GIRMOS: Gemini Infrared Multi-Object Spectrograph

Preliminary Design Document

Document Number: GIRMOS.SYS.DD.0009.B

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Revisions

Revision	**Change Description**	**Date**
A	Initial Draft	2022-03-22
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1 Introduction

1.1 Purpose

This document provides an overview of the GIRMOS design, its subsystems, analyses at instrument level, and integration and test procedures.

1.2 Applicable Documents

Applicable Documents are those documents containing information that is considered binding in the context of this document. Unless otherwise specified, the latest version of the Applicable Document shall be used. In case of conflict between an Applicable Document and this document, this document shall take precedent.

AD	Document #	Title
[AD-01]	GIRMOS.MGMT.PLN.0002	Project Management Plan (PMP)
[AD-02]	GIRMOS.SYS.SPE.0021.B	Mass and Balance Budget Worksheet
[AD-03]		
[AD-04]		
[AD-05]		
[AD-06]		
[AD-07]		
[AD-08]		
[AD-09]		

1.3 Reference Documents

Reference documents are those documents that are included for information purposes only. They may provide additional background or context, but are non-binding in the context of this document.

RD	Document #	Title
[RD-01]	GIRMOS.OSEL.DD.0008	OSEL Preliminary Design Description Document
[RD-02]	ANSI/AIAA S-120A-2015	Mass Properties Control for Space Systems
[RD-03]	GIRMOS.MGMT.LIS.0006	Risk Register
[RD-04]	GIRMOS.SYS.SPE.0022	Volume, Power, Coolant Budget Worksheet

1.4 Acronyms/Abbreviations

Acronym	Meaning
GIRMOS	Gemini Infrared Multi-Object Spectrograph
TBC	To Be Confirmed
TBD	To Be Determined

2 Overview

The Gemini Infrared Multi-Object Spectrograph (GIRMOS) is an adaptive optics-fed multi-object integral field spectrograph with a parallel imaging capability. It is funded by the Canada Foundation of Innovation, provincial research funding agencies, the National Research Council of Canada (NRC), and the Gemini observatory.

GIRMOS implements multi-object adaptive optics (MOAO) for each of its four spectrographs by taking advantage of the infrastructure offered by Gemini upcoming wide-field AO facility at Manuakea. The instrument offers the ability to observe four objects simultaneously within the Gemini-North AO (GNAO) system's field-of-regard or a single object by tiling the four fields that feed light to four separate spectrographs. The MOAO system applies an "open-loop" AO correction at the location of each spectroscopic field, improving upon the image quality produced by the observatory AO system.

Each integral field spectrograph has an independent set of selectable spatial scales (0.025″, 0.05″, and 0.1″/spaxel) and spectral resolution (R~3,000 and ~8,000) within an operating band of 0.95 – 2.4μm. These spatial scales correspond to individual spectrograph fields of view of 1x1″, 2x2″, and 4x4″, respectively. The spectrographs are designed to be effective for low surface brightness imaging and high angular resolution science, requiring the use of image slicers. GIRMOS's imager offers imaging over 85x85″ imaging field over the 0.9 – 2.4μm band at a plate scale of 21 mas (Nyquist sampled at *H*-band). The imager can function in a parallel data acquisition mode with just minor vignetting spectroscopic pickoffs when they are deployed.

3 Gemini North Adaptive Optics

The Gemini North Adaptive Optics (GNAO) upgrade project will deliver wide field ground layer adaptive optics (GLAO) correction over 2' and laser tomographic adaptive optics (LTAO) correction over ~20"x20" in the Northern hemisphere. The GNAO effort will build on experience with the Gemini Multi-conjugate System (GeMS) at Gemini South, but it will employ the latest technologies for improved performance in support of the next generation of AO-assisted instruments at Gemini North. Being designed for queue observing and time domain follow-up, GNAO will make AO observations routine. With a corrected field-of-view of about 2 arcmin and spatial resolution similar to that of JWST, GNAO will take advantage of Maunakea's outstanding conditions for AO performance and establish GN as the premier ground-based facility for wide-field AO studies. Finally, GNAO will offer the ability to carry out transient follow-up by being able to carry out target acquisition and AO loop closure within 10 minutes.

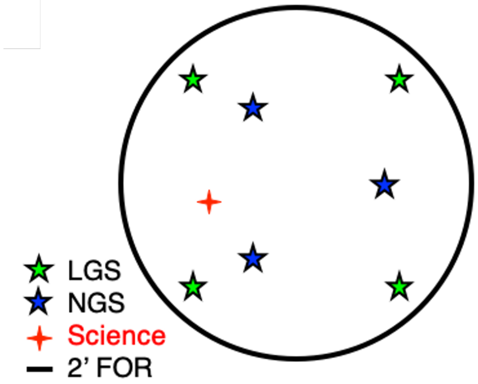


Figure 1 Configuration of GNAO LGS and NGS constellations. The GIRMOS science field can be located anywhere within the 2' field-of-regard.

GNAO is being designed with GIRMOS in mind as a first light instrument. Given that GNAO only has a single deformable mirror, GNAO to offer two scientific modes to satisfy GIRMOS science programs: 1) GLAO that corrects for only turbulence in the lower atmosphere offering a large, corrected field with modest improvement in image quality, and 2) LTAO that corrects for a narrow field at high diffraction-limited image quality. To accomplish these modes, GNAO requires a constellation of four laser guide stars (LGS) in a fixed configuration and up to three sufficiently bright natural guide stars (NGS) within the 2' field-of-regard (FOR), which is shown in Figure 1. GNAO passes on the necessary wavefront sensor and mirror command information to GIRMOS to enable MOAO and optical corrections along a specific line-of-sight within the 2' FOV.

The GNAO system is still in the development phase with its key component, the AO bench (AOB), that still needs to be designed. The AOB bench serves as the intermediate optical system between Gemini telescope and GIRMOS and carries out the first stage atmospheric correction. The AOB is currently entering Phase A (conceptual design) study, with Phase B (full design and build) starting sometime next year. There is some design risk to the GIRMOS project as the AO parameters (e.g., number of actuators in the deformable mirror) and optical design specifications have not been finalized. Additionally, the expected completion of GNAO will likely be one year after GIRMOS.

4 Science

When GIRMOS becomes available, it will be ideally positioned as a workhorse instrument for the Gemini community behind the Gemini North Adaptive Optics (GNAO) system. Its multiplexing capability will make it particularly efficient for large surveys, and these are likely to dominate 8-meter-class science in that era. At that time, both JWST and Euclid will be operational and providing exciting new IR bright targets for spectroscopic follow-up. Gravity wave detectors such as LIGO in combination with imaging follow-up will providing well-localized gravitational wave sources. Likewise, the Rubin Observatory and the SKA pathfinders will be detecting exotic transient sources, and ALMA will be in an era of providing large, well-characterized surveys. GIRMOS will be the forefront AO instrument for observing large samples of the sources discovered by these state-of-the-art telescopes.

The GIRMOS science team has developed a broad set of spectroscopic and imaging science cases, 13 detailed spectroscopic and three imaging cases in total, that cover a wide range of topics. The science cases are organized into three groups: 1) Galactic Science, 2) The Nearby Universe, 3) Extragalactic Science, and 4) Transients. Broadly speaking the Galactic and star formation science cases tend to drive the requirements on spectral coverage and spectral resolution. Extragalactic science generally involves much fainter targets and primarily drives the angular resolution and sensitivity requirements for GIRMOS. The targeted science cases cover the following topics:

1. High- and low-mass star formation within the Milky Way
2. The formation process of the Milky Way super-massive black hole and its environment
3. Intermediate-mass black hole formation and chemodynamics of globular clusters
4. The nature of optical, infrared, radio, and gravity-wave transients
5. Relationship between cold gas, star formation, and dynamics in galaxies at $z > 1$
6. Ultra-high angular resolution studies of distant galaxies aided by gravitational lensing
7. Relative roles of internal processes and environment at the peak of galaxy formation
8. Galaxies, black holes, and globular cluster formation processes at “Cosmic Dawn”

Given the wide-ranging needs of the science team and the complexity of requirements flow down process, the GIRMOS science and system engineering team focused on two spectroscopic cardinal science cases and one simultaneous imaging and spectroscopic case to develop the instrument. The most critical science case is a large distant galaxy ($1 < z < 3$) survey that aims to study the dynamical processes that drive galaxy mass assembly around Cosmic Noon. Given that this is a spectroscopic survey program, we focused on time to completion as the chief scientific requirement. This drove many aspects of the instrument such as sensitivity, multiplexing, observing overheads (e.g. AO loop closure, source acquisition, and calibration), and MOAO performance. This led to the development of a highly efficient acquisition and guiding system that ensures the spectrographs remain pointed on their source at high pointing precision for long periods of time. Our estimations show that GIRMOS can yield up to ten times the survey throughput for this type of program compared to existing single-object AO integral field spectrographs due to improved efficiencies from reductions in overheads, higher throughput, and multiplexing.

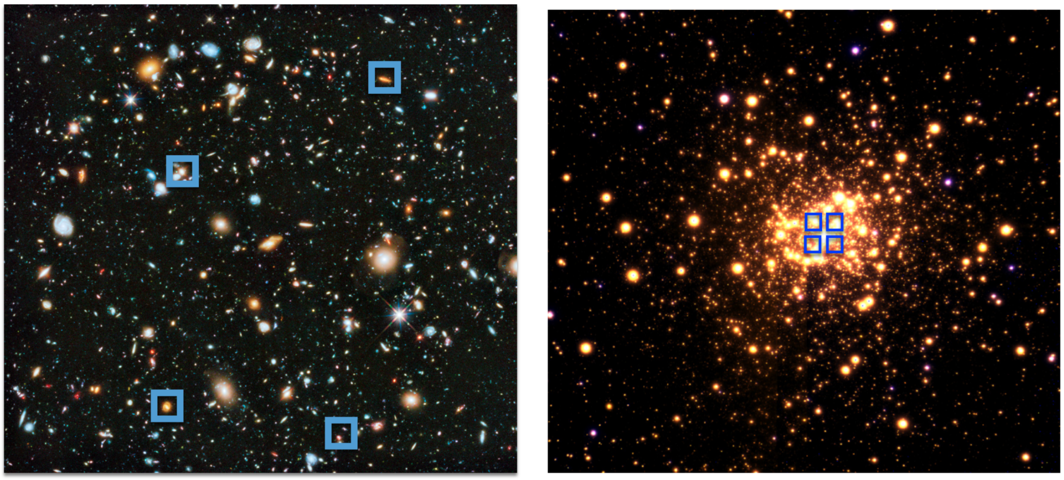


Figure 2 *Left:* An image of the Hubble Extreme Deep Field (XDF)12 with the four GIRMOS 4x4″ IFU fields overlaid on select extragalactic targets. The field shown is approximately 2′ across, which is the size of the GNAO field-of-regard. For these observations MOAO is required to provide high angular resolution imaging required to resolve structures in distant galaxies. *Right:* An observation of the central region of a globular cluster using the GIRMOS tiled mode where the IFUs are arranged in the closest packed arrangement with small gaps between each IFU field. In this mode, the AO correction, particularly LTAO, is provided by GNAO.

The other spectroscopic cardinal case was the search for intermediate-mass black holes in cores of globular clusters. This program requires high angular resolution to resolve the crowded field in the cores that as well as higher spectral resolution to measure the kinematics of stars in the globular cluster core. Not requiring multi-object capability, this program will take advantage of the high-quality narrow-field correction provided by GNAO facility. With these two cardinal cases, we were able to define the key instrument parameters. Of course, additional constraints such as allowable mass and volume budgets, as well as the overall cost of the instrument factored into the final determination of instrument requirements.

A systems engineering approach derived from one advocated by NASA has been adopted for our project. Our Level-0 requirements, which consist of science program requirements and Concept of Operations developed by our science team, is formally flowed down to Level-1 (L1) instrument requirements. L1 performance requirements are further decomposed into L1 budgets that are used to derive Level-2 (L2) subsystem requirements.

The relevant documents are:

- Science Cases: GIRMOS.SCI.DOC.0001.C
- Concept of Operations: GIRMOS.SCI.SPE.0003.D
- Science Requirements (L0): GIRMOS.SCI.RS.0002.C
- Instrument Requirements (L1): GIRMOS.SYS.RS.0002.E

5 GIRMOS Instrument

The GIRMOS instrument consists of a total of 9 subsystems. Seven of them of them are hardware subsystems while two are software based. The subsystems are the instrument structure (ISTR), the field lens assembly (FLA), the calibration system (CAL), the object selection system (OSEL), the MOAO system (MOAO), the integral field spectrograph (IFU), the imager (IMGR), instrument control software (INSW), and observation planning and data pipeline software (OBSW). The overall architecture of GIRMOS is shown in Figure 3 with a mechanical exploded view shown in Figure 4.

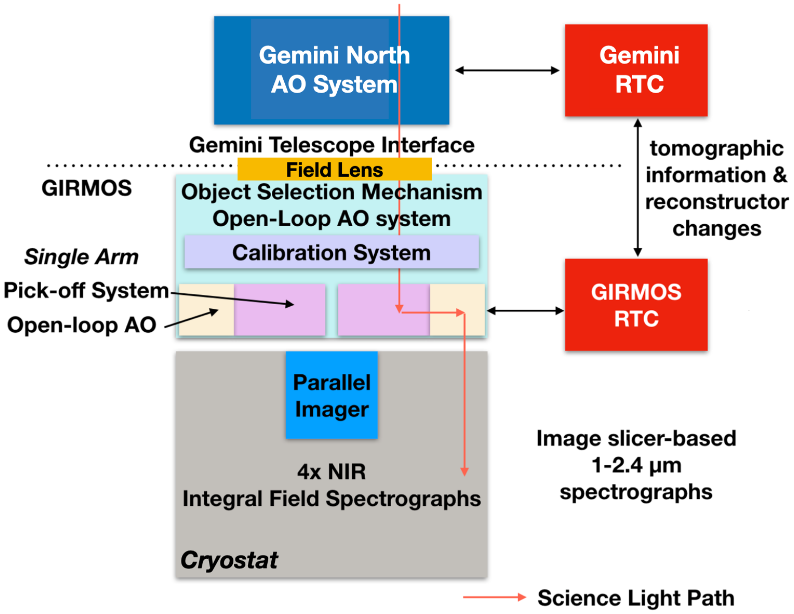
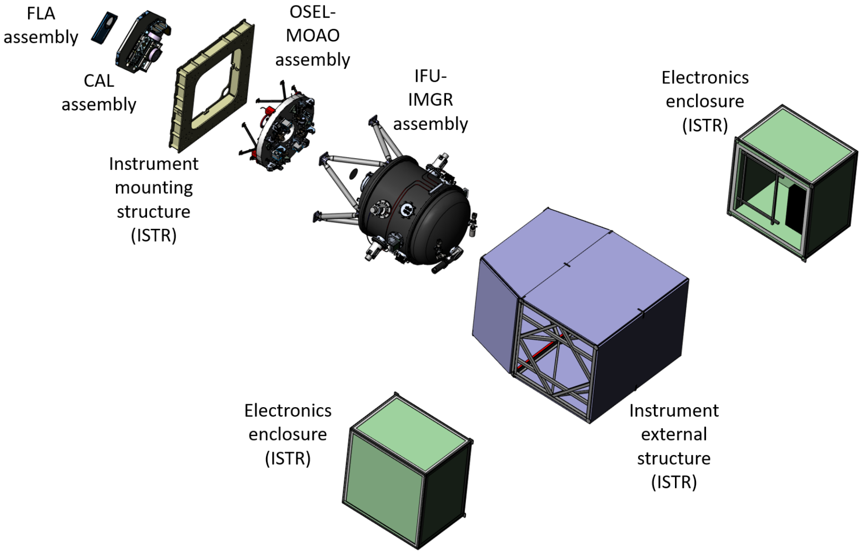


Figure 3 The overall GIRMOS system architecture with all major subsystems shown along with the key Gemini subsystems they will interact with. The science light path is shown by the red arrow. The calibration system is not always in use but can be deployed when necessary. There is a close



interaction between the GIRMOS MOAO and the GNAO systems through their RTCs to ensure optimal AO performance required by the instrument.

Figure 4 GIRMOS System Exploded view of major GIRMOS subsystems. The instrument mounts to the observatory through the telescope mounting flange that attaches to the Gemini telescope's ISS.

5.1 Subsystems

5.1.1 ISTR

The instrument Structure (ISTR) is the main structure of the GIRMOS instrument and provides the interface to Gemini Instrument Support Structure (ISS) and associated services. It also provides the means of mechanically connecting all elements of the GIRMOS system together. Figure 5 shows the three main elements that ISTR is composed of: Internal Structure - INTS (lime green at bottom of image) is the structural pallet to which other elements and subsystems attach; External Structure - EXTS (yellow and grey) is the main external structure; and the Electrical Enclosures - EE (green) are the structures that contain the electrical and electronic components of GIRMOS and maintain them at operational temperatures.

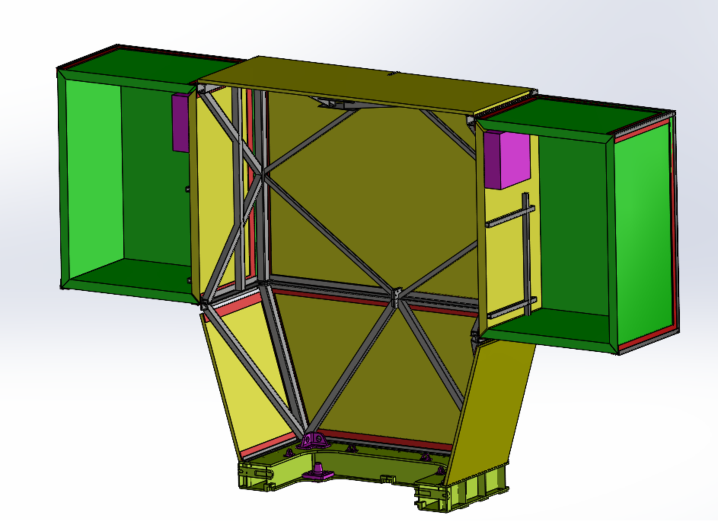


Figure 5 Section view of ISTR with GIRMOS subsystems removed

The EEs contain liquid cooled server racks that house all the instrument's electronics. The EEs are also insulated to minimize any localized heating at the observatory. The EEs have inward facing patch panels that allow electrical connections to the respective subsystems. The document that details the ISTR design can be found here:

- ISTR: 21013-DOC-001-B ISTR Design Report

5.1.2 FLA and CAL

It was determined recently that GNAO exit focus is not telecentric because its exit pupil will be located at the location of the secondary mirror (M2). The pupil formed on the MOAO DM and IFU cold stop would shift laterally by about +/-20% of its diameter when the pickoff arm is moving from the center to the edge of the 2 arcmin FoR. A trade study was done (see Section 4.1.1 in [RD-01]) which led to the need for, and development of, the Field Lens Assembly.

Located at the very opening of the instrument, at its interface with the ISS is the Field Lens Assembly (FLA) consists of a single weak lens. Its purpose is to reimage the GNAO exit pupil to infinity. It will also contain an actuatable cover to prevent light from entering the rest of GIRMOS, which offloads the shutter function from CAL.

The FLA comprises three subassemblies, the Field Lens Structure (FLS), the main structure and housing for the field lens; the Mounted Field Lens (MFL), the lens itself as well as the cell housing the lens; and the Shutter (SHU), the actuatable cover (note: "Shutter" is not meant to imply an optical shutter per se, though that was the original idea when conceived. The shutter is a cover that will move between an open and closed position on a linear stage. For conceptualization, the cover will translate approximately 180mm in one minute to go from opened to close, or vice versa.

The FLA is closely integrated with CAL – it is mounted directly to it, and FLA cabling goes through CAL before making its way to the EE.

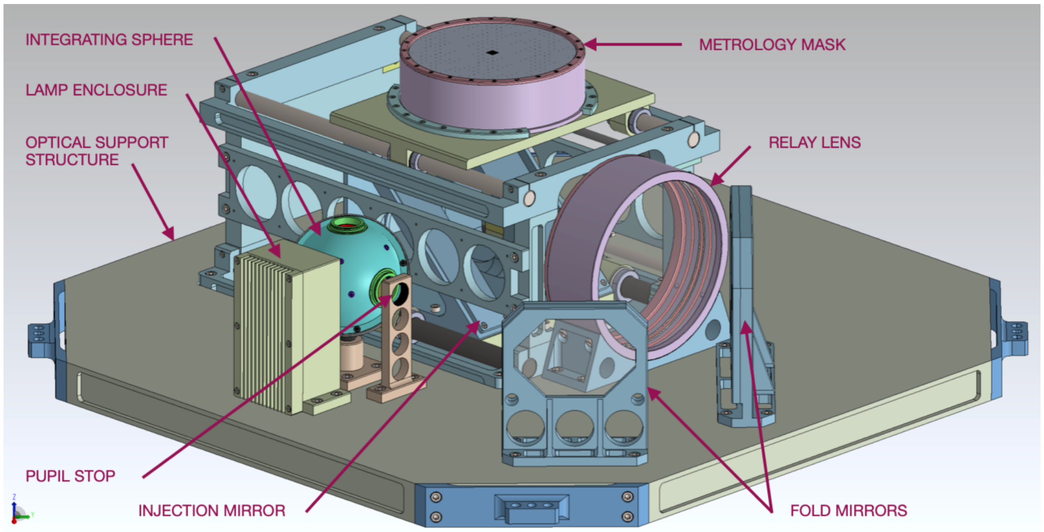


Figure 6 Principal optical components of the CAL subsystem. Light from the telescope enters from below. The two mechanical stages are shown in an intermediate position of their travel. The metrology mask is coincident with the GNAO focal plane when it is fully inserted.

While not always in use within the instrument, the GIRMOS calibration (CAL) system is an essential component of GIRMOS and will be heavily used during integration and testing (I&T). The CAL system, shown in Figure 6, provides flatfielding and spectral calibration for the instrument. Gemini offers a facility calibration system (GCAL), but it is designed for f/16 instruments and is not accessible by instruments behind the GNAO system. Additionally, the GNAO internal calibration system does not offer spectrophotometric calibration capabilities, and therefore, our team has chosen to provide our own. The CAL system provides an f/32.5 output beam that illuminates the full GIRMOS field-of-regard using either a broadband quartz or gas discharge lamp. This allows for the flatfield calibration of the imager and flatfield and spectral calibration of the spectrographs. The CAL system injects the light into the instrument by deploying a folding flat mirror. Additionally, it offers a pinhole mask for calibrating the positioning of pick-off mechanisms in the OSEL system. Deployed into the focal plane, this mask consists of a grid of pinholes that can be used to calibrate the position of each pick-off mechanism across its full range of travel. The mask also serves a dual purpose where it is used to calibrate the image distortion of the imager, which will be used for our pick-off metrology system discussed in the following section. Finally, at the centre of the mask are Ronchi gratings, which can be used to calibrate spatial distortions in the integral field spectrographs. Details of the FLA and CAL subsystems can be found in their corresponding design documents:

- FLA: GIRMOS.FLA.DD.0005.A
- CAL: GIRMOS.CAL.DD.0014.A

5.1.3 OSEL and MOAO

The object selection (OSEL) system plays a critical role in selecting the requested sources from the telescope focal plane. This is achieved by a pick-off mirror close to the GNAO focal plane. In our design, the pick-off system uses an $r - \theta$ mechanism where each mechanism can access approximately 1/4 of the field. Additionally, the four pick-offs can be placed in a closest packed arrangement at the centre of the field with only a small gap (< 2″) between adjacent mirrors for the tiled mode. A trombone maintains a fixed optical path between the telescope focal plane and the powered optics in the OSEL system. The OSEL system has additional requirements as it also includes the MOAO system. It needs to form a pupil on the DM and also includes a figure source and wavefront sensor to monitor the DM surface figure as it operates in open loop. When coupled with a matching OAP inside of the spectrograph cryostat (OAP3), the OSEL forms a high-quality pupil image on the spectrograph cold stop. Two of the mirrors in the OSEL are steerable, M3 and M10, which allows for pupil centration on the DM and the cold stop, respectively. We anticipate using these steerable mirrors to compensate for flexure. All these features are shown in the annotated OSEL optical diagram shown in Figure 7.

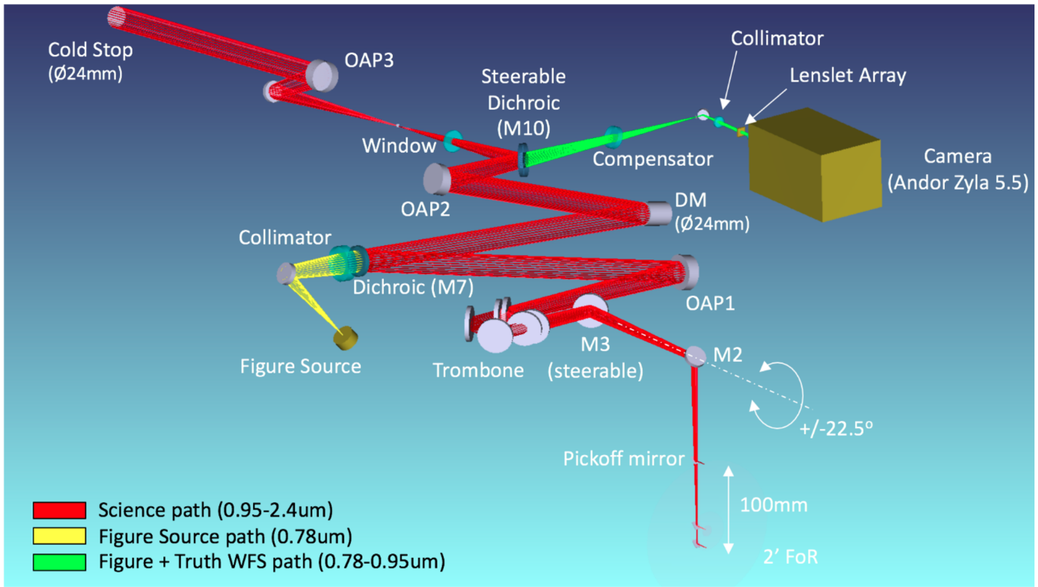


Figure 7 Optical layout of the OSEL system with the key components highlighted. The trombone in the system maintains a fixed optical path between the pick-off mirror and the first off-axis parabolic (OAP) mirror. The OSEL system also has a figure source, when coupled with the wavefront sensor, is used to monitor the DM shape at all times to mitigate creep and go to errors. There are two mirrors on tip/tilt mechanisms, M3 and M10, which are used for pupil centering on the DM and spectrograph cold stop, respectively.

The MOAO system consists of an ALPAO DM292 deformable mirror, a figure source, a custom Shack-Hartmann wavefront sensor that uses the Andor Zyla sCMOS camera, and a real-time controller. The figure source operates in a band that is outside of the spectrograph wavelength coverage, so it does not interfere with science observations. This allows for closed loop DM operation using the figure source where the slope offsets are generated from optimal projections of turbulence obtained from GNAO telemetry. This mitigates any creep/go to errors in the DM. However, we note that this is still an open-loop AO system as it does not directly measure the wavefront error of the observed source. The WFS can also be used as a truth WFS for bright objects to tune and characterize the performance of the MOAO system. Additionally, thanks to the large stroke on the DM, we expect to use some of the stroke to compensate for non-common-path aberrations (NCPA) between GNAO and GIRMOS and pointing/focus errors at the input of the spectrograph.

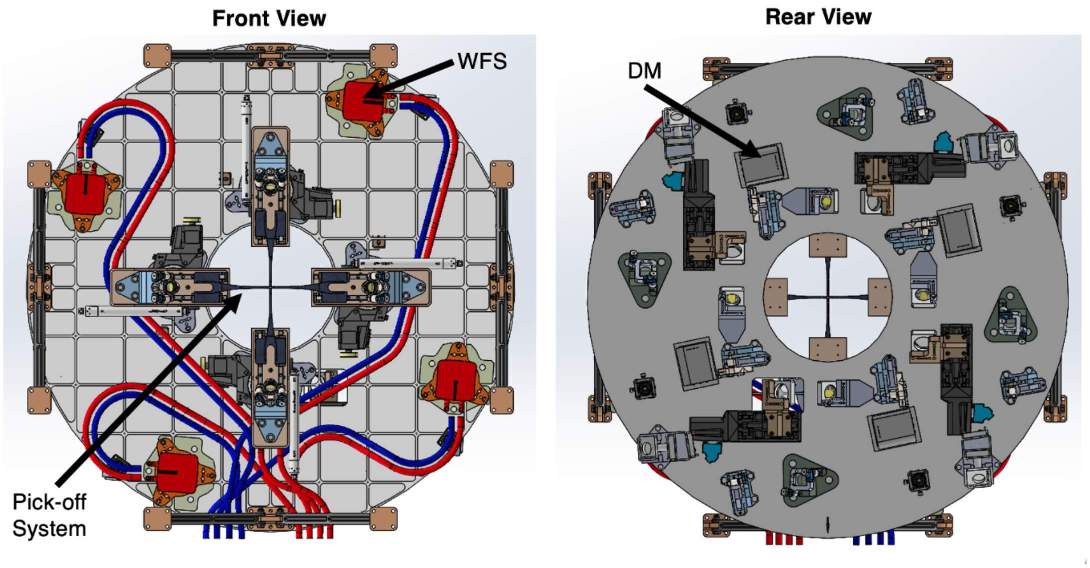


Figure 8 shows the optomechanical layout of the OSEL, which reveals the four replicated optical systems for each spectrograph. The pick-off mechanisms are installed in the front side of the optical breadboard. They also contain small pinholes close to the pick-off mirrors. These pinholes are either illuminated by the CAL system or by the IR sky background during science operations, which is then imaged by the GIRMOS imager. This allows for precision tracking of the pick-off mirror positioning for acquisition and flexure compensation, which allows for significant gain in observing efficiency by reducing acquisition times and the need for periodic reacquisitions.

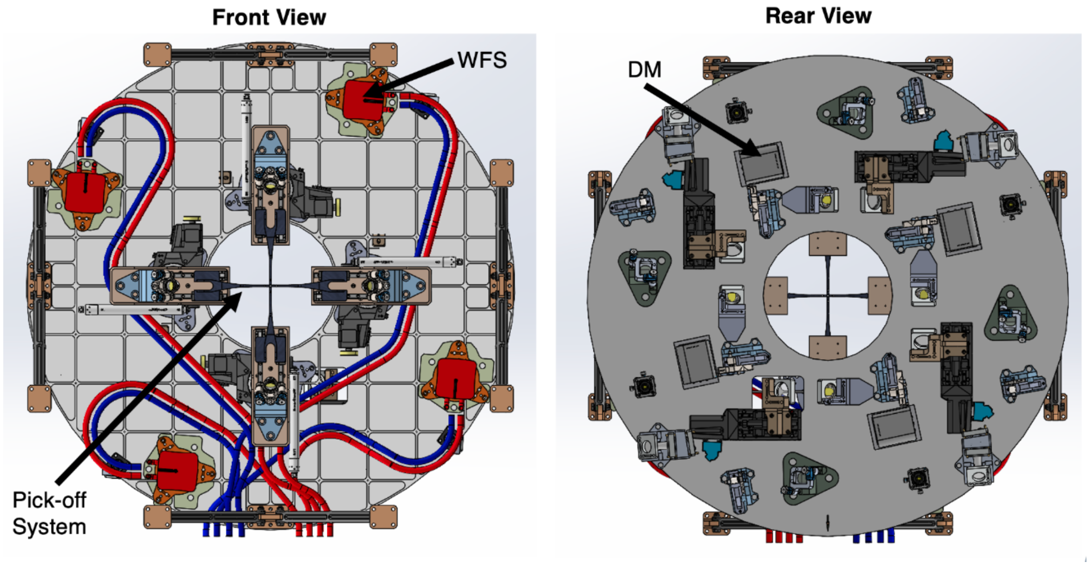


Figure 8 *Left*: Front view of the OSEL system as viewed from the Gemini ISS. The bipods that attach to the telescope mounting flange are visible. The red and blue pipes are the liquid cooling lines for the WFS cameras. *Right*: Rear view of the OSEL system with all major optomechanical components visible.

The OSEL and MOAO subsystems are further discussed in detail in their respective design documents:

- OSEL: GIRMOS.OSEL.DD.0008.A
- MOAO: GIRMOS.MOAO.DD.0016.B

5.1.4 IFU and IMGR

The GIRMOS imager (IMGR) and integral field spectrograph (IFU) subsystem are the most complex components of GIRMOS. A large cryostat houses all four spectrographs and the imager. The Cryostat maintains all the optics and IR detectors at 78K using four Sunpower Cryotel GT Stirling cycle coolers. The inner structure of the cryostat is shown in the figure below (Figure 9).

All the optical components are mounted on a square 6061-T6 alloy Aluminum tube. Each outer surface of this tube serves as an optical bench for each spectrograph. The central cavity of tube houses the imager opto-mechanics. This square tube is supported by a 6061-T6 alloy Aluminum support frame. The cryocoolers for the cryostat are thermally linked to the support frame using Oxygen Free High Conductivity (OFHC) Copper cooling straps. The support frame is rigidly held in place by Grade 5 Titanium alloy (TiAl6V4) bipods supported by a set of Stainless-Steel spherical bearing assemblies that also serve to thermal insulate the cold bench from the cryostat mounting flange. The entire optical bench is surrounded by a Nickel plated 1100 alloy Aluminum radiation shield wrapped in multi-layer insulation (MLI) to act as a radiant heat shield.

The four spectrographs are exactly replicated within the cryostat and follow standard practices for cryogenic design of opto-mechanical mounts. All metallic mirrors and lens mounts were chosen to be made of 6061-T6 alloy Aluminum to match the coefficient of thermal expansion (CTE) of the bench. This includes the integral field unit, which consists of a slicer, pupil mirror arrays, and field mirror arrays. The slicer components, discussed in the following section, will be manufactured using single point diamond turning (SPDT) techniques. Lens mounts were designed to operate at 78K using flexure based mounting designs or radial Teflon pads. Within each spectrograph, a single extrusion is used to mount most of the optical components, except for the grating wheel, spectrograph camera, and detector. Every spectrograph also has three moveable mechanisms: 1) a scale changing mechanism that selects from several lens barrels to switch between the different plate scale modes; 2) a mechanism to insert a lens to image the cold stop for pupil alignment; and 3) a grating wheel that allows the selection of different wavelength and dispersion modes. All other optics are fixed. For the pupil imaging mode, the cold stop is imaged onto the slicer, which is then imaged by the spectrograph optics. High efficiency volume phase holographic (VPH) gratings or grisms (prism+VPH grating) are used for all dispersion modes. Each spectrograph uses a single 2048x2048 HAWAII-2RG HgCdTe (H2RG) detector.

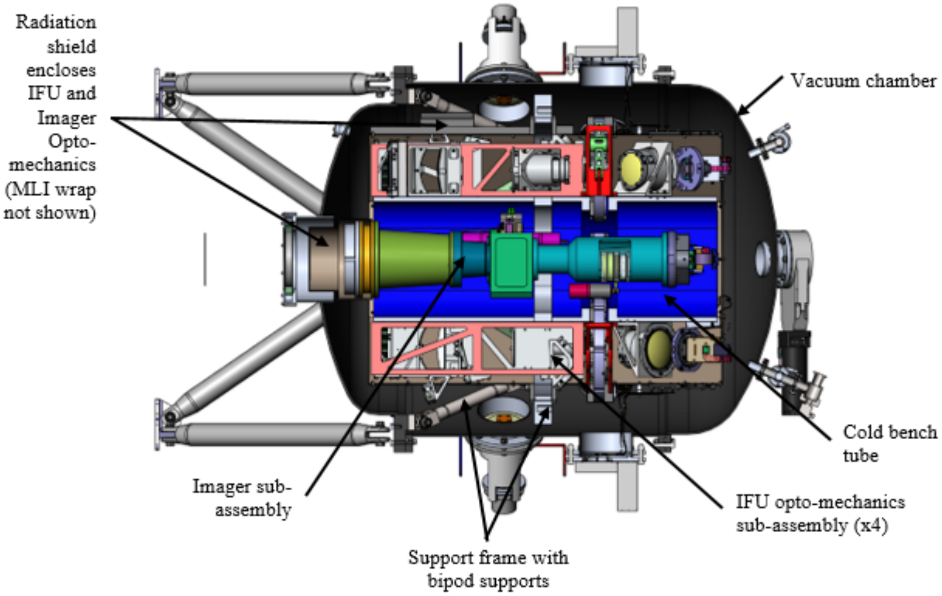


Figure 9 – A cross-sectional view shows the spectrographs/imager within the GIRMOS Cryostat. All components are maintained at 78K. The four spectrographs are mounted on each side of the square cold bench tube (blue). The imager is located inside the tube. All the opto-mechanics are enclosed in an MLI wrapped radiation shield. The cold bench tube and the radiation shield are rigidly held in place using the internal support frame. The cryostat is cooled by four cryocoolers, which in turn are liquid cooled to remove the heat collected within it.

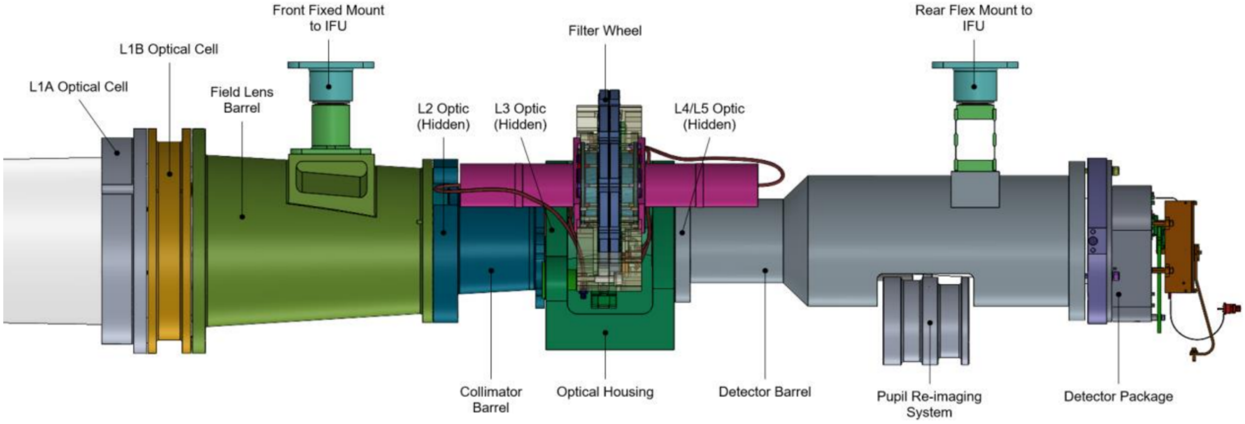


Figure 10 Side view of IMGR showing all major subassemblies.

The general layout of the imager components is shown in Figure 10. It consists of two movable mechanisms:

1) a filter wheel to select from an assortment of broadband and narrow-band filters; and 2) pupil imaging lens insertion mechanism to image the cold stop in the imager onto the detector. During the calibration process, the imager is used to determine the NCPA within the GIRMOS field-of-view. The NCPA calibration is then used to apply slope offsets onto the GNAO DM to remove most of the aberrations. The imager also performs a critical role in the acquisition and guiding during a scientific observation as it acts as a metrology system for the instrument's pick-offs. The imager uses a single 4096x4096 HAWAII-4RG 15μm HgCdTe (H4RG) detector.

Since the imager can continuously view the input focal plane, it is able to determine the location of each OSEL pick-off with respect to the sky thanks to the pinhole in each pick-off. From a single exposure, the imager will be able to calibrate the astrometry of the observed field using stars from the GAIA catalog. This allows for precise positioning of each pick-off in the GNAO focal plane both during initial acquisition and during science observations. This is particularly essential for GIRMOS because its extragalactic survey will predominantly observe very faint sources that will not be visible after a single short integration. This makes it impossible to maintain good image quality while stacking observations if the pick-off positions are not precisely positioned throughout the duration of the observations. Therefore, it is important that the pointing of each spectrograph be maintained to high relative accuracy for at least an hour to ensure sufficient signal-to-noise ratio to detect and centroid on a faint source.

Finally, we describe the readout system used by all five (4 H2RGs and 1 H4RG) detectors used within our instrument. Each of the array will utilize an independent Teledyne SIDECAR ASIC cold electronics coupled with MACIE warm electronics board. Read noise performance is critical for GIRMOS spectroscopic observations, and we intend to carry out up-the-ramp readout scheme to minimize overall read noise.

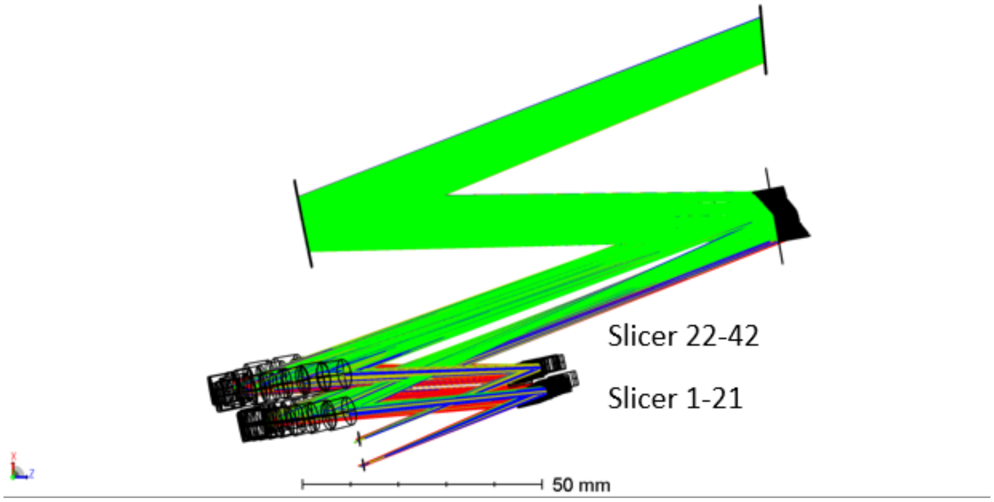
The details of the IFU, and the IMGR can be found in the following respective design documents:

- IMGR: GIRMOS.IMGR.DD.0008.A
- IFU: GIRMOS.IFU.DD.0008.B

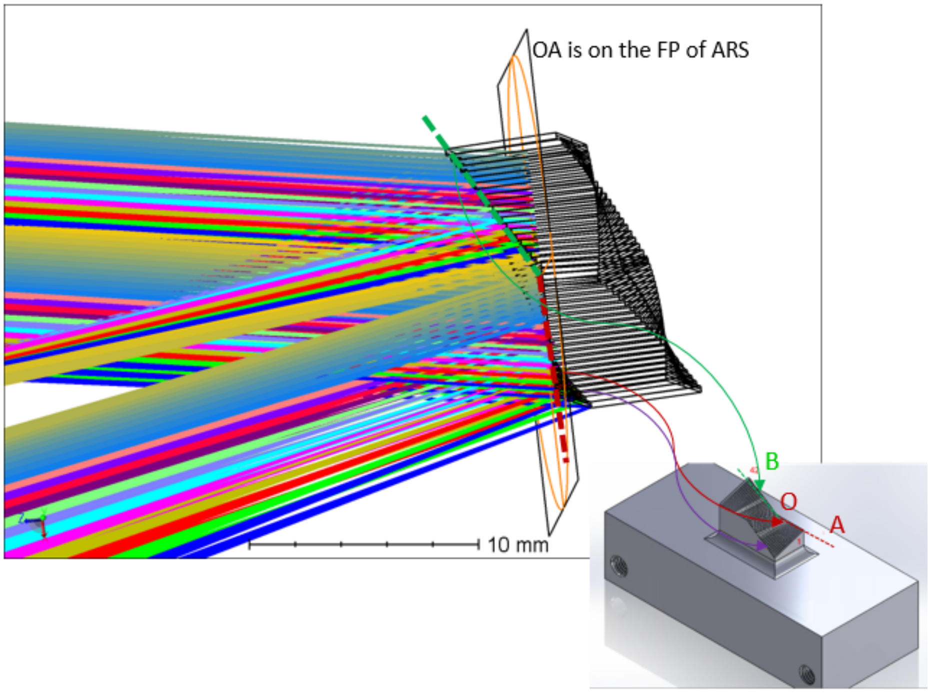
5.1.4.1 Slicer

The slicer (SLI) within each IFU is used for rearranging 2D FOVs into a long slit, as shown Figure 11. The output of the SLI is a staggered continuous pseudo slit, which consists of 42 slit-lets arranged on two rows. The slit-lets are arranged on a flat plane with minimum curvature and minimum gap between 2 adjacent slices. The pseudo slit is designed with high-quality image performance (>80% Strehl Ratio) and F/# variation lower than 0.1%. The output of slicer unit is telecentric, which enables the formation of a common pupil on the surface of disperser. The advanced slicer unit is manufactured through specialized single-point-diamond-turning (SPDT) processes developed by our team. For the more details about the slicer, please refer to the following document:

- SLI: GIRMOS.IFU.DD.00009.A



(a) Layout of advanced slicer (slicing mirror, pupil mirrors, and field mirrors



(b) Layout of slicing mirror

Figure 11 Overall Layout of the GIRMOS Slicer

5.1.5 INSW

INSW – Instrument Software, which in Gemini terms is called the TLC – Top Level Computer and the User Interface (developed at NRC). This is the software used to perform real-time nightly calibrations, operate the instrument, carry out observations, and perform engineering tasks on GIRMOS. It will produce the raw science frames and deliver them to the Gemini science archive.

The INSW consists of a control computer and an Ethernet switch. The computer contains the INSW software that will control and monitor all subsystems and mechanisms on GIRMOS. All subsystems and their components will communicate with the INSW through ethernet interfaces. The INSW will provide software modules to interface with motor controllers and translation stages as well as interface with the temperature monitors, cryocoolers, and detector readouts.

As a cost saving effort, much of the TLC software will be reused from the Gemini Planet Imager (GPI). Additionally initial build of the software (with components only being simulated) will start during the final design phase, leveraging the agile development process. The design document can be found here:

- INSW: GIRMOS.INSW.0006.A

5.1.6 OBSW

The Observing Software (OBSW) is the subsystem in GIRMOS that provides the software tools to process the raw data provided by GIRMOS observations into data products to be used for either (i) observation and quality control or (ii) scientific analysis. The processing software will be developed by the GIRMOS OBSW team within Gemini's DRAGONS data reduction architecture, in close consultation with the Gemini Science User Support Department.

Further, OBSW is responsible for ensuring that appropriate tools to inspect the processed science products are available. Finally, OBSW will provide a data simulator that can be used for either (i) testing the processing software during the development cycle or (ii) for the user to perform detailed data simulation when planning observing programs.

Except for the observation simulation aspect of the data simulator, OBSW operates after the Instrument Software (INSW). INSW is a separate subsystem in the GIRMOS software stack whose purpose is to operate the GIRMOS instrument hardware itself (e.g., during astronomical observations) and to write the raw data. INSW development is not the responsibility of OBSW.

The third part of the GIRMOS software stack, which includes the tools to estimate the required signal-to-noise and set-up observations, will get implemented by Gemini as part of the GPP framework. Its implementation is not the responsibility of either of the two GIRMOS software teams.

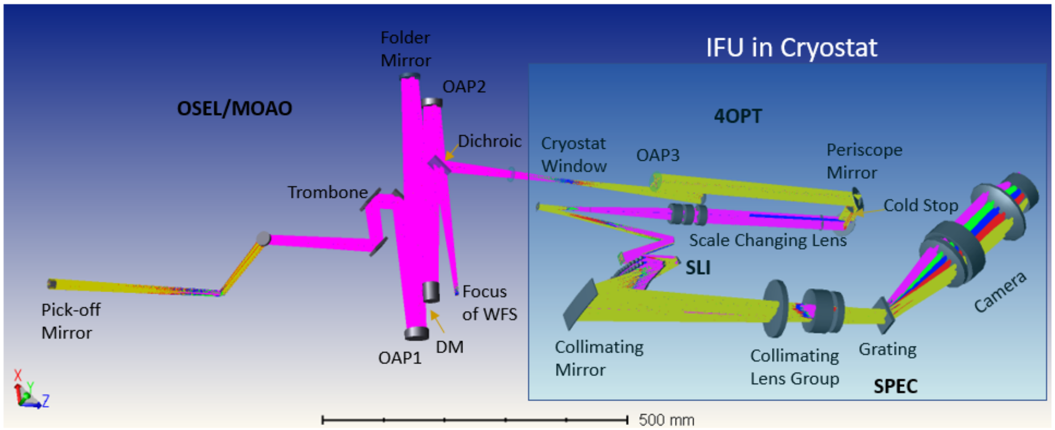
OBSW interacts with users (e.g., night-time instrument operators, support astronomers, data analysis scientists), and parts of it are integrated into automatic Gemini Observatory operations. The design document can be found here:

- OBSW: GIRMOS.OBSW.DD.0013.A

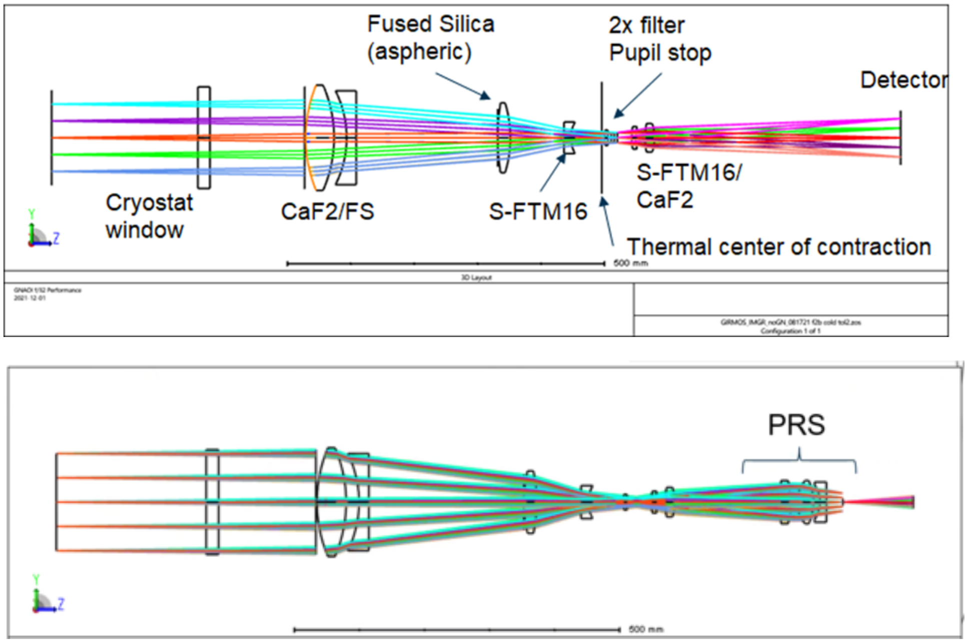
6 Optical Design Overview

The overall end-to-end optical design of IFU is shown as Figure 6(a). Given the requirement to observe faint distant objects, an image slicer-based spectrograph was chosen for its unparalleled performance in background subtraction as well as maximal use of detector pixels. The GIRMOS spectrograph's optical design consists of two components, OSEL/MOAO systems, and the IFU itself. The OSEL/MOAO, which is at ambient temperature, has an actuated pick-off arm that can select a source within the GNAO field and direct the light to a deformable mirror that is part of the MOAO system. The corrected light then passes into a cryostat where the IFU optics are kept at cryogenic temperature (78K). The IFU consists of fore optics (4OPT) with a selectable plate scale that reimages the input field onto the slicer (SLI). The SLI delivers the pseudo slit that feeds the spectrograph (SPEC). The IFU offers three different spatial scale modes through a scale-changing optics mechanism and two different spectral resolutions through a choice of six dispersers (3 volume phase holographic (VPH) gratings, and 3 grisms) to cover all spectral bands.

The IMGR is an independent system from the IFU, which is feed by the GNAO passing through the FLA. The IMGR offers two different modes, one is the imaging mode, and the other one is the pupil imaging mode. The IMGR is an imaging system consisting of a six-lens element system which forms a pupil at a cold stop. The filters are located near the pupil location. The imaging mode reimage the corrected GNAO fields onto the detector using a selecting filter. The pupil imaging mode is used to image the cold stop in the imager onto the detector, which is implemented by inserting a pupil relay lens group. This is required to initially align the GNAO exit pupil onto the IMGR cold stop. The layout of the IMGR is shown as Figure 6 (b).



(a) End-to-end Optical Design of OSEL/MOAO+ IFU. The pick-off is located very close to the GNAO output focal plane.



(b) Optical design of the imager. *Top*: The imager is able to image a significant portion of the corrected GNAO field. Bottom: The pupil reimaging mode is able to image the cold stop onto the detector.

Figure 12 : End-to-end Optical Design of OSEL/MOAO+IFU and IMGR.

7 Mechanical Design Overview

The GIRMOS mechanical layout is shown in the Figure below. GIRMOS is composed of six sub-systems namely the FLA, CAL, OSEL, IFU, IMGR and the ISTR. The FLA is located at the bottom surface of the instrument mounting structure (yellow plate in the Figure below), attached to CAL. Moving further down the optical axis into the instrument we have the CAL system embedded within a pocket inside the instrument structure. The OSEL follows the CAL and is mounted onto the inner surface of the instrument structure using bipod supports. The IFU and IMGR are kept at cryogenic temperatures and located within a Cryostat mounted on bipod supports directly following the OSEL. Finally, the ISTR includes the instrument mounting structure and is the external structure of the instrument which encloses all other sub-systems and additionally includes two electronic enclosures on either side of the instrument to hold all electronic equipment.

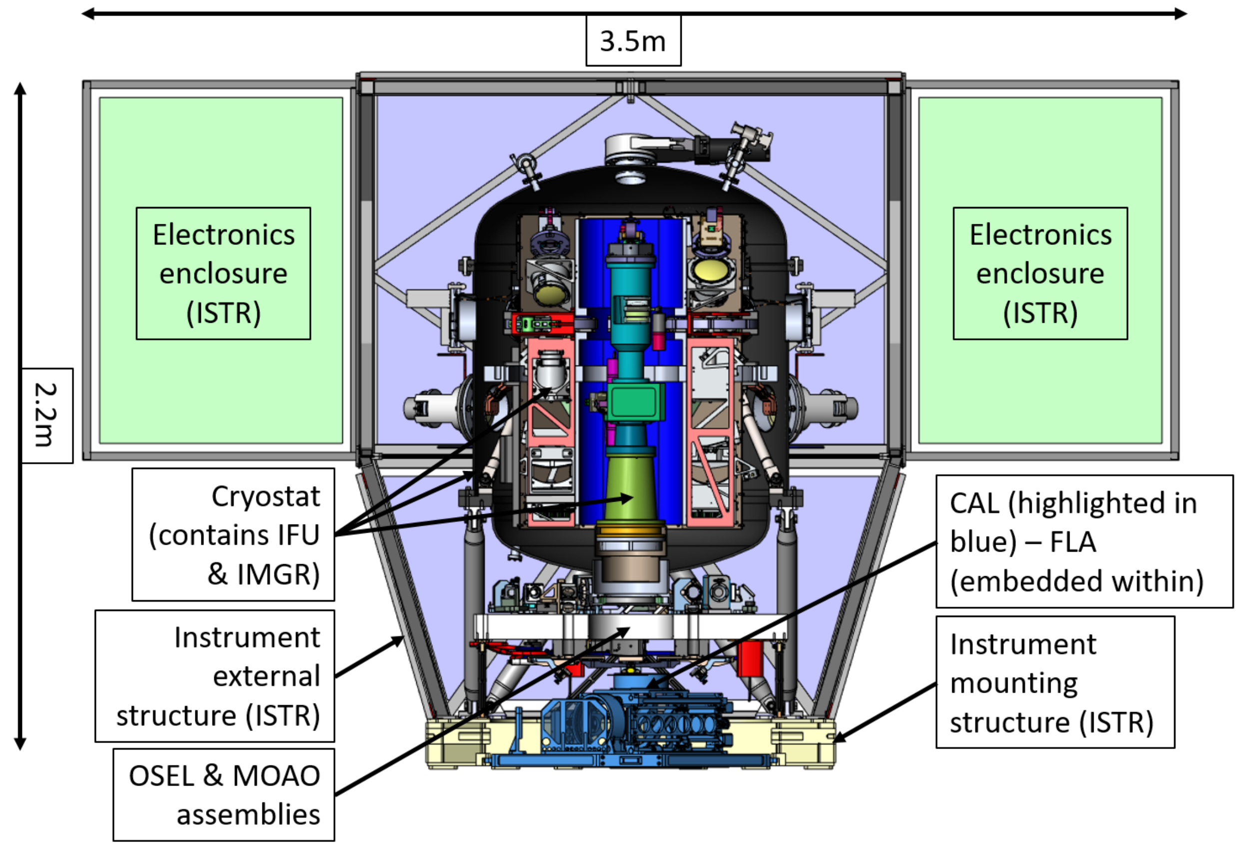


Figure 13 Partial side section view of the instrument enclosure showing the relative position of the various subsystems within it. The overall height of the instrument is 2.2m and the width is 3.5m. The overall mass of the instrument is close to 2000 kg.

8 Electrical Design Overview

8.1 Introduction

The purpose of this section, the Electrical Design Overview (EDO), is to present all the electric components in the GIRMOS instrument. The EDO is a living document that will be revised at strategic points as the design matures over time. This EDO describes the instrument design as they exist currently.

8.1.1 General description and functional overview of the electrical design

The electrical drawing is a three-level schematic. Level 0 presents the inter-connection of the subsystems, then the GIRMOS to the ISS. Level 1 presents the high-level schematic for each subsystem. Then the final level, level 2 contains all the sensors and actuators of the subsystems. Between levels 1 and 0 there are patch panels for each subsystem. The figure below presents a simplified version of level 0 and 2. Detailed schematics can be found here: GIRMOS.SYS.DWG.0040.B. And the overall instrument interconnects are found here: GIRMOS.SYS.DWG.0036.A. The schematic drawing from level 1 to level 2 is a responsibility for each subsystem. Figure 14 presents the interconnection of different subsystems of the instrument. This presentation a high-level drawing of the instrument. Details drawing are presented in the documents aforementioned.

Each subsystem manages its rack mount components, the cables that travel from the electronics enclosure (EE) to its subsystem. On one face of the EE there is a patch panel for each subsystem that routes the cabling between the subsystem to its corresponding rack mount components.

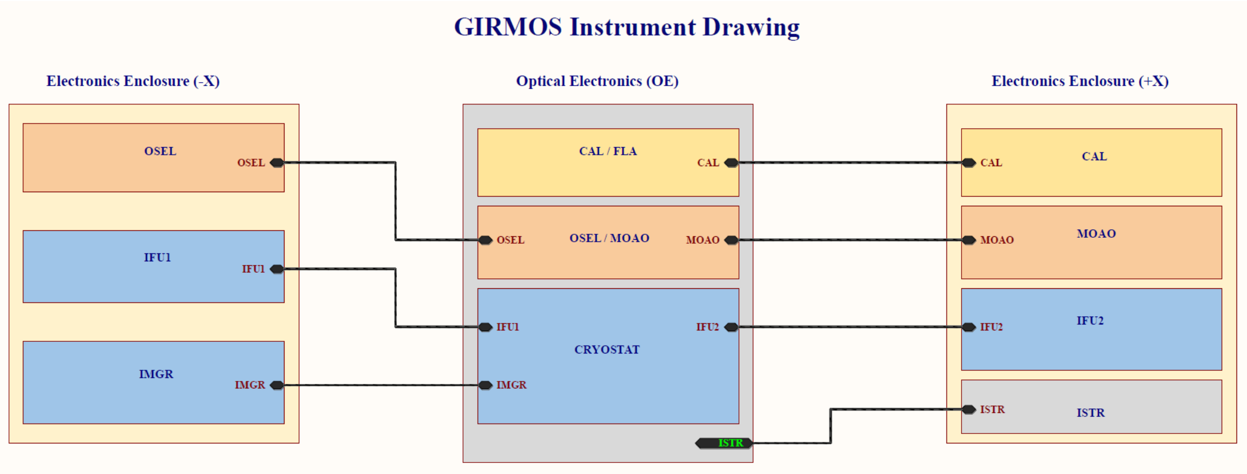


Figure 14 High Level GIRMOS Instrument drawing

8.1.2 Summary of cabling design and connectors

Different cables and wires are used throughout the instrument. However, the cables and wires that are installed inside the cryostat must be picked judiciously due to the environment in which there are going to be. The environment being vacuum and cryogenic, Kapton insulated cables will be used inside the cryostat. The cables contain twisted pairs of wires and are shielded to bound the wires together. The number of pairs is a function of the number of signals the cable has to carry. A schematic for the instrument shows the cable connection. The instrument wire ampacity will be de-rated to 75% for expected loads current. Thus, to achieve the same safe level the connectors and cables must be rated accordingly.

In addition, the AC power is provided to the GIRMOS via two locking, dual 3-prong, 120 VAC outlets (NEMA L5-30) mounted on the cable wrap interface plate. Table 1 shows the recommended connectors to be used for the AC connection between the ISS and the instrument patch panel. On the other side, the connector at the cable that mates with the connector at the GIRMOS patch panel are going to be a circular MIL-style bayonet connector. Table 2 shows the connection of the wire inside the connector supplying the AC power to the instrument.

Table 1: AC Power Connectors

Connector at ISS Service Panels	NEMA L5-30R
Connector at Instrument Patch Panels	CA3100R16-10PB-F80 (or CA3100E16-10PB-F80 or equivalent)
Connector at Cables	CA3106E16-10SB-F80

Table 2: Circular MS*16-10 Power Connector Pinout

Pin	Wire Color	Signal

A	BLACK	HOT
B	WHITE	NEUTRAL
C	GREEN	EARTH GND

Table 3 presents supplementary connectors that will be used throughout the instrument’s subsystems.

Table 3: Supplementary connector used in the instrument

Part number	Description
FTACIR19V	CONNECTOR,19-PIN MIL-C-26482 CIRCULAR, CRIMP, VAC
IFDRG197011	19-PIN Mil-C-26482
FTACIR19AS	Connector,19-PIN MIL-C-26482 Circular, solder, ATM
MDM-21PBS-A174	D-Sub Micro-D Connectors
MDM-21PCBR-A174-F222	D-Sub Micro-D Connectors
D38999-F35P	Circular MIL Spec Connector
M83513/02-CN	D-Sub MIL Spec Connectors SLDRCUP/SLASH CONN SKT/MET SHLL 21CNT

8.1.3 Motor controller selection

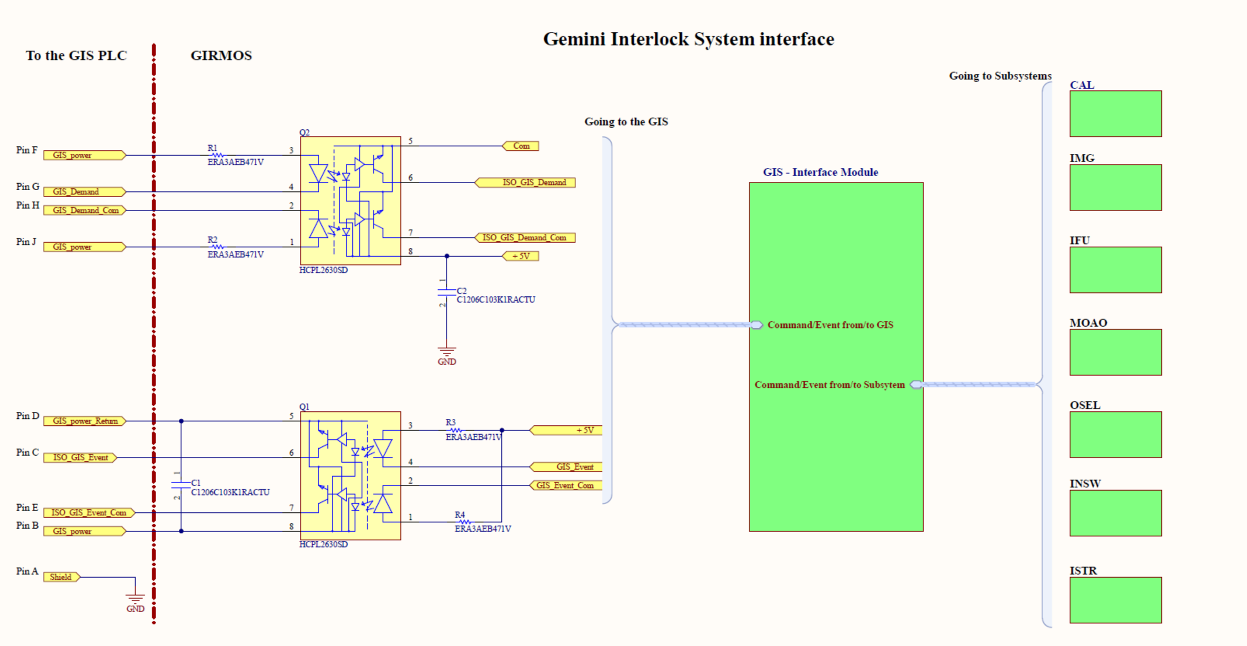
The motion controller’s choice has been based on the previous experience that the INSW team has worked with the module. All motion controllers will use the Galil controller. The IFU and the IMAGER subsystem are using the Galil-DMC-40x0 where x denotes the number of axes. The Galil-DMC-40x0 is a modular device therefore, there are some parameters to be chosen for a specific application. The different modules to be specified to have a complete unit are the main control board (DMC), the communication board (CMB), and the interconnect module (ICM). In addition to that, there is a possibility of choosing an internal amplifier (AMP or SDM).

8.1.4 Gemini Interlock System interface

Gemini Interlock System (GIS) is an Alan-Bradley PLC-based safety system with components mounted on the telescope structure that monitor many safety aspects of the overall instrument system. One of the requirements is the isolation of the communication signals. The signals shall be optically isolated TTL open collector type for outputs to the GIS and will be sourced by an open collector output from the GIS. In addition, Gemini recommends that the optical isolation be installed by the instrument builder inside the instruments’ thermal enclosure to avoid ground loops and antennae. The image below presents the approach we adopted to interface with the GIS taking into account the isolation of the signal.

The GIRMOS communicates with the GIS with only two signals wires which are complementary. Thus, the communications from each subsystem to the GIS are managed by a GIS interface module (GISIM). The GISIM is part of the instrument and install inside the electronic enclosure. The GISIM has sufficient electronics to translate all the events signals into two wires signals acceptable by the PLC communication module.

Signal coming from the GIRMOS to the GIS is called event and from the GIS to the GIRMOS is called demand. An event is reported to the GIS throughout the GISIM. Thus, to be able to report an event the subsystem reports the event to the GISIM then the GISIM format the signal into two wires before sending it to the GIS. A reverse process is happening for the demand coming from the GIS. The two ways communication is maintained by the GISIM and the events are reported continuously. Once the event is reported to the GIS, appropriate action is taken to attend to the nature of the event.



The picture shows how the demand can travel from the GIS to the isolator stage first then to the GISIM where the signal is level shift to be able to give the command to the particular subsystem. The way around, in case of the event the signal will go from the subsystem where the event is coming, reaching the GISIM then the GIS through the isolator.

9 Layout Drawing

This section serves to highlight the layout of the GIRMOS Cryostat and the IFU and Imager opto-mechanics relative to the GIRMOS Cryostat and show where they are positioned within it. The GIRMOS Cryostat is housed within the instrument external structure (ISTR). The Cryostat is mounted to the instrument mounting structure (contained in the ISTR) which attaches all subsystems to it directly apart from the Imager (IMGR) and the Field Lens Assembly subsystems (FLA) via four bipod support structures. It sits above the OSEL sub-assembly and between the two instrument electronics enclosures (part of the ISTR). The figure below shows the relative layout of the Cryostat within the instrument and the various subsystems. The FLA is hidden in a machined pocket within the CAL mounting plate and not shown in Figure 15.

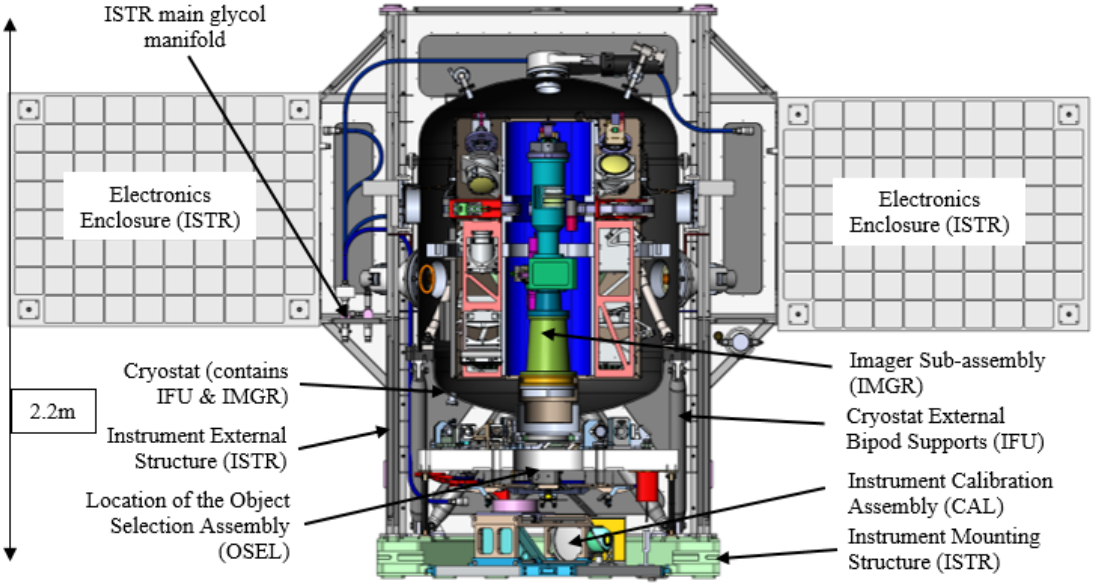


Figure 15 **Partial side section view of the instrument enclosure showing the relative position of the Cryostat within GIRMOS as well as the various subsystems in and around it. The overall height of the instrument is 2.2m and the width is 4.2m. The Cryostat is about 1m in diameter and 2m in height including its supports.**

10 Manufacturability Assessment

A standard process was put in place for manufacturability assessments where individual subsystem teams were responsible for ensuring the manufacturability of their respective subsystems. The GIRMOS project manager and mechanical systems lead reviewed the assessments. Please read the respective design documents for further details on manufacturability.

11 Optical Analyses

The performance analysis is done in two parallel chains, which are the IMGR and the IFU subsystems. The end-to-end (from telescope focal plane to the detector) analyses are presented for the IMGR and the IFU, which includes all upstream GIRMOS optical systems, in the following design documents:

- IMGR: GIRMOS.IMGR.DD.0008.A
- IFU: GIRMOS.IFU.DD.0008.B

More detailed analyses of the intervening subsystems can be found in the following design documents:

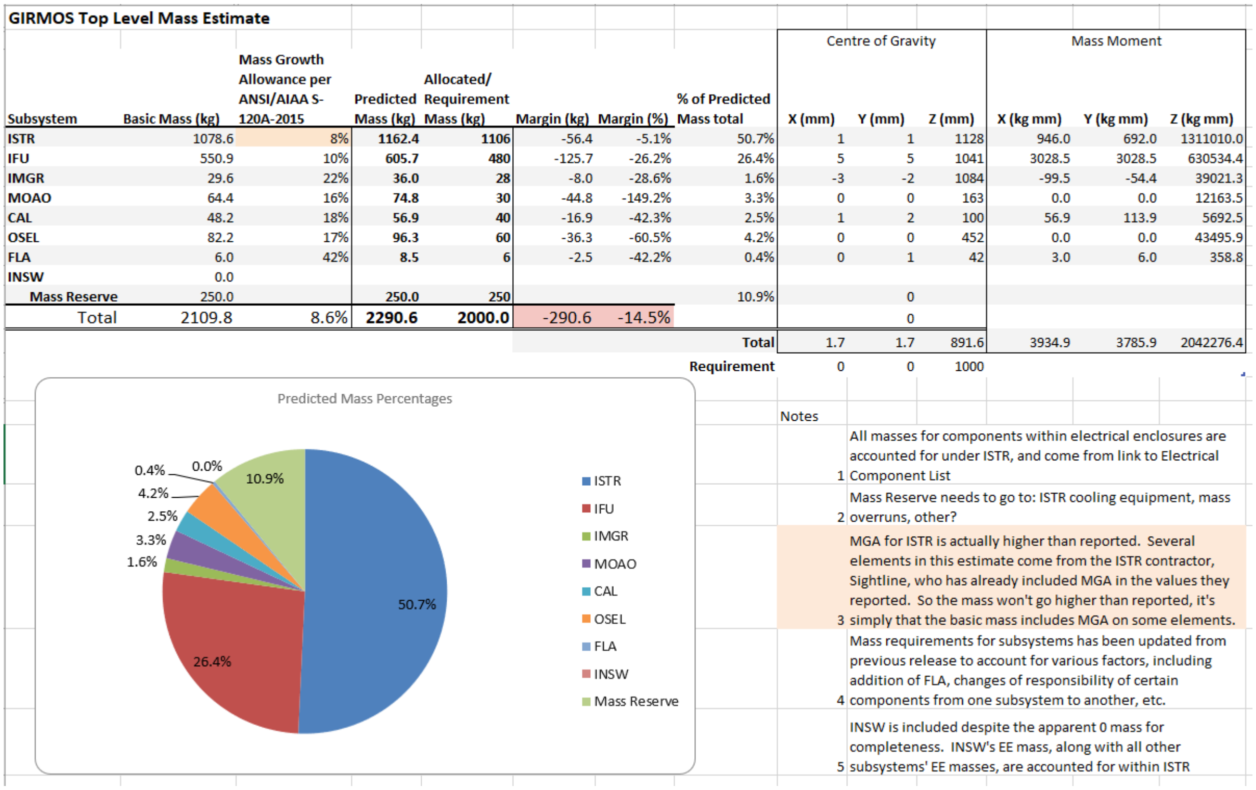
- FLA: GIRMOS.FLA.DD.0005.A
- CAL: GIRMOS.CAL.DD.0014.A
- OSEL: GIRMOS.OSEL.DD.0008.A
- MOAO: GIRMOS.MOAO.DD.0016.B

12 Mechanical Analyses

Detailed mechanical analyses of each subsystem are presented in their respective design documents. Here we discuss several instrument level analyses that were carried out.

12.1 Mass Budget

The mass budget is reported in full detail in [AD-01]. Each subsystem was allocated a Do Not Exceed (DNE) mass requirement for their system and for its electronics enclosure equipment. Top-level mass budget roll-up presented in Figure 16. The current best estimate for GIRMOS mass, including appropriate mass growth allowance and 12.5% system mass reserve, is 2290.6kg.



GIRMOS Top Level Mass Estimate

								Centre of Gravity			Mass Moment		
Subsystem	Basic Mass (kg)	Mass Growth Allowance per ANSI/AIAA S-120A-2015	Predicted Mass (kg)	Allocated/ Requirement Mass (kg)	Margin (kg)	Margin (%)	% of Predicted Mass total	X (mm)	Y (mm)	Z (mm)	X (kg mm)	Y (kg mm)	Z (kg mm)
ISTR	1078.6	8%	1162.4	1106	-56.4	-5.1%	50.7%	1	1	1128	946.0	692.0	1311010.0
IFU	550.9	10%	605.7	480	-125.7	-26.2%	26.4%	5	5	1041	3028.5	3028.5	630534.4
IMGR	29.6	22%	36.0	28	-8.0	-28.6%	1.6%	-3	-2	1084	-99.5	-54.4	39021.3
MOAO	64.4	16%	74.8	30	-44.8	-149.2%	3.3%	0	0	163	0.0	0.0	12163.5
CAL	48.2	18%	56.9	40	-16.9	-42.3%	2.5%	1	2	100	56.9	113.9	5692.5
OSEL	82.2	17%	96.3	60	-36.3	-60.5%	4.2%	0	0	452	0.0	0.0	43495.9
FLA	6.0	42%	8.5	6	-2.5	-42.2%	0.4%	0	1	42	3.0	6.0	358.8
INSW	0.0												
Mass Reserve	250.0		250.0	250			10.9%		0				
Total	2109.8	8.6%	2290.6	2000.0	-290.6	-14.5%			0				
							Total	1.7	1.7	891.6	3934.9	3785.9	2042276.4
							Requirement	0	0	1000			

Notes

1	All masses for components within electrical enclosures are accounted for under ISTR, and come from link to Electrical Component List
2	Mass Reserve needs to go to: ISTR cooling equipment, mass overruns, other?
3	MGA for ISTR is actually higher than reported. Several elements in this estimate come from the ISTR contractor, Sightline, who has already included MGA in the values they reported. So the mass won't go higher than reported, it's simply that the basic mass includes MGA on some elements.
4	Mass requirements for subsystems has been updated from previous release to account for various factors, including addition of FLA, changes of responsibility of certain components from one subsystem to another, etc.
5	INSW is included despite the apparent 0 mass for completeness. INSW's EE mass, along with all other subsystems' EE masses, are accounted for within ISTR

Figure 16 Detailed Mass and CoG Data

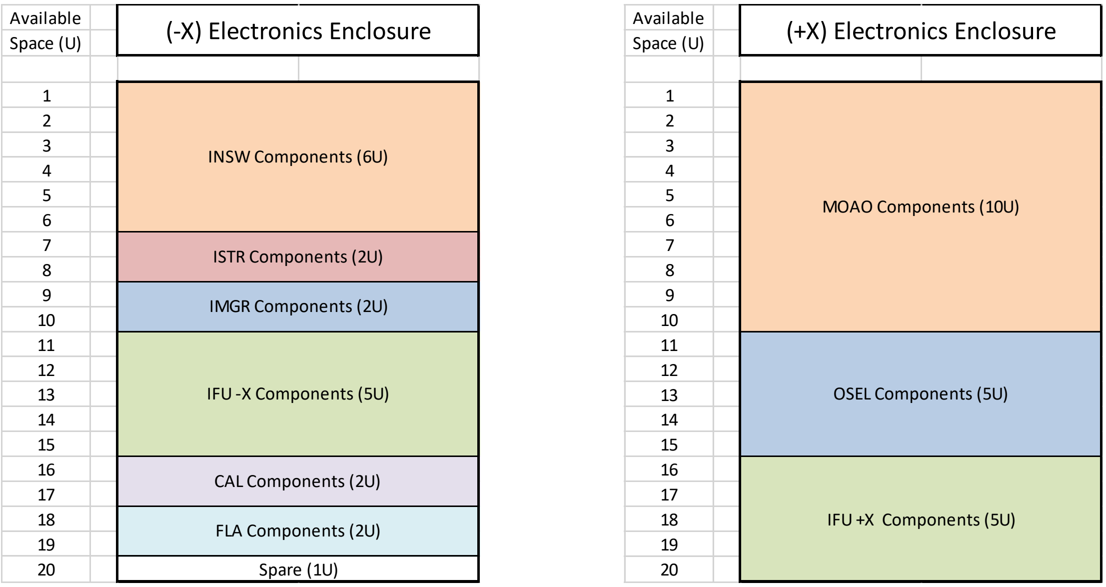
The detailed budget has been updated from the previous release to include both a formal mass growth allowance (MGA) and a system level contingency reserve. The MGA follows *Mass Properties Control for Space Systems ANSI/AIAA S-120A-2015* [RD-02]. The way mass is reported, and its growth is tracked, have been updated to reflect this. Specifically, subsystems report their basic mass, that is the mass they have determined their design to be based on CAD models and actuals. The subsystems then assess, based on the maturity of their design, a mass growth allowance on top of their basic mass. A system-level mass contingency reserve of 250kg is additionally held to account for unforeseen changes to the design, and needs for additional components, as was seen during this phase with the addition of the Field Lens Assembly (FLA). The total system mass is therefore the sum of the subsystem basic mass estimates, plus mass growth allowance, plus system mass reserve. The resulting mass margin is the difference between this sum and the mass requirement of 2000kg. As design progresses, the MGA should come down to reflect confidence in maturity of design. System mass reserve may be similarly decreased or allocated as needed.

For each component, the centre-of-mass (CoM) is estimated from the instrument CAD model. The mass and CoM of each component is then used to calculate the overall instrument centre-of-mass. The result must be equal to the L1 Instrument centre-of-mass requirement (x,y,z) = (0,0,1000 mm) +/- a small (TBD) tolerance. While no tolerance value has been made available, the intent is to design GIRMOS and each subsystem such that their CoMs are naturally very close to the CoM requirement, with the built-in ability to trim mass and ballast to get the CoM as close to the requirement as is necessary.

As stated near the start of this section, the GIRMOS system mass, inclusive of MGA and System reserve, exceeds the allowable mass by almost 15%. This issue is covered in the GIRMOS Risk Register [RD-03] as RID 11. The main reason for the mass requirement exceedance, at an instrument level, is that subsystems were not able to meet their mass allocations including mass growth allowance. A second small reason is the realized need for the Field Lens Assembly, which was not budgeted for in mass. Given the disproportionate masses of the subsystems, and in particular ISTR and IFU, at this time the main focus of efforts to resolving the exceedance is through mass reduction of these two subsystems. Work to date on ISTR has shown very good results in reducing mass by optimizing design of the GIRMOS Mounting Structure and External Structure. There are several relatively simple design changes planned to the IFU that should yield further mass savings. It is worth noting that for ISTR and IFU, there have not been, nor are there currently planned any formal mass reduction activities. We believe that simple design updates, commensurate with typical critical design, keeping mass optimization in mind, will get the system mass very close to, or below, the 2000kg requirement.

12.2 EE Volume Budget

The Electrical/Electronics Enclosure (EE) volume allocations and management are contained in [RD-04]**Error! Reference source not found.**. The current design of GIRMOS is to use two server racks, one in each EE (+X and -X). Each rack will have 20U of space, where a “U” is a server rack standard unit of vertical measurement. It is 44.45mm or 1.75 inches in height. Standard server rack equipment such as servers, shelves, patch panels, etc. are all sized in U’s, with a standard 19-inch width, and various depths, up to approximately 593mm. At the beginning of the program, volume allocations were made to each subsystem, defining the number of U’s their electronics could take up. During preliminary design, several changes were made to the EE volume allocation based on some subsystems needing more or less space, and the addition of the FLA, itself needing 2U. Note that late in preliminary design, the IFU allocation was updated to accommodate cryostat cable routing optimization, and some rearranging of the EE allocations was done (in consultation with, and causing no detrimental effects to, each affected subsystem).



Available Space (U)	(-X) Electronics Enclosure
1	INSW Components (6U)
2	
3	
4	
5	
6	
7	ISTR Components (2U)
8	
9	IMGR Components (2U)
10	
11	IFU -X Components (5U)
12	
13	
14	
15	
16	CAL Components (2U)
17	
18	FLA Components (2U)
19	
20	Spare (1U)

Available Space (U)	(+X) Electronics Enclosure
1	MOAO Components (10U)
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	OSEL Components (5U)
12	
13	
14	
15	
16	IFU +X Components (5U)
17	
18	
19	
20	

Figure 17 Electrical Enclosure Volume Allocation

12.3 Opto-Mechanical Alignment and FEA

The most sensitive optical systems to flexure are the OSEL and IFU since their optics need to be coaligned to a high degree to ensure the best optical performance. We have carried out an initial FEA of the two subsystems to evaluate the impact of gravity flexure on the OSEL output focal plane and exit pupil location and how it compares to the flexure with the IFU input focal plane and pupil stop.

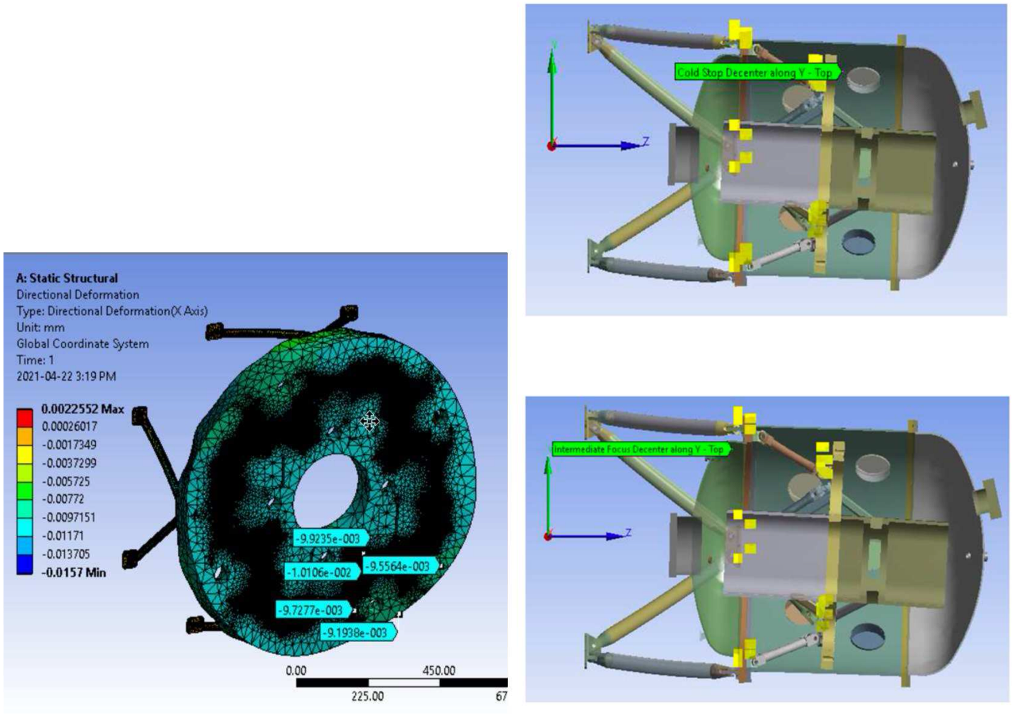


Figure 18 Displacements due to gravity from zenith to horizon (Pointing positions of OSEL bench (left) and IFU cryostat (right))

In this analysis only the flexures of the bi-pods supporting OSEL and the IFU are considered. The goal of this analysis is to assess the relative displacement of OSEL bench with respect to the IFU cryostat due to gravity when the telescope slews from zenith to the horizon. This is to estimate the required travel on OSEL/MOAO tip/tilt mechanisms (DM and M10) to recenter the exit pupil and image on the IFU cold stop and intermediate focus (IF) respectively.

Figure 18 shows the static deformations of the OSEL bipod/bench and the IFU cryostat when the instrument interface plane goes from horizontal (telescope at zenith) to vertical. Indeed, the entrance optical axis of each IFU channel is defined by the position of the IF (which also corresponds to the position of the slicer or detector since the IFU bench is assumed rigid) and of the cold stop center. We observe a 24 mas shift on the IFU focal plane, which exceeds the minimum required 6 mas. This can be easily corrected by applying some tilt on the DM. More detailed FEA analysis will be done in the Critical Design Phase to fully assess the optical impact of the internal flexure of each subsystem and the relative flexure between subsystems. For more details about this analysis, please review Section 7.2.2.5 of the OSEL design document.

13 Electrical Analyses

13.1 Power Draw Budget

This section discusses the entire system power budget for the instrument. The observatory is capable of supplying 2.88kW to a single electronics enclosure (EE).

At the telescope (ISS), four outlets are available 2 UPS and 2 Main (dirty power) outlets. The power limit is 2.88 KW / 120 VAC for each electronic enclosure. Therefore, we assign one UPS outlet to one electronics enclosure. The 2 Main (dirty power) are not used because it is not backed up in case of power failure. The maximum current rating for each UPS or main breaker is 24 Amps max.

Furthermore, the estimated power consumption of different equipment was established. The power budget is presented in the table below. As the project evolve and attain a certain level of maturity, the power budget was calculated and presented in the table below. The total power obtains for each electronic is below the 2.88Kw maximum capacity of the power supply at the telescope. At this stage of the project, the power budget was calculated using the maximum power rating of the components. This will give more margin as all the components are not working at their maximum capacities.

Table 4: (-X) Electronics Enclosure components

Subsystems	**Power Budget** (W)
INSW	565
ISTR	323
IMGR	263
IFU -X	914
CAL	24
FLA	29
Spare	
Total	**2118**

Table 5: (+X) Electronics Enclosure components

Subsystems	**Power Budget** (W)
MOAO	1502
OSEL	407
IFU +X	687
Total	**2596**

Given in Table 4 and Table 5, the calculated total power budgets for the (-X) EE and (+X) are 2118W and 2596W, respectively. Compared with the maximum power that the observatory can supply, the instrument will require 74% and 90% for the (-X) and (+X) EEs, respectively. This demonstrates that the observatory can supply the maximum power required by the instrument. In addition, the probability of having all the electrical components work at full power all the time is very low. Therefore, the 74% and 90% usage will likely be lower in actual use.

13.2 Grounding and shielding Plan

This section describes recommended grounding practices as applicable to the GIRMOS instrument. Because issues related to grounding are broad and deep in scope, this document only describes potential grounding issues as they apply specifically to the GIRMOS instrument.

13.2.1 Grounding plan

The Telescope Protective Earth Ground (Chassis) point is at the ISS, and this point should be kept as the protective earth ground. To avoid the possibility of ground loops the following approaches have to be taken:

- The use of optic fiber cables is highly recommended. Where the optic fiber cannot be used, the use of isolated twisted pair is recommended for interconnection.
- Power outlets ground inside the electronics enclosures (power bar) should be ground isolated from the structure of the electronic enclosure.
- RS-232, USB, or any other interconnect signal interfaces that include ground can be a potential source of ground loop. The solution is to isolate the COTS from the structure of the thermal enclosure and use the UPS ground as the protective ground.

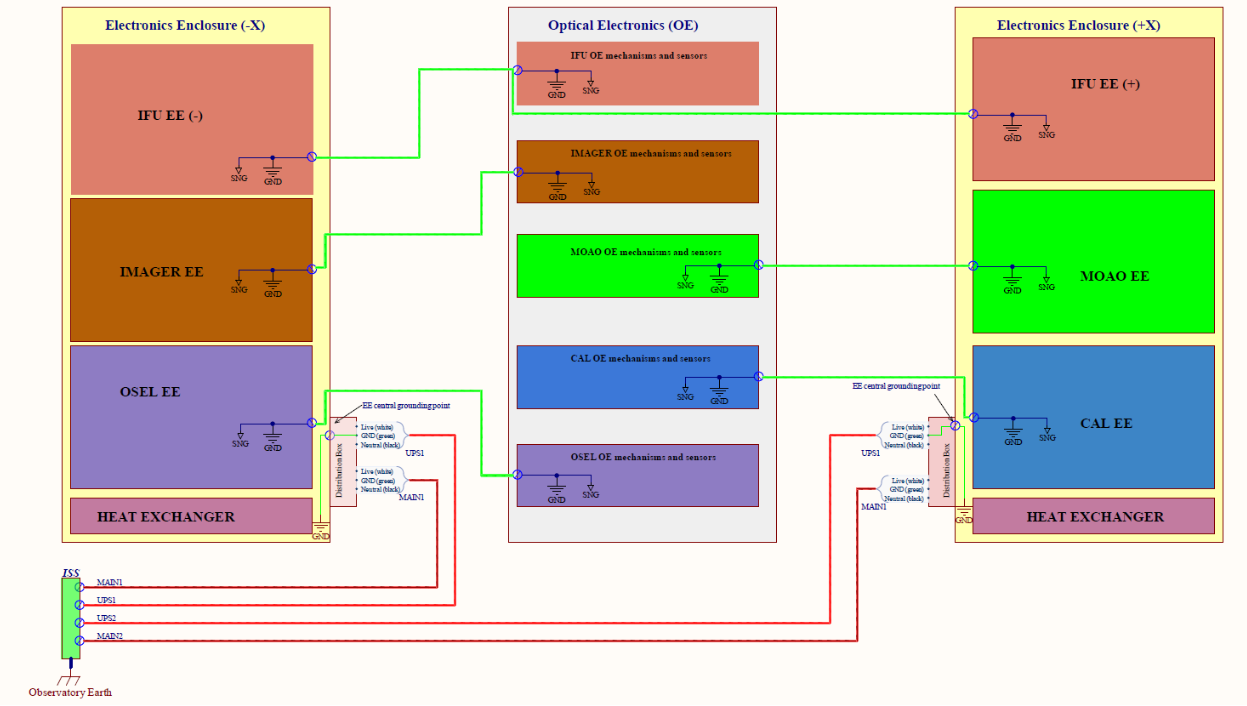


Figure 19: Instrument Grounding Scheme

13.2.2 Shielding plan

The figure below presents the shielding approach used and how it is connected to the ground. The ground has been divided into three branches. The one containing a high noise generation component is called dirty ground; the medium noise generation is called the clean ground and finally, the one having the sensitive component is also called clean ground. The figure below shows the approach with many details. In this figure, an example of connecting the motor and its cable shield is presented to show how the connection will be done. The low current components are like the sensor's controller and other none motor controllers. Taking imaging being at the heart of the entire instrument we separated its ground from the other clean ground. This approach will avoid the coupling of other clean ground components. In addition to the approach presents above, another detail for the sensor cable is presented below showing. In the figure, one can see that the chassis ground and shield are all connected to the electronics enclosure.

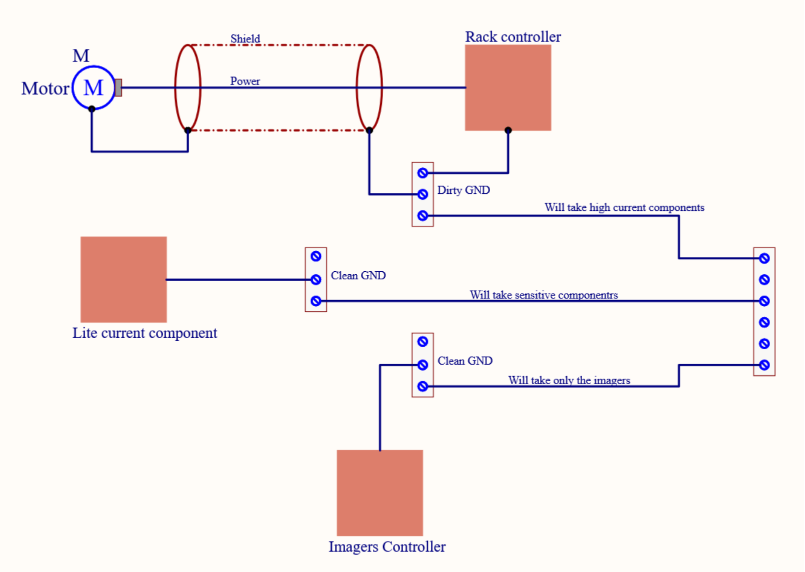


Figure 20: Ground branches and shield

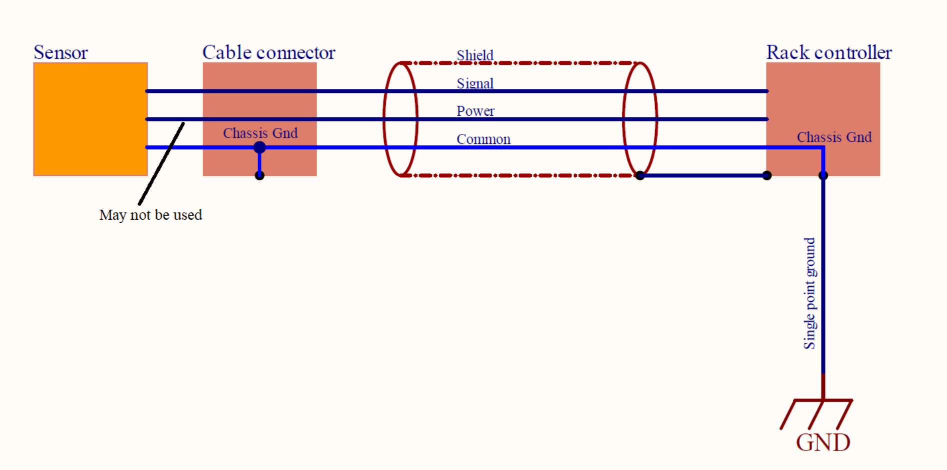
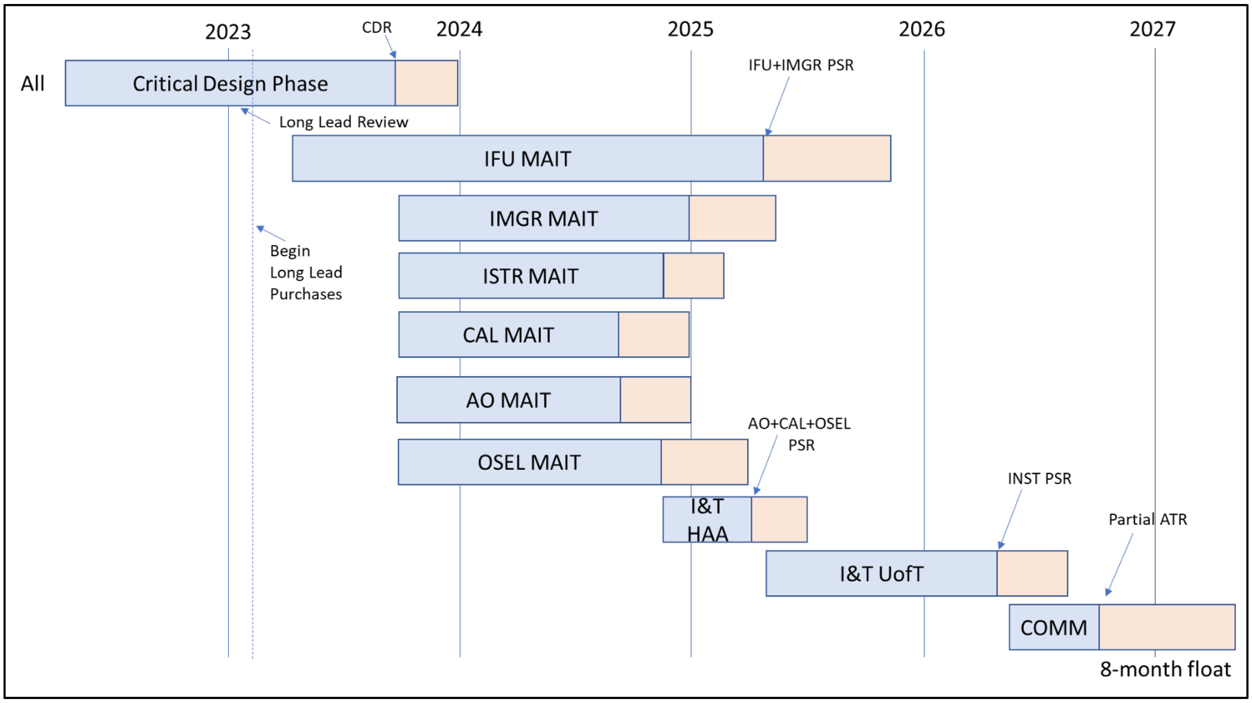


Figure 21: Shielding sensor cable

14 Preliminary MAIT Flowchart



The instrument MAIT begins with the Long Lead Review that takes place in Q1 2023. All subsystems will participate in this review to determine their design maturity and begin purchasing long lead items such as optics and image sensors. The MAIT process completes during the partial acceptance test review (ATR) at the telescope. We expect a partial ATR as GNAO is likely not ready at that time. GIRMOS can be partially validated at the telescope without GNAO. We expect the beam from the telescope to be significantly vignetted as it will be an f/16 beam. Nonetheless, the exit pupil will be located at the correct location. We will be carrying out a detailed study of the requirements that can be validated without GNAO early in the Critical Design Phase. A complete ATR will happen after first light with GNAO sometime later.

15 Preliminary Integration and Test Plan (I&T)

As shown in the MAIT flowchart, the overall integration of the GIRMOS instrument happens in two stages, first in the HAA I&T space in Victoria, BC, and then to the I&T space in Toronto, ON. HAA has a substantial I&T space where multiple astronomical instruments have been integrated and tested. Toronto is in the process of refurbishing a large lab that can handle an instrument the scale of GIRMOS. The Toronto I&T space is expected to become available early 2023.

The assumption is that every subsystem will be independently verified their requirements with their own test equipment prior to moving to integration with other subsystems. It is understood that there will be some requirements that can only be verified when two or more subsystems are integrated. One example of this is the MOAO system that is deeply integrated with OSEL.

The first step involves the integration of the FLA/CAL/OSEL/MOAO with the ISTR mounting structure at NRC-HAA in Victoria, BC. The second step involves the delivery of the integrated FLA/CAL/OSEL/MOAO system to the Toronto I&T facility, which will become available Q1 of 2023, where the IFU cryostat will be integrated, and the full end-to-end system will be tested. The CAL system will be essential for testing the end-to-end system, thanks to how closely it mimics the output beam of the GNAO system. Additionally, there will be an on-axis telescope simulator/AO verification unit (AOVU), that will test the overall imaging performance of each IFU optical chain with realistic residual turbulence and open-loop AO correction. The light from the AOVU, which simulates an on-axis GNAO beam, will pass through every optical component of the instrument. Upon completion of all these tests GIRMOS will undergo a pre-ship review after which it will be shipped to Gemini-North.

15.1 Optical Alignment during I&T

15.1.1 Subassembly alignment

There are numerous complexities associated with the optical alignment of all the subsystems. It is worth noting that there are five optical subassemblies (FLA, CAL, OSEL/MOAO, IMGR, and IFU) in the instrument. There are four independent channels in OSEL/MOAO and IFU. This requires a considerable number of focal planes and pupil planes to be aligned: 11 of each! We must also consider the structural stack-up of the different subsystems, which are all referenced to the ISTR's ISS mounting plate (Figure 22).

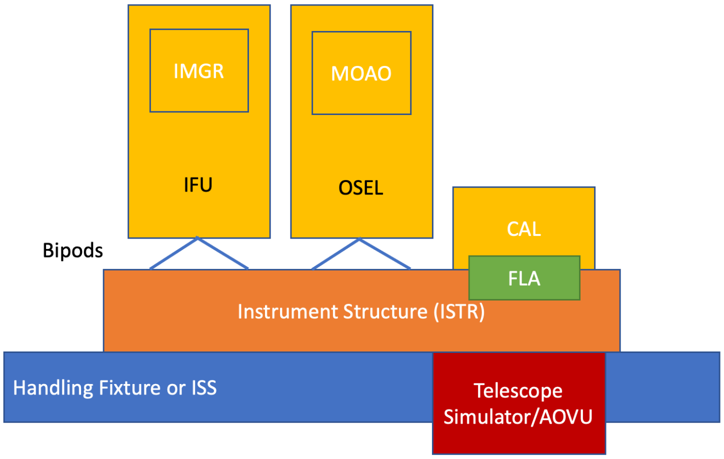


Figure 22 Structural stack-up of GIRMOS subsystems.

The relative alignment of the individual subsystems (FLA/CAL, OSEL/MOAO, and IFU/IMGR) can be adjusted through fine adjustments in their mounting points on the ISTR plate.

At HAA, the FLA/CAL unit will be delivered along with the ISTR mounting plate. These systems will be assembled with the OSEL/MOAO unit. The CAL metrology pinhole mask will help assess the quality of alignment of the OSEL with respect to the ISTR mounting plate. Once fully integrated, this intermediate assembly will be tested for gravity flexure on an Unertl table (Figure 23) as well as in a cold chamber to evaluate the performance at lower temperatures. The overall system will be tested with the AOVU to ensure the MOAO system is fully operational. This will be confirmed by observing the quality of the point spread function at the output focal plane of each OSEL arm. An initial flexure model will be developed and tested on the Unertl table. A preship review for these subsystems will take place at this point.

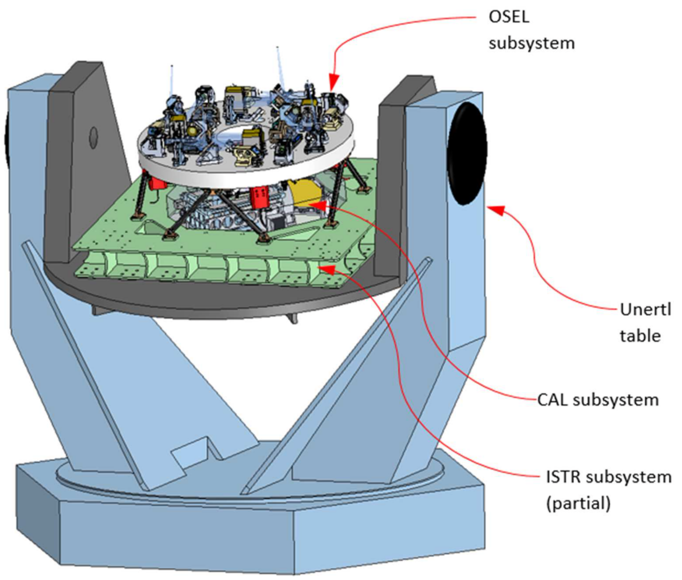


Figure 23 Unertl table with OSEL, CAL, and ISTR telescope mounting frame

This assembly configuration will be shipped to Toronto for final integration with the IFU cryostat, which will be close to completion upon arrival of GIRMOS front units. After being inspected, the IFU cryostat will be integrated into these subsystems after its preship review.

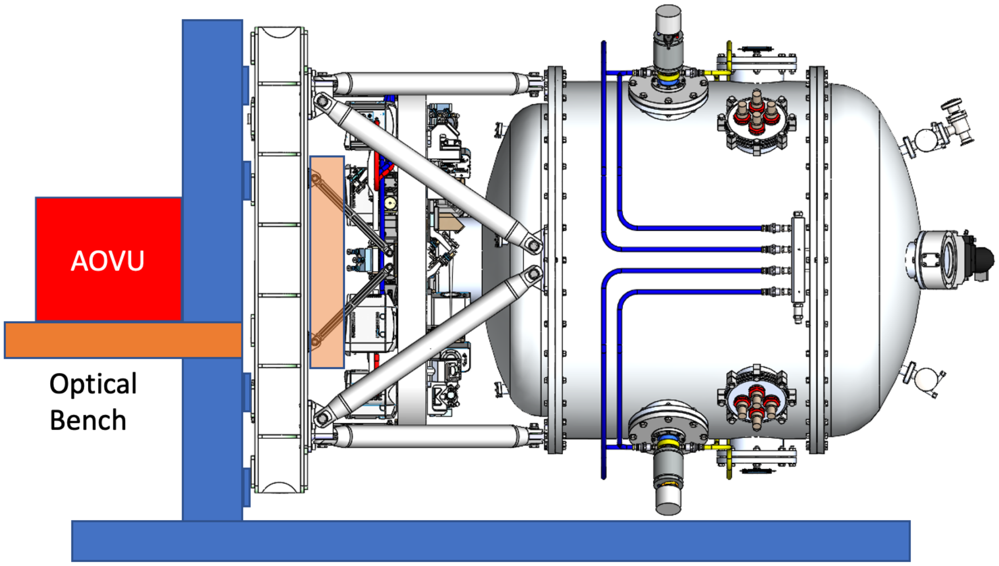


Figure 24 IFU integrated onto the rest of the subsystems.

With the IFU cryostat operation, the CAL system with its metrology mask in place will be used to first align the IMGR focal plane and pupil plane by adjusting shims on the cryostat mounting interface. This will require tip/tilt/decenter/focus adjustments.

Once this is complete, the alignment process will move onto each OSEL/IFU arm. Given that the four OSEL arms will have been prealigned to produce output focal planes that match the input focal planes of the IFUs, decenter adjustments will be made to the IFU cryostat to match the location of the focal planes. The IFUs will be operational so the necessary adjustments can be measured in real-time. Internal mirrors in OSEL can be adjusted to align the exit pupils with the cold stop of each spectrograph. The CAL metrology mask will be used to ascertain the image quality of each IFU arm.

The performance of each IFU channel will be validated by having the OSEL pick-offs probe their full range of motion to select different spots on the CAL metrology mask.

15.1.2 Flexure Measurements

After completing the optical alignment, the full instrument structure will be mounted onto the instrument, and it will be attached to its rotatable handling cart. We will carry out flexure measurements using the CAL metrology mask for the imager and each IFU channel by rotating the instrument about a single axis and determine the magnitude of flexure in the spectral and spatial directions. These measurements will be compared with FEA models to assess the design. Full flexure maps will be generated later at the Gemini observatory using its instrument simulator. These maps will be used to generate look-up tables for the pick-off mechanism positioning as well as pointing and pupil centering corrections for each IFU channel.

15.2 Operational Validation

At the Toronto I&T space, all operational and Gemini facility level requirements of the instrument will be tested. This includes validating the mass and power consumption/dissipation.

15.3 Telescope/On-Sky Validation

Depending on the status of GNAO when GIRMOS ships to Gemini, there are two possible paths. The more likely path is to test the instrument behind an uncorrected f/16 beam. This will be able to validate the pointing performance of the instrument along with its spectral performance, particularly throughput when the f/16 beam vignetting is accounted for. Gemini will effectively be a 4-meter telescope. The plate scales can be measured, albeit for a different f/#, and validated. Pupil image quality could also be measured by observing the sharpness of the central obscuration and the secondary supports.

There is a potential for the MOAO system to also operate in a truth wavefront sensor mode where it can make use of a bright natural guide star to close the AO loop and produce good image quality. This can in turn be used to test the image quality of the spectrographs. As mentioned earlier, a more substantial study will need to be carried out to determine which of the instrument requirements can be sufficiently validated using the f/16 beam.

When GNAO becomes available, GIRMOS will be integrated with the system and several key tests will be carried out prior to going on sky. One would involve the measurement of non-common-path-aberration (NCPA) aberrations using the pinhole mask with GNAO and the imager using phase diversity techniques to get the best image quality. A look-up table for spectrograph NCPA will also be generated as a function of pick-off arm position. Another test will be to apply known shapes on the GNAO mirror using internal calibration sources and correct for them with the GIRMOS DMs. This tests proper communication between the two RTCs.

On-sky we will test the two GIRMOS modes behind GNAO, MOAO and LTAO. MOAO performance will be evaluated on each individual IFU channel, while LTAO performance will be validated both by the IMGR and IFU channels in tiled mode. The imager will also be used to validate the GNAO GLAO mode.

16 Preliminary Quality/Product Assurance Plan

The GIRMOS Quality Assurance and Product Assurance (QA and PA) plan is contained within the GIRMOS Program Management Plan, see [AD-01]. As a high-level summary, QA and PA are being handled in two categories, the instrument level (i.e., GIRMOS as a whole) and the subsystem level.

16.1 FMECA

At the Instrument level, a Failure Modes Effects and Criticality Analysis will be done shortly after PDR to assess where likely failures are within the current design of GIRMOS, and how severe they will be. Using the results of this analysis, resources can be targeted to the specific areas where they are needed most.

16.2 DIAA I&T Processes

Currently in development and leveraging decades of experience designing and building complex optical systems, telescope instruments, and spaceflight hardware, the Dunlap Institute will use internal processes in a number of areas to ensure QA and PA during GIRMOS development. These processes will cover, but are not limited to:

- Material handling/stores
- Facility requirements, certifications, and processes
    - Cleanroom certification/maintenance/validation
    - Temperature and humidity monitoring/logging/remediation plan
    - Electrostatic Discharge (ESD)-safe workstations
    - Foreign Object Debris (FOD) mitigation processes/training
- Non-Conformance Reports (NRCs)
- Material Review Boards (MRBs)
- Request for Deviation and Waivers (RDW) process

At the Subsystem level, each subsystem has their own set of standards and processes for QA and PA. Where applicable, these will also be applied at a system level. They include:

- Vendor approvals/site audits
- Mandatory Inspection Points (MIPs) during manufacture/assembly
- Review of vendor-provided certificates of conformance (C of Cs), test reports, inspection reports
- Attend vendor design reviews (where appropriate)
- Inspection of incoming parts (where applicable)
- Certification of operators/specialists

17 Handling & Test Equipment (H&T)

The instrument handling and test equipment for the overall instrument are discussed in detail within the ISTR design document.