been involved with AO related projects since the late 1980s; he developed the control system, and was project engineer, for the ASP Muhlmann Prize-winning CFHT HRCam image stabilizer; developed the software architecture for the ALTAIR AO system; and was responsible for operational support of the GeMS AO System Real-Time Controller

Stacy Kang, Mechanical Designer

Stacy Kang has more than 35 years' experience in mechanical design and drafting support which includes 15 years at Gemini. She has successfully completed the Adaptive Optics, Toptica, Transition, GMOS, GNIRS, and ongoing small projects. She has the drafting skills and knowledge to successfully complete all drawings to the ASME Y14.5-1994 standard and to do geometric dimensioning and tolerancing using Autodesk Inventor.

17 Appendix B: NSF Feedback, Comments & Questions re. PEPs Submitted 12/31/19

Below are responses to questions submitted by the NSF regarding GNAO and RTC Project Execution Plans submitted 31 December 2019. We are including this appendix temporarily, for convenience. When these issues have been satisfactorily resolved, we will remove the appendix. Please note that the page and section numbers are per the original documents. They have likely changed in this current version.

Page	Section	GNAO Comment #1
10	1.2	The GNAO PEP notes that a mature set of project requirements will be presented at the Conceptual Design review. NSF requests that Gemini include these in the FY2019 annual GEMMA program report (including any impact on project milestones or budget).
	Response	Request noted, we will do that.

Page	Section	RTC Comment #1
7	1.1.1	The RTC top-level requirement that "GeMS performance using the new RTC must be at the same level of performance as the current RTC" seems like a very modest technical requirement. Are there additional capabilities that this system will provide at Gemini-S (that will be described in future versions of the PEP)? (Please be sure to include an updated list of Key Requirements in a future reporting, once these have been finalized, explaining any changes to initial requirements. Please also track and report progress being made against these requirements in subsequent reporting.)
	Response	The main benefits of a new RTC for GeMS will be reliability and maintainability. The GeMS RTC faults quite often, costing observing time, and, since the GeMS RTC is essentially a black box, there's no way to fix it.

Page	Section	GNAO Comment #2
11	Table 2	Each of the instrument AO technical requirements needs to be linked to the corresponding scientific requirement (Table 1) to ensure any trade-off analyses that occur during detailed design or fabrication can be directly related and understood in terms of its impact on the science produced.
	Response	We agree. We are working on flowing down requirements along with backward links and will present a full set at our CoDR. For now we have removed the AO requirements table.

Page	Section	RTC Comment #2
15	2.3	Here the PEP states that "when the RTC project requires feasibility and trade studies, [the project] will solicit stakeholder feedback". Please expand on this statement. Who are the stakeholders referred to here? And how will the project interact with outside experts to ensure that plans are sound?
	Response	Since GNAO and RTC are now merged, the stakeholders include all of the GNAO stakeholders (scientists, AOWG, etc.). But, in addition, since we are striving to make the RTC suitable to serve as the foundation for other projects, stakeholders can include other instrument builders (for GPI 2.0 and GIRMOS being 2 examples).

Page	Section	GNAO Comment #3
11	Table 2	Facility requirements such as environmental temperature ranges and stability for operating and non-operating conditions should be included, either explicitly in this document if they are unique to GNAO, or through referenced technical requirements. If these are included in another requirements or standards document, please include the applicable document numbers.
	Response	These are included in "ICD 1.9/5.0 Science and Facility Instruments to Transport, Observatory and Operations Environments ICD (version C)", referenced in Table 3. We made a note in the table.

Page	Section	RTC Comment #3
16	3.1	The project development plan states that the RTC schedule will run "behind" the GNAO schedule in order to integrate GNAO requirements and synchronize build schedules. This sounds like a very sensible plan. But who will be responsible for managing interactions between the two groups, and how will that person ensure that everyone is 'on the same page'? For example, how will risks associated with GNAO be incorporated into the RTC risk register, and vice-versa?
	Response	Since GNAO and RTC are now merged, the two groups are the same, as is the project plan, etc.

Page	Section	GNAO Comment #4
11	Table 2	Are there any requirements for reliability, maintainability, availability (RAM), or operational lifetime?
	Response	Yes, we have preliminary RAM requirements as in the following table.

	RAMS Requirements		
GNAO-70	Mean time between failures	Mean time between failures shall be TBD (consistent with <2% unexpected downtime)	
GNAO-71	Electronics Reliability	Shall comply with Applied R&M Manuel for Defence Systems Deratting Requirements	
GNAO-72	Mechanical Reliability	Shall comply with TBD Mechanical Standard.	
GNAO-73	Reliability	<2% unexpected downtime from scheduled telescope time	<1% downtime from scheduled telescope time
GNAO-74	Lifetime	20 years	30 years
GNAO-75	Safety	Shall compy with safety standards defined in Science and Facility Instruments Common Requirements Specification INST-REQ-0001	
GNAO-76	Availiability	Shall be availiable on any given night	
GNAO-77	Accessability	Shall provide access to critical components.	

Page	Section	GNAO Comment #5
13-14	2.1	Sect. 2.1 again suggests a somewhat confusing management structure within GEMMA and, in this case, GNAO. The "project manager reports both to the program manager and project sponsor", and "the project team will grow in size and depending on the duties will either report to the project manager or another member of the GNAO management team". This section also notes that "recruitment is underway for a Senior AO Scientist and a Senior Project Manager". Will these be the same person and, if not, who will be in charge of the GNAO project? It is important that clear lines of communication and authority are established within each project and the program as a whole.
	Response	Yes, we agree, this was somewhat confusing. We have streamlined, refined, and clarified the management structure, both above and within GNAO/RTC.

Page	Section	GNAO Comment #6
20	Definitions	There is no indication of a separate requirements document for software. Is there any software (custom or commercial) used in the GNAO at the Data Link, Network, or higher layers?
	Response	Yes, there will be software in GNAO/RTC in 3 main categories: AOS top-level control computer (TLC), LGS control computers, and the RTC. A fourth category could be external software needed to operate the system – but our plan is to make that web-based and so minimal. We've included the software to support the web-based operation in our plan as needed.

Page	Section	GNAO Comment #7
23	3.1.4	Although NSF requires regular updates on progress and milestones associated with each GEMMA project and will offer input if appropriate, the foundation recommends removing the NSF Program Officer from the approval process for "end-of-stage deliverables" ahead of the CoDR. NSF acknowledges that its representatives will participate in the conceptual design stage solely as observers.
	Response	We understood and have removed that wording.

Page	Section	GNAO Comment #8
26	Schedule	There are no software development tasks or activities identified. Is this correct?
	Response	Software development tasks are included in the AOS, LGS, and RTC work as required. Please see the WBS dictionary and Gantt Chart for details.

Page	Section	GNAO Comment #9
33	4.10	Who authorizes the use of schedule contingency? Is there budget contingency associated with schedule contingency?
	Response	The PM, with the concurrence of the PI and the Executive Committee Chair, will authorize the use of schedule contingency. There is no explicit budget contingency associated with schedule contingency. This is because we would expect to have to use schedule contingency due to inadequate resources during the project phases rather than because we have badly underestimated the work. If the second of these ends up being the case (or both), we would utilize our 22% budget contingency.

Page	Section	GNAO Comment #10
37	8.2	As written, approvals to change requests are made by a single person, the Project Manager. This is not a project management best practice. At a minimum project change requests should be reviewed by the Systems Engineering Lead, the PM, and the Project Controls Lead.
	Response	We agree. We will, instead, have a change control board consisting of at least the PM, PI, and SE; with others, such as the PS, available for consultation.

Page	Section	GNAO Comment #11
37	8.2	There is reference in this section to changes "outside of the tolerances" for which the Project Manager must consult the Project Sponsor. Where and how are the PM tolerances for change approval defined? Why is the Program Manager (& Portfolio Manager) not consulted rather than (or in addition to) the Project Sponsor? "Tolerances" need to be explicitly defined in a project document, normally either in the Change Control Management document or Project Charter.
	Response	Yes, we agree. We have set these tolerances as: a budget impact of greater than $200k or schedule impact of greater than one month will invoke the need for concurrence from the Executive Committee Chair. In any case, regardless of the amounts, all changes will be reported to the Executive Committee Chair.