GSAOI
Conceptual Design Review Documentation

Vol. 3

Submitted to the International Gemini Project Office
under
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Research School of Astronomy and Astrophysics
Australian National University
Canberra, Australia

August 20-21, 2002

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MANAGEMENT PLAN

GSAOI
Conceptual Design Review Document

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List of Acronyms

AAO	Anglo Australian Observatory
ADC	Analog-to-Digital Converter
AIPS	Astronomical Image Processing System
ANU	Australian National University
ARIES	Australian Resource Identification and Environment Satellite
ASIC	Application Specific Integrated Circuit
BOM	Bill Of Materials
CAD	Computer Aided Design
CASPIR	Cryogenic Array Spectrometer/Imager
CCD	Charge Coupled Device
CD	Compact Disk
CDR	Critical Design Review
CICADA	Computerized Instrument Control And Data Acquisition
CoDR	Conceptual Design Review
CNC	Computer Numeric Control
CWS	Cold Work Surface
DBS	Double Beam Spectrograph (RSAA)
DC	Detector Controller
DHS	Data Handling System
DSP	Digital Signal Processor
DVM	Design Verification Matrix
E&C Cert.	Electronics and Communications Certificate
EDM	Electric Discharge Machine
E-mail	Electronic Mail
EPROM	Erasable Programmable Read Only Memory
ESD	Electro-Static Discharge
ESP	Enterprise Solutions Project (PeopleSoft)
FEA	Finite Element Analysis
FMECA	Failure Modes, Effects and Criticality Analysis
FPRD	Functional and Performance Requirements Document
FTE	Full Time Employment
GSAOI	Gemini South Adaptive Optics Imager
IC	Instrument Committee (RSAA)
ICD	Interface Control Document
ICS	Instrument Control System
IDL	Interactive Data Language
ISS	Instrument Support Structure
IR	Infra-Red
IRAF	Image Reduction Analysis Facility
MACHO	MAssive Compact Halo Object
MCAO	Multi-Conjugate Adaptive Optics
MSO	Mount Stromlo Observatory
MSSSO	Mount Stromlo and Siding Spring Observatories (now RSAA)
NCR	Non Conformance Report
NICI	Near Infra-red Coronagraph Imager (Gemini)
NIFS	Near-infrared Integral Field Spectrograph (Gemini/RSAA)
NIRI	Near-InfraRed Imager (Gemini)
OIWFS	On-Instrument Wave-Front Sensor
PA	Product Assurance
PC	Personal Computer (Wintel)
PCB	Printed Circuit Board
PDR	Preliminary Design Review

PERT	Program Evaluation and Review Technique (U.S.A. Navy)
PLD	Programmable Logic Device
PS	Project Scientist
QA	Quality Assurance
QAO	Quality Assurance Officer
RAO	Risk Assurance Officer
RSAA	Research School of Astronomy and Astrophysics
SBRC ACE-2	Santa Barbara Research Center Array Control Electronics - 2
SDSU	San Diego State University
SIR	Status Information Record
SMD	Surface Mount Device
STL	Standard Template Library
TQM	Total Quality Management
UP&CO	University Purchasing & Contract Office (ANU)
WBS	Work Breakdown Structure
WCA	Worst Case Analysis
WFI	Wide Field Imager
WWW	World Wide Web
VLT	Very Large Telescope
XRM	X-Ray-Monitor, ESA Integral Space Satellite

1 GSAOI Project Overview

The Gemini South Adaptive Optics Imager (GSAOI) will be the workhorse instrument used with Gemini's Multi-Conjugate Adaptive Optics (MCAO) system. In September 2001, the Research School of Astronomy and Astrophysics (RSAA) proposed to perform a Conceptual Design Study for GSAOI. Two groups were selected by Gemini in November 2001 to perform Conceptual Design Studies. The RSAA Conceptual Design Study contract was signed in April 2002 and forms the basis of this report.

The objective of the GSAOI project is the design, construction, installation, commissioning, and timely handover of GSAOI to satisfy the MCAO imaging needs of the Gemini community.

In response, the Director of RSAA has declared that GSAOI will be the highest priority development for the RSAA engineering sections after delivery of the Near-infrared Integral Field Spectrograph (NIFS) to Gemini North.

To fulfil Gemini's objectives, the development of GSAOI will be fast-tracked to ship the instrument to Chile in mid 2006 for deployment on the Gemini South telescope at Cerro Pachon later that year. To accomplish this feat with minimum risk, the cryostat, the instrument control system, and significant parts of the On-Instrument Wave-Front Sensor (OIWFS) and software will be duplicated directly from the RSAA design for NIFS.

GSAOI shipment to Gemini South will take place on, or before, 25 August 2006.

Major milestones of this fast-tracked project are as follows:

Start of work	16 Sep 2002
Preliminary Design Review	15 Apr 2003
Critical Design Review	30 Sep 2003
Empty Cryostat Reaches Operating Temperature	14 Jun 2004
Start of First Cool Down (mechanisms)	23 Feb 2005
Start of Second Cool Down (optics and detectors)	20 May 2005
Instrument Shipment	10 Mar-2006 - 25 Aug 2006
Project Closeout	20 Mar 2007

This report, Volume three of a four-volume set, contains management information pertaining to the GSAOI Conceptual Design Review. This information includes planning, scheduling, and human resource allocations, presented within the context of the organisational structure of the RSAA, a member of the Institute of Advanced Studies (IAS) at the Australian National University (ANU). For reasons of confidentiality, details of GSAOI Cost To Completion are reserved for Volume 4.

The fundamental approach to management is a standard product-based approach that embodies proven and established best practice in project management, thereby ensuring that GSAOI plans are realistic and focussed on delivering results within the constraints of time and budget.

2 Project Definition

2.1 Project Deliverables and End Products

- GSAOI, comprising
    - Cryostat;
    - Imager;
    - On-Instrument Wave-Front Sensor;
    - Mechanisms Control System;
    - Temperature Control System;
    - Detector Control System; and
    - Control Software;
- Handling Equipment;
- Specialised Alignment Tools and Jigs;
- Documentation Set; and
- Training of Gemini staff.

2.2 Shipment Date

GSAOI shipment to Gemini South will take place on, or before, 25 August 2006.

2.3 Delivery Location

GSAOI shall be delivered to Cerro Pachon, Chile.

2.4 Assumptions, Constraints, and Risks

The development of GSAOI will be fast-tracked to ship the instrument to Chile in mid 2006 for deployment on the Gemini South telescope later that year. To accomplish this feat with minimum risk, the cryostat, the instrument control system, and significant parts of the On-Instrument Wave-Front Sensor (OIWFS) and software will be duplicated directly from the RSAA design for NIFS.

GSAOI will be the highest priority development for the RSAA engineering sections after the delivery of NIFS to Gemini North. Experience at RSAA indicates that inadequate resourcing is the greatest risk to project schedule. The RSAA acknowledges this fact and will address it by assigning 10 full-time staff to GSAOI.

2.5 Referenced Documents

Document ID	**Source**	**Title**
GEM00304A	IGPO	GSAOI CoDR Statement of Work
GSAOI SDN01.02	RSAA	GSAOI Operational Concept Definition Document
GSAOI-SDN01.03	RSAA	GSAOI Functional and Performance Requirements Document

3 Project Organisation

3.1 RSAA Organisation Structure

The capacity of the Research School of Astronomy and Astrophysics to undertake leading-edge research is underpinned by highly skilled technical staff whose skills and expertise complement those of the academic staff. RSAA technical sections have both operational and instrument development functions. Operational issues such as instrumentation changes on telescopes, maintenance, and observer support are directed by the Associate Director of Operations. Conversely, the development of innovative instrumentation is directed by the Associate Director for Instrumentation Development.

The RSAA organisational chart for instrumentation development is depicted in Figure 1. Executive authority for instrumentation development resides with the RSAA Director, who approves the instrumentation projects to be undertaken and determines their relative priorities, taking advice from the RSAA Instrument Committee (IC) through its chairperson, the Associate Director for Instrumentation Development. The RSAA Technical Projects Manager is under the direction of the Associate Director and advises him and the IC on overall resourcing, scheduling, and budgeting of all RSAA projects. The Technical Projects Manager also performs the duties of Project Manager for one or more specific significant projects. Management of other projects is delegated to other staff members who act as project managers.

The design, development, and construction of instrumentation is a team effort comprising four technical sections, each led by a Section Head:

1. The opto-mechanical Design Office, together with the Optical and Mechanical Workshops.
2. The Electronics Section, including the Detector Laboratory.
3. The Computer Section. In addition to instrument development, the section develops and maintains the computing infrastructure for data reduction, numerical modeling, and general use.
4. The Siding Spring Technical Section, which is formally under the control of the Associate Director of Operations because its main roles are maintenance and observing support. However, a limited fraction of its effort can be applied to development work, and only for this function does it report to the Technical Projects Manager.

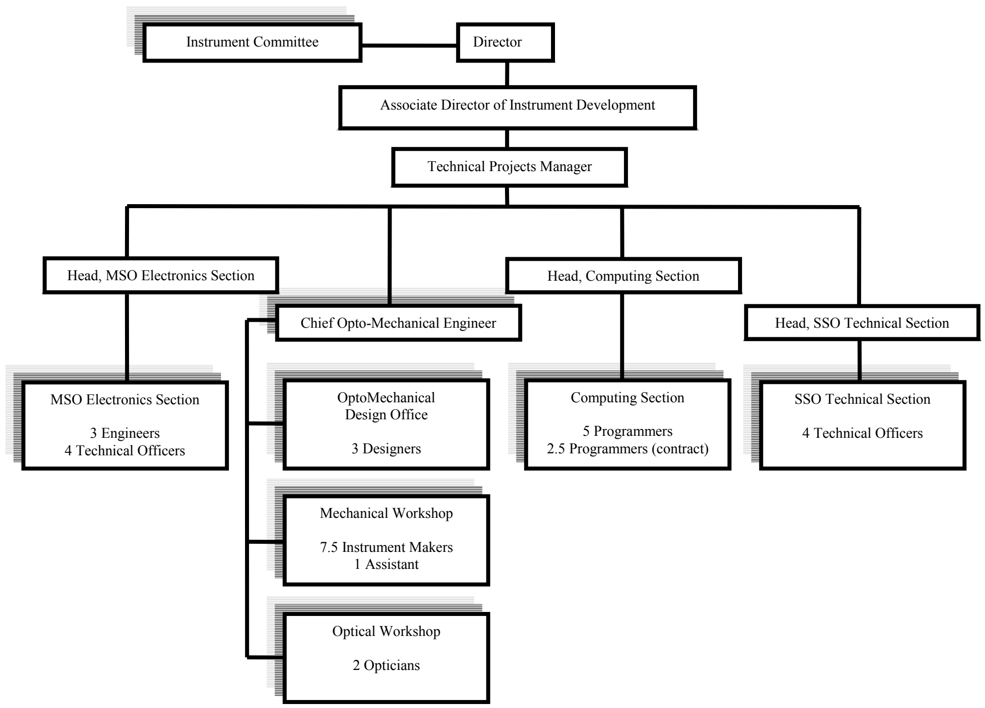


Figure 1: RSAA organisational chart for instrumentation development.

3.2 RSAA Project Management Organisational Structure

The overall project management scheme for instrument development associated with a given end-user (stakeholder) is depicted in Figure 2. The Project Team is responsible for the development of the instrument and reports directly to a delegated Project Scientist, the end-user (Stakeholder), and Technical Projects Manager.

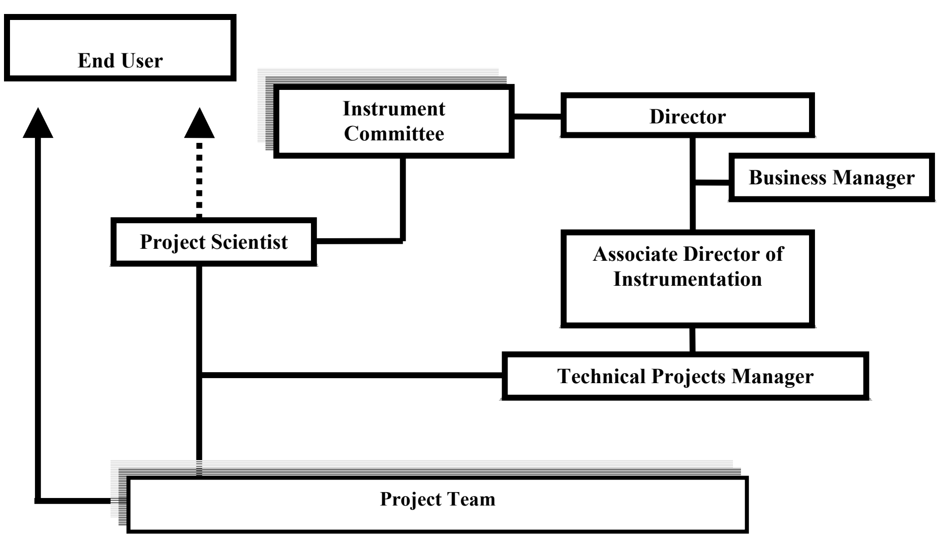


Figure 2: Project management organisational chart for instrument development.

A team-based organization is central to RSAA instrument development. This makes the RSAA more organic and responsive to demands, because work teams are used as basic building blocks. Such teams comprise personnel from different functional groups or sections. These cross-functional teams share responsibilities and have significant decision-making authority.

3.3 GSAOI Team Organisation

The RSAA approach to GSAOI will be triple-headed, with a Project Scientist, Project Manager, and a Project Engineer being assigned to the project. The instrument development effort is led by the Project Scientist (PS) who is responsible for establishing the scientific objectives and requirements for the instrument and serves as a technical monitor of the project to ensure that the instrument meets these criteria. The Project Manager (PM) has overall responsibility for planning and controlling the project to ensure that the objectives of the project are achieved on time and on budget, whilst maintaining quality standards. The PM acts as spokesperson for the project and has control of all project finances. The Project Engineer (PE) provides project and system engineering the project. The PE is responsible for the development of an appropriate instrument design and the implementation of that design to meet the scientific requirements. The project team organisational chart for GSAOI development is depicted in Figure 3.

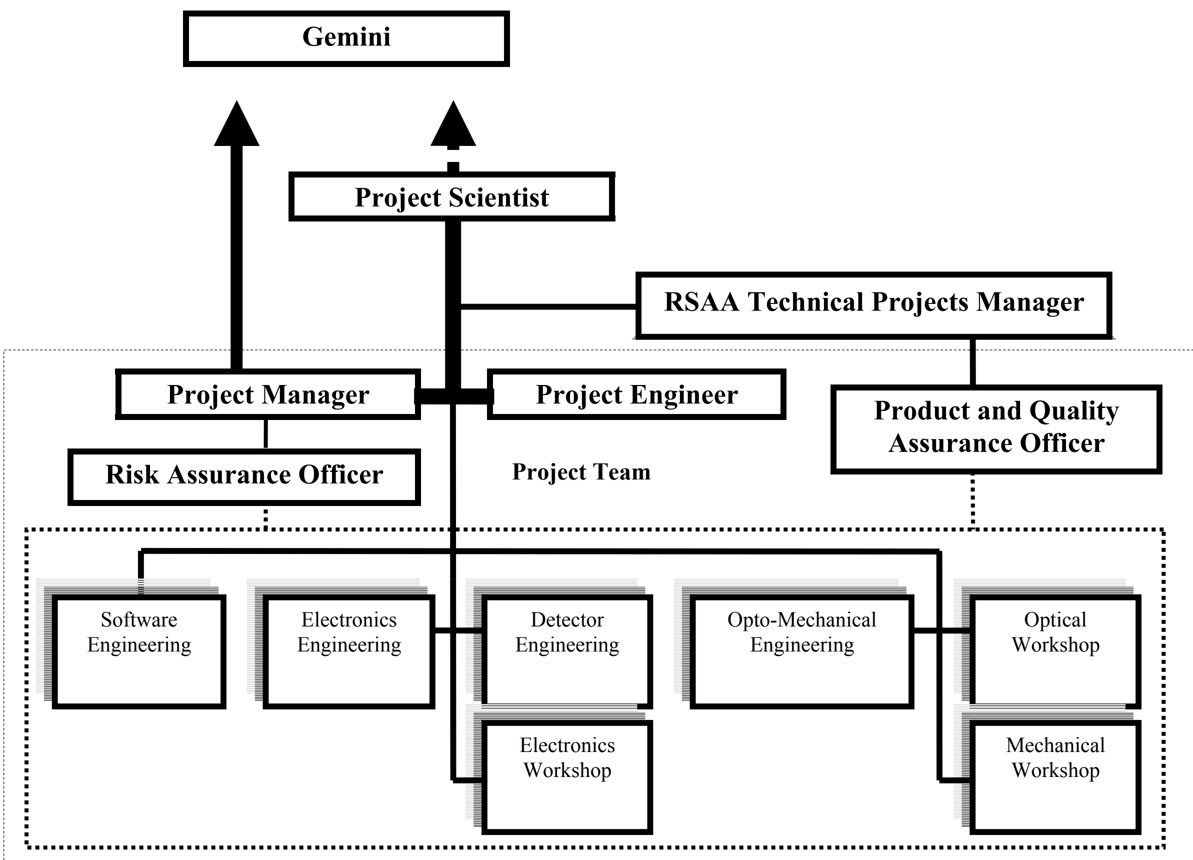


Figure 3: GSAOI project team organizational chart for instrument development.

The RSAA technical sections are led and managed by section heads. In delegating work, staff are assigned tasks with full responsibility for carrying out that task, within the budgetary constraints imposed by the Project Manager. When delegating responsibilities for tasks, staff are also delegated enough authority to carry out the tasks, with the means to make decisions, give direction, and call upon resources necessary to fulfil their responsibilities. When such responsibility is delegated, staff are held accountable for achieving results. However, ultimate responsibility and accountability resides with the person doing the delegating. This process is assured through regular meetings in which staff report upward on the status and quality of their performance of the task in question.

In accordance with standard RSAA procedure, staff members report their time use to their given Section Heads, who pass this to the Project Manager for tracking of resource allocations. Any proposed capital expenditure on a project has to be approved by the Project Manager to control and track costs. The Project Manager also reports to the Technical Projects Manager who assumes responsibility for coordinating all RSAA instrument development activity. These reports provide the basis for submission of regular progress reports to the IC.

The GSAOI Project Scientist, Project Manager, and Project Engineer will meet monthly with the RSAA Director, Associate Director for Instrumentation, Business Manager, and Technical Projects Manager to report on technical, schedule, and budget aspects of the project status.

Formal design reviews shall be conducted for the GSAOI project as a Gemini requirement. Project progress meetings shall be regularly used to informally review designs as they progress. At critical points in the design cycle, designs shall be checked by peers or supervisors. Testing during the integration, test, and commissioning phases of the GSAOI project shall be thorough, formalised, and fully documented.

3.4 RSAA Capabilities and Facilities

General Experience	• Instrument and telescope design and construction. • Controlling low noise CCD and IR area detectors. • Optical, mechanical, and electrical procurement, nationally and internationally. • Support for most astronomical software and common PC and Mac applications. • Project management of technical projects.
Opto-Mechanical Design Office	• PC-based CAD systems. • Instrument design software, including AutoCAD 2000, Zemax, and OptiCAD. • Long experience in design of instrumentation used by RSAA.
Mechanical Workshop	• 2 CNC computer control mills with full range of tools; software to import CAD drawings. • Full range of manual lathes and mills. • Full welding capability for MIG/TIG for fabricating structures. • Access to ANU campus EDM machines and CNC lathes and mills. • Clean room facilities. • High vacuum instrumentation; access to leak detection apparatus.
Clean Room Facility	• Class 100k according to FED STD 201. • Laminar flow bench and tent Class 100 AS3.5. • 26 m^2 floor area.

Electronics Design	• Design of low noise electronics. • Design of complex logic circuits. • Design of computer interfaces and real time control systems. • Printed circuit board layout for through-hole and surface mount components. • PROTEL CAD systems: schematic capture, simulation, PCB layout.
Electronics Workshop	• ESD trained staff, construction to MIL-STD2000. • Faraday room facility. • Design of surface mount multi-layer (up to 8 layers) circuit boards. • Capability for small scale surface mount technology circuit board assembly. • Construction and wiring for cryogenic applications. • Software control of instruments and telescopes. • Experience using latest AutoCAD, Protel, and CUPL software. • High speed analog and digital oscilloscopes. • 96 channel 200 MHz Philips logic analyzer. • High accuracy computing multimeter. • Advantech LOGICTOOL-48 logic programmer capable of programming the SDSU-2 EPROMs and PLDs.
Detector Laboratory	• 32.6 m^2 floor area. • Optical rail with accessories. • Vibration isolation table with accessories. • Laboratory lasers, lens suite, electronic camera, and control computer. • Lumogen coating plant. • Vacuum pumps and pressure gauges.
Optical Workshop	• One-off or prototype work a speciality. • Optical design and evaluation, close relationship with world expert Australian optics designer. • Spherical optics up to 400 mm, experienced in aspherics. • Large range of materials: optical glasses, fused silica, crystals, semiconductors, and metals. • Design and manufacture of standard colored glass filters for astronomical use. • Optical thin film coatings can be arranged through expert Australian subcontractors. • In-house aluminum coatings for front surface mirrors up to 1.8 m. • FIZEAN interferometer. • Suite of test spheres. • Zemax software.
Computer Section	• Expertise in implementing and using major astronomical applications, including Image Reduction Analysis Facility (IRAF), Interactive Data Language (IDL), and Astronomical Image Processing System (AIPS). • System-level support of Unix/Solaris (Sparc,X86), IBM-compatible PC/Win95/NT, and Apple Macintosh platforms. • Programming expertise with C, C++, Fortran, Pascal, Java, Perl, and Tcl languages. • Software design and implementation for major instruments, including CICADA, WFI, and NIFS.

3.5 Parent Organisation, The Australian National University

The Australian National University was established in 1946 by the Commonwealth Government as Australia's only completely research-oriented university, without undergraduate faculties, to undertake "postgraduate research and study, both generally and in relation to subjects of national importance to Australia". From the beginning, the University was seen as an institution that would strengthen Australia's research effort by pursuing research at the highest levels. This unique character was modified in 1960 when teaching faculties were added through amalgamation with the Canberra University College. The result was a university with two parts: the Institute of Advanced Studies, comprising the research schools with research and graduate training responsibilities, and the School of General Studies (now known as The Faculties) comprising faculties with undergraduate and graduate teaching and research responsibilities. The Institute of the Arts became a part of the University in 1992, adding yet another dimension to its structure. Figure 4 shows this structure.

The Institute of Advanced Studies consists of ten Research Schools; the Research School of Astronomy and Astrophysics, the Research School of Biological Sciences, the Research School of Chemistry, the Research School of Earth Sciences, the Research School of Information Sciences and Engineering, The John Curtin School of Medical Research, the Research School of Pacific and Asian Studies, the Research School of Physical Sciences and Engineering, the Research School of Social Sciences, and the Centre for Resource and Environmental Studies. The School of Mathematical Sciences is operated jointly with The Faculties. Several features contribute to the Institute's distinctive place in the Australian research system. It is funded through a block grant and through access to Australian Research Council (ARC) competitive funds. Its staff undertake full-time research and research training. It attracts a wide range of researchers from Australia and overseas, and it provides in one location a range of outstanding research facilities. The combination of these features offers special opportunities for research and research training. The Institute of Advanced Studies is involved in nine government-funded Cooperative Research Centres in the fields of robust and adaptive systems, plant sciences, optics, the control of vertebrate pest populations, advanced computational systems, research data networks, tropical savannahs, water quality and regolith studies.

The Faculties comprises six faculties (Arts, Asian Studies, Economics and Commerce, Engineering and Information Technology, Law, and Science) and the Institute of the Arts. Each faculty is concerned with the instruction of students for the degrees of bachelor and master, and with research and the supervision of candidates for doctoral degrees.

The Australian National University currently hosts six centers (the Asia Pacific School of Economics and Management, the Centre for Cross-Cultural Research, the Humanities Research Centre, the National Centre for Epidemiology and Population Health, the NHMRC Psychiatric Epidemiology Research Centre, and the Centre for Aboriginal Economic Policy Research).

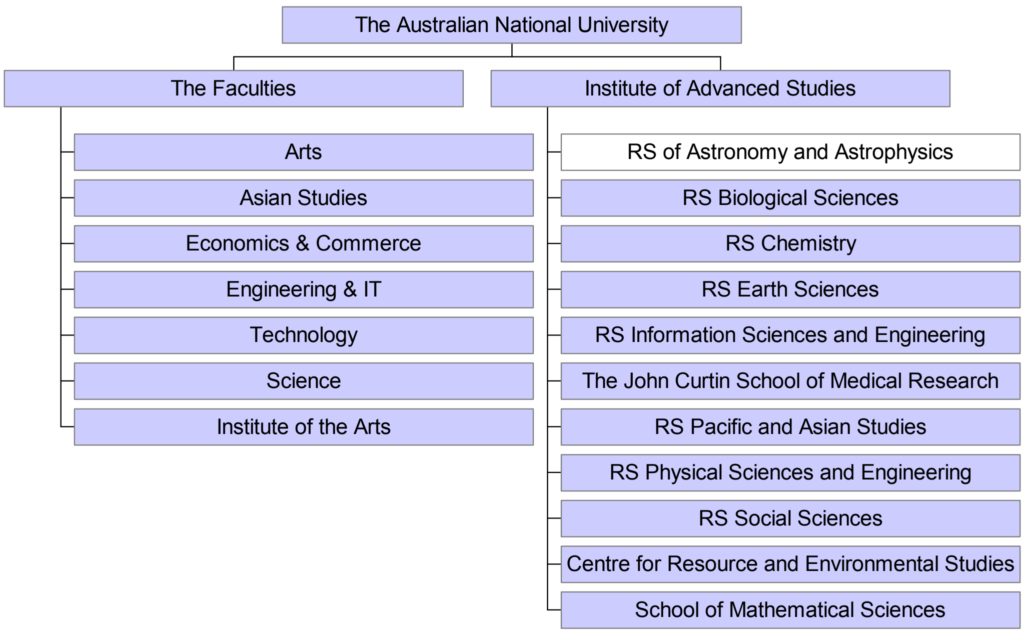


Figure 4: Structure of the Australian National University.

3.5.1 Financial Capability

The Australian National University is funded from three principal sources: Commonwealth Government grants; income generated competitively from public and private sources for research and teaching; and from full-fee paying students. The University's Commonwealth Government operating grant is provided a) to support the teaching and research responsibilities of The Faculties on the same basis as other Australian universities; b) as block funding to support the special national and international roles of the Institute of Advanced Studies in research and research training; and c) for capital works and equipment. From 2002, the ANU will receive part of its funding from competitive Australian Research Council (ARC) grants, in return for a reduction of block funding. The University's budget is prepared on a rolling triennial basis, reflecting the way in which the Commonwealth Government's operating grant is provided to the University.

3.5.1.1.1 Resources and Budget

In 2001, total ANU revenues from ordinary activities were $479,818 million excluding ANUTECH (ANU Commercial Arm) and $513,425 million including ANUTECH. Total operating expenses from ordinary activities were $421,911 million excluding ANUTECH and $443,625 including ANUTECH. The $64 million difference between revenues and operating costs reflects non-cash components such as depreciation and accruals, the increase from initial land valuations and funding for capital acquisitions, plant and equipment.

Total University assets have been calculated at about $1.5 billion with liabilities held against them of $0.5 billion. The balance is reflected in equity. Cash reserves fell by $42 million to $115 million. This fall partially reflected a major capital building program.

Table 1: ANU Operating Revenue for the Year Ending 31 December 2001

(ANU Annual Report 2001, http//www.anu.edu.au/pad/pubs/)

Operating Revenues	**Consolidated ($'000)**		**University ($'000)**	
	2001	**2000**	**2001**	**2000**
Commonwealth Government Grants	275,274	256,684	275,274	256,726
Higher Education Contribution Scheme	24,778	23,588	24,778	23,588
State Government Grants	882	971	882	971
Fees and Charges	23,130	21,051	23,130	17,543
Interest	33,409	23,316	21,784	23,312
Dividends	16,799	17,949	16,799	17,949
Other Investment Revenue	10,650	24,921	10,650	10,580
Consultancy and Contract Research	50,098	38,325	30,595	24,927
Sales of Goods and Services	22,535	25,119	22,401	20,951
Gain on Disposal of Assets	544	1,169	526	1,169
Other Revenue	23,249	17,694	20,922	19,065
Increase from Initial Land Valuation*	32,077		32,077	
Total Revenues	**513,425**	**450,787**	**479,818**	**416,781**

*The University has valued its major holdings of land that are occupied on Perpetual Lease. The first valuation, which is not a cash inflow, is required by Accounting Standards to be shown in this statement.

4 Work Breakdown Structure

The Work Breakdown Structure (WBS) chart in Figure 5 shows the first two levels of the WBS for the project. The detailed Gantt chart in Annex 1 shows the WBS to the lowest level, while the full breakdown with the costs associated with each line item is shown in Vol. 4, Appendix B, of this four-volume CoDR document set.

4.1 Costing

For reasons of confidentiality, GSAOI costing details have been reserved for Volume 4 of this 4 volume document set. Cost estimates cover all materials, equipment and services, and salaries and benefits budgeted for the construction of GSAOI. It also includes workplace overhead where applicable. A full cost spreadsheet (BOM) has been completed using Microsoft Excel. The costs have been estimated at the lowest practicable WBS level where sufficient detail exists to provide reliable cost estimates and risk-based contingency analyses.

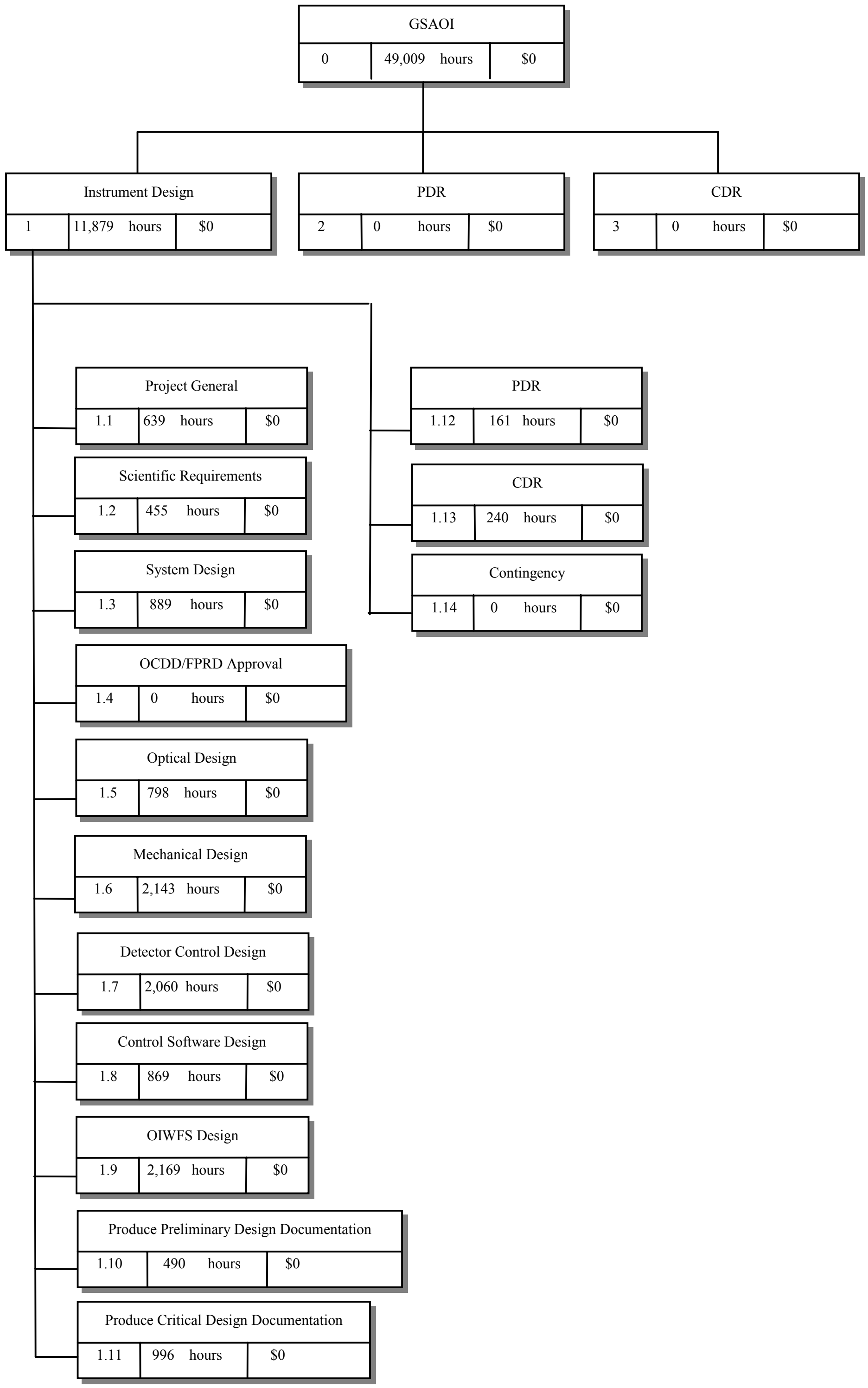
4.2 GSAOI Critical Design Study

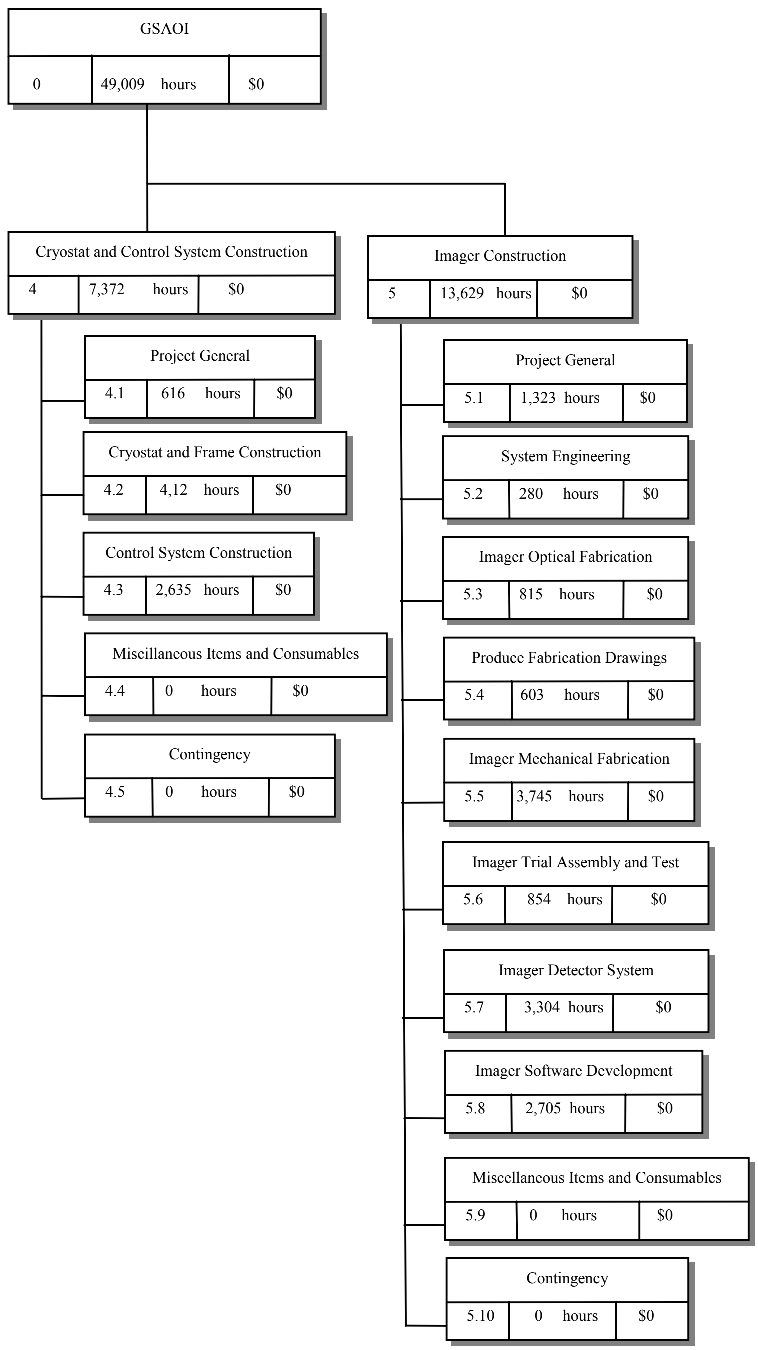
During the GSAOI Critical Design Study, the optical design is to be finalized, the mechanical design is to be progressed through to the completion of models from which manufacturing drawings can be produced, the detector system is to be designed in full detail, and the overall software system design is to be completed.

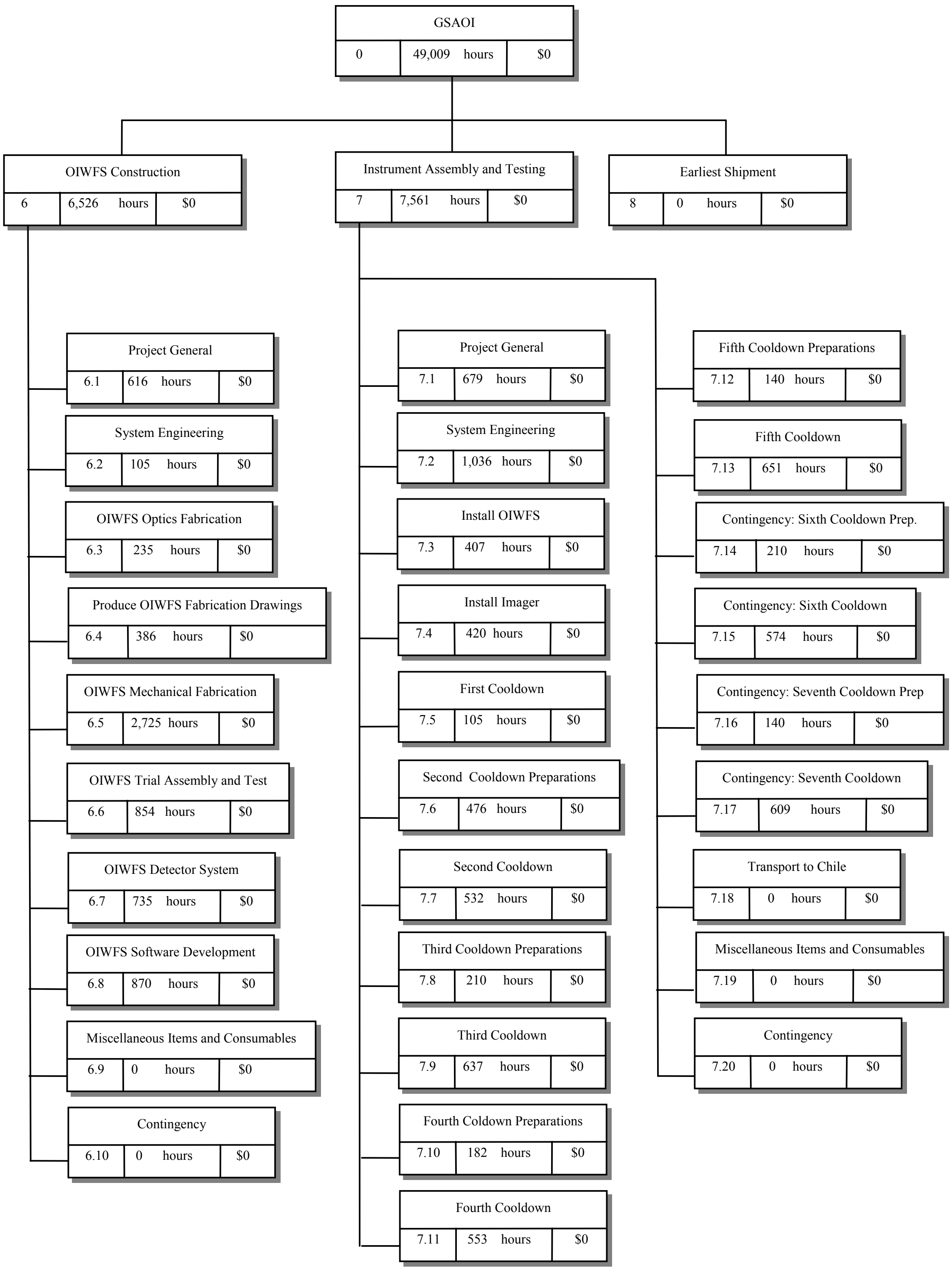
This project phase ends with the Critical Design Review and includes a mini-Preliminary Design Review halfway through. At the Preliminary Design Review (PDR) only the following issues will be addressed:

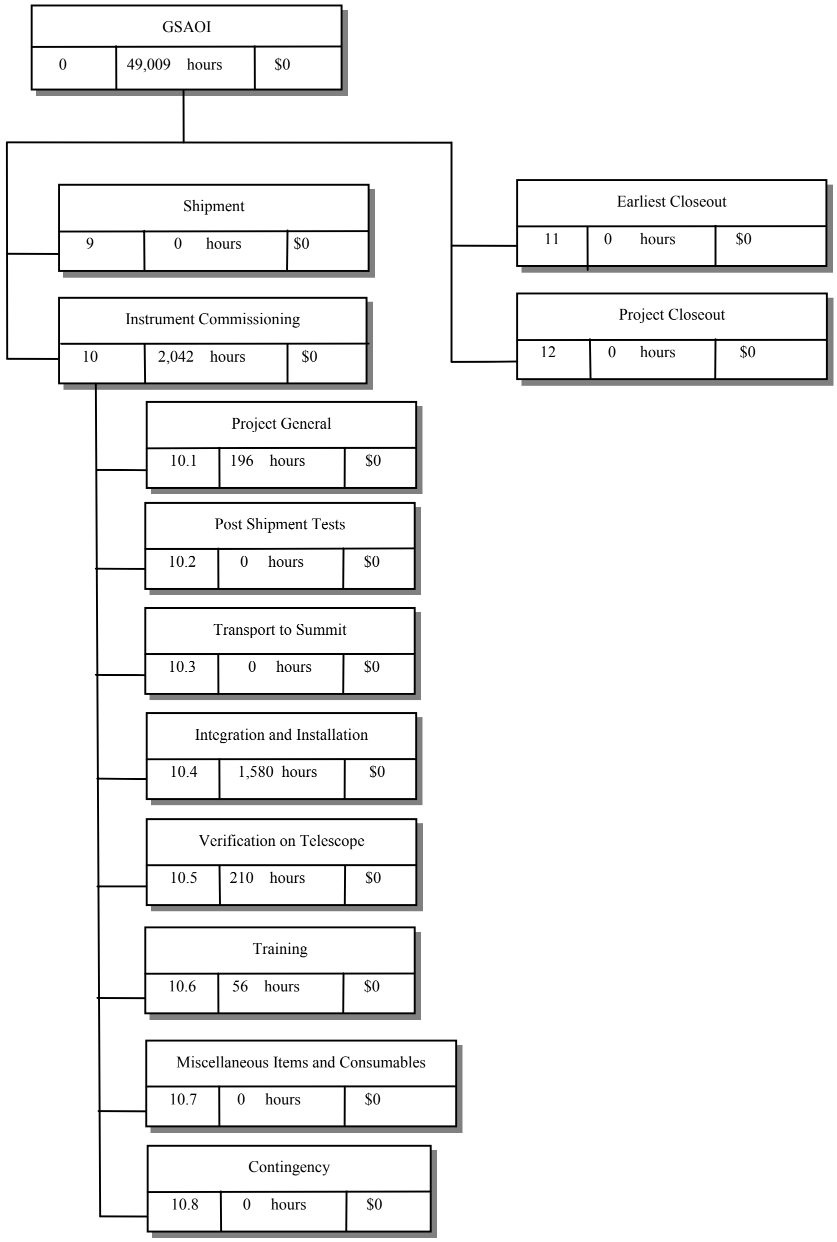
- Developments in the optical design.
- Developments in the detector design.
- The detector controller choice: SDSU or ASIC.

Figure 4: GSAOI Work Breakdown Structure




GSAOI
0 49,009 hours $0
Cryostat and Control System Construction
4 7,372 hours $0
Project General
4.1 616 hours $0
Cryostat and Frame Construction
4.2 4,12 hours $0
Control System Construction
4.3 2,635 hours $0
Miscellaneous Items and Consumables
4.4 0 hours $0
Contingency
4.5 0 hours $0
Imager Construction
5 13,629 hours $0
Project General
5.1 1,323 hours $0
System Engineering
5.2 280 hours $0
Imager Optical Fabrication
5.3 815 hours $0
Produce Fabrication Drawings
5.4 603 hours $0
Imager Mechanical Fabrication
5.5 3,745 hours $0
Imager Trial Assembly and Test
5.6 854 hours $0
Imager Detector System
5.7 3,304 hours $0
Imager Software Development
5.8 2,705 hours $0
Miscellaneous Items and Consumables
5.9 0 hours $0
Contingency
5.10 0 hours $0


GSAOI
0 49,009 hours $0
OIWFS Construction
6 6,526 hours $0
Instrument Assembly and Testing
7 7,561 hours $0
Earliest Shipment
8 0 hours $0
Project General
6.1 616 hours $0
System Engineering
6.2 105 hours $0
OIWFS Optics Fabrication
6.3 235 hours $0
Produce OIWFS Fabrication Drawings
6.4 386 hours $0
OIWFS Mechanical Fabrication
6.5 2,725 hours $0
OIWFS Trial Assembly and Test
6.6 854 hours $0
OIWFS Detector System
6.7 735 hours $0
OIWFS Software Development
6.8 870 hours $0
Miscellaneous Items and Consumables
6.9 0 hours $0
Contingency
6.10 0 hours $0
Project General
7.1 679 hours $0
System Engineering
7.2 1,036 hours $0
Install OIWFS
7.3 407 hours $0
Install Imager
7.4 420 hours $0
First Cooldown
7.5 105 hours $0
Second Cooldown Preparations
7.6 476 hours $0
Second Cooldown
7.7 532 hours $0
Third Cooldown Preparations
7.8 210 hours $0
Third Cooldown
7.9 637 hours $0
Fourth Coldown Preparations
7.10 182 hours $0
Fourth Cooldown
7.11 553 hours $0
Fifth Cooldown Preparations
7.12 140 hours $0
Fifth Cooldown
7.13 651 hours $0
Contingency: Sixth Cooldown Prep.
7.14 210 hours $0
Contingency: Sixth Cooldown
7.15 574 hours $0
Contingency: Seventh Cooldown Prep
7.16 140 hours $0
Contingency: Seventh Cooldown
7.17 609 hours $0
Transport to Chile
7.18 0 hours $0
Miscellaneous Items and Consumables
7.19 0 hours $0
Contingency
7.20 0 hours $0


GSAOI
0 49,009 hours $0
Shipment
9 0 hours $0
Instrument Commissioning
10 2,042 hours $0
Earliest Closeout
11 0 hours $0
Project Closeout
12 0 hours $0
Project General
10.1 196 hours $0
Post Shipment Tests
10.2 0 hours $0
Transport to Summit
10.3 0 hours $0
Integration and Installation
10.4 1,580 hours $0
Verification on Telescope
10.5 210 hours $0
Training
10.6 56 hours $0
Miscellaneous Items and Consumables
10.7 0 hours $0
Contingency
10.8 0 hours $0

Any optical design issues still outstanding at the Conceptual Design Review need to be addressed. The manufacturing details of all optical components need to be specified. The optical blanks for in-house fabrication have to be ordered and contracts let for the supply of filters.

In the area of mechanical design, full assembly drawings of the imager are to be produced. These, together with information from NIFS will be used for flexure analysis. We are planning a short and intensive fabrication phase, and it would be advantageous to start fabrication of some components early to reduce the risk of fabrication delays due to unexpected variations in workshop staff availability and the potential impact of other workloads. We would identify components for early fabrication taking into account the least impact of possible design changes in the latter part of the Critical Design Study or at the CDR.

The design of the OIWFS system will be completed to the same level as that of the imager. Decisions will have to be made on which items will be fabricated in-house. The blanks for in-house fabrication have to be ordered and contracts let for the supply of the remaining lenses and mirrors.

The baseline design for the detector system uses the SDSU controller. The ASIC solution will be investigated further and a final choice will be presented at PDR. The detector controller, either in SDSU or ASIC form, is a long lead-time item that should be ordered as soon as possible after PDR. The operation of the controller will have to be fully verified upon delivery. The wiring from the controller to the detector has to be fully detailed with circuit diagrams showing all signals, connectors, and printed circuit boards. The test cryostat wiring has to be designed and manufactured. The DSP code for the detector controller needs to be designed

The overall software system design should be finalized and the GSAOI Component Controller software should be ready for testing. The Detector Controller software design should be completed and coding should be under way for the detector engineering software.

Other items to be delivered are final ICDs, tables of contents for all manuals, a draft Spares List, the Acceptance Test Plan, the Integration and Test Plan, the Verification and Commissioning Plan, and the Safety Review.

4.3 Cryostat and Control System Manufacture

Commencing immediately at the start of the project, the following NIFS items will be duplicated, except for some relatively minor changes, namely

- Integration frame;
- ISS interface plate;
- Cryostat;
- Cooling system; and
- Instrument control system.

With the recent NIFS experience and the NIFS hardware still at RSAA for comparison, this work can be undertaken with great efficiency.

After assembly, parts of the control software and the instrument control system will be tested during a cool down of the empty cryostat.

4.4 Imager Construction

Optical manufacture, both in-house and subcontracted, will commence following the Preliminary Design Review.

After the Critical Design Review, fabrication drawings for the mechanical construction work will be produced and fed into the workshop as drawings become available. As soon as practicable, trial assembly of modules will start while further fabrication takes place. Optical alignment procedures can be tested and the control system can be used to check mechanism operation under full software control.

The test focal plane will be assembled, the detector controller made operational, and the engineering detector will be installed in the test cryostat. After verification of its operation it will be transferred to the GSAOI cryostat for assembly tests, while the final focal plane with the science detector is tested and optimised in the test cryostat.

The engineering detector control software, based on the NIFS version of the RSAA CICADA system, will be completed in time for testing of the engineering detector system. The full detector control software needs to be completed before the detector systems are integrated in the GSAOI cryostat. The NIFS Component Controller and Instrument Sequencer software will be finalized and tested.

The user and maintenance manuals will be prepared.

4.5 OIWFS Construction

Optical materials for the OIWFS and other optical elements as identified are to be ordered after PDR so fabrication work can start on their arrival.

After the Critical Design Review, fabrication drawings for the mechanical construction work will be produced and fed into the workshop as they become available. As soon as practicable, trial assembly of modules will start while further fabrication takes place.

The OIWFS detector system is a straight copy of that of NIRI and NIFS. It will be assembled and only undergo warm testing before installation in the GSAOI cryostat.

The OIWFS software development includes new control software for the beam steering mirror mechanism and testing of the mechanism control.

4.6 Instrument Assembly and Test

A trial assembly of the imager will take place first on a dummy cold work surface plate. Following rectification of any problems found, the imager can be integrated into the cryostat. The assembly and test phase comprises five cool downs with an extra two as contingency. There is little NIFS experience for this phase, as it has only just had its first cool down.

The aims of the cool downs are as follows:

- Cool down 1: cold testing of mechanisms;
- Cool down 2: optics and detector systems installed, basic testing and focus measurements;
- Cool down 3: focus adjustments, alignment adjustments, further optical testing, flexure testing;
- Contingency 1: repeat cool down 3 until optical performance is satisfactory;
- Cool down 4: science detector installed, detector optimization;
- Contingency 2: repeat cool down 4 until detector performance is satisfactory; and
- Cool down 5: final verification and pre-shipment acceptance tests.

At the end of this phase, GSAOI will be packed and transported to the Gemini facility in Chile.

Note: the project plan places the contingency cool downs after the fifth cool down to determine the earliest possible shipment date if contingency cool downs are not required.

4.7 Instrument Commissioning

After transportation to the Gemini base facility in Chile, key acceptance tests will be repeated to check for transport damage. GSAOI is transported to the summit and connected to the various interfaces to integrate it with the observatory systems. It will then be prepared for commissioning on the telescope.

Training for Gemini operations and maintenance staff will be provided, the manuals will be updated and the record documents will be finalized.

The GSAOI commissioning phase is based on the NIFS Integration and Test Plan and Verification and Commissioning Plan as recently submitted to Gemini.

5 Schedule

A comprehensive schedule of work to design, construct, assemble, test, and commission GSAOI has been developed and will be monitored by the GSAOI Project Manager to facilitate management of the project. It comprises detailed schedules for the development of each work package and includes the resources required for each step. Based on these details, an overview of GSAOI will be maintained, complete with cost and manpower needs as a function of time and with milestones.

A detailed schedule that depicts the fabrication of each GSAOI subsystem and their ultimate installation and commissioning has been assembled in Microsoft Project. This detailed schedule depicts the completion of deliverables within each work package. It is built of tasks that are linked to describe work flow and interdependencies. An overview of the schedule for the GSAOI development is depicted in Figure 6. A fully detailed Gantt chart appears in Annex 1 of this document.

The work on the completion of NIFS has a major impact on the availability of resources for GSAOI. The schedule presented here takes this into account. Details on how RSAA intends to ensure a smooth transition of resource allocation from NIFS to GSAOI are discussed in §6.1.

5.1 Milestones

The proposed milestones for this project are shown in Table 2 below.

Table 2: GSAOI Milestones

Milestone	Milestone Description	Date
1	Start of work	16 Sep 2002
2	Preliminary Design Review	15 Apr 2003
3	Critical Design Review	30 Sep 2003
4	Empty Cryostat Reaches Operating Temperature	14 Jun 2004
5	Start of First Cool Down (mechanisms)	23 Feb 2005
6	Start of Second Cool Down (optics and detectors)	20 May 2005
7	Instrument Shipment	10 Mar-2006- 25 Aug 2006
8	Project Closeout	20 Mar 2007

5.2 Critical Design Study

The Critical Design Study will take twelve months and concludes with the Critical Design Review in September 2003. The date of the review is driven by the work to be done and the availability of suitably qualified and experienced staff to do it.

A mini-Preliminary Design Review is proposed halfway though the design phase in April 2002.

5.3 Cryostat and Control System Manufacture

The construction work on the cryostat, integration frame, and instrument control system will commence immediately at the start of the project. Fabrication will be completed in November 2003. Assembly will culminate in an empty cryostat cool down in June 2004.

ID	WBS	Task Name	Work
0	0	Gemini South Adaptive Optics Imager	49,009 hrs
1	1	Instrument Design	11,879 hrs
2	1.1	Project General	639 hrs
8	1.2	Scientific Requirements	455 hrs
13	1.3	System Design	889 hrs
25	1.4	OCDD/FPRD Approval	0 hrs
26	1.5	Optical Design	798 hrs
40	1.6	Mechanical Design	2,143 hrs
60	1.7	Detector Control Design	2,060 hrs
85	1.8	Control Software Design	869 hrs
96	1.9	OIWFS Design	2,169 hrs
126	1.10	Produce Preliminary Design Documentatic	490 hrs
127	1.11	Produce Critical Design Documentation	966 hrs
128	1.12	PDR	161 hrs
129	1.13	CDR	240 hrs
130	1.14	Contingency	0 hrs
131	2	PDR	0 hrs
132	3	CDR	0 hrs
133	4	Cryostat & Control System Construction	7,372 hrs
134	4.1	Project General	616 hrs
138	4.2	Cryostat and Frame Construction	4,121 hrs
171	4.3	Control System Construction	2,635 hrs
191	4.4	Miscellaneous Items & Consumables	0 hrs
192	4.5	Contingency	0 hrs
193	5	Imager Construction	13,629 hrs
194	5.1	Project General	1,323 hrs
201	5.2	System Engineering	280 hrs
204	5.3	Imager Optical Fabrication	815 hrs
231	5.4	Produce Fabrication Drawings	603 hrs
250	5.5	Imager Mechanical Fabrication	3,745 hrs
269	5.6	Imager Trial Assembly & Test	854 hrs
278	5.7	Imager Detector System	3,304 hrs
322	5.8	Imager Software Development	2,705 hrs
331	5.9	Miscellaneous Items & Consumables	0 hrs
332	5.10	Contingency	0 hrs
333	6	OIWFS Construction	6,526 hrs
334	6.1	Project General	616 hrs
338	6.2	System Engineering	105 hrs
340	6.3	OIWFS Optics Fabrication	235 hrs
361	6.4	Produce OIWFS Fabrication Drawings	386 hrs
377	6.5	OIWFS Mechanical Fabrication	2,725 hrs
394	6.6	OIWFS Trial Assembly & Test	854 hrs
403	6.7	OIWFS Detector System	735 hrs
409	6.8	OIWFS Software Development	870 hrs
414	6.9	Miscellaneous Items & Consumables	0 hrs
415	6.10	Contingency	0 hrs
416	7	Instrument Assembly and Testing	7,561 hrs
417	7.1	Project General	679 hrs
422	7.2	System Engineering	1,036 hrs
427	7.3	Install OIWFS	407 hrs
434	7.4	Install Imager	420 hrs
441	7.5	First Cooldown	105 hrs
448	7.6	Second Cooldown Preparations	476 hrs
456	7.7	Second Cooldown	532 hrs
467	7.8	Third Cooldown Preparations	210 hrs
471	7.9	Third Cooldown	637 hrs
483	7.10	Fourth Cooldown Preparations	182 hrs
486	7.11	Fourth Cooldown	553 hrs
498	7.12	Fifth Cooldown Preparations	140 hrs
500	7.13	Fifth Cooldown	651 hrs
509	7.14	Contingency: Sixth Cooldown Preparat	210 hrs
513	7.15	Contingency: Sixth Cooldown	574 hrs
524	7.16	Contingency: Seventh Cooldown Prepa	140 hrs
526	7.17	Contingency: Seventh Cooldown	609 hrs
537	7.18	Transport to Chile	0 hrs
538	7.19	Miscellaneous Items & Consumables	0 hrs
539	7.20	Contingency	0 hrs
540	8	Earliest Shipment	0 hrs
541	9	Shipment	0 hrs
542	10	Instrument Commissioning	2,042 hrs
543	10.1	Project General	196 hrs
548	10.2	Post-shipment Tests	0 hrs
549	10.3	Transport to Summit	0 hrs
550	10.4	Integration and Installation	1,580 hrs
551	10.5	Verification on Telescope	210 hrs
552	10.6	Training	56 hrs
553	10.7	Miscellaneous Items & Consumables	0 hrs
554	10.8	Contingency	0 hrs
555	11	Earliest Closeout	0 hrs
556	12	Project Closeout	0 hrs

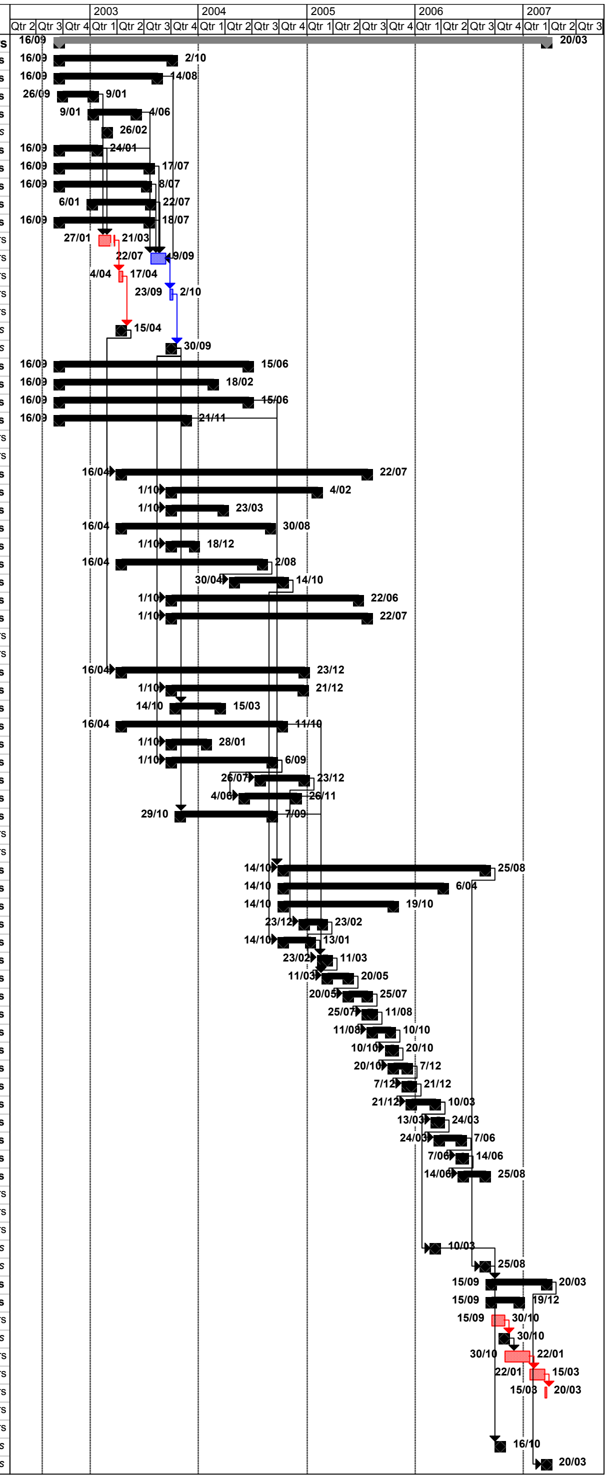


Figure 4: GSAOI Schedule

5.4 Test Cryostat Manufacture

The manufacture of a test cryostat large enough for testing the GSAOI focal plane assembly is not shown on the GSAOI plan, as it is part of RSAA infrastructure improvements to be executed at RSAA's expense.

RSAA is currently investigating some existing designs to reduce the design effort required. Construction can then be undertaken during the GSAOI design phase.

5.5 Imager and OIWFS Manufacture

The manufacture of mechanical parts for the imager and OIWFS will commence as soon as fabrication drawings are being produced after CDR. It is envisaged to have up to six instrument makers working on GSAOI for this period. This is the full complement of workshop staff and, depending on progress and other workload, some work may be outsourced to local machine shops to ease the load. The fabrication work must be completed by August 2004 for the imager and September 2004 for the OIWFS. Trial assembly for these systems will take to October and November 2004, respectively.

The fabrication of all optical elements for both the imager and OIWFS could not be accommodated within the available time in the optical workshop. The fabrication of a selection of elements will be outsourced to take optical manufacture off the critical path. In addition, it will be necessary to order optical materials after PDR to gain time. The optics need to be completed part way through the trial assembly of the mechanical systems, in August and October 2004.

Detector construction work will start after CDR and lead to testing of the detector multiplexer and then the engineering detector in the test cryostat. A working engineering detector system needs to be available for the second cool down starting in May 2005. The science grade detector will be tested in the test cryostat until it is integrated in the GSAOI cryostat in October 2005.

The detector control software effort is phased so that test software will be available in time for testing the detector multiplexer in early 2004, and the final software will be ready for the scool downs. The Components Controller software, as it only represents a minor change from NIFS, should be ready for testing with the mechanisms as they are being assembled.

5.6 Instrument Integration and Test

The installation of the imager and OIWFS in the cryostat plus five cool down, test, warm up, and problem-fixing cycles are expected to take up to fourteen months. As contingencies, two more cool downs are budgeted and scheduled. These add another five months.

A final (seventh) cool down cycle is planned to accommodate pre-delivery acceptance tests. On successful conclusion of these tests, GSAOI will be warmed up, packed, and transported to the Gemini base facility in Chile.

5.7 Instrument Commissioning

Commissioning will start by repeating a number of acceptance tests to check for transport damage. The instrument will then be transported to the summit and integrated into the observatory systems. Two months will elapse from arrival in Chile to being ready for the first night on the telescope. GSAOI will be tested, commissioned, and verified under varying observing conditions during the commissioning nights, and any problems will be rectified. Gemini staff will be trained in the operation and maintenance of the instrument. The commissioning time will depend on the time made available and on the nature and seriousness of any problems encountered.

5.8 Schedule Risks

This section highlights the schedule risks and the actions taken to reduce them.

Table 3: GSAOI Schedule Risk Mitigation Strategy

Item	Area of Concern	Risk Level	Risk Mitigation Plan
1	NIFS	Medium	• Lead designer for NIFS Assembly and Test is not involved in GSAOI. • Delay NIFS commissioning until after GSAOI CDR.
2	Design Staffing	Medium	• Recruit additional designer immediately.
3	Optical Materials Delivery	High	• Order early.
4	Detector Delivery	High	• Order early.
5	Focal Plane Delivery	High	• Order early.
6	Detector Controller Delivery	Medium	• Order early.
7	Detector Development	Medium	• Ensure adequate staffing and support. Build test cryostat.

6 Resourcing

The RSAA Instrument Committee has declared GSAOI to be the highest priority for the engineering sections next to NIFS. Nevertheless, experience at RSAA indicates that inadequate resourcing is the greatest risk to a project schedule, together with late delivery of major externally-sourced items.

To cope with demands on the engineering sections, RSAA staffing is regularly reviewed. Two new mechanical designers and a second member of the Optical Workshop staff were recently appointed. Part-time and short-term appointments are regularly made in the Computing Section to perform on-going system administration and maintenance duties, thus freeing up permanent staff to undertake project work. RSAA has recruited a second detector engineer to ease the work load in this area. A new appointment has been made to the position of RSAA Technical Projects Manager. The transfer of the management duties of the technical sections to this new position frees up the NIFS Project Manager to also undertake the project management for GSAOI.

The GSAOI plan requires the effort of two more mechanical designers. RSAA will appoint one more designer as this fits in with its long-term strategy. The other designer will be contracted from Auspace, a local aerospace company, for a limited period. This arrangement worked well during the NIFS Critical Design Study.

a simplified version of the GSAOI project organizational hierarchy is shown in Figure 7, whilst a more detailed representation is deferred to Figure 10. The development effort for GSAOI is led by the Project Scientist (Peter McGregor) who is responsible for the establishing the science mission and scientific requirements for the instrument and eventually for ensuring that the instrument will meet these criteria. The Project Engineer (John Hart) is responsible for the development of a suitable design and implementation of that design to build an instrument, which meets the scientific requirements. The Project Manager (Jan van Harmelen) has responsibility for the development of a budget and a schedule for the project and then for the completion of the instrument within the constraints of this budget and schedule, at the same time maintaining quality standards.

Such a triple headed approach is considered appropriate for a project of this complexity and cost. All three key project personnel hold senior continuing appointments in RSAA and have the skills and experience in a multi-disciplinary approach to telescope and instrument development necessary for the success of this project. They have worked with each other on various RSAA projects as well as NIFS over a long period of time.

Information about the team members can be found in §10.3.

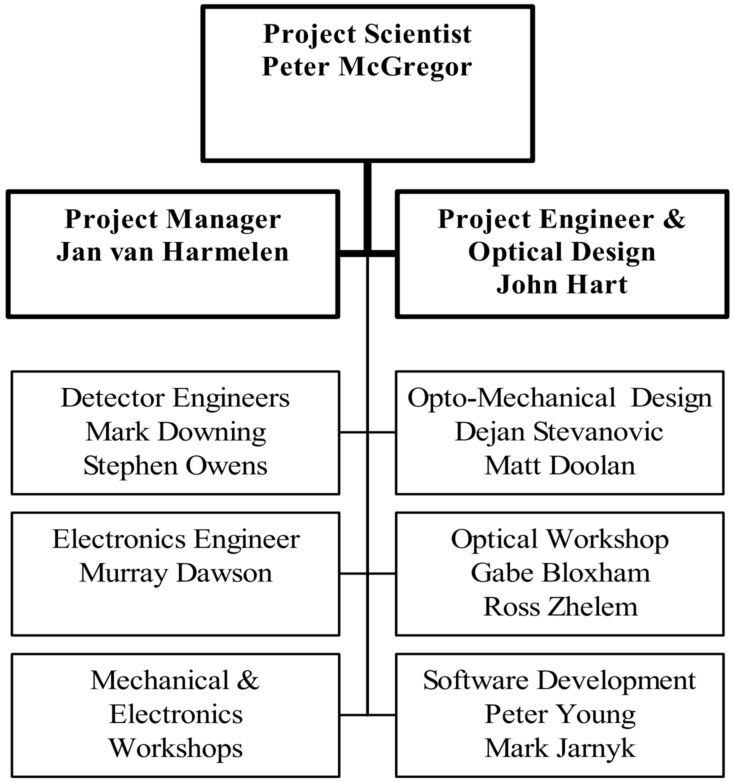


Figure 7: GSAOI project organization chart.

6.1 GSAOI and NIFS

A major consideration for the resourcing of the GSAOI work is the remaining work on NIFS. The NIFS assembly and test phase overlaps with most of the GSAOI design study. NIFS commissioning necessitates that key personnel spend considerable time in Hawaii. This was scheduled to take place in the period leading up to the GSAOI CDR.

The following steps have been taken to ensure that NIFS assembly and test and GSAOI design can both progress as required during the overlap period.

- Peter Conroy, opto-mechanical designer, will lead the NIFS assembly and test effort. He has not been scheduled to work on GSAOI.
- There is sufficient workshop capacity to support the NIFS assembly, disassembly, and problem solving while the GSAOI cryostat and test cryostat fabrication are in progress.
- Stephen Owens, the new detector engineer, will take over the major part of the remaining NIFS detector development allowing Mark Downing to concentrate on the GSAOI detector system. Owens and Dawson will assist Downing with some aspects of the GSAOI design.
- Completion of the NIFS detector software development is planned by the end of 2002. While testing and bug fixing will take some effort in the first half of 2003, GSAOI detector software development can start.
- The average GSAOI load on other staff members involved in NIFS has deliberately been kept low to allow for their support of NIFS assembly and test as required.
- Restructuring of the management of the RSAA technical sections will allow Van Harmelen to be dedicated to NIFS and GSAOI project management.

To ensure an orderly transition to NIFS commissioning and the preparations for the GSAOI CDR, RSAA proposes to delay the NIFS commissioning until after the GSAOI CDR. This causes a two months delay in the completion of the NIFS project. The alternative, delaying the GSAOI CDR until after NIFS commissioning, carries the risk that any delays with NIFS will also delay GSAOI.

6.2 Design

The Project Engineer (John Hart) will execute most of the system engineering, with assistance from the Project Scientist and Project Manager where required. He is also the main optical designer who can call upon the specialized optical design skills of the Project Scientist and Gabe Bloxham. Also available is Damien Jones of Prime Optics, who is an excellent contract optics designer. Hart is also a mechanical designer. Dejan Stevanovic and Matt Doolan are the other designers at RSAA who are available for the GSAOI design effort. Hart and Bloxham have been associated with RSAA for a long time and have been involved in the design of many of its most successful instruments. Stevanovic and Doolan are relatively new members of the mechanical design team. RSAA can also call on the assistance of designers from Auspace, a local aerospace and engineering firm. To complete the design work on the timescale proposed, one more designer will be appointed at RSAA.

The RSAA Detector Engineer (Mark Downing) will be responsible for all aspects of the GSAOI detector system. Downing is a senior electronics engineer who is the detector engineer for NIFS and designed and implemented the RSAA CASPIR IR detector system and has experience with SDSU controllers in CCD applications. Stephen Owens joined RSAA in September 2001 as a detector engineer and has been involved in the implementation of the NIFS detector system. Mark Menzies, a senior electronics technician with experience in the production of the NIFS detector system, will fabricate the detector electronics system and the OIWFS detector system.

The electronic design aspects of GSAOI are limited to modifications of the NIFS control system. These tasks are allocated to Murray Dawson, the RSAA Chief Electronics Engineer. Technical officers Andre de Gans and Hans Lawatch will undertake manufacture.

The GSAOI software effort will be led by the head of the RSAA Computing Section, Peter Young, who has lead the NIFS software development and developed the CICADA CCD control and observing system and has been involved in the software development for the 2.3m tip-tilt secondary mirror system. He will be assisted by other Computing Section members as required, and by software engineer Mark Jarnyk, who has implemented the NIFS Component Controller software.

6.3 Manufacture

RSAA has an Optical Workshop operated by Gabe Bloxham. He is able to manufacture specialized optical elements. Ross Zhelem is a new staff member assisting Bloxham. A new polishing machine was recently acquired and an interferometer will be added to the test equipment.

The RSAA Mechanical Workshop is staffed by a foreman, six technicians, and an assistant. All are on continuing appointments with the exception of the assistant. The Mechanical Workshop can also accommodate more staff on a contract basis. In recent years, we have been very successful in attracting machinists on short-term appointments and in having parts fabricated by local machine shops. The workshop capacity was recently expanded by the acquisition of a second numerically-controlled milling machine.

The RSAA Electronics Workshop is nominally staffed by three technicians on continuing appointments and there is access to the Siding Spring Observatory Technical Section for assistance if need be. CAD systems for printed circuit board layout are available and detector system and cryostat wiring are routinely produced.

The software design team will also undertake software coding.

6.4 Assembly and Test

The Project Engineer, John Hart, will lead the assembly and test effort. Some of the other designers will also be heavily involved. Later, the Detector Engineer and an electronics technician will become involved. Software testing will involve the whole software team. The Project Scientist will become more involved as testing proceeds. Any other staff may be called upon for problem rectification.

6.5 Commissioning

The Project Scientist, the Detector Engineer, the leading software developer, and one of the opto-mechanical designers make up the core team to support the commissioning of GSAOI. Experience during the preceding integration and test phase may influence the choice of staff to send out.

7 Project Management

7.1 GSAOI Project Management Approach

Project management at RSAA provides a standard product-based approach that embodies proven and established best-practice in project management. This management approach is widely recognised and understood, so providing a common language for all participants in the project. It also provides significant benefits to RSAA and the end user, through the controllable use of resources and the ability to manage project risk more effectively. Tailoring this product-based management approach to GSAOI will ensure that the GSAOI plans are focused on delivering results and are not simply about planning when the various activities on the project will be done.

The GSAOI project has been divided into manageable stages, thereby enabling efficient control of resources and regular progress monitoring throughout the project lifecycle. These stages have been subdivided into processes, each of which has been defined with key inputs and outputs, together with the specific objectives to be achieved and activities to be carried out. To facilitate this activity, the various roles and responsibilities for managing the GSAOI project are fully described and have been tailored to suit both the size and complexity of the GSAOI project, and the skills and expertise of RSAA personnel.

The fundamental approach to management of the GSAOI project will be based on quantitative scheduling and estimation, incorporating appropriate quality control measures. Microsoft Project will be used to develop and monitor schedules and Microsoft Excel spreadsheets will be used to manage costs at the project team level. The Australian National University accounting system will be involved at a higher level. Computer-based tools will be used to improve the efficiency of communication.

As demonstrated by NIFS, benefits of the RSAA Management Plan for GSAOI will include the following:

- A controlled and organised start, middle, and end;
- Regular reviews of progress against the plan and budget;
- Flexible decision points;
- Automatic management control of any deviations from the plan;
- The involvement of GSAOI management and Gemini at the right times and places during the project lifecycle; and
- Good communication channels between the project, project management, and Gemini.

Throughout the GSAOI project lifecycle, the team will abide by the Quality Management Principle: a comprehensive and fundamental principle for leading and operating an organisation that is aimed at continually improving performance over the long term by focusing on customers while addressing the needs of all stakeholders. The direct customer for GSAOI is the International Gemini Project Office and, ultimately, the research astronomer using the instrument. Many different groups within the Gemini partnership are stakeholders.

The GSAOI Product Assurance Plan (Annex 3 of this document) defines a set of plans and procedures that will be implemented to ensure that the plans and procedures contained in this Management Plan are being followed and are effective.

7.2 Work Authorisation

Having executive authority for instrumentation development, the RSAA Director approves the instrumentation projects to be undertaken by RSAA and determines their relative priorities, taking advice from the RSAA Instrument Committee (IC) through its chairperson, the Associate Director for Instrumentation Development. The Director has approved the IC recommendation to make GSAOI the highest priority next to NIFS. Upon delivery of NIFS to Gemini North, GSAOI will assume the highest priority of all RSAA instrumentation development projects.

7.3 Requirements Management

Requirement definition begins with an overall objective and operational concepts or scenarios. A requirement is a capability or feature of a system that is needed by a user to achieve a specific objective. Collectively, GSAOI requirements define the intended behaviour of the GSAOI instrument. Complete understanding of the intended behaviour of the GSAOI instrument is therefore mandatory in order to

- Specify that behaviour;
- Design the system;
- Verify that the system does what it is supposed to do;
- Measure the level of quality achieved; and
- Forecast the resource effort involved.

In response to the Gemini request for the delivery of GSAOI, the RSAA has implemented a systematic approach to identifying, organising, communicating, and managing both the static and dynamic requirements of the GSAOI project. A primary result of this approach is a requirements specification that defines the complete external behaviour of the GSAOI instrument to be delivered. These requirements are specified in the GSAOI Operational Concept Definition Document and the Functional and Performance Requirements Document. The GSAOI requirements hierarchy is depicted in Figure 8.

The Requirements Management Process will comprise three basic actions:

- Requirement Definition;
- Requirement Verification; and
- Requirement Analysis.

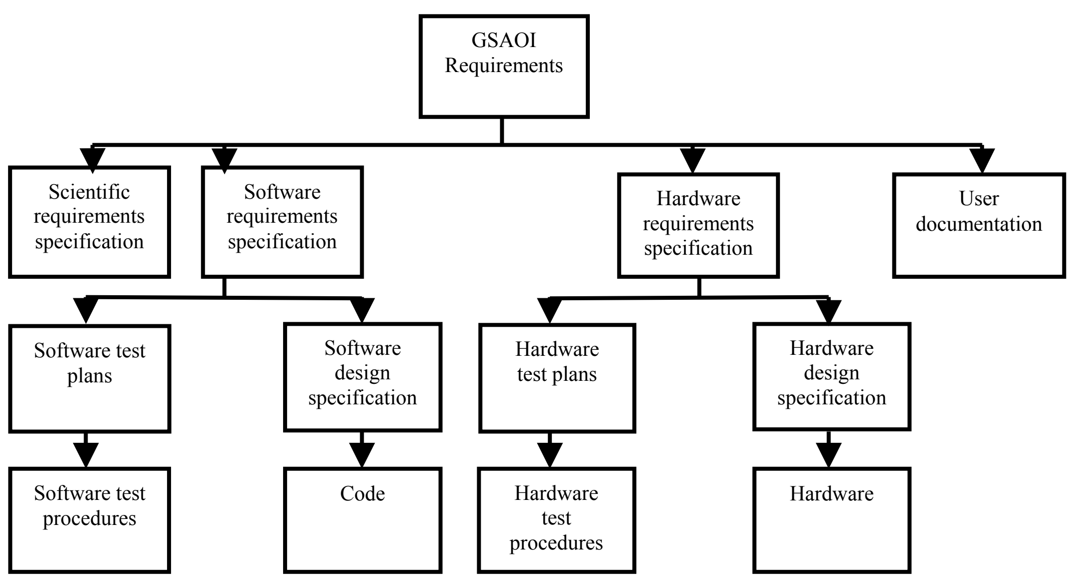


Figure 8. GSAOI requirements hierarchy.

Within the framework of the Requirements Management Process, GSAOI requirements shall be reported and specified within textual documents. Documented requirement specifications will have an associated identifier. Revisions to such source documents will be conducted throughout the GSAOI lifecycle. These revisions will be associated with changes or potential changes to any of the requirements, or with work completed to date. Conflict and inconsistency between requirements will be resolved and documents will be parsed to resolve requirements that are grammatically incorrect or defy unambiguous interpretation.

7.4 Reporting Process

In line with standard RSAA procedures, GSAOI team members will report their time usage to their Section Heads, who will pass the relevant information to the GSAOI Project Manager for project tracking. Any proposed expenditure on a project has to be approved by the Project Manager to enable him to control and track costs. Together with progress information reported at regular weekly meetings for GSAOI, this enables the Project Manager to complete and submit regular progress reports to Gemini and the IC. For GSAOI, this reporting will be on a monthly basis both to the Gemini Project Office and to the IC. The monthly reports will be of a general nature similar to those used for NIFS and will include more explicit comparison of actual and budgeted cost. Similarly, monthly meetings will be scheduled with the RSAA Director to report on GSAOI schedule, budget, and status.

7.5 Construction and Fabrication

Ultimately, the appropriate Section Head is responsible for the delivery of each component on time, within budget, and to specification. Fabrication of components and subsystems will be done in-house or, on occasions, by outside vendors working under subcontract to RSAA. A description of the components in each work package is described in the GSAOI WBS and Bill Of Materials (BOM).

7.6 Reviews, Checking, and Testing

Formal design reviews will be conducted for GSAOI as a Gemini requirement. Internally, GSAOI progress meetings will be used to regularly review processes and stages as they progress. At critical points in the design cycle, peers or supervisors check designs. Testing during the integration and test phase and commissioning phases will be thorough, formalized, and fully documented.

7.7 Communications Management Process

GSAOI project communications are based on distribution lists corresponding to personnel groups with similar interests. These groups include the following:

- Core project team members;
- Other team members;
- Other staff members;
- Subcontractors;
- RSAA executive management; and
- Gemini.

GSAOI communication vehicles include meetings, minutes of meetings, status reports, e-mail, internet website, contributions to Gemini newsletters, and telecommunications.

Communications matrices are presented in Annex 2 of this document.

7.8 Documentation and Configuration Management Process

In response to the absolute necessity of maintaining document control procedures within GSAOI, a librarian has been appointed within the GSAOI team. The GSAOI Librarian will assume responsibility and authority for overall document control. Under overview by the Librarian, responsibility for maintenance of a given document will reside with the corresponding owner (author).

All documents, whether electronic or hard copy, will be uniquely identifiable within the framework of the GSAOI project. In all cases, changes to documents will be tracked and their distribution will be recorded throughout the document's development and subsequent revision processes. To this end, the following document control procedures have been implemented:

- **Version control**
  - to provide unique identification by assignment a version number to each document;
- **Build status control**
  - by maintaining a version development history through subsequent releases and revisions;
- **Controlled documents**
  - by assigning unique numbers to final versions of documents before distribution to recipients that are to be kept updated if the document changes; and
- **Distribution control**
  - by maintaining a recipients list for distributed copies.

For efficiency, the level of document control will vary and will correspond to the intended purpose and ownership of the document.

In the case of technical drawings, which are also subject to Document and Configuration Management, the management processes will accommodate management procedures previously implemented within the RSAA technical sections. Technical drawings will be stored in hard-copy format, electronic format associated with the CAD packages on CD and disk drive media, and on microfiche.

Key GSAOI document sets, including Gemini deliverables, will be archived electronically on a dedicated hard disk that is archived automatically on a regular basis. Moreover, current versions of all documents will also be stored on new read-only CD media at regular intervals. Previous versions will be kept in the disk archive library. Hardcopies of past and present issues of documents will be kept in the hardcopy archive library. Only the most recent issue of a given document will be released for revision purposes.

All GSAOI documents will be accessible from the RSAA GSAOI website, including minutes of relevant project meetings. Navigation through the website document archive will be facilitated by a list of documents and associated hyperlinks. Read-only access will be granted to external users of this website. This site will also provide the primary source of most recent documents to the GSAOI team.

Long-term storage of GSAOI documentation is an on-going concern. The stability of storage media will be tracked by the librarian and documents will be transcribed to current technological media if an obsolete format is encountered.

Within the framework of the GSAOI project, document sets have already been established and will be subject to on-going development throughout the GSAOI lifecycle. Together, these control measures will ensure internal efficiency and the delivery of GSAOI documents in accordance with time-schedule.

7.9 Conflict Management Process

Most decisions will be made at the GSAOI sub-project level. In general, conflicts will be resolved within regular work-package and technical section team meetings, held on a weekly basis at minimum. If conflicts do arise, decisions can be appealed to the following entities in the order given:

1. Section Head.
2. Project Manager.
3. Technical Projects Manager.
4. Associate Director for Instrumentation.
5. RSAA Instrument Committee.

7.10 Quality Management Process

The GSAOI team is committed to work in accordance with the principles of Total Quality Management to provide products and services that fulfil, or exceed, the end-user's expectations. This, in turn, increases productivity and lowers the cost. The GSAOI project team will abide by the six fundamental concepts of Total Quality Management:

1. A committed and involved management to provide long-term top-to-bottom organisational support;
2. An unwavering focus on Gemini;
3. Effective utilisation of the total RSAA human resource;
4. Continuous process improvement;
5. Treating subcontractors and Gemini as partners; and
6. Establishing performance indicators for the GSAOI management process.

The implementation of these concepts is facilitated by the existence of an effective and integrated quality system as part of the RSAA infrastructure and that all personnel, including the Director, are committed to its implementation. The broad range of research and development tasks, engineering services, and system functions provided by RSAA has resulted in the implementation and maintenance of a Quality Assurance System to control these diverse activities. This is achieved by integrating fundamental management techniques, established performance indicators reflecting technical and scientific requirements of processes, technical tools, and vigilant monitoring of outcomes against performance indicators.

The provisions of the RSAA Quality Assurance System will be applied to GSAOI operations and will be imposed on all subcontractor operations in a manner that is "fit for purpose".

The GSAOI Quality Assurance System is structured to provide an environment within which engineering and administration personnel alike may conduct their activities in a manner controlled by procedure rather than policing. Senior engineering personnel are selected to function as check authorities for day-to-day design review and inspection requirements. One person is assigned the responsibility of being the Project Quality Assurance Officer (QAO). For GSAOI, the QAO will be the Product Assurance Officer (PAO). The PAO has responsibility for the quality needs of the project and reports to the RSAA Technical Projects Manager who advises the GSAOI Project Manager in respect of these needs. The design and administrative infrastructures within which the team must operate are clearly defined.

7.10.1 Objectives

The objectives of the GSAOI quality plan can be summarised as follows:

- To explain and demonstrate how the GSAOI team will ensure control of the quality and integrity of all its activities related to the GSAOI project.
- To outline the RSAA quality system and show how the GSAOI project will operate within this system and be compliant with Gemini requirements.
- To provide timely output of information from the quality assurance mechanism and ensure that this information is incorporated into the design, manufacture, procurement, and test activities with minimum impact on cost or schedule.

- To provide detection of non-conformances or incompatibilities and, in response, timely and positive corrective actions.
- To ensure optimum reliability and safety and the sound translation of GSAOI contractual requirements into design, manufacture, tests, and deliverables.
- To allocate suitably qualified personnel with the experience and training to provide controlled and supervised conformance with the contractual requirements.

7.10.2 Quality Assurance Organisation

Responsibility for the project quality plan and organisation shall reside with the Technical Projects Manager. The Technical Projects Manager will appoint a Product Assurance Officer (PAO) for the project. Reporting to the PAO, the head of each RSAA technical section will serve as section Product (and Quality) Assurance Officer.

The PAO will have internal responsibility for ensuring that all aspects of GSAOI comply with the requirements of the RSAA Quality Control System, the Quality Plan, and the Statement of Work. That is, the PAO will verify that all deliverable items associated with the project, including equipment designed or manufactured, is of adequate quality to meet the standards set out in the contract.

Sectional PAOs will be responsible for verifying that all activities and deliverables within their respective sections are of appropriate quality and will report to the project PAO.

The GSAOI Project Manager will have responsibility for the implementation of any corrective actions identified within the project and associated tracking of the project Work Breakdown Structure and resource allocation.

The GSAOI team will maintain and apply a quality and product assurance plan and perform the project and engineering management in accordance with that plan. Subcontractors shall work in accordance with relevant components of the plan. This plan is for the complete, integrated technical effort and incorporates all tasks to be conducted as part of that effort. The GSAOI Product Assurance Plan is given in Annex 3 of this document. The Quality Assurance organisational structure at the RSAA is shown in Figure A3.1 of this plan.

7.10.3 Reporting Arrangements

External and internal reporting on quality will be conducted on an exception basis. The Project Manager will be notified of any project quality non-conformance issues and corrective action requests that are discovered as a result of internal tracking or general observations of the Product Assurance Officer. Details of significant problems or potential problems including non-conformances and corrective actions will be included in the monthly Progress Report. Internally the Product Assurance Officer will report any deviations in the equipment manufacture or design to the Project Manager when they are encountered.

7.11 Inspection and Acceptance

Section Heads will be responsible for assuring that appropriate procedures are in place at the sub-project level to ensure components and assemblies are inspected sufficiently to assure that they meet technical specification. Acceptance of components and systems will be done by those directly responsible for them. When appropriate, inspection visits will be made to vendor shops or industrial firms fabricating or preparing components for GSAOI.

7.11.1 Quality Control of Subcontractors

As part of the project quality control process, GSAOI Quality Assurance delegates may conduct audits of a subcontractor’s quality system to ensure that there is compliance with the requirements of the contract. In addition, the GSAOI team will perform inspections of the work in progress and deliverable items procured from a subcontractor to ensure they meet the quality requirements of the contract. GSAOI team delegates will also attend testing to be performed by a subcontractor as necessary.

7.11.2 Quality Control of All Other Work Undertaken for the Project

All other work undertaken as part of the project will be subjected to standard RSAA procedures. This covers all the critical aspects that will ensure compliance with Gemini contractual requirements. Key features are as follows:

1. Planning of review meetings to ensure that outputs are reconciled to the requirements of Gemini throughout the project;
2. The authorising, recording, and implementation of changes to specifications and designs;
3. Control and monitoring of procurement;
4. Control and registration of documents; and
5. Configuration of documents and designs.

7.12 Risk Management

The RSAA is committed to delivering the most versatile, highest quality, most reliable instrument. Quality Assurance begins at the design stages and continues throughout product development, and all stages of manufacturing and supply. The adoption by RSAA of standard industrial workshop practices provides an accelerated means of reducing risks under all operating conditions.

The approach of the GSAOI team to risk management and abatement will be consistent with the Australian standard on risk management, AS/NZS 4360, and will include the systematic application of management policies, procedures, and practices to tasks of

1. Risk identification,
2. Risk analysis,
3. Risk evaluation,
4. Risk reduction plans,
5. Risk monitoring, and
6. Documentation.

Unidentified risks can be a major threat to the outcomes and success of the project. However, identified risks can also be the source of positive outcomes. Knowing exactly how and why they arise should identify how and why better outcomes will be achieved. In this context, the GSAOI Risk Management Plan has been designed to provide a disciplined approach to risk assessment and management throughout the GSAOI project life cycle. It provides a systematic decision making process that efficiently identifies risks and assesses their risk level, taking account of cost, schedule, performance, and safety. Identified risks are then addressed through modification of project plans to include risk reduction plans.

7.12.1 GSAOI Project Risk Management Responsibilities

The GSAOI Project Manger will appoint a Risk Assurance Officer who will have overall responsibility for ensuring that the project is continuously monitored for risk, and identified risks are properly tracked, reported, and documented. The GSAOI Project Manager will be responsible for ensuring that risk mitigation plans are implemented when the situation demands. It is the responsibility of all members of the GSAOI team to report all identified risks to the Risk Assurance Officer. Management staff are also responsible for reporting risk to relevant staff of the GSAOI team and to the RSAA Instrumentation Committee.

The GSAOI Risk Assurance Organisation is shown in Figure 9.

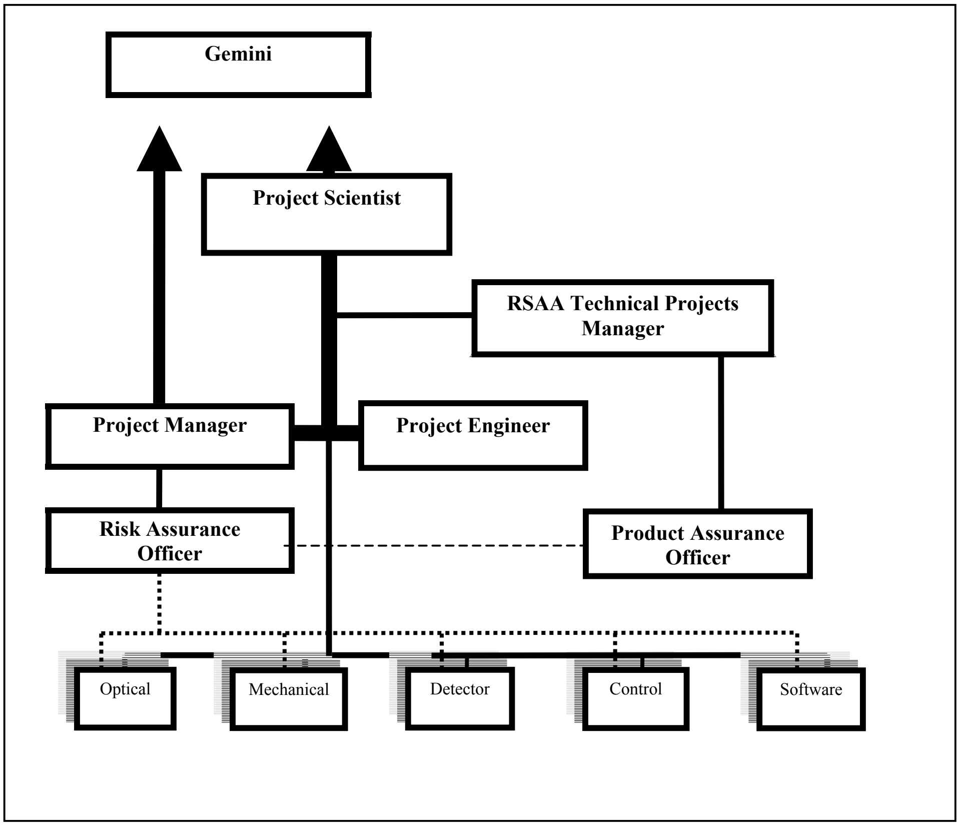


Figure 5: GSAOI Risk Assurance Organisation. The GSAOI Project Manager will serve as GSAOI Risk Assurance Officer (RAO). Delegates from each primary risk area monitor risk and report to the RAO.

7.13 Accounting Systems and Policies

There will be two levels of accounting: team and University. The Project Manager and other project staff will do team accounting. This local accounting will allow the team to more closely track and manage the expenditures of the project. Microsoft Project and Excel will be used as the primary tools. The team accounting will be the basis for the required monthly management reports. Team accounting will be unofficial until it is reconciled with the University accounting system. The RSAA administrative staff operate the University accounting system for all financial transactions by RSAA, including those related to projects. The accounting operations and financial management of the University are supported by the University's Enterprise Solutions Project (ESP) PeopleSoft Financial System, a major element of the University's administrative computing network. Other administrative computing applications include Maximo, Human Resources, and Student 2.1. The central feature of ESP Financials is the general ledger, which comprises a comprehensive and detailed recording system with associated ledger maintenance and financial reporting capabilities. Closely integrated with the general ledger are the major transaction processing modules. These provide facilities for

- The payment of accounts;
- Recording of receipts;
- Processing of journal entries;
- Budget and encumbrance management; and
- Recording of information relating to inventory.

The Australian National University "Purchasing and Contracting Policy and Procedures 2000" was developed by the University Purchasing and Contracts Office (UP&CO). This document is "intended to be dynamic, reflecting continuing developments in purchasing and contracting practice and in the incorporation of changing legislative and environmental requirements" (www.anu.edu.au/finance/). The policy and procedures are to be followed by all Australian National University authorised delegates, managers, and staff involved in purchasing and contracting to ensure that ethical and sound purchasing practices underpin the achievement of value for money outcomes. The document applies to the purchase of all goods and services, and associated contracts.

The procurement of equipment, materials, and services will comply with the University's guidelines for procurement and will be consistent with standard Federal and State guidelines. No problems are foreseen as these guidelines allow exceptions to the quotation and tendering processes for specialised supplies.

7.14 Subcontractor Management Process

Subcontracted organisations may consist of commercial companies, consultants, or groups within the ANU community. In all cases, the subcontracted organisation must identify an administrative, managerial, and technical representative if applicable.

Subcontractors may be engaged by the GSAOI project team to acquire goods or services needed to successfully complete the GSAOI project. This process will usually be addressed using the mechanism of a purchase order. In some cases, the tendering process may be invoked. Central to RSAA business management operations is a clear understanding of the essentials of subcontracting and subcontract management. This is essential to control or influence the activities of the process and the conditions of the contract in order to obtain (or provide) the resources and the services needed in the manner required. RSAA contract management procedures are in accordance with the ANU Contract Policies and Procedures (http://www.anu.edu.au/cabs/policies/).

When products or services are to be acquired in support of a given project, necessary requirements of quality, cost, and timing shall be met to ensure that the project remains on schedule and within budget. If the situation warrants, subcontracting will involve assistance from legal departments within the ANU.

Generally, subcontracts will be time-phased, sequential processes that include clear-cut pre-award, award, and post-award phases. That is, projects progress from the contracting process through to the pre-award phase where specific and detailed descriptions of requirements are provided so that items can be accurately costed in preparation for the requisition to be transmitted to subcontractors (i.e., tender document for solicitation of tender). During this phase, due consideration will be given to the prospective supplier list and the contractor experience list. Having evaluated all bids or proposals received, a request for final offer will be sought The contractor offering the best overall combination of technical, management, and cost proposals satisfying the requirements will generally be selected. During the post-award phase, terms of the agreement will be reduced to written form and the following management functions will be implemented:

- Production and construction surveillance;
- Quality control, planned in terms of specifications and descriptions and monitored on a continuous basis to detect deviations;
- Inspection and acceptance to determine conformance to specifications on a continual basis using predetermined milestones to inspect various aspects of work so that decisions can be made to address any identified non-conformities;
- Change management, to minimise changes to drawings and specifications etc.;
- Payment, generally progress payments made after inspection and receiving documented certification of conformance to specifications; and
- Contract administration to ensure that the terms of the contract are being observed (including legal interfaces, safety requirements, closure, and retirement of the contract).

7.15 Project Management Tools Usage

Computer-based management tools will play a central role in GSAOI project management, both from the RSAA perspective and that of Gemini. Such management tools are essential for project with the scope of GSAOI and will provide improved efficiency of work scheduling, tracking, and production planning, These tools also assist with both sequential and concurrent engineering components of the Work Breakdown Structure. Integration of these engineering components has been facilitated by RSAA's commitment to Total Quality Management.

In particular, Microsoft Project 2000 will be used for

- Work Breakdown Structures;
- Work Packages;
- Gantt Charts;
- Network Diagrams;
- PERT/Critical Path Method network diagrams;
- Creating GSAOI project plans;
- Monitoring GSAOI schedules and work progress; and
- Communicating information about GSAOI to the RSAA Instrument Committee and Gemini.

This software will be used in conjunction with other computer-based tools, including spreadsheet, cost estimating, network scheduling, decision analysis and technical design tools. GSAOI software tools and uses are presented in Annex 4 of this document.

7.16 Safety Plan

The design, construction, commissioning, and operation of GSAOI will be done in strict accordance with the health and safety standards of the ANU. On-site, all procedures will be in accordance with ANU OH&S guidelines, staff handbook, and all other applicable standards established by University governance. The Project Manager, Quality Assurance Officer, and all supervisors will be appointed as Safety Officers for GSAOI. Details of the GSAOI Safety Plan are given in Annex 5 of this document.

8 RSAA GSAOI Project Team

8.1 RSAA GSAOI Team Composition

GSAOI will be managed by the RSAA project team. Responsibilities for managing the project are represented by the organisation chart depicted in Figure 10.

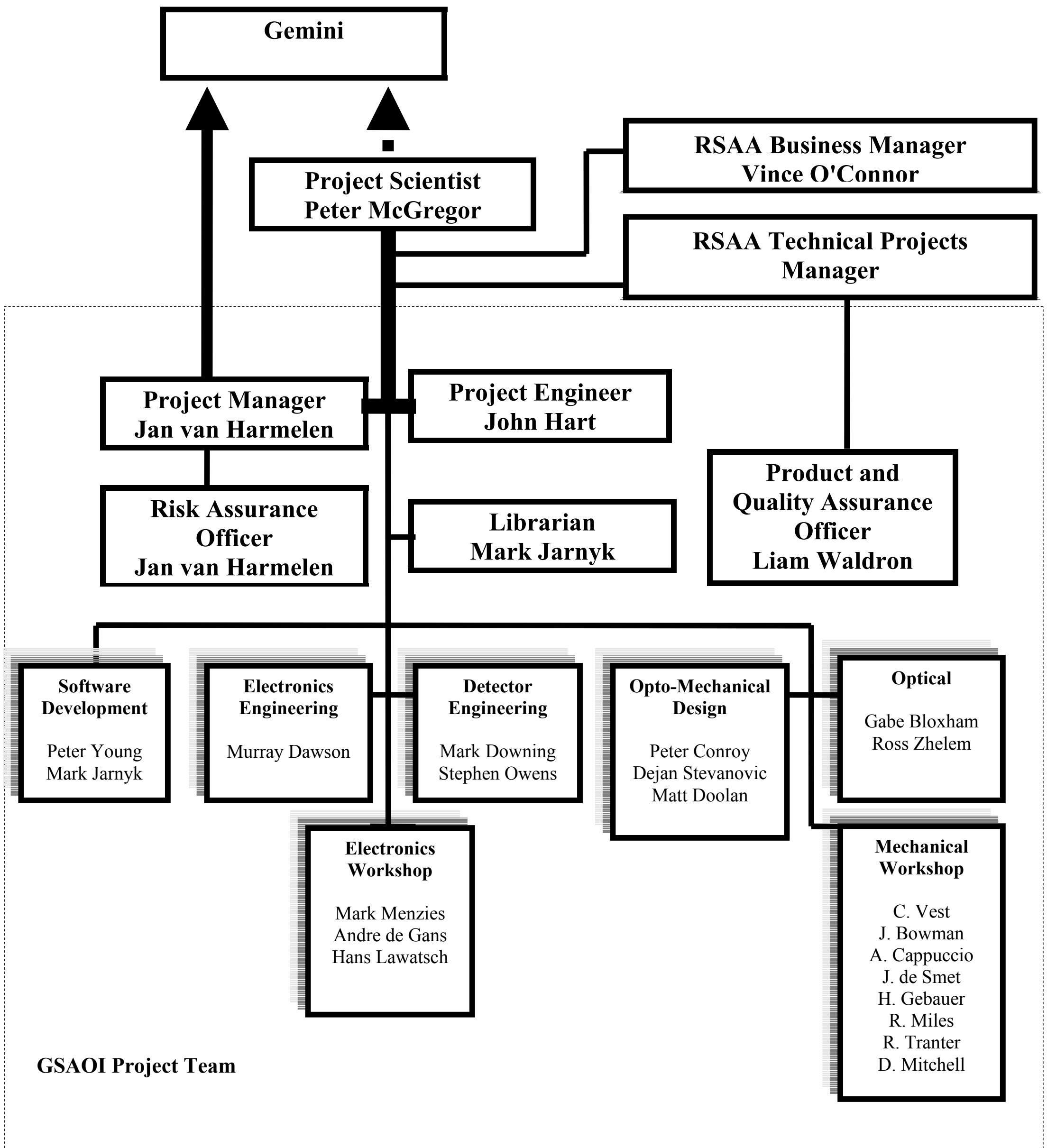


Figure 6: RSAA GSAOI project team responsibilities.

8.2 RSAA GSAOI Team Member Responsibilities and Authority

Role	Responsibility
RSAA Executive and Support	
Director	Penny Sackett
Business Manager	Vince O'Connor
Associate Director of Instrumentation	Michael Bessell
Technical Projects Manager	Liam Waldron
GSAOI Project Team Core	
Project Scientist	Peter McGregor
Project Manager	Jan van Harmelen
Project Engineer	John Hart
Risk Assurance Officer	Jan van Harmelen
Product and Quality Assurance Officer	Liam Waldron
GSAOI Librarian	Mark Jarnyk
Head, Opto-Mechanical Design Office	John Hart
Opto-Mechanical Design Engineer 1	Dejan Stevanovic
Opto-Mechanical Design Engineer 2	Matthew Doolan
Head, Optical Workshop	Gabriel Bloxham
Foreman, Mechanical Workshop	Cole Vest
Chief Electronics Engineer	Murray Dawson
Chief Detector Engineer	Mark Downing
Head, Software Development	Peter Young
Software Engineer	Mark Jarnyk
GSAOI Other Team Members	
Opto-Mechanical Designer	Peter Conroy (available after delivery of NIFS)
Electronics and Detector Engineer	Stephen Owens
Senior Technical Officer, Electronics	Mark Menzies
Technical Officer, Electronics	Andre de Gans
Technical Officer, Electronics	Hans Lawatch
Software Engineer	William Roberts
Mechanical Design Engineer (Auspace Ltd.)	Leigh Pfitzner

8.3 RSAA GSAOI Team Member Information Sheets

Information Sheet for Peter J. McGregor

Name: Peter J. McGregor

Title: Senior Fellow

Project Assignment

Functions: Project Scientist
Time: 0.9 FTE for whole of the project

Education:

Degree	Year	Field
BSc (Hons)	1976	Physics
PhD	1982	Astronomy

Experience

Experience at ANU: 19 years at RSAA

Description of Experience: 1984 – Present: McGregor has been an active faculty member of Mount Stromlo and Siding Spring Observatories and then the Research School of Astronomy & Astrophysics. He originally worked with Harry Hyland developing and using single InSb detector photometers and scanning spectrometers on ANU telescopes and on the Anglo-Australian Telescope. Since 1989, he has led the infrared effort at MSSSO/RSAA. McGregor was the Project Scientist for the Cryogenic Array Spectrometer Spectrograph (CASPIR), which was commissioned on the ANU 2.3 m telescope in 1994. This in-house development involved many of the current NIFS team in constructing a 1-5 μm camera and grism spectrometer based on a SBRC InSb 256×256 detector array. McGregor defined the scientific rationale, conceived the instrument characteristics, applied for and won funding, worked with engineers in developing the instrument design, participated in the optical, detector, and software aspects of the project, and commissioned and supported the instrument on ANU's premier telescope. These skills are directly applicable to his role as project scientist for NIFS. McGregor has been a member of the MSSSO/RSAA Instrument Committee since 1989, and a member of their Telescope Allocation Committee since 1986. Since 1991, McGregor has served as Project Scientist for NIFS.

McGregor has authored nearly 50 scientific publications.

Other Experience: 2 Years

Description of Experience: 1982-1983: Prior to joining MSSSO/RSAA, McGregor was a Carnegie Fellow at The Observatories of the Carnegie Institute of Washington. McGregor worked with Eric Persson and Tom Geballe using and maintaining a near-infrared Fabry-Perot/grating spectrometer built by Persson and Geballe primarily for studies of star formation regions on the Palomar 5 m and Las Campanas 2.5 m telescopes. McGregor developed a close association with Keith Matthews (Caltech) that continues to this day.

Other Experience and Qualifications: McGregor was a member of the Advisory Committee on Instrumentation for the Anglo-Australian Telescope from 1995 to 1997. He was a member of the Australian Resource Information And Environment Satellite (ARIES-1) System Design Review panel in 1997. In 1998, he chaired the Critical Design Review committee for IRIS2 developed by the Anglo-Australian Observatory.

Contingency Plans: If McGregor becomes unable to carry out his duties, Gary DaCosta would carry out these duties until a suitable substitute could be identified.

Information Sheet for Jan van Harmelen

Name: Jan van Harmelen

Title: NIFS/GSAOI Project Manager

Project Assignment
Functions: Project Management and Risk Assurance
Time: 0.6 FTE for the duration of the project

Education:

Degree	Year	Field
Kandidaats	1969	Electrical Engineering
Doctoraal	1972	Electrical Engineering

Experience
Experience at ANU: 23 Years at RSAA
Description of Experience: 1991-Present: NIFS Project Manager, GSAOI Project Manager and Risk Assurance Officer.

1983 – 1991: Chief Electronics Engineer of Mount Stromlo and Siding Spring Observatories (MSSSO, now RSAA). Responsible for overall management of projects progressing through RSAA Technical Sections, for management of specific projects and for the operations of the Electronics Sections. Recent project management: RSAA Wide Field Imager (8k x 8k CCD mosaic) now nearing completion, tip-tilt system for RSAA 2.3 m telescope (1996-1998). Chaired the MSSSO Technical Coordination Committee for refurbishment of 50" MACHO Telescope (1990-1992) and for completion of the 2.3 m telescope (1985-1987). Supervision of up to 15 engineers and technicians working at both Mount Stromlo and Siding Spring Observatories on these and other projects, and on maintenance and operations. Electrical and electronics design for 50", 74" and 2.3 m telescope control (sub-)systems and for instrument control systems: 2.3 m Double Beam Spectrograph (DBS) and Imager. Software design and implementation of small telescope and DBS and Imager control systems. Software for integration of tip-tilt with the 2.3 m telescope control system.

1979-1983: Electronics Engineer at Siding Spring Observatory responsible for daily operation of ANU telescopes. Design of several electrical and electronic sub-systems for the 2.3 m telescope.

Other Experience: 9 Years
Description of Experience: 1975-1979: Lecturer in Electronics, Western Australian Institute of Technology (now Curtin University).

1973-1974: Instrumentation Engineer, Trials Division of the Royal Dutch Army.

1970-1972: Development of a weather balloon navigation system, University of Delft.

Contingency Plans: If Van Harmelen becomes unable to carry out his duties, Waldron would initially take over his project duties till a new project manager could be recruited. In the likely case that the new project manager does not have a background in an astronomy-related field, McGregor and Hart would provide a higher level of input, possibly necessitating delegation of some of their tasks to other team members, or to other RSAA staff.

Information Sheet for John Hart

Name: John Hart

Title: Chief Mechanical Engineer

Project Assignment
Functions: Project Engineer**,** Optical and mechanical design and analysis
Time: 60% FTE for whole of the project

Education:

Degree	Year	Field
BE (UNSW)	1967	Mechanical Engineering

Experience
Experience at ANU: 33 Years at RSAA
Description of Experience: 1969 – Present: Employed initially as a project engineer to work on the design and development of telescopes and instrumentation. The major project undertaken in that role was the upgrading of the Reynolds telescope. After about three years the duties were extended to include supervision of the Mechanical Engineering Section. Since then, major projects to which a substantial contribution have been made include the 2.3 m Telescope, the 50” telescope refurbishment, CASPIR, the 2.3 m tip tilt system, the G-Mount facility, the MSO visitor’s centre heliostat and spectroheliostat, the up grade of the 40” telescope tube and the design of the PN Spectrograph. Hart is currently the Project Engineer for NIFS.

Other Experience: 2 Years
Description of Experience: Project engineer at Chrysler Australia, working on the development of brakes and suspensions for Valiant cars.

Contingency Plans: If John Hart becomes unable to carry out his duties, a new section head will be recruited and project responsibilities will be redistributed.

Information Sheet for Gabriel Bloxham

Name: Gabriel J Bloxham

Title: Senior Technical Officer, Optical Workshop

Project Assignment

Functions: Assist in optical design: ray tracing, specification. Manufacture and procurement of optics. Assist in testing and alignment.

Time: 0.4 FTE as needed during design, fabrication and testing phases.

Education:

Degree	Year	Field
Diploma	1972	Applied Physics

Experience

Experience at ANU: 30 Years at RSAA

Description of Experience: 1978 – Present: Assist in the design and development of the Optical instrumentation at this observatory, and for other clients. Procurement and specification of optics, filters and coatings. Manufacture of a wide range of optical components for both in house instrumentation, and for outside contracts. The experience ranges from crystal lens components, all specialised optical glasses in refractive optics, and mirrors from many substrates. Some experience in aspherics and conic surfaces. Major projects: 2.3m CASPIR, Double Beam Spectrograph, Imager and Planetary Nebula spectrograph, NIFS. Currently manufacturing the NIFS camera optics.

1972 –1978: Research assistant duties and detector testing and development.

Contingency Plans: If Gabe Bloxham would be unable to carry out his duties, another member of the group (Hart) would need to specify the optics and arrange for all optics to be manufactured by a sub-contractor.

Information Sheet for Peter Conroy

Name: Peter Garth Conroy

Title: Senior Draftsman

Project Assignment

Functions: Opto-mechanical subsystem designer and detailer. Perform necessary engineering analysis. Oversee construction and commissioning.
Time: 0.9 FTE for the whole of the project after delivery of NIFS.

Education:

Degree	Year	Field
Mech Eng Certificate	1974	Mechanical Engineering
Optical Design Short Course	1990	Optical Design

Experience
Experience at ANU: 31 years at RSAA
Description of Experience:

Some projects I have contributed to over the last 15 years are: NIFS, Antarctic DIMM, Antarctic FOS, Wide Field Imager Exposure Controller, Wide field Imager Dewar, Wide Field Imager Tip-Tilt, 74" Autoguider System, 2.3 m Autoguider System. Seconded for one year to the European VLT - Australis project. Direct CCD Detectors and Exposure Controller Systems. Test and Calibration Systems for CCD Detectors,

Large long term projects include the 2.3 m Nasmyth Imager and the 2.3 m Nasmyth Double Beam Spectrograph. Photon Counting Systems Development.

Other Experience:
Description of Experience:

Two years at university electrical engineering school building early microcircuit fabrication unit.
Two years in the electronics industry with PCB manufacture and component assembly.
Six years in pharmaceutical industry working with automatic machinery.

Contingency Plans: If Conroy becomes unable to carry out his duties John Hart will recruit a replacement and in the short term some aspects of the design could be sub-contracted to Auspace.

Information Sheet for Dejan Stevanovic

Name: Dejan Stevanovic

Title: Mechanical Engineer, RSAA

Project Assignment
Functions: Mechanical Design
Time: 1.0 FTE for the duration of the project

Education:

Degree	Year	Field
B.Sc. (Hons.)	1995	Aerospace Engineering
Ph.D.	2002	Materials Engineering/Computational Mechanics

Experience
Experience at ANU: 1year at RSAA
4 years at the Dept. of Engineering
Description of Experience: 2001 – Present: Mechanical Design Engineer. Involved in NIFS detailed mechanical design. Developed detailed design and documentation for the filter wheel, tri-fold tower, corrector tower and NIFS baffling system. Design mechanical layouts for the GSAOI CoDR documentation.

1998 – 2001: PhD in Damage Mechanics of Composite Materials. Designed and implemented a novel manufacturing process for advanced polymer composites, improving their fracture resistance by 80%. Conducted a broad spectrum of mechanical tests of polymers and polymer composites. Developed various finite element models by using state-of-the-art engineering CAD and FEA software to obtain numerical support for the test results.

Responsible for GSAOI mechanical design presented at CoDR.

Other Experience: 2 Years at the Institute of Security, Belgrade, Yugoslavia (Government Agency involved in developing and implementing security and surveillance systems)
Description of Experience: 1996-1998: Mechanical Engineer. Developed mechanical components and subsystems for several electro-optical surveillance systems.

Contingency Plans: If Dejan Stevanovic becomes unable to carry out his duties, other members of the RSAA mechanical section (specifically, Peter Conroy) will fill in until a replacement can be recruited.

Information Sheet for Matthew Doolan

Name: Matthew Doolan

Title: Mechanical Engineer, RSAA

Project Assignment
Functions: Mechanical Design
Time: As required by the Senior Mechanical Engineer.

Education:

Degree	Year	Field
B.Sc.	1996	Computer Science
B.E.	1998	Systems Engineering (Mechanical Systems)
Ph.D.	2002	Manufacturing Engineering

Experience
Experience at ANU: 6 months at RSAA
4 years at the Dept. of Engineering
Description of Experience: 1998-2002: PhD in Force Signature Analysis of Sheet Metal Stamping. Developed a novel method of sheet metal stamping process control at the Ford Australia Stamping Operations plant. Conducted a wide range of both experimental work and computer generated simulations. This provided the ability to predict failures and suggest preventative process changes.

Contingency Plans: If Matthew Doolan becomes unable to carry out his duties a new Mechanical Engineer will be recruited.

Information Sheet for Mark Downing

Name: Mark D. Downing

Title: Senior Detector Engineer

Project Assignment
Functions: Design of detector systems, detector characterization.
Time: 0.6 FTE for whole of the project

Education:

Degree	Year	Field
B. Appl. S.	1978	Engineering
M. Appl. S.	1980	Engineering

Experience
Experience at ANU: 22 Years at RSAA
Description of Experience: 1980 – Present: Detector Engineer responsible for maintaining and developing the School's CCD and IR detector systems. Primary responsible is for detector and detector electronics. Extensive experience with Astromed, Santa Barbara and SDSU-1 and SDSU-2 detector controllers. Major detector projects involvement include NIFS spectrograph detector, Wide Field Imager (8k x 8k CCD mosaic with dual SDSU-2 controller) (1998-2000), tiptilt system for RSAA 2.3 m telescope (1996-1998), CASPIR IR Imager and Spectrograph (1991-1994), RSAA 2.3 m telescope IR system upgrade (1986-1990). Other projects include participation in the design and construction of the electronic control system for RSAA 2.3 m Telescope (1980-1986). Currently NIFS Detector Engineer.

Contingency Plans: If Mark Downing becomes unable to carry out his duties, then Stephen Owens and Murray Dawson will take over. They will be assisted by McGregor and Van Harmelen.

Information Sheet for Murray Dawson

Name: Murray I. Dawson

Title: Engineer in Charge, MSO Electronics, RSAA

Project Assignment

Functions: Control System Hardware
Time: 0.4 FTE for the duration of the project.

Education:

Degree	Year	Field
BEng	1985	Electronics, Computing, & Communication
MEng	1992	By Research, Digital Signal Processing

Experience
Experience at ANU:

2 years at RSAA.
1 year at Dept of Engineering.

Description of Experience:

2000 – Present: Engineer in Charge, MSO Electronics. Responsible for management of operations and projects within the MSO Electronics section of RSAA. Responsible for NIFS control system design and manufacture.

Other Experience: 14 Years
Description of Experience:

1999 – 2000: Computer Engineer, Dept of Engineering ANU. Responsible for computer network, hardware configuration and purchasing, as well as a number of laboratories.
1995 – 1999: Engineering Branch Australia Post Queensland. Managed state engineering operations – 20 staff, $2M p.a. budget. Electrical Project Manager for $7M medium parcel sorting machine development.
1986 – 1995: Lecturer and Tutor, Queensland University of Technology.

Contingency Plans: If Murray Dawson becomes unable to carry out his duties, a new section head will be recruited and project responsibilities will be redistributed. Van Harmelen will assume temporary responsibility for development of the GSAOI Instrument Control System.

Information Sheet for Peter J Young

Name: Peter Young

Title: Head, Computer Section

Project Assignment
Functions: Software Development
Time: 0.5 FTE for whole of the project

Education:

Degree	Year	Field
BSc	1980	Computer Science

Experience
Experience at ANU: 14 Years at RSAA
Description of Experience: 1989 – Present: First employed at RSAA as VMS systems programmer. Moved into Unix (Solaris) system management as VMS declined during 1990. Started working on data acquisition and instrument control software from 1994. Main designer and developer of RSAA's CICADA system (see http://www.mso.anu.edu.au/computing/cicada). This project has been running for 6 years with recent development to support the RSAA/AAO 8kx8k Wide Field Imager. Package is written in C++ and is a multitask distributed design. Promoted to Head of RSAA Computer Section in 1995. Currently completing NIFS Detector Controller software.

Other Experience: 8 Years
Description of Experience: 1985-1989: Programmer/mathematician, CSIRO Division of Fisheries, Hobart, Tasmania. Member of the population dynamics team studying the southern blue-fin tuna fishery. Developed population models, simulations and database code on VAX and Macintosh hardware using Fortran and Object Pascal.
1985: Programmer, Department of Geography, University of Tasmania. Worked on a project that used GMS satellite images for surveying the sunlight budget for Australian capital cities. 1984-1985: Programmer, Hydro-Electric Commission, Tasmania. Worked on critical path method software for engineering projects using Pascal on VAX equipment.
1982-1984: Programmer, Computing Section, University of Newcastle, NSW. Assigned to the departments of Geography, Chemical Engineering and Biological Sciences for various application programming tasks including contour mapping, numerical analysis and databases. 1981-1982: Research Assistant, Department of Geomorphology, RSPacS, ANU, Canberra. Worked on application programming tasks in Fortran and Pascal including databases, modeling and graphics.

Contingency Plans: If Peter Young becomes unable to carry out his duties, Mark Jarnyk will take over his GSAOI responsibilities with assistance from other members of the RSAA Computing Section having CICADA experience.

Information Sheet for Mark Jarnyk

Name: Mark Jarnyk

Title: **Senior** Software Engineer

Project Assignment
Functions: Software Engineer, GSAOI Librarian
Time: 0.6 FTE for whole of the project

Education:

Degree	Year	Field
BEng	1985	Communications Engineering
MEng	1990	Electronics Engineering
PhD	1997	Physics

Experience
Experience at ANU: 4 Years at RSAA
Description of Experience: 1999– Present: Software Engineer (Electronics Section) RSAA. Developed control system for Antarctic Telescope. This control system, running on two QNX systems, controls the motion of the altazimuth mount as well as data acquisition from two CCD cameras. Currently completing NIFS IS, CC and OIWFS CC Software.

Other Experience:
Description of Experience:
Australian Scientific Instruments, Canberra, Australia
1997-1998: New Ventures Manager - Responsible for sourcing new products to be developed and manufactured.
1996-1997: Project Manager - MASIF Project. Managed a team who designed and produced a surface forces instrument.
1995-1996: Software Engineer - Updated and maintained the code which controlled the operation of a large (in fact, the largest) commercial mass spectrometer.

Other Experience and Qualifications:
Australian National University
1994-1995 Research Assistant
Contract development work for Nissin Electric Co of Japan
Ferntree Computers: Consultant Trainer
AT&T Bell Telephone Laboratories: Visiting Scientist for three months
Thomson – CSF (Paris): Visiting Scientist for one month
Freelance Software Engineer:
Programming jobs for Department of Employment, Education and Training, Royal Melbourne Institute of Technology, Telecom Australia, Technisearch, and Australian Geological Survey.
Royal Melbourne Institute of Technology: Tutor

Contingency Plans: If Mark Jarnyk becomes unable to carry out his duties a new software engineer will be recruited without delay. The effort available from the RSAA Computer Section will be adjusted to fill any gap. Young would assist the new appointment gain experience in EPICS.

Information Sheet for William Roberts

Name: William Roberts

Title: Senior Programmer, RSAA

Project Assignment
Functions: Software programmer
Time: 0.2 FTE for whole of the project

Education:

Degree	Year	Field	Insitution
BSc	1979	Mathematics, Physics	Australian National University
Grad. Dip.	1983	Computer Science	Canberra College of Advanced Education

Experience
Experience at ANU: 10 years at RSAA
Description of Experience: 1991 – Present: First employed at RSAA as a Research Assistant to the then Director, Alex Rodgers. Transferred to the Computer Section in 1993 and joined the team working on a data acquisition and instrument control system (CICADA – see www.mso.anu.edu.au/computing/cicada). Involved with the overall system design; mainly responsible for the user interface. As a result of work on this project, gained experience with Unix, C, C++, Motif.

Other Experience: 11 Years
Description of Experience:1980 - 1991: Various programming jobs working for large government departments and software companies producing systems for large financial institutions.

Contingency Plans: If William Roberts becomes unable to carry out his duties, Peter Young, who has a similar set of experiences, interests, and qualifications, would carry out these duties until a suitable substitute could be identified.

Information Sheet for Stephen Owens

Name: Stephen Owens

Title: Detector Engineer, RSAA

Project Assignment
Functions: Detector Engineer
Time: As required to assist the Senior Detector Engineer.

Education:

Degree	Year	Field
E&C Cert.	1975	Electronics and Communications
B.Sc.	1993	Physics
M.Sc.	1998	Physics

Experience
Experience at ANU: 1 Year at RSAA
Description of Experience: SDSU CCD controller integration.

Other Experience: 35 years
Description of Experience:
1997 – 2001 Geoterrex-Dighem, Perth.
Electronics Manager
1996 – 1997 University of Sydney, work on Masters thesis.
1995 – 1996 NSW Police Service, Special Technical Investigations Branch.
Senior Engineer
1966 – 1995 University of Sydney, School of Physics, Astronomy Department.
Started as Junior Laboratory Assistant, last position held: Senior Technical Officer Grade 3.
During the final ten years of this period, designed and constructed most of the electronics systems associated with the Sydney University Stellar Interferometer (SUSI) at Narrabri, NSW. Experience with CCD cameras, laser metrology, motor controllers, and data acquisition systems.

Contingency Plans: If Stephen Owens becomes unable to carry out his duties a new detector engineer will be recruited.

Information Sheet for Liam Waldron

Name: Liam Waldron

Title: RSAA Technical Projects Manager

Project Assignment

Functions: Product and Quality Assurance Officer
Time: 0.1 FTE for the duration of the project

Education:

Degrees	Year	Field
BScHons	1986	Applied Physics
PhD	1991	Astronomy and Instrumentation

Other Qualifications:

MIEAust CPEng: Chartered Professional Engineer and Member of the Institution of Engineers, Australia. Project Management; Information Technology and Electronics Engineering 1998
SMIEEE: Senior Member of the Institute of Electrical and Electronics Engineers, U.S.A. 1997.

Experience
Experience at ANU: 4 years, 3 months at RSAA
Description of Experience: April 2002 – Present: Technical Projects Manager of RSAA. Responsible for overall management of RSAA engineering resources and technological projects; specific project management of nominated significant projects; and human resources management. Current project management: Systemic Infrastructure Initiative and upgrade of Siding Spring Observatories.
1998-April 2002: School Facilities and Research Services Engineer, RSC.

Other Experience: 12 Years

July-Oct 1998: Scientist/Engineer, development of CW Electromagnetic Boundary Wind Profiler, School of Physics, Aust. Defence Force Acad. ADFA
May 97-July 98: Physicist/Electronic Engineer. Management of upgrade and operation of Fourier Transform Spectrometer for Thermoluminescence Dating; Geophysical field-work. Uni. Adelaide.
Aug 96-May 97: Physicist, X-Ray Astronomy; Low-Temperature Mossbauer. Physics, ADFA
1995-1996 EC human and Mobility Programme Fellowship. Management, design and setup of microposition scanning test facility to characterise new hybrid multi-pixel photodiode detectors in collaboration with EC industry. Istituto Nazionale di Fisica Nucleare Pisa, Italy.
1995 Contracted Consultant: Design and testing of integrated window/collimator for space-borne X-ray detector, Istituto di Astrofisica Spaziale, Rome Italy.
1992-1995: European Space Agency Research Fellow, IAS Rome Italy
1992-1995: Project Manager, Mart-Lime telescope, Spectrum XG satellite Consortium, IAS Rome
1994-1995: Porposed Project manager, XRM/IBIS, ESA Integral M2 Satellite. IAS Rome Italy.
1990-1991: Teaching Fellow and Research Assistant in X-ray Astronomy, Dept. Physics, ADFA
1988: Acting Facility Manager, Joint Australian-NASA Balloon Launching Facility, Alice Springs
1986-1991: Development of ground and Balloon Borne instrumentation and software for X-ray Astronomy. Data analysis, analysis software, and science. Dept. Physics, ADFA.

Publications: (co-)authored around 35 refereed scientific or engineering publications.

Contingency Plans: If Liam Waldron becomes unable to carry out his duties, Van Harmelen, McGregor, and Hart would initially take over his project duties until a new technical projects manager could be recruited.

9 RSAA Track Record

RSAA has a long history as Mount Stromlo and Siding Spring Observatories in designing, constructing, and supporting common-user state-of-the-art astronomical instrumentation. It is currently constructing the Near-infrared Integral Field Spectrograph (NIFS) for Gemini North. Prior to that, RSAA bid for the Gemini Near-Infrared Coronagraph Imager (NICI). Recent internal projects include the 8k×8k Wide-Field Imager (WFI) CCD mosaic and the near-infrared Cryogenic Array Spectrometer/Imager (CASPIR) and its tip-tilt secondary mirror system on RSAA's 2.3 m telescope at Siding Spring Observatory. RSAA employ a staff of ~ 30 to support their instrumentation development program. Its headquarters at Mt. Stromlo Observatory near Canberra includes mechanical, optical, and electronics workshops. RSAA owns and operates Siding Spring Observatory that hosts the 4 m Anglo-Australian Telescope and the United Kingdom Schmidt Telescope, as well as the 2.3 m and other smaller telescopes of the Australian National University.

RSAA routinely implements strict project management procedures on instrumentation projects.

With its experience and facilities, RSAA is well placed to design, construct, and commission the Gemini South Adaptive Optics Imager for the Gemini observatories.

NIFS

NIFS will be well known to the Gemini community. It is an innovative near-infrared integral field spectrograph that will be used with the ALTAIR facility adaptive optics system on Gemini North to perform near diffraction-limited imaging spectroscopy. NIFS divides its 3.0″×3.0″ field of view into 29 slitlets, each ~ 0.1″ wide. These slitlets are reformatted into a long "staircase" slit image that is fed to the spectrograph. The spatial sampling along the slit image is 0.04″/pixel. The integral field unit uses a reflective diamond machined mirror array design. The spectrograph delivers two-pixel resolving powers of ~ 5300 that will be sufficient to work in the dark sky regions between strong terrestrial OH airglow emission lines.

NIFS is the first Gemini instrument to re-use existing instrument designs in order to fast track the development process. The Critical Design Review for NIFS was held in April 2001. It is scheduled for commissioning in 2003.

WFI

The Wide Field Imager (WFI) is an 8k×8k CCD mosaic used at the prime focus of the 3.9 m Anglo-Australian Telescope (AAT) and the Cassegrain focus of the ANU 40-inch telescope at Siding Spring Observatory. WFI uses eight 4096×2048 MIT/Lincoln Labs CCDs. The cryostat, filter wheel and shutter mechanisms, corrector lens assemblies, support structure, CCD controllers, and control and user interface software were designed and constructed at RSAA with input from Auspace. The CCD focal plane was assembled and tested by Gerry Lupino of GL Scientific in Hawaii. WFI was commissioned on the 40-inch telescope in September 2000 and on the AAT in December 2000.

CASPIR

RSAA designed and constructed the highly successful CASPIR[1] near-infrared imager/spectrograph (McGregor et al. 1994) that is in operation on the ANU 2.3 m alt-azimuth telescope at Siding Spring Observatory. Peter McGregor was the Project Scientist for CASPIR, and many of the CASPIR design team now head up the NIFS project team. CASPIR was used to record unique images of the impacts of comet Shoemaker-Levy 9 with Jupiter in 1994. It is based on a 1-5 μm 256×256 SBRC InSb detector array. It produces image scales of 0.5″/pixel and 0.25″/pixel, and includes standard broad-band and a wide range of narrow band filters covering the 1-5 μm region. PK50 glass is used to block filter red leaks longward of 2.5 μm. The optics consist of sapphire, CaF_2, BaF_2, and MgO crystal lenses that were manufactured at RSAA and anti-reflection coated in Australia. CASPIR includes both plane and cross-dispersed replicated grisms

[1] http://www.mso.anu.edu.au/observing/docs/manual/manual.html

on BaLF50 glass prisms that deliver two-pixel resolving powers of ~ 500 and 1100, respectively, with a 1″ wide slit. It includes a Wollaston prism polarimetric analyzer , as well as coronagraph occulting disks and pupil masks. The camera body is cooled to ~ 70 K from the first stage of a two-stage CTI-Cryogenics closed cycle helium refrigerator. The 256×256 SBRC detectors are susceptible to microphonic noise from the cooler head. This has been eliminated in the standard way by mounting the cooler head on rubber bushes and a metal bellows arrangement designed in-house. The detector array is cooled from the second stage of the cooler and accurately servoed to a temperature of 32 K using a Lake Shore Cryotronics temperature controller. The detector is controlled using the SBRC ACE-2 drive electronics and a four-channel data system designed and constructed at RSAA. This system consists of two 2-channel 500 kHz, 16-bit ADC cards close to the instrument that transmit digitized data to a four-channel transputer-based preprocessor. The user interface is via a VAX Station 3200 that interacts with the telescope control computer for efficient, automated execution of a predefined observing sequence.

ANU 2.3 m Telescope Tip-Tilt Secondary

The ANU 2.3 m telescope at Siding Spring Observatory uses a tip-tilt system on the Cassegrain secondary mirror feeding the CASPIR imager/spectrograph. The system was designed and constructed at RSAA. It uses Physik Instrumente piezoelectric drivers incorporating strain gauge sensors for closed-loop control to position the secondary mirror, and a 64×64 pixel fast read-out CCD to monitor the position of a reference star. The optical CCD sensor views the telescope focal plane through a dichroic mirror that reflects infrared light to CASPIR. The CCD sensor is mounted on an X-Y stage that allows selection of any object within 2.5′ of the science object. The free-air seeing at Siding Spring Observatory is mediocre by international standards with the FWHM recorded at V in the 2.3 m dome having a mode of ~ 1.5″. The tip-tilt secondary system routinely delivers images at 2 μm with ~ 0.7″ FWHM in these conditions, as theory predicts for a 2 m telescope operating at 2 μm. The tip-tilt system ensures accurate positioning of objects on CASPIR's 1″ wide grism slits and is essential for registering images obtained at wavelengths longward of 3 μm where, in general, no objects are visible on individual exposures.

RSAA CICADA User Interface

RSAA software staff developed the CICADA[2] multi-process, distributed, multi-platform application for the control of astronomical instruments and of the data flow from detector systems. The different parts of the multi-process system are designed to operate in a pipeline processing, cooperating co-process environment for the efficient movement of data from and the simultaneous control of multiple parts. It is distributed and multi-platform because a user operating from an observer's workstation can control components of the instrument hosted by different, perhaps heterogeneous, computers. Each host in the system is accessible over a local area network or wide area network that can be configured for optimal data flow. CICADA has been used principally in the control of large format CCDs, such as WFI, with Leach and Astromed controllers, and is also used to control the 2.3 m telescope tip-tilt secondary mirror system. CICADA is in operation at RSAA, the University of Tasmania, and the University of Virginia.

JACARA

RSAA worked jointly with the University of New South Wales to build a site-testing telescope for Antarctica. RSAA staff designed and built two components of this telescope: a low power (< 20W) alt-azimuth mount with a pointing accuracy of a few arcseconds, that is capable of supporting two 70 kg telescopes; and a differential motion monitor (a telescope based on Celestron-14 optics). This mount and telescope, together with their RSAA designed and built electronics and software, have operated continuously for two years at the South Pole in extreme conditions without the need of maintenance.

Other RSAA Instruments

RSAA staff designed and supervised the construction of the 2.3 m telescope at Siding Spring Observatory. The telescope was commissioned in 1984 and uses what were at the time innovative features of an alt-

[2] http://www.mso.anu.edu.au/computing/cicada/cicada_adass96/cicada_adass96.html

azimuth mount, rotating building, and thin primary mirror. The Cassegrain focus is optimized for operation in the thermal infrared.

The main optical instruments on the 2.3 m telescope are the Double Beam Spectrograph (DBS; Rodgers, Conroy, & Bloxham 1988) and the Nasmyth B Imager (Rodgers, Bloxham, & Conroy 1993). Both were designed and constructed at RSAA. The DBS is an efficient medium-resolution dual-beam spectrograph. It uses a selection of dichroic mirrors located behind a single 6′ long slit to feed light into separate blue and red spectrographs. Folded f/1 Schmidt cameras provide fully-sampled spectra with a 2″ slit width. Each spectrograph is separately optimized for high throughput. The Nasmyth B Imager is a transmissive focal reducer for optical imaging, low resolution grism spectroscopy, and coronography. It features collimated beam filters and tiltable narrow-band filters in a telecentric section. Both instruments can be used with multi-slit masks for multi-object spectroscopy.

10 Subcontractors and Consultants

10.1 Auspace

CAPABILITIES AND SERVICES

Based on its experience in space systems and related areas, Auspace has developed an extensive range of capabilities and services that can be offered to prospective customers and teaming partners. Auspace has a proven reputation with its many customers, both government and private.

Capabilities

- Multidisciplinary Project Management
- Instrumentation Design and Development
- Electro-optics systems design and assembly
- Small Satellite Systems and Launch Systems
- Precision Assembly, Integration and Test
- Communications Systems
- Training Courses
- Quality Systems
- Satellite Earth Stations
- Synthetic Aperture Radar
- Mechanical/Structural/Thermal Engineering
- High Reliability electronic equipment
- Satellite Ground Support
- Real-time software
- Hi-Rel Systems Engineering

Services

- Design and development
- Applied research and development
- Consultancies
- Feasibility Studies
- Engineering Services
- Project Teaming and Collaboration
- Contracting Out Experienced Personnel

Mechanical and Electro-optic Engineering Capabilities
A corner stone of Auspace expertise is its broad based mechanical engineering capability. High reliability electro-optic and electronics areas are complemented by our mechanical, thermal and optical capabilities. These have been applied to a wide range of hardware solutions for applications that include instruments for astronomy, airborne and space remote sensing and special purpose ground test equipment. Purpose designed facilities in Canberra include a Class 100/10000 cleanroom and laminar flow work benches, thermal vacuum chambers, a Stirling cycle cryo-cooler, design software tools, and a wide range of electronic and optical test equipment and fittings. Auspace operates an IS09001-1994 accredited Quality System. Our mechanical and electro-optic design capabilities cover the range of activities from drafting or analysis tasks to complete projects including all phases from conceptual design to delivery of an integrated and tested system.

Specific capabilities include:

- Project management of complex instrument design and integration tasks.
- Electro-optic instrument system/mechanical/thermal/optical design, component assembly, instrument integration, testing and calibration.
- Detector technologies.
- Vacuum system design and manufacture.
- Cleanroom operation and management.
- 3D Solid Modeling
- Design drafting
- Manufacturing drawings and specifications
- Finite Element Analysis
- Thermal design and analysis
- Component procurement
- Test Specification and Procedures

We utilize an evolving suite of CAE tools to support this work. Typically, we will work with the customer, and specialist partners, where required, to establish the user requirements and interfaces. In general, each of our design and AIT engineers is competent in a number of complementary fields and are used to working in multi-disciplinary project groups.

Past design and construction projects

- Australian Resource Information and environment Satellite (ARIES). As a founder member of the Aries consortium Auspace is responsible for provision of the Space Segment. At this time the pre-implementation conceptual design study has been successfully completed.

- Advanced Along Track Scanning Radiometer (AATSR). Prime contractor for the infrared and visible focal plane assemblies and fore-optics, and the mechanical redesign of the Signal Preamplifier Assembly and Integrated Electronics Unit.

- Along Track Scanning Radiometer 2. (ATSR-2). Prime Contractor for the infrared focal plane array, now in orbit on the ERS-2 satellite.

- Endeavour Ultraviolet Telescope. Prime Contractor for the Australian Space Telescope flown on the NASA space shuttle in 1992 and 1995.

- Wide Field Imager. (WFI). Thermal, vacuum and mechanical design for a vacuum vessel and liquid nitrogen dewar to hold the electronics and detector system for use with the Siding Springs Observatory 40" telescopes.

- Airborne Multispectral Scanner. (AMS). Program management and system design of a high performance airborne multispectral scanner for mining applications.

- Atmospheric Pressure Scanner (APS). Mechanical and thermal design and construction of experimental, airborne, version of an instrument concept intended to measure ground atmospheric pressure from a satellite in low earth orbit.

- Gemini Near-infrared Integral Field Spectrograph (NIFS). Design of precision cryogenic mechanisms.

Quality Systems

Auspace understands the importance of quality products and services, and is accredited to IS09001:1994. Auspace was one of the first Australian companies to achieve the quality endorsed company status. Auspace's quality system is capable of achieving the higher requirements of space as well as implementing suitable ISO9001 standards for consultancies and other ground based work, while maintaining organizational effectiveness and efficiency. Auspace has maintained this accreditation since 1993 by continually updating and improving our system. As part of the Cooperative Research Centre for Satellite Systems program, Auspace has been contracted to set up the quality system for the CRC. The initial part of this project included a quality training course to identify to the CRC members the need for quality and explained the International quality standard IS09001.

10.2 Prime Optics

PRIME OPTICS

OPTICAL SYSTEMS DESIGN

Prime Optics is an optical design consultancy service offering research and development of optical systems for scientific, industrial and commercial applications. The services that are currently provided include:

- system assessment.
- design & feasibility studies.
- final designs of optical systems.
- opto-mechanical design assistance, with CAD support.
- assistance with fabrication, system assembly, testing, troubleshooting and calibration.

Basic research is fundamental to the development of fine optical systems. A rigorous and wide-ranging approach is used which is supported by extensive in-house literature and a diverse personal network both in Australia and overseas. Results of original research are occasionally published.

CAPABILITY & EXPERIENCE

Since its establishment in 1990, **Prime Optics** has provided the Optical Design for several major new astronomical instrument developments, including:

- **2dF**: the new wide field corrector for the **AAT** and its spectrographs. This instrument has commenced a galactic survey of the southern skies.
- **CASPIR**: IR instrumentation for the **MSSSO**. This instrument delivered most of the early IR pictures of the collision of Comet Shoemaker-Levy with the planet Jupiter.
- **AUSTRALIS**: Preliminary research for the IR spectrographs for the European Southern Observatory's 8 m telescopes.
- **IRIS2**: IR spectrograph/imager for the **AAT**.
- **PNS**: the Planetary Nebula Spectrograph for the **WHT** and **TNG** telescopes.
- **EMIR**: the first-light IR spectrograph for **GRANTECAN**.
- **Prime Optics** has supported the CSIRO (Australia) Atmospheric Pressure Sounder project with VIPAC through Optical Design, calibration, alignment and testing.
- **Prime Optics** has an ongoing association with BHP, LaserDyne Technologies and GBC Instruments with several commercial developments in the construction phase.
- **Prime Optics** is assisting several parties in the development of commercial products.
- **Prime Optics** uses in-house Optical Design software and is therefore not restricted by the limitations of proprietary products. Software is developed or adapted on-demand for unusual applications.

10.3 GL Scientific

GL SCIENTIFIC

GL Scientific was founded in 1996, and specializes in the design and fabrication of scientific instruments, with emphasis on astronomical instrumentation. Our specialty involves the development of large detector focal planes, both for optical and infrared imaging, and the systems and components that such focal planes require. For example, GL Scientific has developed/delivered the following products:

Turn-key systems:

- Cryogenically cooled CCD mosaic cameras with detectors as large as 150mm x 150mm and having 8K x 8K pixels. System components:
- Cryogenically cooled IR array mosaic focal planes as large as 4kx4k pixels for ground and space-based imaging cameras.

Flight focal planes for satellite imaging systems.

- GL Scientific provided the soft x-ray coded-aperture detectors for the NASA High Energy Transient Explorer Satellite.
- Precision mosaic packages and multi-chip ceramic modules for the Infrared Imagers being made by Rockwell Scientific for the Next Generation Space Telescope.

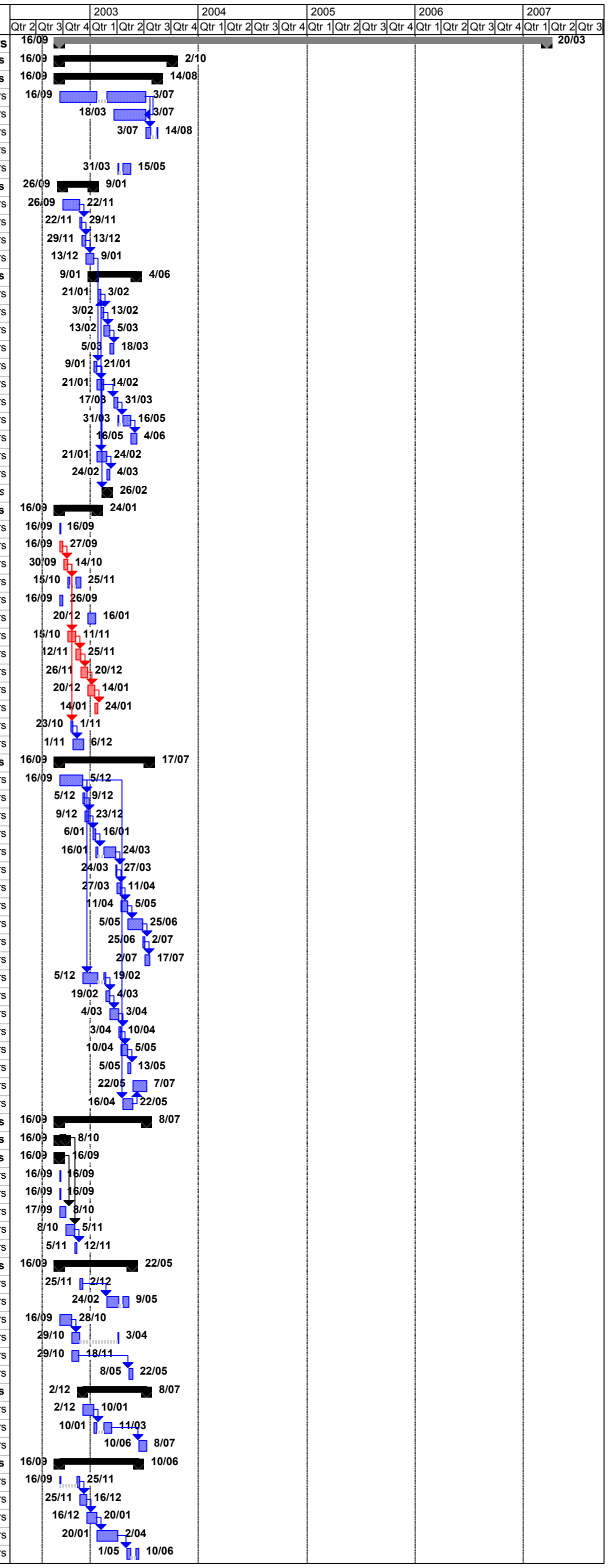
GL Scientific provides engineering services for the design of detector systems and their components for numerous groups. A small list of GL Scientific customers includes:

- Massachusetts Institute of Technology
- Caltech
- University of Washington
- Columbia University
- Dartmouth College
- Penn State University
- Yale Observatories:
- Keck Observatory
- Canada France Hawaii Telescope
- Subaru Telescope
- Anglo-Australian Observatory
- Gemini Observatory
- Observatories of the Carnegie Institute of Washington
- MDM Observatory
- National Optical Astronomy Observatories
- European Southern Observatory
- Mount Stromlo and Siding Springs Observatory (Australia)
- NASA Goddard Space Flight Center
- Lawrence Berkeley National Lab
- Rockwell Scientific
- IBM Corporation
- KLA-Tencor

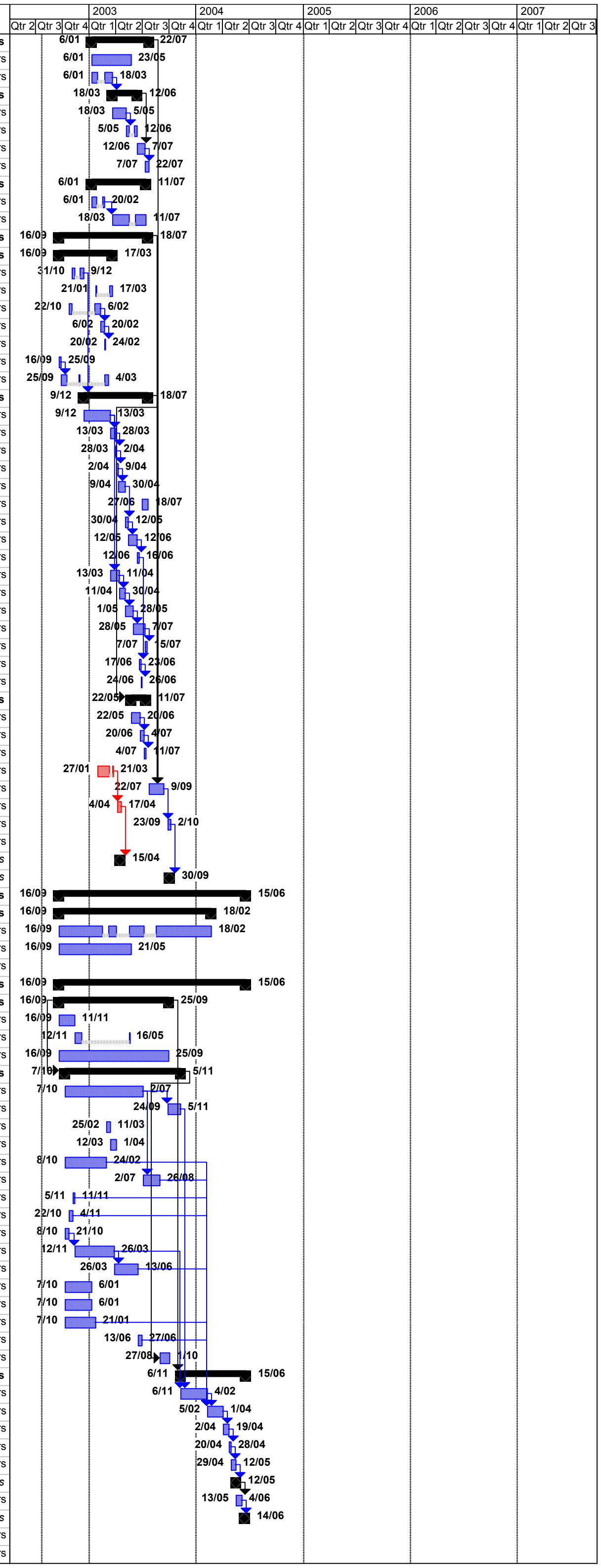
ANNEXES

1 A Detailed Gantt Chart of the GSAOI Schedule

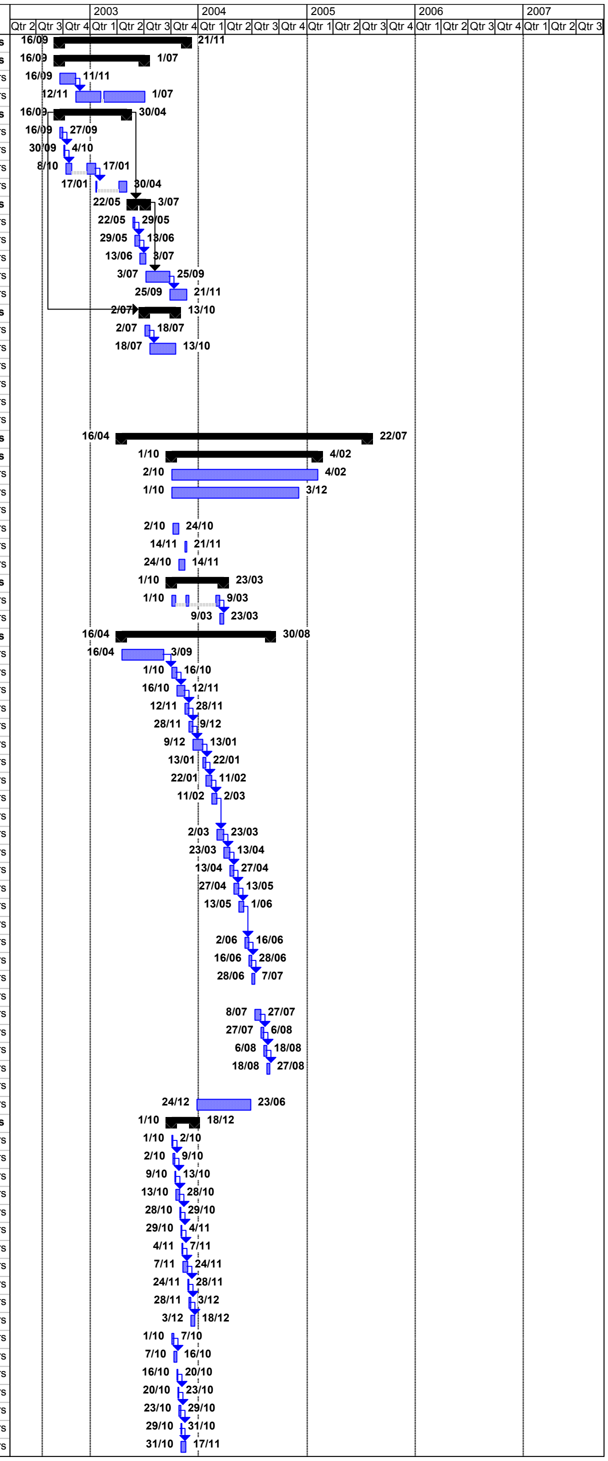
ID	WBS	Task Name	Work
0	**0**	**Gemini South Adaptive Optics Imager**	**49,009 hrs**
1	**1**	**Instrument Design**	**11,879 hrs**
2	**1.1**	**Project General**	**639 hrs**
3	1.1.1	Project Management	350 hrs
4	1.1.2	Quality Assurance	49 hrs
5	1.1.3	Revise Plan & Budget	105 hrs
6	1.1.4	Travel	0 hrs
7	1.1.5	PS Miscellaneous	135 hrs
8	**1.2**	**Scientific Requirements**	**455 hrs**
9	1.2.1	Science Case	280 hrs
10	1.2.2	Refine Performance Predictions	35 hrs
11	1.2.3	Verification & Commissioning Plan	70 hrs
12	1.2.4	Refine OCDD	70 hrs
13	**1.3**	**System Design**	**889 hrs**
14	1.3.1	Refine Requirements Analysis	35 hrs
15	1.3.2	Refine Space/Mass/Power Budgets	56 hrs
16	1.3.3	Refine Optical Error Budget	56 hrs
17	1.3.4	Refine Flexure Budget	35 hrs
18	1.3.5	Refine FPRD	35 hrs
19	1.3.6	Acceptance Test Plan	70 hrs
20	1.3.7	Integration & Test Plan	70 hrs
21	1.3.8	Safety Review	70 hrs
22	1.3.9	Final ICDs	210 hrs
23	1.3.10	Tables of Contents for Manuals	175 hrs
24	1.3.11	Draft Spares List	77 hrs
25	*1.4*	*OCDD/FPRD Approval*	*0 hrs*
26	**1.5**	**Optical Design**	**798 hrs**
27	1.5.1	Measure MgO Refractive Index	0 hrs
28	1.5.2	Collimator Design	105 hrs
29	1.5.3	Camera Design	105 hrs
30	1.5.4	Pupil Viewer Design	70 hrs
31	1.5.5	Filter Selection	35 hrs
32	1.5.6	Optical Coatings	35 hrs
33	1.5.7	Optical Tolerancing	98 hrs
34	1.5.8	Ghost Image Analysis	35 hrs
35	1.5.9	Alignment Requirements	105 hrs
36	1.5.10	Wavefront Error Budget	35 hrs
37	1.5.11	Transmission	35 hrs
38	1.5.12	Revise Nominal Specifications	35 hrs
39	1.5.13	Determine Temperature Compensate	105 hrs
40	**1.6**	**Mechanical Design**	**2,143 hrs**
41	1.6.1	General Configuration	400 hrs
42	1.6.2	Design Window Mount	15 hrs
43	1.6.3	Design Coldbox	75 hrs
44	1.6.4	Design Field Splitter	60 hrs
45	1.6.5	Design Field Mask Wheel	225 hrs
46	1.6.6	Design Field Lens	23 hrs
47	1.6.7	Design First Stage Collimator (incl 1s	75 hrs
48	1.6.8	Design Second Stage Collimator (incl	75 hrs
49	1.6.9	Design Filter Wheels	250 hrs
50	1.6.10	Design Fast Shutter	35 hrs
51	1.6.11	Design First Stage Camera (incl 3rd F	75 hrs
52	1.6.12	Design Utility Wheel	225 hrs
53	1.6.13	Design Second Stage Camera	60 hrs
54	1.6.14	Design Detector System	150 hrs
55	1.6.15	Design Baffling	35 hrs
56	1.6.16	Design CWS Plate Details	75 hrs
57	1.6.17	Design Cold Link System	45 hrs
58	1.6.18	Design Alignment System	175 hrs
59	1.6.19	Stability Analysis	70 hrs
60	**1.7**	**Detector Control Design**	**2,060 hrs**
61	**1.7.1**	**Focalplane Design**	**100 hrs**
62	**1.7.1.1**	**GL Scientific Contract**	**0 hrs**
63	1.7.1.1.1	Final Focalplane	0 hrs
64	1.7.1.1.2	Test Focalplane	0 hrs
65	1.7.1.2	RSAA Interfacing	100 hrs
66	1.7.2	Detector Design	140 hrs
67	1.7.3	Detector Controller Decision	35 hrs
68	**1.7.4**	**SDSU Controller Design**	**805 hrs**
69	1.7.4.1	Controller Configuration and Ord	35 hrs
70	1.7.4.2	Controllers Acceptance Test, Ca	245 hrs
71	1.7.4.3	Bias Board Design	210 hrs
72	1.7.4.4	Bias Board Layout	140 hrs
73	1.7.4.5	Output Load Board Design	105 hrs
74	1.7.4.6	Output Load Board Layout	70 hrs
75	**1.7.5**	**SDSU Controller DSP Software Des**	**420 hrs**
76	1.7.5.1	Familarize new timing boot code	140 hrs
77	1.7.5.2	Compose DSP to host interface (	140 hrs
78	1.7.5.3	Compose detector operational re	140 hrs
79	**1.7.6**	**Detector Wiring Design**	**560 hrs**
80	1.7.6.1	Motherboard Design	70 hrs
81	1.7.6.2	Motherboard Layout	105 hrs
82	1.7.6.3	Flex Circuit Design	105 hrs
83	1.7.6.4	Flex Circuit Layout	175 hrs
84	1.7.6.5	Controller Wiring	105 hrs



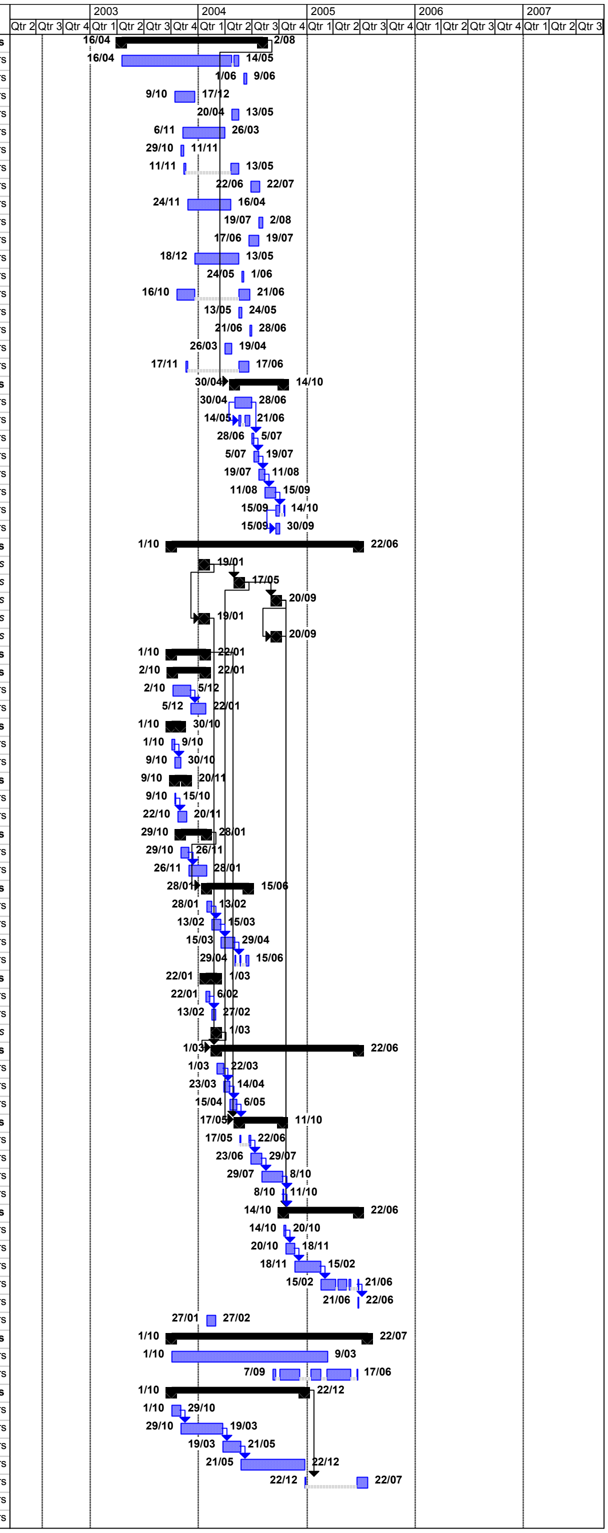
ID	WBS	Task Name	Work
85	**1.8**	**Control Software Design**	**869 hrs**
86	1.8.1	Software Management	63 hrs
87	1.8.2	Setup Development System	150 hrs
88	**1.8.3**	**Component Controller Software**	**224 hrs**
89	1.8.3.1	Adapt NIFS CC s/w	140 hrs
90	1.8.3.2	Document GSAOI System	84 hrs
91	1.8.4	Instrument Sequencer Software	83 hrs
92	1.8.5	Temperature Control System	54 hrs
93	**1.8.6**	**Detector Controller Software**	**295 hrs**
94	1.8.6.1	Select IOC Hardware	70 hrs
95	1.8.6.2	DC Software Design	225 hrs
96	**1.9**	**OIWFS Design**	**2,169 hrs**
97	**1.9.1**	**OIWFS Optical Design**	**479 hrs**
98	1.9.1.1	Finalise Optical Design	120 hrs
99	1.9.1.2	Filter Selection	35 hrs
100	1.9.1.3	Optical Tolerancing	100 hrs
101	1.9.1.4	Alignment Requirements	70 hrs
102	1.9.1.5	Transmission	14 hrs
103	1.9.1.6	Revise Nominal Specifications	35 hrs
104	1.9.1.7	Determine Temperature Comper	105 hrs
105	**1.9.2**	**OIWFS Mechanical Design**	**1,445 hrs**
106	1.9.2.1	General Configuration	400 hrs
107	1.9.2.2	Design WFS Coldbox	75 hrs
108	1.9.2.3	Design WFS Field Lens	23 hrs
109	1.9.2.4	Design WFS Primary Beam Fold	36 hrs
110	1.9.2.5	Design WFS Collimator	60 hrs
111	1.9.2.6	Design WFS Beam Steerer	110 hrs
112	1.9.2.7	Design WFS Secondary Beam F	60 hrs
113	1.9.2.8	Design WFS Field Mask Wheel	150 hrs
114	1.9.2.9	Design WFS Pupil Relay	20 hrs
115	1.9.2.10	Design WFS Filter Wheel	120 hrs
116	1.9.2.11	Design WFS Tertiary Beam Fold	40 hrs
117	1.9.2.12	Design WFS Field Relay	110 hrs
118	1.9.2.13	Design WFS Detector System	150 hrs
119	1.9.2.14	Design WFS Baffling	35 hrs
120	1.9.2.15	Design WFS Alignment Aids	35 hrs
121	1.9.2.16	Design WFS Detector Controller	21 hrs
122	**1.9.3**	**OIWFS Detector System Design**	**245 hrs**
123	1.9.3.1	OIWFS Detector PCB Design	140 hrs
124	1.9.3.2	OIWFS Detector Wiring Design	70 hrs
125	1.9.3.3	OIWFS Detector Controller Desi	35 hrs
126	1.10	Produce Preliminary Design Documentatic	490 hrs
127	1.11	Produce Critical Design Documentation	966 hrs
128	1.12	PDR	161 hrs
129	1.13	CDR	240 hrs
130	1.14	Contingency	0 hrs
131	*2*	*PDR*	*0 hrs*
132	*3*	*CDR*	*0 hrs*
133	**4**	**Cryostat & Control System Construction**	**7,372 hrs**
134	**4.1**	**Project General**	**616 hrs**
135	4.1.1	Project Management	560 hrs
136	4.1.2	Quality Assurance	56 hrs
137	4.1.3	Travel	0 hrs
138	**4.2**	**Cryostat and Frame Construction**	**4,121 hrs**
139	**4.2.1**	**Design & Supervision**	**770 hrs**
140	4.2.1.1	Design Changes	280 hrs
141	4.2.1.2	Procurement	140 hrs
142	4.2.1.3	Supervision	350 hrs
143	**4.2.2**	**Fabrication**	**2,490 hrs**
144	4.2.2.1	Vacuum Jacket Prefab	0 hrs
145	4.2.2.2	Vacuum Jacket Machining	210 hrs
146	4.2.2.3	Window Mount Construction	70 hrs
147	4.2.2.4	Environmental Cover Constructic	105 hrs
148	4.2.2.5	Cryocooler System Construction	630 hrs
149	4.2.2.6	Cold Work Surface Construction	280 hrs
150	4.2.2.7	Floating Shield Construction	35 hrs
151	4.2.2.8	Temperature Control System Co	70 hrs
152	4.2.2.9	Wiring Connector System Constr	70 hrs
153	4.2.2.10	Construct Radiation Shields	600 hrs
154	4.2.2.11	Handling Equipment Constructio	350 hrs
155	4.2.2.12	ISS Interface Plate Construction	0 hrs
156	4.2.2.13	Auxiliaries Frame	0 hrs
157	4.2.2.14	Cryocoolers & Bellows	0 hrs
158	4.2.2.15	Vacuum Gauge and Fittings	70 hrs
159	4.2.3	Plating/Coating/Anodising	0 hrs
160	**4.2.4**	**Assembly and Development**	**861 hrs**
161	4.2.4.1	Clean, Polish & Bake-out Compc	420 hrs
162	4.2.4.2	Assemble VJ, Rad Shields, Cryo	280 hrs
163	4.2.4.3	Pump & Vacuum Test 1	35 hrs
164	4.2.4.4	Leak Rectification	56 hrs
165	4.2.4.5	Pump & Vacuum Test 2	35 hrs
166	*4.2.4.6*	*Cryostat Holds Vacuum*	*0 hrs*
167	4.2.4.7	Empty Cryostat Cooldown	35 hrs
168	*4.2.4.8*	*Cryostat Reaches Operating Ter*	*0 hrs*
169	4.2.5	Miscellanious Items & Consumables	0 hrs
170	4.2.6	Contingency	0 hrs



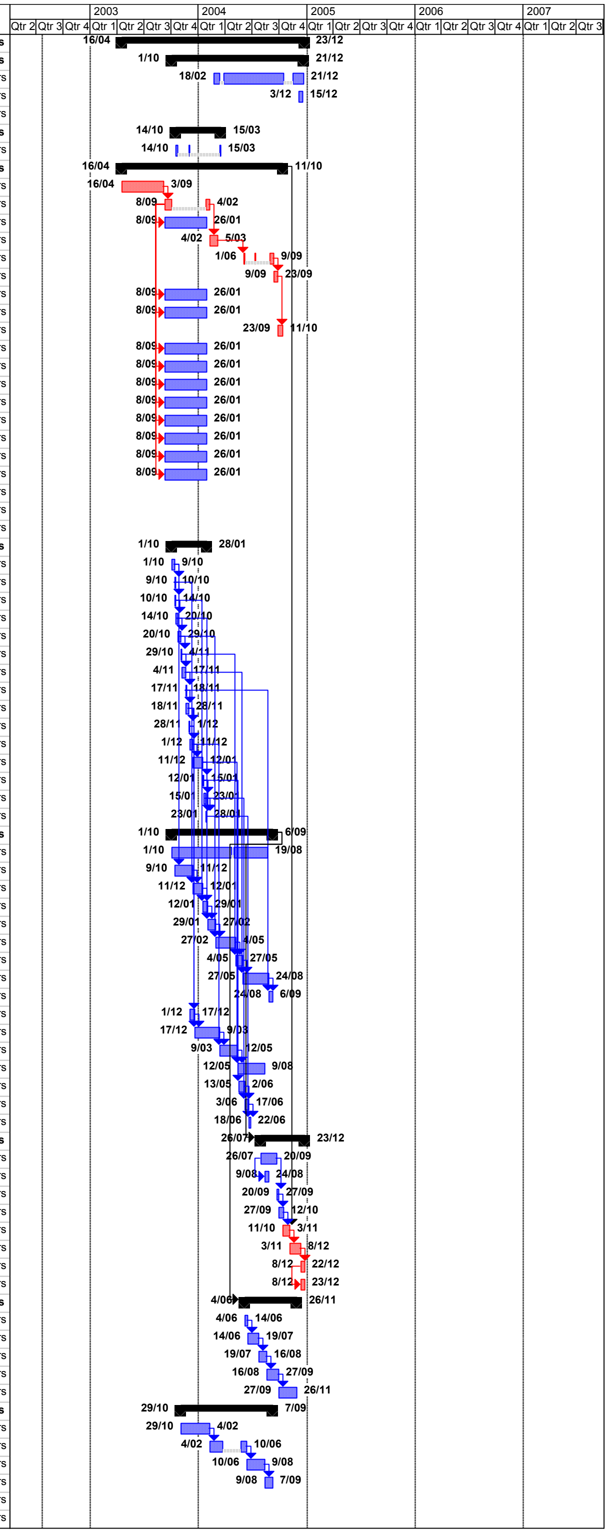
ID	WBS	Task Name	Work
171	**4.3**	**Control System Construction**	**2,635 hrs**
172	**4.3.1**	**Design & Supervision**	**840 hrs**
173	4.3.1.1	Design Changes	280 hrs
174	4.3.1.2	Supervision	560 hrs
175	**4.3.2**	**CC Fabrication**	**420 hrs**
176	4.3.2.1	Thermal Enclosure	70 hrs
177	4.3.2.2	VME Crate and Network installat	35 hrs
178	4.3.2.3	Phytron Backplane Frame Fabric	210 hrs
179	4.3.2.4	Cryocooler Drive Frame Fabricat	105 hrs
180	**4.3.3**	**DC Fabrication**	**175 hrs**
181	4.3.3.1	Thermal Enclosure	35 hrs
182	4.3.3.2	Detector Controllers Installation	70 hrs
183	4.3.3.3	Imager Detector Temperature Cc	70 hrs
184	4.3.4	Cable Manufacture	420 hrs
185	4.3.5	Cryostat Internal Wiring	280 hrs
186	**4.3.6**	**Mechanical**	**500 hrs**
187	4.3.6.1	Control System Mechanical Desi	80 hrs
188	4.3.6.2	Control System Mechanical Worl	420 hrs
189	4.3.7	Miscellanious Items & Consumables	0 hrs
190	4.3.8	Contingency	0 hrs
191	4.4	Miscellaneous Items & Consumables	0 hrs
192	4.5	Contingency	0 hrs
193	**5**	**Imager Construction**	**13,629 hrs**
194	**5.1**	**Project General**	**1,323 hrs**
195	5.1.1	Project Management	980 hrs
196	5.1.2	Quality Assurance	98 hrs
197	5.1.3	Travel	0 hrs
198	5.1.4	Web Page Maintenance	105 hrs
199	5.1.5	Public Outreach	35 hrs
200	5.1.6	PS Miscellanious	105 hrs
201	**5.2**	**System Engineering**	**280 hrs**
202	5.2.1	Produce Record Documents	175 hrs
203	5.2.2	Final Spares List	105 hrs
204	**5.3**	**Imager Optical Fabrication**	**815 hrs**
205	5.3.1	Order Optical Materials	0 hrs
206	5.3.2	Construct Window Lens	40 hrs
207	5.3.3	Construct Field Splitter Mirror	80 hrs
208	5.3.4	Construct Field Lens	50 hrs
209	5.3.5	Construct Beam Folder Mirror 1	30 hrs
210	5.3.6	Construct Collimator Lens 1	45 hrs
211	5.3.7	Construct Beam Folder Mirror 2	30 hrs
212	5.3.8	Construct Collimator Lens 2	45 hrs
213	5.3.9	Construct Collimator Lens 3	50 hrs
214	5.3.10	Collimator Glass Contingency	0 hrs
215	5.3.11	Construct Camera Lens 1	50 hrs
216	5.3.12	Construct Camera Lens 2	45 hrs
217	5.3.13	Construct Beam Folder Mirror 3	30 hrs
218	5.3.14	Construct Camera Lens 3	45 hrs
219	5.3.15	Construct Camera Lens 4	45 hrs
220	5.3.16	Camera Glass Contingency	0 hrs
221	5.3.17	Construct Pupil Viewer Lens 1	35 hrs
222	5.3.18	Construct Pupil Viewer Lens 2	35 hrs
223	5.3.19	Construct Pupil Viewer Lens 3	30 hrs
224	5.3.20	Pupil Viewer Glass Contingency	0 hrs
225	5.3.21	Construct Defocus Lens Inside 1	35 hrs
226	5.3.22	Construct Defocus Lens Inside 2	30 hrs
227	5.3.23	Construct Defocus Lens Outside 1	35 hrs
228	5.3.24	Construct Defocus Lens Outside 2	30 hrs
229	5.3.25	Defocus Glass Contingency	0 hrs
230	5.3.26	Filters	0 hrs
231	**5.4**	**Produce Fabrication Drawings**	**603 hrs**
232	5.4.1	Window Mount	5 hrs
233	5.4.2	Coldbox	25 hrs
234	5.4.3	Field Splitter	20 hrs
235	5.4.4	Field Mask Wheel	75 hrs
236	5.4.5	Field Lens	7 hrs
237	5.4.6	First Stage Collimator (incl 1st Folde	25 hrs
238	5.4.7	Second Stage Collimator (incl 2nd Fc	25 hrs
239	5.4.8	Filter Wheels	75 hrs
240	5.4.9	Fast Shutter	25 hrs
241	5.4.10	First Stage Camera (incl 3rd Folder)	25 hrs
242	5.4.11	Utility Wheel	75 hrs
243	5.4.12	Second Stage Camera	20 hrs
244	5.4.13	Detector System	50 hrs
245	5.4.14	Baffling	15 hrs
246	5.4.15	Detector Controller Mount	21 hrs
247	5.4.16	CWS Plate	25 hrs
248	5.4.17	Cold Link System	15 hrs
249	5.4.18	Alignment System	75 hrs



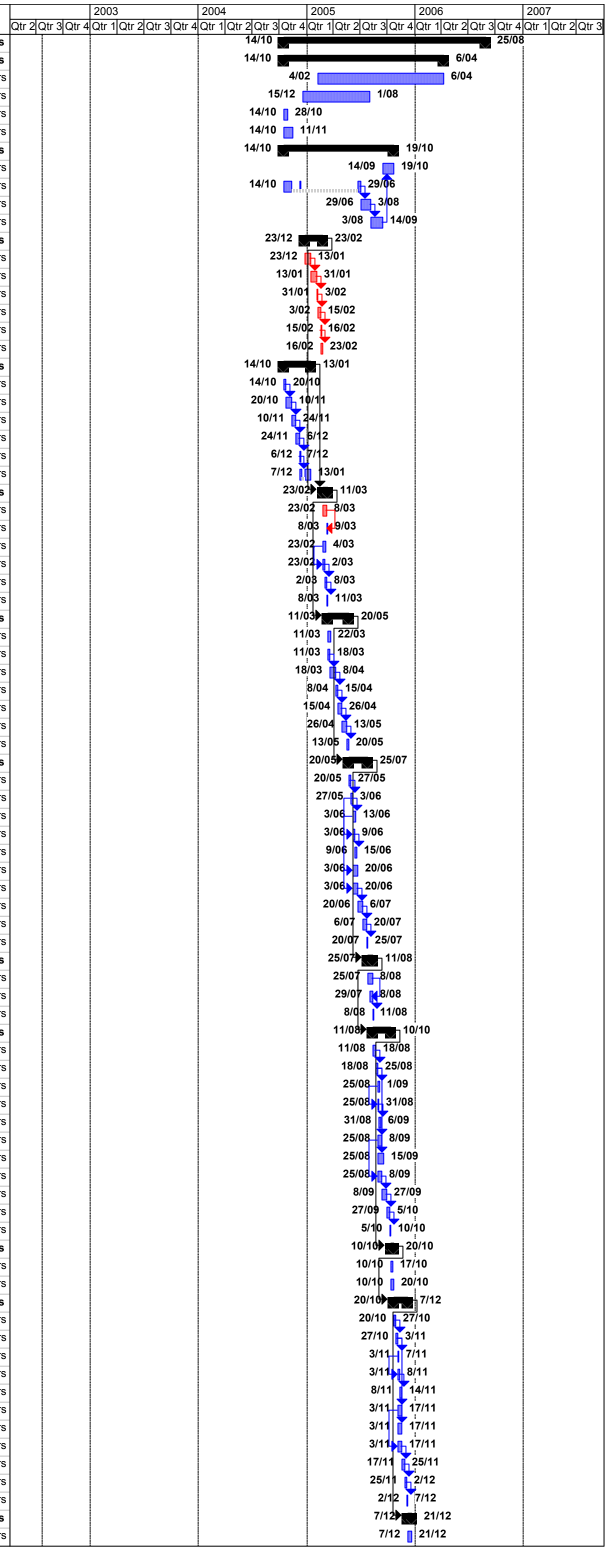
ID	WBS	Task Name	Work
250	**5.5**	**Imager Mechanical Fabrication**	**3,745 hrs**
251	5.5.1	Supervision	350 hrs
252	5.5.2	Construct Window Mount	40 hrs
253	5.5.3	Construct Coldbox	0 hrs
254	5.5.4	Construct Field Splitter	100 hrs
255	5.5.5	Construct Field Mask Wheel	600 hrs
256	5.5.6	Construct Field Lens Mount	60 hrs
257	5.5.7	Construct First Stage Collimator (incl	160 hrs
258	5.5.8	Construct Second Stage Collimator (i	120 hrs
259	5.5.9	Construct Filter Wheels	600 hrs
260	5.5.10	Construct Fast Shutter	70 hrs
261	5.5.11	Construct First Stage Camera (incl 3r	120 hrs
262	5.5.12	Construct Utility Wheel	600 hrs
263	5.5.13	Construct Second Stage Camera	40 hrs
264	5.5.14	Construct Detector System	500 hrs
265	5.5.15	Construct Baffling	50 hrs
266	5.5.16	Construct Detector Controller Mount	35 hrs
267	5.5.17	Construct Cold Link System	100 hrs
268	5.5.18	Construct Alignment System	200 hrs
269	**5.6**	**Imager Trial Assembly & Test**	**854 hrs**
270	5.6.1	Assemble without Optics and Detecto	280 hrs
271	5.6.2	Mechanism Control Wiring	91 hrs
272	5.6.3	Install Covers and Baffles	35 hrs
273	5.6.4	Problem Rectification 1	105 hrs
274	5.6.5	Install Optics	70 hrs
275	5.6.6	Test Optics	105 hrs
276	5.6.7	Test Mechanism Operation	98 hrs
277	5.6.8	Test Components Controller s/w	70 hrs
278	**5.7**	**Imager Detector System**	**3,304 hrs**
279	*5.7.1*	*Bare Mux Delivery*	*0 hrs*
280	*5.7.2*	*Engineering Detectors Delivery*	*0 hrs*
281	*5.7.3*	*Science Detectors Delivery*	*0 hrs*
282	*5.7.4*	*Test Focalplane Delivery*	*0 hrs*
283	*5.7.5*	*Final Focalplane Delivery*	*0 hrs*
284	**5.7.6**	**SDSU Controller Assembly**	**693 hrs**
285	**5.7.6.1**	**Firmware/Test Software**	**350 hrs**
286	5.7.6.1.1	Write and Test DSP code	210 hrs
287	5.7.6.1.2	Test CICADA	140 hrs
288	**5.7.6.2**	**Bias Boards**	**175 hrs**
289	5.7.6.2.1	Manufacture	35 hrs
290	5.7.6.2.2	Test	140 hrs
291	**5.7.6.3**	**Output Load Boards**	**168 hrs**
292	5.7.6.3.1	Manufacture	28 hrs
293	5.7.6.3.2	Test	140 hrs
294	**5.7.7**	**Prototype Detector System**	**189 hrs**
295	5.7.7.1	Flex Circuit Manufacture	70 hrs
296	5.7.7.2	External Cryostat Wiring Manufa	119 hrs
297	**5.7.8**	**Detector Final System**	**287 hrs**
298	5.7.8.1	Finalize designs and layout	56 hrs
299	5.7.8.2	Flex Circuit Manufacture	70 hrs
300	5.7.8.3	External Cryostat Wiring Manufa	119 hrs
301	5.7.8.4	Detector IOC Connector Panel	42 hrs
302	**5.7.9**	**Electrostatic Protection**	**84 hrs**
303	5.7.9.1	Design Shorting Connectors	49 hrs
304	5.7.9.2	Manufacture Shorting Connector	35 hrs
305	*5.7.9.3*	*Test Cryostat Available*	*0 hrs*
306	**5.7.10**	**Test-Cryostat Operation**	**1,981 hrs**
307	5.7.10.1	Confirm Test-Cryostat Operation	105 hrs
308	5.7.10.2	Assemble Test-Focalplane into T	105 hrs
309	5.7.10.3	Do Temperature Cooldown Tests	105 hrs
310	**5.7.10.4**	**Detector Prototype System**	**588 hrs**
311	5.7.10.4.1	Assemble	28 hrs
312	5.7.10.4.2	Benck Test with Bare Mux	175 hrs
313	5.7.10.4.3	Install in Cryostat with Engir	385 hrs
314	5.7.10.4.4	Ready for installing in GSAC	0 hrs
315	**5.7.10.5**	**Detector Final System**	**1,078 hrs**
316	5.7.10.5.1	Assemble	28 hrs
317	5.7.10.5.2	Benck Test with Bare Mux	175 hrs
318	5.7.10.5.3	Install in Cryostat with Engir	385 hrs
319	5.7.10.5.4	Install and Characterise Scie	490 hrs
320	5.7.10.5.5	Ready for installing in GSAC	0 hrs
321	5.7.11	Test Detector Control S/W	70 hrs
322	**5.8**	**Imager Software Development**	**2,705 hrs**
323	5.8.1	Software Management	350 hrs
324	5.8.2	IS and CC Software	638 hrs
325	**5.8.3**	**Detector Controller Software**	**1,612 hrs**
326	5.8.3.1	EPICS Changes	92 hrs
327	5.8.3.2	Adapt NIFS s/w - CICADA	484 hrs
328	5.8.3.3	SDSU PMC I/f Device Driver	320 hrs
329	5.8.3.4	Adapt NIFS s/w - VxWorks	716 hrs
330	5.8.4	Data Reduction Software	105 hrs
331	5.9	Miscellaneous Items & Consumables	0 hrs
332	5.10	Contingency	0 hrs



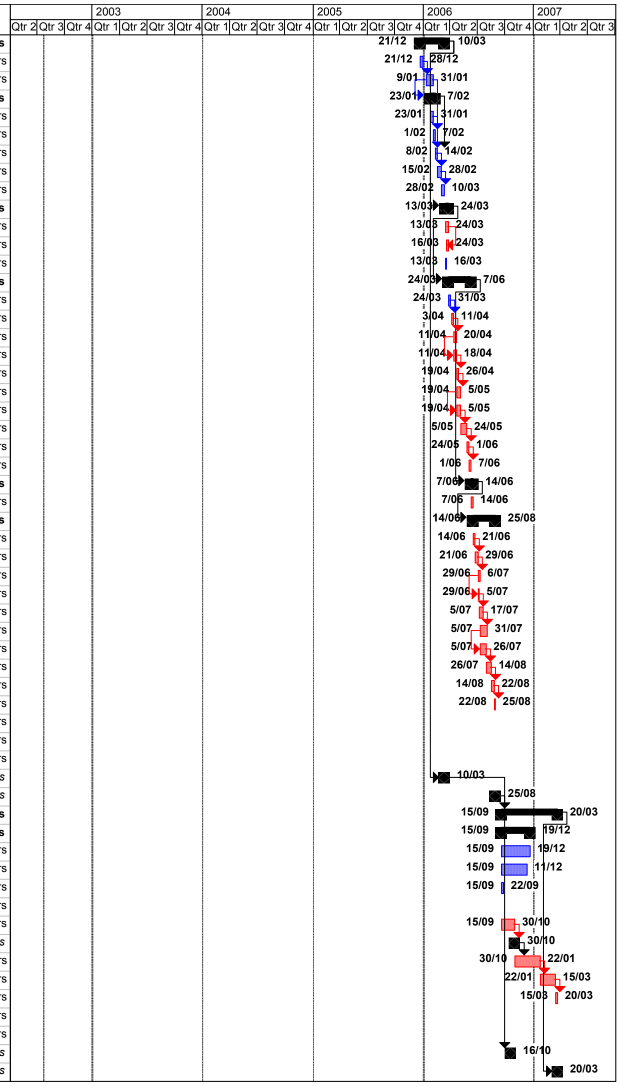
ID	WBS	Task Name	Work
333	**6**	**OIWFS Construction**	**6,526 hrs**
334	**6.1**	**Project General**	**616 hrs**
335	6.1.1	Project Management	560 hrs
336	6.1.2	Quality Assurance	56 hrs
337	6.1.3	Travel	0 hrs
338	**6.2**	**System Engineering**	**105 hrs**
339	6.2.1	Produce Record Documents	105 hrs
340	**6.3**	**OIWFS Optics Fabrication**	**235 hrs**
341	6.3.1	Order Optical Materials	0 hrs
342	6.3.2	Construct WFS Field Lens	55 hrs
343	6.3.3	Construct WFS Primary Beam Folder	0 hrs
344	6.3.4	Construct WFS Collimator First Lens	45 hrs
345	6.3.5	Construct WFS Collimator Second Le	45 hrs
346	6.3.6	Construct WFS Collimator Third Lens	45 hrs
347	6.3.7	Construct WFS Beam Steerer Mirror	0 hrs
348	6.3.8	Construct WFS Secondary Beam Fol	0 hrs
349	6.3.9	Construct WFS Pupil Relay Lens	45 hrs
350	6.3.10	Construct WFS Tertiary Beam Folder	0 hrs
351	6.3.11	Construct WFS Field Relay First Lens	0 hrs
352	6.3.12	Construct WFS Field Relay Second L	0 hrs
353	6.3.13	Construct WFS Field Relay Prism	0 hrs
354	6.3.14	Construct WFS Field Relay Third Len	0 hrs
355	6.3.15	Construct WFS Field Relay Fourth Le	0 hrs
356	6.3.16	Construct WFS Field Relay Fifth Lens	0 hrs
357	6.3.17	Construct WFS Field Relay Sixth Len	0 hrs
358	6.3.18	WFS Glass Contingency	0 hrs
359	6.3.19	WFS Filters	0 hrs
360	6.3.20	WFS Apertures	0 hrs
361	**6.4**	**Produce OIWFS Fabrication Drawings**	**386 hrs**
362	6.4.1	WFS Coldbox	25 hrs
363	6.4.2	WFS Field Lens	7 hrs
364	6.4.3	WFS Primary Beam Folder	14 hrs
365	6.4.4	WFS Collimator	20 hrs
366	6.4.5	WFS Beam Steerer	40 hrs
367	6.4.6	WFS Secondary Beam Folder	20 hrs
368	6.4.7	WFS Field Mask Wheel	50 hrs
369	6.4.8	WFS Pupil Relay	10 hrs
370	6.4.9	WFS Filter Wheel	40 hrs
371	6.4.10	WFS Tertiary Beam Folder	10 hrs
372	6.4.11	WFS Field Relay	40 hrs
373	6.4.12	WFS Detector Mount	50 hrs
374	6.4.13	WFS Baffling	15 hrs
375	6.4.14	WFS Alignment Aids	35 hrs
376	6.4.15	WFS Detector Controller Mount	10 hrs
377	**6.5**	**OIWFS Mechanical Fabrication**	**2,725 hrs**
378	6.5.1	Supervision	280 hrs
379	6.5.2	Construct WFS Coldbox	0 hrs
380	6.5.3	Construct WFS Field Lens Mount	60 hrs
381	6.5.4	Construct WFS Primary Beam Folder	80 hrs
382	6.5.5	Construct WFS Collimator	150 hrs
383	6.5.6	Construct WFS Beam Steerer	300 hrs
384	6.5.7	Construct WFS Secondary Beam Fol	120 hrs
385	6.5.8	Construct WFS Field Mask Wheel	400 hrs
386	6.5.9	Construct WFS Pupil Relay	60 hrs
387	6.5.10	Construct WFS Tertiary Beam Folder	80 hrs
388	6.5.11	Construct WFS Filter Wheel	300 hrs
389	6.5.12	Construct WFS Field Relay	300 hrs
390	6.5.13	Construct WFS Detector Mount	400 hrs
391	6.5.14	Construct WFS Baffling	105 hrs
392	6.5.15	Construct WFS Alignment Aids	70 hrs
393	6.5.16	Construct WFS Detector Controller M	20 hrs
394	**6.6**	**OIWFS Trial Assembly & Test**	**854 hrs**
395	6.6.1	Assemble without Optics and Detecto	280 hrs
396	6.6.2	Mechanism Control Wiring	91 hrs
397	6.6.3	Install Covers and Baffles	35 hrs
398	6.6.4	Problem Rectification 2	105 hrs
399	6.6.5	Install Optics	70 hrs
400	6.6.6	Test Optics	105 hrs
401	6.6.7	Test Mechanism Operation	98 hrs
402	6.6.8	Test Components Controller s/w	70 hrs
403	**6.7**	**OIWFS Detector System**	**735 hrs**
404	6.7.1	Detector Procurement	35 hrs
405	6.7.2	Detector Mounting Board	140 hrs
406	6.7.3	Detector Wiring	140 hrs
407	6.7.4	Detector Controller	210 hrs
408	6.7.5	Detector Optimization	210 hrs
409	**6.8**	**OIWFS Software Development**	**870 hrs**
410	6.8.1	OIWFS CC Software	310 hrs
411	6.8.2	OIWFS DC Software	245 hrs
412	6.8.3	Testing CC with OIWFS Hardware	210 hrs
413	6.8.4	Testing IS with OIWFS Hardware	105 hrs
414	6.9	Miscellaneous Items & Consumables	0 hrs
415	6.10	Contingency	0 hrs



ID	WBS	Task Name	Work
416	**7**	**Instrument Assembly and Testing**	**7,561 hrs**
417	**7.1**	**Project General**	**679 hrs**
418	7.1.1	Project Management	490 hrs
419	7.1.2	Quality Assurance	49 hrs
420	7.1.3	Web Page Maintenance	70 hrs
421	7.1.4	Refine Plan to Completion	70 hrs
422	**7.2**	**System Engineering**	**1,036 hrs**
423	7.2.1	Finalise Record Documents	266 hrs
424	7.2.2	Service and Calibration Manual	315 hrs
425	7.2.3	Software Maintenance Manual	140 hrs
426	7.2.4	User's Manual	315 hrs
427	**7.3**	**Install OIWFS**	**407 hrs**
428	7.3.1	Disassemble Trial Assembly	28 hrs
429	7.3.2	Components Surface Treatment	70 hrs
430	7.3.3	Outgas in Vacuum Tank	36 hrs
431	7.3.4	Assemble in Cryostat	91 hrs
432	7.3.5	Repeat Mechanism Operation Tests	7 hrs
433	7.3.6	Problem Rectification 3	175 hrs
434	**7.4**	**Install Imager**	**420 hrs**
435	7.4.1	Disassemble Trial Assembly	28 hrs
436	7.4.2	Components Surface Treatment	105 hrs
437	7.4.3	Outgas in Vacuum Tank	35 hrs
438	7.4.4	Assemble in Cryostat	70 hrs
439	7.4.5	Repeat Mechanism Operation Tests	7 hrs
440	7.4.6	Problem Rectification 4	175 hrs
441	**7.5**	**First Cooldown**	**105 hrs**
442	7.5.1	First Cooldown, test pressure and ten	14 hrs
443	7.5.2	Determine Detector Block Thermal In	14 hrs
444	7.5.3	Test Mechanisms Operation Cold	42 hrs
445	7.5.4	Test Components Controller s/w	21 hrs
446	7.5.5	Test Instrument Sequencer s/w	14 hrs
447	7.5.6	Warmup	0 hrs
448	**7.6**	**Second Cooldown Preparations**	**476 hrs**
449	7.6.1	Problem Rectification 5	168 hrs
450	7.6.2	Install Imager Optics	28 hrs
451	7.6.3	Imager Optics Initial Alignment	70 hrs
452	7.6.4	Install Imager Engineering Detector	56 hrs
453	7.6.5	Install OIWFS Optics	35 hrs
454	7.6.6	OIWFS Optics Initial Alignment	70 hrs
455	7.6.7	Install OIWFS Detector	49 hrs
456	**7.7**	**Second Cooldown**	**532 hrs**
457	7.7.1	Cooldown	0 hrs
458	7.7.2	Confirm Operation and Alignment	168 hrs
459	7.7.3	Test Mechanisms Operation Cold	28 hrs
460	7.7.4	Test Components Controller s/w	21 hrs
461	7.7.5	Test Instrument Sequencer s/w	21 hrs
462	7.7.6	Test Engineering Detector	105 hrs
463	7.7.7	Test s/w	70 hrs
464	7.7.8	Check Optical Alignment	70 hrs
465	7.7.9	Test OIWFS/Imager Flexure	49 hrs
466	7.7.10	Warmup	0 hrs
467	**7.8**	**Third Cooldown Preparations**	**210 hrs**
468	7.8.1	Problem Rectification 6	140 hrs
469	7.8.2	Adjust Imager Optical Alignment	35 hrs
470	7.8.3	Adjust OIWFS Optical Alignment	35 hrs
471	**7.9**	**Third Cooldown**	**637 hrs**
472	7.9.1	Cooldown	0 hrs
473	7.9.2	Confirm Operation and Alignment	168 hrs
474	7.9.3	Test Mechanisms Operation Cold	28 hrs
475	7.9.4	Test Components Controller s/w	21 hrs
476	7.9.5	Test Instrument Sequencer s/w	21 hrs
477	7.9.6	Test Engineering Detector	105 hrs
478	7.9.7	Test & Optimise OIWFS Detector	105 hrs
479	7.9.8	Test s/w	70 hrs
480	7.9.9	Check Optical Alignment	70 hrs
481	7.9.10	Test OIWFS/Imager Flexure	49 hrs
482	7.9.11	Warmup	0 hrs
483	**7.10**	**Fourth Cooldown Preparations**	**182 hrs**
484	7.10.1	Problem Rectification 7	140 hrs
485	7.10.2	Install Science Detector	42 hrs
486	**7.11**	**Fourth Cooldown**	**553 hrs**
487	7.11.1	Cooldown	0 hrs
488	7.11.2	Confirm Operation and Alignment	168 hrs
489	7.11.3	Test Mechanisms Operation Cold	14 hrs
490	7.11.4	Test Components Controller s/w	21 hrs
491	7.11.5	Test Instrument Sequencer s/w	21 hrs
492	7.11.6	Test Science Detector	105 hrs
493	7.11.7	Test & Optimise OIWFS Detector	70 hrs
494	7.11.8	Test s/w	70 hrs
495	7.11.9	Check Optical Alignment	35 hrs
496	7.11.10	Test OIWFS/Imager Flexure	49 hrs
497	7.11.11	Warmup	0 hrs
498	**7.12**	**Fifth Cooldown Preparations**	**140 hrs**
499	7.12.1	Problem Rectification 8	140 hrs



ID	WBS	Task Name	Work
500	**7.13**	**Fifth Cooldown**	**651 hrs**
501	7.13.1	Cooldown	0 hrs
502	7.13.2	Characterise Science Detector	140 hrs
503	**7.13.3**	**Test Imager Optical Quality**	**98 hrs**
504	7.13.3.1	Characterise Optical Performanc	70 hrs
505	7.13.3.2	Check Optical Alignment	28 hrs
506	7.13.4	Test OIWFS/Imager Flexure	77 hrs
507	7.13.5	Instrument Acceptance Tests at RSA	196 hrs
508	7.13.6	Warmup and Packing	140 hrs
509	**7.14**	**Contingency: Sixth Cooldown Preparat**	**210 hrs**
510	7.14.1	Problem Rectification 9	140 hrs
511	7.14.2	Adjust Imager Optical Alignment	35 hrs
512	7.14.3	Adjust OIWFS Optical Alignment	35 hrs
513	**7.15**	**Contingency: Sixth Cooldown**	**574 hrs**
514	7.15.1	Cooldown	0 hrs
515	7.15.2	Confirm Operation and Alignment	175 hrs
516	7.15.3	Test Mechanisms Operation Cold	28 hrs
517	7.15.4	Test Components Controller s/w	21 hrs
518	7.15.5	Test Instrument Sequencer s/w	21 hrs
519	7.15.6	Test Engineering Detector	140 hrs
520	7.15.7	Test s/w	70 hrs
521	7.15.8	Check Optical Alignment	70 hrs
522	7.15.9	Test OIWFS/Imager Flexure	49 hrs
523	7.15.10	Warmup	0 hrs
524	**7.16**	**Contingency: Seventh Cooldown Prepa**	**140 hrs**
525	7.16.1	Problem Rectification 10	140 hrs
526	**7.17**	**Contingency: Seventh Cooldown**	**609 hrs**
527	7.17.1	Cooldown	0 hrs
528	7.17.2	Confirm Operation and Alignment	175 hrs
529	7.17.3	Test Mechanisms Operation Cold	28 hrs
530	7.17.4	Test Components Controller s/w	21 hrs
531	7.17.5	Test Instrument Sequencer s/w	21 hrs
532	7.17.6	Test Science Detector	175 hrs
533	7.17.7	Test s/w	70 hrs
534	7.17.8	Check Optical Alignment	70 hrs
535	7.17.9	Test OIWFS/Imager Flexure	49 hrs
536	7.17.10	Warmup	0 hrs
537	7.18	Transport to Chile	0 hrs
538	7.19	Miscellaneous Items & Consumables	0 hrs
539	7.20	Contingency	0 hrs
540	*8*	*Earliest Shipment*	*0 hrs*
541	*9*	*Shipment*	*0 hrs*
542	**10**	**Instrument Commissioning**	**2,042 hrs**
543	**10.1**	**Project General**	**196 hrs**
544	10.1.1	Project Management	140 hrs
545	10.1.2	Quality Assurance	21 hrs
546	10.1.3	Web Page Maintenance	35 hrs
547	10.1.4	Travel and Accommodation	0 hrs
548	10.2	Post-shipment Tests	0 hrs
549	*10.3*	*Transport to Summit*	*0 hrs*
550	10.4	Integration and Installation	1,580 hrs
551	10.5	Verification on Telescope	210 hrs
552	10.6	Training	56 hrs
553	10.7	Miscellaneous Items & Consumables	0 hrs
554	10.8	Contingency	0 hrs
555	*11*	*Earliest Closeout*	*0 hrs*
556	***12***	***Project Closeout***	***0 hrs***



2 Communications Management Plan

For the purposes of planning project communications, project stakeholders are divided into groups with similar interests. These groups and their perceived information needs are described in the table below. Note that the project team may have no communication at all with certain stakeholders, such as end users.

2.1 Communication Needs Analysis

Stakeholder Description	Information Needs
Core GSAOI team members	• Detailed understanding of project scope, objectives, strategies, timeline, etc. • Detailed activity status (progress) information for the overall project at any given time. • Knowledge of problems or issues that may cause overall impact to project, particularly those assigned to one's own area or which may directly affect that area. • Description and impact of changes to approved documents. • Knowledge of potential impacts to stakeholders caused by the project. • Planned events external to this project that may have an impact on project activities.
Other GSAOI team members	• General understanding of project scope, objectives, strategies, timeline etc. • Awareness of resource impacts in terms of labour required by the project from each section of RSAA. • Advanced knowledge of nature and timing of changes (impacts) to RSAA.
Peer project teams	• Awareness of project scope and timeline. • Awareness of resource impacts in terms of labour required by the project from each section of RSAA. • Advanced knowledge of impacts to RSAA.
RSAA Executive	• Detailed activity status (progress) information for the overall project at any given time.
Subcontractors	• Detailed knowledge of subcontracted sub-project scope, requirements, and timeline. • Knowledge of sub-contract problems or issues that may cause overall impact to project. • Description and impact of changes to relevant approved planning documents.
Gemini	• Detailed understanding of project scope, objectives, strategies, and timeline. • Detailed activity status (progress) information for the overall project at prescribed times. • Description and impact of changes to approved documents. • Events external to this project that may have an impact on project activities.
Other RSAA technical staff members	• Includes those affected by the project but not directly participating in the project. • Advanced knowledge of nature and timing of changes (impacts) to individual work areas. • Training on new equipment, systems, or procedures.

2.2 Communication Vehicles

Vehicles	Comments/Usage
Core team status meetings	• Scheduled weekly. • Primary audience includes core project team members. • Provides forum to discuss status, issues, strategies, and other information relevant to technical teams. • Provides interface between this project and external organisations, including peer project teams. • Not intended as a working session to address specific topics in detail. • May be supplemented with "ad-hoc" working session meetings with limited audience when needed.
Core team meeting minutes	• Documents decisions and action item assignments from core team meetings. • Facilitates communication with team members (core team and others) who are unable to attend they core team meeting but are interested in discussions and outcomes.
Fortnightly Status Report	• Provides summary information on project status and issues, focusing on quantitative rather than qualitative status. • Provides advance notification of near-term upcoming events, as well as other information of general interest.
Technical team meetings	• Scheduled as needed. • Includes members of specific technical teams (e.g Electronics). • Provides forum for in-depth planning, status reporting, and discussion of topics specific to a single area. • Provides communication between core team and other project participants.
Management reports to RSAA Director	• Scheduled monthly for presentation at monthly meetings. • Formal mechanism for ensuring Director is informed about GSAOI status.
GSAOI management meetings with Director	• Scheduled monthly. • Provides formal mechanism for communication between GSAOI Management and RSAA Director.
Status reports to Gemini	• Scheduled monthly. • Provides formal mechanism for communication between GSAOI Management and Gemini.
Teleconferences with Gemini	• Scheduled monthly. • Provides formal mechanism for communication between GSAOI team and Gemini. • Provides forum for open and in-depth technical discussions on a range of technical issues.
E-mail	• At the project level, provides primary distribution mechanism for core team meeting minutes, announcements, status reports, and more. • For technical teams, supplements meetings as method of distributing information and resolving questions or issues.

Vehicles	Comments/Usage
Project internet web site	• A general-purpose information resource containing project planning documents, current status information, current issues, meeting minutes, and most other formal documents produced during the course of the project. • Updated regularly with latest information.
Submissions to Gemini Newsletter	• Produced twice yearly for submission to the Australian Gemini Project Scientist. • Used to provide general information (status etc.) to Gemini stakeholders (members of the Astronomical community) who are not direct participants. • Targets Gemini stakeholders who may not receive or be willing to review more detailed information.
Periodic social events	• Facilitates informal communication between those who might not otherwise have an opportunity to interact outside of project meetings.

2.3 Communication Matrix

Comm's Vehicle	Core GSAOI Team Members	Other GSAOI Team Members	Peer Project Teams	RSAA Executive Management	Subcont-ractors	Gemini	Other RSAA Staff Members
Core Team Status Meetings	P	S	S	P	X	X	S
Core Team Meeting Minutes	P	S	S	P	S	X	S
Weekly Status Reports	P	P	S	S	S	X	S
Technical Team Meetings	S	P	S	S	P	X	S
E-Mail	P	P	S	S	S	S	S
GSAOI Internet Site	P	P	P	S	P	P	P
Monthly Teleconference	P	S	X	S	S	P	X
Monthly Reports	P	S	X	P	X	P	X
Gemini Newsletter	S	S	P	S	P	P	P
Project Reviews	S	S	P	S	P	P	P
Social Events	P	P	P	P	P	P	P

3 Product Assurance Plan (GSAOI Quality Assurance)

3.1 Scope

The GSAOI Product Assurance Plan specifies the basic product assurance activities for GSAOI. This plan defines the product assurance program, together with methods and policies for meeting requirements as specified in the contractual documents for the GSAOI project. It describes in detail the activities to be used during the definition, design, procurement, development, manufacture, assembly, test, and delivery phases. After discussion, approval, and official release, it will become the Product Assurance Plan applicable to the GSAOI team and subcontractors. Its requirements will be imposed upon all participants in the GSAOI project, whatever their level or role.

Subcontractors will not necessarily be requested to present a specific Product Assurance Plan. Rather, before acceptance and delivery, they may be requested to present a Compliance Matrix in accordance with this Product Assurance Plan, to assess their compliance to its paragraphs. Any proposed change will have to be negotiated with the GSAOI Project Manager.

3.2 Applicability

3.2.1 General

This document defines the methods and policies for product assurance activities in the GSAOI project to be applied to all hardware and to all associated software and ancillary subsystems. The GSAOI team has the responsibility to implement these policies during all phases of the Project, in accordance with RSAA and Gemini requirements. The GSAOI team shall be responsible for imposing the same policies, when applicable, on all subcontractors.

3.2.1.1 Statements of Compliance

All parties engaged in GSAOI activities, including major subcontractors, will be asked to present statements of compliance, or a compliance matrix, of specific tasks and deliverables in response to the requirements of applicable paragraphs of this present plan. Statements will include relevant remarks, notes and references, and will provide the GSAOI team with a clear understanding of the level of compliance status.

3.3 Product Assurance Management and Organisation

3.3.1 Product Assurance Management

The GSAOI Project Scientist (PS) and Project Manager (PM) are responsible for ensuring the implementation of effective product assurance (PA) in compliance with contractual requirements. The GSAOI Product Assurance Officer (PAO), a member of RSAA, is responsible to the PS and PM for management and implementation of the approved PA plan. He will act as focal point within the project for all PA matters, including those involving subcontractors. The PAO has direct and unimpeded access to GSAOI and RSAA management. The Technical Projects Manager will serve as GSAOI Product Assurance Officer and will be supported by the RSAA Section Heads.

The PAO will interface with the PM for all matters related to PA disciplines. The PM will be responsible for reporting to Gemini the status of the PA activities, in accordance with project requirements.

The GSAOI PAO will also have direct interface with the PAOs in each technical section and any subcontractors. He will coordinate the tasks to be performed by each subontractor concerning PA activities.

The PAO is responsible for the following activities:

- Implementation and maintenance of the project PA tasks, in accordance with the contents of the present plan;
- Planning of PA activities;
- Verification that the required PA activities are covered;
- Directives and instructions to the PA managers of any subcontractors;
- Verification and audits on processes and manufacturing procedures;
- Reporting on the status of PA activities;
- Implementation of a nonconformance processing system;
- Review of applicable documents;
- Provision of support to Gemini representatives involved in PA work; and
- Control of PA schedule and costs.

All major subcontractors will appoint a PAO within their own organization, with the same tasks, but limited to those applicable to them and their suppliers. The subcontractor's PAO will be the point of reference for all PA matters in the project and will be in close contact with the GSAOI PAO.

3.3.2 Product Assurance Organisation and Planning

The organization chart of PA in the GSAOI project is given in Figure A3.1.

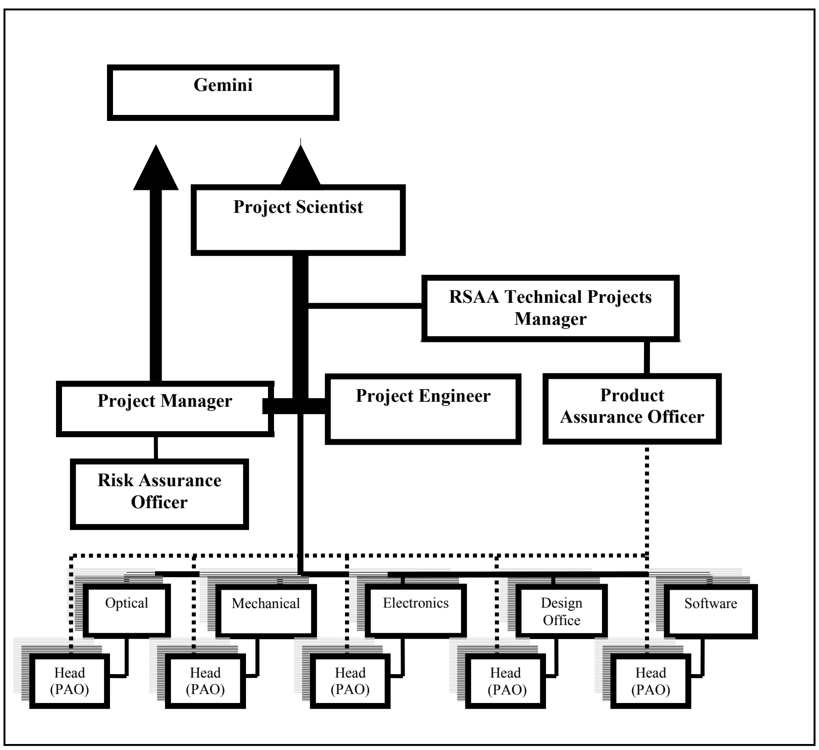


Figure A3.1: GSAOI Product Assurance organisation. The GSAOI Product Assurance Officer (PAO) is a delegate of the Technical Projects Manager. The Head of each technical section will serve as section Product Assurance Officer.

PA tasks will be planned consistently with the project schedule whilst taking into account the product characteristics. PA planning is a direct responsibility of the GSAOI PAO.

3.3.3 Right of Access

All members of the GSAOI team have right of access to all areas involved with the GSAOI project, both at RSAA or subcontractor facilities. This right also includes access to relevant documentation and records.

3.3.4 Subcontractor Selection and Control

All subcontractors will be selected according to the characteristics of the products to be provided and their capability to meet relevant PA requirements. The PA requirements to be imposed on subcontractors will be tailored to the criticality of the product and will be given in the Statement of Work relevant to the subject or subcontract. The subcontractor will state its compliance with these requirements by means of a Compliance Matrix. The Compliance Matrix will be evaluated by the GSAOI team PAO.

3.3.4.1 Subcontractor Selection

All possible subcontractors, whatever the level of their contract, will be evaluated to determine their capability to meet the PA requirements applicable to the project. The GSAOI team PAO will be allowed to participate in the evaluation of any subtiers selected by subcontractors.

3.3.4.2 Subcontractor Control

To ensure that PA requirements are met during all phases of the project, Subcontractors may be subjected to control activities. If deemed necessary for the intrinsic characteristics of the product, subcontractors may be required to present a statement of compliance or a Compliance Matrix. Subcontractors will allow access to their facilities by the GSAOI PAO. Subcontractor control will be accomplished by performing the following tasks:

- Review and approval of the subcontractor PA Compliance Matrix;
- Approval of subcontractor’s documentation;
- Periodically scheduled communications;
- Review of critical processes;
- Scheduled formal events such as test and delivery reviews;
- Other requirements of the Gemini Project Office, as stated in the GSAOI Construction Contract.

3.3.5 Documentation and Reporting

The GSAOI PAO and section PAOs will review all documents that affect, or may affect, the product assurance aspects of activities. The purpose of documents review is as follows:

- Ensure full compliance with specifications and requirements; and
- Ensure compliance with project PA requirements.

The flow of documents and their release will be subject to configuration control. The GSAOI Librarian will be responsible to the PM and PAO for configuration control.

3.3.6 Tracking

The major PA task is to identify potential critical areas within the GSAOI project activities. These areas include processes, materials, personnel, and procedures. Once potential critical areas have been identified, they will be communicated to the Project Manager who will devise and implement appropriate policies. PA will continue to track critical areas to evaluate the effectiveness of the policies adopted to reduce their criticality and to notify the Project Manager of their deficiencies and the corrective actions to be adopted. For those areas known to be critical from the beginning of activities, the PAO will schedule periodic reviews.

3.4 Parts

All parts to be used for the GSAOI project will be subjected to the control policies described hereinafter, thus assuring compliance with the general PA and performance requirements of the project. These policies are considered to be applicable at any level and at all phases of the contract.

3.4.1 Parts Procurement Control

Existing RSAA parts procurement control will be used to ensure that the procured parts are of the quality level required for the project.

The GSAOI team PAO will be responsible for review of the procurement activities performed by the GSAOI team and subcontractors.

3.4.2 Parts Selection

Part selection will be in accordance to the following general rules that are not exhaustive:

- Use of parts that are fit for purpose.
- Maximum use of previously used parts with established reliability record.
- Minimisation of the number of part types and families.
- Long-term procurement availability. The presence of multiple sources is preferable.
- Vacuum and thermal cycling integrity for parts subjected to vacuum or cryogenic temperatures.

3.4.3 Prohibited Parts

Use of parts with limited life, known instability, or potential safety hazards will be avoided.

3.4.4 Vacuum and Cryogenics Hardness

For vacuum and cryogenic applications, precedence will be given to parts not requiring further evaluation of their process capabilities and manufactured by known sources. Parts for which vacuum and cryogenic performance data are not available will generally not be used in vacuum or at cryogenic temperatures. When unavoidable, such parts will be used only after testing under operational environmental conditions before implementation.

3.4.5 Incoming Parts Inspection

Upon receipt of parts, an inspection will be performed to ensure that quality requirements are met. The incoming inspection will involve the following:

- Sample visual inspection for marking, scratching, lead or body integrity, and any other mechanical defect;
- Verification of packaging conditions; and
- Correspondence to purchase order in terms of type, quality, and quantity.

3.4.6 Handling and Storage of Parts

The incoming "inspector" of procured parts will be the intended recipient. The intended recipient will be conversant with handling techniques of critical items. Particular care will be taken to prevent damage to electronics components from electrostatic discharge (ESD) or to optical components from abrasion or touching. Relevant RSAA personnel devoted to parts inspection have been trained in ESD principles and handling of optics. All parts received will be stored in areas appropriate to the requirements specified by the manufacture.

3.5 Materials and Processes

Existing RSAA policies will be applicable to both the materials and processes associated with deliverable hardware, in order to ensure it meets design, quality and performance requirements. Supported by section POAs, the PAO is responsible for ensuring control on the selection, procurement and qualification of materials and processes.

3.5.1 Selection of Materials and Processes

Whenever possible, precedence will be given to materials and processes already used with success in previous projects. All selected materials and processes will be evaluated for performance and integrity in the given operational environment.

3.5.1.1 Selection of Materials

Materials will be selected in accordance with design, quality, and performance requirements applicable to the given application. Particular care will be taken to avoid specific areas of concern, such as

- Corrosion,
- Health and Safety risks or hazards,
- Susceptibility to operational environmental conditions,
- Outgassing,
- Deposition of contaminants on detector or optical surfaces,
- Flammability, and
- Galvanic effect.

3.5.1.2 Selection of Processes

Processes are selected on the basis of their compatibility with the materials to which they are to be applied and their capability to meet the specified requirements for quality and performance. Precedence will be given to well-established processes, already used by the RSAA in previous projects.

3.5.1.3 Controls on Processes

Preference will be given to familiar processes with known procedures that will be reviewed by the relevant GSAOI team member prior to process application. The process procedures will identify all parameters to be maintained under control to ensure that the final product meets design requirements. Manufacturing and control tools will be monitored and maintained to guarantee proper results. The environmental and cleanliness conditions of the areas where the processes are conducted will be maintained at the appropriate level. They will be monitored for contamination.

3.5.2 Audits

Processes performed at RSAA facilities will be subject to regular audits by the ANU Occupational Health and Safety Unit, for compliance with Occupational Health and Safety legislation and WorkCover codes of practice.

3.5.3 Prohibited Materials

Materials that pose a safety hazard or could cause contamination during all phases of the project will not be used, unless specifically approved by the GSAOI team.

Examples of materials to be avoided include the following:

- Beryllium – Oxide;
- Cadmium;

- Tantalum;
- Zinc;
- Mercury; and
- Asbestos cements.

Should one of these materials be necessary for use on GSAOI, risk assessment will be performed and dedicated plans will be prepared. This will be reviewed by the relevant RSAA Section Head, in accordance with ANU OHS policy and "Duty of Care", to minimise the effects on safety and contamination. Notification of the material will be given to Gemini and the material will be flagged for inclusion in the GSAOI Safety Review if it is part of the deliverable instrument.

3.6 Cleanliness and Contamination Control

The environmental conditions associated with cleanliness and contamination control will be maintained at a standard that complies with the requirements applicable to the product. This includes all environments pertaining to storage, assembly, test, and inspection. Critical operations will be conducted within dedicated clean-room facilities or on laminar-flow benches that are isolated by tents.

Detectors, optical assemblies and benches, cryostats and other items associated with them will be handled and assembled in existing areas with appropriate cleanliness conditions. Standard RSAA practices and precautions for prevention of contamination of critical surfaces include the following:

- Correct handling of critical parts;
- Appropriate cleaning methods, with knowledge of points within the manufacturing flow where cleaning will be required;
- Knowledge of purity requirements of cleaning agents;
- Appropriate preventative methods for contamination mitigation;
- Vigilant monitoring of cleanliness level of all manufacturing and assembly work areas; and
- Standard detection methods for determining contamination level on critical surfaces.

3.7 Reliability Assurance

Reliability for GSAOI is specified in terms of overall efficiency. The GSAOI Science Requirement is to lose no more than 2% of scheduled observing time to equipment failure, with less than 1% downtime as a goal. With GSAOI functioning normally, time spent pumping, cooling or warming the instrument prior to mounting or dismounting GSAOI on the telescope shall not be considered downtime.

In order to ensure that the requirements for reliability are met, a high reliability will be achieved early in the GSAOI design and development process. During the design phase, GSAOI will be reduced to its simplest functional form. Single point failures that may lead to significant downtime shall be identified by design engineers. Where necessary, redundancy requirements or critical spares shall be identified. When a system-predicted reliability is deemed to be satisfactory, the system will be developed by selecting and using the most reliable parts, preference being given to those proven by past experience. After assembly, the system will be tested and analysed to demonstrate the capabilities of the system. If failures occur, redesign will be considered in meeting reliability requirements.

3.7.1 Flexure and Stress Analyses

Flexure and stress analyses will be conducted by opto-mechanical design engineers to verify nominal performance of opto-mechanical assemblies and sub-assemblies in accordance with operational performance requirements. Failure modes and effects will be analysed to determine the need for design changes or other actions. In accordance with critical items identified in previous analyses of NIFS qnd using real data from NIRI, detailed stress analysis of lens mounting assemblies will be performed in the conceptual design of GSAOI. The following procedure will be adopted for flexure and stress analyses of GSAOI:

- Identify potential risk;
- Perform detailed flexure and stress analyses of identified risk;
- Verify; and
- Take appropriate preventative action.

3.7.2 Production and Test Reliability

All proposed process, fabrication, assembly, test, packaging and storage procedures will be analysed to ensure that related operations are considered in advance. This foreknowledge shall minimise critical aspects that can otherwise impact on hardware reliability.

3.8 Safety Assurance

The objective of the GSAOI safety assurance is to minimise and control all conditions and operations that pose a safety (or health) hazard to personnel, or may cause damage to equipment. The safety assurance is directed at the following:

- Identification of sources of potential or confirmed hazard through the following:
    - Consulting previous analyses and reference lists;
    - Using the knowledge and expertise of the project team;
    - Brainstorming;
    - Referring to existing checklists and reference lists; and
    - Checking that all significant stages in the process have been identified.
- Analysis to determine corrective actions that must be implemented to mitigate or control the hazard.
- An effective design and review program to ensure that
    - Hazards are identified;
    - Hazards are eliminated; and
    - subsystem design is compliant with safety requirements.

Categories of hazardous event will be established to promote immediate identification of hazard level:

- **Catastrophic:**
    - Loss of life, life threatening;
    - Permanent disabling injury; and
    - Health hazard resulting in occupational illness.
- **Critical:**
    - Temporary disabling injury or temporary occupational illness;
    - Loss of, or major damage to, major instrument subsystems ;
    - Loss of, or major damage to, public or private property; and
    - Long term detrimental environmental effects.
- **Marginal:**
    - Minor non-disabling injury or occupational illness;
    - Minor damage to instrument subsystems ;
    - Minor damage to public or private property; and
    - Temporary detrimental environmental effects;
- **Negligible**
    - Any other hazard.

3.8.1 Safety Approach

Consideration will be given to safety in the early phase of design and special attention will be given to safety implications of any identified risks. Design engineers will take account of all potential hazards when developing technical solutions and relevant manufacturing processes. Hazard analysis goals shall include the following:

- Identification of all hazards that the system will encounter and/or generate;
- Incorporation of design and operational procedures to eliminate or compensate for such hazards; and
- Implementation of design review procedures and tests (including numerical simulations) to ensure hazards are identified and eliminated, and safety requirements are met.

Hazards analysis will cover all aspects of the GSAOI Project.

3.8.2 Hazard Reduction and Control

All identified hazards will be eliminated or controlled in accordance with requirements of safety. This will be accomplished through the following:

- Minimum hazard level design approaches, with the selection of appropriate design features;
- Design solutions with protection and tolerance of failure and/or operator error;
- Design precautions and safety factor margins; and
- Use of automatic safety devices where preventative actions or design solutions are precluded.

Appropriate warning and safety labels will be used to indicate potential hazards to personnel.

All work practices at the RSAA will be conducted in strict accordance with the Occupational Health and Safety Policies of the Australian National University and the Australian Occupational Health and Safety (Commonwealth Employment) Act 1991.

Safety aspects of the GSAOI project will be traced during design reviews. Implementation of safety measures is the responsibility of the PAO who will work closely with GSAOI design engineers and Project Manager during all aspects of the GSAOI project. The GSAOI Safety Review document is scheduled for presentation at the GSAOI CDR.

3.9 Quality Assurance (QA)

QA project activities will be implemented in accordance with the project schedule. QA personnel will perform their duty under the direction of the PAO. The PAO is responsible for resource allocation of QA staff in accordance with schedule milestones.

3.9.1 Design and Development QA

The QA programme will ensure that deliverable hardware and software is fully compliant with the requirements at the end of the design phase. Procedures adopted will assure that design engineers take full account of requirements pertaining to parts, materials, manufacturing procedures, reliability, and safety. These procedures will include the following:

- Regular review and update of design documentation;
- Scheduled formal reviews throughout project lifecycle;
- The issue of Design Verification Matrices (DVM); and
- Acceptance testing survey.

3.9.2 Design Verification Matrix

DVMs will be used to provide evidence that the design meets all specified design requirements. Any non-compliance arising should be identified in this process. DVM philosophy provides a trace of all documents including technical notes, drawings, test results, qualification reports and operational manuals. The Design Verification Matrix will be presented as a checklist in the GSAOI Acceptance Test plan.

3.9.3 Document Review

3.9.3.1.1 Manufacturing Documents Review

This family of documents includes work instructions, historical records, process specifications, and assembly procedures. These will be reviewed against appropriate requirements by the PAO, or section PAO, before commencement of manufacturing.

3.9.3.1.2 Test Procedures

Test procedures will indicate the purpose of the test, the item to be tested, parameters to be tested, the test equipment to be used, and the environmental conditions under which the test is to be performed.

3.9.4 Procurement Quality Assurance

Purchase orders and associated specifications will clearly define all requirements pertaining to procured materials, parts, or services. Orders associated with critical or complex technical and schedule impacts will be issued with a "Statement of Work" detailing all aspects of work to be performed by the subcontractor. Using their terminology, the subcontractor shall be required to restate the issued "Statement of Work" back to the GSAOI team. This quality assurance measure will identify any misinterpretations or ambiguities associated with the "Statement of Work", thereby minimising the possibility of critical or complex technical and schedule impacts.

3.9.4.1 Procurement Sources

Subcontractors will be evaluated under an established QA system in order to ascertain their ability to meet the requirements of quality, budget, and time schedule.

3.9.4.2 Subcontractor and Supplier Surveillance and Audit

The level of control to be applied will vary depending on the product characteristics, previous experience, facilities, and complexity of tasks to be performed. Particular effort will be made to maintain an effective non-conformance reporting system in order to provide a closed loop on defects and corrective actions.

3.9.5 Manufacturing Quality Assurance

Items manufactured or assembled by subcontractors will be subject to QA inspection by the PAO and section PAOs to ensure compliance with applicable requirements. QA will ensure that

- Items are compatible with drawings, specifications and procedures.
- The documents in use are the latest issue and under configuration control.
- Inspection records are complete.
- Accompanying documentation reflects the as-built configuration of the item.

3.9.6 Manufacturing Control Plan

A detailed plan (Work Breakdown Structure and Tracking Gantt Chart) defining all steps of manufacturing flow, inspection steps and methods, and mandatory inspection points will be prepared to allow the GSAOI team complete overview of the work to be performed.

3.9.6.1 Personnel Training and Certification

Processes and operations associated with criticalities will require dedicated personnel training and certification. Certification of internal personnel will be in accordance with ANU standards. The aptitude of personnel to perform the process or operation will be verified by Section Heads.

3.9.6.2 Metrology and Calibration

Under section PAO supervision, metrology control will be implemented by all GSAOI team sections, to ensure that all test equipment is properly calibrated.

3.9.7 Test Quality Assurance

Acceptance tests will be performed in accordance with documented procedures that are specific to the given item under test. Test plan and procedure documents will be subject to review in order to verify compliance with project requirements. The PAO, or section PAO, will monitor tests and confirm the following:

- Applicable test procedures are followed.
- The test facilities are under the calibration system.
- Data obtained are correctly reported.
- Detected non-conformances are recorded and processed.
- Tests are performed within required test environmental conditions.
- The test will be stopped in the case of danger to personnel or damage to the item.

The PAO, or section PAO, will review test data for compliance with applicable requirements upon completion of tests.

3.9.7.1 Test Procedures

Dedicated test procedures will be prepared for each test to be performed on hardware and software. Together, these will form the GSAOI Acceptance Test Plan for each requirement listed in the GSAOI Functional and Performance Requirements Document (FPRD).

Each test procedure will include the following:

- Configuration of test item.
- Detailed test methods.
- Test setup and equipment.
- Test environmental conditions.
- Test limits and tolerances.
- Success Criteria.

At the completion of each test, a test review will be performed to include the following:
- Verification of test completion.
- Review of test results.
- Review of non-conformances.
- Completeness of test data reports.
- Release of test results.

Test results will be reported on an exception basis only, so as not to impede progress in fast tracking the GSAOI project.

3.9.8 Handling, Storage, Packaging and Shipping Control

3.9.8.1 Handling

The PAO, with assistance from section PAOs, will verify that manufacturing, test, transportation, and delivery documentation contains appropriate instructions for the correct handling of equipment or that dedicated procedures are in place. The implementation of correct handling procedures will be verified by visual inspections during manufacturing flow. Non-conformances will result in modification to internal work practices or handling procedures. All critical events will be monitored by the PAO, or section PAOs, to ensure that the integrity of items is adequately protected against the adverse effects of deterioration associated with mis-handling. When the handling situation demands, special handling devices will be supplied and these will be maintained and inspected to ensure that they are both adequate and safe for their intended use. Where the potential for deterioration is likely, protective film, wrapping, or dedicated environmental containment vessels will be employed.

3.9.8.1.1 Contamination Control

The PAO and section PAOs will verify that specific requirements of contamination control are implemented throughout all phases of the GSAOI project. During all GSAOI project phases, contamination control requirements will be identified by drawings, equipment specifications, process specifications and procedures. Existing RSAA cleanliness control protocols provide instructions for the control of pressure, humidity, temperature, noise, particular contaminants, and surface-film contaminants, together with detailed instructions for cleaning operations.

Critical operations, involving surfaces or assemblies with high sensitivity to particular and molecular contamination, will be conducted within properly controlled clean-room facilities. When operations in such facilities are not feasible, laminar flow benches will be deployed.

3.9.8.1.2 ESD Protection

The PAO and section PAOs will monitor and verify that correct internal procedures are implemented to avoid damage to sensitive electronic parts and assemblies from ESD. Whenever necessary, dedicated written procedures will be prepared. ESD protection will be referenced in historical records and work instructions. The guidelines for ESD policies will be the following:

- All relevant personnel will have received instruction and training in ESD protection.
- Proper grounding and electrically-conductive packaging practices will be employed.
- Written procedures will be made available to personnel.
- Use of non-cotton garments will be avoided.
- All personnel will be connected to ground.
- All instruments will be connected to a common ground during test phases.
- Electronics construction, testing, and interfacing will be performed in an appropriate environment.

3.9.8.2 Storage Control

The PAO and section PAOs will ensure that procedures are followed to protect items in storage from deterioration, damage, loss, or confusion between parts. Items in store will be tracked by means of inventory. Storage environments will be maintained in accordance with requisite storage and cleanliness levels demanded by applicable specifications. Periodic inspection and safety control will be performed by the PAO.

3.9.8.3 Packing Control

Packaging operations will be monitored by the PAO. Such operations will ensure the protection of hardware and software against deterioration, contamination, and damage from handling, transportation, and shipping. Packing methods will be detailed in specifications and drawings.

Final visual inspections will be performed on hardware and documented prior to packing. The packing of items will be performed in appropriately controlled environmental conditions. The PAO will witness the sealing of packages and crates. Levelling and shock indicators will be provided both internal and external to the packaging crate(s). The exterior of the packing crates will be marked and labelled to allow precise and immediate identification of the contents.

3.9.8.4 Shipping Control

The PAO will monitor the shipping phase to ensure that all operations and procedures are carried out correctly, and that packing and correlated documentation is in accordance with project requirements.

3.10 Non Conformance Reporting (NCR) and Control

Non conformances comprise all apparent or proven conditions which are not compliant with applicable requirements. Control procedures will be established to maintain non conformances under control during all phases of design, manufacture, and testing. This will ensure that all items or materials that fail to meet applicable requirements will be identified and will be withdrawn from the manufacturing cycle for corrective action.

Minor non conformances comprise those non conformances that do not adversely affect performance, interface, reliability, lifetime, maintainability, weight, health, or safety. Major non compliances comprise all other non conformances. Depending upon classification, a non conformance will be addressed by one of the following dispositions:

- **Use as is**, when the item is found to be completely usable;
- **Modify** when the item can be made to conform by rework and/or reapplication of the original process;
- **Repair** when the item can be recovered by application of additional materials and/or processes;
- **Scrap** when the item is totally unfit for purpose; and
- **Return to supplier** for replacement when the item fails incoming inspection.

Non conformances will be reported and circulated amongst the GSAOI team. Responsibility for corrective action(s) will reside with the appropriate design engineer(s). Non conformance impact and proposed corrective action(s) will be reflected in prompt updates to the GSAOI schedule which will be tracked on a regular basis.

3.11 Configuration Control

Configuration control will be implemented to ensure that all received or issued project documentation is correctly filed, approved, and released. The GSAOI Librarian shall have responsibility for configuration control. All documents will be filed, maintained, and released by configuration control. The designated GSAOI Librarian will be responsible for ensuring that a GSAOI document Configuration Status List is maintained.

First issues of all documentation will be reviewed by the PS, PM, and PAO to ensure compliance with objectives

3.11.1 Software Configuration Control

Software and software-related documents will be placed under configuration control. Software configuration control will provide identification of the baseline configuration, control of modifications and their implementation, control and reporting of non conformances, and verification that prescribed corrective actions have been implemented.

3.12 Software QA

The GSAOI software development team has established a comprehensive QA program that covers all phases of the software lifecycle. Software development will be in-house and this program covers all in-house activities.

Software non-conformances will be treated, classified, and reported in the same manner as hardware non conformances. Dispositions and corrective actions will be defined by software specialists of the GSAOI team.

3.12.1 Hardware/Software Interaction Analysis

QA on items shall take into account the associated software and its interaction with hardware. The aim of this activity is to avoid damage or over-stress caused by software commands and to prevent critical hardware failures due to software invoked actions. Software development will be in unison with hardware control system development and will involve close liaison between software and hardware design engineers. Throughout the development lifecycle, hardware/software interaction will be analysed during regularly tests of software with hardware control systems.

4 GSAOI Software Management and Production Tools

GSAOI software management and production tools and uses are identified in the following matrix:

SW Tool	SW Tool Usage							
	Project Management	Spread-Sheet	Cost Estimating	Decision Analysis	Technical Design	Document Sets	Communi-cation	Process Control
Microsoft Project 2000	X	X	X	X		X		
Microsoft Excel	X	X	X					
Microsoft Word	X					X		
Microsoft PowerPoint							X	
Microsoft Access	X							
Framemaker V6 (Sun)						X		
Acrobat Adobe							X	
PeopleSoft Enterprise Solutions Project ESP	X	X	X	X				
IDL				X	X		X	
Zemax					X			
Protel Spice					X			X
MasterCam					X			X
Kaleidagraph				X			X	
Netscape							X	
Internet Explorer							X	
Gemini UAE GNU make					X			
Altivec					X			
VxWorks WindRiver Tornado 2.x and GNU compilers (Solaris)					X			
Sun Forte 6 c++ and debugger					X			
CVS								X
EPICS EDD/DM					X			
EPICS capfast					X			

5 GSAOI Safety Plan

5.1 Purpose

GSAOI project management requires that the controls specified in this Project Safety Plan (PSP) be applied to efficiently and safely perform all operations associated with the GSAOI project. These operations are associated with the design, manufacture, storage, assembly, preparation, servicing, and operation of GSAOI. In this plan, GSAOI safety is divided into two categories: instrument design safety and occupational health and safety.

5.2 Introduction

GSAOI is a facility Gemini instrument. Safety in the GSAOI context involves assessing risks to personnel, the instrument, the telescope, and the Gemini South facility. Potential safety risks will occur during initial assembly and testing of the instrument, transportation of the instrument to Cerro Pachon, preparation and servicing of the instrument prior to observing, installation of the instrument on the telescope, servicing of the instrument while at the telescope, and during normal operation of the instrument on the telescope.

Initial assembly and testing of GSAOI shall be compliant with the occupational health and safety policies and practices of the Australian National University (ANU).

The Gemini Environmental ICD specifies the environment in which other GSAOI operations will be performed.

5.3 Instrument Design Safety

5.3.1 Applicable Safety Documents

The following is a partial list of relevant safety documents. The list is expected to change as the project evolves:

Gemini Documents

Gemini Project Safety Program, PG-PM-G0009
Gemini Instrument Safety Policy, PG-I-G0010
Science and Facility Instruments to Facility Handling Equipment Interface Control Document, ICD 1.9/2.7
Gemini Electronic Design Specification, SPE-ASA-G0008
Gemini Facility Handling Equipment and Procedures for Instrumentation, ICD-G0015
Gemini Acronym Glossary, PG-S-G0008

OSHA Documents (www.osha.gov)

OSHA Regulations (Standards - 29 CFR)
Part 1910 Occupational Safety and Health Standards
Subpart G - Occupational Health and Environmental Control (1910.94 to 1910.98)
Subpart J - General Environmental Controls (1910.144, 1910.145, 1910.147)
Subpart M - Compressed Gas and Compressed Air Equipment (1910.166 to 1910.169)
Subpart S - Electrical (1910.301 to 1910.399)

5.3.2 Division of Responsibilities

The GSAOI Safety Review document is a separate document that shall be submitted at CDR and it will identify safety issues associated with the GSAOI instrument. A safety audit table shall be included within this CDR document and will identify the responsibility for the indicated safety issue.

5.3.3 Organization of the GSAOI Safety Review

The GSAOI Safety Review shall be presented at the GSAOI CDR and shall include the following:

- Design Safety Requirements
    - This section shall list the design requirements relating to safety. The design of the instrument as it relates to these issues shall be discussed. This shall include design principles for those items for which detailed design work is incomplete.

- General Safety Issues
    - This section shall discuss those safety issues relating to transportation of GSAOI, preparation of the instrument on site, servicing of the instrument on site, and normal operation on the telescope. General considerations on handling shall be discussed in this section.

- Safety Related Documentation and Training

5.3.4 Design Safety Requirements

Consideration will be given to the following design safety requirements in the GSAOI Safety Review:

- Mechanical
    - structural integrity, weld joints, bolts, materials, corrosion, sharp edges, lifting points, handling fixtures and balancing, protection of delicate components, stability of handling carts, storage cart, and equipment cover.
- Mechanism operations
    - loss of power, hazard to personnel, labelling of mechanisms, wear of mechanisms, and manual operation of mechanisms.
- Electrical
    - grounding, power, high voltage, over-current protection, overheating prevention and protection, cryocoolers, helium pressure interlock, detectors, access to instrument, cable ratings, connectors, component ratings, and fans.
- Optics
    - protection against thermal shock, and protection against surface contamination.
- Detector
    - protection against surface contamination.
- Software
    - Controllers and instrument sequencers.
- Vacuum
    - protection against overpressure, safety during pumping, and use of cryogens.
- Pneumatics
    - compressed air.
- Coolants
    - thermal enclosures, detector controllers and transfer lines.
- Instrument related issues

    - transportation between dome and instrument preparation room, changing the orientation of the instrument, installation on the telescope, telescope balancing, personnel protection from moving mechanisms, electric shock, change of components on the Telescope, and use of the engineering interface.
- Service and support related issues
    - Vacuum pumping the cryostat, warm up procedures, assembly/disassembly of GSAOI, personnel protection from internal moving mechanisms, and electric shock.
- Safety of GSAOI in transit
    - shipping container, and condition of GSAOI during shipping.
- Safety related documentation and training, and
- GSAOI Safety Audit.

5.4 Occupational Health and Safety

5.4.1 ANU Occupational Health and Safety Policy

RSAA and the GSAOI team will ensure that, to the best of its ability, the GSAOI instrument will conform to all relevant site safety requirements applicable to Cerro Pachon. The GSAOI team will also ensure that all aspects of the GSAOI project will conform to both Gemini and ANU safety documents, where applicable.

5.4.2 Applicable Occupational Health and Safety Documents

The following is a partial list occupational health and safety documents that are relevant to the ANU:

ANU OHS Documents (www.anu.edu.au/cabs/policies)

Occupational Health and Safety Agreement (1261/1987)
Occupational Health and Safety Courses
Occupational Health and Safety Policies, Implementation of (1666/1988)
Occupational Health and Safety Policy (31/1998)

Other Applicable Documents(www.anu.edu.au/hr/ohs)

Occupational Health and Safety (Commonwealth Employment) Act No. 30 199, Australia
Occupational Health and Safety Agreement, ANU and Trades and Labour Council affiliated Unions
Management OHS Responsibility and the University's OHS System
Workplace Arrangements for OHS Administration
ANU Hazard / Near-Miss Report
ANU Injury Exposure Report
ANU OHS Unit, OHS Audit
ANU OHS Unit, Safety Audit Checklist
ANU OHS Audit Programme
ANU Advanced OHS Courses
ANU Advanced OHS Courses

5.4.3 Policy

It is the policy of RSAA and the GSAOI team

- To implement the ANU's Occupational Health and Safety policies and procedures; and
- To ensure that the School, general facilities and technical workshops are as healthy and safe a working environment as is reasonably practicable.

5.4.4 Administrative Framework

Policies determined by the ANU OH&S Policy Committee (www.anu.edu.au/hr/ohs) identify the responsibilities of individuals, Heads of Areas (such a workshop section Heads), Executive Officers and School Directors.

The Executive Officer of RSAA, the RSAA Business Manager, is responsible to the Director for the satisfactory operation of all safety practices within the RSAA. Area Supervisors and Section Heads are, in turn, responsible to the Business Manager for delegated authority in safety matters. These matters include staff training, and adherence to statutory requirements and ANU policies. They are responsible for monitoring and promoting safety in their respective areas. More specifically, and with reference to OHS ANU Policy Circular No. 1368 (www.anu.edu.au/hr/ohs), GSAOI section Heads will

- actively practice, and foster proper attitudes towards health and safety matters in their staff ;
- advise staff on appropriate reporting procedures for hazards, incidents and injuries;
- arrange for their staff to be instructed in safe and healthy working procedures, and to be warned about all known hazards, including how to eliminate, avoid or minimise them;
- ensure that good housekeeping standards are maintained in their areas of control; and
- co-operate with health and safety representatives in their areas.

Each member of the GSAOI team shall have an overriding responsibility for ensuring that their own work environment is conducive to good health and safety by:

- taking personal action to eliminate, avoid or minimise hazards of which he or she is aware;
- complying with all occupational health and safety instructions;
- making proper use of all safety devices and personal protective equipment;
- seeking information and advice where necessary before carrying out new or unfamiliar work;
- maintaining dress standards appropriate for the work being done;
- being familiar with emergency and evacuation procedures and the location, and use, of emergency equipment;
- being aware of who is the Occupational Health and Safety Representative for the work area; and
- bringing to the attention of the immediate supervisor any unsafe situation or procedure.

5.4.5 Strategy

RSAA Occupational Health and Safety strategy is

- To remove hazards and dispense with hazardous operations as far as reasonably practicable.
- To establish protocols for hazardous operations which minimise the risk as far as reasonably practicable.
- To ensure that all relevant personnel are trained to apply effective precautionary and remedial procedures through formal coursework.
- To identify and control both existing and potential hazards.
- To routinely monitor and review safety aspects of RSAA facilities and to promote the application of safety practices; and
- To facilitate reporting of new hazards and to implement changes to rectify them promptly.

Workplace accidents and occupational diseases are caused by definable and identifiable hazards in the workplace. OHS hazards and their attendant risks can be reduced as far as is reasonably practicable and acceptable by employing appropriate risk management. The risk management process employed by the GSAOI team will be in accordance with standard ANU policy, namely:

1. **Identify the hazards.** Systematically, identify all situations or events that could give rise to potential of injury or disease. Methods for identifying hazards will include inspections and audits of the workplace, feedback and concerns from staff during inspections or team meetings, and reference to relevant ANU safety manuals.
2. **Assess the risks.** Gather information about each hazard identified and use the information to assess the likelihood of each hazard actually causing harm.
3. **Control the Risks according to the following hierarchy.**
    - Eliminate the hazard from the workplace
    - Substitute or modify the hazard by replacing it with something less dangerous
    - Isolate the hazard by physically removing it from the workplace.
    - Employ engineering method to control the hazard at its source.
    - Administrative controls or management strategies to ensure the health and safety of staff.
    - Use of personal protective equipment
4. **Monitor and Review the process**. Maintain records to help with further identification of hazards and review effectiveness of risk control.

The GSAOI team will maintain effective occupational health practice. This will involve

- Anticipation of harmful outcomes associated with occupations, processes and materials;
- Recognition of potentially harmful environmental factors;
- Evaluation of exposure to staff from such factors; and
- Control to reduce exposure level below established exposure standards.

5.4.6 Training and Coursework Requirements

The ANU OHS Unit offers a wide range of both advanced and general OHS courses. Members of the GSAOI team shall attain appropriate knowledge of Occupational Health and Safety practices by participation in all ANU safety courses relevant to their duties. ANU safety courses (www.anu.edu.au/hr/ohs) are listed below.

- Advanced OH&S Courses
    - Laser Safety
    - Chemical Safety
    - Corrosives Safety
    - Compressed Gas and Cryogenic Safety
    - Workshop and Trade Safety
    - Electrical Safety
    - Electrical Safety Refresher (yearly)
    - Safe Work at Heights
    - Safe Work at Heights Refresher (yearly)
    - Confined Spaces
    - Confined Spaces Refresher (yearly)

- General OH&S Courses
    - OHS Principles and Practices for Managers, Supervisors and OHS Committee Members
    - Health and Safety Representatives (HSR) OHS Training
    - Senior First Aid

- Senior First Aid Refresher
- Advanced First Aid
- Advanced First Aid Refresher
- Remote Area First Aid
- CPR
- CPR Refresher
- Self Contained Breathing Apparatus
- Manual Handling Skills
- Occupational Strains Prevention

For specialist training that is not available at the ANU, participation in external training courses will be encouraged.

6 Risk Management Plan

6.1 Risk Components

Risk comprises two components, namely likelihood and consequence. Increased risk results from a combination of increase in likelihood that a failure will occur and an increase in the negative consequence of a failure.

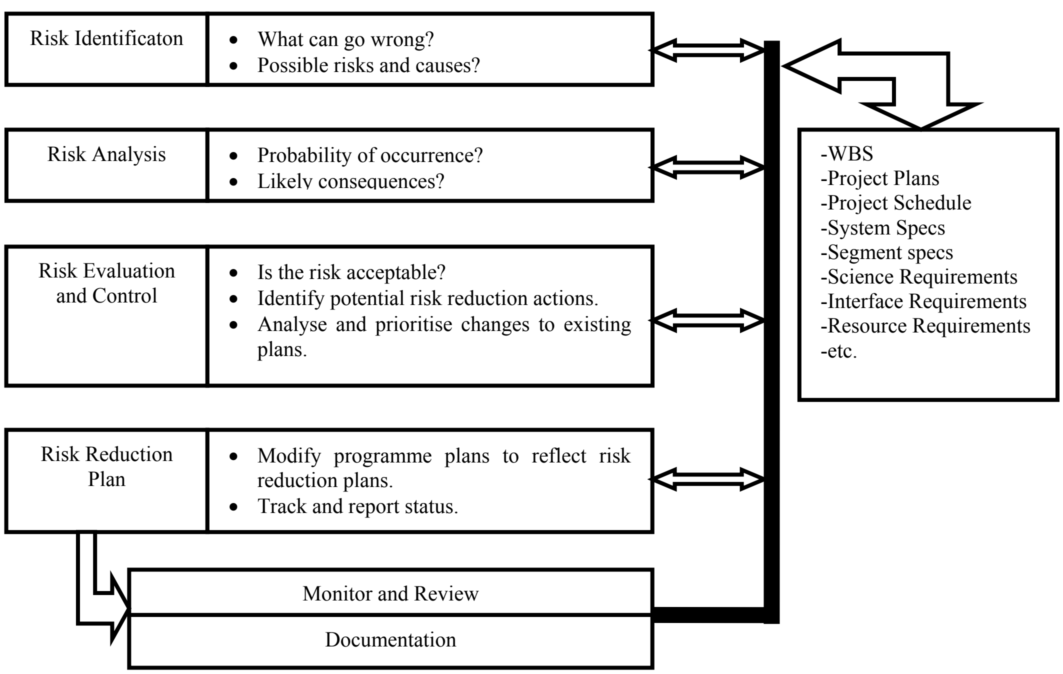
6.2 Risk Levels

The GSAOI Project Team will adopt 3 broad risk levels:

Risk Level	Description	Remedial Action
High	Consequences would disrupt schedule, increase cost and/or degrade performance,	Special intervention by way of review or changes to operations will probably overcome issues.
Medium	Consequences would threaten the efficiency or effectiveness through minor disruption to schedule, increase in cost and/or degradation of performance	Can be dealt with internally.
Low	little or no potential for disruption to schedule, increase in cost and/or degradation of performance	Dealt with by routine activities.

6.3 Risk Management Process

The GSAOI risk management process comprises the following steps:



GSAOI documentation and information used during the risk management process include the Work Breakdown Structure, Project Schedule (Tracking Gantt Chart), Segment Specifications, Architecture Descriptions, Costing, Procurement List, Resource Lists, Product Assurance Plan, technical design specifications, scientific requirements, and interface descriptions. An essential feature of the risk management process is the continuous monitoring and review of every step.

The risk management process provides the impetus for execution of the identified risk reduction plan at the appropriate technical or managerial level. In addition, it provides management with regular updates on the status of all potential and identified risks. Each segment is continuously evaluated for potential risks through the formulation and implementation phases.

6.3.1 Identifying Risk

Several techniques will be used to identify risks and the interactions between a source of risk and elements put at risk. These include the following:

- Consulting previous risk analyses and reference lists;
- Using the knowledge and expertise of the GSAOI team;
- Brainstorming (imagining everything that could happen);
- Numerical simulation or analysis;
- Cost-performance modelling;
- Referring to existing check lists and reference lists; and
- Checking that all stages in the process have been identified.

Risk identification tables (Figure A6.1) will be used to facilitate the identification of risks.

Sources of Risk

Sources of Risk	Description

Elements at Risk

Elements at Risk	Description

Risk Identification Table. To indicate whether a relationship exists between sources of risk and elements at risk from tables above (Yes/No).

Sources of Risk	Elements at Risk				

Figure A6.1: Example Risk Report Forms.

6.3.2 Risk Analysis and Evaluation

Risks are analysed and categorised into the broad levels of risk. Naturally, some risk analyses will be subjective or depend on various assumptions being correct, whilst others will be objective and supported by precise estimates and other data. Risk evaluation is achieved by mapping the relationship between likelihoods and impacts in a matrix. By comparing the level of risk found during the analysis process with previously established risk criteria, risk can be evaluated by deciding whether or not the risk can be accepted. Unacceptable risks that require further management effort are identified.

Several methods will be used to determine the probability of a failure occurring and its consequences. They are broadly classified as qualitative, semi-quantitative, and quantitative.

- The most common are qualitative methods such as expert evaluation and intuition. This is the lowest cost form of risk assessment but an evaluation with the lowest level of integrity. This method utilises ranking scales that comprise words to rate the likelihood and consequences of risk. This will be used when the level of risk does not justify time and resources for a full analysis or where numerical data are inadequate or unavailable. It will be used for preliminary screening of risks.
- The semi-quantitative method allocates a number to a qualitative scale chosen so as to avoid bias in the results of the estimate.
- The quantitative method uses numerical values and will be used in cases where the likelihood and consequences can be quantified and the expense can be justified by the benefits. It provides the highest integrity of assessment.

6.3.3 Risk Mitigation and Control.

Having compared the level of risk found during the analysis process with previously established risk criteria, appropriate programme actions shall be taken to mitigate the risk. These actions may be summarised as follows:

High Risks, require extensive risk mitigation planning that may include changes to baseline and the implementation of new processes and changes to development or operational approaches, changes in scheduling or cost profiles, or reallocation of significant resources. The risk mitigation status and mitigation plan shall be reported to project management on a weekly basis at minimum, or more often if deemed necessary.

For *Medium Risks*, alternative processes may need to be considered. In some cases, risk mitigation plans may be developed if deemed necessary. Risk mitigation status shall be reported to project management on a weekly basis for evaluation to determine whether the situation is improving.

For *Low Risks*, no special attention will be given by project management, although lower level activities may be initiated to monitor the situation.

In preparing a Risk Mitigation Plan, a range of risk reduction options, recommendations and their associated resource costs shall be presented to senior management to enable selection and approval of the most cost and time effective option within an acceptable level of risk. The agreed Plan will document methods for implementing the chosen options and will identify responsibilities and individual accountabilities, schedules, expected outcomes of risk reduction strategies, costing, and performance measures for the subsequent review process to be established. Responsibility for reducing risk will be delegated to those best able to manage the risk. The Plan will also include a mechanism to enable evaluation of the implementation options against performance criteria, individual responsibilities and other objectives. Critical implementation milestones will be monitored.

The implementation of the risk mitigation plan shall be integrated with other planning and management activities. All aspects shall be documented. If a residual risk remains after remedial action, a decision will be made as to whether this risk should be retained or whether the risk assessment and implementation process should be repeated.

6.3.4 GSAOI Project Risk Management Responsibilities

It is the responsibility of the Risk Assurance Officer, in liaison with the Project Manager, Project Scientist and Product Assurance Manager, to ensure that the project is continuously monitored for risk, identified risks are properly tracked, reported and documented, and that risk mitigation plans are implemented when the situation demands. The GSAOI Project Manager will serve as GSAOI Risk Assurance Officer and will receive input from delegates in each primary risk area. The GSAOI Project Manager is also responsible for reporting risk to programme levels and the RSAA Instrumentation Committee. The GSAOI Risk Assurance Organisation is shown in Figure 3.1.

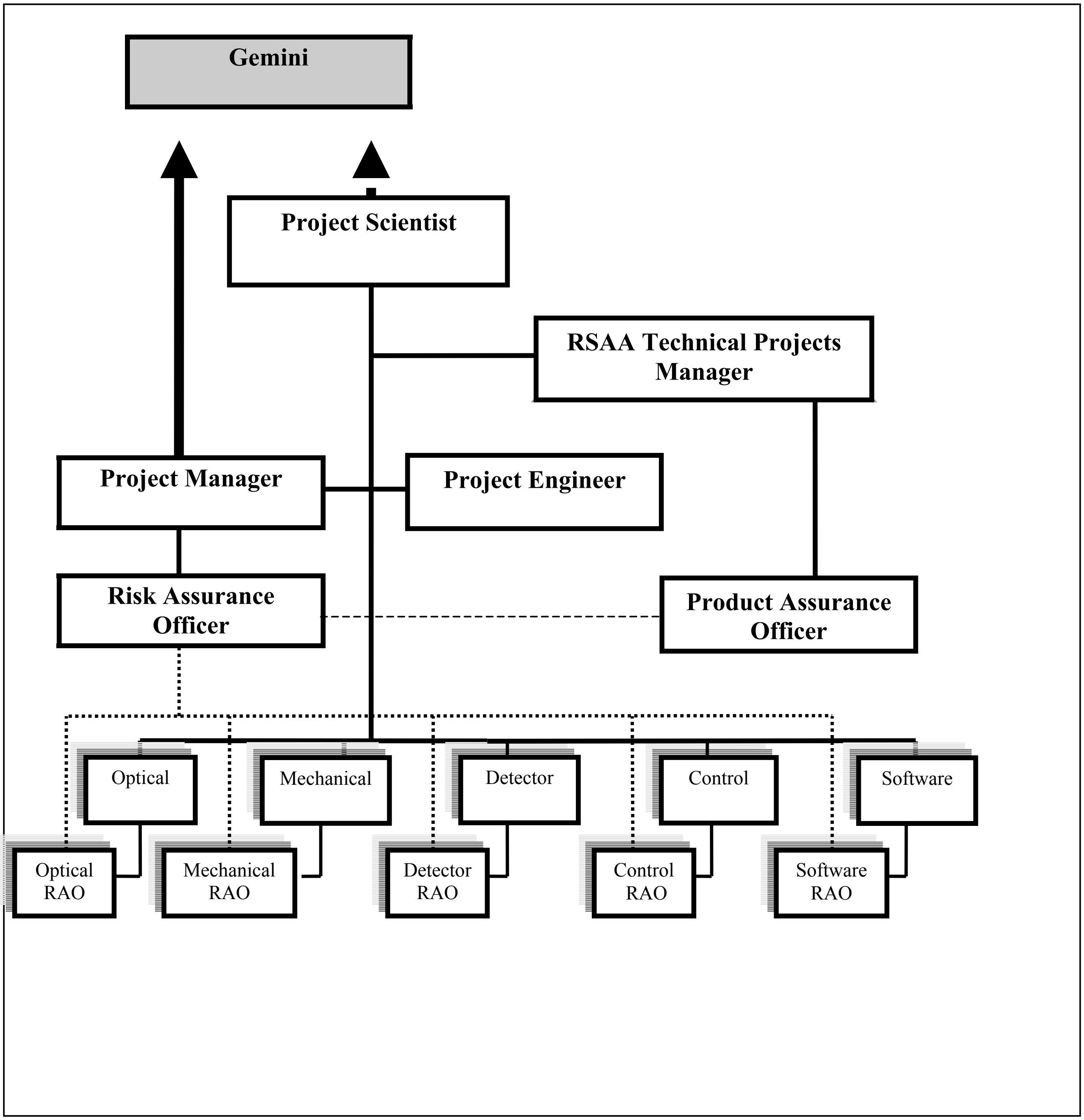


Figure A3.2: GSAOI Risk Assurance Organisation. The GSAOI Project Manager will serve as GSAOI Risk Assurance Officer (RAO). Delegates from each primary risk area monitor of risk and report to the RAO.

6.3.5 Risk Register and Specific Action Plans

For tracking purposes, a dynamic Risk Register will be maintained. Higher priority risks will be transferred from the risk register to a Risk Mitigation (Reduction) Plan.

Risk	Likelihood	Potential impact	Adequacy of existing risk reduction measures or controls	Consequence Rating	Levels of risk (from Risk Matrix)	Priority Rating
Identified risk (a)						
Identified risk (b)						
Identified risk (c)						
Identified risk (d)						

RISK	REF:
Risk Scenario:	
Summary- Recommended Response and Impact: *Summary Detail:* *Recommended Response:*	
Action Plan: **1. Proposed Action(s):** **2. Link to (other actions):** **3. Responsibility:** **4. Resource requirements:** **5. Schedule:** **6. Performance Indicators:** **7. Reporting and monitoring required:** **Prepared By:** Date:	**Reviewed By:** Date: **Authorised By:** Date:

Adapted from Australian/New Zealand Standard AS/NZS 4360 - 1995

Identified Risk Action Plan

GSAOI

AUSTRALIAN NATIONAL UNIVERSITY

System Design Note 1.03

Created: 14 May 2002
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FUNCTIONAL AND PERFORMANCE REQUIREMENTS DOCUMENT

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Revision History

Revision No.	Author & Date	Approval & Date	Description
Revision 1	Peter J. McGregor 29 November 2001	John Hart 1 March 2002	Draft initial document.
Revision 2	Peter J. McGregor 23 April 2002	Jan van Harmelen 23 April 2002	Revised initial document.
Revision 3	Peter J. McGregor 23 July 2002	Jan van Harmelen 25 July 2002	Revised for CoDR.

Contents

7 Purpose

The Gemini South Adaptive Optics Imager (GSAOI) Operational Concept Definition Document (OCDD) defines the scientific requirements of the GSAOI instrument and describes operational scenarios. These are translated into technical requirements in the GSAOI Functional and Performance Requirements Document (FPRD). Other technical requirements for Gemini facility instruments derive from the GSAOI Conceptual Design Study Statement of Work (GEM00304A). The scientific and technical requirements are summarized in this FPRD, and their relationships are identified so that all functional and performance requirements can be traced from top-level science requirements.

The two purposes of the GSAOI FPRD are to provide the Gemini scientific community with an understanding of what GSAOI will do and how quickly or how well it will do it, and to provide engineers with the requirements on which to base the GSAOI design. The design is derived from this document. This document takes precedence over other design and fabrication documents. The design must serve the requirements in this document completely. Every feature of GSAOI should be traceable to a requirement in this document, and there should be no features of GSAOI that are not required by this document.

GSAOI will be designed in stages, with a review after each stage is complete. Comments from the review committee will be folded into the design, so the requirements will change as the design changes. Therefore, this document will be updated as needed after each major design review to maintain the correspondence between requirements and design. This current version reflects the status at the Conceptual Design Review.

8 Applicable Documents

Document ID	Source	Title
GEM00304A	IGPO	GSAOI CoDR Statement of Work
GSAOI-OCDD-1	RSAA	GSAOI Operational Concept Definition Document
ICD 1.1.1/1.9	IGPO	Telescope Structure, Drives, and Brakes to Science Instruments ICD
ICD 1.1.11/1.9	IGPO	Telescope Control to Science Instruments ICD
ICD 1.1.13/1.9	IGPO	Interlock System to Science Instruments ICD
ICD 1.5.3	IGPO	Instrument Support Structure IDC
ICD 1.5.3/1.9	IGPO	Instrument Support Structure to Science Instruments ICD
ICD 1.6/1.10	IGPO	A&G System to On-Instrument WFS ICD
ICD 1.9/3.1	IGPO	Science Instruments to Observatory Control ICD
ICD 1.9/3.2	IGPO	Science Instruments to Data Handling ICD
ICD 1.9/3.6	IGPO	Science Instruments to System Services ICD
ICD 1.10	IGPO	On-Instrument Wave Front Sensor ICD
ICD 1.10.1	IGPO	OIWFS Feed Optics System ICD
ICD 1.10.2	IGPO	OIWFS Camera/Controller ICD
ICD 16	IGPO	The Parameter Definition Format
SPE-ASA-G0008	IGPO	Gemini Electronic Design Specification
SPE-C-G0037	IGPO	Gemini Software Design Description
SPE-S-G0041	IGPO	Gemini System Error Budget Plan
	AT&T Bell Laboratories, 1988	Ott, H. W., Noise Reduction Techniques in Electronic Systems, Second Edition

9 List of Acronyms

ASIC	Application Specific Integrated Circuit
CICS	Core Instrument Controller Software
DHS	Data Handling System
EPICS	Experimental Physics and Industrial Control System
FPRD	Functional and Performance Requirements Document
GIS	Gemini Interlock System
GSAOI	Gemini South Adaptive Optics Imager
ICD	Instrument Control Document
ICS	Instrument Control System
IGPO	International Gemini Project Office ("Gemini" or "the Project")
IOC	Input-Output Controller
ISS	Instrument Support Structure (the "cube")

LAN	Local Area Network
MCAO	Multi-Conjugate Adaptive Optics
NDR	Non-Destructive Read
NGS	Natural Guide Star
NIFS	Near-infrared Integral Field Spectrograph
NIRI	Near Infra-Red Imager
OCDD	Operational Concept Definition Document
OCS	Observatory Control System
OIWFS	On-Instrument Wave Front Sensor
SDSU-2	Second generation San Diego State University detector controller

10 Introduction

This document represents the current understanding of the capabilities and performance of the Gemini South Adaptive Optics Imager (GSAOI) to be designed, fabricated, tested, delivered, and commissioned by the Australian National University for use on the Gemini 8-m telescopes.

GSAOI will be the workhorse instrument used with Gemini's Multi-Conjugate Adaptive Optics (MCAO) system. GSAOI is a diffraction-limited imaging instrument. It will use a single imaging scale of 0.02″/pixel and have a square field of view 85″ on a side. GSAOI will be equipped with broad-band *Z*, *J*, *H*, *Ks* and *K* filters and narrow-band zero-redshift emission line filters. High sensitivity is essential to achieve the demanding science goals that have been set for the instrument. A pupil viewing system that will allow the internal cold stop to be accurately aligned with the telescope exit pupil will aid in realizing this sensitivity. A near-infrared On-Instrument Wave Front Sensor (OIWFS) will track flexure variations between MCAO and GSAOI, monitor focus variations at the same wavelength as the science observation, and act as a tip-tilt reference for MCAO when required.

11 Optical Requirements

11.1 System Functional Requirements

11.1.1 MCAO Compatibility

REQ-OCD-0001: GSAOI will accept the MCAO f/34 input beam with a pupil near the telescope secondary mirror.

11.1.2 Imager

REQ-OCD-0002: GSAOI will have an imager channel for science observations.

11.1.3 OIWFS

REQ-OCD-0003: GSAOI will have an OIWFS channel for monitoring tip-tilt motion due to flexure variations between MCAO and GSAOI, for monitoring focus changes due to variations in the height of the atmospheric sodium layer, and for performing fast tip-tilt and focus sensing when substituting for one of the MCAO Natural Guide Star (NGS) sensors.

11.2 System Performance Requirements

11.2.1 Vacuum Environment

REQ-FPR-0001: All optical components and coatings will meet all performance requirements when operated in a vacuum of less than 10^{-5} Torr at operational temperatures down to 65 K.

11.2.2 Thermal Cycling

REQ-FPR-0002: The performance of all optical components and coatings will not be degraded by repeated thermal cycling at a maximum rate of temperature change of 0.25 K/minute over the operating, storage, and transportation temperature ranges.

11.3 Imager Functional Requirements

11.3.1 Imager Wavelength Coverage

REQ-OCD-0004: The imager will operate in the wavelength range from 0.9-2.4 μm.

11.3.2 Imager Spatial Sampling

REQ-OCD-0005: The imager will have a scale of ~ 0.02″/pixel.

11.3.3 Imager Field-of-View

REQ-OCD-0006: The imager will have a field-of-view of > 80″×80″.

11.3.4 Imager Cold Stop

REQ-OCD-0007: The imager will include a fixed cold stop at an image of the MCAO exit pupil. The cold stop will be sized so as not to vignette the imager beam while reducing background radiation to the greatest extent possible.

11.3.5 Imager Pupil Viewer

REQ-OCD-0008: The imager will have a facility for viewing an image of the MCAO exit pupil.

11.3.6 Imager Non-Common Path Phase Errors

REQ-OCD-0009: The imager will be capable of measuring low-order wave front errors through the entire optical path to the imager detector with a spatial resolution of ~ 200 mm referenced to the telescope primary mirror.

Notes and Comments:

1. Measurement of the wave front error at the imager detector will permit the removal of static aberrations due to the imager optics.
2. It is envisaged that this requirement will be met by recording pupil images on either side of focus, analyzing the images with the Roddier program, and inputting the result to the MCAO system as coefficients of low order Zernike polynomials.

11.3.7 Imager Filters

11.3.7.1 Imager Filter Suite

REQ-OCD-0010: The imager will be able to interchange between any of the following filters:

No.	Filter	λ_c (μm)	$\Delta\lambda$ (μm)
1	*Z*	1.010	0.220
2	*J*	1.250	0.180
3	*H*	1.650	0.290
4	*Ks*	2.145	0.310
5	*K*	2.200	0.330
6	*J* continuum	1.207	0.018
7	*H* continuum	1.570	0.024
8	CH_4 (short)	1.580	0.095
9	CH_4 (long)	1.690	0.101
10	*Ks* continuum	2.090	0.031
11	*Kl* continuum	2.270	0.034
12	He I 1.0830 μm	1.083	0.016
13	H I Pγ	1.094	0.016
14	H I Pβ	1.282	0.019
15	[Fe II] 1.644 μm	1.644	0.025
16	H_2O	1.996	0.050
17	H_2 1-0 S(1)	2.122	0.032
18	H I Brγ	2.166	0.032
19	H_2 2-1 S(1)	2.248	0.034
20	CO 2-0 (bh)	2.294	0.034
21	CO 3-1 (bh)	2.323	0.035
26	Blocked	…	…

11.3.7.2 Imager Filter Transmission

REQ-FPR-0003: The imager filters will have an on-band transmission greater than 80%, and an off-band transmission less than 10^{-4}.

11.3.7.3 Imager Filter Wedge

REQ-FPR-0004: The imager filters will have a wedge angle that produces an image deflection at the imager detector of < 1 pixel.

11.3.8 Imager Calibration

REQ-OCD-0011a: The imager focal plane wheel will contain one blocked position for recording bias frames.

REQ-OCD-0011b The imager filter wheel will contain one blocked position for recording bias frames.

REQ-OCD-0011c The imager utility wheel will contain one blocked position for recording bias frames.

11.3.9 Optical Baffling

REQ-FPR-0005: GSAOI will be baffled such that the baffling does not reduce the imager throughput.

11.3.10 Imager Pupil Viewer Resolution

REQ-OCD-0012 The imager pupil viewer will have a resolution of < 100 mm equivalent at the Gemini telescope primary mirror.

11.4 Imager Performance Requirements

11.4.1 Imager Strehl Ratio

REQ-OCD-0013: The total wave front error introduced by the imager optical system will be < 65 nm RMS over the wavelength range 0.9–2.4 μm. This corresponds to a Strehl ratio of > 0.94 at a wavelength of 1.6 μm.

Notes and Comments:

1. The optical image quality error budget is discussed in Gemini System Error Budget Plan, SPE-S-G0041.
2. The MCAO optical error budget places a tighter constraint on the science instrument. This is the origin of the above requirement.
3. The Marechal approximation, $S \sim \exp\text{-}(2\pi\sigma/\lambda)^2$, is used to convert RMS wave front error, σ, to Strehl ratio, S, at wavelength, λ.

11.4.2 Imager Distortion

REQ-OCD-0014: The imager will cause a geometrical distortion at the detector of < 0.1%.

11.4.3 Imager System Throughput

REQ-OCD-0015: The imager will have a total system throughput over its required wavelength range of ≥ 25% including the telescope, imager optics, filter, and detector, but not including the throughput of the MCAO science path.

11.4.4 Imager Instrumental Background

REQ-OCD-0016: The imager will have an internal instrument background less than either the natural background from the observed science field or the dark current of the detector whichever is greater.

11.4.5 Imager Ghost Images

REQ-OCD-0017: Ghost images generated in the imager optics must be at a level below 10^{-5} of the parent image.

11.4.6 Imager Sensitivity

REQ-OCD-0018: The imager will be capable of detecting point sources with K = 23.0 mag in 3600 s with a signal-to-noise ratio of 10 through a 0.08″×0.08″ aperture.

11.4.7 Imager On-Detector Guide Window Performance

REQ-OCD-0041: The imager On-Detector Guide Window should be able to determine the centroid of a star with K < 19 mag to an RMS accuracy of 1/20 of the image full width at half maximum in a 30 s exposure and sense tip-tilt corrections in 0.01 s exposures on stars with K < 11 mag.

Notes and Comments:

1. There is a ~ 91% probability of having a guide star with $K \leq 19$ mag within a random 2′ diameter field at the Galactic pole, and probabilities of ~ 2.3% at the Galactic pole, ~ 2.8% at b =60º, and ~ 5.8% at b =30º for a $K \leq 11$ mag guide star.
2. MCAO fields are not random in that MCAO NGSs must be present for MCAO operation.

11.4.8 Imager Pupil Viewer Sensitivity

REQ-OCD-0019: The imager pupil viewer will be capable of detecting the expected background emission in the K band with a signal-to-noise ratio of > 10 in a 1 min integration.

11.5 OIWFS Functional Requirements

The OIWFS may use the on-chip guide window capability of the HAWAII-2RG imager detectors for tip-tilt/flexure monitoring. Then, a separate OIWFS will be needed only for monitoring focus variations due to relatively slow variations in the height of the atmospheric sodium layer. Focus monitoring is a relative measurement (separation between star images) so this removes the requirement to strictly control differential flexure between the imager detector and the OIWFS detector.

11.5.1 OIWFS Wavelength Coverage

REQ-OCD-0020: The OIWFS will operate in the wavelength range from 0.9-2.4 μm.

11.5.2 OIWFS Spatial Sampling

REQ-OCD-0021: The OIWFS will have a scale of ~ 0.065″/pixel.

11.5.3 OIWFS Field-of-View

REQ-OCD-0022: The OIWFS will have a circular field-of-view of 0.5″ in diameter when read out at 200 Hz and a facility for increasing the field diameter to > 5″×5″ for acquiring guide stars. Degraded image quality of the larger field-of-view is acceptable.

11.5.4 OIWFS Cold Stop

REQ-FPR-0006: The OIWFS will include a cold stop at an image of the MCAO exit pupil.

Notes and Comments:

1. It will not be possible to independently align the imager and OIWFS cold stops to the MCAO exit pupil. The imager alignment will take priority.

11.5.5 OIWFS Guide Star Patrol Field

REQ-OCD-0023: The OIWFS will have a patrol field for acquiring guide stars extending to the full 60″ radius of the available MCAO field.

11.5.6 OIWFS Vignetting

REQ-OCD-0024: The OIWFS beam pick-off will not vignette the imager field.

11.5.7 OIWFS Filters

11.5.7.1 OIWFS Filter Suite

REQ-OCD-0025: The OIWFS will be able to interchange between any of the following filters to match its wavelength sensitivity to the band pass selected for the imager:

No.	**Filter**	**λ_c (μm)**	**$\Delta\lambda$ (μm)**
1	Clear	...	...
2	*Z*	1.010	0.220
3	*J*	1.250	0.180
4	*H*	1.650	0.290
5	*Ks*	2.145	0.310
6	*K*	2.200	0.330
7	*ZJ*	1.120	0.440
8	*HK*	1.935	0.860

9	Blocked	…	…
10	Spare	…	…

11.5.7.2 OIWFS Filter Transmission

REQ-FPR-0007: The OIWFS filters will have an on-band transmission greater than 80%, and an off-band transmission less than 10^{-4}.

11.5.7.3 OIWFS Filter Wedge

REQ-FPR-0008: The OIWFS filters will have a wedge angle that produces an image deflection at the OIWFS detector of < 1 pixel.

11.5.8 Shack-Hartmann Prism

REQ-OCD-0026: The OIWFS will use a fixed four-facet Shack-Hartmann prism operated in collimated light to sense wave front focus variations in two perpendicular directions.

11.5.9 OIWFS Calibration

REQ-OCD-0027: The OIWFS filter wheel will contain one blocked position for recording bias frames.

Notes and Comments:

1. The OIWFS ICDs are:
   - OIWFS (ICD 1.10)
   - OIWFS Feed Optics System (ICD 1.10.1)
   - OIWFS Camera/Controller (ICD 1.10.2)

11.6 OIWFS Performance Requirements

11.6.1 OIWFS Strehl Ratio

REQ-OCD-0028: The total wave front error introduced by the OIWFS optical system will be < 120 nm RMS over the wavelength range 0.9–2.4 μm. This corresponds to a Strehl ratio of > 0.81 at a wavelength of 1.6 μm.

Notes and Comments:

1. Diffraction at the OIWFS prism increases the OIWFS image size by a factor of ~ 2, so the wave front error requirement is relaxed by a factor of ~ 2.
2. The Marechal approximation, $S \sim \exp(-(2\pi\sigma/\lambda)^2)$, is used to convert RMS wave front error, σ, to Strehl ratio, S, at wavelength, λ.

11.6.2 OIWFS System Throughput

REQ-OCD-0029: The OIWFS will have a total system throughput over its required wavelength range of ≥ 15% including the telescope, OIWFS optics, filter, and detector, but not including the throughput of the MCAO science path.

11.6.3 OIWFS Sensitivity

REQ-OCD-0030: The OIWFS should be able to determine the centroid of a star image with $K < 18$ mag to an RMS accuracy of 1/20 of the image full width at half maximum in a 30 s exposure and sense tip-tilt and focus corrections in 0.01 s exposures on stars with $K < 10$ mag.

Notes and Comments:

1. There is a ~ 80% probability of having a guide star with $K \leq 18$ mag within a random 2′ diameter field at the Galactic pole, and probabilities of ~ 0.9% at the Galactic pole, < 2.7% at b =60º, and < 5.8% at b =30º for a $K \leq 10$ mag guide star.
2. MCAO fields are not random in that MCAO NGSs must be present for MCAO operation.
3. The MCAO field center can be adjusted to pass the near-infrared light of one of the MCAO NGSs to the OIWFS.

12 Mechanical Requirements

12.1 System Functional Requirements

12.1.1 Mechanical Duplication

REQ-FPR-0100: The mechanical design will duplicate NIRI/NIFS components to the greatest extent possible.

12.1.2 Instrument Alignment Provision

REQ-FPR-0101: A means will be provided for establishing alignment of the imager cold stop to within 1% of the projected size of the MCAO exit pupil.

Notes and Comments:

1. This requirement does not necessarily lead to the inclusion of interactive alignment aids in the design. Off-telescope alignment, together with a verification test could suffice.

12.1.3 Mechanical and Thermal Tolerances

REQ-FPR-0102: Where adequate mounting precision cannot be provided by dead reckoning, convenient means will be provided to measure the misalignment of optical components of the imager under ambient conditions, and then adjust their alignment with a precision that allows the optical performance specification to be met. Where thermally induced misalignment is significant, theoretically derived compensation will be applied.

12.1.4 Temperature Gradients

REQ-FPR-0103: Thermal effects due to temperature gradients outside the cryostat, inside the cryostat, and near the detector will be considered in the design of GSAOI. Realistic limits will be set according to the NIRI performance. [**TBD**]

12.1.5 Thermal Transients

REQ-FPR-0104: Thermal transient effects during cool-down or warm-up will be considered in the design of GSAOI. Realistic limits will be set according to the NIRI performance. [**TBD**]

12.1.6 Instrument Volume

12.1.6.1 Space Requirement

REQ-FPR-0105: GSAOI will be designed to fulfill the space requirements for an instrument attached to the ISS.

Notes and Comments:

1. Space requirements are specified in ICD 1.1.1/1.9.

12.1.6.2 Thermal Enclosures

REQ-FPR-0106: All GSAOI thermal enclosures mounted on the ISS will be counted in the space requirements given above.

12.1.6.3 Access to Thermal Enclosures

REQ-FPR-0107: The thermal enclosures will be accessible without removing GSAOI from the ISS.

12.1.6.4 Access to Vacuum Ports

REQ-FPR-0108: Vacuum ports on GSAOI will be accessible without removing the instrument from the ISS.

12.1.6.5 Access to Cooling Water Ports

REQ-FPR-0109: Cooling water ports on GSAOI will be accessible without removing the instrument from the ISS.

12.1.6.6 Access to Dry Air Ports

REQ-FPR-0110: Dry air ports on GSAOI will be accessible without removing the instrument from the ISS.

12.1.6.7 Mechanical Connections

REQ-FPR-0111: All mechanical connections on GSAOI will be accessible without removing the instrument from the ISS and while mounted with other instruments.

12.1.7 Instrument Mass

12.1.7.1 Total Mass

REQ-FPR-0112: GSAOI, including its support frame, thermal enclosures, electronics, and all cabling and services connections, will have a mass of 2000 kg.

12.1.7.2 Center of Gravity

REQ-FPR-0113: GSAOI, including its support frame, thermal enclosures, electronics, and all cabling and services connections, will have a center of gravity on the port axis 1000 mm from the mechanical interface on the ISS.

12.1.7.3 Balance Tolerance

REQ-FPR-0114: In any orientation of the telescope and rotator, the out-of-balance caused by GSAOI must not exceed 400 Nm with respect to the telescope elevation axis. This will include static imbalance and any change in mass moment due to moving elements.

12.1.7.4 Ballast Weight

REQ-FPR-0115: A ballast weight and its supporting structure shall be supplied as required to meet the above requirements.

Notes and Comments:

1. Mass and center of gravity requirements are specified in ICD 1.5.3/1.9.

12.1.8 Cooling System

12.1.8.1 Closed-Cycle Coolers

REQ-FPR-0116: GSAOI will use a cryogenic closed-cycle cooling system.

12.1.8.2 Cooler Vibration

REQ-FPR-0117: Adequate measures will be taken to ensure that the use of cryogenic closed cycle coolers does not introduce sufficient vibrations into the mechanical structure to prevent meeting all rigidity, alignment, tracking, and other performance requirements.

12.1.9 Vacuum System

12.1.9.1 Vacuum System Facilities

REQ-FPR-0118: GSAOI will use a duplicate at Gemini South of the vacuum system facilities used by NIRI in the staging and holding areas at Gemini North.

12.1.9.2 Vacuum Pump Capacity and Selection

REQ-FPR-0119: GSAOI will use the same type of vacuum pump as NIRI.

12.1.9.3 Vacuum Operating Procedure and Set-Up

REQ-FPR-0120: GSAOI will use the same vacuum system operating procedures and set-up as NIRI.

12.1.9.4 Vacuum Test Set-Up

REQ-FPR-0121: GSAOI will use a duplicate at Gemini South of the vacuum system test set-up used for NIRI at Gemini North.

12.1.10 Mechanisms Operation

12.1.10.1 Mechanism Safety

REQ-FPR-0122: No mechanism will move in the event of loss of electrical power.

12.1.11 Environmental Cover

REQ-FPR-0123: GSAOI will be fitted with an environmental cover that can be operated either by the control system or manually in case of power failure.

12.1.12 Dust Removal System

REQ-FPR-0124: The GSAOI environmental cover will be fitted with a dry air blowing dust removal system that will also avoid condensation on the window.

12.1.13 Instrument Handling

REQ-FPR-0125: The GSAOI support frame shall have feet allowing the instrument to be stored freestanding, and attachment points for the Gemini instrument handling facilities.

12.1.14 Metric Dimensioning

REQ-FPR-0126: Metric dimensions will be used in GSAOI.

12.1.15 Metric Dimensions on Drawings

REQ-FPR-0127: Metric dimensions in millimeters will be used in all as-built drawings, with dimensions called out to 0.01 mm.

12.1.16 Metric Fasteners

REQ-FPR-0128: All screws, bolts, nuts, tapped holes, and fasteners will be of standard metric sizes, and called out as such on the as-built drawings.

12.2 System Performance Requirements

12.2.1 Instrument Alignment Maintenance

REQ-FPR-0129: The alignment of the GSAOI imager cold stop with the MCAO exit pupil will be maintained to the accuracy specified in REQ-FPR-0101 in any attitude of the telescope and rotator, and on any port of the Instrument Support Structure.

12.2.2 Tracking with the OIWFS

REQ-FPR-0130: Tracking performance when using the GSAOI OIWFS will result in less than 0.1 pixel tracking error on the imager detector per any 15° attitude change of the instrument.

12.2.3 Cryogenic Cooling System

12.2.3.1 Cool Down Time

REQ-FPR-0131: GSAOI will have a cryogenic cooling system with the capability to cool the instrument from room temperature to operating conditions in **TBD** hours or less. Realistic limits will be set according to the NIRI performance.

12.2.3.2 Warm Up Time

REQ-FPR-0132: GSAOI will not require more than **TBD** hours to warm up the entire instrument from operating conditions to room temperature. Realistic limits will be set according to the NIRI performance.

12.2.3.3 Thermal Stability

REQ-FPR-0133: The surface on which the imager optical system is mounted will have an active temperature control system providing a variable temperature to be referenced to the center of the cold work surface between 65 K and 75 K with a stability of ±0.5 K.

12.2.4 Mechanisms Operation

12.2.4.1 Mechanism Set Time

REQ-OCD-0031: Individual GSAOI mechanisms should be set within 30 s.

12.2.4.2 Mechanism Configuration Time

REQ-OCD-0032: A complete reconfiguration of the GSAOI instrument should be achieved in < 1 min.

12.2.4.3 Repeatability of Configuration

REQ-FPR-0134: The total error at the detector resulting from reconfiguration of all mechanisms will be less than 0.5 pixels.

12.2.5 Downtime

REQ-FPR-0135: GSAOI will have a downtime of < 2% scheduled time on the telescope and, where possible, component failure shall result in gradual performance degradation.

12.3 Imager Functional Requirements

12.3.1 Imager Focal Plane Wheel

REQ-OCD-0033: The imager will have a focal plane wheel for interchanging the following elements:

No.	Focal Plane Wheel Contents
1	Blocked
2	Clear
3	Focus mask
4	Spare

12.3.2 Imager Filter Wheel

REQ-FPR-0136: The imager will have one or more filter wheels with provision for up to 30 filters.

12.3.3 Fast Shutter

REQ-OCD-0044: GSAOI will contain a fast shutter for pausing imager exposures.

12.3.4 Imager Utility Wheel

REQ-OCD-0034: The imager will have a utility wheel for interchanging the following elements:

No.	Utility Wheel Contents
1	Clear
2	Pupil viewer
3	Convex defocus lens
4	Concave defocus lens
5	Blocked

12.3.5 Imager Detector

12.3.5.1 Imager Detector Alignment

REQ-FPR-0137: The imager detector will be mounted such that the detector surface coincides with the imager focal plane over the full extent of the detector, the spacing between individual detectors in the mosaic is ≤ 2.5 mm, and the columns of each detector are parallel to < 4 pixel in 2048.

Notes and Comments:

1. The location of each detector within its chip carrier will have to be measured to < 18 μm accuracy to achieve this requirement.

12.3.5.2 Imager Detector Mechanical Interface

REQ-FPR-0138: The imager detector will be mounted such that, once adjusted, it can be removed and [illegible]talled without necessitating optical realignment.

12.3.5.3 Imager Detector Thermal Interface

REQ-FPR-0139: The imager detector will be thermally coupled to the cold head by high thermal conductivity material. The detector will be actively maintained at operating temperature by an electric heating element.

12.3.5.4 Imager Detector Optical Interface

REQ-FPR-0140: Means will be provided to measure the imager detector defocus error under operational conditions, and then adjust the position of the imager detector with a precision that is finer than that corresponding to the spatial resolution of the imager.

12.4 Imager Performance Requirements

12.4.1 Imager Focal Plane Wheel

12.4.1.1 Imager Focal Plane Wheel Orientation Stability

REQ-FPR-0141: The imager focal plane wheel will maintain the orientation of the active element to < ±0.1 mm along the optical axis, the equivalent of < ±0.1 pixels at the imager detector perpendicular to the optical axis, and with a tilt of < ±0.07 degrees, which is equivalent to a motion of 0.1 mm along the optical axis at a radius of 80 mm (~ 60″) from it.

12.4.1.2 Imager Focal Plane Wheel Setting Accuracy

REQ-FPR-0142: The imager focal plane wheel will set to an accuracy of < ±0.1″ equivalent on the sky.

12.4.1.3 Imager Focal Plane Wheel Setting Time

REQ-FPR-0143: The imager focal plane wheel will complete a motion from one position to the diametrically opposite position and confirm completion within 30 s.

12.4.2 Imager Filter Wheel

12.4.2.1 Imager Filter Wheel Orientation Stability

REQ-FPR-0144: The imager filter wheel will maintain the orientation of the active element to < ±0.1 mm along the optical axis, < ±0.1 mm perpendicular to the optical axis, and with a tilt of < ±0.25 degrees, which is equivalent to a motion of ~ ±0.1 mm along the optical axis at a radius of 15 mm (i.e., half the beam diameter) from it.

12.4.2.2 Imager Filter Wheel Setting Accuracy

REQ-FPR-0145: The imager filter wheel will set to an accuracy of < ±0.1 mm at the wheel.

12.4.2.3 Imager Filter Wheel Setting Time

REQ-FPR-0146: The imager filter wheel will complete a motion from one position to the diametrically opposite position and confirm completion within 30 s.

12.4.3 Fast Shutter Response Time

REQ-FPR-0163: The imager fast shutter will respond to open and close commands in < 1 s.

12.4.4 Imager Utility Wheel

12.4.4.1 Imager Utility Wheel Orientation Stability

REQ-FPR-0147: The imager utility wheel will maintain the orientation of the active element to < ±0.1 mm along the optical axis, < ±0.05 mm perpendicular to the optical axis, and with a tilt of < ±0.01 degrees to maintain pupil viewer image quality.

12.4.4.2 Imager Utility Wheel Setting Accuracy

REQ-FPR-0148: The imager utility wheel will set to an accuracy of < ±0.1 mm at the wheel.

12.4.4.3 Imager Utility Wheel Setting Time

REQ-FPR-0149: The imager utility wheel will complete a motion from one position to the diametrically opposite position and confirm completion within 30 s.

12.5 OIWFS Functional Requirements

12.5.1 OIWFS Steerable Mirror

REQ-FPR-0150: The OIWFS steerable mirror will scan over angles equivalent to a field 120″ in diameter on the sky.

12.5.2 OIWFS Aperture Wheel

REQ-OCD-0035: The OIWFS will have an aperture wheel for interchanging the following elements:

No.	OIWFS Aperture Wheel Content
1	Clear
2	0.52″ diameter circular aperture
3	2.6″ offset square aperture
4	5.2″ offset square aperture
5	Spare
6	Blocked

12.5.3 OIWFS Filter Wheel

REQ-FPR-0151: The OIWFS will have a filter wheel with provision for up to 10 filters.

12.5.4 OIWFS Detector

12.5.4.1 OIWFS Detector Mechanical Interface

REQ-FPR-0152: The OIWFS detector shall be mounted such that, once adjusted, it can be removed and reinstalled without necessitating optical realignment.

12.5.4.2 OIWFS Detector Thermal Interface

REQ-FPR-0153: The OIWFS detector will be thermally coupled to the cold head by high thermal conductivity material. The detector will be actively maintained at operating temperature by an electric heating element.

12.5.4.3 OIWFS Detector Optical Interface

REQ-FPR-0154: Means will be provided to measure the OIWFS detector defocus error under operational conditions, and then adjust the position of the OIWFS detector with a precision that is finer than that corresponding to the spatial resolution of the OIWFS.

12.6 OIWFS Performance Requirements

12.6.1 OIWFS Steerable Mirror

12.6.1.1 OIWFS Steerable Mirror Orientation Stability

REQ-FPR-0155: The OIWFS steerable mirror will be maintained in position to < ±0.1 mm along the optical axis and in orientation to the equivalent of < ±0.1 pixels at the imager detector.

12.6.1.2 OIWFS Steerable Mirror Setting Accuracy

REQ-OCD-0036: The OIWFS steerable mirror will set to an accuracy equivalent to < ±0.1″ on the sky so that the guide star is within the 0.52″ OIWFS aperture.

12.6.1.3 OIWFS Steerable Mirror Setting Repeatability

REQ-OCD-0037: The OIWFS steerable mirror will set with repeatability equivalent to < ±0.04″ on the sky.

12.6.1.4 OIWFS Steerable Mirror Setting Time

REQ-FPR-0156: The OIWFS steerable mirror will complete a motion from one position to the diametrically opposite position of its field and confirm completion within 30 s.

12.6.2 OIWFS Aperture Wheel

12.6.2.1 OIWFS Aperture Wheel Orientation Stability

REQ-FPR-0157: The OIWFS aperture plane wheel will maintain the orientation of the active element to < ±0.1 mm along the optical axis, the equivalent of < ±0.5 pixels at the OIWFS detector perpendicular to the optical axis, and with a tilt of < ±10 degrees, which is equivalent to a motion of < 0.1 mm along the optical axis at a radius of 0.3 mm (~ 0.25″) from it.

12.6.2.2 OIWFS Aperture Wheel Setting Accuracy

REQ-FPR-0158: The OIWFS aperture wheel will set to an accuracy of < ±0.5 pixels at the OIWFS detector.

12.6.2.3 OIWFS Aperture Wheel Setting Time

REQ-FPR-0159: The OIWFS aperture wheel will complete a motion from one position to the diametrically opposite position and confirm completion within 30 s.

12.6.3 OIWFS Filter Wheel

12.6.3.1 OIWFS Filter Wheel Orientation Stability

REQ-FPR-0160: The OIWFS filter wheel will maintain the orientation of the active element to < ±0.1 mm along the optical axis, < ±0.1 mm perpendicular to the optical axis, and with a tilt of < ±0.4 degrees, which is equivalent to a motion of ~ ±0.1 mm along the optical axis at a radius of 15 mm (i.e., half the beam diameter) from it.

12.6.3.2 OIWFS Filter Wheel Setting Accuracy

REQ-FPR-0161: The OIWFS filter wheel will set to an accuracy of < ±0.1 mm at the wheel.

12.6.3.3 OIWFS Filter Wheel Setting Time

REQ-FPR-0162: The OIWFS filter wheel will complete a motion from one position to the diametrically opposite position and confirm completion within 30 s.

Notes and Comments: The OIWFS ICDs are:

- OIWFS (ICD 1.10)
- OIWFS Feed Optics System (ICD 1.10.1)
- OIWFS Camera/Controller (ICD 1.10.2)

13 Detector Requirements

13.1 Imager Detector Functional Requirements

13.1.1 Imager Detector Device

REQ-FPR-0200: The imager detector will be a 4096×4096 mosaic of four Rockwell HAWAII-2RG HgCdTe/CdZnTe MBE devices with 2048×2048 18 μm pixels and separated by 2.5 mm.

13.1.2 Imager On-Detector Guide Window

REQ-OCD-0038: The imager will have a facility for defining and processing data from a rectangular guide window on the imager detector that will be used for tip-tilt sensing.

13.1.3 Imager Detector Electrical Interface

REQ-FPR-0201: The electrical interface to the imager detector will be through suitable sockets.

13.1.4 Imager Detector Controller

13.1.4.1 Imager Detector Controller Type

REQ-FPR-0202: The imager detector will be controlled either by SDSU-2 detector controllers or Application Specific Integrated Circuits (ASICs) under development at Rockwell.

13.1.4.2 Imager Detector Controller Mechanical Interface

REQ-FPR-0203: If the imager detector controller uses SDSU-2 controllers, they will be mounted on an external wall of the cryostat. The controller power supply will be mounted in one of the thermal enclosures.

13.1.4.3 Imager Detector Controller Thermal Interface

REQ-FPR-0204: If the imager detector controller uses SDSU-2 controllers, they will be actively cooled with the coolant supplied via the Cassegrain Rotator Utilities Box.

13.1.4.4 Imager Detector Controller Readout Methods

REQ-FPR-0216: The imager detector controller will support double correlated sampling and Fowler sampling read out methods for the imager detector.

13.1.4.5 Imager Detector Controller Integration Times

REQ-FPR-0217: The imager detector controller will support integration times for the imager detector from 1 s to 10,000 s.

13.1.4.6 Imager Detector Controller Fowler Samples

REQ-FPR-0219: The imager detector controller will allow between 1 and 64 Fowler samples to be obtained before and after the integration in the Fowler sampling read out method.

13.1.4.7 Imager Detector Controller Number of Coadds

REQ-FPR-0220: The imager detector controller will support the coaddition of between 1 and 1000 imager detector data frames before the result is transferred to the DHS and archived.

13.1.4.8 Imager Detector Controller Regions of Interest

REQ-FPR-0229: The imager detector controller will support fixed-format regions of interest with pre-defined 64×64, 256×256, 512×512, and 1024×1024 pixel windows at the center of the mosaic and at the centers of each HAWAII-2RG detector.

13.1.4.9 Imager Detector Controller Guide Window Definition

REQ-FPR-0221: The imager detector controller will support the definition of an On-Detector Guide Window in one of the four detectors of the mosaic.

13.1.4.10 Imager Detector Controller Guide Window Integration Time

REQ-FPR-0222: The imager detector controller will support integration times for the imager On-Detector Guide Window from 10 ms to 1000 s.

13.2 Imager Detector Performance Requirements

13.2.1 Imager Detector Read Noise

REQ-OCD-0039: The imager detector will employ read noise reduction techniques, such as Fowler sampling, to achieve an effective read noise of < 10 e.

13.2.2 Imager Detector Dark Current

REQ-OCD-0040: The imager detector will have a dark current < 0.1 e s^{-1} pix^{-1}.

13.2.3 Imager Detector Stability

13.2.3.1 Imager Detector Bias Variations

REQ-FPR-0205: Over a period equal to the longest integration time of 3600 s, bias variations will be < 50 electrons.

Notes and Comments:

1. The lowest background signal is expected to be ~ 0.67 e s^{-1} in the H I Pγ filter. This will produce an RMS noise of ~ 50 e in 3600. Bias drifts should be less than this background noise.

13.2.3.2 Imager Detector Gain Variations

REQ-FPR-0206: Over a period equal to the longest integration time of 3600 s, gain variations will be less than the photometric stability of the atmosphere, which is taken to be 1%.

13.2.4 Imager Detector Maximum Continuous Frame Rate

REQ-FPR-0223: The imager detector will be read out at a maximum continuous frame rate of at least 0.05 Hz.

Notes and Comments:

1. The 20 s minimum frame time comprises a 5 s read time prior to integration, a 5 s read time after integration, and 10 s in which to process the data and transfer it to the DHS.
2. Current information is that the DHS can handle 2.8 MB/s. A full imager detector frame in Real*4 format contains 64 MB, so the minimum transfer time to the DHS is currently 22.9 s. **[TBD]** Actually, testing has shown that best achievable rate when the DHS server runs on SunBlade 1000 with 2x900MHz CPUs and 1GB RAM is 2.2MB/s.

3. Processing (summing, averaging, coadding and unraveling pixels) of a full imager detector frame is expected to take an additional ~ 2.3 s using a 400 MHz SVGM5 processor with the Altivec vector unit.
4. A speed increase for the DHS by a factor of ~ 3 would be required by upgrading existing Gemini hardware and software. Testing at RSAA has shown that this is currently not achievable.
5. Higher continuous frame rates may be achieved by pipelining the data read and data transfer functions. This will not reduce the time to record a single frame.

13.2.5 Imager On-Detector Guide Window Maximum Continuous Frame Rate

REQ-FPR-0224: The imager On-Detector Guide Window will be read out at a maximum continuous frame rate of ≥ 100 Hz using a 12×12 pixel guide window. Guide window reads must continue while the imager detector is being read out.

13.3 OIWFS Detector Functional Requirements

13.3.1 OIWFS Detector Device

REQ-FPR-0207: The OIWFS detector will be of the same type as used in NIRI; a Rockwell HAWAII-1 HgCdTe/PACE device with 1024×1024 18.5 μm pixels.

13.3.2 OIWFS Detector Electrical Interface

REQ-FPR-0208: The electrical interface to the OIWFS detector will be through a suitable socket.

13.3.3 OIWFS Detector Controller

13.3.3.1 OIWFS Detector Controller Type

REQ-FPR-0209: The OIWFS detector will be controlled by a SDSU-2 controller.

13.3.3.2 OIWFS Detector Controller Mechanical Interface

REQ-FPR-0210: The OIWFS detector controller will be mounted on an external wall of the cryostat. The controller power supply will be mounted in one of the thermal enclosures.

13.3.3.3 OIWFS Detector Controller Thermal Interface

REQ-FPR-0211: The OIWFS detector controller will be actively cooled with the coolant supplied via the Cassegrain Rotator Utilities Box.

13.3.3.4 OIWFS Detector Controller Readout Method

REQ-FPR-0225: The OIWFS detector controller will support the double correlated sampling read out method for the OIWFS detector.

13.3.3.5 OIWFS Detector Controller Guide Window Definition

REQ-FPR-0226: The OIWFS detector controller will support the definition of rectangular guide window on the OIWFS detector.

13.3.3.6 OIWFS Detector Controller Integration Times

REQ-FPR-0227: The OIWFS detector controller will support integration times for the OIWFS detector from 10 ms to 100 s.

13.3.3.7 OIWFS Detector Controller Number of Coadds

REQ-FPR-0228: The OIWFS detector controller will support the coaddition of between 1 and 1000 OIWFS detector data frames before the result is transferred to the A&G IOC for tip-tilt and focus processing.

13.4 OIWFS Detector Performance Requirements

13.4.1 OIWFS Detector Read Noise

REQ-FPR-0212: The OIWFS detector will have an effective read noise of < 20 e.

13.4.2 OIWFS Detector Dark Current

REQ-FPR-0213: The OIWFS detector will have a dark current < 1.0 e s^{-1} pix^{-1}.

13.4.3 OIWFS Detector Stability

REQ-FPR-0214: Over a period of 30 s, bias variations will be less than the read noise.

13.4.4 OIWFS Detector Maximum Continuous Frame Rate

REQ-FPR-0215: The OIWFS detector guide window will be read out at a maximum continuous frame rate of > 100 Hz using a 24×24 pixel guide window.

Notes and Comments:

1. The OIWFS ICDs are:
   - OIWFS (ICD 1.10)
   - OIWFS Feed Optics System (ICD 1.10.1)
   - OIWFS Camera/Controller (ICD 1.10.2)

14 Control System Requirements

14.1 Mechanism Control System Functional Requirements

14.1.1 Mechanism Control System Duplication

REQ-FPR-0300: The mechanism control system will duplicate the NIRI/NIFS mechanism control system to the greatest extent possible.

14.1.2 Mechanism Control System Operability

REQ-FPR-0301: All mechanisms and controlled features of GSAOI will be controllable by a Gemini-standard IOC computer.

14.1.3 Mechanisms

REQ-FPR-0302: The mechanism control system will control the following mechanisms:

Mechanism	Type	Positions
Environmental cover	Open/closed	2
Imager focal plane wheel	Rotary	4
Imager upper filter wheel	Rotary	15
Imager lower filter wheel	Rotary	15
Imager fast shutter	Rotary	4
Imager utility wheel	Rotary	5
OIWFS steerable mirror axis-A	Linear	…
OIWFS steerable mirror axis-B	Linear	…
OIWFS steerable mirror axis C	Linear	…
OIWFS aperture wheel	Rotary	6
OIWFS filter wheel	Rotary	10

14.2 Mechanism Control System Performance Requirements

14.2.1 Configuration Time

REQ-FPR-0303: The control system overhead on the mechanism configuration times will be such that the total GSAOI configuration time is within the limit set by REQ-OCD-0031.

14.2.2 Impact on Mechanism Accuracy

REQ-FPR-0304: The accuracy of the GSAOI controllable mechanisms will not be limited by the performance of the control system.

14.2.3 Impact on Scientific Performance

REQ-FPR-0305: The control system will not degrade the scientific performance of GSAOI. In particular, attention shall be given to the impact of the control actuators and sensors on the thermal regime of the instrument, including their thermal radiation.

14.3 Temperature Control System Functional Requirements

14.3.1 Temperature Control System Duplication

REQ-FPR-0306: The temperature control system will duplicate the NIRI/NIFS temperature control system to the greatest extent possible.

14.3.2 CWS Plate Temperature

REQ-FPR-0307: The GSAOI optical elements will be temperature stabilized by heat sinking to the cold work surface plate that is temperature controlled by the temperature control system.

14.3.3 Imager Detector Temperature Control

REQ-FPR-0308: The imager detector assembly will have an active temperature control system providing a variable temperature to be set at the optimum temperature for the detector between 60 K and 70 K.

14.3.4 OIWFS Detector Temperature Control

REQ-FPR-0309: The OIWFS detector assembly will have an active temperature control system providing a variable temperature to be set at the optimum temperature for the detector between 60 K and 70 K.

14.3.5 Limiting Rate of Temperature Change

REQ-FPR-0310: If the thermal characteristics of GSAOI introduce extreme rates of temperature change on cooling down, the temperature control system will limit the rate of change at the detector to 0.25 K per minute.

14.3.6 Speeding the Warming Up

REQ-FPR-0311: If the thermal characteristics of GSAOI are such that warming up by turning off the cryo-coolers will not meet the requirement in REQ-FPR-0132, the temperature control system will actively heat the detector and the cold plate to speed the warming up, so that GSAOI meets this requirement, but the rate of change of temperature shall be limited to 0.25 K per minute.

14.3.7 Temperature Monitoring

14.3.7.1 Temperature Sensors

REQ-FPR-0312: In addition to the sensors for temperature control, temperature sensors are required to monitor the cryogenic environment within the vacuum jacket at the following locations:

1. On the first stage of the cryocooler that cools the imager detector.
2. On the attachment of the cold strap from this cryocooler to the cold work surface plate.
3. On the edge of the cold work surface plate furthest removed from the cryocooler cold straps.
4. On the getter assembly that is connected to the second stage of the cryocooler which is not used to cool the imager detector.

14.3.7.2 Temperature Sensor Interfaces

REQ-FPR-0313: The temperature sensor read-out interface will be part of the Engineering Interface as described in §16.1.3.

Notes and Comments:

1. GSAOI electronics temperature is monitored by the Gemini thermal enclosure system. Power to the thermal enclosures will be cut if the temperature exceeds 50°C.

14.4 Temperature Control System Performance Requirements

14.4.1 CWS Plate Temperature Stability

REQ-FPR-0314: The GSAOI cold work surface plate will be temperature stabilized to < 0.5 K as required by REQ-FPR-0133.

14.4.2 Imager Detector Temperature Stability

REQ-FPR-0315: The imager detector assembly will be temperature stabilized to < 1 mK, which will allow it to meet the bias stability requirements of REQ-FPR-0205.

14.4.3 OIWFS Detector Temperature Stability

REQ-FPR-0316: The OIWFS detector assembly will be temperature stabilized to < 0.1 K, which will allow it to meet the bias stability requirement of REQ-FPR-0214.

15 Electrical and Electronic Requirements

15.1 Electrical and Electronic Functional Requirements

15.1.1 Grounding and Shielding

REQ-FPR-0400: Separate ground returns will be provided for low-level signals, noisy components such as relays and motors, and hardware components such as mechanical enclosures, chassis, and racks.

Notes and Comments:

1. Good grounding practice is discussed in Ott, H. W., Noise Reduction Techniques in Electronic Systems, Second Edition, AT&T Bell Laboratories, 1988, Chapter 3.
2. Gemini electronic design standards are described in Gemini Electronic Design Specification, SPE-ASA-G0008.

15.1.2 Electrostatic Discharge

REQ-FPR-0401: The GSAOI design will ensure that sensitive components are protected from electrostatic discharge.

Notes and Comments:

1. Electrostatic discharge is discussed in Ott, H. W., Noise Reduction Techniques in Electronic Systems, Second Edition, AT&T Bell Laboratories, 1988, page 332.
2. Gemini electronic design standards are described in Gemini Electronic Design Specification, SPE-ASA-G0008.

15.1.3 Power Dissipation

REQ-FPR-0402: Individual elements exposed to the air volume will not attain a temperature 2°C above ambient.

15.1.4 Cassegrain Cable Wrap Interfaces

The requirements on the electrical and electronics interfaces with the Cassegrain cable wrap are included in §17.1.

Notes and Comments

1. Cassegrain cable wrap interfaces are provided by the break out panels on the ISS.

16 Software Requirements

16.1 Software Functional Requirements

16.1.1 Software Duplication

REQ-FPR-0500: The GSAOI software system will duplicate the NIRI/NIFS software system to the greatest extent possible.

16.1.2 Conforming Instrument

REQ-FPR-0501: GSAOI will be a "conforming" instrument, in that it will use EPICS and conform to Gemini software and control system standards and the requirements listed below.

16.1.2.1 Use of EPICS

REQ-FPR-0502: GSAOI will use a standard Gemini configuration of a workstation for the operator interface, connected to an EPICS-based system used for controlling motors, coolers, and heaters and for receiving status information from sensors.

16.1.2.2 EPICS System

REQ-FPR-0503: The EPICS system will be a standard Gemini unit (VME crate, Motorola PPC VME Architecture Single Board Computer, VxWorks operating system.).

16.1.2.3 Interfaces to the Gemini System

REQ-FPR-0505: Interfaces to the Gemini system will conform to the descriptions presented in the Core Instrument Control Software (CICS) documentation. In particular, all Observatory Control System (OCS) commands to, and responses from, GSAOI will be by CAD, CAR and SIR EPICS records as described in the CICS documentation. Interfaces to other Gemini subsystems will conform to the relevant Interface Control Documents.

Notes and Comments:

1. The Gemini Software Design Description (SPE-C-G0037) contains guidelines for developing Gemini-compatible software.
2. Low-level software in GSAOI will be a mixture of EPICS code and C/C++ coded tasks, both running directly on VxWorks.

16.1.3 Engineering Interface

16.1.3.1 Engineering Interface Function

REQ-FPR-0506: GSAOI will provide a means for command and control of GSAOI mechanisms and imager detector controller, and data capture from the imager detector without the need for having Gemini control systems (i.e., the Observatory Control System and the Telescope Control System) present or connected.

16.1.3.2 Engineering Interface Physical Interface

REQ-FPR-0507: The Engineering Interface will use a Sun/Solaris workstation of the same type as that used for the Instrument Control System that runs with other Gemini control systems.

16.1.3.3 Engineering Interface User Interface

REQ-FPR-0508: To the extent practicable, the user interface in the Engineering Interface should appear to a user to be similar to the NIRI Engineering Interface.

16.1.3.4 Engineering Interface Command and Control

REQ-FPR-0509: The Engineering Interface will be capable of commanding and controlling all GSAOI mechanisms and reading status from all GSAOI sensors.

16.1.3.5 Engineering Interface Data Capture

REQ-FPR-0510: The Engineering Interface will be capable of capturing data from GSAOI imager detector, but not from the OIWFS detector.

Notes and Comments:
1. It is expected (but not required) that the Engineering Interface would use at least DM, a part of EPICS, in its implementation.
2. Not all data readout modes need be supported. The data that is captured may require extensive processing normally done by the GSAOI Instrument Control System or the Gemini Data Handling System (DHS) to be intelligible. There is no requirement for the Engineering Interface to perform this data processing, which may be done off-line on another system to analyze results. The Engineering Interface may send unscrambled data to the DHS to be shown in a Quick Look Display.

16.1.4 Mechanisms Control

16.1.4.1 Mechanism Control Operability

REQ-FPR-0511: All mechanisms and controlled features of GSAOI will be controlled through the standard EPICS control paths from the Instrument Control System.

16.1.4.2 Mechanisms

REQ-FPR-0512: The software system will control the following mechanisms:

Mechanism	Type	Positions
Environmental cover	Open/closed	2
Imager focal plane wheel	Rotary	4
Imager upper filter wheel	Rotary	15
Imager lower filter wheel	Rotary	15
Imager fast shutter	Rotary	4
Imager utility wheel	Rotary	5
OIWFS steerable mirror axis-A	Linear	…
OIWFS steerable mirror axis-B	Linear	…
OIWFS steerable mirror axis C	Linear	…
OIWFS aperture wheel	Rotary	6
OIWFS filter wheel	Rotary	10

16.1.4.3 Generic Filter Wheel

REQ-FPR-0513: The software system will maintain the concept of a single virtual filter wheel to the user such that any filter combination can be selected with a single filter command.

16.1.4.4 No Clear Optical Path

REQ-FPR-0514: The software system will prevent clear positions being simultaneously configured in the imager upper and lower filter wheels by first positioning the blocked position in the upper filter wheel before configuring the lower filter wheel and then completing the configuration of the upper filter wheel.

16.1.5 Temperature Control

16.1.5.1 CWS Plate Temperature

REQ-FPR-0515: The software system will configure the temperature controller stabilizing the temperature of the cold work surface plate.

16.1.5.2 Imager Detector Temperature Control

REQ-FPR-0516: The software system will configure the temperature controller stabilizing the temperature of the imager detector assembly.

16.1.5.3 OIWFS Detector Temperature Control

REQ-FPR-0517: The software system will configure the temperature controller stabilizing the OIWFS detector assembly.

16.1.5.4 Temperature Monitoring

REQ-FPR-0520: The software system will log and report temperatures from the temperature sensors monitoring the cryogenic environment within the vacuum jacket and at the detectors.

16.1.5.5 Imager Detector Temperature During Warm Up

REQ-FPR-0548: The software system will maintain the imager detector temperature between 5º and 20º higher than the Cold Work Surface plate temperature during warm up.

Notes and Comments:

1. The detector is maintained at a slightly elevated temperature to ensure that gases released during warm up do not condense on the detector.

16.1.5.6 OIWFS Detector Temperature During Warm Up

REQ-FPR-0549: The software system will maintain the OIWFS detector temperature between 5º and 20º higher than the Cold Work Surface plate temperature during warm up.

Notes and Comments:

1. The detector is maintained at a slightly elevated temperature to ensure that gases released during warm up do not condense on the detector.

16.1.6 Imager Detector

16.1.6.1 Imager Detector Controller DSP Code

REQ-FPR-0521: The software system will down load DSP code to the SDSU-2 detector controllers controlling the imager detector.

16.1.6.2 Imager Detector Controller Configuration

REQ-FPR-0522: The software system will initialize the SDSU-2 detector controllers controlling the imager detector by setting bias and clock voltages, selecting timing files, and clearing data buffers.

16.1.6.3 Imager Detector Read Out

REQ-FPR-0523: The software system will control all functions associated with defining and executing an exposure of the imager detector. This includes defining the read out method, integration time, and number of coadded data frames.

16.1.6.4 Imager Detector Read Out Methods

REQ-FPR-0524: The software system will support correlated double sampling and Fowler sampling read out methods of the imager detector.

16.1.6.5 Imager Detector Integration Times

REQ-FPR-0525: The software system will support integration times for the imager detector from 5 s to 10,000 s.

16.1.6.6 Imager Detector Fowler Samples

REQ-FPR-0527: The software system will allow between 1 and 64 Fowler samples to be obtained before and after the integration in the Fowler Sampling read out method.

16.1.6.7 Imager Detector Number of Coadds

REQ-FPR-0530: The software system will support the coaddition of between 1 and 1000 imager detector data frames before the result is transferred to the DHS and archived.

16.1.6.8 Imager Detector Data Unscrambling

REQ-FPR-0531: The software system will unscramble data from the four imager detectors and transfer a single data frame with a consistent orientation to the DHS.

16.1.6.9 Imager Detector World Coordinate System

REQ-FPR-0550 The software system will obtain world coordinate information from calibration files and the Telescope Control System (TCS), compute standard FITS WCS parameters, then pass these to the Data Handling System (DHS) for inclusion in the FITS header.

16.1.6.10 Imager Detector Regions of Interest

REQ-FPR-0551: The software system will support fixed-format regions of interest on the imager detector with pre-defined 64×64, 256×256, 512×512, and 1024×1024 pixel windows at the center of the mosaic and at the centers of each HAWAII-2RG detector.

16.1.6.11 Imager On-Detector Guide Window Definition

REQ-FPR-0532: The software system will include a means for defining an On-Detector Guide Window in one of the four imager detectors and for defining the guide window integration time.

16.1.6.12 Imager On-Detector Guide Window Data Acquisition

REQ-FPR-0533: The software system will control the read out of the On-Detector Guide Window defined for the imager detector and oversee the transfer of data to the A&G IOC for tip-tilt processing.

Notes and Comments:

1. The imager On-Detector Guide Window clocking must be performed by the imager detector controller. This means that the guide window must be defined via the GSAOI DC IOC software. This IOC may also have to initiate read outs.

2. A second, synchronized SDSU-2 containing a timing card and a video card will be connected to the guide window output channel. This SDSU-2 will digitize the pixel data and transmit them to the A&G IOC via an optical fiber and VME interface, as is done for the NIRI, GNIRS, and NIFS OIWFSs.
3. ASICs control of the imager detector will necessitate development of VME-based ASIC interface hardware.

16.1.6.13 Imager On-Detector Guide Window Integration Times

REQ-FPR-0534: The software system will support integration times for the imager On-Detector Guide Window from 10 ms to 1000 s.

16.1.6.14 Imager Pause and Resume

REQ-FPR-0535: The software system will pause imager exposures when the fast shutter is closed and resume them when it is opened.

16.1.6.15 Observing Modes

REQ-OCD-0043: GSAOI will support a View mode for acquiring temporary imaging data and an Observe mode for acquiring archived imaging data.

16.2 Software Performance Requirements

16.2.1 Mechanisms Control

16.2.1.1 Configuration Time

REQ-FPR-0542: The software system overhead on the mechanism configuration times will be such that the total GSAOI configuration time is within the limit set by REQ-OCD-0031.

16.2.1.2 Impact on Mechanism Accuracy

REQ-FPR-0543: The accuracy of the GSAOI controllable mechanisms will not be limited by the performance of the software system.

16.2.2 Temperature Control

16.2.2.1 Impact on Temperature Control Accuracy

REQ-FPR-0544: The accuracy of the GSAOI temperature control will not be limited by the performance of the software system.

16.2.3 Imager Detector

16.2.3.1 Imager Detector Maximum Continuous Frame Rate

REQ-FPR-0545: The software system will read out a full imager detector frame, process the data, and transfer it to the DHS at a maximum continuous frame rate of $\geq$ 0.05 Hz (20 s/frame).

Notes and Comments:

1. The 20 s minimum frame time comprises a 5 s read time prior to integration, a 5 s read time after integration, and 10 s in which to process the data and 20 s to transfer it to the DHS. Data processing and transfer begin when the post-integration reads begin.
2. Current information is that the DHS can handle 2.8 MB/s. A full imager detector frame in Real*4 format contains 64 MB, so the minimum transfer time to the DHS is currently 22.9 s. **[TBD]** Actually, testing has shown that best achievable rate when the DHS server runs on SunBlade 1000 with 2x900MHz CPUs and 1GB RAM is 2.2MB/s.

3. Processing (summing, averaging, coadding and unraveling pixels) of a full imager detector frame is expected to take an additional ~ 2.3 s using a 400 MHz SVGM5 processor with the Altivec vector unit.
4. A speed increase for the DHS by a factor of ~ 3 would be required by upgrading existing Gemini hardware and software. Testing at RSAA has shown that this is currently not achievable.
5. Higher continuous frame rates may be achieved by pipelining the data read and data transfer functions. This will not reduce the time to record a single frame.

16.2.3.2 Imager On-Detector Guide Window Maximum Continuous Frame Rate

REQ-FPR-0546: The software system will be capable of reading out at least a 12×12 pixel guide window on the imager detector and transferring the data to the A&G IOC at a maximum continuous frame rate of ≥ 100 Hz.

Notes and Comments:

1. This is a requirement on the SDSU-2 or ASIC DSP code controlling the imager detector.
2. The GSAOI DC IOC software may form part of the guide window data path if the imager detector is controlled by an ASIC that has a VME interface to the DC IOC.

17 External Interfaces

17.1 Cassegrain Rotator Interfaces

17.1.1 Instrument Support Structure Interface

REQ-FPR-0600: GSAOI will interface mechanically to the Gemini Instrument Support Structure (ISS).

17.1.1.1 ISS Ports

REQ-FPR-0601: GSAOI will be capable of being mounted on and used at any side-looking science instrument ISS port or the upward-looking port at the bottom of the ISS.

17.1.1.2 Instrument Mounting Plate Flatness

REQ-FPR-0602: The GSAOI mounting interface will be repeatable within the optical tolerances of the alignment between GSAOI and ISS when removed and replaced.

17.1.1.3 Instrument Mounting Plate Material

REQ-FPR-0603: The GSAOI mounting interface will take into account the material of which the ISS is made and will hold differential temperature effects to a level that permits GSAOI to meet all optical alignment and safety requirements over the entire operating temperature range.

17.1.1.4 Instrument Mounting Plate Fasteners

REQ-FPR-0604: The fasteners that are engaged for load transfer from the Cassegrain handling rig will be sized for a safe working load that includes a static and dynamic factor of safety to accommodate predicted loads on the Gemini telescope.

17.1.1.5 Optical Feed

REQ-FPR-0605: GSAOI will accept and use the MCAO optical feed, which is approximately f/34 with a focal length of 272 m. The beam comes to a focus 300 mm from the ISS mounting surface inside GSAOI.

Notes and Comments:

1. The ISS to Science Instrument ICD is 1.5.3/1.9. The ISS introductory ICD (ICD 1.5.3) is also relevant.
2. Fastener design must accommodate the changing direction of the gravity vector due to rotation of the ISS and positioning of the telescope.

17.1.2 Helium Interface

REQ-FPR-0606: GSAOI will obtain helium for its cryocoolers and return low pressure helium through the connectors provided in the Cassegrain Rotator Utility Box appropriate to each instrument port.

Notes and Comments:

1. The helium interface is described in ICD 1.9/3.6.

17.1.2.1 Number of Helium Connections

REQ-FPR-0607: GSAOI will have one high pressure connection for the entire instrument, and one low pressure return for the entire instrument. Each of these lines will have appropriate tees on the instrument to service the cryocooler heads.

17.1.2.2 Length of Helium Line Runs

REQ-FPR-0608: The high and low pressure lines to the Cassegrain Rotator Utility Box will be of a length that permits GSAOI to meet the requirement of REQ-FPR-0601.

17.1.2.3 Helium Line Flexibility

REQ-FPR-0609: The high and low pressure lines to the Cassegrain Rotator Utility Box will be flexible enough to permit easy routing, connection, disconnection, and dressing for operation.

17.1.2.4 Type of Helium Connectors

REQ-FPR-0610: The high-pressure line will connect to the Cassegrain Rotator Utility Box using a connector described in ICD 1.9/3.6.

Notes and Comments:
1. It is expected that Gemini will provide a helium supply of 3200 SLPM at a pressure of 300 psi. All helium delivered to GSAOI is expected to be 99.999% pure.
2. Details of the helium supply are in ICD 1.9/3.6.

17.1.3 Electric Power Interface

REQ-FPR-0611: GSAOI will derive its electric power through the connectors provided on the Cassegrain Rotator Utility Box appropriate to each instrument port.

Notes and Comments:
1. The power interface is part of ICD 1.9/3.6.

17.1.3.1 Number of Electric Power Connections

REQ-FPR-0612: GSAOI will have two electric power connections for the entire instrument. One connection will provide "clean" power for the computer and electronics, while the other will provide "dirty" power for the cryocoolers and fans. The "dirty" connection should provide optional 220 V./3 phase power for the cryocoolers. GSAOI shall have appropriate runs from a junction box to serve all instrument power needs.

17.1.3.2 Length of Electric Power Line Runs

REQ-FPR-0613: The power line to the Cassegrain Rotator Utility Box will be of a length that permits GSAOI to meet the requirement of REQ-FPR-0601.

17.1.3.3 Electric Power Line Flexibility

REQ-FPR-0614: The electric power line to the Cassegrain Rotator Utility Box will be flexible enough to permit easy routing, connection, disconnection, and dressing for operation.

17.1.3.4 Type of Electric Power Connectors

REQ-FPR-0615: AC power is provided to the science instrument via two, dual 3-prong, 120 VAC outlets (NEMA 5-15) mounted on the cable wrap interface plate. One outlet pair is UPS-conditioned power and the other is building mains power. The cable connector at the interface to the instrument is a circular MIL-style connector, MS3106R16-10S. The corresponding instrument connector must be an MS3100R16-10P. AC voltage at both observatories will be 120 VAC. Line frequency for Cerro Pachon is 50 Hz, while the Mauna Kea frequency is the US standard 60 Hz.

Notes and Comments:
1. Gemini will provide an electric power supply as described in ICD 1.9/3.6.

17.1.4 Cooling Water Interface

REQ-FPR-0616: GSAOI will derive cooling water supply (and return) for electronic enclosures and any other use through the connectors provided on the Cassegrain Rotator Utility Box appropriate to each instrument port.

17.1.4.1 Number of Cooling Water Connections

REQ-FPR-0617: GSAOI will have one cooling water supply connection and one return line connection for the entire instrument. GSAOI will have appropriate tees from these lines to serve all instrument cooling water needs.

17.1.4.2 Length of Cooling Water Runs

REQ-FPR-0618: The cooling water lines to the Cassegrain Rotator Utility Box will be of a length that permits GSAOI to meet the requirement of REQ-FPR-0601.

17.1.4.3 Cooling Water Line Flexibility

REQ-FPR-0619: The supply and return lines to the Cassegrain Rotator Utility Box will be flexible enough to permit easy routing, connection, disconnection, and dressing for operation.

17.1.4.4 Type of Cooling Water Connectors

REQ-FPR-0620: The cooling water lines will connect to the Cassegrain Rotator Utility Box using a connector of type Parker #FS-501-8FP Quick Disconnect and of female gender. The connector will not permit more than a drop or two of coolant to escape the system when connecting or disconnecting the supply and return lines, and will not leak during normal operation.

17.1.4.5 Resistance to Glycol

REQ-FPR-0621: The cooling water lines and connectors will not be damaged in any way when used with a cooling solution containing glycol-ethylene.

Notes and Comments:

1. It is expected that Gemini will provide a cooling water supply of 12 liters/minute at a pressure of 15 psi and a temperature of 0°C. The low-pressure return line is expected to carry 12 liters/minute at a pressure of 10 psi and a temperature of 4°C.
2. Coolant mixture is expected to be 60/40 water/glycol-ethylene.
3. The cooling water interface is described in ICD 1.9/3.6.

17.1.5 Signal, Control, and Data Interfaces

REQ-FPR-0622: GSAOI will receive and provide all signal, control, and data paths through the connectors provided on the Cassegrain Rotator Utility Box appropriate to each instrument port.

17.1.5.1 Number of Signal, Control, and Data Connections

REQ-FPR-0623: GSAOI will have one connection for the entire instrument to the appropriate Cassegrain Rotator Utility Box for each of the following, if needed. GSAOI will have appropriate tees from these lines to serve all instrument needs. In/out signals marked with * must be bridged at the cable wrap connector plate when not connected to instruments.

Circuit	Connector Type Cable Wrap	Instrument	Cable Connector
Control LAN in*	Fiber duplex SC	Fiber duplex SC	Fiber
Control LAN out*	Fiber duplex SC	Fiber duplex SC	Fiber
Time LAN in*	BNC Female	BNC Female	Coax RG58
Time LAN out*	BNC Female	BNC Female	Coax RG58
Terminal Server Console Port	Fiber duplex SC	Fiber duplex SC	Fiber
Data bus (star)	Fiber duplex SC	Fiber duplex SC	Fiber
Auxiliary Boot	KPSE00F18-11S	KPSE00F18-11P	Multi-connector
Interlock System	MS3120-F12-10S	MS3120-F12-10S	#22AWG, twisted pairs

Notes and Comments:

1. The event bus is used for chopping, which GSAOI will not require.
2. The Video LAN is non-existent.
3. GSAOI will not have to connect to the synchro bus.

17.1.5.2 Length of Signal, Control, and Data Runs

REQ-FPR-0624: The signal, control, and data lines to the Cassegrain Rotator Utility Box will be of a length that permits GSAOI to meet the requirement of REQ-FPR-0601.

17.1.5.3 Signal, Control, and Data Line Flexibility

REQ-FPR-0625: The signal, control, and data lines to the Cassegrain Rotator Utility Box will be flexible enough to permit easy routing, connection, disconnection, and dressing for operation.

Notes and Comments:

1. ICD 1.9/3.6 contains references to all but the non-existent video LAN and the Interlock System that is described in ICD 1.1.13/1.9.
2. There is also an auxiliary boot RS-232 to each instrument IOC control. Control, Time, Synchro, and Event LANs are in/out connector pairs.

17.1.6 Vacuum Interfaces

REQ-FPR-0626: GSAOI will be provided with interfaces for the connection of vacuum lines when the instrument is attached to the ISS at the telescope.

Notes and Comments:

1. It is not intended to provide vacuum lines in the ISS. This requirement is to provide for the ability to evacuate GSAOI when the instrument is attached to the ISS at the telescope.
2. Under normal conditions the instrument will be evacuated in the lab. If necessary, portable equipment will be used to evacuate GSAOI at the telescope.

17.1.7 Dry Air Interface

REQ-FPR-0627: GSAOI will derive dry air for flushing the cryostat window from the supply line on the Cassegrain Rotator Utility Box appropriate to each port.

17.1.7.1 Number of Dry Air Line Connections

REQ-FPR-0628: GSAOI will have one connection to the dry air supply for the entire instrument. GSAOI will have appropriate tees from this line to serve all instrument dry air supply needs.

17.1.7.2 Length of Dry Air Lines

REQ-FPR-0629: The dry air lines to the Cassegrain Rotator Utility Box will be of a length that permits GSAOI to meet the requirement of REQ-FPR-0601.

17.1.7.3 Dry Air Line Flexibility

REQ-FPR-0630: The dry air lines to the Cassegrain Rotator Utility Box will be flexible enough to permit easy routing, connection, disconnection, and dressing for operation.

17.1.7.4 Type of Dry Air Line Connector

REQ-FPR-0631: The dry air line will connect to the Cassegrain Rotator Utility Box using a connector of type Aeroquip #FD40-1014-06-06, Male half, non-valved, Male pipe end fitting.

Notes and Comments:
1. It is expected that Gemini will provide an air supply of 120 SLPM at a pressure of 80 -100 psi.
2. The dry air supply interface is covered in ICD 1.9/3.6.
3. The air supply from the ISS is compressed air. This can be used for flushing the entrance window if an in-line filter is used to trap any residual water that is in the line.

17.2 Control Systems Interfaces

17.2.1 Observatory Control System to GSAOI Instrument Sequencer

REQ-FPR-0632: A Parameter Definition Format document describing the CAD/CAR and SIR records used by the Instrument Sequencer will be presented.

Notes and Comments:
1. The Observatory Control System Interface is described in ICD 1.1.11/1.9.
2. The Parameter Definition Format document is defined in ICD 16.

17.2.2 Observatory Control System to GSAOI Components Controller

REQ-FPR-0633: A Parameter Definition Format document describing the CAD/CAR and SIR records used by the imager Components Controller will be presented.

Notes and Comments:
1. The Observatory Control System Interface is covered by ICD 1.9/3.1.
2. The Parameter Definition Format document is defined in ICD 16.

17.2.3 Observatory Control System to GSAOI Detector Controller

REQ-FPR-0634: A Parameter Definition Format document describing the CAD/CAR and SIR records used by the imager Detector Controller will be presented.

Notes and Comments:
1. The Observatory Control System Interface is covered by ICD 1.9/3.1.
2. The Parameter Definition Format document is defined in ICD 16.

17.2.4 Acquisition and Guidance Unit to GSAOI OIWFS Components Controller

REQ-FPR-0635: A Parameter Definition Format document describing the CAD/CAR and SIR records used by the OIWFS Components Controller will be presented.

Notes and Comments
1. The A&G system to OIWFS interface is covered by ICD 1.6/1.10.

2. The OIWFS is described in ICD 1.10.

17.2.5 Acquisition and Guidance Unit to GSAOI OIWFS Detector

REQ-FPR-0636: The OIWFS SDSU-2 detector controller will interface to the Acquisition and Guide Unit through a fiber optics cable and operate according to the relevant NIRI ICD.

17.2.6 Data Handling System Interface

REQ-FPR-0637: GSAOI will use the DHS for permanent and temporary storage of GSAOI science data and GSAOI calibration frames, and transient storage of GSAOI data for display.

Notes and Comments:

1. The Data Handling System Interface is defined in ICD 1.9/3.2, and the physical interface is included in ICD 1.9/3.6.

17.2.7 Interlock System Interface

REQ-FPR-0638: GSAOI will interface with the Gemini Interlock System (GIS).

17.2.7.1 Interlock System Mechanical Interface

REQ-FPR-0639: GSAOI will provide a cable to connect to the GIS. The cable will use a connector of type MS3126F12-10S to connect to the Instrument Services connector plate (of type MS3120F12-F10P; supplied by Gemini), and a connector of type MS3126F12-10P to connect to the Instrument Thermal Enclosure connector plate (of type MS3120F12-10S).

17.2.7.2 Interlock System Electrical Interface

REQ-FPR-0640: Signals between GSAOI and GIS will be optically isolated by GSAOI. The signals from GSAOI will be a conjugate pair of open-collector outputs. The signals from the GIS will be a conjugate pair of open-collector outputs.

Notes and Comments:

1. Leaving a door open on a thermal enclosure requires a complete stop of the telescope.
2. Some local interlocks should immediately notify the operator that GSAOI has shut down. For example: a helium failure or overheating of the electronics.
3. The physical interface is described in ICD 1.9/3.6.
4. The electrical interface is described in ICD 1.1.13/1.9.

17.2.8 Events Bus Interface

REQ-FPR-0641: GSAOI does not use the Event Bus.

Notes and Comments:

1. The physical interface is described in ICD 1.9/3.6.

17.2.9 Synchro Bus Interface

REQ-FPR-0642: GSAOI does not use the Synchro Bus.

Notes and Comments:

1. The physical interface is described in ICD 1.9/3.6.
2. The Synchro Bus In/Out Connector is dual SC fiber.

17.2.10 Time LAN Interface

REQ-FPR-0643: GSAOI will interface with the Time LAN to time-stamp images.

Notes and Comments:

1. The physical interface is described in ICD 1.9/3.6.
2. The Time LAN to IOC thermal enclosure is BNC in and BNC out.

18 Environmental Requirements

18.1 Altitude Environment

18.1.1 Transportation Altitudes

REQ-FPR-0700: GSAOI will be capable of being transported at any altitude between -70 m and 4,200 m by any transportation mode. GSAOI will be capable of being transported by commercial jet with pressurized cargo compartments at altitudes up to 15 km.

18.1.2 Storage Altitudes

REQ-FPR-0701: GSAOI will be capable of being stored in or out of its shipping container at any altitude between -70 m and 4,200 m.

18.1.3 Operation Altitudes

REQ-FPR-0702: GSAOI will be capable of being operated at any altitude between -70 m and 4,200 m.

Notes and Comments:

1. GSAOI must work at the Base Facility, at an altitude of approximately sea level, and at the telescopes on Mauna Kea and Cerro Pachon.

18.2 Temperature Environment

18.2.1 Operational Environment

REQ-FPR-0703: GSAOI operational temperature environment will be limited to -15 to +25°C.

18.2.2 Survival Environment

REQ-FPR-0704: GSAOI will be capable of surviving a temperature range of -20 to +50°C without damage.

18.2.3 Transport Environment

REQ-FPR-0705: GSAOI will be capable of withstanding a temperature range of -20 to +50°C during transport without damage.

18.3 Humidity Environment

REQ-FPR-0706: GSAOI will be capable of being transported and stored, in a wide range of humidity environments in the range 0 to 100% relative humidity, with condensing moisture.

Notes and Comments:

1. Operation of GSAOI at high relative humidity levels will cause condensation on the cryostat window. Using heaters on the window or a hot air system are incompatible with the thermal management of the telescope. Dry, ambient temperature air will be provided in the ISS for window flushing.

18.4 Vacuum Environment

REQ-FPR-0707: GSAOI will maintain a vacuum of < 10^{-5} torr inside the cryostat.

18.4.1 Creating the Vacuum

REQ-FPR-0708: GSAOI will provide a means to evacuate its cryostat while the instrument is on its handling rig in the instrument support area, and while it is attached to the ISS.

18.4.2 Vacuum Duration Cold

REQ-FPR-0709: GSAOI will be capable of being kept cold and operated without measurable degradation of scientific performance for 3 months.

18.4.3 Vacuum Duration Warm

REQ-FPR-0710: If needed, the instrument will be capable of being kept at room temperature without contamination of the detector or internal optics significantly affecting the scientific performance for at least 3 months without pumping.

Notes and Comments:

1. Instruments will be pumped down in the instrument support facility, and then transported to the telescope.
2. Operating vacuum may only be obtained with a cold instrument.

18.5 Mechanical Environment

REQ-FPR-0711: GSAOI will be capable of operating in the mechanical environment of the Gemini telescopes and their base facilities, and will be capable of withstanding shipment among Tucson, Hilo, Mauna Kea, and Cerro Pachon.

18.5.1 Telescope Slew Rates

REQ-FPR-0712: GSAOI will be capable of withstanding slew rates of 2° per second in azimuth and 0.75° per second in elevation, or any combination of these along with rotation of the Cassegrain rotator to maintain alignment with the parallactic angle as it changes at these slew rates. All optics and mechanisms will meet their flexure and alignment specifications at these rates.

Notes and Comments:

1. The rotator requires faster slew rates than specified for maintaining parallactic angle.

19 Other Requirements

19.1 Documentation

REQ-FPR-0800: GSAOI will be delivered with adequate documentation to facilitate the operation, maintenance, and repair of the instrument.

19.1.1 Users Manual

REQ-FPR-0801: The Users Manual will be written to enable a new user of GSAOI to easily get acquainted with the operation of the instrument.

19.1.2 Service and Calibration Manual

REQ-FPR-0802: A manual will be written to enable Gemini technical support personnel to maintain GSAOI. This manual shall include documentation to describe the observations required to allow calibration of GSAOI data.

19.1.3 Software Maintenance Manual

REQ-FPR-0803: A Software Maintenance manual will be provided to enable Gemini software maintenance staff to maintain the GSAOI software.

19.1.4 As-Built Drawings

REQ-FPR-0804: The as-built drawings will show all dimensions in millimeters, down to 0.01 mm. All fasteners specified in these drawings will be standard metric sizes. All drawings will otherwise be to RSAA standards used in instruments of similar size, function, and complexity.

19.1.5 Drawing Standards

REQ-FPR-0805: All drawings will comply with Australian Standard AS1100 or a Gemini approved standard.

19.1.6 Drawing Numbering System

REQ-FPR-0806: All drawings will be numbered in accordance with Gemini instructions.

19.1.7 Drawing Filing System

REQ-FPR-0807: Drawings will be maintained in electronic format. Final drawings will be provided in AutoCAD format and converted to PDF format on CDROM. Paper based printouts will be produced when necessary. A database of drawings will be maintained in Microsoft Access format.

Notes and Comments:

1. Final released drawings will be maintained by IGPO.
2. The software applications needed to access or read the electronic versions includes:
   AutoCAD R2000i
   Mechanical Desktop V5
   Protel 99SE

19.2 Training

REQ-FPR-0808: The GSAOI development team will provide training documentation and a training course to Gemini operations personnel on the operation, maintenance, and repair of GSAOI.

19.3 Reliability

19.3.1 Downtime

REQ-OCD-0042: GSAOI will have a downtime of < 2% scheduled time on the telescope and where possible, component failure shall result in gradual performance degradation.

19.3.2 Spares

REQ-FPR-0809: Single point failures that may result in significant downtime will be determined and, where necessary, critical spares will be identified.

19.3.3 Continuous Duty

REQ-FPR-0810: GSAOI will be designed and built for continuous operation. Modules containing moving parts, e.g., cryocooler cold heads, will be designed or selected to meet the REQ-OCD-0042 (§19.3.1) assuming continuous operation.

19.4 Maintainability and Serviceability

19.4.1 Standard Components

REQ-FPR-0811: Wherever possible, GSAOI will use unmodified commercially available standard components.

19.4.2 Modularity

REQ-FPR-0812: To the extent possible, GSAOI will be designed to be modular.

19.4.3 Access

REQ-FPR-0813: Access to components and subassemblies will be considered in the GSAOI design, particularly for those elements that are accessed frequently. Tool and hand clearances will be considered, as well as space required to remove modules, visual access to components (or a means to feel their correct position and alignment, e.g., for electronic connectors).

19.4.4 Alignment

REQ-FPR-0814: Alignment of optical components will be achieved to the greatest extent possible by accurate machining of locating fixtures.

Notes and Comments:

1. This can be achieved by machining captive thick shims to achieve the assembled tolerances, but the intention is to avoid an involved re-alignment procedure on assembly or re-assembly.

19.4.5 Relative Equipment Arrangements

REQ-FPR-0815: Equipment will be located with due consideration of the sequence of operations involved in maintenance procedures. To the greatest extent possible, the most accessible locations will be reserved for the items requiring most frequent access.

19.4.6 Subassemblies

REQ-FPR-0816: Subassemblies of the equipment that require more frequent service (inspection, adjustment, repair, or replacement) will be configured as plug-in modules or, if in racks, as drawers that can be withdrawn easily.

19.4.7 Handling

REQ-FPR-0817: Modules greater than 20 kg in mass will have suitable handles for use in removing, replacing, and carrying them. Handles will be located such that the vector sum of resultant handling forces will pass close to the center of gravity of the unit.

19.4.8 Revisability

REQ-FPR-0818: Multilayer electronic boards will not be used unless they are replaceable as a module. Backplane interconnections between custom boards are discouraged.

19.5 Lifetime

REQ-FPR-0819: GSAOI will be designed for an operational lifetime of 10 yr without a major overhaul. Components likely to affect the lifetime requirement will be identified.

19.6 Materials

19.6.1 Toxic Products and Formulations

REQ-FPR-0820: No toxic products and formulations will be used for the development, construction, and maintenance of GSAOI.

19.7 Electromagnetic Radiation

19.7.1 Electromagnetic Radiation Generation

REQ-FPR-0821: GSAOI will not significantly add to the electromagnetic radiation of its operating environment.

19.7.2 Susceptibility to Electromagnetic Radiation

REQ-FPR-0822: GSAOI performance will not be compromised by the existing electromagnetic radiation of its operating environment.

19.8 Workmanship

REQ-FPR-0823: Standard RSAA workshop practices will apply to workmanship in development and construction.

19.9 Safety

REQ-FPR-0824: Normal considerations, including compliance with applicable regulations, will apply in the areas of mechanical, electrical, and electrostatic safety.

19.10 Human Engineering

REQ-FPR-0825: Human engineering considerations will apply especially with respect to handling of system items required in readying GSAOI for use on the telescope and its removal after use, and in the design of the user interfaces.

20 Appendices

20.1 Requirements Tabulation

The following table shows the progress towards meeting the requirements at each of several milestones.

Notes and Comments:

TBD	The requirement has not been (fully) defined yet.
Des	The requirement is met by the current state of the design.
RSAA	The requirement is met by RSAA design and manufacturing procedures.
TOC	A table of contents has been prepared for this manual.
Doc	A (draft) document has been prepared.
No	The current state of the design does not meet the requirement.

Requirement	Description	CoDR	PDR	CDR	Acceptance Test	
					RSAA	Tel.
REQ-OCD-0001	MCAO Compatibility					
REQ-OCD-0002	Imager					
REQ-OCD-0003	OIWFS					
REQ-OCD-0004	Imager Wavelength Coverage					
REQ-OCD-0005	Imager Spatial Sampling					
REQ-OCD-0006	Imager Field-of-View					
REQ-OCD-0007	Imager Cold Stop					
REQ-OCD-0008	Imager Pupil Viewer					
REQ-OCD-0009	Imager Non-Common Path Phase Errors					
REQ-OCD-0010	Imager Filter Suite					
REQ-OCD-0011	Imager Calibration					
REQ-OCD-0012	Imager Pupil Viewer Resolution					
REQ-OCD-0013	Imager Strehl Ratio					
REQ-OCD-0014	Imager Distortion					
REQ-OCD-0015	Imager System Throughput					
REQ-OCD-0016	Imager Instrumental Background					
REQ-OCD-0017	Imager Ghost Images					
REQ-OCD-0018	Imager Sensitivity					
REQ-OCD-0019	Imager Pupil Viewer Sensitivity					
REQ-OCD-0020	OIWFS Wavelength Coverage					
REQ-OCD-0021	OIWFS Spatial Sampling					
REQ-OCD-0022	OIWFS Field-of-View					
REQ-OCD-0023	OIWFS Guide Star Patrol Field					
REQ-OCD-0024	OIWFS Vignetting					
REQ-OCD-0025	OIWFS Filter Suite					
REQ-OCD-0026	Shack-Hartmann Prism					
REQ-OCD-0027	OIWFS Calibration					
REQ-OCD-0028	OIWFS Strehl Ratio					
REQ-OCD-0029	OIWFS System Throughput					
REQ-OCD-0030	OIWFS Sensitivity					
REQ-OCD-0031	Mechanism Set Time					
REQ-OCD-0032	Mechanism Configuration					

Requirement	Description	CoDR	PDR	CDR	Acceptance Test	
					RSAA	Tel.
	Time					
REQ-OCD-0033	Imager Focal Plane Wheel					
REQ-OCD-0034	Imager Utility Wheel					
REQ-OCD-0035	OIWFS Aperture Wheel					
REQ-OCD-0036	OIWFS Steerable Mirror Setting Accuracy					
REQ-OCD-0037	OIWFS Steerable Mirror Setting Repeatability					
REQ-OCD-0038	Imager On-Detector Guid					
REQ-OCD-0039	Imager Detector Read Noise					
REQ-OCD-0040	Imager Detector Dark Current					
REQ-OCD-0041	Imager On-Detector Guide Window Performance					
REQ-OCD-0042	Downtime					
REQ-OCD-0043	Observing Modes					
REQ-OCD-0044	Fast Shutter					
REQ-FPR-0001	Vacuum Environment					
REQ-FPR-0002	Thermal Cycling					
REQ-FPR-0003	Imager Filter Transmission					
REQ-FPR-0004	Imager Filter Wedge					
REQ-FPR-0005	Optical Baffling					
REQ-FPR-0006	OIWFS Cold Stop					
REQ-FPR-0007	OIWFS Filter Transmission					
REQ-FPR-0008	OIWFS Filter Wedge					
REQ-FPR-0100	Mechanical Duplication					
REQ-FPR-0101	Instrument Alignment Provision					
REQ-FPR-0102	Mechanical and Thermal Tolerances					
REQ-FPR-0103	Temperature Gradients					
REQ-FPR-0104	Thermal Transients					
REQ-FPR-0105	Space Requirement					
REQ-FPR-0106	Thermal Enclosures					
REQ-FPR-0107	Access to Thermal Enclosures					
REQ-FPR-0108	Access to Vacuum Ports					
REQ-FPR-0109	Access to Cooling Water Ports					
REQ-FPR-0110	Access to Dry Air Ports					
REQ-FPR-0111	Mechanical Connections					
REQ-FPR-0112	Total Mass					
REQ-FPR-0113	Center of Gravity					
REQ-FPR-0114	Balance Tolerance					
REQ-FPR-0115	Ballast Weight					
REQ-FPR-0116	Closed-Cycle Coolers					
REQ-FPR-0117	Cooler Vibration					
REQ-FPR-0118	Vacuum System Facilities					
REQ-FPR-0119	Vacuum Pump Capacity and Selection					
REQ-FPR-0120	Vacuum Operating Procedure and Set-Up					
REQ-FPR-0121	Vacuum Test Set-Up					
REQ-FPR-0122	Mechanism Safety					

Requirement	Description	CoDR	PDR	CDR	Acceptance Test	
					RSAA	Tel.
REQ-FPR-0123	Environmental Cover					
REQ-FPR-0124	Dust Removal System					
REQ-FPR-0125	Instrument Handling					
REQ-FPR-0126	Metric Dimensioning					
REQ-FPR-0127	Metric Dimensions on Drawings					
REQ-FPR-0128	Metric Fasteners					
REQ-FPR-0129	Instrument Alignment Maintenance					
REQ-FPR-0130	Tracking with the OIWFS					
REQ-FPR-0131	Cool Down Time					
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REQ-FPR-0133	Thermal Stability					
REQ-FPR-0134	Repeatability of Configuration					
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REQ-FPR-0136	Imager Filter Wheel					
REQ-FPR-0137	Imager Detector Alignment					
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REQ-FPR-0139	Imager Detector Thermal Interface					
REQ-FPR-0140	Imager Detector Optical Interface					
REQ-FPR-0141	Imager Focal Plane Wheel Orientation Stability					
REQ-FPR-0142	Imager Focal Plane Wheel Setting Accuracy					
REQ-FPR-0143	Imager Focal Plane Wheel Setting Time					
REQ-FPR-0144	Imager Filter Wheel Orientation Stability					
REQ-FPR-0145	Imager Filter Wheel Setting Accuracy					
REQ-FPR-0146	Imager Filter Wheel Setting Time					
REQ-FPR-0147	Imager Utility Wheel Orientation Stability					
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REQ-FPR-0150	OIWFS Steerable Mirror					
REQ-FPR-0151	OIWFS Filter Wheel					
REQ-FPR-0152	OIWFS Detector Mechanical Interface					
REQ-FPR-0153	OIWFS Detector Thermal Interface					
REQ-FPR-0154	OIWFS Detector Optical Interface					
REQ-FPR-0155	OIWFS Steerable Mirror Orientation Stability					

Requirement	Description	CoDR	PDR	CDR	Acceptance Test	
					RSAA	Tel.
REQ-FPR-0156	OIWFS Steerable Mirror Setting Time					
REQ-FPR-0157	OIWFS Aperture Wheel Orientation Stability					
REQ-FPR-0158	OIWFS Aperture Wheel Setting Accuracy					
REQ-FPR-0159	OIWFS Aperture Wheel Setting Time					
REQ-FPR-0160	OIWFS Filter Wheel Orientation Stability					
REQ-FPR-0161	OIWFS Filter Wheel Setting Accuracy					
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REQ-FPR-0163	Fast Shutter Response Time					
REQ-FPR-0200	Imager Detector Device					
REQ-FPR-0201	Imager Detector Electrical Interface					
REQ-FPR-0202	Imager Detector Controller Type					
REQ-FPR-0203	Imager Detector Controller Mechanical Interface					
REQ-FPR-0204	Imager Detector Controller Thermal Interface					
REQ-FPR-0205	Imager Detector Bias Variations					
REQ-FPR-0206	Imager Detector Gain Variations					
REQ-FPR-0207	OIWFS Detector Device					
REQ-FPR-0208	OIWFS Detector Electrical Interface					
REQ-FPR-0209	OIWFS Detector Controller Type					
REQ-FPR-0210	OIWFS Detector Controller Mechanical Interface					
REQ-FPR-0211	OIWFS Detector Controller Thermal Interface					
REQ-FPR-0212	OIWFS Detector Read Noise					
REQ-FPR-0213	OIWFS Detector Dark Current					
REQ-FPR-0214	OIWFS Detector Stability					
REQ-FPR-0215	OIWFS Detector Maximum Continuous Frame Rate					
REQ-FPR-0216	Imager Detector Controller Readout Methods					
REQ-FPR-0217	Imager Detector Controller Integration Times					
REQ-FPR-0218	Not Used					
REQ-FPR-0219	Imager Detector Controller Fowler Samples					
REQ-FPR-0220	Imager Detector Controller Number of Coadds					
REQ-FPR-0221	Imager Detector Controller					

Requirement	Description	CoDR	PDR	CDR	Acceptance Test	
					RSAA	Tel.
	Guide Window Definition					
REQ-FPR-0222	Imager Detector Controller Guide Window Integration Time					
REQ-FPR-0223	Imager Detector Maximum Continuous Frame Rate					
REQ-FPR-0224	Imager On-Detector Guide Window Maximum Continuous Frame Rate					
REQ-FPR-0225	OIWFS Detector Controller Readout Method					
REQ-FPR-0226	OIWFS Detector Controller Guide Window Definition					
REQ-FPR-0227	OIWFS Detector Controller Integration Times					
REQ-FPR-0228	OIWFS Detector Controller Number of Coadds					
REQ-FPR-0229	Imager Detector Controller Regions of Interest					
REQ-FPR-0300	Mechanism Control System Duplication					
REQ-FPR-0301	Mechanism Control System Operability					
REQ-FPR-0302	Mechanisms					
REQ-FPR-0303	Configuration Time					
REQ-FPR-0304	Impact on Mechanism Accuracy					
REQ-FPR-0305	Impact on Scientific Performance					
REQ-FPR-0306	Temperature Control System Duplication					
REQ-FPR-0307	CWS Plate Temperature					
REQ-FPR-0308	Imager Detector Temperature Control					
REQ-FPR-0309	OIWFS Detector Temperature Control					
REQ-FPR-0310	Limiting Rate of Temperature Change					
REQ-FPR-0311	Speeding the Warming Up					
REQ-FPR-0312	Temperature Sensors					
REQ-FPR-0313	Temperature Sensor Interfaces					
REQ-FPR-0314	CWS Plate Temperature Stability					
REQ-FPR-0315	Imager Detector Temperature Stability					
REQ-FPR-0316	OIWFS Detector Temperature Stability					
REQ-FPR-0400	Grounding and Shielding					
REQ-FPR-0401	Electrostatic Discharge					
REQ-FPR-0402	Power Dissipation					
REQ-FPR-0500	Software Duplication					
REQ-FPR-0501	Conforming Instrument					

Requirement	Description	CoDR	PDR	CDR	Acceptance Test	
					RSAA	Tel.
REQ-FPR-0502	Use of EPICS					
REQ-FPR-0503	EPICS System					
REQ-FPR-0504	Not Used					
REQ-FPR-0505	Interfaces to the Gemini System					
REQ-FPR-0506	Engineering Interface Function					
REQ-FPR-0507	Engineering Interface Physical Interface					
REQ-FPR-0508	Engineering Interface User Interface					
REQ-FPR-0509	Engineering Interface Command and Control					
REQ-FPR-0510	Engineering Interface Data Capture					
REQ-FPR-0511	Mechanism Control Operability					
REQ-FPR-0512	Mechanisms					
REQ-FPR-0513	Generic Filter Wheel					
REQ-FPR-0514	No Clear Optical Path					
REQ-FPR-0515	CWS Plate Temperature					
REQ-FPR-0516	Imager Detector Temperature Control					
REQ-FPR-0517	OIWFS Detector Temperature Control					
REQ-FPR-0518	Not Used					
REQ-FPR-0519	Not Used					
REQ-FPR-0520	Temperature Monitoring					
REQ-FPR-0521	Imager Detector Controller DSP Code					
REQ-FPR-0522	Imager Detector Controller Configuration					
REQ-FPR-0523	Imager Detector Read Out					
REQ-FPR-0524	Imager Detector Read Out Methods					
REQ-FPR-0525	Imager Detector Integration Times					
REQ-FPR-0526	Not Used					
REQ-FPR-0527	Imager Detector Fowler Samples					
REQ-FPR-0528	Not Used					
REQ-FPR-0529	Not Used					
REQ-FPR-0530	Imager Detector Number of Coadds					
REQ-FPR-0531	Imager Detector Data Unscrambling					
REQ-FPR-0532	Imager On-Detector Guide Window Definition					
REQ-FPR-0533	Imager On-Detector Guide Window Data Acquisition					
REQ-FPR-0534	Imager On-Detector Guide Window Integration Times					
REQ-FPR-0535	Imager Pause and Resume					

Requirement	Description	CoDR	PDR	CDR	Acceptance Test	
					RSAA	Tel.
REQ-FPR-0536	Not Used					
REQ-FPR-0537	Not Used					
REQ-FPR-0538	Not Used					
REQ-FPR-0539	Not Used					
REQ-FPR-0540	Not Used					
REQ-FPR-0541						
REQ-FPR-0542	Mechanisms Control					
REQ-FPR-0543	Impact on Mechanism Accuracy					
REQ-FPR-0544	Impact on Temperature Control Accuracy					
REQ-FPR-0545	Imager Detector Maximum Continuous Frame Rate					
REQ-FPR-0546	Imager On-Detector Guide Window Maximum Continuous Frame Rate					
REQ-FPR-0547	Not Used					
REQ-FPR-0548	Imager Detector Temperature During Warm Up					
REQ-FPR-0549	OIWFS Detector Temperature During Warm Up					
REQ-FPR-0550	Imager Detector World Coordinate System					
REQ-FPR-0551	Imager Detector Regions of Interest					
REQ-FPR-0600	Instrument Support Structure Interface					
REQ-FPR-0601	ISS Ports					
REQ-FPR-0602	Instrument Mounting Plate Flatness					
REQ-FPR-0603	Instrument Mounting Plate Material					
REQ-FPR-0604	Instrument Mounting Plate Fasteners					
REQ-FPR-0605	Optical Feed					
REQ-FPR-0606	Helium Interface					
REQ-FPR-0607	Number of Helium Connections					
REQ-FPR-0608	Length of Helium Line Runs					
REQ-FPR-0609	Helium Line Flexibility					
REQ-FPR-0610	Type of Helium Connectors					
REQ-FPR-0611	Electric Power Interface					
REQ-FPR-0612	Number of Electric Power Connections					
REQ-FPR-0613	Length of Electric Power Line Runs					
REQ-FPR-0614	Electric Power Line Flexibility					
REQ-FPR-0615	Type of Electric Power Connectors					
REQ-FPR-0616	Cooling Water Interface					
REQ-FPR-0617	Number of Cooling Water					

Requirement	Description	CoDR	PDR	CDR	Acceptance Test	
					RSAA	Tel.
	Connections					
REQ-FPR-0618	Length of Cooling Water Runs					
REQ-FPR-0619	Cooling Water Line Flexibility					
REQ-FPR-0620	Type of Cooling Water Connectors					
REQ-FPR-0621	Resistance to Glycol					
REQ-FPR-0622	Signal, Control, and Data Interfaces					
REQ-FPR-0623	Number of Signal, Control, and Data Connections					
REQ-FPR-0624	Length of Signal, Control, and Data Runs					
REQ-FPR-0625	Signal, Control, and Data Line Flexibility					
REQ-FPR-0626	Vacuum Interfaces					
REQ-FPR-0627	Dry Air Interface					
REQ-FPR-0628	Number of Dry Air Line Connections					
REQ-FPR-0629	Length of Dry Air Lines					
REQ-FPR-0630	Dry Air Line Flexibility					
REQ-FPR-0631	Type of Dry Air Line Connector					
REQ-FPR-0632	Observatory Control System to GSAOI Instrument Sequencer					
REQ-FPR-0633	Observatory Control System to GSAOI Components Controller					
REQ-FPR-0634	Observatory Control System to GSAOI Detector Controller					
REQ-FPR-0635	Acquisition and Guidance Unit to GSAOI OIWFS Components Controller					
REQ-FPR-0636	Acquisition and Guidance Unit to GSAOI OIWFS Detector					
REQ-FPR-0637	Data Handling System Interface					
REQ-FPR-0638	Interlock System Interface					
REQ-FPR-0639	Interlock System Mechanical Interface					
REQ-FPR-0640	Interlock System Electrical Interface					
REQ-FPR-0641	Events Bus Interface					
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REQ-FPR-0643	Time LAN Interface					
REQ-FPR-0700	Transportation Altitudes					
REQ-FPR-0701	Storage Altitudes					
REQ-FPR-0702	Operation Altitudes					
REQ-FPR-0703	Operational Environment					
REQ-FPR-0704	Survival Environment					
REQ-FPR-0705	Transport Environment					
REQ-FPR-0706	Humidity Environment					
REQ-FPR-0707	Vacuum Environment					

Requirement	Description	CoDR	PDR	CDR	Acceptance Test	
					RSAA	Tel.
REQ-FPR-0708	Creating the Vacuum					
REQ-FPR-0709	Vacuum Duration Cold					
REQ-FPR-0710	Vacuum Duration Warm					
REQ-FPR-0711	Mechanical Environment					
REQ-FPR-0712	Telescope Slew Rates					
REQ-FPR-0800	Documentation					
REQ-FPR-0801	Users Manual					
REQ-FPR-0802	Service and Calibration Manual					
REQ-FPR-0803	Software Maintenance Manual					
REQ-FPR-0804	As-Built Drawings					
REQ-FPR-0805	Drawing Standards					
REQ-FPR-0806	Drawing Numbering System					
REQ-FPR-0807	Drawing Filing System					
REQ-FPR-0808	Training					
REQ-FPR-0809	Spares					
REQ-FPR-0810	Continuous Duty					
REQ-FPR-0811	Standard Components					
REQ-FPR-0812	Modularity					
REQ-FPR-0813	Access					
REQ-FPR-0814	Alignment					
REQ-FPR-0815	Relative Equipment Arrangements					
REQ-FPR-0816	Subassemblies					
REQ-FPR-0817	Handling					
REQ-FPR-0818	Revisability					
REQ-FPR-0819	Lifetime					
REQ-FPR-0820	Toxic Products and Formulations					
REQ-FPR-0821	Electromagnetic Radiation Generation					
REQ-FPR-0822	Susceptibility to Electromagnetic Radiation					
REQ-FPR-0823	Workmanship					
REQ-FPR-0824	Safety					
REQ-FPR-0825	Human Engineering					

GSAOI

AUSTRALIAN NATIONAL UNIVERSITY

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OPERATIONAL CONCEPT DEFINITION DOCUMENT

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Revision 1	Peter J. McGregor 30 November 2001	Gary Da Costa 1 March 2002	Draft initial document.
Revision 2	Peter J. McGregor 5 March 2002	Jan van Harmelen 23 April 2002	Revised initial document.
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Contents

[3] With major contributions from Gary Da Costa, Michael Dopita, Paul Francis, Ken Freeman, Brian Schmidt, Chris Tinney, and Peter Wood.

21 Purpose

This document describes the operational concept model for the Gemini South Adaptive Optics Imager (GSAOI). The document summarizes the science cases for which the instrument has been designed, relates these to the design requirements, and discusses the key functional and performance requirements that the instrument must meet. Key operational scenarios of the GSAOI instrument are identified and discussed, especially in terms of the requirements the instrument places on other parts of the Gemini system. These scenarios are described in sufficient detail for technically and scientifically skilled, but non-expert, readers to understand.

22 Applicable Documents

Document ID	Source	Title
	IGPO	Conceptual Design Review Documents, MCAO for Gemini-South
REV-AO-G0172	IGPO	MCAO for Gemini South Preliminary Design Report
RPT-AO-G0107	IGPO	The Science Case for the Multi-Conjugate Adaptive Optics System on the Gemini South Telescope Version 2.0

23 List of Acronyms

2MASS	Two Micron All Sky Survey
ACS	Advanced Camera for Surveys
ADC	Atmospheric Dispersion Corrector
AGB	Asymptotic Giant Branch
ALTAIR	Altitude-Conjugated Adaptive Optics for Infrared
AO	Adaptive Optics
AOM	Adaptive Optics Module
BS	Beam Splitter
BTO	Beam Transfer Optics
CCD	Charge Coupled Device
CDM	Cold Dark Matter
CM	Centering Mirror
CMD	Color-Magnitude Diagram
dE	Dwarf Elliptical
DM	Deformable Mirror
DSS	Digitized Sky Survey
DWFS	Diagnostic Wave Front Sensor
FWHM	Full Width at Half Maximum
GCAL	Gemini Calibration Unit
GNIRS	Gemini Near-InfraRed Spectrograph
GSAOI	Gemini South Adaptive Optics Imager
HAWAII	HgCdTe Astronomical Wide Area Infrared Imager
HST	Hubble Space Telescope
ICM	Intracluster Medium
IGPO	International Gemini Project Office
IMF	Initial Mass Function
IOC	Input-Output Controller
ISAAC	Infrared Spectrometer and Array Camera
ISS	Instrument Support Structure
KM	K-Mirror
LLT	Laser Launch Telescope
LMC	Large Magellanic Cloud
LS	Laser System
MBE	Molecular Beam Epitaxy
MCAO	Multi-Conjugate Adaptive Optics
MCAO-CS	MCAO Control System
NGS	Natural Guide Star
NICMOS	Near-Infrared Camera and Multi-Object Spectrograph
NIFS	Near-infrared Integral Field Spectrograph
NIRI	Near Infra-Red Imager
OAP	Off Axis Parabola
ODGW	On-Detector Guide Window
OIWFS	On-Instrument Wave Front Sensor
PDR	Preliminary Design Review
PM	Pointing Mirror
PNe	Planetary Nebulae
PSF	Point Spread Function
PWFS	Peripheral Wave Front Sensor
SALSA	Safe Aircraft Localization and Satellite Acquisition
SBF	Surface Brightness Fluctuation

SDSU	San Diego State University
SMC	Small Magellanic Cloud
SNe	Supernovae
TTM	Tip-Tilt Mirror
USNO	United States Naval Observatory
VLT	Very Large Telescope
WFPC2	Wide Field and Planetary Camera 2
WFS	Wave Front Sensor

24 Introduction

The Gemini 8-m telescopes are designed to achieve unprecedented ground-based image quality using adaptive optics (AO) techniques. This has been demonstrated with Hokupa'a on Gemini North, and soon will be extended with the commissioning of ALTAIR. These are classical AO systems that are restricted in their corrected fields and sky coverage. The Gemini South Multi-Conjugate Adaptive Optics (MCAO) system is being designed to overcome these limitations. MCAO will provide uniform, diffraction-limited image quality at near-infrared wavelengths across an extended field-of-view. Useful levels of atmospheric seeing correction will be achieved over a full two arc minute diameter field-of-view, the maximum possible with the Gemini telescope design. Sky coverage will also be comparable to the ALTAIR laser guide star (LGS) system, or somewhat superior to it. MCAO will use three deformable mirrors conjugated to distinct altitude ranges in the atmosphere. These will be driven with commands computed from wave front sensor measurements of five LGSs and three natural guide stars (NGSs). Mean zenith Strehl ratios of 0.2 at *J*, 0.4 at *H*, and 0.6 at *K* will be achieved in median seeing on Cerro Pachon over a one arc minute diameter field using bright NGSs. These will decline to 0.05 at *J*, 0.18 at *H*, and 0.39 at *K* at a zenith distance of 45º. The MCAO system will be able to operate with fewer than three NGSs but with reduced performance.

The Gemini South Adaptive Optics Imager (GSAOI) will be the workhorse instrument used with MCAO. GSAOI is a near-infrared, diffraction-limited, imaging system. It consists of an imager that forms the science channel, and an On-Instrument Wave Front Sensor (OIWFS) that monitors slow tip-tilt variations due to flexure between MCAO and GSAOI and slow focus variations due to changes in the height of the atmospheric sodium layer. The imager has a single fixed-format camera with 0.02″ pixels that Nyquist sample the 0.042″ FWHM diffraction-limited images produced at 1.65 μm, but slightly under-samples the 0.032″ FWHM images at *J*, and slightly over-samples the 0.057″ FWHM images at *K*. The GSAOI imager uses a mosaic of Rockwell HAWAII-2RG HgCdTe/CdZnTe Molecular Beam Epitaxy (MBE) detectors with 4080×4080 18 μm pixels arranged in four 2040×2040 quadrants each separated by 2.5 mm. Thus the GSAOI imager records a square field-of-view 84.7″ on a side. The imager optics have stable, low, and quantifiable distortion to permit high precision astrometric observations. A comprehensive suite of broad-band and narrow-band filters is available. GSAOI combines high throughput with uniform image quality to provide a high sensitivity MCAO imaging system.

Section 25 of this document contains a description of the GSAOI instrument. The science cases for which GSAOI has been designed are described in Section 26. Setup and calibration requirements for GSAOI are described in Section 27. Section 28 contains descriptions of observing scenarios. The scientific requirements that follow from these science programs are listed in Section 29.

25 Instrument Description

25.1 Basic Instrument Parameters

- Wavelength range: 0.9-2.4 μm.
- Pixel size: 0.02″×0.02″ on sky.
- Broad-band filters: *Z*, *J*, *H*, *Ks*, *K*.

- Narrow-band filters: zero-redshift emission lines.
- Detector: 4080×4080 pixel Rockwell HAWAII-2RG HgCdTe/CdZnTe MBE, 18 μm pixels.
- Fast cold shutter: Command driven from MCAO.
- Pupil viewer: Inserted without disturbing imager optics.
- Near-infrared On-Instrument Wave Front Sensor.
  - Wavelength range: 0.9-2.4 μm.
  - Steerable over 120″ FOV.
  - Image scale: 0.065″/pixel.
  - Filters: *Z*, *J*, *H*, *Ks*, *K*, *ZJ*, *HK*.
  - Instantaneous field-of-view: 0.5″ diameter.

25.2 Imager Description

The imager is the GSAOI science path. The 2′ diameter f/34 MCAO output field is directed to GSAOI by the science fold mirror in the Instrument Support Structure (ISS). The beam passes through the GSAOI cryostat window and the central 85″×85″ square science field passes undeflected to the imager. The beam comes to focus 300 mm inside the cryostat at the focal plane wheel. The beam passes through a field lens and collimator that form a pupil image in collimated light where the internal cold stop is located. Two filter wheels are also located in the collimated beam section. The beam then passes to the camera that reimages the focal plane onto the imager detector at a scale of 0.02″/pixel. A utility wheel allows a lens group to be positioned temporarily within the camera to record an image of the cold stop on the imager detector. This pupil image is used to accurately align the cold stop with the MCAO exit pupil. Convex and concave lenses in the utility wheel produce defocused star images at the detector. These images are used to measure static wave front phase errors that are nulled using the MCAO deformable mirror DM0.

25.2.1 Focal Plane Wheel

The focal plane wheel contents are listed in Table 4. The "Blocked" position is used for recording bias and dark exposures. The "Clear" position is used for routine imaging. The "Focus mask" consists of an array of pinholes that are used for calibration purposes, such as calibrating astrometric distortion within the imager.

Table 4: GSAOI Focal Plane Wheel Contents

Position	Content
1	Blocked
2	Clear
3	Focus mask
4	Spare

25.2.2 Filter Wheels

The contents of the imager filter wheels are listed in Table 5 and Table 6. These contain standard near-infrared broad-band filters and zero redshift near-infrared emission and absorption line filters.

Table 5: Upper Filter Wheel Contents

Position	Content	λ_c (μm)	$\Delta\lambda$ (μm)
1	Clear	…	…
2	*Z*	1.010	0.220
3	*J*	1.250	0.180
4	*H*	1.650	0.290
5	*Ks*	2.145	0.310
6	*K*	2.200	0.330
7	*J* continuum	1.207	0.018
8	*H* continuum	1.570	0.024
9	CH_4 (short)	1.580	0.095
10	CH_4 (long)	1.690	0.101
11	*Ks* continuum	2.090	0.031
12	*Kl* continuum	2.270	0.034
13	Spare	…	…
14	Spare	…	…
15	Spare	…	…

Table 6: Lower Filter Wheel Contents

Position	Content	λ_c (μm)	$\Delta\lambda$ (μm)
1	Clear	…	…
2	He I 1.0830 μm	1.083	0.016
3	H I Pγ	1.094	0.016
4	H I Pβ	1.282	0.019
5	[Fe II] 1.644 μm	1.644	0.025
6	H_2O	1.996	0.050
7	H_2 1-0 S(1)	2.122	0.032
8	H I Brγ	2.166	0.032
9	H_2 2-1 S(1)	2.248	0.034
10	CO 2-0 (bh)	2.294	0.034
11	CO 3-1 (bh)	2.323	0.035
12	Blocked	…	…
13	Spare	…	…
14	Spare	…	…
15	Spare	…	…

25.2.3 Fast Shutter

A fast cold shutter is located near the cold stop. This shutter can be closed by the MCAO system in periods of poor adaptive optics correction or when the MCAO Safe Aircraft Localization and Satellite Acquisition system is forced to shut down the MCAO lasers due to the proximity of an aircraft or satellite to the telescope beam. The GSAOI imager exposure is paused while the shutter is closed and resumes once the MCAO system has reopened the shutter.

25.2.4 Utility Wheel

The contents of the utility wheel are listed in Table 7. The "Clear" position is used for routine imaging. The pupil viewer is used to accurately align the cold stop with the MCAO exit pupil and so minimize the background reaching the imager detector. The convex and concave defocus lenses produce defocused images that are used to derive static wave front phase errors at the imager detector. These phase errors are nulled using the MCAO deformable mirror DM0 (§25.2.7). The "Blocked" position is used for bias and dark exposures.

Table 7: Utility Wheel Contents

Position	Content
1	Clear
2	Pupil viewer
3	Convex defocus lens
4	Concave defocus lens
5	Blocked

25.2.5 Imager Detector

The imager detector is a 4080×4080 pixel mosaic of four three-side buttable 2040×2040 pixel Rockwell HAWAII-2RG HgCdTe/CdZnTe MBE devices with 18 μm pixels. The four detectors are each separated by ~ 2.5 mm. An additional four rows and columns around the outer edge of each detector are not illuminated. These are read out as reference pixels. HAWAII-2RG devices have high quantum efficiency even at short wavelengths, low dark current, low remnance, and no significant on-chip amplifier glow **(TBD!)**. The imager detector mosaic is read out in ~ 10 s through 16 video lines. Fowler sampling and correlated double-sampling readout methods are implemented.

Each device also has a programmable rectangular guide window capability. A rectangular guide window of 8×8, 12×12, 16×16, or 32×32 pixels is specified. This is then read out rapidly during the imager exposure to monitor tip-tilt and flexure variations directly on the imager detector. It will usually be convenient to use the near-infrared images of the MCAO NGSs for this purpose.

25.2.6 Imager Quick Look Displays

It is envisaged that data from the imager detector will be presented in two Quick Look Displays; the View Mode Quick Look Display and the Observe Mode Quick Look Display. Temporary data will be obtained and displayed in View Mode, but not archived. Science data will be obtained and displayed in Observe Mode. Observe Mode data will be archived. This convention is adopted in the observing scenario descriptions in §28.

25.2.7 Non-Common Path Phase Errors

Imaging performance is improved if the MCAO deformable mirror that is conjugated to ground level (DM0) can be configured to correct non-common path wave front phase errors introduced by the imager optics. Normally, the MCAO Diagnostic Wave Front Sensor is used to flatten the wave front exiting the MCAO system. It is preferable to ensure that the wave front reaching the imager detector is flat. This will be achieved by recording images on either side of focus and analyzing them in the manner described by Roddier& Roddier (1993). The light source for these images will be the MCAO NGS source simulator. This is a 5×5 grid of fiber-fed sources that will produce separated defocused images. The images will be defocused using the convex and concave defocus lenses in the imager utility wheel. The images will be analyzed using the Roddier program, and the coefficients of low-order Zernike polynomials characterizing the wave front error will be input to the MCAO system.

25.2.8 Imager Sensitivities

Imager sensitivity has been quantified using a model for the object and background signals and the estimated detector dark current (0.05 e/s/pix) and read noise (5 e using multiple reads). The model assumes a detector quantum efficiency of ~ 60%, based on the Rockwell HAWAII-1 array. The HAWAII-2RG device may have a quantum efficiency up to ~ 85% (Hall, priv. comm.). Background signals considered are airglow emission and thermal emission from the sky, telescope, MCAO system, cryostat window, and cryostat interior. Limiting magnitudes for a total on-source integration time of 1 hr in 0.4″ seeing through a 0.08″×0.08″ square aperture are listed for each filter in Table 8 along with the Strehl ratio that was assumed for that filter and the sky brightness that resulted.

Saturation magnitudes for each filter are also listed in Table 8. These are calculated for an assumed minimum integration time of 5 s and a detector full well depth of 50,000 e. The same 0.4″ seeing and Strehl ratios listed in Table 8 apply. The faint broad -and saturation magnitudes present a calibration problem: faint near-infrared photometric standards typically have *K* ~ 10-12 mag (e.g., Persson et al. 1998). It is necessary to read out only a sub-region of the imager detector so as not to saturate these standard stars. The brightest Persson et al. (1998) standards can be recorded in a 512×512 sub-region (10.2″×10.2″) that is read out 16 times faster than the full array using a minimum integration time of 0.3 s.

Table 8: Imager Sensitivities (10:1 in 1 hr)

Filter	Limiting Magnitude (mag)	Saturation Magnitude (mag)	Assumed Strehl Ratio	Sky Brightness (mag/arcsec^2)
Z	24.9	13.2	0.2	17.2
J	23.5	12.6	0.2	14.9
H	23.5	12.9	0.4	13.9
Ks	23.2	12.3	0.6	13.4
K	23.2	12.2	0.6	13.3
J continuum	22.4	10.2	0.2	15.0
H continuum	22.4	10.4	0.4	14.1
CH_4 (short)	23.0	11.9	0.4	13.9
CH_4 (long)	22.9	11.7	0.4	13.8
Ks continuum	22.2	9.9	0.6	13.8
Kl continuum	21.9	9.6	0.6	13.5
He I 1.0830 μm	22.9	10.3	0.2	16.0
H I Pγ	22.9	10.3	0.2	16.1
H I Pβ	21.8	10.1	0.2	13.9
[Fe II] 1.644 μm	22.1	10.3	0.6	13.7
H_2O	22.8	10.4	0.6	14.4
H_2 1-0 S(1)	22.0	9.9	0.6	13.4
H I Brγ	22.1	9.6	0.6	13.7
H_2 2-1 S(1)	22.0	9.7	0.6	13.5
CO 2-0 (bh)	21.8	9.6	0.6	13.3
CO 3-1 (bh)	21.6	9.5	0.6	13.0

Modeled background signals for each filter with an integration time of 600 s are listed in Table 9. The dark current is assumed to contribute 30 e/pix in this integration time. It is clear from Table 9 that airglow line emission dominates for all broad-band filters and most narrow-band filters. Thermal emission from the MCAO system makes a significant contribution in the two broad *K* bands and is dominant in the longer wavelength narrow-band filters. These background signals ensure that GSAOI will be background limited in all broad-band filters with integration times > 10 s and in all narrow-band filters with integration times > 150 s with a read noise of 10 e; many filters will be strongly background limited in these times.

Table 9: Imager Background Contributions (600 s)

Filter	Airglow (e/pix)	Sky Thermal (e/pix)	Telescope Thermal (e/pix)	MCAO Thermal (e/pix)	Window Thermal (e/pix)	Total (e/pix)
Z	2152	0	0	0	0	2182
J	11182	0	0	0	0	11212
H	25130	1	4	13	1	25180
Ks	12822	236	1394	4289	276	19049
K	11007	554	2421	7448	483	21945
J continuum	1132	0	0	0	0	1162
H continuum	1873	0	0	0	0	1903
CH_4 (short)	8942	0	0	1	0	8973
CH_4 (long)	9465	0	2	5	0	9501
Ks continuum	1248	8	63	193	12	1554
Kl continuum	212	64	342	1053	68	1770
He I 1.0830 μm	423	0	0	0	0	453
H I Pγ	381	0	0	0	0	411
H I Pβ	2867	0	0	0	0	2897
[Fe II] 1.644 μm	2621	0	0	0	0	2652
H_2O	1032	40	39	121	8	1269
H_2 1-0 S(1)	1875	4	88	271	17	2285
H I Brγ	796	8	115	353	23	1325
H_2 2-1 S(1)	491	37	284	874	57	1774
CO 2-0 (bh)	65	90	414	1273	83	1954
CO 3-1 (bh)	66	139	531	1634	107	2507

25.2.9 Imager On-Detector Guide Window Sensitivities

The imager On-Detector Guide Window (ODGW) performance has been estimated using the imager performance model to generate star frames that have then been centroided and the RMS centroiding accuracy determined from 200 simulated guide star frames. Limiting magnitudes that achieve a centroiding accuracy of ~ 2 mas (i.e., 0.1 pix) in integration times of 0.01 s and 30 s are listed for each broad-band filter in Table 10.

Table 10: Imager ODGW Sensitivities (2 mas RMS)

Filter	Limiting Magnitude 10 ms integration (mag)	Limiting Magnitude 30 s integration (mag)
Z	13.9	22.0
J	13.1	21.2
H	12.7	20.5
Ks	12.0	19.8
K	11.9	19.7

25.2.10 Comments on Astrometric Precision

High precision astrometry will be a prominent application of MCAO and GSAOI. Differential astrometric techniques with CCDs have been shown to be extremely powerful. As long as the targets observed are unresolved (i.e., are stars), the precision with which the differential position of an object can be measured is limited only by the signal-to-noise ratio achieved and the long-term stability of the instrument in question.

Astrometric programs on 2 to 4 m telescopes are routinely measuring differential object positions to 1/500th of a FWHM (Tinney 1996; Tinney et al. 1995; Monet et al. 1992).

The improved resolution offered by MCAO, the removal of differential seeing effects, and the operation of the GSAOI instrument in the infrared offer prospects for a dramatic improvement in the quality of ground-based differential astrometry.

Differential seeing is the crucial factor in determining the precision of ground-based differential astrometry. Over any field-of-view, the motions of different objects due to the atmosphere are different and become increasingly different at larger separations. Differential seeing effects always remain, even though the measured positions of targets average over time towards the underlying 'true' position (in the absence of the atmosphere). The dramatic improvement in differential seeing achieved by MCAO should significantly lower this systematic limitation, opening the way for a major breakthrough of the 1mas precision barrier by GSAOI.

Remaining systematic effects to be dealt with are differential atmospheric refraction and differential atmospheric color refraction. These impose limitations on the observing strategy (essentially observing only within ~ 1 hr of the meridian, and observing all epochs at near identical hour angles), but otherwise do not impact on scientific performance.

The photon-counting requirements for high precision astrometry remain: for a 50 mas FWHM observation at H band, measurement of a 500 μas position is possible with signal-to-noise ratio of 100, corresponding to $H \sim 21.0$ mag in 1 hr, and of a 160 μas position at $H = 21.0$ mag in ~ 10 hr.

These precisions are unprecedented for objects of these magnitudes. Astrometry at this level can; confirm or deny the membership of faint members of galactic open and globular clusters; obtain parallaxes for targets inaccessible due to their faintness, redness, or extinction to GAIA; measure the proper motions of most of the Local Group galaxies over a period of 5-10 yr. Some of these specific scientific issues are addressed in the science driver descriptions presented in §26.

25.3 OIWFS Description

The GSAOI OIWFS performs two functions; 1) it is routinely used to monitor slow tip-tilt variations due to flexure between MCAO and GSAOI and slow focus variations due to changes in the height of the atmospheric sodium layer, and 2) it can substitute for one of the three MCAO NGS wave front sensors when the only available guide star is highly obscured. The imager ODGWs are preferred for both tip-tilt monitoring functions if suitable guide stars are available. However, the imager ODGWs cannot be used to discern focus variations. This makes the OIWFS the natural place to monitor slow focus variations because of its close proximity to the imager detector. The MCAO LGS sensors monitor fast atmospherically induced focus variations, but these sensors cannot discern slow changes in the height of the LGSs that induce focus drifts in the science path. The MCAO NGS sensors are quadrant detectors that sense tip-tilt only.

Light that is not passed to the imager is reflected to the OIWFS (Figure 7). The science field contains essentially the entire inscribed square within the 2′ diameter circular MCAO field. Consequently, OIWFS guide stars can only be selected from within the four crescent shaped regions near the edge of the MCAO field. Three MCAO NGSs are required within the MCAO field, so it will usually be convenient to pass the near-infrared image of one of these stars to the OIWFS.

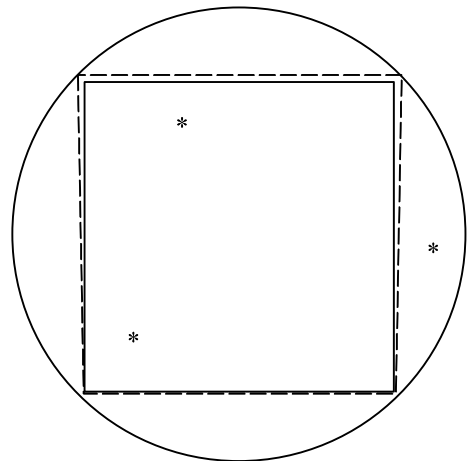

Figure 7: OIWFS field geometry. The circle indicates the extent of the 2′ diameter MCAO field. The square indicates the extent of the 85″×85″ imager field. The dashed lines indicate the limits of the region not vignetted by the field splitter mirror. Observations with MCAO and GSAOI may require one of the MCAO NGSs to be located within the OIWFS acquisition field.

The OIWFS optics first form a pupil image in collimated light at a steerable mirror. This mirror is tilted to direct the selected guide star image through the OIWFS aperture. The diverging guide star light is then re-collimated, passes through the OIWFS filter and Shack-Hartmann prism, and is then re-imaged at the OIWFS detector at a scale of 0.065″/pixel. The OIWFS Shack-Hartmann prism is a four-facetted prism that forms four images of the guide star on the OIWFS detector each separated by ~ 0.5″ with each image originating from a different quadrant of the pupil. Monitoring the positions of the four images senses wave front tip-tilt. Monitoring the separations of perpendicular image pairs senses focus variations in both directions. Diffraction at the four-facetted prism broadens each OIWFS image by a factor of two compared to the imager channel.

25.3.1 OIWFS Steerable Mirror

The OIWFS steerable mirror must set to an accuracy of < 0.02″ on the sky and be repeatable to < 0.01″ so that guide stars can be reacquired accurately on the imager and OIWFS detectors.

25.3.2 OIWFS Aperture Wheel

The contents of the OIWFS aperture wheel are listed in Table 11. The OIWFS must be read out at a frame rate of 200 Hz when monitoring fast tip-tilt variations. The field-of-view is then restricted to ~ 0.52″ (i.e., four 8×8 pixel regions read out at 10 μs/pix). Acquiring guide stars with this small aperture is inefficient, so 40×40 and 80×80 pixel acquisitions windows are used for this purpose. The windows are offset from the optical axis because the 8×8 pixel guide window must be located near the output amplifier. The "Blocked" position is used to record bias and dark exposures of the OIWFS detector.

Table 11: OIWFS Aperture Wheel Contents

Position	Content
1	Clear
2	0.52″ diameter circular aperture
3	2.6″ offset square aperture
4	5.2″ offset square aperture
5	Spare
6	Blocked

25.3.3 OIWFS Filter Wheel

It is desirable to sense tip-tilt and focus variations at the same wavelength as used for the science exposure. It is also desirable to use as broad a pass band as possible so that faint OIWFS guide stars can be used. Consequently, a range of broad-band filters is provided in the OIWFS filter wheel (Table 12).

Table 12: OIWFS Filter Wheel Contents

No.	Filter	λ_c (μm)	$\Delta\lambda$ (μm)
1	Clear	...	...
2	*Z*	1.010	0.220
3	*J*	1.250	0.180
4	*H*	1.650	0.290
5	*Ks*	2.145	0.310
6	*K*	2.200	0.330
7	*ZJ*	1.120	0.440
8	*HK*	1.935	0.860
9	Blocked	…	…
10	Spare	…	…

25.3.4 OIWFS Detector

The OIWFS detector is a 1024×1024 pixel HAWAII-1 device. This is the same OIWFS detector used in NIRI, GNIRS, and NIFS. The detector is read out at 10 μs/pixel by an SDSU-2 detector controller. This restricts the region that can be read out at a high speed to 0.5″×0.5″ on the sky.

25.3.5 OIWFS Sensitivities

The imager sensitivity model can be used to predict OIWFS sensitivities under the assumptions that both channels have similar throughputs and that the detector read noise is 10 e for single readouts (i.e., no multiple sampling). Allowance is also made for the fact that the OIWFS forms four separate images of each guide star. We further assume that each image must be centroided to an accuracy of 0.002″ (0.1 pix), which is ~ 1/20 of the image FWHM at *H*. We therefore require a signal-to-noise ratio of at least 20 per image per integration. Table 13 lists OIWFS sensitivities for each filter and for integration times of 5 ms (corresponding to fast tip/focus monitoring) and 30 s (corresponding to slow flexure/focus monitoring). It is apparent that full tip-tilt/focus monitoring is possible for only very bright guide stars. Flexure/focus monitoring should be possible on objects approaching the limit of the MCAO NGS sensors. It may be possible to go ~ 1 mag fainter with the OIWFS by using *ZJ* and *HK* filters that combine two standard broad bands.

Table 13: OIWFS Sensitivities (20:1 per image)

Filter	Limiting Magnitude 5 ms integration (mag)	Limiting Magnitude 30 s integration (mag)
Z	10.4	19.6
J	9.9	18.4
H	10.4	18.5
Ks	9.9	18.2
K	9.9	18.1
ZJ	11.0	19.4
HK	11.1	18.9

The availability of faint guide stars at near-infrared wavelengths has been investigated by Spagna[4] for NGST. He tabulates cumulative star counts from which probabilities can be calculated that the 2′ diameter MCAO field for any science object will contain at least one guide star brighter than a particular limit. These probabilities are plotted in Figure 8 where it can be seen that the probability of finding at least one $K \leq 10$ mag guide star in an MCAO field is essentially zero (0.09%) while the probability of finding at least one $K \leq 18$ mag guide star somewhere in the MCAO field is high (99.9% at $b = 30°$, 88.9% at $b = 60°$, and 80.3% at $b = 90°$).

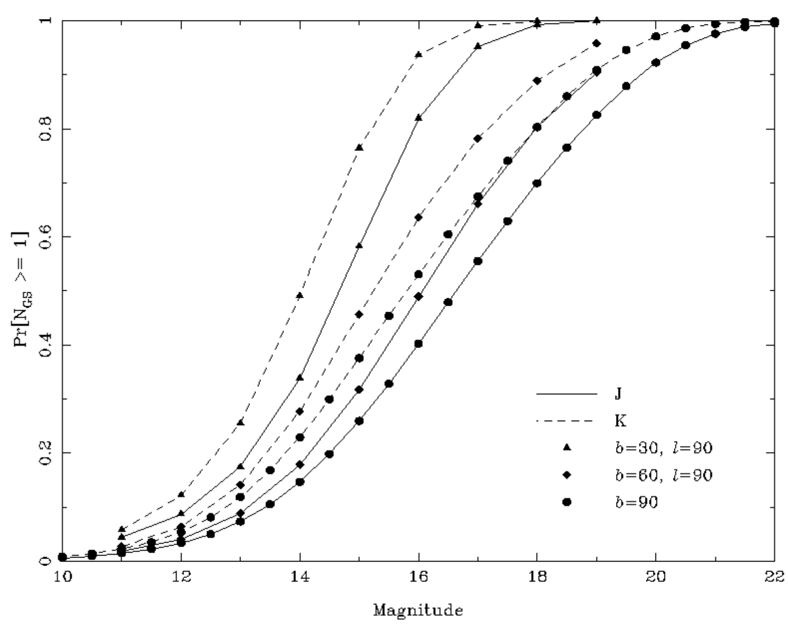

Figure 8: Guide star acquisition probabilities at *J* (*solid* lines) and *K* (*dashed lines*) for Galactic latitudes of 30º (*triangles*), 60º (*diamonds*), and 90º (*circles*).

25.4 Cryostat and Auxiliary Systems

GSAOI is a fast-tracked instrument that is intended to be available for MCAO commissioning. Duplicates of the NIRI/NIFS cryostat, integration frame, instrument control system, and control software will be used to reduce development time (Figure 9).

[4] http://www.ngst.nasa.gov/public/unconfigured/doc_0422/rev_03/NGST_GS_report5.pdf

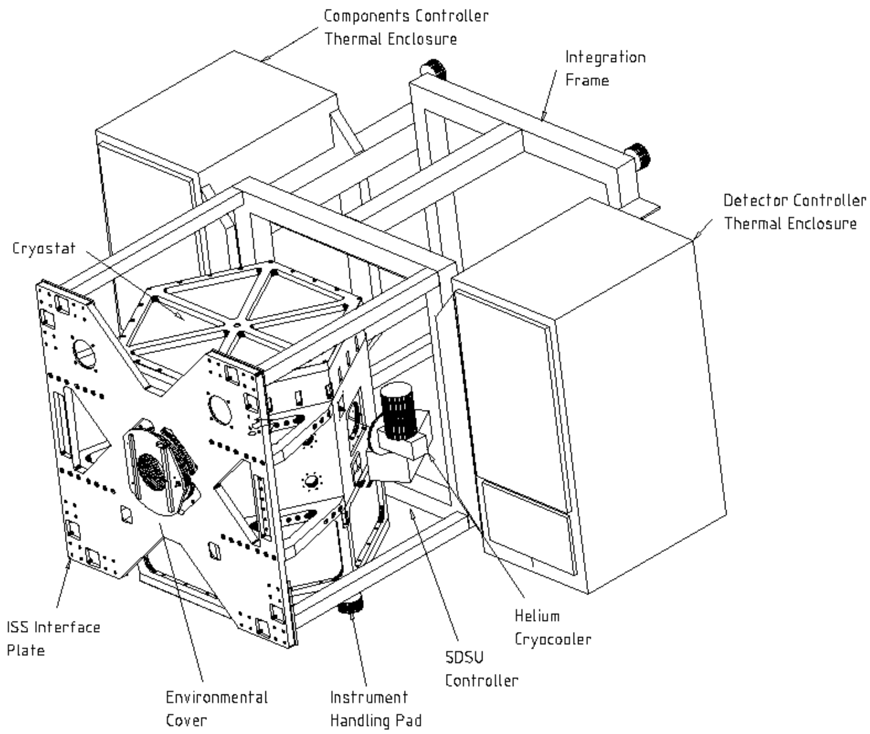

Figure 9: GSAOI cryostat, ISS interface plate, integration frame, and thermal enclosures.

The cryostat is a hexagonal cylinder 1.0 m in diameter and 1.3 m long. It is cooled by two CoolPower 5/100T helium cryocoolers. The circular cryostat window has been enlarged to accommodate the 2 arc minute diameter f/34 MCAO field. The exterior of GSAOI is similar to NIRI and NIFS in other ways. An environmental cover is located in front of the cryostat window to protect it and prevent dust accumulation when GSAOI is not in use. The cryostat mounts on the ISS via the ISS interface plate. The two SDSU-2 controllers used to control the imager and OIWFS detectors mount directly on the outside of the cryostat. All other electronics are located in two thermal enclosures.

The two thermal enclosures are carried on the integration frame. One thermal enclosure contains the mechanism and temperature control electronics and the Instrument Control System Input-Output Controller (IOC). The second thermal enclosure contains the SDSU-2 power supplies and the Detector Control System IOC. The integration frame mounts on the ISS interface plate along with the cryostat but does not load the cryostat.

25.5 Gemini Systems

Use of MCAO with GSAOI imposes several restrictions on the use of other Gemini systems.

- The ISS AO fold mirror must be deployed to use MCAO. This means that PWFS2 cannot also be deployed.
- The ISS science fold mirror is used to direct light from GCAL to the science instrument. This light does not pass through MCAO so is unsuitable for flat field calibration of GSAOI.
- The acquisition camera can be used to define accurate relative coordinates of suitable GSAOI OIWFS and MCAO NGSs.
- It is desirable to have the ability to insert a matrix mask within the MCAO system at the first telescope focal plane. This would be used to calibrate astrometric distortion in the whole MCAO/GSAOI optical train.

25.6 Satellite Interference

A laser beacon is not permitted to interfere with satellites, either by causing damage or by corrupting data from the satellite. A Laser Clearing House must vet proposed observations and allocate observing windows. These observing windows are typically shorter than 15 min duration. Consequently, science observations must either be limited to the available observing window, or they must be paused and the laser beam shut off when an observing window is not available. There should be no signal-to-noise ratio penalty for interrupting background-limited imaging observations in this way (see §25.2.8). The fast cold shutter in GSAOI can be used to interrupt imager exposures for short periods.

The laser beam must also be shut off when the beam crosses the field-of-view of a neighboring telescope (which is expected to occur approximately once per night), and when the MCAO Safe Aircraft Localization and Satellite Acquisition system detects the presence of an aircraft.

26 Science Drivers

26.1 Overview

GSAOI will be the workhorse instrument for Gemini's MCAO system. The key science drivers for GSAOI were identified at a Gemini community workshop at Santa Cruz in October 2000. These were detailed in the Multi-Conjugate Adaptive Optics (MCAO) Preliminary Design Review (PDR) documentation. The science cases that have been elaborated include:

- Low mass stellar and substellar mass functions in young star-forming regions such as the Orion Nebula cluster.
- Stellar population variations in star-forming regions such as Ophiuchus, Corona Australis, and Chamaeleon.
- Open cluster mass functions to the bottom of the H-burning sequence and the end of the white dwarf cooling sequence to provide independent age determinations.
- Mass functions in nearby globular clusters over a range of metallicities.
- Stellar populations of super-star cluster analogs in the Galaxy and Magellanic Clouds such as NGC 3603 and 30 Doradus.
- SN1a zero point calibration via red giant branch tip star distances to E/S0 galaxies.
- Stellar populations in starburst regions of nearby galaxies.
- Evolution of dwarf irregular versus elliptical galaxies in different environments.
- Early chemical histories of nearby galaxy spheroids.
- Intergalactic stars in nearby galaxy clusters.
- Color distributions among extragalactic globular clusters.
- Spatially resolved spectral energy distributions of high redshift field galaxies.
- Evolution of galaxies in clusters.

It is of key importance to determine whether these science cases can be achieved with the proposed GSAOI instrument and, if not, what more restricted observations are possible. Both limiting sensitivity and guide star availability must be considered in making this assessment.

We add the following science cases to the above list. These projects are of prime interest to GSAOI science team members:

- Missing mass in Magellanic Cloud planetary nebulae.
- Proper motions of Local Group galaxies.
- Stellar populations in dwarf galaxies.
- Measuring H_0 out to 60 Mpc using red supergiants.
- Measuring the bulk motion of galaxies to $cz < 6000$ km s^{-1} with surface brightness fluctuations.

- The formation of the disks of disk galaxies.
- Exploring dark energy via high redshift supernovae.

For each of these cases we now describe the science goal, and then ask the following questions:
- Is the science goal achievable within the sensitivity limits of the proposed instrument?
- Are MCAO guide stars available?
- Does the observation place special requirements on the instrument design?

26.2 The Orion Nebula - A Detailed Study of a Nearby Massive Star-Forming Region

26.2.1 Science Goal

This project was proposed in the MCAO Science Case (RPT-AO-G0107). Deep imaging at *J*, *H*, and *K* is required to identify all stellar objects, brown dwarfs, and planetary mass objects in the central region of the Orion Nebula Cluster down to ~ 1 Jupiter mass. This is required to establish the initial mass function (IMF) in a region of intense massive star formation. A detailed knowledge of the stellar and substellar IMF is fundamental to understanding fragmentation processes in molecular clouds, determining the nature of starburst galaxies, and describing the chemical evolution of the Universe.

The potential for high quality astrometry with MCAO provides a new means of identifying contaminating foreground stars. The Orion Nebula Cluster proper motion is predominantly along the line of sight, so large transverse motions may indicate contaminating sources (0.5 mas yr^{-1} for a transverse velocity of 1 km s^{-1} at the distance of the Orion Nebula). Background stars remain a problem and in fact Lucas et al. (2001) have shown that some J = 17-18 mag background stars are seen through the molecular cloud. This problem will increase towards J = 23 mag, so the interpretation of color-magnitude diagrams obtained towards Orion will critically depend on assigning accurate membership probabilities.

Accurate membership probabilities can be assigned even for a system with low proper motion like Orion to $H \sim 21$ mag over a 2 yr period (250 μas in 4 hr per epoch; c.f. §25.2.10). This corresponds to masses down to ~ 3-5 M_J, and represents a significant improvement in the robust assignment of cluster membership over what is currently possible through spectroscopy at the $H \sim$ 17-18 mag level. Proper motion information will permit a very robust determination of the Orion Nebula Cluster mass function down to well below the ~ 10 M_J deuterium-burning limit. This mass range overlaps with mass function measurements for extra-solar planets already being obtained from radial velocity work.

26.2.2 Sensitivity Limit

Photometry to $J \sim 26$ mag and H and $K \sim 25$ mag over a 6×6 arcmin field was original proposed in order to reach 1 M_J objects in the Orion Nebula Cluster. The revised limiting magnitude ($H \sim 23.5$, 10:1 in 1 hr) is more restrictive. However, it will still be possible to detect 2 M_J objects with ages of ~ 2×10^6 yr in the cluster in 4 hr exposures and to confidently assign membership probabilities to 3-5 M_J objects. This can be seen from Figure 10 where H magnitudes based on the models of Baraffe et al. (2002) are plotted for planets and brown dwarfs of different masses and ages of 1 Myr and 5 Myr.

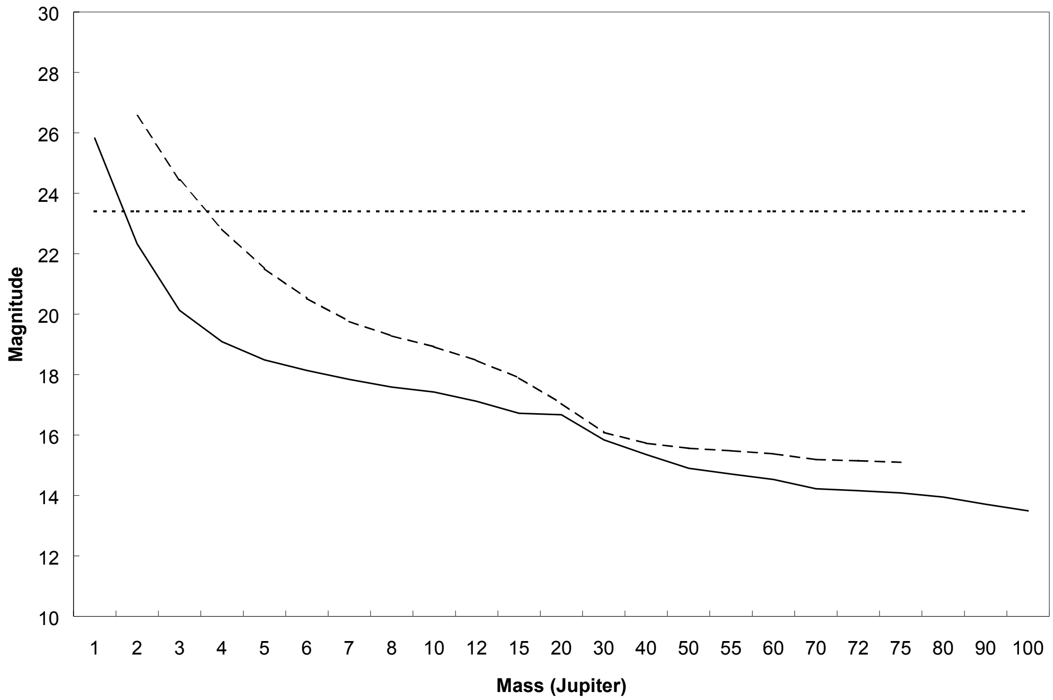

Figure 10: *H* magnitudes of 1 Myr old (*solid curve*) and 5 Myr old (*dashed curve*) planets and brown dwarfs of different masses from Baraffe et al. (2002). The horizontal line corresponds to the 10:1 in 1 hr limit.

26.2.3 Guide Star Availability

There is no difficulty finding suitable guide stars in the center of the Orion Nebula Cluster, as shown in Figure 11. This figure shows DSS, 2MASS, WFPC2, and NICMOS images centered on θ^1C Ori (the DSS image is saturated by nebula emission). The fields of the four GSAOI detectors are overlaid, along with the outline of the 2′ diameter MCAO field and the track of the five MCAO LGSs. Three MCAO NGSs are marked by triangles. A small circle marks the OIWFS star.

The bright nebular background and the bright Trapezium stars limit the sensitivity for detecting faint point sources in the central region. Figure 12 shows a region 3′ east of θ^1C Ori. There are no WFPC2 or NICMOS images of this field and the DSS image remains saturated, so no USNO stars are cataloged. The 2MASS near-infrared image suggests that suitable guide stars exist. However, other material will have to be consulted to confirm these selections.

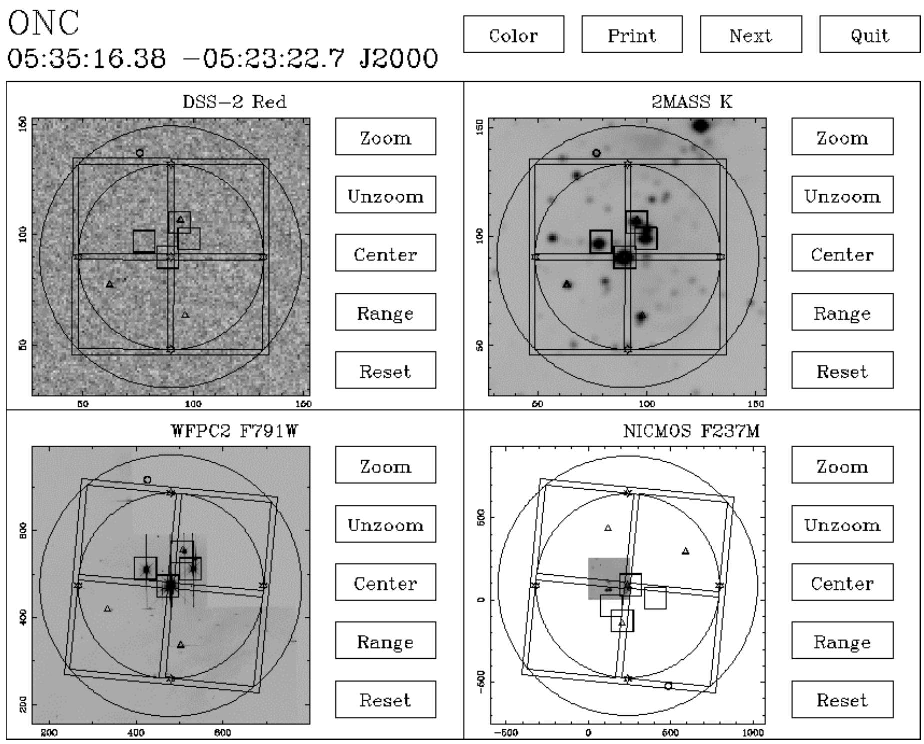

Figure 11: DSS, 2MASS, WFPC2, and NICMOS images of the Orion Nebula Cluster central region. Small squares mark USNO catalog stars. The four GSAOI detectors and the first fold mirror are indicated by squares. The large outer circle delimits the MCAO field. Stars mark the five LGSs. Small triangles mark the three NGSs. A small circle marks the OIWFS guide star.

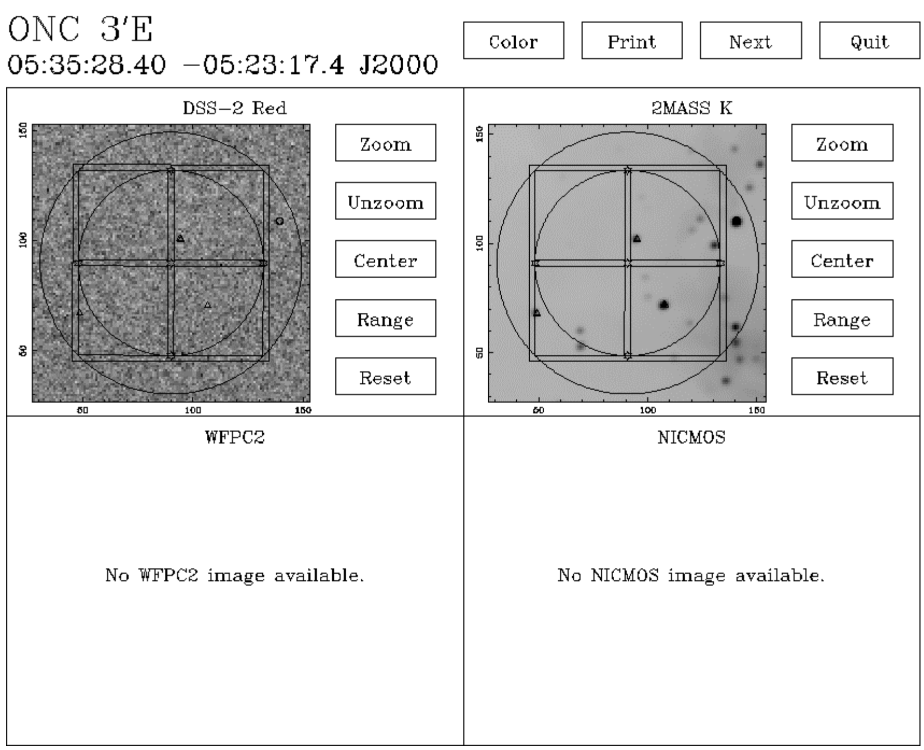

Figure 12: DSS and 2MASS images of a region 3′ east of the Orion Nebula Cluster.

26.2.4 Special Requirements

The main requirement of this project is to detect faint unresolved objects in the vicinities of multiple bright stars. Low ghost image intensities and low scattered light levels in the imager will be essential.

Long-term high astrometric precision is also essential. The critical issue is whether the astrometric distortion is repeatable at a level significantly below the targeted precision of ~ 250 μas per epoch, for likely changes of the instrument due to flexure and temperature variations. Astrometric distortion residuals of ~ 50 μas per epoch may be required to achieve this.

A simple and straightforward way to calibrate distortion is by imaging a matrix mask at the first telescope focal plane in the MCAO system. Failing that, an acceptable result might be achieved by imaging the 5×5 grid of the MCAO NGS source simulator. The focus mask in the GSAOI focal plane wheel will contain an array of pinholes that will at least allow distortion within the imager to be calibrated.

26.3 Young Stellar Super-Clusters

26.3.1 Science Goal

This project was proposed in the MCAO Science Case (RPT-AO-G0107). It requires deep *J*, *H*, and *K* imaging of Galactic and Magellanic Cloud analogs of the super star clusters identified in starburst galaxies. Super star clusters dominate the star formation in starburst galaxies, and have almost certainly been involved in the star formation history of the Galaxy. Understanding the stellar populations in these massive star-forming regions, and in particular the interplay between high- and low-mass star formation, is a key goal of this project. Mass functions ranging from the massive O-type stars to objects below the hydrogen-burning limit will be studied in nearby young super star clusters such as NGC 3603 in the Galaxy and 30 Dor in the Large Magellanic Cloud. Measurements in narrow-band filters (such as CO and Brγ) will give information on the stellar populations.

26.3.2 Sensitivity Limit

NGC 3603 has been measured in 0.4″ seeing down to $J \sim 21$ mag with ISAAC on the VLT (Brandl et al. 1999). These observations sampled down to masses of ~ 0.1 $M_{\rm Sun}$ (~ 100 M_J), assuming an age of ~ 1 Myr. Extending this a further 2.5 mag to the estimated GSAOI *J* limit (~ 23.5 mag 10:1 in 1 hr), or below, will reach substellar objects with masses < 13 M_J.

Images of similar depth in the 30 Dor region will reach pre-main sequence stars with masses of a few ×0.1 $M_{\rm Sun}$ assuming an age of ~ 1 Myr.

26.3.3 Guide Star Availability

NGC 3603 fits easily within the GSAOI field-of-view (Figure 13). There appears to be an abundance of MCAO NGSs, although the lack of USNO catalog stars leaves their brightness uncertain. The lack of a 2MASS image complicates the selection of an OIWFS guide star.

The region of the 30 Dor cluster is shown in Figure 14. There appears to be no problem identifying suitable guide stars. However, their brightness cannot be determined from the USNO catalog because the DSS images are saturated.

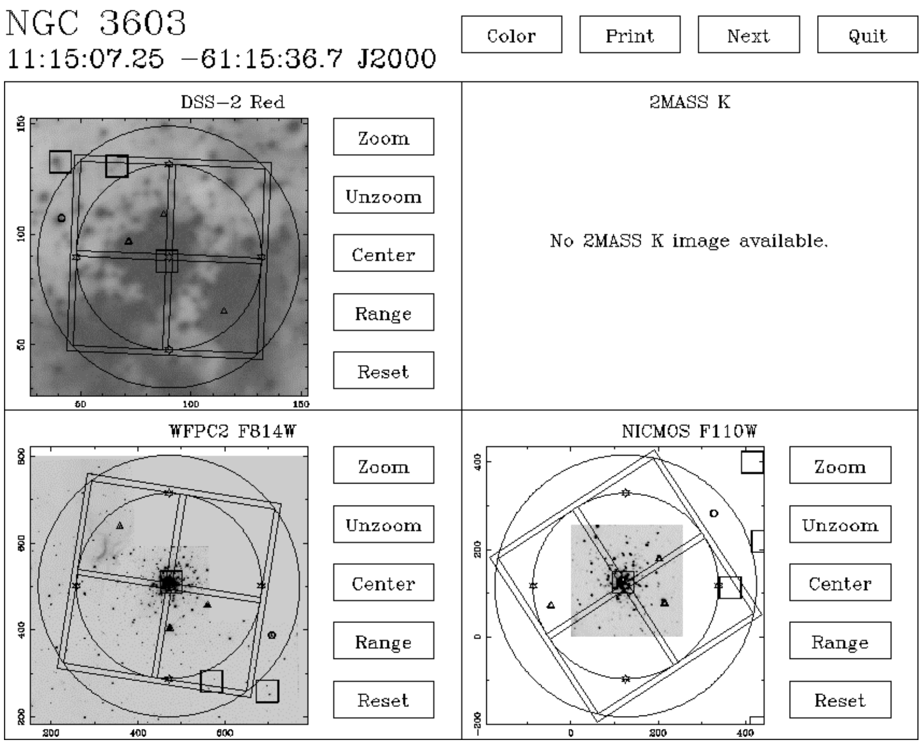

Figure 13: DSS, WFPC2, and NICMOS images of the NGC 3603 star cluster.

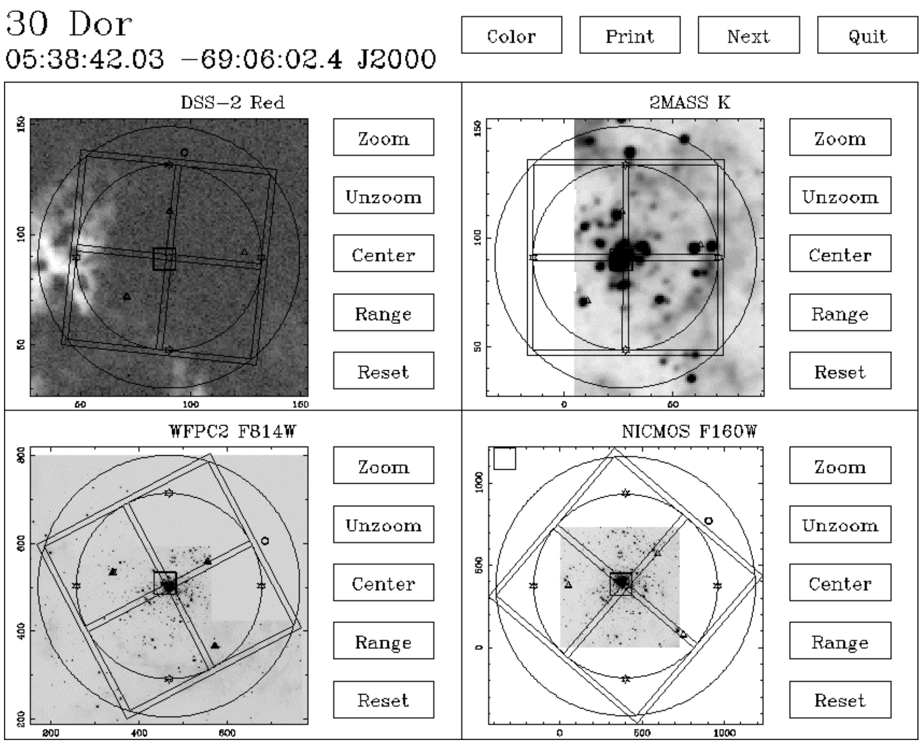

Figure 14: DSS, 2MASS, WFPC2, and NICMOS images of the 30 Dor star cluster.

26.3.4 Special Requirements

The main requirements for this project are high Strehl ratio to reduce crowding, a stable and uniform point spread function (PSF) over the field to permit accurate photometry, and low ghost image intensity to permit high dynamic range measurements in the vicinities of bright stars. The latter will be assisted by implementing the linear fitting readout method (i.e., integration up the ramp). This readout method records useful data for pixels that ultimately saturate in the full integration time. A large field-of-view is required, but also good sampling of the PSF at all wavelengths.

26.4 White Dwarf Cooling Ages in Galactic Open Clusters

26.4.1 Science Goal

This project was proposed in the MCAO Science Case (RPT-AO-G0107). The goal is to detect the termination of the white dwarf cooling sequence in nearby open star clusters, and hence derive cluster ages that are independent of the normal main sequence turnoff method. The cooling sequence ends at intrinsically faint magnitudes even for young clusters and contamination by stellar and extragalactic interlopers has always been a concern. The potential for accurate proper motion measurements with GSAOI offers a means of overcoming this difficulty. Proper motion measurements will be especially useful for distinguishing white dwarfs from distant star-forming blue galaxies.

A large area must be mosaiced in order to ensure that the cluster white dwarf luminosity function is adequately sampled.

26.4.2 Sensitivity Limit

Six nearby open clusters spanning a range of ages were identified in the MCAO Science Case; NGC 6405, NGC 2516, NGC 3532, NGC 3680, NGC 6253, and Coll 261. The white dwarf sequence termination has been detected in the 570 Myr old open cluster NGC 2099 at $M_V = 11.95\pm0.3$ mag (Kalirai et al. 2001), as expected from its main sequence turnoff age and white dwarf cooling models. This suggests that the white dwarf termination should be detectable with GSAOI in the first four of the clusters listed, with the termination at $H \sim 23.4$ mag in the oldest of these, NGC 3680. Termination magnitudes in the older clusters, NGC 6253 and Coll 261, are expected to be significantly below the GSAOI sensitivity limit of $H \sim 23.5$ mag (10:1 in 1 hr).

26.4.3 Guide Star Availability

There appears to be no shortage of guide stars towards these Galactic open clusters. The extreme central region of NGC 6405 is shown in Figure 15.

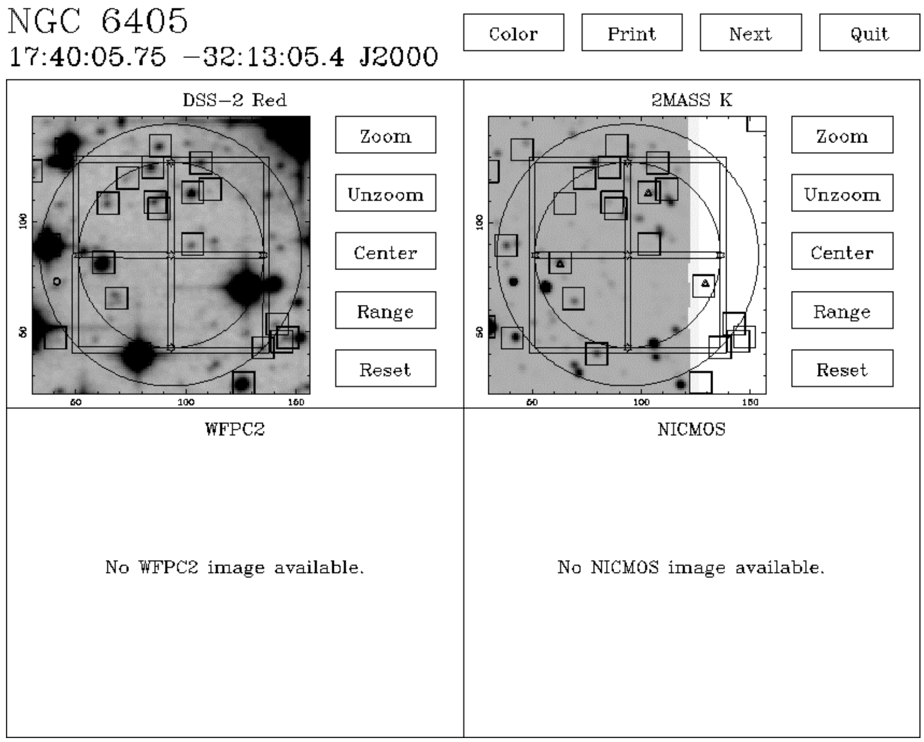

Figure 15: DSS and 2MASS images of the extreme central region of the open cluster NGC 6405.

26.4.4 Special Requirements

The main requirement for this project is high astrometric precision to identify open cluster members. The maximum possible field size with good PSF sampling is desirable to increase the number of detected stars. Stars are expected over a range of ~ 10 mag so high dynamic range is also desirable.

26.5 Globular Cluster Mass Functions Over a Range of Metallicities

26.5.1 Science Goal

This project was proposed in the MCAO Science Case (RPT-AO-G0107). It aims to probe the main sequence mass function and substellar limit in old metal-poor Galactic globular clusters. The mass limit of stars at the bottom of the hydrogen-burning main sequence is predicted to be metallicity dependent: this prediction will be tested. Deep *JHK* images reaching the end of the population-II main sequence are required for several globular clusters. Measurements of proper motions will be used to identify cluster members and remove field stars.

26.5.2 Sensitivity Limit

The MCAO Science Case lists five southern globular clusters that are suitable for this project; NGC 6553, NGC 104, NGC 6121, NGC 6752, and NGC 6397. The bottom of the hydrogen-burning main sequence in globular clusters should occur at $M_J \sim 13$ mag and $M_K \sim 11$ mag. Sixteen fields and at least two filters are required per cluster, so exposure times are effectively limited to ~ 1 hr. Given the expected GSAOI sensitivities ($J \sim 23.5$ mag and $K \sim 23.2$ mag 10:1 in 1 hr), it is likely that the bottom of the main sequence will be detectable in only NGC 6121 and NGC 6397, and detection at *J* will be difficult even in these clusters ($J \sim 24.7$ mag and $K \sim 22.7$ mag for NGC 6121; $J \sim 24.8$ mag and $K \sim 22.8$ mag for NGC 6397). The bottom of the main sequence is expected to be at $J > 26.0$ mag and $K > 24.0$ mag in the other clusters.

The revised GSAOI sensitivity limits severely impact the science potential of this project.

26.5.3 Guide Star Availability

There is no difficulty identifying guide stars, at least in the central regions of NGC 6121 and NGC 6397. The core of NGC 6121 is shown in Figure 16.

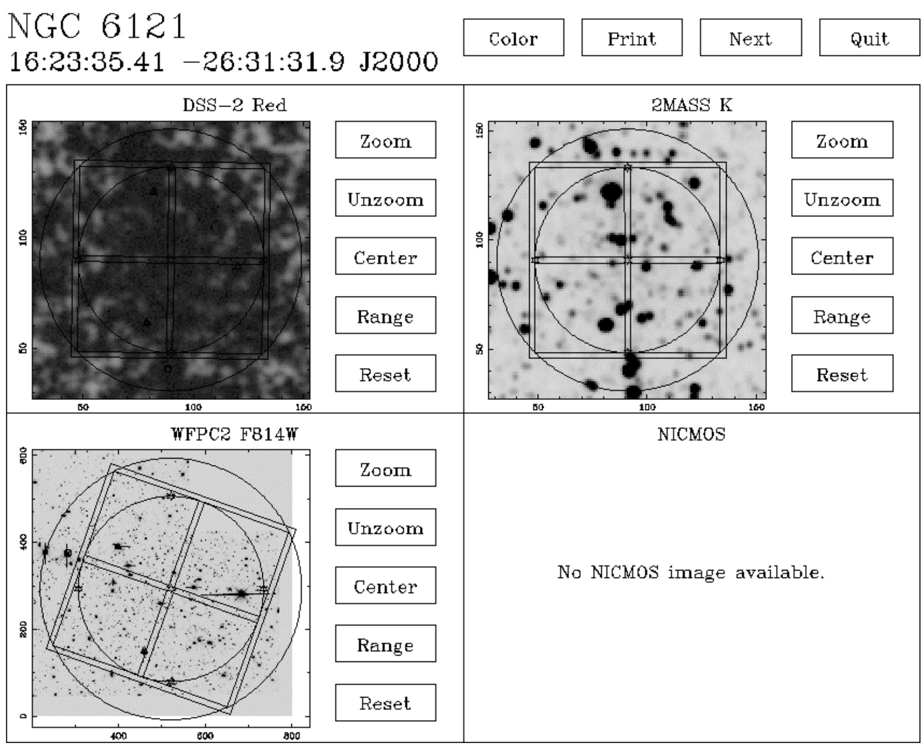

Figure 16: DSS, 2MASS, and WFPC2 imagers of the core of the globular cluster NGC 6121.

26.5.4 Special Requirements

A uniform PSF across the GSAOI field-of-view is required to perform accurate photometry at faint levels.

26.6 Missing Mass in Magellanic Cloud Planetary Nebulae

26.6.1 Science Goal

Despite vast increase in our understanding of the evolutionary nature of planetary nebulae (PNe) during the last three decades, a central question remains: *where is the missing mass?* Theoretical evolutionary tracks predict that all stars with masses in the range 1.4-8 M_{Sun} should become PNe. According to the models, much of the mass of these stars is lost during a series of thermal pulses in the asymptotic giant branch (AGB) phase of evolution. Observations reveal that the central star mass is close to 0.6 M_{Sun}, except for a few Peimbert Type I nebulae (e.g., NGC 6302 with 0.8 M_{Sun}, or a handful of objects in the LMC). However, the ionized nebular mass of the PN is typically of order 0.1 M_{Sun}, and the derived mass is found to depend very strongly on the radius of the nebula. Clearly, much of the mass of the planetary nebula shell must remain un-ionized, and much of it may be in molecular form. This molecular gas has been mapped in the 110.2 GHz (1-0) transition of ^{12}CO in a number of nearby PNe. These observations confirm the much greater extent of the nebula in molecular gas. In the infrared, the nebula can be mapped in the 2.122 μm 1-0 S(1) and 2.248 μm 2-1 S(1) lines of molecular hydrogen, which in most objects seem to be fluorescently excited by UV radiation from the central star. Generally speaking, the size of the observed nebula is larger, and the estimated molecular hydrogen masses much greater, than the ionized gas component. The nebula of NGC 7027 (Dayal et al. 2000) is a splendid example of this.

For Galactic objects, accurate mass inventories are bedeviled by uncertainties in the PN distance scale, which can only be resolved by the study of a population of PN at a known distance and having low field reddening. The Magellanic Cloud PNe are ideal for this. At optical wavelengths, the Hubble Space Telescope (HST) has been used to systematically investigate the morphologies and ionization of the ionized component. These data typically have a spatial resolution of a little better than 0.1″, which corresponds to a linear resolution of ~ 0.02 pc at the distance of the LMC. This is quite sufficient to reveal the internal morphology, given that the typical diameter of a PNe is about 0.1 pc and some objects are as large as 1.0 pc across including the faint outer structure.

With its superb spatial resolution, the GSAOI instrument will be ideally suited to perform a systematic study of both the PNe and the proto-planetary nebulae in the Magellanic Clouds at a spatial resolution that matches the observations that have been made by HST of the ionized gas components. The quality of the images that could be obtained would be comparable with the NICMOS images that HST has obtained of PNe towards the Galactic center. Not only can the extent and distribution of the molecular hydrogen be determined, but the PNe can also be mapped in the [Fe II] 1.644 μm line, which in some PNe reaches an intensity in excess of 2×10^{-14} erg cm^{-2} s^{-1} arcsec^{-1} (Welch et al. 1999) and which traces the positions of shocks driven into the molecular shell by the high pressure of the ionized zone and fast winds that have shaped the PNe morphology.

For the Magellanic Cloud PNe, these data will enable us to derive quantitative data that cast direct light on the evolution of PNe and on their AGB precursors. The positions of the central stars on the Hertzsprung-Russell diagram are known, we can distinguish between H-burning and He-burning stars, and the dynamical ages of the nebulae can be determined for these PNe.

26.6.2 Sensitivity Limit

The average intensity of [Fe II] 1.644 μm emission in the outer parts of the Galactic planetary nebula Hubble 12 is ~ 8×10^{-15} erg s^{-1} cm^{-2} arcsec^{-2} (Welch et al. 1999). The sensitivity limit for GSAOI in the [Fe II] 1.644 μm filter is expected to be ~ 4×10^{-15} erg s^{-1} cm^{-2} arcsec^{-2} (10:1 per resolution element in 1 hr). This is comfortably below the expected average intensity, so it will be possible to confidently detect any low surface brightness structure that is present.

26.6.3 Guide Star Availability

Twenty-six LMC PNe (Vassiliadis et al. 1998 and references therein) with HST data have been searched for suitable MCAO guide stars. Acceptable guide stars are probably available for all of these targets. We illustrate this with the example of LMC-SMP 2 in Figure 17. Nevertheless, it is apparent that the ability to dither the image to achieve accurate sky subtraction is often restricted by the need to have suitable guide stars at every dither position.

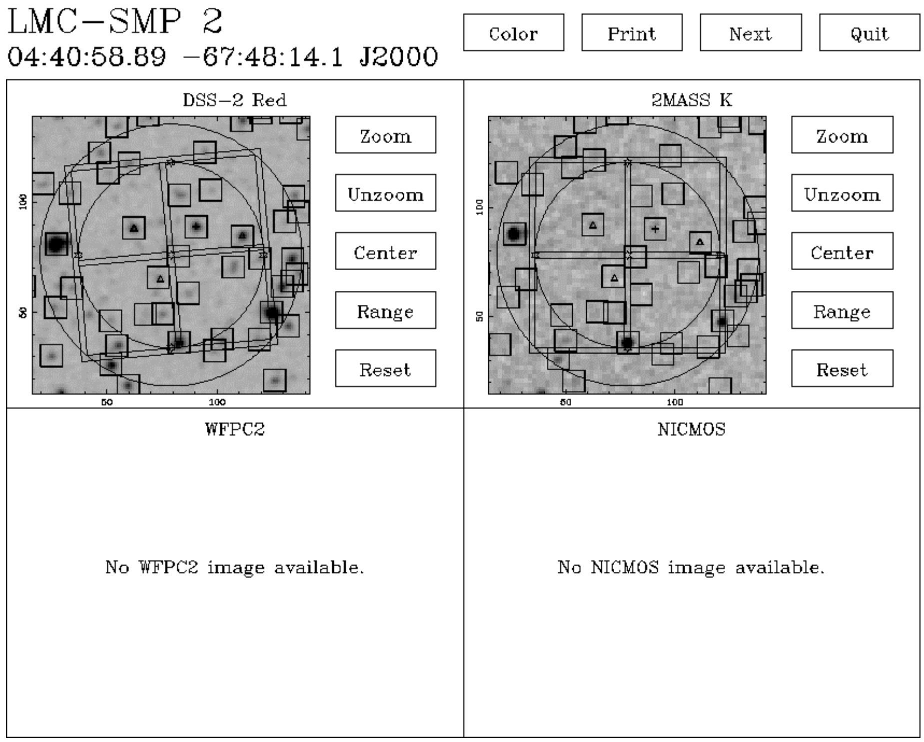

Figure 17: DSS and 2MASS images of the LMC planetary nebula LMC-SMP 2. A small cross identifies the target.

26.6.4 Special Requirements

The Large and Small Magellanic Clouds have heliocentric Doppler shifts of +260 and +150 km s^{-1}, respectively. The "zero redshift" narrow band emission line filters should be sufficiently wide (or have appropriately shifted central wavelengths) to ensure that emission lines from both Galactic and Magellanic Cloud objects are passed with good transmission.

A means of rapidly traversing the OWIFS guide field to acquire new guide stars will contribute significantly to the efficiency with which dithered observations are obtained.

A uniform PSF over the GSAOI field will permit deconvolution algorithms to be used to further improve spatial resolution.

26.7 Proper Motions of Local Group Galaxies

26.7.1 Science Goal

The accretion of satellites (Searle & Zinn 1978) has become recognized as being of fundamental importance to the formation and evolution of the Milky Way halo. This model was initially proposed because differences in the globular cluster populations in the inner and outer halo suggested the existence of an age spread (Zinn 1993; van den Bergh 1993). Studies in recent years have provided several lines of evidence to support the importance of the accretion scenario, including:

- Numerous examples of kinematic substructures along independent lines of sight that suggest the halo is threaded with "streams" of stars (e.g., Arnold & Gilmore 1992; Côté et al. 1993; Majewski et al. 1994).
- The discovery of the "smoking gun" of the Sagittarius dwarf spheroidal galaxy that has been "caught in the act" of being disrupted by the Milky Way (Ibata et al. 1994).

However, the properties of a typical accretor remain unclear.

It has been long suggested that the Milky Way satellites define a plane about the Galactic center (Kunkel & Demers 1976; Lynden-Bell 1976). More recently, two separate planes have been proposed (Majewski et al. 1994; Lynden-Bell & Lynden-Bell 1995). If such "mega-streams" are associated with a single accretion event, a typical accretor would have a mass comparable to the Magellanic Clouds. Alternatively, accretion events may have involved only single dwarf spheroidal-like satellites, implying a "maximally chaotic" outer halo in which a typical stream has a mass of $< 10^8\ M_{Sun}$, and the "mega-streams" are not dynamically significant. The distinction between high- and low-mass accretors is important. The latter (10^7-$10^8\ M_{Sun}$) will produce kinematically distinct streams that survive for long times in the halo, while negligibly heating the Galactic thin disk. The accretion of a massive satellite, however, would produce a kinematically indistinct cloud of stars and heat the disk to much larger scale heights than we see today.

Space velocities will allow us to determine how well mixed the outer halo really is, and test directly for the existence of the "mega-streams". Proper motions are vital for this, as they alone distinguish between chance alignments and true streams. Precise proper motions for the Galaxy's satellites are essential if we are to distinguish between these models.

Such data are also of fundamental importance to the determination of the gravitational potential of the Galaxy at large galactocentric radii, and to the measurement of the total mass of our Galaxy.

GSAOI offers the prospect of the precise measurement for many southern hemisphere satellite galaxies such as Fornax, Sculptor, Carina, Sextans, Phoenix, and others. Dedicated surveys have revealed the presence of unresolved quasars behind many of these target galaxies (Tinney et al. 1997; Tinney 1999), and similar surveys of the remaining targets will be straightforward to carry out. At the magnitudes of interest, both quasars *and* suitable giants in the galaxies for use as a "galaxy" reference frame are available (the technique is to measure the quasar's reflex motion relative to a frame of galaxy giants). At precisions of ~ 180 μas per epoch over 5 years, 1σ precisions for proper motion measurement of ~ 40 μas yr^{-1} become feasible, making the proper motions of all these galaxies detectable in a program totaling ~ 200-300 hr over 5 years.

26.7.2 Sensitivity Limit

The Sculptor, Sextans, Carina, Fornax, Phoenix dwarf spheroidal galaxies have distance moduli of 19.5, 19.7, 20.0, 20.7, and 23.2, respectively. The red giant branch tip occurs at $M_K \sim -6.5$ mag, so these star will be detected at $K \sim 13.0$, 13.2, 13.5, 14.2, and 16.7 mag, respectively. These objects are easily measured with GSAOI. Integration times will be set by the required astrometric precision, rather than photometric precision.

26.7.3 Guide Star Availability

Guide star availability will depend on the positions of background quasars projected on the foreground galaxy. This is uncertain at present.

26.7.4 Special Requirements

Long-term high astrometric precision is essential.

26.8 Stellar Populations in Dwarf Galaxies

26.8.1 Science Goal

It is probably no exaggeration to claim that the most important outstanding question in the study of the formation and evolution of dwarf galaxies is the origin of the remarkable diversity of star formation histories observed among the dwarf Ellipticals (a class that includes the so-called dwarf Spheriodals) of the Local Group. Prior to the first hints of a discrepancy in the early 1980s, the paradigm that dEs galaxies consist entirely of old stars was universally accepted, and amongst those unfamiliar with developments in the field, this view is still surprisingly prevalent. Yet it is now abundantly clear that the simple picture of dEs as consisting of entirely old (age > 10 Gyr) stars is no longer valid. For example, among the Milky Way's dE companions we see systems with dominant old populations, systems with minor intermediate-age (age ~ 2 to 10 Gyr) components, and systems where the intermediate-age component dominates the old stars. Even in these latter systems there is further variety; in Carina the on-going star formation occurred in a number of discrete episodes while in Fornax it was approximately continuous. This variety of star formation histories is not restricted to the Galaxy's companions. Recent observations with HST/WFPC2 have shown that M31's dEs have also had extended epochs of star formation.

Despite the large amount of observational data available for Local Group dEs, there is currently no explanation for the diversity of star formation histories, only hints. For example, among the Galaxy's companions there is a tendency for the systems with stronger intermediate-age components to lie at larger Galactocentric distances. This also appears to be the case for M31's companions where, at least among the lower luminosity dE companions, it is the more distant system And II that has a definite intermediate-age population; systems closer to M31 lack such stars. These results suggest that proximity to a "parent galaxy" influences the evolution of dwarf galaxies. Indeed, recent theoretical simulations have shown how a dwarf irregular on an initial "plunging" orbit in the Milky Way halo can be converted into a dE satellite. At the same time it is notable that, with one exception, all the isolated dwarfs in the Local Group are not dEs; they show either recent or on-going star formation. The one local exception to this hypothesis that "parent galaxies" nurture initial gas-rich dwarf companions into dE galaxies, is the isolated dE Tucana. Despite its lack of association with any large galaxy, it nevertheless possesses a dominant old stellar population and there are no signs of any intermediate-age component. The existence of this system demonstrates that proximity to a large galaxy cannot be the only factor governing the evolution of dwarf galaxies.

To make progress in understanding the processes that govern dwarf galaxy evolution, we need to study systems beyond the Local Group. Such studies can be targeted at dEs that occupy a variety of environments, thereby allowing us to more readily distinguish between intrinsic properties and "parent galaxy" influence. In particular, we need to target a sizeable fraction of the dEs within our "Local Volume", the sphere of radius ~10 Mpc centered on the Local Group, seeking to establish what fraction of these systems show intermediate-age populations. This volume includes the relatively loose Sculptor Group, the more compact Cen A group, and a variety of other galaxy aggregations such as the loose association of galaxies that contain the Circinus galaxy at a distance of 6-7 Mpc. The observational signature of an intermediate-age population is the presence of upper-AGB stars, i.e., stars with sufficient mass to evolve on the AGB to luminosities above that of the red giant branch tip. For such stars there is a good correlation between the luminosity of the brightest upper-AGB star and the age of the intermediate-age component. The observations are best done at near-infrared wavelengths since these pass bands cover the wavelengths where the majority of the flux is emitted. Bolometric corrections are therefore small and well defined and the amplitude of variability is much reduced relative to the optical. Single epoch *J* and *K* band measurements then suffice for a determination of the bolometric magnitudes (two pass bands are required as the bolometric correction to the *K* magnitude is a function of *J-K* color). Although current near-infrared imagers can reach upper-AGB stars in the nearer of the dEs within the Local Volume using relatively long integration times, given the likelihood of a diversity of star formation histories, a sizeable sample of dwarfs in a variety of environments needs to be studied if underlying trends are to be revealed. GSAOI is the ideal instrument with which to carry out this program.

26.8.2 Sensitivity Limit

An 8-10 Gyr old upper-AGB star, the upper limit to what we might call an intermediate-age population, has a bolometric magnitude $M_{\mathrm{Bol}} \sim -4.1$ mag and $M_{\mathrm{K}} \sim -6.8$ mag with $J–K \sim 1.2$. We need to measure the bolometric magnitude to a precision of ~ ±0.2 mag, including both photometric and distance modulus uncertainties. This can be achieved if both the *J* and *K* magnitudes are measured to a signal-to-noise ratio of ~ 10. The expected GSAOI sensitivities are such that the upper-AGB component can be measured for any dE within the 10 Mpc sphere of the Local Volume in ~ 1 hr of on-source integration at *K* and 5 hr of integration at *J*. This is sufficient sensitivity to allow targeting of a well-defined sample of dEs covering a range of both intrinsic properties (surface brightness, total magnitude, length scale, etc.) and environmental parameters (distance from potential parent galaxy, parent galaxy type, local galaxy density, orbit timescales/crossing times, etc.).

26.8.3 Guide Star Availability

There are sufficient candidate dE galaxies within the Local Volume that restricting the sample to only those systems with appropriate guide stars is not likely to be a severe requirement. The relatively small size of the targets also allows some flexibility in the positioning, increasing the probability of acquiring a suitable set of guide stars. An example is show in §28.1.

26.8.4 Special Requirements

The program described here is essentially a routine application of the GSAOI and therefore does not impose any special requirements on the instrument other than a uniform PSF across the field to permit accurate photometry.

26.9 Calibration of the Supernovae Ia Zeropoint

26.9.1 Science Goal

This project was proposed in the MCAO Science Case (RPT-AO-G0107). The goal is to measure red giant branch tip distances to E/S0 galaxies containing supernovae (SNe) Ia. These SNe Ia can then be used to tighten the SNe Ia distance scale calibration. The red giant branch tip occurs at $M_J \sim -5.3$ mag and $M_K \sim -6.5$ mag, but it is necessary to reach somewhat below the tip in order to make a confident detection. The MCAO Science Case lists seven E/S0 galaxies with well measured SNe Ia; NGC 1316, NGC 5128, NGC 4374, NGC 1380, NGC 4526, NGC 5253, and NGC 5003.

26.9.2 Sensitivity Limit

The expected GSAOI sensitivity ($J \sim 23.5$ mag and $Ks \sim 23.2$ mag 10:1 in 1 hr) is such that the red giant branch tip is likely to be detectable only in NGC 5128 and NGC 5253 at $J \sim 22.5$ mag and $Ks \sim 21.3$ mag and $J \sim 22.9$ mag and $Ks \sim 21.7$ mag, respectively. The red giant branch tip has already been detected in NGC 5128 (Soria et al. 1996). The red giant branch tip occurs at $J \sim 25.1$ mag and $K \sim 23.9$ mag in NGC 5005 and at $J > 25.7$ mag and $K > 24.5$ mag in the other five galaxies. It is therefore likely that GSAOI will permit only a minor improvement in the SNe Ia distance scale calibration.

26.9.3 Guide Star Availability

Suitable guide stars appear to be available in a field ~ 1.5 arcmin SE of the nucleus of NGC 5253 (Figure 18). The MCAO NGSs have $R \sim 15.8$, 18.0, and 18.1 mag in the USNO catalog. Concerns about the calibration of the USNO catalog in the southern hemisphere dictate caution in choosing the two fainter stars. The OIWFS guide star has $R \sim 16.7$ mag, but the absence of a 2MASS image leaves its near-infrared brightness uncertain.

Guide stars are available in a field 4′ south of NGC 5128.

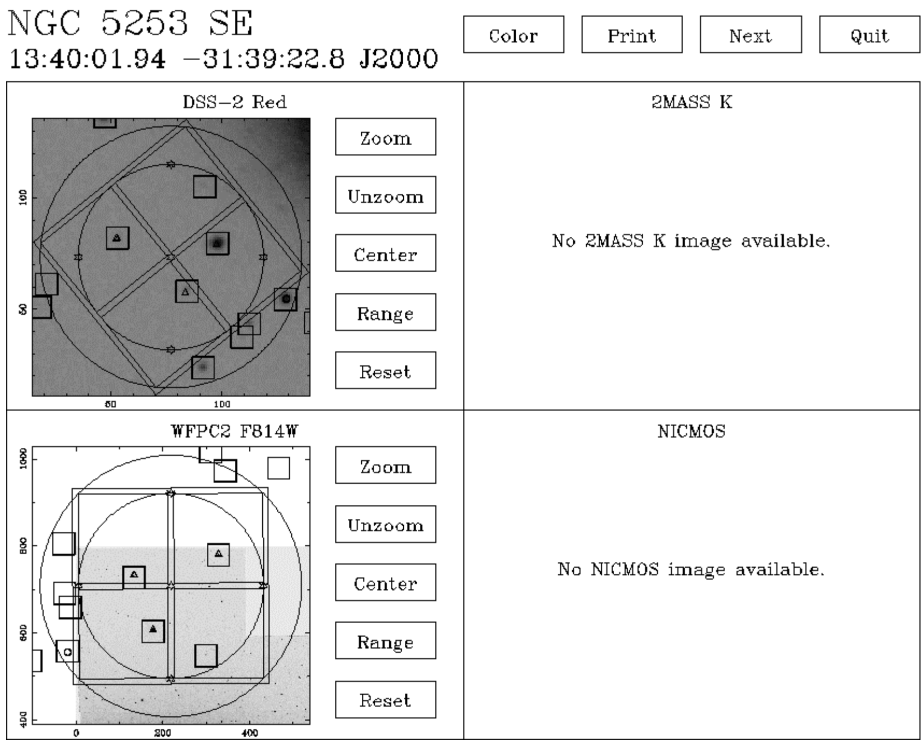

Figure 18: DSS and WFPC2 images of a field ~ 1.5 arcmin SE of NGC 5253.

26.9.4 Special Requirements

The project is essentially a routine application of the GSAOI and therefore does not impose any special requirements on the instrument other than a uniform PSF across the field to permit accurate photometry.

26.10 Intracluster Stars in Nearby Galaxy Clusters

26.10.1 Science Goal

This project was proposed in the MCAO Science Case (RPT-AO-G0107). Faint intracluster light is seen in some of the more distant galaxy clusters. It is currently believed to come from stars stripped from galaxies by the harassment process (fast encounters of galaxies leading to impulsive heating and then stripping by the tidal field of the cluster). This belief needs to be more firmly established.

In the nearer clusters, like Virgo and Fornax, observations of diffuse light are very difficult. Individual stars are much more useful tracers of the stellar intracluster medium (ICM) in nearby clusters; intracluster planetary nebulae have already been detected in the Virgo and Fornax clusters.

Galaxies of intermediate mass are believed on theoretical grounds to be the ones most affected by harassment. They can be transformed into loosely bound dwarfs, with much of their stellar mass lost into the ICM. The harassment process would produce a stellar ICM with substantial substructure in space and velocity. This can be tested directly, and some progress has been made in this direction using the planetary nebulae.

Red giants are much more abundant than planetary nebulae, and provide ideal probes of the ICM. In principle, one can use color-magnitude diagrams (CMDs) of the upper giant branch of the intracluster stellar population to derive the surface density distribution and the metallicity of the stellar ICM. This would allow us to quantify the spatial substructure of the ICM; also, using the metallicity-luminosity relation for galaxies, it would give useful observational constraints on the kinds of galaxies that have contributed most to the stellar ICM.

The observational goal is then to construct stellar CMDs in many locations of the Virgo and Fornax clusters; these are the nearest significant galaxy clusters, and are both known to contain a stellar ICM.

26.10.2 Sensitivity Limit

Here is the problem. To do anything useful on the stellar ICM, we need a CMD down to at least 1 mag below the tip of the red giant branch. The brightest red giants have M_J = -5.5, M_H = -6.2, and M_K = -6.5 mag. The distance modulus of the Virgo and Fornax clusters is ~ 31.0. So we need images with a signal-to-noise ratio of at least 5 at J = 26.5, H = 25.8, and K = 25.5 mag. This seems well out of reach for the GSAOI. Even with a small aperture of 4×4 pixels, the integration times at J, H, and K are about 60, 20, 20 hr, respectively.

26.11 Measuring H_0 Out to 60 Mpc Using Red Supergiants

26.11.1 Science Goal

Despite intense efforts using HST over the past decade, there is still fierce debate about the value of the Hubble Constant, although most people now agree that it has a value between 55 and 80 km s^{-1} Mpc^{-1}. The HST Key Project team has presented the most significant body of work (Freedman et al. 2001). They used Cepheid variables out to 20 Mpc as the calibrating method for a host of secondary distance indicators such as Type Ia supernovae, surface brightness fluctuations, and the Tully Fisher method. However, the small numbers of objects, difficulties in HST CCD calibrations, large extinction corrections, and the difficulty of combining surface brightness fluctuation distances to early-type galaxies with Cepheid distances to late type galaxies have all complicated this work. Luminous red supergiants provide a new method of measuring the Hubble constant that is independent of Cepheid distances. The red supergiant method offers high precision, ease of use, low vulnerability to extinction, and a single method that can be applied to the LMC, SMC, nearby galaxies, and other late-type galaxies out to 60 Mpc with GSAOI.

The brightest red supergiants pulsate with periods of 400 to 900 days and have M_K ~ -11 (Wood, Bessell, & Fox 1983). Typical full K band amplitudes are ~ 0.25 mag. These luminous red supergiants lie on a K-log P relation with scatter about the relation of ~ 0.25 mag. The LMC has roughly 20 of these variable red supergiants so that a galaxy of this relatively small size can give a distance modulus accurate to ~ 0.05 mag. Larger spiral galaxies will yield larger numbers of red supergiants and hence a more accurate distance modulus. Imaging in the K band maximizes the contrast between the red supergiants and the galaxy background. Red supergiants will be found by their variability, which distinguishes them from bright star clusters.

The degree of contrast of the red supergiants against the galaxy background is a relevant concern that will be more problematic at larger distances. If a typical background giant star has M_K ~ -5 mag, its apparent magnitude at a distance of ~ 60 Mpc is K ~ 28.9 mag. There are ~ 83 such giant stars per 0.06″×0.06″ resolution element in a region with a K band surface brightness of ~ 18.0 mag $arcsec^{-2}$. Background fluctuations due solely to statistical variations in the number of these stars will be at the level of ΔK ~ ±0.1 mag per resolution element. The addition of a single M_K = -11 mag red supergiant to this background will cause a fluctuation of -1.5 mag per resolution element. Consequently, it is very unlikely that surface brightness fluctuations due to variations in the number of background stars will impede measurement of the luminous red supergiants.

26.11.2 Sensitivity Limit

A signal-to-noise ratio of ~ 25 is required to detect variability. The GSAOI K band sensitivity is such that a M_K ~ -11 mag red supergiant can be detected with this signal-to-noise ratio at 60, 50, 40, 30, and 20 Mpc in 3.6, 1.7, 0.7, 0.2, and 0.04 hr. Approximately 12 such measurements spread over ~ 2 years at 2-3 month intervals are required to determine a pulsation period. At least three galaxies are required at each distance, so this project will require a total of ~ 250 hr of integration time to complete.

This program can be expanded easily to increase the number of galaxies surveyed, and improve the precision of Hubble constant measurement.

26.11.3 Guide Star Availability

There is a multitude of acceptable galaxies at distances < 60 Mpc, so it is convenient to choose only galaxies that have suitable guide stars.

26.11.4 Special Requirements

A uniform PSF is required over the GSAOI field to allow accurate measurement of stars across the entire galaxy.

26.12 Measuring the Bulk Motions of Galaxies to cz < 6000 km/s with Surface Brightness Fluctuations

26.12.1 Science Goal

It is widely accepted that the evolution of the large scale structure of the Universe is driven by dark matter. Understanding this dark matter continues to be one of Astronomy's great unsolved problems. Measuring the bulk motions of galaxies allows us to map the overall mass distribution of the Universe in a way that is independent of the luminous matter in galaxies. Each galaxy whose motion is measured, serves as a test particle of the gravitational field around it. With large numbers of accurately measured objects it is possible reconstruct the mass distribution of material in the Universe. Unfortunately, this has not been easy – since the first results of 15 years ago of the "Great Attractor" (Lynden-Bell et al. 1988), the field has been littered with contradictory results and findings that are still not understood. The heart of the problem has been finding a way to obtain large numbers of accurate distances between $0 < cz < 10{,}000$ km s^{-1}. GSAOI can make significant progress in this field by measuring *H* band surface brightness fluctuation (SBF) distances to hundreds of galaxies in this range. Already SBF has been used at optical wavelengths to probe motions at $cz < 2000$ km s^{-1}, but this work was hampered by the fact that much of the action happens outside of 2000 km s^{-1} (Tonry et al. 2000).

H band surface brightness fluctuations (Jensen et al. 2001) provide distances accurate to ~ 0.12 mag, and are limited, in the case of GSAOI, by contamination from globular clusters at $cz > 8000$ km s^{-1}, not by photometric uncertainty. Using observations of ~ 100 SBF galaxies in the direction of the Great Attractor, the location, mass, and extent of the Great Attractor could finally be ascertained by looking at the motion of galaxies on all sides of this object. An additional survey of ~ 500 galaxies at $cz < 6000$ km s^{-1} across the whole sky would provide a new scale measurement of bulk motions in the current Universe, and provide a measurement of the scales over which dark matter clusters.

26.12.2 Sensitivity Limit

A 0.12 mag *H* band SBF measurement requires reaching $H \sim 23$ mag with a signal to noise ratio of 10. GSAOI can reach this level of sensitivity in ~ 0.4 hr of integration time. This level of integration is appropriate for nearly all the galaxies in the bulk motion sample. In total, we estimate that this program needs ~ 200 hr of integration time to carry out its objectives, although the program could be expanded to any amount of observing time by increasing the sample of galaxies.

26.12.3 Guide Star Availability

There are tens of thousands of acceptable galaxies at $cz < 6000$ km s^{-1}, and therefore it is possible to choose those galaxies that have appropriate guide stars.

26.12.4 Special Requirements

A uniform PSF over the GSAOI field is required to accurately measure the surface brightness fluctuations. The large field of GSOAI also would allow multiple galaxies to be imaged simultaneously in those nearby clusters and groups that have appropriate guide stars.

26.13 The Formation of the Disks of Disk Galaxies

26.13.1 Science Goal

The formation of the disks of disk galaxies remains poorly understood. Cold Dark Matter (CDM) simulations have difficulty in reproducing the observed properties of disks. For example:

- The disks that are formed in the simulations have significantly smaller scale lengths and less angular momentum than real galactic disks.

- Many disk galaxies have only the thin disk component, with no bulge or significant thick disk. This means that they formed in a very quiescent way, with no star formation occurring before the gas disk had settled. Furthermore, since the epoch of disk settling, there cannot have been any significant disturbance by the mergers and interactions that are such a feature of the CDM simulations.

Other important problems include:

- Almost all disk galaxies have an exponential radial surface brightness distribution. The reason for this exponential form is not known; nor is it known when the exponential form is established.

- The exponential disks are typically truncated radially at a radius of about 3 exponential scale lengths. This truncation is an important and probably fundamental indicator of the nature of the galaxy formation process. At this time, the reason for the truncation is not known. Here are some of the many possibilities:
    - The truncation may reflect the maximum angular momentum of baryons in the protogalaxy, or
    - It may be caused by tidal interactions of lumps of dark + baryonic matter early in the hierarchical aggregation process, or
    - It may be the radius where the gas density goes below the critical density for star formation, or
    - It may be associated with the viscous evolution of the star-forming disk (which itself may also lead to the exponential light distribution).

Almost everything that we know about galactic disks comes from disks at low redshift, so little is known about when the fundamental properties of the disks were established. MCAO gives us the opportunity to study the detailed structure of galactic disks at earlier epochs, to a redshift $z = 1$.

The primary goal is to see if the exponential nature of the disks, their characteristic scale lengths and their truncation are already established at $z = 1$. To achieve this goal, we need the high spatial resolution and high near-infrared sensitivity offered by the GSAOI. Observationally, we would aim to study galaxies over a range of redshifts, but at the same rest-frame mean wavelength. We would compare low redshift galaxies observed in the *I* band with galaxies at $z = 0.5$ in the *J* band and at $z = 1$ in the *H* band.

Resolution: For a disk galaxy like the Milky Way, with a scale length of 4 kpc, the expected truncation radius at $z = 1$ in a standard Λ-universe is about 1.8″. Such galaxies are very well suited to surface photometry in *J* and *H* with GSAOI.

Near-infrared imaging: For low redshift spirals, the large scale structure of the disk depends on wavelength. This is partly due to the star formation history and partly to internal absorption. We therefore need to compare low and higher redshift galaxies with observations at the same rest-frame mean wavelength. Although one could cover the redshift range z = 0 to 1 using observations in B and I, this would be far from ideal; dust and star formation affect the surface photometry much more at shorter wavelengths. It is better to make the low redshift observations in the I band and the higher redshift observations in the near-infrared.

We would propose to survey disk galaxies in the field and in a sample of clusters, at redshifts around z = 0.5 (J), z = 1 (H) and z = 1.7 (Ks).

26.13.2 Sensitivity Limit

The goal is to do surface photometry of our disk galaxies out to a radius of ~ 3.5 scale lengths. We estimate the required integration times, assuming conservatively that the intrinsic (rest-frame) central surface brightness of our galactic disks is independent of redshift and similar to that most commonly seen among normal low redshift disks (μ_I = 19.8 mag arcsec^{-2} or 1.5×10^{-17} erg cm^{-2} s^{-1} Å^{-1} arcsec^{-2}). We also assume that the typical exponential scale length is 4 kpc. Using ellipse-fitting surface photometry, with 6 radial bins extending out to 3.5 scale lengths, and requiring a signal-to-noise ratio of 3 in the outermost bin, we would need an integration time of ~ 30 min at J for the z = 0.5 galaxies and 3.5 hr at H for the z = 1 galaxies.

For disks of normal rest-frame surface brightness, the observed surface brightness at z = 1.7 is too faint for us to do this kind of photometry in the K band. However, if the rest frame surface brightness is one magnitude brighter than the value adopted above, K band surface photometry becomes possible; an integration time of 3.5 hr is needed to achieve a signal-to-noise ratio of 3 at 3.4 scale lengths. We note that (i) many low redshift galaxies do have central surface brightnesses that are brighter than the standard value adopted in the previous paragraph; (ii) the intrinsic surface brightness of disks at z = 1.7 may well be higher than at z = 0, depending on their star formation history.

26.13.3 Guide Star Availability

This project can be done in any high latitude fields so galaxies will be selected based on proximity to suitable guide stars.

26.13.4 Special Requirements

Uniformity of the PSF over the GSAOI field is very desirable for deriving the surface brightness profiles.

26.14 Color Gradients in High Redshift Field Galaxies

26.14.1 Science Goal

The observational study of high redshift field galaxies is one of the major thrusts of current research. The goals are twofold:

- To take snapshots of the galaxy population at different cosmic epochs, and understand physically what we are seeing. For example, what are the fuzzy objects at z = 3 and why are they so blue?

- To tie these different snapshots together into a coherent picture of the history and evolution of the Universe. For example, will those fuzzy objects at z = 3 turn into a galaxy like our own?

Specific questions include:
- When did bulges form?
- Why are galaxy disks so much larger than predicted by CDM?
- How important are mergers?
- How and when were metallicity gradients established?

These goals are discussed in detail in the MCAO Science Case (RPT-AO-G0107). GSAOI can address them statistically using high spatial resolution imaging of a large sample of galaxies at a range of redshifts. The bulge and disk luminosities and colors will be measured separately for each galaxy. The multivariate distribution function of these properties, as a function of redshift, will then be compared with the output of *n*-body and semi-analytic simulations to place limits on the formation and evolution physics.

The galaxy sample will need to be large (several hundred galaxies) to get reasonable statistics as a function of redshift since galaxies are diverse in their properties. The study must reach redshifts of $z > 0.5$ to probe sufficiently large look-back times to sample evolutionary effects.

A combination of high spatial resolution imaging and sensitive detection at near-infrared wavelengths is required to address the science goals.

Resolution: At redshifts above one, 1″ corresponds to ~ 8 proper kpc, fairly independent of redshift. Thus significantly sub-arcsec resolution is needed to resolve most galaxies. In particular, unless the resolution is substantially better than 0.1″, it is not possible to decompose galaxies into their disk and bulge components and measure their separate properties.

Near-infrared imaging: WFPC3 and ACS on HST will provide deep, high-resolution optical imaging of high redshift field galaxies. Near-infrared imaging with comparable resolution will be needed, for the following reasons:

- Short-lived O and B stars dominate the flux of most galaxies below rest-frame 400 nm. The ultra-violet flux is thus a measure of some combination of the instantaneous star formation rate and the dust obscuration. It tells us little or nothing about the older stellar population, metallicity, age, mass, etc. At redshifts above 1.5, observed-frame near-infrared imaging is thus needed to see beyond rest-frame 400 nm.
- Tying together observations at different redshifts requires observations at the same rest-frame wavelengths. *JHK* imaging allows us to observe galaxies in the rest-frame *B* band out to $z = 4$.
- Imaging at near-infrared wavelengths give us a view of galaxy morphology less affected by dust obscuration.

We have simulated the appearance of high redshift galaxies with GSAOI. Local galaxies were shifted to high redshifts, convolved with a MCAO PSF, and noise added. For a total (atmosphere, telescope, AO, imager, and detector) throughput of 25%, we should be able to perform accurate bulge-disk deconvolutions down to $K \sim 21.3$ mag, provided that the PSF is reasonably well known. At this limit, there will be around 30 galaxies in an 80″×80″ field, with a median redshift of $z \sim 1.2$. A sample of ~ 1000 galaxies will be required to get reasonable statistics across the whole range of morphologies and redshifts. Imaging each galaxy at *J* and *Ks* will require around ten nights observing.

If we can reach $K = 21$ mag, MCAO will have a multiplex advantage of around ten over conventional AO. In addition, the relative uniformity of the PSF across the GSAOI field will be very important in performing accurate bulge-disk decompositions, as documented in the MCAO Science Case. Thus large surveys of field galaxies will not be possible without MCAO.

NICMOS camera 3 has pixels that are too large for reliable bulge-disk decomposition. Cameras 2 and 1 have more suitable pixel sizes. Simulations of their performance relative to MCAO show that they do well in the central regions of galaxies but the high dark current and read noise badly affect the data a few tenths of an arcsec from the galaxy center. Our simulations suggest that MCAO will get suitable data for sources about 1 mag deeper than NIC2 in the *H* band. In addition, the fields-of-view of the NIC1 and NIC2 cameras (11″ and 19″, respectively) are too small to get more than one galaxy per pointing.

26.14.2 Sensitivity Limit

To get a useful multiplex advantage over conventional AO, we need to reach $K = 20$ mag or better, with exposure times of order one hour, and sufficient signal-to-noise ratio to measure color gradients and do a disk-bulge deconvolution. Our simulations suggest that this is achievable with a total throughput (including atmosphere, telescope, AO, instrument and detector) of 25%. GSAOI is expected to exceed this requirement.

26.14.3 Guide Star Availability

This project can be carried out in any part of the high galactic latitude sky. There is no particular advantage in doing contiguous regions. Targets can thus be chosen based on the availability of suitable guide stars.

26.14.4 Special Requirements

Uniformity of the PSF across the field is important for the galaxy decomposition.

26.15 Exploring Dark Energy Via High Redshift Supernovae

26.15.1 Science Goal

Type Ia supernovae have emerged as one of the sharpest tools in the astrophysicist's shed for measuring extragalactic distances, with a precision of ~ 6%. These exploding stars have shown, through observations made by the High-Z SN Search Team and the Supernova Cosmology Project that the Universe is accelerating in its expansion, a result that indicates the cosmos must be filled with some previously unknown form of dark energy. By studying Type Ia supernovae with GSAOI we can accurately trace the cosmic expansion to $z \sim 2$, learning key physical properties of the dark energy.

Different types of dark energy affect the rate at which the Universe expands depending on their effective equation of state. For example, the cosmological constant has an equation of state, $w \equiv \rho/p = -1$, where as quintessence – a scalar field – has $w > -1$. Each variant of dark energy has it own evolving equation of state that produces a signature in the Hubble diagram of the SNe Ia. With current instrumentation, we can find and follow SNe Ia to $z = 1.1$. To move beyond this redshift, we need an instrument with near-infrared sensitivity such as GSAOI.

Complementary optical spectral observations of the host galaxy are useful to accurately measure the redshift of the SN.

26.15.2 Sensitivity Limit

Table 14 lists the brightness at maximum light of a SN Ia as a function of redshift assuming a Lambda Cosmology ($\Omega_\Lambda = 0.7$, $\Omega_M = 0.3$). The integration time needed to adequately detect it with GSAOI is also tabulated. It is apparent that SNe can be measured in the *H* band to $z > 2$ using GSAOI.

To achieve an accurate (~ 0.2 mag) distance measurement, each SN must be observed in two bands at maximum light with a total signal-to-noise ratio of all observations combined > 20. In addition, they should be followed for > 15 days in the rest frame at approximately five epochs with a signal-to-noise ratio > 5, at which point they will be ~ 0.7 mag fainter than at maximum light. A sample of > 10 objects is required to adequately constrain the SN Ia Hubble diagram at $z > 1.1$. In total, this program will require approximately 40 nights of observing time.

Table 14: Predicted SN Ia Magnitudes

Redshift	SN Ia Brightness				GSAOI Imaging Time (hrs)				Total Integration Time per SN
	Z	*J*	*H*	*K*	*Z*	*J*	*H*	*K*	(hrs)
1.2	23.8	23.6	23.6		0.2	1.4	1.4		14.5
1.3	24.2	23.8	23.7		0.3	2.1	1.7		19.5
1.4	24.5	23.9	23.7		0.6	2.5	1.7		22.0
1.5		24.1	23.7	23.8		3.6	1.7	3.6	28.7
1.6		24.3	23.8	23.9		5.2	2.1	4.4	30.0
1.7		24.5	23.9	24.1		7.6	2.5	6.3	40.3
1.8		24.6	23.9	24.2		9.1	2.5	7.6	45.4
1.9		24.8	24.1	24.2		13.2	3.6	7.6	52.1
2.0		24.9	24.2	24.2		15.8	4.4	7.6	56.5

26.15.3 Guide Star Availability

Supernovae can be discovered either using HST+WFPC3/ACS in pre-selected locations that have guide stars. Recent work with HST has demonstrated that two images, separated by 1 month in the rest frame will yield 1 SN Ia per 50 square arcminutes to $z < 2$. A HST program with ACS can survey to $Z = 26$ mag in 3 orbits and therefore uncover 1 SN Ia to $z < 2$ per 15 orbits.

Alternatively, GSAOI could be used to search around pre-selected guide stars for very distant SNe Ia at $z \sim 2$ in the *H* band using its full 85″×85″ field-of-view; a perfect PSF is not necessary for SN discovery. The rate of discovery in this mode will be ~ 1 SN per ~ 40 hr of integration time. This could be achieved through utilizing observations from other programs as appropriate.

26.15.4 Special Requirements

A uniform PSF across the GSAOI field is required to accurately measure the SN photometry as it rises and falls in its brightness. The observations need broadband filters that are matched to their optical rest frame equivalent. For example, for a SN at $z = 1.9$, *H* band matches rest frame *V* band.

27 Setup and Calibration Requirements

27.1 Daytime GSAOI Setup and Calibration

Most GSAOI programs use a standard setup and require a basic set of calibration observations to be obtained during the afternoon prior to observing. These standard setup and calibration observations are described here. The MCAO startup and calibration is part of this setup, so those procedures for this that are described in the MCAO Operational Concept Definition Document are repeated here where appropriate. The various MCAO subsystems are the Adaptive Optics Module (AOM), Diagnostic Wave Front Sensor (DWFS), Laser System (LS), Beam Transfer Optics (BTO), Laser Launch Telescope (LLT), MCAO Control System (MCAO-CS), and Safe Aircraft Localization and Satellite Acquisition (SALSA) system. The AOM consists of the first Off-Axis Parabola (OAP-1), Deformable Mirrors DM2, DM1, and DM0, the Tip-Tilt Mirror (TTM), the Beam Splitter (BS1), the Atmospheric Dispersion Corrector (ADC), and the second Off-Axis Parabola (OAP-2).

27.1.1 GSAOI Bias and Dark Frames

Imager bias frames are obtained by selecting the "Blocked" positions in the GSAOI focal plane wheel, lower filter wheel, and utility wheel, and recording a sequence of minimum duration (5 s) exposures.

Typically 10-15 such exposures each consisting of 12 coadds each (1 min of data) will be obtained so that cosmic ray events can be removed by median filtering during data reduction.

- Close the GSAOI environmental cover.
- Set the GSAOI focal plane wheel to the "Blocked" position.
- Set the GSAOI lower filter wheel to the "Blocked" position.
- Set the GSAOI utility wheel to the "Blocked" position.
- Set the GSAOI imager detector readout method to Fowler Sampling and load the appropriate timing file.
- Set the View Mode integration time to 5 s (the minimum), number of Fowler samples to 1, and number of coadds to 1.
- Set the Observe Mode integration time to 5 s, number of Fowler samples to 1, and number of coadds to 12.
- Record an Observe Mode bias frame.
- The bias frame is automatically displayed in the Observe Mode Quick Look Display.
- Load the bias frame as the View Mode Quick Look Display subtraction file; the subtracted frame is displayed.
- Load the bias frame as the Observe Mode Quick Look Display subtraction file; the subtracted frame is displayed.
- Set the Observe Mode repeats to 14.
- Record an Observe Mode sequence.
- The bias-subtracted bias frames are automatically displayed in the Observe Mode Quick Look Display.

Dark frames can be obtained by repeating the above sequence for each exposure time used for science observations.

- Close the GSAOI environmental cover.
- Set the GSAOI focal plane wheel to the "Blocked" position.
- Set the GSAOI lower filter wheel to the "Blocked" position.
- Set the GSAOI utility wheel to the "Blocked" position.
- Set the GSAOI imager detector readout method to Fowler Sampling and load the appropriate timing file.
- Set the View Mode integration time to 5 s, number of Fowler samples to 1, and number of coadds to 1.
- Load the previous bias frame as the View Mode Quick Look Display subtraction file; the subtracted frame is displayed.
- Set the Observe Mode integration time to an appropriate value, say 60 s, number of Fowler samples to 3, and number of coadds to 1.
- Load the previous bias frame as the Observe Mode Quick Look Display subtraction file; the subtracted frame is displayed.
- Set the Observe Mode repeats to 5.
- Record an Observe Mode sequence.
- The bias-subtracted dark frames are automatically displayed in the Observe Mode Quick Look Display.

OIWFS bias frames are obtained by selecting the "Blocked" positions in the OIWFS aperture wheel and filter wheel, and recording a sequence of minimum duration exposures. The OIWFS is controlled by the A&G IOC. The procedure for recording OIWFS bias frames is unknown to us, but the configuration is as follows:

- Close the GSAOI environmental cover.
- Set the OIWFS aperture wheel to the "Blocked" position.
- Set the OIWFS filter wheel to the "Blocked" position.
- Select an appropriate minimum exposure time.

- Exposure the OIWFS detector.
- Open the GSAOI environmental cover.
- Set the OIWFS aperture wheel to the 20″ position.
- Set the OIWFS filter wheel to the *K* position.

27.1.2 MCAO AOM Calibrations

- Measure the bias and read noise levels in each wave front sensor (WFS) CCD.
- Insert the LGS reference source flip mirrors, turn on the reference sources, and center them in the fields-of-view of the higher-order WFSs. Measure and store the reference gradients sensed by each WFS for a known flat wave front at the WFS. Measure WFS gains and tilt transfer functions by scanning the reference sources.
- Set the figure of each deformable mirror using previously calibrated actuator commands, cycling the mirror if necessary to avoid hysteresis effects (these commands do not necessarily flatten the mirrors, but should produce a corrected wave front at the science instrument). Center the TTM. Insert the simulated NGS sources. Adjust the TTM and focus on DM1 to null the tip-tilt/focus measurements from the OIWFS. Insert the DWFS, and measure wave front quality across the field.
- Insert and turn on the simulated LGS sources. Measure and store the gradients sensed by each LGS WFS for the calibrated DM actuator commands. Repeat at several LGS ranges.
- Close the tip-tilt and higher-order AO control loops to verify stability.
- Open the tip-tilt and higher-order AO control loops.
- Turn off the LGS reference sources and retract the LGS reference source flip mirrors.
- Turn off and retract the simulated NGS sources.
- Retract the DWFS.

- Insert the simulated NGS sources.
- Open the GSAOI environmental cover.
- Set the GSAOI focal plane wheel to the "Clear" position.
- Set the GSAOI upper filter wheel to the *H* filter.
- Set the GSAOI lower filter wheel to the "Clear" position.
- Set the GSAOI utility wheel to the convex defocus lens.
- Record an Observe Mode image.
- Set the GSAOI utility wheel to the concave defocus lens.
- Record an Observe Mode image.
- Process the two images with the Roddier program.
- Enter Zernike coefficients to deform the MCAO DM0 to correct non-common path wave front errors due to the GSAOI imager.

27.1.3 GSAOI Flat Field Frames

There are three ways in which GSAOI imager flat field frames could be recorded; exposures of the “Black Body” lamp in the Gemini Calibration Unit (GCAL), exposures of the illuminated dome interior, and exposures of the sky. The first of these (i.e., GCAL exposures) suffer from the fact that the GCAL beam is introduced via the ISS science fold mirror and so does not include the effects of the MCAO optics. Lamp-on minus lamp-off exposures of the dome interior are the best way of recording the response of the telescope/MCAO/GSAOI system to transmitted light. The large number of warm optical elements in MCAO means that their thermal emission is likely to be significant in single exposures. Sky exposures offer the advantages of being recorded through the full optical system and at the same time as the science observation. However, the thermal emission component from the warm optics cannot be removed. This unknown offset leads to an erroneous determination of the relative pixel sensitivities.

The true instrumental response will be measured using star exposure grids during commissioning. This will be used to define the preferred flat fielding procedure. Experience in flat fielding AO images will also be obtained with ALTAIR and NIRI. For now, we describe a procedure for recording lamp-on/lamp-off exposures of the dome interior. The minimum exposure time of 5 s will typically be used with typically 12 coadds for a total integration time of 60 s.

- Deploy the AO fold and science fold mirrors, and command the MCAO deformable mirrors to their nominal figures.
- Open the MCAO shutters.

- Open the GSAOI environmental cover.
- Set the GSAOI focal plane wheel to the "Clear" position.
- Set the GSAOI upper filter wheel to the *Ks* filter position.
- Set the GSAOI lower filter wheel to the "Clear" position.
- Set the GSAOI utility wheel to the "Clear" position.
- Set the OIWFS aperture wheel to the 0.52″ circular aperture position.
- Set the OIWFS filter wheel to the *Ks* position.
- Set the OIWFS steerable mirror to a nominal position.
- Set the GSAOI imager detector readout method to Fowler Sampling and load the appropriate timing file.
- Set the View Mode integration time to 5 s (the minimum), number of Fowler samples to 1, and number of coadds to 1.
- Load the previous bias frame as the View Mode Quick Look Display subtraction file; the subtracted frame is displayed.
- Set the Observe Mode integration time to 5 s, number of Fowler samples to 1, and number of coadds to 12.
- Set the Observe Mode repeats to 5.
- Load the previous bias frame as the Observe Mode Quick Look Display subtraction file; the subtracted frame is displayed.

- Slew the telescope to point to an appropriate place on the dome interior.
- Switch dome lights OFF.
- Record an Observe Mode sequence.
- The bias-subtracted lamp-OFF frames are automatically displayed in the Observe Mode Quick Look Display.
- Record similar OIWFS exposures, if required.
- Load a lamp-OFF frame as the Observe Mode Quick Look Display subtraction file; the subtracted frame is displayed.
- Switch dome lights ON.
- Record an Observe Mode sequence.
- The lamp-OFF-subtracted lamp-ON frames are automatically displayed in the Observe Mode Quick Look Display.
- Obtain similar OIWFS exposures, if required.
- Repeat for other imager filters, and OIWFS filters if required.

27.1.4 MCAO Laser Startup

The startup procedure for the Laser System is **TBD**.

27.2 Nighttime GSAOI Setup and Calibration

27.2.1 Twilight GSAOI Flat Field Frames

The three methods of recording flat field frames were listed in §27.1.3. It is desirable to obtain high signal-to-noise ratio sky flats to complement dome flats. Twilight sky flats can be recorded with the same setup used in §27.1.3.

27.2.2 Nighttime MCAO Calibration

The primary purpose of the nighttime MCAO calibration sequence is to establish a common bore sight reference between the BTO and the OIWFS. AO loop performance may also be characterized on a known reference field if desired. This operation should not take more than 5 minutes once the telescope is on the object, and eventually should be fully automated as an observing script. The sequence starts with the laser running and all laser shutters closed.

- Open the laser shutter at the LS/BTO interface. Close each beam pointing and centering loop through the BTO in sequence, using images from the pre-alignment cameras as necessary. Verify beam pointing, centering, quality, and power for each beam using the diagnostic sensors. Open the pointing and centering loops, and close the laser shutter at the LS/BTO interface. These operations may be performed at the end of the day.
- Open the LLT dust cover.
- Slew the telescope to a reference star. The active optics PWFS1 guide star is acquired and the telescope's tracking and active optics are enabled. The SALSA and internal safety systems are operating.
- Initiate MCAO-CS control of the BTO centering mirror (CM), pointing mirror (PM), and de-rotation K-mirror (KM). These elements are positioned using a lookup table with the telescope pointing angle as input.
- Deploy the AO fold and science fold mirrors, and command the deformable mirrors to their nominal figures.
- Acquire the reference star with the OIWFS. Switch telescope tip-tilt control from PWFS1 to the OIWFS, and track using the TTM and M2.
- The reference star is now imaged or sensed by the BTO beam near- and far- field diagnostic sensors. Adjust PM and CM so that the star images are correctly centered. Move the BTO corner cube shutter to the closed position.
- Open the laser shutter at the LS/BTO interface. Close each beam centering and pointing loop through the BTO in sequence. Verify beam pointing, centering, quality, and power for each beam and polarization at the diagnostic sensor.
- Zoom the LGS WFS to focus at the nominal range for the current elevation angle.
- Open the laser beam dump shutter in the BTO to propagate the laser to the sky, and verify that signal is detected from each guide star at the LGS WFS.
- Shutter the laser, open the OIWFS tracking loop, and proceed to the first observation.

27.2.3 Nighttime GSAOI Flux Calibration

GSAOI flux calibration will be achieved in the usual way by recording images of standard star fields. The procedure for acquiring a science field is described in §27.3.

27.2.4 Nighttime GSAOI Geometrical Distortion Calibration

Proper mosaicing of GSAOI imager frames will require accurate registration of both the four individual GSAOI imager detector frames and any dithered mosaic sets. The correct registration of the four imager detector frames can be achieved by recording exposures of suitable astrometric reference fields.

27.3 MCAO Science Field Acquisition

Acquisition of the science field with MCAO is a routine setup procedure that will be described only once here. The science field is observed with the acquisition camera to determine the precise locations and magnitudes of the guide stars for the MCAO NGS WFS and the OIWFS. This information is used to compute the MCAO control algorithm and position the NGS WFS probe arms.

The OIWFS tip-tilt source can either be the location of the OIWFS guide star or the location of a guide star in any one of the four imager On-Detector Guide Windows. The square guide window is specified by selecting the window size (8×8, 12×12, 16×16, 32×32) and defining its center. This can be determined either from the acquisition camera frame or directly from an imager detector exposure of the science field. In the following, we assume that the OIWFS guide star supplies the OIWFS tip-tilt reference.

Target acquisition should take a maximum of 2 minutes, and should eventually be automated as part of the observing script.

The AO fold and science fold mirrors are already deployed. The GSAOI environmental cover is open, and the all GSAOI mechanisms are in their observing positions.

- Slew the telescope to the science object coordinate.
- The instrument rotator position angle is set during the slew, and subsequently maintained at this angle.
- Set PWFS1, the MCAO NGS WFS, and the OIWFS to the absolute positions of their respective guide stars.
- Select PWFS1 as the primary tracking reference.
- PWFS1 acquires its guide star and begins active correction.
- Shutter the laser at the LS/BTO interface.
- The BTO pointing, centering, orientation, and polarization control elements are set to their nominal (calibrated) values for the current zenith angle.
- The SALSA and internal laser safety systems are operating.
- Command the deformable mirrors to their nominal figures.
- Acquire the OIWFS guide star, and switch to tracking using the OIWFS, the MCAO TTM, and M2.
- Acquire the MCAO NGS WFS guide stars.
- Adjust the NGS WFS locations to center the guide stars on each sensor. This compensates for flexure and any residual uncertainty in the positions of the stars. This will require several seconds to one minute to average out turbulence effects.
- Zoom the LGS WFS to focus at the nominal range of the sodium layer for this elevation angle.
- Open the laser shutter at the LS/BTO interface. Close each beam centering and pointing loop through the BTO in sequence. Verify beam pointing, centering, quality, and power for each beam and polarization at the diagnostic sensor, and also the orientation of the LGS constellation. Verify that signal is detected on the LGS WFS.
- Close the high bandwidth BTO tip-tilt loops to center the LGS spots on the LGS WFS.
- Switch to tracking using the MCAO NGS WFS. Close the DM control loop using the MCAO WFSs.
- Close the supervisory control loops for LGS WFS focus and NGS WFS bore sight using the OIWFS tip-tilt and focus measurements as input.
- Perform the science instrument integration. AO performance can be monitored using the output displayed by several of the supervisory loops (estimated PSFs, open- and closed-loop turbulence statistics, LGS signal level,…).
- Open the DM control loops and return to tracking using only the OIWFS. Open the BTO control loops, and shutter the laser at the LS/BTO interface. Open the OIWFS tracking loop and proceed to the next observation.

27.4 Nightly Shutdown

27.4.1 GSAOI Shutdown

GSAOI should be left in a safe configuration at the end of observing.

- Close the GSAOI environmental cover.
- Set the GSAOI focal plane wheel to the "Blocked" position.
- Set the GSAOI lower filter wheel to the "Blocked" position.
- Set the GSAOI utility wheel to the "Blocked" position.
- Set the OIWFS aperture wheel to the "Blocked" position.
- Set the OIWFS filter wheel to the "Blocked" position.

27.4.2 MCAO AOM Shutdown

- Open the DM control loops. Open the BTO control loops, and shutter the laser at the LS/BTO interface. Open the OIWFS tracking loop.
- Close the MCAO shutters.

27.4.3 MCAO Laser Shutdown

The shutdown of the LS should be automated and transparent to the end user.

28 Observing Scenarios

A typical actual observing scenario is described in this section in order to elaborate on the science descriptions in §26 and to identify and illuminate the requirements GSAOI places on other parts of the Gemini telescope system.

28.1 Evolution of Dwarf Irregular Versus Elliptical Galaxies

28.1.1 Scientific Background

Small galaxies are classified as one of two types; dwarf ellipticals and dwarf irregulars. Not only their appearance, but also some of their fundamental properties (e.g., gas content, star formation history, *M*/*L* ratios) are dramatically different. Does the environment play a role in governing the star formation history of dwarf elliptical galaxies? Is there an evolutionary link between dwarf ellipticals and dwarf irregulars?

The Milky Way companion dwarf ellipticals (called dwarf spheroidals for historical reasons) show a variety of star formation histories. These vary from "basically old" (ages greater than about 10 Gyr) to "dominated by intermediate-age" (from 2 to about 10 Gyr). The star formation histories also vary in their details. In some cases, they show obvious "episodes" of star formation separated by quiescent periods, while in other cases it appears that continuous star formation has occurred. At present there is little understanding of this diversity. However, there are a number of distinctive features of the Local Group dwarf galaxies as follows:

- One important clue may be a "correlation" with the distance from the Milky Way: the dwarf ellipticals with larger intermediate-age fractions are generally at larger distances. This hints at the influence of parent galaxy/environment. Possible factors include tidal influence, Galactic winds, ram pressure stripping, high X-ray or UV flux; in short, anything that might affect gas content evolution or conditions for early star formation.
- In the M31 system, at least for the lower luminosity dwarf ellipticals (i.e., not NGC 147/185/205), the situation is strikingly different. The intermediate-age populations are less obvious compared to the Milky Way's companions; e.g., there is no system near M31 known to have a population younger than approximately 5 Gyr, whereas there are at least 3 Galactic companions with ~ 1-3 Gyr populations. Also, the system with the youngest intermediate-age population (~ 6-8 Gyr) is the most distant from M31.
- There are low-luminosity galaxies, mostly dwarf irregulars or transition objects, in the Local Group that are not directly associated with the Galaxy or M31 (e.g., WLM, LGS3, and Phoenix). All contain young stars and varying amounts of H I. This again hints at some effect from the environment, but the fact that the isolated dE Tucana contains only old stars indicates that this cannot be the complete story.
- Two dwarf ellipticals in the M81 group, which is a much more compact environment than the Local Group, have been studied with HST. Both systems show strong upper-AGB populations; i.e., stars more luminous than those of the red giant branch tip. This by itself is an indication of a significant intermediate-age population. The intermediate-age populations in Galactic dwarf ellipticals were actually first recognized via identification of the upper-AGB (carbon) stars.

28.1.2 Proposed Observations

The plan is to measure *J*, *K* magnitudes for the upper-AGB stars in dwarf ellipticals beyond the Local Group. This should give bolometric magnitudes that in turn yield age estimates (the luminosity at the AGB-tip is higher for younger systems). Near-infrared measurements are an advantage for these studies since variability (all upper-AGB stars are variable at some level) is much less in the near-infrared than in the optical. The sensitivity limit of NIRI (and FLAMINGOS-I/II) allows surveying dwarf ellipticals just beyond the Local Group with long integration times per galaxy. However, to go beyond this requires the fainter limiting magnitudes that only MCAO/GSAOI can provide. In the southern hemisphere, the dwarf ellipticals in the Centaurus group and in the most distant part of the Sculptor Group are prime targets. Going further in distance, there is the loose association of galaxies that contain the Circinus galaxy at a distance of 6-7 Mpc, the Leo I Group, and perhaps the Virgo and Fornax galaxy clusters.

We focus on *J* and *Ks* observations of the Centaurus A group dwarf elliptical ESO219-010 (Jerjen, Freeman, & Binggeli 2000).

28.1.3 Planning the Observation

Celestial coordinates for ESO219-010 are obtained from Jerjen et al. The Perl script *gs_search.pl* is used to plan the observation. This retrieves and displays DSS, 2MASS, WFPC2, and NICMOS images of the field. In the case of ESO219-010, only a red DSS-2 image is available (Figure 19). The object is offset from the field center to avoid the gaps between each detector. The object will be positioned within each imager detector quadrant in order to maximize the on-source integration time and to measure the sky flux. The coordinates of the four field centers are listed in Table 15. The dither spacing must be at least as large as the PSF wings of the bright stars within the science field. The low Galactic latitude of ESO219-010 makes MCAO NGSs abundant. We choose U0375_16981750 (*R* = 15.0 mag), U0375_16981181 (*R* = 17.1 mag), and U0375_16978938 (*R* = 17.6 mag). These three stars are distributed in an appropriate triangle about ESO219-010. Different OIWFS guide stars must be selected for the four field centers. These are listed in Table 15 and are marked by a small yellow circle in each frame of Figure 19. They have *R* magnitudes in the range 16.1 to 16.7: their near-infrared magnitudes are unknown.

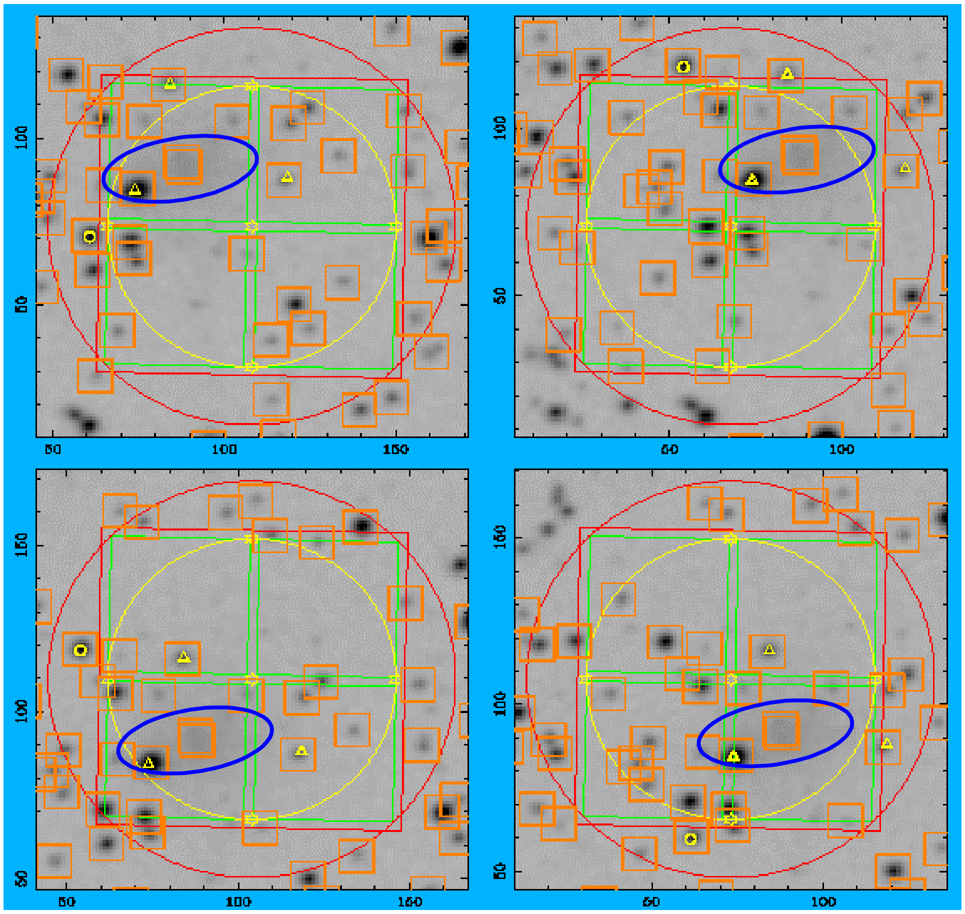

Figure 19: Plan for ESO219-010 observation made with *gs_search.pl*. The DSS-2 image of ESO219-010 is shown as a grayscale. The blue ellipse indicates the object. The fields of the four GSAOI imager detectors are shown in green. A red circle indicates the 2' diameter MCAO field. A red square marks the outline of the GSAOI first fold mirror. The LGS constellation is shown in yellow. The actual LGSs will appear somewhere on the yellow circle depending on the time of observation. US Naval Observatory catalog stars are enclosed in orange boxes. The three NGS selected are marked by yellow triangles. A small yellow circle marks the OIWFS guide star.

Table 15: Field Centers for ESO219-010 Observation

Quadrant	RA (J2000)	Dec	OIWFS GS	*R* mag
1	12:56:07.72	-50:08:53.9	U0375_16982637	16.1
2	12:56:11.95	-50:08:57.5	U0375_16983137	16.4
3	12:56:08.21	-50:08:17.3	U0375_16983137	16.4
4	12:56:11.46	-50:08:20.1	U0375_16982555	16.7

28.1.4 Daytime Calibrations

The standard daytime calibration procedure will be followed, including recording GSAOI imager bias and dark frames and dome flat field frames. These procedures are described in §27.1 above.

28.1.5 Nighttime Calibrations

Twilight sky flat field frames will be obtained as described in §27.2.1 above. An astrometric field will be measured to define the geometrical distortion calibrations for each imager detector and their relative offsets. This procedure is described in §27.2.4 above. Nearby flux standard star will be measured in both the *J* and *K* filters before and after the science exposures. This procedure is described in §27.2.3 above.

28.1.6 Setup Prior to Observation

The observation setup consists of the following actions:

- Open the GSAOI environmental cover.
- Set the GSAOI focal plane wheel to the "Clear" position.
- Set the GSAOI upper filter wheel to the "Clear" position.
- Set the GSAOI utility wheel to the "Clear" position.
- Set the GSAOI lower filter wheel to the "Blocked" position to avoid saturating the imager detector.
- Set the OIWFS aperture wheel to the 0.52″ circular aperture position.
- Set the OIWFS filter to the "Blocked" position to avoid saturating the OIWFS detector.
- Slew telescope to the first field center coordinate.
- The instrument rotator is set to 0° position angle on the sky during the slew, and subsequently maintained at this angle.
- The AO feed mirror and ISS science fold mirror are deployed.
- The MCAO shutters are open.
- Set PWFS1, the MCAO NGS WFSs, and OIWFS to the absolute positions of their respective guide stars.
- Set the GSAOI imager detector readout method to Fowler sampling and load the appropriate timing file.

When the telescope has settled:

- Set the GSAOI upper filter wheel to the *Ks* position.
- Set the GSAOI lower filter wheel to the "Clear" position.
- Set the OIWFS filter wheel to the *Ks* position.

Begin active and adaptive correction as described in §27.3 above.

- Set the View Mode integration time to 5 s, number of Fowler samples to 1, and number of coadds to 1.
- Set the Observe Mode integration time, number of Fowler samples, and number of coadds to the View Mode values.
- Load a previous bias frame as the Observe Mode Quick Look Display subtraction file; the subtracted frame is displayed.
- Offset the telescope to a sky position 2′ north.
- Wait for the telescope to settle.
- Record an Observe Mode exposure.
- The bias-subtracted frame is automatically displayed in the Observe Mode Quick Look Display.
- Load the sky frame as the View Mode Quick Look Display subtraction file; the subtracted frame is displayed.
- Offset the telescope back to the first field center coordinate.
- Wait for the telescope to settle.
- Resume active and adaptive correction.
- The sky-subtracted imager field is continuously updated in the View Mode Quick Look Display.

28.1.7 Science Observation Sequence

Record pre-observation bias frame:

- Set the Observe Mode integration time to 5 s (the minimum), number of Fowler samples to 1, and number of coadds to 12.
- Set the GSAOI lower filter wheel to the "Blocked" position.
- Record an Observe Mode bias frame.
- The bias-subtracted bias frame is automatically displayed in Observe Mode Quick Look Display.
- Load the bias frame as the Observe Mode Quick Look Display subtraction file; the subtracted frame is displayed.
- Set the GSAOI lower filter wheel to the "Clear" position.

Perform science observation sequence:

- Set the Observe Mode integration time to 60 s, number of Fowler samples to 8, and number of coadds to 1 for a 60 s integration.
- Record an Observe Mode exposure.
- The bias-subtracted frame is automatically displayed in the Observe Mode Quick Look Display.
- Load the object frame as the Observe Mode Quick Look Display subtraction file; the subtracted frame is displayed.
- Offset the telescope to the second field center coordinate.
- Wait for the telescope to settle.
- Resume active and adaptive correction.
- Record an Observe Mode exposure.
- The sky-subtracted frame is automatically displayed in the Observe Mode Quick Look Display.
- Offset the telescope to the third field center coordinate.
- Wait for the telescope to settle.
- Resume active and adaptive correction.
- Record an Observe Mode exposure.
- The sky-subtracted frame is automatically displayed in the Observe Mode Quick Look Display.
- Offset the telescope to the fourth field center coordinate.
- Wait for the telescope to settle.
- Resume active and adaptive correction.
- Record an Observe Mode exposure.
- The sky-subtracted frame is automatically displayed in the Observe Mode Quick Look Display.
- Repeat sequence on a 0.5″ dither grid as required.

Record post-observation bias frame:

- Set the Observe Mode integration time to 5 s (the minimum), number of Fowler samples to 1, and number of coadds to 12.
- Set the GSAOI lower filter wheel to the "Blocked" position.
- Load the pre-observation bias frame as the Observe Mode Quick Look Display subtraction file; the subtracted frame is displayed.
- Record an Observe Mode bias frame.
- The bias-subtracted bias frame is automatically displayed in Observe Mode Quick Look Display.
- Load the bias frame as the Observe Mode Quick Look Display subtraction file; the subtracted frame is displayed.

29 Summary of Scientific Requirements

The science programs discussed above lead to the following science requirements for GSAOI.

29.1 MCAO Compatibility

REQ-OCD-0001: GSAOI will accept the MCAO f/34 input beam with a pupil near the telescope secondary mirror.

29.2 Imager

REQ-OCD-0002: GSAOI will have an imager channel for science observations.

29.3 OIWFS

REQ-OCD-0003: GSAOI will have an OIWFS channel for monitoring tip-tilt motion due to flexure variations between MCAO and GSAOI, for monitoring focus changes due to variations in the height of the atmospheric sodium layer, and for performing fast tip-tilt and focus sensing when substituting for one of the MCAO NGS sensors.

29.4 Imager Wavelength Coverage

REQ-OCD-0004: The imager will operate in the wavelength range from 0.9-2.4 μm.

29.5 Imager Spatial Sampling

REQ-OCD-0005: The imager will have a scale of ~ 0.02″/pixel.

29.6 Imager Field-of-View

REQ-OCD-0006: The imager will have a field-of-view of > 80″×80″.

29.7 Imager Cold Stop

REQ-OCD-0007: The imager will include a fixed cold stop at an image of the MCAO exit pupil. The cold stop will be sized so as not to vignette the imager beam while reducing background radiation to the greatest extent possible.

29.8 Imager Pupil Viewer

REQ-OCD-0008: The imager will have a facility for viewing an image of the MCAO exit pupil.

29.9 Imager Non-Common Path Phase Errors

REQ-OCD-0009: The imager will be capable of measuring low-order wave front errors through the entire optical path to the imager detector with a spatial resolution of ~ 200 mm referenced to the telescope primary mirror.

29.10 Imager Filter Suite

REQ-OCD-0010: The imager will be able to interchange between any of the following filters:

No.	Filter	λ_c (μm)	$\Delta\lambda$ (μm)
1	*Z*	1.010	0.220
2	*J*	1.250	0.180
3	*H*	1.650	0.290
4	*Ks*	2.145	0.310
5	*K*	2.200	0.330
6	*J* continuum	1.207	0.018
7	*H* continuum	1.570	0.024
8	CH_4 (short)	1.580	0.095
9	CH_4 (long)	1.690	0.101
10	*Ks* continuum	2.090	0.031
11	*Kl* continuum	2.270	0.034
12	He I 1.0830 μm	1.083	0.016
13	H I Pγ	1.094	0.016
14	H I Pβ	1.282	0.019
15	[Fe II] 1.644 μm	1.644	0.025
16	H_2O	1.996	0.050
17	H_2 1-0 S(1)	2.122	0.032
18	H I Brγ	2.166	0.032
19	H_2 2-1 S(1)	2.248	0.034
20	CO 2-0 (bh)	2.294	0.034
21	CO 3-1 (bh)	2.323	0.035
26	Blocked	…	…

29.11 Imager Calibration

REQ-OCD-0011a: The imager focal plane wheel will contain one blocked position for recording bias frames.

REQ-OCD-0011b The imager filter wheel will contain one blocked position for recording bias frames.

REQ-OCD-0011c The imager utility wheel will contain one blocked position for recording bias frames.

29.12 Imager Pupil Viewer Resolution

REQ-OCD-0012 The imager pupil viewer will have a resolution of < 100 mm equivalent at the Gemini telescope primary mirror.

29.13 Imager Strehl Ratio

REQ-OCD-0013: The total wave front error introduced by the imager optical system will be < 65 nm RMS over the wavelength range 0.9–2.4 μm. This corresponds to a Strehl ratio of > 0.94 at a wavelength of 1.6 μm.

29.14 Imager Distortion

REQ-OCD-0014: The imager will cause a geometrical distortion at the detector of < 0.1%.

29.15 Imager System Throughput

REQ-OCD-0015: The imager will have a total system throughput over its required wavelength range of ≥ 25% including the telescope, imager optics, filter, and detector, but not including the throughput of the MCAO science path.

29.16 Imager Instrumental Background

REQ-OCD-0016: The imager will have an internal instrument background less than either the natural background from the observed science field or the dark current of the detector whichever is greater.

29.17 Imager Ghost Images

REQ-OCD-0017: Ghost images generated in the imager optics must be at a level below 10^{-5} of the parent image.

29.18 Imager Sensitivity

REQ-OCD-0018: The imager will be capable of detecting point sources with $K = 23.0$ mag in 3600 s with a signal-to-noise ratio of 10 through a 0.08″×0.08″ aperture.

29.19 Imager Pupil Viewer Sensitivity

REQ-OCD-0019: The imager pupil viewer will be capable of detecting the expected background emission in the K band with a signal-to-noise ratio of > 10 in a 1 min integration.

29.20 OIWFS Wavelength Coverage

REQ-OCD-0020: The OIWFS will operate in the wavelength range from 0.9-2.4 μm.

29.21 OIWFS Spatial Sampling

REQ-OCD-0021: The OIWFS will have a scale of ~ 0.065″/pixel.

29.22 OIWFS Field-of-View

REQ-OCD-0022: The OIWFS will have a circular field-of-view of 0.5″ in diameter when read out at 200 Hz and a facility for increasing the field diameter to > 5″×5″ for acquiring guide stars. Degraded image quality of the larger field-of-view is acceptable.

29.23 OIWFS Guide Star Patrol Field

REQ-OCD-0023: The OIWFS will have a patrol field for acquiring guide stars extending to the full 60″ radius of the available MCAO field.

29.24 OIWFS Vignetting

REQ-OCD-0024: The OIWFS beam pick-off will not vignette the imager field.

29.25 OIWFS Filter Suite

REQ-OCD-0025: The OIWFS will be able to interchange between any of the following filters to match its wavelength sensitivity to the band pass selected for the imager:

No.	Filter	λ_c (μm)	$\Delta\lambda$ (μm)
1	Clear	...	...
2	*Z*	1.010	0.220
3	*J*	1.250	0.180
4	*H*	1.650	0.290
5	*Ks*	2.145	0.310
6	*K*	2.200	0.330
7	*ZJ*	1.120	0.440
8	*HK*	1.935	0.860
9	Blocked	…	…
10	Spare	…	…

29.26 Shack-Hartmann Prism

REQ-OCD-0026: The OIWFS will use a fixed four-facet Shack-Hartmann prism operated in collimated light to sense wave front focus variations in two perpendicular directions.

29.27 OIWFS Calibration

REQ-OCD-0027: The OIWFS filter wheel will contain one blocked position for recording bias frames.

29.28 OIWFS Strehl Ratio

REQ-OCD-0028: The total wave front error introduced by the OIWFS optical system will be < 120 nm RMS over the wavelength range 0.9–2.4 μm. This corresponds to a Strehl ratio of > 0.81 at a wavelength of 1.6 μm.

29.29 OIWFS System Throughput

REQ-OCD-0029: The OIWFS will have a total system throughput over its required wavelength range of ≥ 15% including the telescope, OIWFS optics, filter, and detector, but not including the throughput of the MCAO science path.

29.30 OIWFS Sensitivity

REQ-OCD-0030: The OIWFS should be able to determine the centroid of a star image with $K < 18$ mag to an RMS accuracy of 1/20 of the image full width at half maximum in a 30 s exposure and sense tip-tilt and focus corrections in 0.01 s exposures on stars with $K < 10$ mag.

29.31 Mechanism Set Time

REQ-OCD-0031: Individual GSAOI mechanisms should be set within 30 s.

29.32 Mechanism Configuration Time

REQ-OCD-0032: A complete reconfiguration of the GSAOI instrument should be achieved in < 1 min.

29.33 Imager Focal Plane Wheel

REQ-OCD-0033: The imager will have a focal plane wheel for interchanging the following elements:

No.	Focal Plane Wheel Contents
1	Blocked
2	Clear
3	Focus mask
4	Spare

29.34 Imager Utility Wheel

REQ-OCD-0034: The imager will have a utility wheel for interchanging the following elements:

No.	Utility Wheel Contents
1	Clear
2	Pupil viewer
3	Convex defocus lens
4	Concave defocus lens
5	Blocked

29.35 OIWFS Aperture Wheel

REQ-OCD-0035: The OIWFS will have an aperture wheel for interchanging the following elements:

No.	OIWFS Aperture Wheel Content
1	Clear
2	0.52″ diameter circular aperture
3	2.6″ offset square aperture
4	5.2″ offset square aperture
5	Spare
6	Blocked

29.36 OIWFS Steerable Mirror Setting Accuracy

REQ-OCD-0036: The OIWFS steerable mirror will set to an accuracy equivalent to $< \pm 0.02''$ on the sky.

29.37 OIWFS Steerable Mirror Setting Repeatability

REQ-OCD-0037: The OIWFS steerable mirror will set with repeatability equivalent to $< \pm 0.01''$ on the sky.

29.38 Imager On-Detector Guide Window

REQ-OCD-0038: The imager will have a facility for defining and processing data from a rectangular guide window on the imager detector that will be used for tip-tilt sensing.

29.39 Imager Detector Read Noise

REQ-OCD-0039: The imager detector will employ read noise reduction techniques, such as Fowler sampling, to achieve an effective read noise of < 10 e.

29.40 Imager Detector Dark Current

REQ-OCD-0040: The imager detector will have a dark current < 0.1 e s^{-1} pix^{-1} with a goal of < 0.01 e s^{-1} pix^{-1}.

29.41 Imager Detector Guider Performance

REQ-OCD-0041: The imager detector guider should be able to determine the centroid of a star with $K < 19$ mag to an RMS accuracy of 1/20 of the image full width at half maximum in a 30 s exposure and sense tip-tilt corrections in 0.01 s exposures on stars with $K < 11$ mag.

29.42 Downtime

REQ-OCD-0042: GSAOI will have a downtime of < 2% scheduled time on the telescope and where possible, component failure shall result in gradual performance degradation.

29.43 Observing Modes

REQ-OCD-0043: GSAOI will support a View mode for acquiring temporary imaging data and an Observe mode for acquiring archived imaging data.

29.44 Fast Shutter

REQ-OCD-0044: GSAOI will contain a fast shutter for pausing imager exposures.

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