GEMMA
Gemini North Adaptive Optics
Project Execution Plan

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A-GNAO-002

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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
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)
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
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

The purpose of the Gemini North Adaptive Optics (GNAO) Project Execution Plan (PEP) is to describe how Gemini will execute the project to deliver the new GNAO facility.

1.1 Scientific Objectives

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. In late 2017, GeMS received a new, more stable Toptica laser that has improved the reliability and efficiency of its performance.

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 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 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~2;
- 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 and the JWST. GNAO 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 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 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 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 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 award 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 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. By the CoDR, we will have formed a strategy to build a full science team to assist with the remaining stages of the project.

1.2 Scientific Requirements

A number of top-level and AO technical requirements for GNAO Facility were identified during the creation of the proposal based on previous research and design work for a potential GNAO facility. These requirements are based on physical constraints and lessons learned from GeMS. These requirements are contained in Table 1 and Table 2 below.

During the Conceptual Design Stage, the project will re-evaluate the set of top-level requirements based on maturing the science cases, following our requirements identification processes and start to perform required trade studies. A mature set of top-level requirements will be presented at CoDR with clear justifications for any cases and if required the results of supporting trade studies.

Top Level Requirement		
Parameter	**Requirement**	**Goal**
Corrected Field of View	2’ circular diameter	2’ circular diameter
Strehl ratio in K-band (2.2um) with 3 NGSs under median seeing conditions	30% uniform over the entire FoV	50% uniform over the entire FoV
PSF astrometry accuracy with 3 NGSs	0.2 mas	0.1 mas
System must run under seeing condition	up to 1.2” @ 0.5 μm	1.5” @ 0.5μm
Sky coverage with 1 NGS	60% at galactic pole	75% at galactic pole
Sky coverage with 3 NGSs	20% at galactic pole	30% at galactic pole
Wavelength	GNAO shall deliver a science corrected beam between 850nm < λ < 5μm	GNAO shall deliver a science corrected beam between 600nm < λ < 5μm

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

Operation constraints	Shall deliver an AO corrected beam to any science instrument mounted on the telescope on any given night while requiring no more than 2 trained staff for operations.	
Overhead	Shall have no more than 0.5 hours of overhead per science observation.	Shall have no more than 0.25 hours of overhead per science observation.

Table 1: Initial list of top-level requirements for the GNAO Facility

AO Technical Requirements		
Parameter	**Requirement**	**Goal**
AO loop rate under median sodium column density	at least 500 Hz	at least 1 kHz
AO loop stability	AO loop shall be stable over science exposure. ~30 min	AO loop shall be stable over the longest possible science observation ~4 hours
Tip Tilt Loop	At least 1 NGS and up to 3	At least 1 NGS and up to 5
Number of lasers required to create a constellation of 4 to 6 laser guide stars	2 Lasers	3 Lasers
Science Calibrations	Shall provide internal sources for science calibrations.	Shall use existing telescope subsystems science calibrations
LGS spot size as measured open loop at telescope focal plane under median seeing condition	1.2”	1.1”

Table 2: Initial instrument AO technical requirements identified for the GNAO Facility

In addition to requirements stemming from the Science Cases and Concept of Operations, GNAO shall comply with the relevant requirements, specifications and interfaces contained within Gemini's internal set of ICD and Specification documents:

- Gemini Observatory Facility Instrument Common Requirements and Standards Specification
- ICD 1.9/5.0 Science and Facility Instruments to Transport, Observatory and Operations Environments ICD
- ICD 1.5.3/1.9 ISS to Science Instruments ICD
- ICD 1.9/3.6 Science and Facility Instruments to ISS System Services ICD
- ICD 1.9/2.7 Science Instruments to Facility Handling Equipment ICD
- ICD-G0014 Optomechanical Coordinate System
- GIAPI Builder Req-01302009 GIAPI Software Requirements for Instrument Builders
- GIAPI C++ Language Glue API ICD (version 11) GIAPIUse-08292006 GIAPI Design and Use
- 1.1.13/1.9 Interlock System to Science Instruments ICD
- ICD 10 EPICS Synchro Bus Driver
- ICD 20 Synchro Bus - Node/Page Specifications

During the Conceptual Design Stage, we shall verify that our Interface Control Documents needed for GNAO are current and complete.

1.3 Facility/Infrastructure

AURA and Gemini Observatory has 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 into its current portfolio of development projects and existing operational commitments.

1.4 Scientific & Broader Societal Impacts

Please refer to the GEMMA Program Execution Plan.

2 Organization

During the Conceptual Design Stage, the project will create a Project Management Plan which will contain a project communication plan.

2.1 Internal Governance & Organization

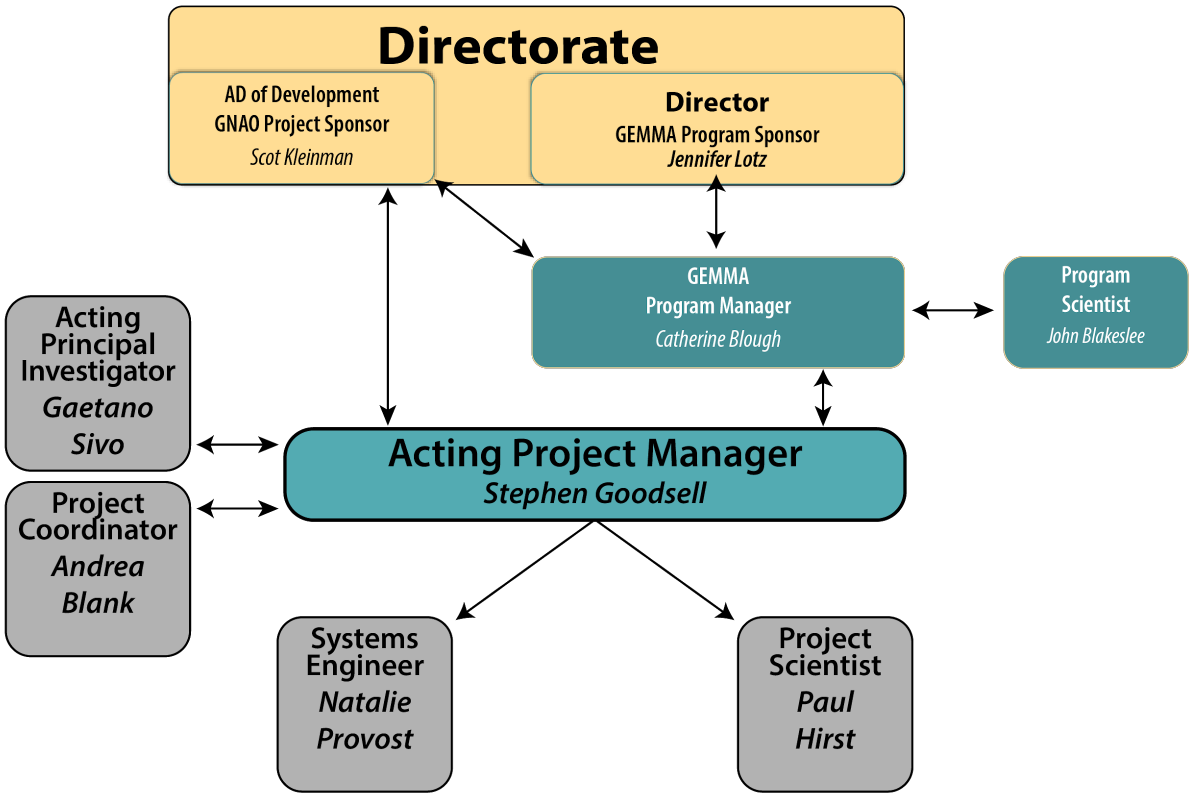


Figure 1 *Current Project Organizational Structure*

Figure 1 shows the current internal Organization Structure of the project. The GNAO Management Team consists of the Project Manager, Principal Investigator, System Engineer and Project Scientist. The Project Management Team is supported by a Project Coordinator.

Role	CoDS Assignee	Notes
Program Sponsor	Scot Kleinman	
Principal Investigator	Gaetano Sivo	See below
Project Manager	Stephen Goodsell*	See below
System Engineer	Natalie Provost	

Project Scientist	Paul Hirst	
Project Coordinator	Andrea Blank	

Table 3 *GNAO CoDS Roles*

The Project Manager reports both to the Program Manager and to the Project Sponsor. Please refer to section 2.2 of the GEMMA Program Execution Plan.

Recruitment is currently underway for a senior AO Scientist and a senior Project Manager for the GNAO project. GNAO timescales are aggressive and it is the observatory's highest priority development project. Ideally changes to staff assignments in Table 3 would not be made during the Conceptual Design Stage, but made after the Conceptual Stage Review. However, we plan to supplement the CoDS Assignees with the new hires until the end of the stage. However, given limited resources and the need to balance GNAO with existing project commitments, the uncertainty of recruitments and the current level of detailing, it may not be possible to wait until the Conceptual Stage Review.

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 will include both AURA staff and contractors potentially working on management, engineering and science tasks. We expect the project structure to stabilize by the end of the Conceptual Design Stage. Also, during the Conceptual Design Stage, the project shall create an Adaptive Optics Working Group and a GNAO Science Team.

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. During the Conceptual Design Stage, the project team will hold weekly status meetings to track the status of the project.

2.2 External Organization

Please refer to the GEMMA Program Execution Plan for External Organization and Communication.

The majority of the communication to stakeholders, public and community will flow through the GEMMA Program Manager, GEMMA Program Sponsor, the GEMMA Program Scientist and GNAO Project Sponsor and Public Information and Outreach. This includes the NSF Quarterly Status Report as written in the CSA and any status information flowing to the public such as quarterly articles for newsletters, social media announcements and website updates.

The exceptions are interactions required with the community to progress the project such as formation and interactions with external members of the science team, the formation and interactions with external members of the Adaptive Optics Working Group and interactions with contractors.

2.3 Partnerships

In designing and building GNAO, 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). 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's top-level requirements. The internal GNAO science team will also reach out to the Gemini science community for user input on desired science capabilities for GNAO. The Gemini STAC and Board will also have insight and participation in these efforts. 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.

We have identified the AOWG members and are planning a group kickoff meeting in January 2019. Thereafter, we will meet virtually at least every two months as the work requires.

2.4 Roles and Responsibilities

Please refer to the GEMMA Program Execution Plan for external organization roles and responsibilities.

2.5 Community Relations and Outreach

Please refer section 3.6 of the GEMMA Program Execution Plan.

3 Design and Development

3.1 Project Plan

3.1.1 GNAO Scope

The NSF CSA award funds the GNAO project from its planning stage to the completion of the first-light commissioning stage. First-light commissioning is defined as obtaining science results with GNAO and the planned first-light instrument Gemini North Adaptive Optics Imager (GNAOI).

The GNAO project continues beyond the first-light commissioning stage to continue commissioning and beyond until it is fully integrated into regular science operations.

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

- GNAOI:
  - The design, manufacture, integration, test and delivery is **outside** the scope of the NSF CSA award and **outside** the scope of the GNAO project.
  - GNAOI will be funded using Gemini Instrumentation Development Fund.
  - Gemini plan to release a Request for Proposal (RfP) for GNAOI in Q2-2019 and place a contract with an external organization to design, manufacture, integrate, test and deliver the instrument.
  - GNAOI will be delivered to Gemini North by Dec 2023.
  - The integration between GNAOI and GNAO is **inside** the scope of the NSF CSA award and GNAO project.
  - Successful first-light science demonstration and a significant science result press-release is **inside** the scope of the NSF CSA award and the GNAO project.
- Adaptive Secondary Mirror (ASM):
  - A feasibility study, a post-conceptual design, and anything beyond, including placing any specific external contracts, is **outside** the scope of the NSF CSA award and GNAO project.
  - A conceptual design to the extent which allows relevant trade studies to keep an ASM as a future possible GNAO upgrade is **inside** the scope of the NSF CSA award and GNAO project.
- Complete GNAO Commissioning, Science Verification and Facility Optimization:
  - Complete GNAO commissioning includes commissioning the full GNAO on-sky parameter space is **outside** the scope of the NSF CSA award but **inside** the scope of the GNAO project.
  - Science Verification, which could include early science observations while on-sky optimization occurs is **outside** the scope of the NSF CSA award but **inside** the scope of the GNAO project.
  - Facility Optimization, includes meeting facility FTE support requirements and base facility operations is **outside** the scope of the NSF CSA award but **inside** the scope of the GNAO project.
  - The GNAO project ends on completion of the facility optimization and successful handover from Gemini Development to Gemini Science Operations.

This Project Execution Plan currently focuses on the scope within the NSF CSA and will be expanded in the future to include scope outside the NSF CSA award, but inside the scope of the GNAO project.

3.1.2 GNAO End-of-project Deliverables

The end-of-project GNAO Deliverables currently include:

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

3.1.2.1 GNAO Facility

The GNAO Facility includes all the operational hardware and software to meet the set of requirements and fulfill the set of identified science cases.

The Facility consists of the subsystems required to create the facilities laser guide stars and the subsystems required to detect the natural and laser guide stars and apply corrections to the deformable optical elements in the system.

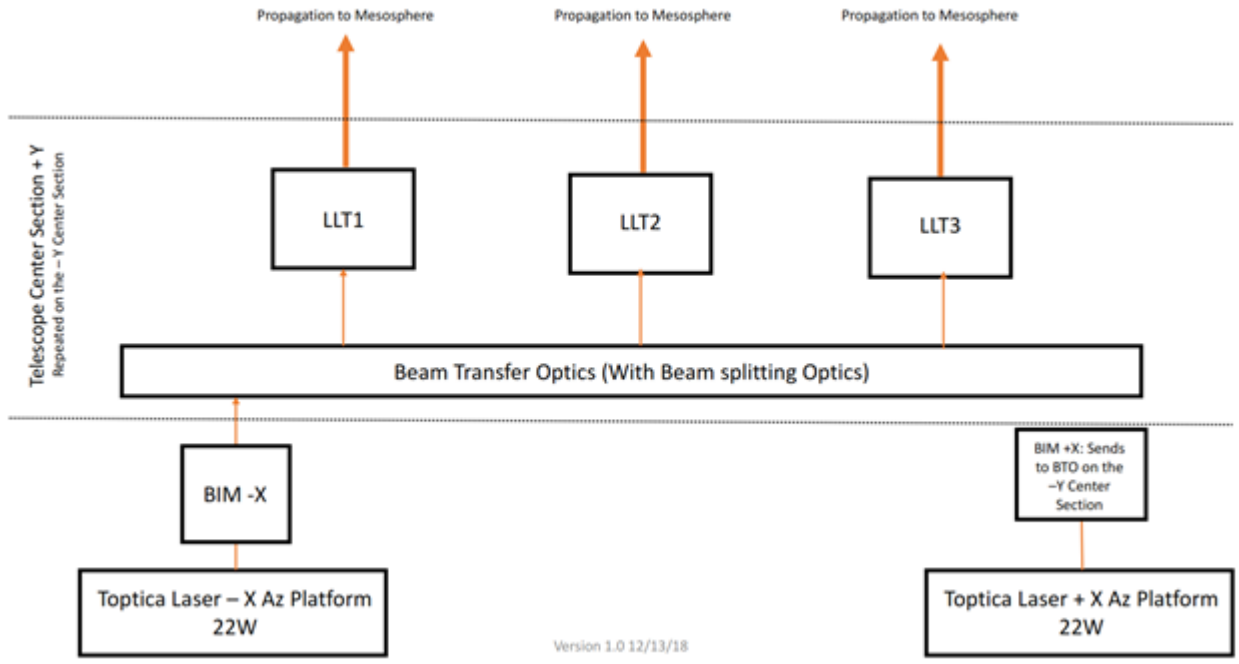


Figure 2 *Block Diagram of the Laser Launch Subsystems*

Figure 2 shows a block diagram of the laser launch subsystems. Each Toptica laser will be placed on one of the two azimuth platforms of the telescope. A Beam Injector Module (BIM) will inject the beam into a series of free space Beam Transfer Optics (BTO) that will then transfer the beams to two new telescope elevation platforms that will each have 3 LLTs. As the beam encounters its injection point into LLT1 it will pass through a beam splitter that will send ⅓ of the beam power to LLT1 and allow the remainder to pass to the LLT2 injection point (between LLT1 and LLT3) where a second beam splitter will send ½ of the power to LLT2 and allows the other ½ to continue to LLT3. Inside of each LLT there will be a small optical bench used to steer the position of the beam on the LLT itself and ensure that the beam has the proper circular polarization on sky.

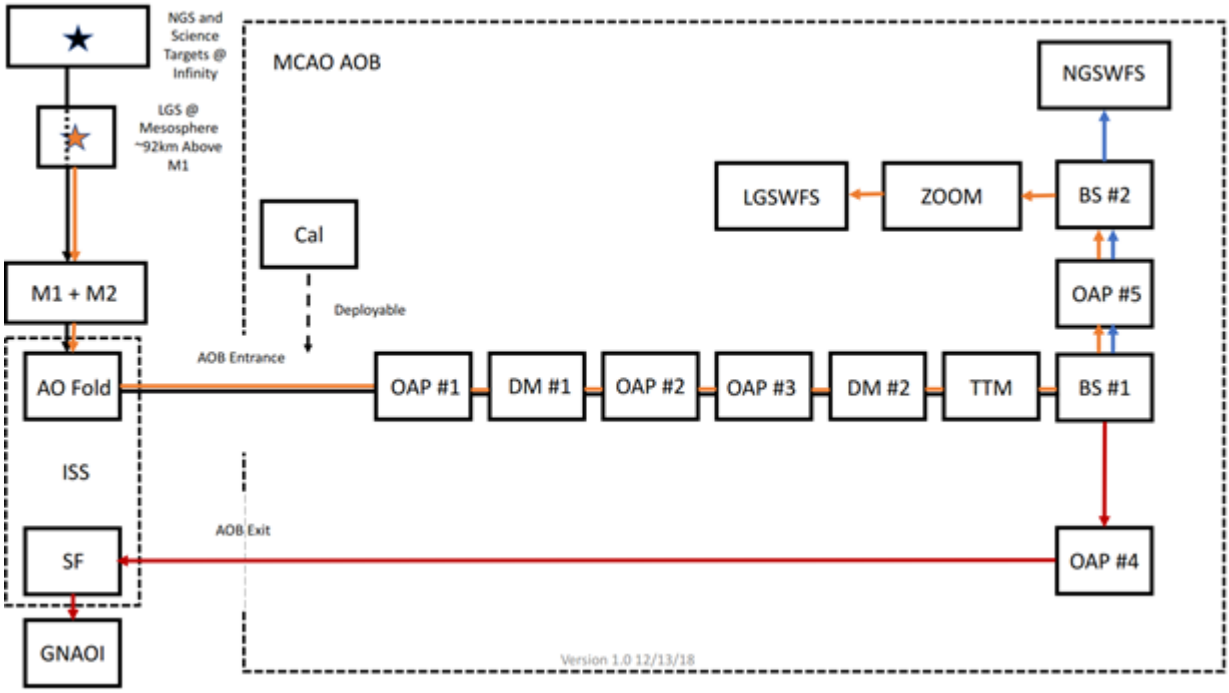


Figure 3 *Block Diagram of the return path subsystems*

Figure 3 shows a block diagram of the return path subsystems. As LGS and NGS light enters the AOB from the AO Fold all light goes through a series of common optical elements that include the 2 DMs, 1 full OAP relay, half of the second OAP relay, and the TTM. Light is then split by a beam splitter to send optical and laser light to the WFSs while IR light is sent to the science fold to be sent to the science cameras. At this point the second OAP relay is closed on each path. Because we will use sodium guide stars, we will use a second beam splitter to separate the sodium light and the remaining optical light. A special 589 nm dichroic will be used to send the laser light to the LGSWFSs while the remaining optical light will go to the NGSWFS.

3.1.2.2 GNAO Documentation Set

The initial GNAO Documentation Set is given below in Table 4. This set will be reviewed during the Conceptual Design Stage of the project.

	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)[1]	✓	✓	✓	✓	✓	✓
	GNAO-07	Conceptual Design Document (CoDD)	✓					
	GNAO-08	CoD End Stage Report	✓					
	GNAO-09	Preliminary Design Stage Plan	✓					
	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-14	Critical Design Stage Plan		✓				
	GNAO-15	Critical Design Document (CDD)			✓			
	GNAO-16	Assembly, Integration and Verification Plan			✓			
	GNAO-17	CD End Stage Report			✓			
	GNAO-18	Assembly, Integration and Verification (AIV) Stage Plan			✓			
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				✓		
	GNAO-29	Telescope Integration (TI) Stage Plan				✓		
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 4 *GNAO Documentation Set: Matrix listing end-of-stage documents*

The purpose of each document is provided below. The composition, description, and change control approach for the GNAO Conceptual Design Deliverables is contained with the GNAO Conceptual Design Stage Plan.

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, mostly with the GNAO Facility.

Design Document (Conceptual, Preliminary, Critical): Communicates the current end-of-stage design of the GNAO Facility, the GNAO Associated Hardware, and the GNAO 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.

Stage Plans: Communicates the tasks, schedule, and cost breakdown of the next stage of the project.

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 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 facility such that it could be duplicated.

Recommended Spares List: Provides the observatory with a list of GNAO hardware components the project believes are important for Gemini to obtain. It shall include a list of GNAO Facility and GNAO 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 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 Facility after telescope integration.

Commissioning and Science Verification Report: Documents the results of the activities, observations and analyses specified in the Commissioning and Science Verification Plan (CSVP)

3.1.2.3 GNAO Facility Associated Hardware

GNAO facility associated hardware includes deliverable hardware that are not part of the GNAO 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). This will also include an initial set of GNAO facility spares.

3.1.2.4 GNAO Facility Associated Software

GNAO facility associated software includes deliverable software items that are not part of the GNAO 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. 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. This deliverable will be detailed during the Design Phase of the project.

3.1.2.7 Staff GNAO 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 Project Structure

The GNAO project shall be divided into 3 phases and 6 stages as shown in Figure 4 below.

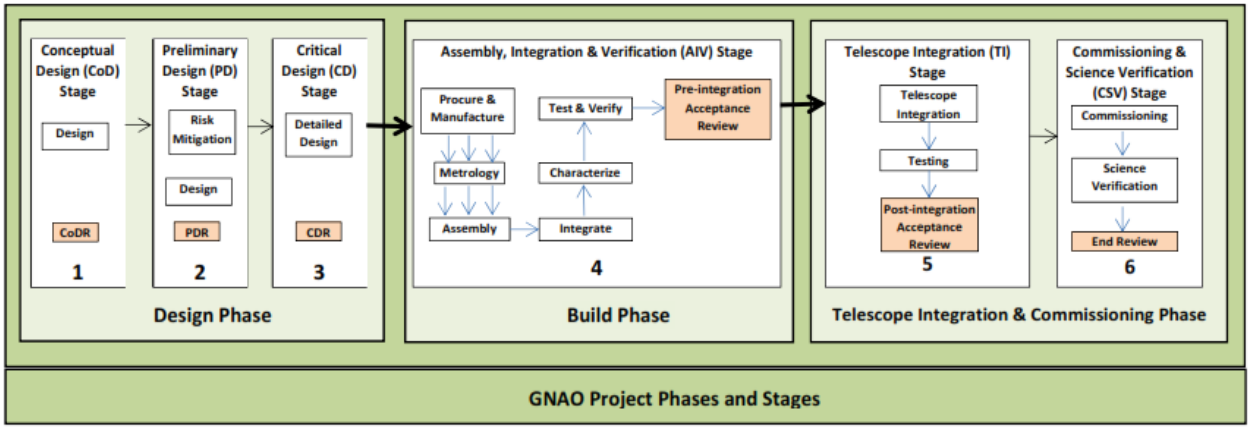


Figure 4 *GNAO Project Phases and Stages*

3.1.3.1 Design Phase

The Design Phase of the project is the phase in which Gemini develops the design of the GNAO 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 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 facility, the GNAO Associated Software and the GNAO 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 Contractor transports, tests, integrates, and commissions the GNAO Contract Deliverables. This phase has been divided into two stages:

- Telescope Integration Stage
- Commissioning and Science Verification Stage

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 Project Design Kick off Meetings and Design Reviews

Each stage shall begin with a kickoff meeting and conclude with an end-of-stage review. The GNAO project plan includes hosting a beginning of stage kickoff meeting within 15 working days of the beginning of each stage. Attendees in person should include all key project team members including the Principal Investigator, Project Manager, System Engineer, Project Scientist and program staff where desired.

At each kickoff meeting the GNAO 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 the date contained with the stage's stage 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 Deliverables at the end of each stage can be found in table 4, GNAO documentation set.

The review evaluation criteria shall be circulated to the GNAO 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 Project Manager and the NSF Program Officer are confident that the GNAO project will have all end-of-stage deliverables ready by a certain date, they 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 Project Manager may be tasked with making the logistical arrangements. The GNAO 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 Project Manager and the NSF Program Officer shall decide whether the GNAO project can proceed to the next design stage or whether to require additional work (including, possibly, an additional review) to correct identified shortcomings.

3.2 Development Budget and Funding Sources

The funding profile for WBS 1.2 GNAO is shown in the table below. The basis of estimate is Gemini heritage Facility Class Instrument actual costs and includes data from the current multi-conjugate adaptive optics system (GeMS) in operation at Gemini South.

GR2120000 GNAO							
	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	-Total Fiscal Years
010 Salaries Wages - Regular	502,669	518,174	502,592	995,941	783,528	380,516	3,683,421
-TOTAL SALARY & WAGES	502,669	518,174	502,592	995,941	783,528	380,516	3,683,421
0FB Fringe Benefits	156,883	161,722	156,859	310,833	244,539	118,759	1,149,596
-TOTAL EE BENEFITS	156,883	161,722	156,859	310,833	244,539	118,759	1,149,596
-TOTAL WAGE & BENEFITS	659,553	679,896	659,451	1,306,775	1,028,067	499,275	4,833,017
800 General Equipment - Purchases - Capital	0	0	841,800	444,114	0	0	1,285,914
-TOTAL GENERAL EQUIP-CAPITAL	0	0	841,800	444,114	0	0	1,285,914
-TOTAL PERMANENT EQUIPMENT	0	0	841,800	444,114	0	0	1,285,914
500 Travel - Domestic - Operations	0	5,231	4,198	24,043	11,331	5,643	50,446
525 Travel - Domestic - Others	9,022	5,955	0	0	9,964	0	24,941
-TOTAL DOMESTIC TRAVEL	9,022	11,186	4,198	24,043	21,295	5,643	75,387
600 Travel - Foreign - Operations	35,443	73,164	28,841	76,763	53,606	64,948	332,765
625 Travel - Foreign - Others	12,027	8,612	7,667	0	37,440	6,014	71,760
-TOTAL FOREIGN TRAVEL	47,470	81,776	36,508	76,763	91,046	70,962	404,525
-TOTAL TRAVEL	**56,492**	**92,962**	**40,706**	**100,806**	**112,341**	**76,605**	**479,912**
100 Office & Materials Supplies	6,222	6,222	6,222	6,222	5,856	5,856	36,600
-TOTAL SUPPLIES	6,222	6,222	6,222	6,222	5,856	5,856	36,600
770 Freight	9,760	9,760	9,760	7,320	6,100	6,100	48,800
-TOTAL OTHER	**9,760**	**9,760**	**9,760**	**7,320**	**6,100**	**6,100**	**48,800**
750 Contracted Services	325,816	240,416	293,408	9,257,157	310,580	97,432	10,524,809
-TOTAL OTHER - SERVICES	325,816	240,416	293,408	9,257,157	310,580	97,432	10,524,809
-TOTAL OTHER DIRECT COSTS	341,798	256,398	309,390	9,270,699	322,536	109,388	10,610,209
-TOTAL EXPENSE	1,057,843	1,029,256	1,851,347	11,122,393	1,462,944	685,268	17,209,051
-GRAND TOTAL	**1,057,843**	**1,029,256**	**1,851,347**	**11,122,393**	**1,462,944**	**685,268**	**17,209,051**

Figure 5 *GNAO Budget*

3.3 GNAO Development Schedule

The Top-Level Schedule showing the start and end dates for the project's phases and stages is provided in Figure 6.

ID	WBS	Task Name	Duration	Start	Finish
1	**1**	**GNAO**	**1566 days**	**Mon 10/1/18**	**Mon 9/30/24**
2	1.1	Project Planning	3.3 mons	Mon 10/1/18	Mon 12/31/18
3	**1.2**	**Design Phase**	**718 days**	**Tue 1/1/19**	**Thu 9/30/21**
4	**1.2.1**	**Conceptual Design Stage**	195 days	**Tue 1/1/19**	**Mon 9/30/19**
62	**1.2.2**	**Preliminary Design Stage**	**262 days**	**Tue 10/1/19**	**Wed 9/30/20**
72	**1.2.3**	**Critical Design Stage**	**261 days**	**Thu 10/1/20**	**Thu 9/30/21**
82	**1.3**	**Build Phase**	**456 days**	**Fri 10/1/21**	**Fri 6/30/23**
83	**1.3.1**	**Assembly, Integration and Verification Stage**	**456 days**	**Fri 10/1/21**	**Fri 6/30/23**
90	**1.4**	**Telescope Integration Phase**	**326 days**	**Sat 7/1/23**	**Mon 9/30/24**
91	**1.4.1**	**Telescope Integration Stage**	**132 days**	**Sat 7/1/23**	**Mon 1/1/24**
98	**1.4.2**	**Commissioning and Science Verification Stage**	**196 days**	**Mon 1/1/24**	**Mon 9/30/24**

Figure 6 *Project Phases and Stages start and end dates*

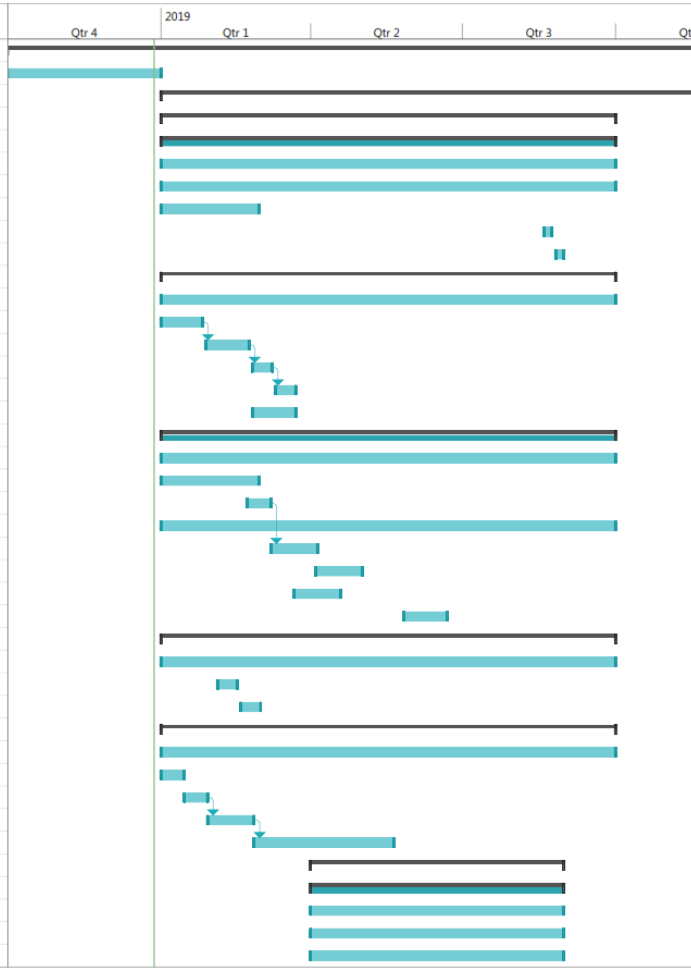
We have adopted a rolling wave approach to project scheduling. The initial Conceptual Design Stage schedule is shown in Figure 7. The deliverable documentation is highlighted in orange, project meetings in green and management reserve in blue.

As the conceptual design stage progresses, we will gain a better understanding of the definition and requirements of the Adaptive Optics Bench and the Laser Guide Star Facility through a combination of requirements identification, trade studies and AO simulation. This will result in changes to the GNAO Facility (1.2.1.6) work packages and tasks.

Once we have a better understanding of the definition and requirements, we will hold detailed planning activities. Based on our resources, available effort and budget we will assess the best approach for completing those tasks on time. Our approach is to assess our internal resources and capabilities and be ready to contract out Conceptual design work at the beginning of April if necessary. We will seek to supplement any internal engineering effort assigned to the project with design engineers on service contracts - managed closely by assigned members of the GNAO Team. This approach will allow us to hold a CoDR on time given the current level of uncertainty in the amount of work required to complete a conceptual design.

During the Conceptual Design we will also define the design tasks beyond the Conceptual Design Stage and retain the option of outsourcing the design, fabrication, assembly and test of major work packages during the Preliminary design stage. Our aim is to reach GNAO and GNAOI first light between April and June 2023.

ID	WBS	Task Name	Duration	Start	Finish
1	**1**	**GNAO**	**1566 days**	**Mon 10/1/18**	**Mon 9/30/24**
2	1.1	Project Planning	3.3 mons	Mon 10/1/18	Mon 12/31/18
3	**1.2**	**Design Phase**	**718 days**	**Tue 1/1/19**	**Thu 9/30/21**
4	**1.2.1**	**Conceptual Design Stage**	195 days	**Tue 1/1/19**	**Mon 9/30/19**
5	**1.2.1.1**	**Project Management**	195 days	**Tue 1/1/19**	**Mon 9/30/19**
6	1.2.1.1.1	Day-to-Day Project Management	195 days	Tue 1/1/19	Mon 9/30/19
7	1.2.1.1.2	Project-level Reporting	195 days	Tue 1/1/19	Mon 9/30/19
8	1.2.1.1.3	Project Management Plan (PMP)	43 days	Tue 1/1/19	Thu 2/28/19
9	1.2.1.1.4	Preliminary Design Stage Plan	5 days	Mon 8/19/19	Fri 8/23/19
10	1.2.1.1.5	Conceptual Design End of Stage Report	5 days	Mon 8/26/19	Fri 8/30/19
11	**1.2.1.2**	**Science**	**195 days**	**Tue 1/1/19**	**Mon 9/30/19**
12	1.2.1.2.1	Science Management	195 days	**Tue 1/1/19**	**Mon 9/30/19**
13	1.2.1.2.2	GNAO Core Science Team Formation	3.8 wks	**Tue 1/1/19**	**Fri 1/25/19**
14	1.2.1.2.3	Driving Science Case Identification	4 wks	**Mon 1/28/19**	**Fri 2/22/19**
15	1.2.1.2.4	Science Requirements Identification	2 wks	**Mon 2/25/19**	**Fri 3/8/19**
16	1.2.1.2.5	Trade Study Identification	2 wks	**Mon 3/11/19**	**Fri 3/22/19**
17	1.2.1.2.6	Science Cases	20 days	**Mon 2/25/19**	**Fri 3/22/19**
18	**1.2.1.3**	**System Engineering**	195 days	**Tue 1/1/19**	**Mon 9/30/19**
19	1.2.1.3.1	System Engineering Management	195 days	**Tue 1/1/19**	**Mon 9/30/19**
20	1.2.1.3.2	Systems Engineering Management Plan (SEMP)	43 days	**Tue 1/1/19**	**Thu 2/28/19**
21	1.2.1.3.3	Con Ops Requirements Identification	2 wks	**Fri 2/22/19**	**Thu 3/7/19**
22	1.2.1.3.4	Concept of Operations Document (ConOps)	195 days	**Tue 1/1/19**	**Mon 9/30/19**
23	1.2.1.3.5	Top-Level Facility Requirements Identification	4 wks	Fri 3/8/19	Thu 4/4/19
24	1.2.1.3.6	Requirements Flowdown	4 wks	**Thu 4/4/19**	**Wed 5/1/19**
25	1.2.1.3.7	Trade Studies	4 wks	**Fri 3/22/19**	**Thu 4/18/19**
26	1.2.1.3.8	Requirements Document (RD)	4 wks	**Mon 5/27/19**	**Fri 6/21/19**
27	**1.2.1.4**	**Product Assurance**	**195 days**	**Tue 1/1/19**	**Mon 9/30/19**
28	1.2.1.4.1	Product Assurance Management	195 days	**Tue 1/1/19**	**Mon 9/30/19**
29	1.2.1.4.2	Safety Management Plan (SMP)	2 wks	**Mon 2/4/19**	**Fri 2/15/19**
30	1.2.1.4.3	Configuration Management	2 wks	**Mon 2/18/19**	**Fri 3/1/19**
31	**1.2.1.5**	**Adaptive Optics**	**195 days**	**Tue 1/1/19**	**Mon 9/30/19**
32	1.2.1.5.1	Adaptive Optics Management	195 days	Tue 1/1/19	Mon 9/30/19
33	1.2.1.5.2	Adaptive Optics Working Group Formation	2 wks	Tue 1/1/19	Mon 1/14/19
34	1.2.1.5.3	Adaptive Optics Requirements Identification	2 wks	Tue 1/15/19	Mon 1/28/19
35	1.2.1.5.4	Adaptive Optics Trade Study Identification	1 mon	Tue 1/29/19	Mon 2/25/19
36	1.2.1.5.5	Adaptive Optics System Simulations	3 mons	Tue 2/26/19	Mon 5/20/19
37	**1.2.1.6**	**GNAO Facility**	**110 days**	**Mon 4/1/19**	**Fri 8/30/19**
38	**1.2.1.6.1**	**Adaptive Optics Bench (Definition and CoD)**	**110 days**	**Mon 4/1/19**	**Fri 8/30/19**
39	1.2.1.6.1.1	Deformable Mirror	110 days	Mon 4/1/19	Fri 8/30/19
40	1.2.1.6.1.2	NGSWFS	110 days	Mon 4/1/19	Fri 8/30/19
41	1.2.1.6.1.3	LGSWFS	110 days	Mon 4/1/19	Fri 8/30/19



ID	WBS	Task Name	Duration	Start	Finish
42	1.2.1.6.1.4	TTM	110 days	Mon 4/1/19	Fri 8/30/19
43	1.2.1.6.1.5	ADC	110 days	Mon 4/1/19	Fri 8/30/19
44	**1.2.1.6.2**	**Laser Guide Star Facility (Definition and CoD)**	110 days	**Mon 4/1/19**	**Fri 8/30/19**
45	1.2.1.6.2.1	Beam Transfer Optics	110 days	Mon 4/1/19	Fri 8/30/19
46	1.2.1.6.2.2	Laser Launch Telescopes	110 days	Mon 4/1/19	Fri 8/30/19
47	1.2.1.6.3	GNAO Real Time Computer	110 days	Mon 4/1/19	Fri 8/30/19
48	1.2.1.6.4	Calibration Source	110 days	Mon 4/1/19	Fri 8/30/19
49	1.2.1.7	System I&T (Not Applicable)			
50	**1.2.1.8**	**Kickoff Meeting & Reviews**	**178 days**	**Mon 1/14/19**	**Wed 9/18/19**
51	**1.2.1.8.1**	**Conceptual Design Stage Kickoff Meeting**	**1 day**	**Mon 1/14/19**	**Mon 1/14/19**
52	1.2.1.8.1.1	Conceptual Design Kickoff Meeting	1 day	Mon 1/14/19	Mon 1/14/19
53	**1.2.1.8.2**	**Conceptual Design Review**	**35 days**	**Thu 8/1/19**	**Wed 9/18/19**
54	**1.2.1.8.2.1**	**Conceptual Design Stage Documentation**	**35 days**	**Thu 8/1/19**	**Wed 9/18/19**
55	1.2.1.8.2.1.1	Conceptual Design Document (CoDD)	24 days	Thu 8/1/19	Tue 9/3/19
56	1.2.1.8.2.1.2	Update Other Deliverables - including PEP	24 days	Thu 8/1/19	Tue 9/3/19
57	1.2.1.8.2.1.3	Circulate CoD Documentation	1 day	Mon 9/2/19	Mon 9/2/19
58	1.2.1.8.2.1.4	Review Preparation	8 days	Tue 9/3/19	Thu 9/12/19
59	1.2.1.8.2.1.5	Conceptual Design Review	2 days	Mon 9/16/19	Tue 9/17/19
60	**1.2.1.9**	**Management Reserve**	**9 days**	**Wed 9/18/19**	**Mon 9/30/19**
61	1.2.1.9.1	Schedule Review	9 days	Wed 9/18/19	Mon 9/30/19
62	**1.2.2**	**Preliminary Design Stage**	**262 days**	**Tue 10/1/19**	**Wed 9/30/20**
72	**1.2.3**	**Critical Design Stage**	**261 days**	**Thu 10/1/20**	**Thu 9/30/21**
82	**1.3**	**Build Phase**	**456 days**	**Fri 10/1/21**	**Fri 6/30/23**
83	**1.3.1**	**Assembly, Integration and Verification Stage**	**456 days**	**Fri 10/1/21**	**Fri 6/30/23**
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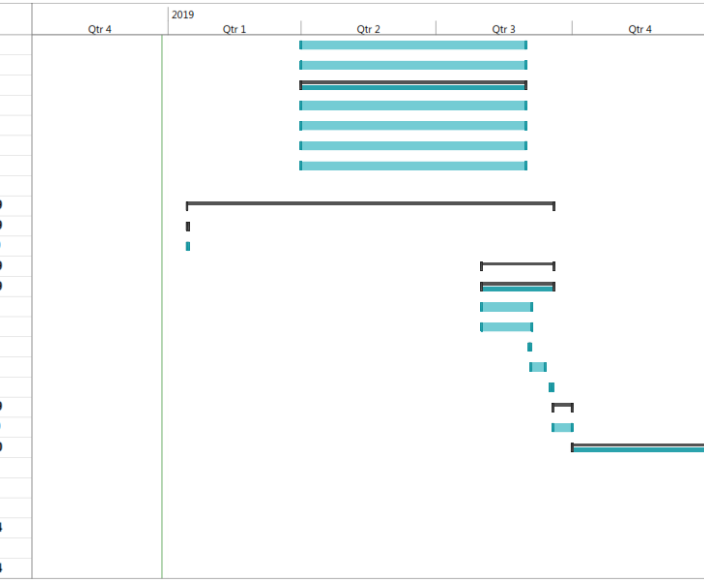

Figure 7 *Conceptual Design Stage schedule*

In addition, there are several inter-project dependencies we will integrate into the plan as the external projects develop and we can synchronize their plans. These dependencies include the GNAO RTC being developed for GNAO via the GEMMA Program RTC project; GNAOI, the first-light image and science instrument we are developing external to the GEMMA program; the adaptive secondary mirror we are also developing external to the GEMMA program; and any additional instruments coming to Gemini for possible use behind GNAO including IGRINS2 and GIRMOS. We provide the initial set of inter-project dependencies below.

1. External project dependencies
    a. RTC
        i. **Provide** GNAO Requirements to RTC project.
        ii. **Co-create** GNAO-RTC Interface Document
        iii. **Receive and Review** RTC design and schedule
        iv. **Receive** RTC Test Report
        v. **Receive** RTC (by TBD)
    b. GNAOI
        i. **Provide** GNAO Specification
        ii. **Provide** GNAO Interfaces
        iii. **Receive** GNAOI Requirements
        iv. **Receive** GNAOI Pre-delivery Test Report
        v. **Receive** GNAOI (by 1/1/24)
    c. ASM
        i. **Provide** GNAO Specification
        ii. **Provide** GNAO Interfaces
        iii. **Receive** Requirements from ASM
        iv. **Receive** ASM Interfaces
        v. **Provide** GNAO Test Report.
    d. Other instruments (IGRINS2, GIRMOS, …?) [Depending on timescales]
        i. **Provide** GNAO Specification
        ii. **Provide** GNAO Interfaces
        iii. **Receive** Requirements from other instruments
        iv. Coordinate scheduling/testing if needed.

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

4 Construction Project Definition

4.1 Summary of Total Project Definition

To meet requirements and as multiple goals, the baseline design for GNAO provides a Multi-Conjugate Adaptive Optics system and 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 to serve current needs and allow for future upgrade paths. The GNAO facility includes two major components that we will develop simultaneously:

- New Laser Guide Star Facility (LGSF).
- Adaptive Optics Bench (AOB).

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 future IDF to incorporate a ASM into GNAO in the future.

This work will occur in collaboration with the GNAO effort. We will design and build GNAO to be compatible with the ASM, but we do not expect to install and commission the ASM until after GNAO is operational. Top level requirements will be identified to ensure that GNAO is ASM ready.

During the Conceptual Design Stage, we will conduct a number of trade studies and simulations to make design choices. The following descriptions include the various options we are currently considering at the beginning of the Conceptual Design Stage.

4.1.1 MCAO Adaptive Optics Bench

We plan to take full advantage of the experience and lessons learned with GeMS in designing the GNAO optical bench. We intend to use a large and dense deformable mirror (DM) as the ground layer DM. Inside of the Adaptive Optics Bench (AOB) we will have at least one more post-focal DM to enable MCAO correction conjugated to Maunakea main turbulent altitude layer. To sample the entire turbulence volume, we propose to use 6 LGSWFSs. They will be Shack-Hartmann WFSs equipped with 16x16 minimum (or higher order, goal is 32x32) sub apertures. Each will be equipped with a very low noise detector to maximize throughput and sensitivity of the centroiding.

Additionally, we will continue to use 1-3 NGSs for the low-order corrections. We propose to use a focal plane detector to measure the tip-tilt (TT). The goal is to reach a limiting magnitude of 18 in the R-band. In order to offer high precision astrometry, we propose to use 4 off-axis parabola design, similar to the NFIRAOS design for the Thirty Meter Telescope (TMT) (Boyer et al. 2016). To not vignette the science path, we will use a dichroic beam splitter that will send optical light (< 600 nm) to the WFSs, and IR light (> 600 nm) to the science camera. This will allow for optical science in the r, i, and z bands (the r-band will be cut-off on the blue end) and will also allow the H-alpha line (656 nm) to be observed with MCAO. The performance will not be

diffraction limited of course, but better than seeing limited observations by a factor 2 to 3 ("super-seeing" mode). As we are post-focal, an off-axis parabola must be placed in the WFS path to complete the relay with the off-axis parabolas in the common path. A special 589 nm dichroic will then be used to send the laser light to the LGSWFSs, while the remaining optical light will go to the Natural Guide Star WaveFront Sensor (NGSWFS).

The AO bench will be designed to adapt itself to a potential upgrade of the system using a new secondary unit for Gemini based on an adaptive secondary mirror, as discussed before. The work on the feasibility and design of this new unit will be performed separately from this project. The AO bench must also have a calibration unit, laser and natural sources to perform standard calibrations such as look-up-tables and non common path aberrations (NCPA) estimations. The AO bench must respect the volume and weight allocated in the space envelope requirements of the AO port of the Instrument Support Structure.

In order to take advantage of the new capabilities offered by GNAO, we intend to build a new science camera that will be used in conjunction with GNAO. GN currently lacks a modern IR imager that will be capable of taking advantage of the wide field at high angular resolution offered by the GNAO MCAO mode. We will build a new IR imager with capabilities similar to the GSAOI instrument used in GS. We will work with our community and governance to define the capabilities of this camera and plan to fund it from existing program funds.

4.1.2 New laser guide star facility

GNAO will require 4 to 6 laser guide stars (LGSs). We propose to generate these guide stars using two commercially available 22W Toptica sodium lasers[2]. Each laser will be used to generate two or three guide stars. The commissioning of the Gemini South Toptica laser with GeMS has shown that a Toptica laser can be effectively split into multiple beams and produce sufficient sodium return for high performance AO[3] . Using six 7.3-watt beams, we expect to be able to run the Laser Guide Star WaveFront Sensor (LGSWFS) at >500 Hz.

As a comparison, GeMS can run at 300 Hz (on average) with its one Toptica laser split in five. The recent commissioning of the Toptica laser at Gemini North with ALTAIR has shown also that the laser is extremely reliable and provides sufficient return. Under all conditions during the commissioning, ALTAIR could run at 1kHz and keep perfect loop stability and good signal to noise ratio in the LGSWFS. Each of the LGS will be side launched from its own laser launch telescope that will be installed onto telescope elevation platforms. We have elected to use side-launched LGS and for each to have its own Laser Launch Telescope (LLT) based on experience with GeMS. In the GeMS case we use one center-mounted LLT to generate five LGSs, and this solution has proven to be unstable in operations. We will build into the GN LGS system the ability to split the lasers into multiple guide stars (maximum six) that can patrol the telescope FoV up to a 9'x9' square, to allow for potential future upgrades to GNAO to include a GLAO mode. In order to keep overhead low, we also envision installing a Laser Pointing

[2] Enderlein et al. Proceedings of the SPIE, Volume 9148, id. 914807 11 pp. (2014).
[3] Sivo et al. 2018, in prep.

Camera (LPC) to assist with laser constellation acquisition on-sky and alignment. The laser pointing camera will be installed at the top end ring of the telescope structure.

4.2 Work Breakdown Structure (WBS)

The GNAO Work Breakdown Structure is subsystem focused rather than discipline focused.

The Work breakdown Structure for the project is provided below. The WBS number refers to the 4th digital (level) in the WBS column in the Gantt Chart (see figure 7). They are the same for each stage. The project is structured such the first three numbers correspond to the project, phase and stage. For clarity they have not been included here.

WBS #	WBS Title	Deliverable
1	Project Management	
2	Science	
3	System Engineering	
4	Product Assurance	
5	Adaptive Optics	
6	GNAO Facility	
7	System I&T	
8	Kickoff Meeting & Reviews	
9	Management Reserves	

Table 5 *Work Breakdown Structure (level 4)*

For the GNAO Facility we have included the next two levels. They will evolve as we continue to define the project and the subsystems of the GNAO Facility

WBS #	WBS Title	Deliverable
6.1	AO Bench	AO Bench
6.1.1	Deformable Mirrors (DM)	Deformable Mirrors
6.1.2	NGSWFS	Natural Guide Star Wavefront Sensors Subsystem
6.1.3	LGSWFS	Laser Guide Star Wavefront Sensors Subsystem
6.1.4	TTM	Tip Tilt Mirror Assembly

6.1.5	ADC	Atmospheric Dispersion Corrector
6.2	Laser Guide Star Facility (LGSF)	Laser guide star subsystem
6.2.1	Beam Transfer Optics	Beam Transfer Optis subsystem
6.2.2	Laser Launch Telescopes	Laser Launch Telescopes subsystem
6.3	GNAO Real Time Computer	Operational RTC
6.4	Calibration Sources	Calibration Sources Subsystem

Table 6 *Work Breakdown Structure (level 5 and 6) for the GNAO Facility*

4.3 WBS Dictionary

A WBS Dictionary will be created during the Conceptual Design Stage of the project.

4.4 Scope Management Plan and Scope Contingency

Scope Management will be documented in the Project Management Plan available at the Conceptual Design Review.

For further details of the scope of the project, see section 3.1.1.

4.5 Cost Estimating Plan, Cost Reports and Baseline Budget

This is covered in section 4.5 of the GEMMA Program Execution Plan.

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 Gemini standard practice 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.

4.7 Cost Book, Cost Model Data Set and Basis of Estimate

This is not a large facility project and the GNAO project is an addition to existing observatory operations - this section is not applicable.

4.8 Funding Profile

We are currently developing the funding profile. The cost summary below is preliminary pending full clarity on scope.

WBS Title	2019	2020	2021	2022	2023	2024	Total
AO Bench	.7	.7	1.3	7.8	1.0	.5	12
Laser Guide Star Facility (LGSF)	.36	.33	.55	3.32	.46	.19	5.21
Total	**1.06**	**1.03**	**1.85**	**11.12**	**1.46**	**0.69**	**17.21**

Table 7 *Project Cost Summary [M$]*

4.9 Baseline Schedule Estimating Plan and Integrated Schedule

See section 3.3 GNAO Development Schedule for the more detailed schedule.

4.10 Schedule Contingency

Gemini requires contractors to maintain a baseline schedule and include schedule contingency beyond the baseline of a reasonable amount (at least 15% beyond the critical path). The schedule, including contingency, shall not exceed the required project completion date. For internal work, we will update the baseline schedule with appropriate contingency at each stage end. The exception will be the Conceptual Design Stage. There are 10 days of schedule reserve after the design review.

5 Staffing

5.1 Staffing Plan

Having a strong technical leader and a strong project manager is essential, given the tight timeline and geographically-distributed staffing. Initial recruitments will fill, as soon as possible, the roles of GNAO Principal Investigator and GNAO Project Manager. To ensure continuity, they will initially work with the Acting Principal Investigator and Project Manager. Full handover will be completed at latest by the Conceptual Design Review.

Given the amount of work currently estimated, contractors to support even the Conceptual Design Stage will be needed. At the end of that stage, based on experience to date, we will decide how to staff the Preliminary Design Stage and beyond. Gemini has in-house expertise that could support the later external contractors, but some additional recruitment at the technical level may be necessary. Figure 8 contains the current GNAO Resource Assignment Matrix which, as described above, will change as the Conceptual Design Stage progresses.

	GNAO Resource Assignment Matrix															
	Last update 20181117															
				October	April	October	April	October	April	October	April	October	April	October	April	
Start yr	Activity	Role	Staff	19A	19B	20A	20B	21A	21B	22A	22B	23A	23B	24A	24B	
2019A	GNAO	PI	AOS TBH	1	1	1	1	1	1	1	1	1	1	1	1	
2019A	GNAO	PM	Jeff	0.8	0	0	0	0	0	0	0	0	0	0	0	
2019A	GNAO	PM	PM TBH	0	1	1	1	1	1	1	1	1	1	1	1	
2019A	GNAO	PI/IS	Gaetano	1	1	1	1	1	1	1	1	1	1	1	1	
2019A	GNAO	SE	Natalie	1	1	1	1	1	1	1	1	1	1	1	1	
2019A?	GNAO	PS	Paul	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	
2019A	GNAO	DPS - GN	TBD	0	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	
2019A	GNAO	DPS - GS	TBD	0	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	
2019A	GNAO	Detector Engineer	TBH	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	
2019A	GNAO	Electronics Engineer	TBH	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	
2019A	GNAO	Mechanical Engineer	TBH	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	
2019A	GNAO	Optical Engineer	TBH	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	
2019A	GNAO	Software Engineer	TBH	0	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	

Figure 8 *The Current GNAO Resource Assignment Matrix*

5.2 Hiring and Staff Transition Plan

We are currently hiring the following three positions for GNAO. Each position has been advertised and a selection committee for each hire has been formed. Interviews have begun for the Senior Project Manager and Senior Systems Engineer position.

Once there is a PI and PM in place and have concluded detailed planning, we will start the recruitment process for other needed positions.

5.2.1 Senior AO Scientist (See Figure 8: PI: AOS - TBH)

We are currently seeking a Senior Project Manager, based at the Gemini North (GN) Observatory in Hilo, Hawaii. Upon hire the Senior AO Scientist will be assigned to GNAO to support the Acting GNAO Principal Investigator in completing the Conceptual Design Stage. The new hire will transition to the PI role at the end of the Conceptual Design Stage and the Acting PI will become the Adaptive Optics Scientist for the project.

5.2.2 Senior Project Manager (See Figure 8: PM: PM - TBH)

We are currently seeking a Senior Project Manager, based at the Gemini North (GN) Observatory in Hilo, Hawaii. Upon hire the Senior Project Manager will relieve the Acting Project Manager to become the GNAO Project Manager.

5.2.3 Senior Systems Engineer (See Figure 8: Engineer: TBH)

A Senior Systems Engineer position will be hired and located at the Gemini North (GN) Observatory in Hilo, Hawaii. The Senior Systems Engineer will primarily support the GN Adaptive Optics (GNAO) and Real Time Computer (RTC) projects. Depending on the skill set they may also fulfill either the fraction Electronics Engineer, Mechanical or Optical Engineering role.

5.2.4 Consultants

A pool of consultants with AO and program management expertise have been identified. A time and materials contract may be used to obtain the skills needed for specific tasks appropriate to the consultant's skillset.

6 Risk and Opportunity Management

6.1 Risk Management Plan

The project will comply with the Gemini PMO Risk Management Plan listed as a Reference Document in the GEMMA Program Execution 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 Risk Register will be developed during the Conceptual Design Stage of the project. It will include:

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 Managment Plan will be developed during the Conceptual Design Stage of the project.

7 Systems Engineering

7.1 Systems Engineering Plan

An initial revision of the GNAO Systems Engineering Management Plan (SEMP) to document the role of systems engineering throughout the GNAO life cycle has been developed. We will refine this plan early in the Conceptual Design Phase to reflect systems engineering process and programmatic details as the system definition matures. The plan will be submitted with the next annual report.

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

- Technical management through all phases
- Concept of Operations Management
- Requirements Management
- System Design
- Interface Management
- System Integration
- Verification and Validation
- Quality Control Management

7.2 Systems Engineering Requirements

We will refine this plan early in the Conceptual Design Phase to reflect systems engineering process and programmatic details as the system definition matures. The plan will be submitted with the next annual report.

7.3 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 define external, internal, functional, and physical interfaces an Interface Definition Document that will be maintained throughout development. This document will be the basis for specifying interface requirements will be documented in an Interface Requirements Document (IRD). We will then manage external and internal interface via Interface Control Documents (ICDs).

7.4 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.

7.5 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 will generate a ConOps as a first step in the Conceptual Design Stage, and will use it as a source of requirements and interface definitions.

7.6 Facility Divestment Plan

This project is not a large facility construction project and implementation is an addition to an existing observatory, this section is not applicable.

8 Configuration Control

8.1 Configuration Control Plan

The end product, as well as all previous product iterations, will be under Configuration Control. This means that all changes made to requirements, technical, cost and schedule are tracked and are subject to the approval of the Program Manager. In addition, changes that do not require control are tracked in the decision tracker and the issues list. Following the GNAO Critical Design Review (CDR) a new or altered requirement can only be approved by the Change Control Board (CCB).

8.2 Change Control Plan

All changes to the project are requested through a Change Request Form and submitted to the Project Manager. The Project Manager will assess the benefit of the change and the impact on cost, timeline and resources available and decides if the change can be implemented. If the scope of the change is outside of the tolerances for the Project Manager, the Project Sponsor will be consulted.

8.3 Documentation Control Plan

Document change control is a systematic approach to managing all changes made to a document. The purpose is to ensure that no unnecessary changes are made, that all changes are approved and documented and there is no unintended use of obsolete documents. Change control encompasses the following activities:

- Creating or updating a document,
- Review and approval of document,
- Version update in Gemini's Document Management Tool (DMT) and release of document

These three steps are essential to effective change control. A document can be changed and its version updated in DMT (released) but without proper review and approval, the document may not be a true reflection of the current system it's describing. Similarly, a document can be updated and approved but never added to DMT and thus will not be used or easily accessible, while the now obsolete version in DMT may be used.

Because change control requires some overhead, Gemini does not require that all documents created go through the change control process. One way to determine whether a document requires change control is if it loses value if it doesn't reflect the current state of the system in discussion. Also, documents that may be referenced for a sustained period of time, such as for the lifecycle of a system or for the lifecycle of a project, should be change controlled. Examples of documents that should be change controlled are:

Documents depicting a system, interface, policy, etc.

- Design / Architecture
- Requirements
- Drawings
- ICDs
- Policies

Operational documents defining processes or procedures, essential to operation of the telescope:

- User manuals
- Service and calibration manuals

Project documents capturing specific decisions or states of the project at a specific time in the life cycle (i.e. documents used at reviews or decision gates):

- ConOps
- Schedule
- Contractor-deliverables

Management documents describing management frameworks:

- Observatory project management plan and systems engineering management plan

In addition, DMT has a secured area required for ITAR related documents.

9 Acquisitions

9.1 Acquisition Plans

The plan to acquire will be included in the Project Management Plan and delivered at the Conceptual Design Stage. A list of acquisitions will be available at the time of the Critical Design Review.

Service contracts may be used to supplement the team during the Conceptual Design Stage to allow the project to complete its set of deliverables before CDR.

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 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. In order to ensure that all hardware, documentation, and reports are delivered on time and in budget, the management team will continue to establish a WBS an include its associated cost and schedule.

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

Gemini has a Project Management Office which 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 in the so called Toolkit.
- Reporting and resource allocation tools
- Training
- Documentation describing
    - Monitor and Control
    - Change Management Process

This methodology and the applicable templates are used throughout this project.

10.2 Earned Value Management System (EVMS)

This is covered in section 10.2 of the GEMMA Program Execution Plan.

10.3 Financial and Business Controls

This is covered in section 10.3 of the GEMMA Program Execution Plan.

11 Site and Environment

11.1 Site Selection

This is not a large facility project. The GNAO project is an addition to existing observatory operations, this section is not applicable.

11.2 Environmental Aspects

This is not a large facility project and implementation is an addition to an existing observatory, this section is not applicable.

12 Cyber Infrastructure

12.1 Cyber-Security Plan

This is covered in section 12.1 of the GEMMA Program Execution Plan.

12.2 Code Development Plan

This is covered in section 12.2 of the GEMMA Program Execution Plan.

12.3 Data Management Plan

This is covered in section 12.3 of the GEMMA Program Execution Plan.

13 Environmental Safety and Health

13.1 Environmental Safety and Health Plans

This is covered in section 13.1 of the GEMMA Program Execution Plan.

The project will create a dedicated Safety Management Plan (see Section 3) during the Conceptual Design Stage which will evolve and be applied as the project advances.

14 Review and Reporting

14.1 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.

14.2 Audits and Reviews

The project's review process is described in section 3. Currently audits are not planned at the project level.

15 Integration and Commissioning

15.1 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 Stage of the project. The Commissioning and Science Verification Plan will be commissioned during the Build Phase of the project.

See section 3 for additional details.

15.2 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 there will be Acceptance Test Plan and an end-of-project review which will assess the readiness of the facility to transfer from the responsibility of Gemini Development to Gemini Science Operations. Based on experience the completeness of the GNAO Documentation Set will be an important entrance criteria for calling the review.

See section 3 for additional details.

16 Project Close-out

16.1 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 within the Project Management Plan, due at the Conceptual Design Review and details contained within the Commissioning and Verification (final project stage) Stage Plan.

16.2 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 Facility Integration and Commissioning. Gemini Development will work closely with Gemini Science Operations throughout the project to review plans to achieve this. No separate transition to operations plan is envisaged.

GNAO Risk Register A - GNAO - 002

Part I. Risk Identification						Part II. Risk Analysis for Existing Controls			Part III. Risk Response							
Name	**Project Risk Category**	**Risk Description (ignoring controls) [use: if, because, then]**	**Impact 1-5 (ignoring controls)**	**Likelihood 1-5 (ignoring controls)**	**Total Risk Score** Low = 1 - 8 Med = 9 - 16 High = 17 - 25	**What Controls (if any) are currently in place?**	**Control Effectiveness 1-5**	**Residual Risk Score** Low = 1 - 8 Med = 9 - 16 High = 17 - 25	**Control or Risk Mitigation Strategy**	**Control effectiveness based on mitigation strategy 1-5**	**Residual Mitigated Risk** Low = 1 - 8 Med = 9 - 16 High = 17 - 25	**Contingency Plan**	**Cost of contingency plan**	**Owner**	**Review Due Date**	**Status**
Late production of Science Cases and CONOPS	Technical	If the Science Cases work is not completed early then the GNAO requirements set will be incomplete, possibly resulting in an inadequate design impacting the schedule.	5	3	**15**	The Science Team was identified early and are working on the science cases.	1	**0**	The Science Team was identified early and are working on the science cases.							
Staffing	Resources	If the two open positions on the GNAO Team (Senior Systems Engineer, Senior Project Manager) are not filled in a timely manner then significant schedule slips might occur due to lack of key staff.	5	4	**20**	Post job advertisements asap	3	**10**	Job advertisements have been posted internally (AURA) and externally							
Internal resource shortage	Resources	If the current team is allocated to other projects then the project may fall behind schedule	3	3	**9**	The project is the second highest priority project in the portfolio.	4	**7**								
Late ASM and GNAOI interface / integration requirements (since they are outside the scope)	Technical	If the requirements are not developed and the interfaces can not be completed the project completion will not be met.	3	3	**9**	The project is the second highest priority project in the portfolio.	3	**5**								
Procurements	Schedule	If procurements are not comleted in a timely manner the scheulde will slip.	5	4	**20**	TBD										
Vendor Delays	Technical	Interface management risk - if the strategy to procure major (non off-the-shelf) subassemblies from different vendors is delayed this may impact schedule and budget.	3	3	**9**	TBD										
Requirements	Technical	GNAO design needs to be compatible with the yet to be built ASM. The opto-mechanical design of the MCAO AOB has to be built in such a way that replacing DM0 with M2 is possible and if not will impact budget and schedule.	3	3	**9**	TBD										