MAORY System MAIT Plan

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Contents

1. INTRODUCTION

1.1 Scope

This document describes the assembly, integration and test plan in Europe of the Multi-conjugate Adaptive Optics RelaY (MAORY) which is one of the first light instruments of the European Extremely Large Telescope (ELT).

The MAORY instrument is designed and developed by a European consortium composed by INAF (Istituto Nazionale di AstroFisica, Italy), CNRS/INSU (Centre National de la Recherche Scientifique/ Institut National des Sciences de l'Univers, France), NUIG (National University of Ireland Galway, Ireland) and ESO (European Southern Observatory, Europe).

The AIT of the overall instrument will take place at INAF-Bologna (Italy), and this document covers:

- Organizational and management aspects related to the overall MAORY AIT
- Responsibility sharing between the partners, including all the deliverables of the various partners
- Basic logistic aspects of the AIT at system level
- The overall MAORY instrument AIT procedure

The AIT is described at system level, while the sub-systems MAIT is described in separated documents prepared at sub-systems level. It is thus clear that the manufacturing of the various parts of the MAORY instrument is addressed at sub-system level in the related MAIT plans, addressing this document only the manufacturing of the handling tools and support equipment necessary for the AIT of the overall MAORY instrument.

The overall suite of documents (may be not fully comprehensive, TBC with ESO) that shall be provided for the PDR/FDR by the AIV team is:

- Europe MAIT Plan (this document) – PDR
- IAA Chile AIT Plan (draft version for PDR, final version for FDR)
- The MAORY Technical Commissioning Plan (FDR)
- The MAORY System Maintenance Manual (FDR)

1.2 Definitions, Acronyms and Abbreviations

AD	Applicable Document
ADP	Acceptance Data Package
AO	Adaptive Optics
AIT	Assembly Integration Test
AIV	Assembly Integration Verification

BIH	Bologna Integration Hall
BoM	Bill of Material
CA	Clear Aperture
CBS	Cost Breakdown Structure
CMP	Configuration Management Plan
CoG	Centre of Gravity
CoI	Co-Investigator
CP	Corrective Plate
CV	Curriculum Vitae
CNRS	Centre National de la Recherche Scientifique
DoF	Degree of Freedom
ELT	European Extremely Large Telescope
EFC	Executive Funding Committee
ESO	European Southern Observatory
DASF	Dichroic Assembly Support Frame
DM	Deformable Mirror
DRD	Document Requirements Definition
FDR	Final Design Review
FoV	Field of View
FTE	Full Time Equivalent
GTO	Guaranteed Time Observing allocation
HT	Handling Tool
HW	Hardware
IAA	Instrumentation Assembly Area
ICDR	Instrument Critical Design Review
IECR	Instrument End of Commissioning Review
IFP	Input Focal Plane
INAF	Istituto Nazionale di AstroFisica
ICH	Instrument Control Hardware
ICS	Instrument Control Software
INSU	Institut National des Sciences de l’Univers
IORR	Instrument Operations Readiness Review
IPAG	Institut de Planétologie et d’Astrophysique de Grenoble

IPDR	Instrument Preliminary Design Review
ISQR	Instrument System Qualification Review
ISRR	Instrument System Requirements Review
KO	Kick Off
LGS	Laser Guide Stars
LGSO	LGS Objective
LOR	Low Order and Reference
LoS	Line of Sight
LT	Laser Tracker
LVDT	Linear Variable Displacement Transducer
MAD	Multi conjugate Adaptive optics Demonstrator
MAIT	Manufacturing Assembly Integration and Test
MAORY	Multi Conjugate Adaptive Optics Relay for ELT
MC	Monte Carlo
MCAO	Multi Conjugate Adaptive Optics
MOA	Maory Optical Alignment
MES	MICADO Emulating Structure
MICADO	Multi-AO Imaging Camera for Deep Observations
MoU	Memorandum of Understanding
MRB	Material Review Board
MS	Motorized Stage
MSS	Main Support Structure
MSQR	MAORY System Qualification Review
MTA	Milestone Trend Analysis
N/A	Not Applicable
NCR	Non Conformity Report
NGS	Natural Guide Star
NIP	Nasmith Interface Plate
NUIG	School of Physics at the National University of Ireland Galway
OA	Optical Alignment
OAA	Osservatorio Astrofisico di Arcetri
OAAB	Osservatorio Astronomico d’ Abruzzo
OAB	Osservatorio Astronomico di Brera

OACN	Osservatorio Astronomico di Capodimonte
OAPD	Osservatorio Astronomico di Padova
OAS	Osservatorio di Astrofisica e Scienza dello Spazio di Bologna
OFP	Output Focal Plane
PA	Product Assurance
PAC	Preliminary Acceptance Review in Chile
PAE	Preliminary Acceptance Europe
PAP	Product Assurance Plan
PDM	Product Data Management
PDR	Preliminary Design Review
PFS	Pre Focal Station
PI	Principal Investigator
MPI	MICADO Pupil Imager
PM	Project Manager
PMP	Project Management Plan
PSF	Point Spread Function
PT	Product Tree
PTT	Piston Tip Tilt
PtoV	Peak to Valley
QE	Quantum Efficiency
RAMS	Reliability, Availability, Maintainability, Safety
RD	Reference Document
RMS	Root Mean Square
RON	Read Out Noise
RR	Retro Reflector
RTC	Real-Time Computer
SAT	System Architect Team
SCAO	Single-conjugate Adaptive Optics
SEq	Support Equipment
SET	System Engineering Team
SMR	Spherically Mounted Retroreflector
SNR	Signal to Noise Ratio
SOW	Statement of Work

SQR	System Qualification Review
SR	Strehl Ratio
SRR	System Requirements Review
SW	Software
TAC	Test and Alignment Camera
TAT	Technical Advisor Team
TBC	To Be Confirmed
TBD	To Be Defined
TBH	To Be Hired
TBW	To Be Written
TCS	Telescope Control Software
TRA	Technology Readiness Assessment
TRL	Technology Readiness Level
TRR	Test Readiness Review
TTF	Tip Tilt & Focus
VCD	Verification Control Document
VLT	Very Large Telescope
WBS	Work Breakdown Structure
WFS	Wavefront Sensor
WP	Work Package
WRT	With Respect To
WS	WorkShop
YPR	Yaw Pitch Roll

2. RELATED DOCUMENTS

2.1 Applicable Documents

The following applicable documents form a part of the present document to the extent specified herein.

AD1 MAORY Agreement
ESO-281109 Version 1

AD2 MAORY (E-ELT MCAO) Statement of Work
ESO-257875 Version 1

AD3 MAORY (E-ELT MCAO) Technical Specification
ESO-254311 Version 1

AD4 Common Requirements for E-ELT Instruments
ESO-254547 Version 2

AD5 Common ICD between the E-ELT Nasmyth Instruments and the Rest of the E-ELT System
ESO-253082 Version 4.1

AD6 MAORY Product Assurance Plan
E-MAO-000-INA-PLA-003 Version 1

AD7 MAORY Risk Management Plan
E-MAO-000-INA-PLA-004 Version 1

AD8 MAORY Risk Analysis Plan
E-MAO-000-INA-RRR-001 Version 1

AD9 CAD 135139 Nasmyth Platform Interfaces

2.2 Reference Documents

The following documents, of the exact version shown herein, are listed as background references only. They are not to be construed as a binding complement to the present document.

RD1 ESO PDM Document Types and Definitions
Number ESO-231062 Version 1

RD2 Systems Engineering General Requirements
ECSS-EST-10C Version 3

RD3 MAORY Management Plan
E-MAO-000-INA-PLA-001 Version 04

RD4 MAORY System Overview
E-MAO-000-INA-DER-001 Version 01

RD5 Donut: Measuring Optical Aberrations from a Single Extrafocal Image
PASP 118: 1165-1175, 2006, Tokovinin & Heathcote

RD6 LBC wavefront reconstruction software upgrade
Technical report, 17 April 2014, Stangalini, M.

RD7 Simulation of the Donut method for MAORY
Technical note, XX 2020, Rodeghiero, G.

RD8 The MICADO first light imager for ELT: cold optics instrument
Proc of SPIE, 2018, Schubert, J., et al.

RD9 MAORY System Optical Design and Analysis Report
E-MAO-SF0-INA-DER-001 Version 01

RD10 MAORY System Design Report
E-MAO-SE0-INA-DER-001 Version 1.0

RD11 MAORY System Analysis Report
E-MAO-SE0-INA-ANR-001 Version 1.0

RD12 MAORY System Interface Description Document issue 1
E-MAO-SE0-INA-ICD-001 Version 1.0

RD13 MAORY Main Structure Design Report
E-MAO-PM0-INA-DER-001 Version 1.0

RD14 PFS Hosted Metrology, ESO AIV Workshop 23 February 2021, S.Guisard et al.

RD15 MAORY AO Test Plan, version 1.0
E-MAO-PV0-NUIG-PLA-001

RD16 MAORY Bill of Material Version 1.0
E-MAO-MCO-INA-BOM-001

RD17 MAORY Hazard List and Analysis Version 1.0
E-MAO-000-INA-DER-001_02

RD18 Calibration Unit Design and Analysis Report Version 1D5
E-MAO-PU0-INA-DER-001_1D5

RD19 MAORY LGS WFS MAIT Plan Version 1.0
E-MAO-PL0-IPA-PLA-015_01

RD20 Test Unit Design Version 1.0
E-MAO-PV0-NUIG-DER-001_D1

RD21 The MICADO first light imager for ELT: derotator design status and prototype results,
Barboza S., et al. SPIE 2018

3. OVERVIEW

The project history, the MAORY consortium and the instrument overview are described in detail in RD3 and RD4. In this section we just briefly recall the main characteristics of the instrument and of the consortium, with the aim of clarifying the framework in which the MAIV process will be carried out.

3.1 Project overview

The MAORY instrument description given here is based on the design developed for the PDR.

3.1.1 Project description

The main function of MAORY is to relay the light beam from the ELT focal plane to the client instrument while compensating the effects of the atmospheric turbulence and other disturbances affecting the wavefront coming from the scientific sources of interest.

MAORY has two operational modes:

- In MCAO mode; wavefront sensing is performed by up to six LGS and three NGS. The NGS are used for both Low-Order and Reference (LOR) sensing; wavefront compensation is performed by means of the telescope's M4/M5 mirrors and by one or two (TBC) post-focal DMs inside MAORY. The choices to implement the MCAO technique and to use LGS for wavefront sensing have been taken to improve the performance uniformity over the field of view and the sky coverage. The MCAO technique has already been demonstrated on sky by MAD on VLT and, together with multiple LGS, by GeMS on the Gemini Telescope.
- In SCAO mode; wavefront sensing is performed by a single NGS as close as possible to the direction of the scientific target in the sky; wavefront compensation is performed in this mode by means of the telescope's M4/M5 mirrors only. The SCAO mode is a joint development between the MAORY and the MICADO consortia (AD2 Statement of Work and AD3 MAORY Technical Specification).

MAORY has to be installed on the ELT Nasmyth platform. It feeds two focal stations: the gravity invariant port for MICADO and the lateral port for another instrument TBD.

The next figure shows the functional block diagram of the instrument.

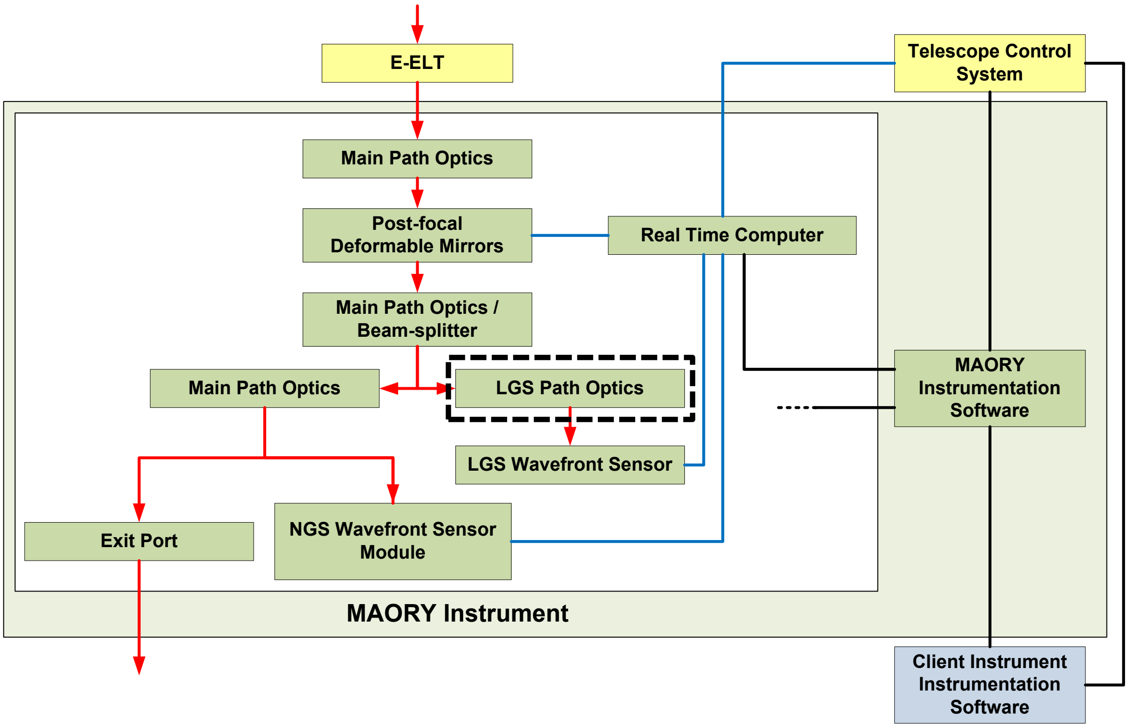


Figure 1. MAORY Instrument functional block diagram. Red arrows: light path. Blue lines: real-time signals. Black lines: non real-time signals. The black dotted line departing from the MAORY Instrumentation Software block indicates that this block has connections with other sub-systems which are not shown in this diagram for simplicity.

3.1.2 The MAORY consortium

The MAORY Consortium is composed of three Institutes: INAF from Italy, CNRS/IPAG from France and NUIG from Ireland. ESO, although not a Consortium partner, provides specific contributions which are described in AD2 Statement of Work.

The lead Institute is INAF. The local institutes within the consortium provide logistic support to the project and the necessary work-power.

All the member institutes provide support to the System Engineering team and to the MAIV team.

3.1.2.1 The MAORY Consortium in Italy

The local Observatories involved in the development of MAORY in Italy are the following:

- INAF OAS (Bologna), providing the MAORY PI, PM; INAF OAS also provides the Bologna Assembly Hall (BAH), where MAORY will be integrated in Europe, and support to the ICH, RTC and MAIV activities.
- INAF OAA (Arcetri - Firenze), providing Adaptive Optics System Engineering and management, DM WP management and procurement, Simulation SW WP management and procurement and NGS WFS WP management and procurement.

- INAF OAAB (Abruzzo – Teramo), providing Calibration Unit WP management and procurement.
- INAF OAB (Brera - Milano), providing System Engineering WP management, Thermal Control System WP management and procurement, Opto-mechanics WP management and procurement and support to the Optical Design WP.
- INAF OACN (Capodimonte - Napoli), providing the Main Structure WP management and procurement and the ICH WP management and procurement.
- INAF OACT (Catania), providing support to the Optical Design WP.
- INAF OAPD (Padova), providing PA WP management, Optical Design WP management, MAIV WP management, ICS WP management and procurement, RTC WP management and procurement and Science WP management.

3.1.2.2 The MAORY Consortium in France

The institute involved in the development of MAORY in France is CNRS/INSU (Centre National de la Recherche Scientifique/Institut National des Sciences de l'Univers) representing IPAG, that is responsible of the LGS WFS WP management and procurement, and will participate to all phases of the MAORY project, from the design phases to the integration and commissioning phases.

3.1.2.3 The MAORY Consortium in Ireland

The institute involved in the development of MAORY in Ireland is the School of Physics at the National University of Ireland Galway (NUIG), that is responsible of the Test Unit WP management and procurement, and will participate to all phases of the MAORY project, from the design phases to the integration and commissioning phases.

3.1.2.4 ESO contribution

ESO is responsible of the System Calibration WP, which carries out the design and development of the MAORY calibration strategy

3.2 Instrument Overview

MAORY is a wide field adaptive optics system, that will serve the MICADO camera and a second instrument TBD. MAORY will take advantage of the ELT M4 adaptive mirror, which will deliver a partially corrected wavefront to the instrument.

MAORY has to provide, as already mentioned, two adaptive optics modes to support MICADO:

- MCAO mode, in which at least two deformable mirrors are conjugated to different altitudes in the atmosphere; one of these deformable mirrors is the telescope M4;
- SCAO mode, in which wavefront compensation is performed using M4 only.

The MCAO mode has to be available at first light with at least one deformable mirror in MAORY, with provision for a second deformable mirror as an upgrade, implying that MAORY has to be designed for two deformable mirrors from the beginning, with one deformable mirror being possibly replaced by a rigid mirror.
The MCAO mode of MAORY is based on the use of 6 LGS. Natural guide star wavefront sensors (3 in the baseline design) are also required to complement LGS measurements.

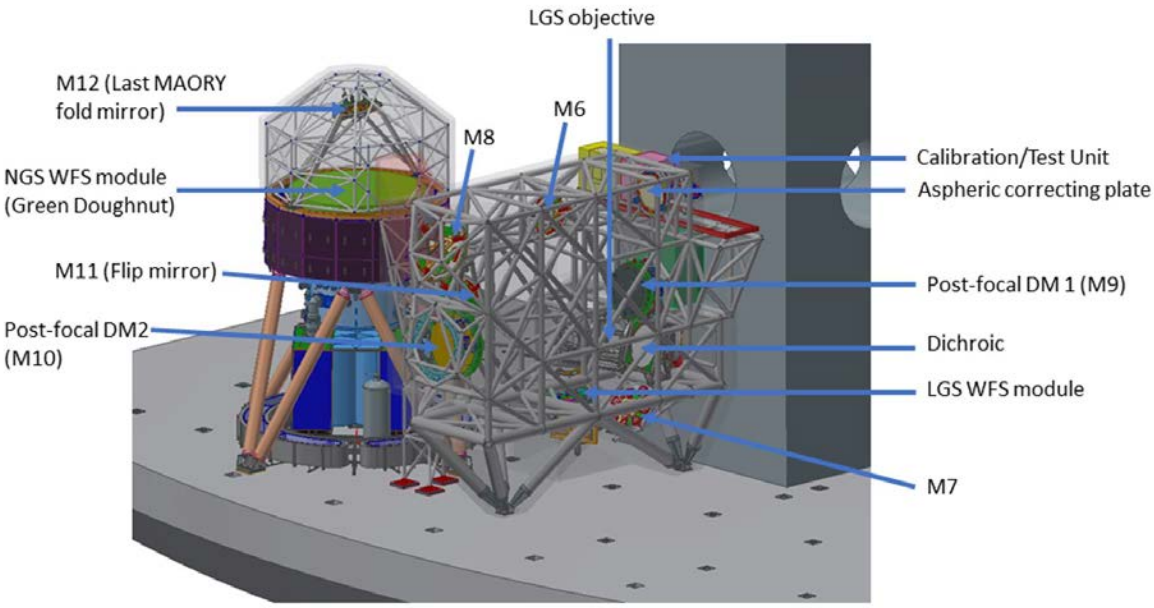


Figure 2: a 3-D view of the MAORY instrument (the thermal cover is shown in transparency) installed on the Nasmyth platform with MICADO

The NGS wavefront sensor and the last MAORY folding mirror (M12) are hosted in the same structure, the so-called Green Doughnut (GD), located above the MICADO instrument.

The MAORY main structure, holding all the opto-mechanics of the bench and the main sub-systems, is a tubular structure which is connected to the Nasmith floor with 3 legs. A thermal cover will maintain the instrument temperature stable within a certain range.

In Figure 2 there is a view of the MAORY instrument, with the main sub-systems highlighted, which will be briefly described in the following section.

3.2.1 The main MAORY sub-systems

In Figure 3 we report the instrument product tree, which identifies the main MAORY sub-systems, that we list in the following, together with the institute responsible of its design and MAIT:

- Main structure (main optical bench and supporting structure, including all the nessary HTs at sub-system level); INAF-OACN (Osservatorio Astrofisico di Capodimonte Napoli) is the responsible of this sub-system.
- Opto-mechanics (all the opto-mechanical components of the main train optical path, which is including all the optical components and their mounts and adjusting mechanism and all the HTs at sub-system level); INAF-OAB is the responsible of the opto-mechanics.
- Deformable Mirrors (two post focal DMs providing the correction of the upper part of the atmosphere, M9/DM1 convex with 1026 actuators, M10/DM2 concave with 1147 actuators); INAF-OAA is responsible of this sub-system.

- The Low Order and Reference (LOR) Module (which implements the Natural Guide Star Wavefront sensing functionalities needed by MAORY in the MCAO mode); INAF-OAA is responsible of this sub-system.
- The LGS WFS module (dedicated to the measurements of the high order wavefront aberrations using as references the laser beams provided by the telescope). IPAG is responsible of this sub-system.
- The Calibration Unit (which is a system dedicated to the MAORY calibration, equipped with light sources simulating the NGSs and LGSs); INAF OAAB ir responsible of this sub-system.
- Instrument Control SW (the SW controlling all the functions of the MAORY instrument and providing interfaces toward ELT and MICADO); INAF OAPD is responsible of such a system.
- E2E Simulation Code (a simulation tool dedicated to estimate the performance of the MCAO system); INAF OAA is responsible of such a system.
- RTC (HW and SW controlling the AO real time MAORY functions); INAF OAPD is responsible of this system.
- Instrument Control Hardware (controllers, power supplies, harnesses and other electronics components to control the MAORY instrument at system level); INAF OACN is responsible of this system.
- Thermal Control System (which provides a passive shielding of the MAORY instrument to maintain the instrument temperature stable within a certain range); INAF OAB is responsible of such a sub-system.
- Test Unit (a support equipment be used at PAE to verify the MAORY AO performances); NUIG is responsible of this sub-system.
- ESO deliverables (WFSs detectors)

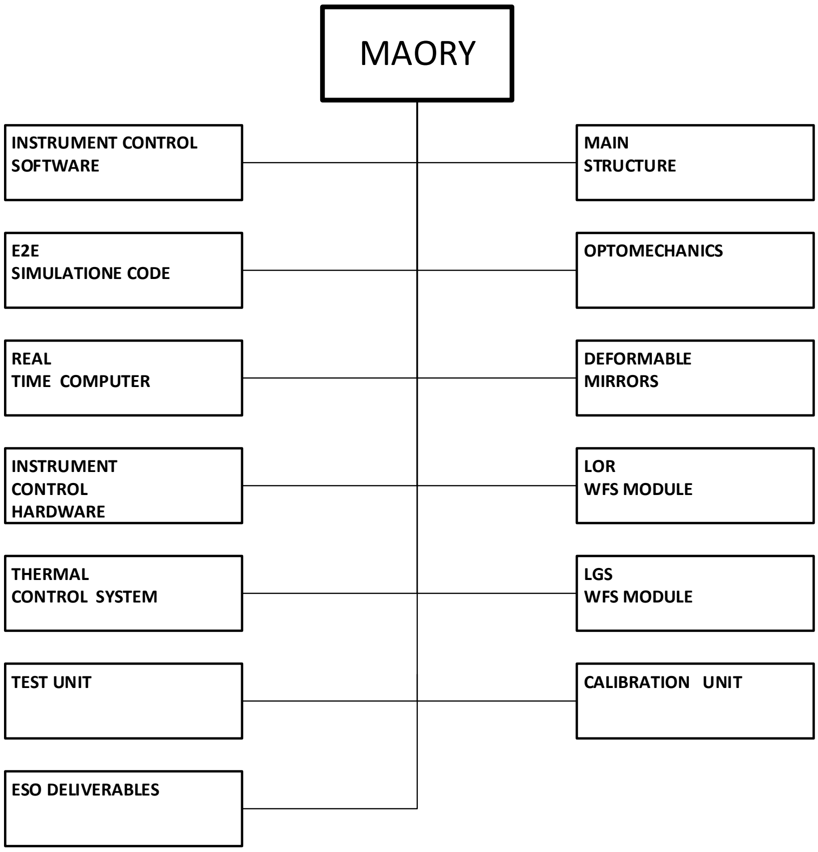


Figure 3: the MAORY instrument product tree

3.3 MAORY MAIT overview

MAORY is a multi-conjugated adaptive optics instrument, which will provide the corrected FoV to the MICADO camera. The latter, due to the delay of the MAORY project for the reasons explained in RD3, will be most probably installed at the ELT before MAORY will be ready. For this reason, and for the difficulties to mimic the telescope behaviour, the final instrument performance of MAORY + MICADO can only be assessed at ELT level. Furthermore, all the final interfaces and the "instrument to telescope alignment" can be only performed at ELT level too.

Therefore, a test/verification strategy has been developed based on:

- partial performance and functional test at MAORY sub-systems level
- even though the MICADO camera will not be available, the alignment procedure will be performed considering the instrument performance throughout the whole FoV, to minimize the risk of more conventional on-axis alignment strategy. MICADO will be simulated by using a test camera moving over the full FoV.
- overall instrument test to characterize the instrument performance on and off-axis in a wide variety of situations
- an "instrument to telescope" alignment procedure defined accordingly the guidelines defined by ESO (RD14), which will be partially reproduced and tested

also in the BIH, by checking the capability to adjust the MAORY MSS within the expected range and accuracy

We also recall the baseline assembly and alignment strategy, which has been presented at the trade-off review, consisting in the following main steps:

1. Main Support Structure (MSS) population with all the opto-mechanics and references for the LT alignment
2. Laser tracker alignment for all of them to their nominal position (wrt Input Focal Plane (IFP) SMRs), within a reasonable accuracy
3. Fine tuning of the WFE acting on M10/DM2 tip/tilt and focus
4. Fine tuning of pupil and exit focal plane position by tip-tilting the last two flat mirrors, M11 and M12

If necessary, the last two steps will be repeated iteratively, since the alignment of DM2 will affect the position of the pupil and of the exit focal plane. No active corrections are necessary to the optics up to M10/DM2, simplifying the AIV procedure.

To this 4 steps, we add the following items:

5. Pupil and focal plane alignment within the LGS WFS
6. MAORY to PFS alignment test
7. MAORY testing phase

Concerning the alignment strategy just presented, it has to be emphasized that the MAORY optical design allows for loose alignment tolerances of all the optics but M10/DM2, the focus and TT of which are the only compensators permitting to fine tune the final optical quality of the wavefront delivered by the system (details are given in sec. 8.1.4).

Given the AIT strategy just presented (which will be validated in Sec. 8.1), we can thus summarize the guidelines of the AIT plan in the following main steps:

- to realize and use an interface plate mimicking the Nasmith floor (Nasmith Interface Plate – NIP), connected to the laboratory floor (TBD) and referenced to the laboratory (where some “permanent” SMRs are installed) through LTs located into the integration hall and SMRs located on such interface
- to install the MSS on such a NIP, and then characterize the MSS stability by checking the movement (vs time and vs T variations) of SMRs positioned on the MSS vs the ones positioned on the BIH and on the NIP
- to install all the dummies with the aim of checking all the interfaces positions under load and, also considering the “as built” optical design re-optimized on the base of the opto-mechanics measured manufacturing errors, re-machine (wherever necessary) the interface plates between the MSS and the opto-mechanics, in a way to have all the interfaces as close as possible to their nominal positions; the interfaces re-machining operations will require the dummies removal and their successive re-installation once the new interfaces will be available, giving the possibility of checking all the installation/dis-installation procedures and Handling Tools (and correct/modify them if necessary); after re-installation, all tbe interfaces of the opto-mechanics will be measured again

- the structure (MES – Micado Emulatiing Structure) holding a “Micado replacement camera” (a test camera installed on a XYZ system spanning the whole FoV), the LOR, the bearing and M12 can now be installed, everything positioned nominally wrt the MAORY bench (LTs used against MSS SMRs and MES SMRs)
- the full thermal cover can also be installed on the MSS and on the MES, with the aim to check the installation procedure and to characterize the thermal behaviour the bench stability (vs time and T changes) in a configuration very similar to the final one
- in this configuration, to check and characterize the overall MSS alignment adjustments (to validate the alignment procedure of MAORY to the PFS)
- only after having a full characterization of the environment and MSS stability with the thermal cover and a verification of the installation/uninstallation procedures, all the dummies and the thermal cover shall be dismounted and we can thus proceed with the installation of the real opto-mechanical sub-systems, perform the cables and pipes installation and routing, and install also the electronic cabinets and the ICS SW in a way that all the motorized functions can also be functionally tested
- the integration of the opto-mechanics will be done using internal MSS LTs against a flange materializing the Input Focal Plane through three SMRs, previously characterized using a CMM
- at this point, the two main phases of the alignment procedure can be carried on, first refining the positioning of all the opto-mechanical components using the LTs (should this operation be possibly done at the moment of the assembly of each opto-mechanical components, this step may be already done at this point, saving the time consuming procedures of accessing the alignment mechanisms of each optics) and after by fine tuning the optical quality on the output focal plane with the only compensator M10/DM2 by acting on its tip-tilt and defocus; eventually, tip-tilt of the last 2 flat mirrors, M11 and M12, can also be remotely actuated to adjust the output pupil and focal plane position
- the latter’s need to be then adjusted also of the LGS WFS, by acting on the LGS-O and on the first and the last LGS-O flat folding mirrors
- last but not least, the test unit will be installed and the test campaign will start

In section 8 we describe in detail the main steps of the MAORY AIT procedure in Bologna, just briefly introduced here.

3.4 MAORY MAIT Items Nomenclature

Table 1 Univocal MAORY items code RD16 and nomenclature used through the current document.

Univocal Item code	Nomenclature used in the MAIT document	Notes
E-MAO-PFK	Schmidt-Plate	
E-MAO-PFA	M6 Assembly	
E-MAO-PFB	M7 Assembly	

E-MAO-PFC	M8 Assembly	
E-MAO-PDA	DM1 Assembly	
E-MAO -PDB	DM2 Assembly	
E-MAO-PFD	Dichroic Assembly	
E-MAO-PFE	M11 Assembly	
E-MAO-PFF	M12 Assembly	
E-MAO-PFG	LGS Fold Mirror 1 Assembly	
E-MAO-PFH	LGS Objective	
E-MAO-PFI	LGS Fold Mirror 3 Assembly	
E-MAO-PFJ	CU Folding Mirror Assembly	
E-MAO-PFL	M9 Dummy Assembly	
E-MAO-PFM	M10 Dummy Assembly	
E-MAO-PN0	LOR WFS Module	
E-MAO-PT0	Thermal Unit	
E-MAO-PU0	Calibration Unit	

4. MANAGEMENT

In this section, the management of the AIT part is described.

4.1 Tasks

The main task that will have to be performed are:

- Bologna AIH (B-AIH) facility preparation
- AIT tools/handlings/Support equipment procurement and commissioning
- MAORY assembly
- MAORY integration
- MAORY test (described in RD XXX)
- MAORY de-integration for shipping preparation
- MAORY shipping
- Bill of Materials (BoM) of all the AIT related stuff (mainly the support equipment, described in sec. 0) preparation
- Reliability, Availability, Maintainability and Safety (RAMS) of all the AIT related stuff (mainly the support equipment, described in sec. 0) preparation

4.2 Inputs

The inputs for the realization of the MAIT plan are coming from the following applicable documents:

- AD2 MAORY (E-ELT MCAO) Statement of Work
  ESO-257875 Version 1
- AD3 MAORY (E-ELT MCAO) Technical Specification
  ESO-254311 Version 1
- AD4 Common Requirements for E-ELT Instruments
  ESO-254547 Version 2
- AD5 Common ICD between the E-ELT Nasmyth Instruments and the Rest of the E-ELT System

  ESO-253082 Version 4.1

and from the following reference documents (some of them being the documents reporting the flow-down of the requirements contained in the applicable documents just mentioned):

- RD10 MAORY System Design Report
  E-MAO-SE0-INA-DER-001 Version 1.0

- RD11 MAORY System Analysis Report
  E-MAO-SE0-INA-ANR-001_01 Version 1.0

- RD12 MAORY System Interface Description Document
  E-MAO-SE0-INA-ICD-001_01 Version 1.0

- RD9 System Optical Design and Analysis Report
  E_MAO-SF0-INA-DER-001 Version 0.1

- RD13 Main Structure Design Report Version 1.0
  E-MAO-PM0-INA-DER-001

- RD14 PFS Hosted Metrology, ESO AIV Workshop 23 February 2021, S.Guisard et al.

4.3 Outputs

The output for the PDR and FDR will be the MAIT sub-system and system documents.

The output of the sub-system AIT for the ARR (the review that will occur at the end of the AIT phase, see section 4.5) will be:

- The sub-system fully integrated and tested, delivered to Bologna
- The documentation and drawings described in section 4.5.

The output of the system AIT phase will be:

- The AIT system report, including test and inspection reports of all the sub-systems
- Verification of high-level software including observation preparation, instrument control and data reduction software.
- The Support Equipment and handling tools for handling and maintaining the instrument.

4.4 Partner-to-Partner deliveries

Concerning the MAIT activities, the only internal delivery will be the bearing to be installed in the MES (see sec. 7.3), that will be delivered from IPAG to the system team, to be used to the BIH as part of the MICADO Emulating Structure.

4.5 Sub-Systems Acceptance Readiness Review (ARR)

The MAORY system consists of 13 complex sub-systems with partners distributed over Europe. For successful execution of the system AIT it is mandatory that all low-level functionality is implemented, tested and debugged at sub-system level before shipment to the system AIT facility. Therefore, before shipping a sub-system to the system AIT facility, an ARR will be done by the MAORY system team, with the purpose of:

- Verifying sub-systems requirements verification
- Verifying sub-system interfaces

The ARR shall produce few documents to be successfully concluded, such as:

- the "**sub-system installation and operation manual"**
- the "**sub-system maintenance manual"**
- the "**sub-system final test report"** including the compliance matrix
- the full set of executive drawings (when applicable, for example for mechanics, optics, electronics).

Part of the ARR may be a pre-visit several months before the ARR to identify open actions to be closed during the ARR meeting. Only after successful conclusion of the ARR, the sub-system will be shipped to Bologna.

4.6 System MAIT organization and responsibilities

The activities in the BIH will be performed following the schedule and the AIT plan guidelines. The AIT activities (described in sec. 8.4), will be grouped in "runs" (TBD for FDR). For every AIT run, there will be a designated team to accomplish the run tasks, often composed by personnel of the system AIT team and personnel of the sub-systems AIT teams. Every run will have a designated run responsible.

Every morning, prior to activities start, a short meeting between the MAORY AIT team should be held, to plan and discuss the daily programmed activities to be performed.

A daily report will be prepared every evening by the MAORY run responsible, to be sent to a distribution list to be agreed upon.

4.6.1 Manufacturing

The manufacturing of the vast majority of the single components constituting MAORY will be under the responsibility of the sub-systems groups. Thus, manufacturing control and quality test will be addressed in the applicable sub-system AIT plan.

Responsibility at system level is to provide all the HTs and SEq necessary for the integration of the opto-mechanics on the MSS (Bench Main Structure). The manufacturing of these items will be out-sourced to an external company and they will be certified for a load higher than the nominal weight they shall carry, considering earthquake condition.

The certification will include proof of lifting test of dummy masses with each HT and SEq.

4.6.2 Assembly & Integration

The System AIT team will support the sub-systems teams for the unloading operations when the subsystems enter the system AIT facility. The sub-sequent sub-system activities (unpacking, inspection, functional test, cleaning) are under the responsibility of the sub-system with support from the system AIT team. A meeting between sub-system and system AIT will decide on the sub-system integration readiness and agree upon the activities to be performed.

The subsystem to system integration activities will be done under joint responsibility of the system AIT and the sub-systems. A meeting between sub-system and system AIT will decide on the sub-system integration completeness.

4.6.3 Testing

During the system testing all the MAORY partners will be involved. This allows to have sharing of knowledge and expertise, and permits to all the partners to get acquainted with the final system, which will be very useful in sight of on-site assembly, commissioning and operations phase.

A test team shall be identified, constituted of at least a System Lead, the Test Unit sub-system members and a scientist. Depending on the test to be performed, the test team will be supported on site or remotely when possible, by an AIT support team, consisting of at least: electronic support, DM operations support, thermal support, RTC support, ICS support.

At the end of the test campaign, the test team shall provide test reports containing conclusion whether the tests were completed successfully, and in negative case describe the non-compliance, the identified causes and a plan to proceed.

The test report will be submitted to a Test Review board for approval/disapproval.

4.7 Shipping preparation

Once the PAE will be successfully concluded, the MAORY instrument has to be prepared for the shipping. The shipping strategy is to transport the instrument completely disassembled, using as much as possible the same containers/box used for the sub-system shipping to Bologna.

The subsystems de-integration activities will be done under responsibility of the system and sub-systems AIT responsible and of the safety manager.

The shipment preparations (i.e. sub-system packaging, including all the HTs and SeQ needed for the AIV in Chile, both as system and at sub-systems level) will be under the responsibility of a packaging company selected by the shipping company, with the supervision of the system and sub-system AIT responsible. The sub-system transport containers shall thus be realized in a way to be re-used for the transport from Europe to Chile, and should be compatible with shipping over sea (meaning the box material shall be compatible with this kind of shipping and all the relevant equipment shall be protected inside the box by a “transport barrier bag” water proof).

Every box will be equipped with shock and tilt sensors, and the MAORY instrument will be insured (possibly with an “all risk” insurance). A responsible of the insurance company will be required to follow both the *boxes closure operations* in Bologna and the *boxes opening operations* in Chile.

A detailed "technical specification document and statement of work of the MAORY instrument shipping" will be prepared for the call for tender that will be issued to select the shipping company.

The transport from Europe to Chile will be coordinated by the MAORY system team.

4.8 AIT Schedule

We present the schedule devised from the estimation of the AI steps duration (and based on the identified predecessors), presented in sec. 8.4.

The schedule presented here shows only the net durations of the AI activities, organized in their logical sequence. In other words, we assume here that the various subsystems and components are available when we need them for assembly and integration.

We emphasize that the AI activity duration estimates have to be further refined introducing the constraints due to the procurement process and the real dates when the subsystems and components will be available.

With the current maturity level of the plan, we envisage a contingency of about 20% to be added to the schedule (not included in Figure 4). The current overall duration of the AI phase is 280 working days (that becomes about 335 days with the just mentioned 20% contingency).

Thus, as soon as we will have reliable estimates on the delivery times of all the other sub-systems, we will be able to present a more realistic AI schedule.

The Testing phase in currently estimated to last 180 working days, with a lower maturity level which pushes to consider a related contingency of about 30%, bringing the estimate to about 235 working days.

1	**Assembly and Integration in Bologna**	**280 days**	**Thu 19/09/24**	**Wed 15/10/25**	
2	8.4.1 The Nasmyth Interface Plate (NIP) installation	3 days	Thu 19/09/24	Mon 23/09/24	56
3	8.4.2 Main Support Structure (MSS) installation	10 days	Tue 24/09/24	Mon 07/10/24	60;2
4	8.4.3 Installation of the LTs on the MSS	1 day	Tue 08/10/24	Tue 08/10/24	60;3
5	8.4.4 IFP flange installation, measurement and dis-installation	1 day	Wed 09/10/24	Wed 09/10/24	60;4
6	8.4.5 Dummies installation and interfaces measurements	15 days	Thu 10/10/24	Wed 30/10/24	67;5
7	8.4.6 Dummies dis-installation	10 days	Thu 31/10/24	Wed 13/11/24	6
8	8.4.7 Opto-mechanics interface plates dismounting and re-machining	1 day	Thu 14/11/24	Thu 14/11/24	7
9	8.4.8 MES installation	5 days	Tue 24/09/24	Mon 30/09/24	59;2
10	8.4.9 MSS characterization (optional)	5 days	Tue 01/10/24	Mon 07/10/24	9
11	8.4.10 Opto-mechanics interface plates re-installation	1 day	Fri 15/11/24	Fri 15/11/24	58;8
12	8.4.11 Dummies re-installation and interfaces measurement	15 days	Mon 18/11/24	Fri 06/12/24	11
13	8.4.12 Thermal enclosure installation	5 days	Mon 09/12/24	Fri 13/12/24	10;60;12
14	8.4.13 MSS and MES Thermal test	30 days	Mon 16/12/24	Fri 24/01/25	13;59
15	8.4.14 Alignment of the MSS to the PFS	1 day	Mon 16/12/24	Mon 16/12/24	13
16	8.4.15 Thermal enclosure dis-installation	2 days	Mon 27/01/25	Tue 28/01/25	14
17	8.4.16 CP (Corrective Plate) dummy dis-installation	1 day	Wed 29/01/25	Wed 29/01/25	16
18	8.4.17 IFP flange installation and measurement	1 day	Thu 30/01/25	Thu 30/01/25	17
19	8.4.18 Dummies dis-installation	10 days	Fri 31/01/25	Thu 13/02/25	18
20	8.4.19 Electronic cabinets installation	10 days	Fri 14/02/25	Thu 27/02/25	19;61
21	8.4.20 Cables and pipes routing	10 days	Fri 28/02/25	Thu 13/03/25	16;61;20
22	8.4.21 Engineering ICS SW installation and test	5 days	Fri 14/03/25	Thu 20/03/25	21;66
23	8.4.22 IFP (Input Focal Plane) flange installation and measurement	1 day	Fri 21/03/25	Fri 21/03/25	19;22
24	8.4.23 Corrective Plate Installation	1 day	Mon 24/03/25	Mon 24/03/25	23;58
25	8.4.24 M6 Installation	1 day	Tue 25/03/25	Tue 25/03/25	24;58
26	8.4.25 M7 Installation	1 day	Wed 26/03/25	Wed 26/03/	25
27	8.4.26 M8 installation	1 day	Thu 27/03/25	Thu 27/03/25	26
28	8.4.27 M9/DM1 Installation	2 days	Fri 28/03/25	Mon 31/03/25	27;68
29	8.4.28 M10/DM2 installation	2 days	Tue 01/04/25	Wed 02/04/25	28;68
30	8.4.29 M11 Installation	1 day	Thu 03/04/25	Thu 03/04/25	29
31	8.4.30 CU selector and CU folding mirror installation	2 days	Fri 04/04/25	Mon 07/04/25	30
32	8.4.31 Calibration Unit installation	2 days	Tue 08/04/25	Wed 09/04/25	31;62
33	8.4.32 Dichroic Installation	1 day	Thu 10/04/25	Thu 10/04/25	32;58
34	8.4.33 First Folding Mirror LGSO Installation	1 day	Fri 11/04/25	Fri 11/04/25	33
35	8.4.34 LGSO installation	2 days	Mon 14/04/25	Tue 15/04/25	34
36	8.4.35 Third folding mirror LGSO Installation	1 day	Wed 16/04/25	Wed 16/04/25	35
37	8.4.36 LGS WFS installation	3 days	Thu 17/04/25	Mon 21/04/25	36;65
38	8.4.37 Electronics functional test	3 days	Tue 22/04/25	Thu 24/04/25	30;61;21;37
39	8.4.38 ICS SW installation and test	10 days	Fri 25/04/25	Thu 08/05/25	38;66
40	8.4.39 RTC installation and test	10 days	Fri 09/05/25	Thu 22/05/25	39;63
41	8.4.40 MES functional test	1 day	Fri 09/05/25	Fri 09/05/25	39;9
42	8.4.41 LOR functional test	2 days	Fri 23/05/25	Mon 26/05/25	40;64
43	8.4.42 Motorized opto-mechanics functional test	1 day	Fri 09/05/25	Fri 09/05/25	39;9
44	8.4.43 MSS to MES Alignment	3 days	Mon 12/05/25	Wed 14/05/25	43
45	8.4.44 CU Alignment	3 days	Thu 15/05/25	Mon 19/05/25	44;62
46	8.4.45 LOR WFS Alignment	3 days	Tue 27/05/25	Thu 29/05/25	45;64;42
47	8.4.46 LGS arm alignment	3 days	Fri 30/05/25	Tue 03/06/25	46;36
48	8.4.47 LGS WFS functional test and alignment	4 days	Wed 04/06/25	Mon 09/06/25	47;65
49	8.4.48 Thermal enclosure installation and test	20 days	Tue 10/06/25	Mon 07/07/25	48;60
50	8.4.49 Fine tuning of the optical quality	2 days	Tue 08/07/25	Wed 09/07/25	49
51	Installation of DM1 and DM2 and functional test	20 days	Thu 10/07/25	Wed 06/08/25	57;50
52	Re-alignment of MAORY bench (from 8.4.43 to 8.4.49)	40 days	Thu 07/08/25	Wed 01/10/25	51
53	8.4.50 Test Unit (TU) installation and characterization	10 days	Thu 02/10/25	Wed 15/10/25	62;50;52
54	TEST PHASE	180 days	Thu 16/10/25	Wed 24/06/26	53;52

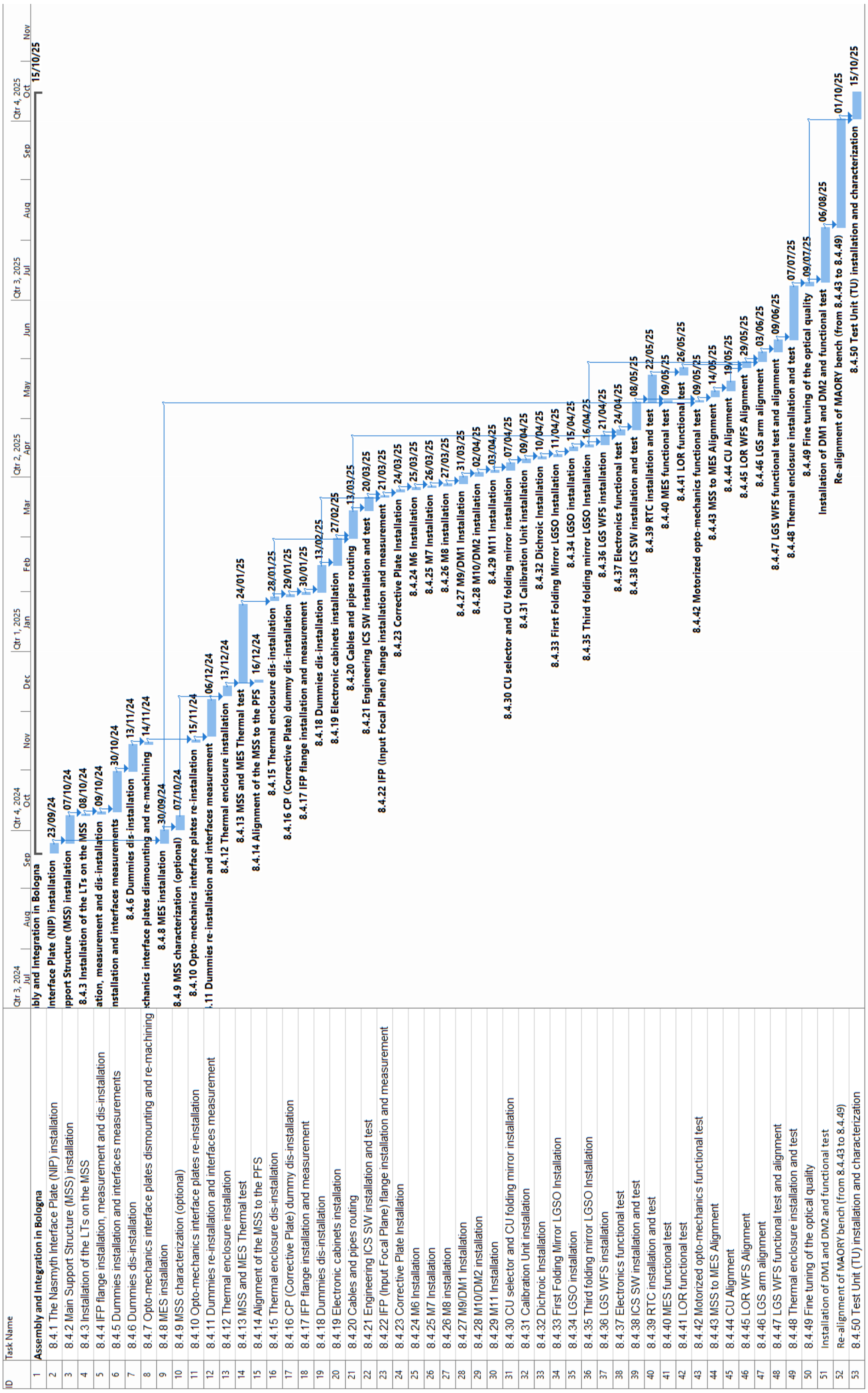


Figure 4: the Assembly and Integration (AI) phase schedule, considering just the net durations of AI activities

4.9 Resources (FTEs)

Personnel involved in the system AIT process and FTEs will be provided at FDR

4.10 AIT Project Meetings and Reviews

- PDR Intermediate Readiness Meeting (IRM): a few months before the PDR (to be agreed between the partners), a draft version of the AIT procedure, of the of the AIT schedule, of the FTEs and of the Verification Matrix shall be available, in a way to make an intermediate readiness meeting with the aim to anticipate possible problems/issues as much in advance as possible, and to have the right time to counteract; Videocon may also be possible.
- FDR IRM: similarly to the PDR IRM, a few months before the FDR (to be agreed between the partners), an advanced draft version of the AIT plan shall be available, in a way to make an intermediate readiness meeting with the aim to anticipate possible problems/issues as much in advance as possible, and to have the right time to counteract; Videocon may also be possible.
- Integration Readiness Meeting: The Integration Readiness Meeting (IRM) is a meeting which will take place during the MAIT phase at the end of the manufacturing phase, after delivery of the major sub systems/components, before starting the real AIT of the sub-system. The purpose of the IRM is to check that all the components are in specification, in a way to ensure that the sub-system AIT can start. Another purpose is to double-check that the activities to be carried out in AIT phase at sub-system level are clearly identified, sorted out and properly scheduled, with properly assigned resources and well assigned responsibilities, and the success criteria for all activities are clear; Videocon may also be possible.
- Test Readiness Meeting: a few months prior to the end of the AIT phase a Test Readiness Meeting (TRM) will be held to confirm that the instrument is ready for the system tests.
- Preliminary Acceptance Europe (PAE): once MAORY has been assembled, aligned and tested at system level, the system acceptance shall be performed. The aim of the PAE is to verify that:
    - The integration of MAORY is completed
    - To verify that the MAORY performance conforms with the technical specification and its applicable documents.
    - To confirm that the verification processes applied to MAORY have demonstrated that the product is free of workmanship errors and is ready for subsequent operational use.
    - To verify that the acceptance verification record is complete at this and all lower levels in the customer-supplier chain.
    - To verify that all deliverable products are available per the approved deliverable items list.
    - To verify the “as-built” product and its constituent components against the required “as designed” product and its constituent components.
    - To verify the acceptability of all waivers and deviations.

- To verify that the Acceptance Data Package is complete.
- To authorize delivery of MAORY.
- To release the MAORY certificate of acceptance.
- To release MAORY for Shipment to the Telescope site.

4.11 ESO staff involvement

Members of the ESO follow up team will be invited during (some but not all) main integration and handling activities during system AIT.

Members of the ESO follow up team will be invited during (some but not all) pre-anticipated maintenance activities during system AIT.

Paranal control software experts are invited several months before PAE to work with the MAORY team to prepare MAORY for integration with the Paranal observatory.

Members of ESO Chile staff that are assigned to assist with the MAORY on-site assembly will be invited during (some) main integration and handling activities to get acquainted and involved with the instrument before shipment to the observatory.

Sub-system teams are encouraged but not obliged to invite ESO follow up team members and ESO Chile staff to get involved with MAORY during the sub-system MAIT.

4.12 Training

The following trainings for all personal working in the System AIT facility is foreseen:

- Cleanroom training
- Safety training
- Electrical risk training
- Fork-lift training
- Crane operation training
- Cherry Picker/Scissor lift operating training
- First-Aid training

4.13 Instrument handover to ESO

The handover of MAORY to ESO will require, in addition to all the inherent manuals (operation manual, maintenance manual, …) dedicated training to ESO personnel both at sub-systems and at system level.

This section will be further detailed upon ESO guidelines for FDR.

4.14 Safety

Safety during AIT both at instrument and at sub-system level is considered of very high importance by the MAORY team. Regular safety briefings will be conducted at the start of each working day/main task, coordinated by the on-site safety responsible. Attendance of safety meeting by the team, local support staff, and safety responsible is mandatory prior to any major activity which every team member will be strongly requested to stick to and follow local safety rules related to:

1. "Safety Introduction course" completed.

2. Wear the proper safety equipment in line with their activities and corresponding working area.

3. Follow instructions when using or being close to special hoisting, lifting, handling tools.

4. Follow instructions when using or being close to light sources, in particular high power Mid Infra-Red laser sources.

5. Follow instructions when using or being close to cryogenic equipment, in particular Liquid Nitrogen cooling systems.

6. Follow instructions when using or being close to electric equipment/line and in particular when working on device/rack with line voltage circuits.

In particular, we identify the following safety related issues, that will further be addressed before FDR in RD17, here reported in arbitrary order:

• Electro Static Discharge – ESD wrist straps

• Eye protection - laser goggles, safety glasses

• Hearing protection

• Working at height – safety harness

• Hoisting, lifting and handling of heavy equipment

• Safety gloves, safety shoes & helmets

• Interlocks

• High voltage and low voltage electrical risk

• Emergency stops

• Cryo-Vacuum safety

• Harmful gasses - O2 measurements

• CE certification for handling tools

• Mental overload, stress and strain

• Operator overload – sharing responsibility during critical operations

• Fire extinguishers

• First aid kits

4.15 Risks

The following risks are identified for the completion of the MAORY system AIT on time:

- Late delivery of the of the BIH

  Mitigation: evaluated the time necessary to find an alternative solution and, accordingly, established check points on the schedule to final select the right path; first check point will, if needed, cause to start looking for an alternative solutions, second check point will in case give the green light for the selected alternative solution. Possible alternatives to be evaluated are: rent/borrow laboratory space from other research institutes (i.e. CNR), rent laboratory space from industries/companies with past experience in this field, rent and refurbish industrial sheds in the area of Bologna/Padova

- Late delivery of long leading items

  Mitigation: early FDR for the optics/opto-mechanics and for the Deformable Mirrors considered in the schedule, in a way to place the orders ASAP

- Limited testing possibility in Europe due to the difficulties to simulate the ELT, the atmosphere and the MICADO camera

  Mitigation: the test unit will simulate the M4 ELT adaptive mirror (with reduced number of actuators), turbulence will be introduced directly on the DMs software-wise, the calibration unit will simulate both NGSs and LGSs to be used from the two wavefront sensors, performance will be checked with a test camera (working in j and H bands) spanning the overall field of view through motorized stages; specific strategies will be agreed with ESO/MICADO team for particular test that would require the MICADO camera, using a combination of test and analysis to verify these particular requirements

4.16 External expertise

Although INAF as the MAORY PI institute has a strong track record in delivering successful astronomical instruments, it is realized that previous instruments were of considerable smaller scale than MAORY. Therefore, it is intended to consult external companies concerning the following topics:

- Hoisting and lifting
- Laser tracker measurements

4.17 Spare Parts Policy

For the time being, we do not foresee spare parts inherent to the system MAIT/AIV work-package.

To be further addressed for FDR.

5. FACILITIES

In this section, we describe the facilities which are available in Bologna for the overall MAORY AIT. For the sake of clarity:

- we call Facility (Fac) a permanent installation, such as an assembly hall, a laboratory, a clean room, a workshop
- we call Handling Tool (HT) whatever device (which may be permanent like an overhead travelling crane or movable such as a jib crane or a trans-pallet or a cherry picker) useful to handle/move/position equipment, which are sometimes commercial products; they are described in sec. 6.
- we call Support Equipment (SEq) whatever handling tool which must be designed and realized on purpose to achieve a certain AIT task, such as an auxiliary mirror to be used for analysing the beam in auto-collimation during the alignment. They are described in sec. 7.

5.1 Institute, Location, Premises

The integration facility is located in Bologna (Bologna Integration Hall, BIH), located in the northern part of Italy, at the premises of INAF-OAS, located in the building of the CNR/INAF Research Area next door, at the address *via Piero Gobetti n. 101, Bologna*. The building is located 10-15 minutes away from a major highway, and is also reachable within 30 minutes walking from the railway station or 10-15 minutes by public transport from the city centre or within 15 minutes of taxi from the Bologna international airport.

An **important issue to be taken into account** when reaching the laboratory, above all for goods shipping, is that at about 500m of distance from the lab the road is going below a bridge where the maximum height allowed for a truck is X.Ym (to be checked).

5.2 Integration Hall

The BIH main integration hall is shown in Figure 5, where the main integration hall, the entrance gates, the external parking area, the technical room (in red colour, hosting the pumps for the air conditioning system and the switches panel of the electric plant) and the control room (in green colour, hosting possibly all the necessary HW to be used during the AIT, such as computers and controllers of needed support equipment, the dimensions of which are 4.4x1.5m) are visible. The technical room is physically separated from the rest of the building to allow relative movements of the two structures in case of earthquake.

The main integration hall is currently hosting most of the facilities needed for the AIT operations, like sufficient access to power, cooling water, liquid nitrogen, UPS line for sensitive equipment.

5.2.1 Drawings and description

The current hall is ~12m high, equipped with an overhead crane. The other dimensions are 17.4m large and 11meters deep, as shown in Figure 8. The BIH entrance has two access door, the smaller of which is ~5.3m large and ~6m high (Figure 7).

The internal side of the walls will be insulated with panels “sandwich like” 60mm thick (see Figure 6), characterized by a thin 5mm metallic external layer filled in the cavity with an insulating material. They will be kept connected to a supporting frame at few cm of distance from the walls, both to let the air flow avoiding humidity creation on the walls and to allow the plants (electric, cooling, …) piping and routing. Such a panel supporting structure will be of course realized in a way to allow the bridge crane movement (see Figure 9). Also on the ceiling, insulating panels of the same type just described will be used. Such panels have a flatness and a painting type washable and compatible with the requirements in term of environmental cleanliness. On the floor, an epoxy resin treatment also washable should also ensure both the necessary grip and the compatibility with the cleanliness requirements.

All the laboratory plants shall have the CE certification.

MORE DETAILS TO BE GIVEN BEFORE THE FDR

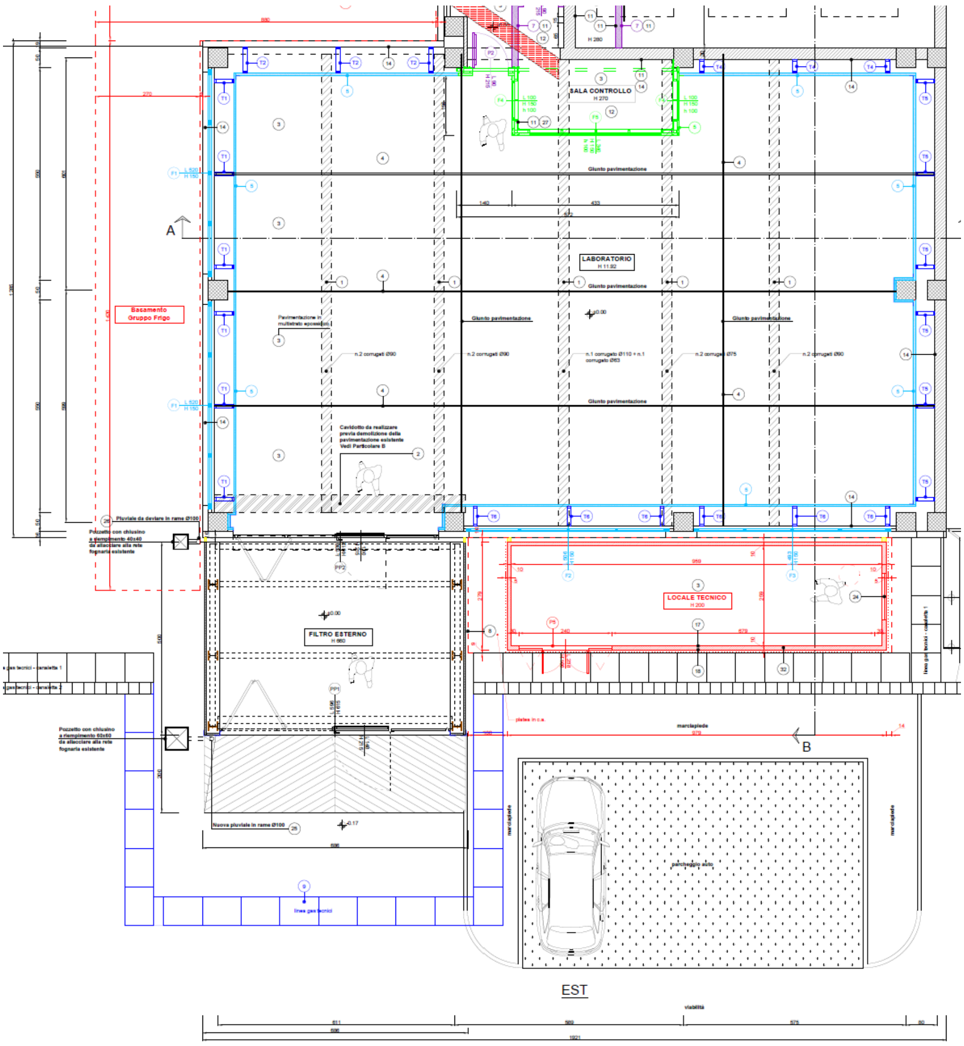


Figure 5: A top view of the BIH, showing in green the control room and in red the technical room

Figure 6: an example of the panel used for the internal lab insulation

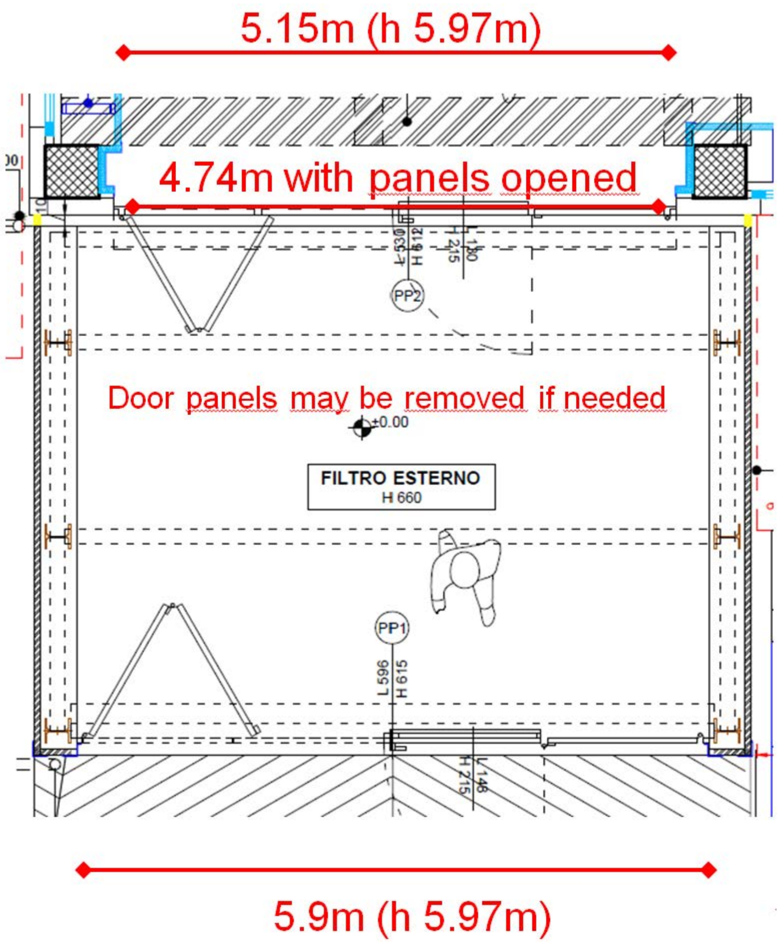


Figure 7: The BIH entrance, characterized by two gates opening as shown in the drawing; the clear aperture of the external entrance gate (the smaller) with the door panels opened is 4.74m, even though in case of need the door panels may be removed

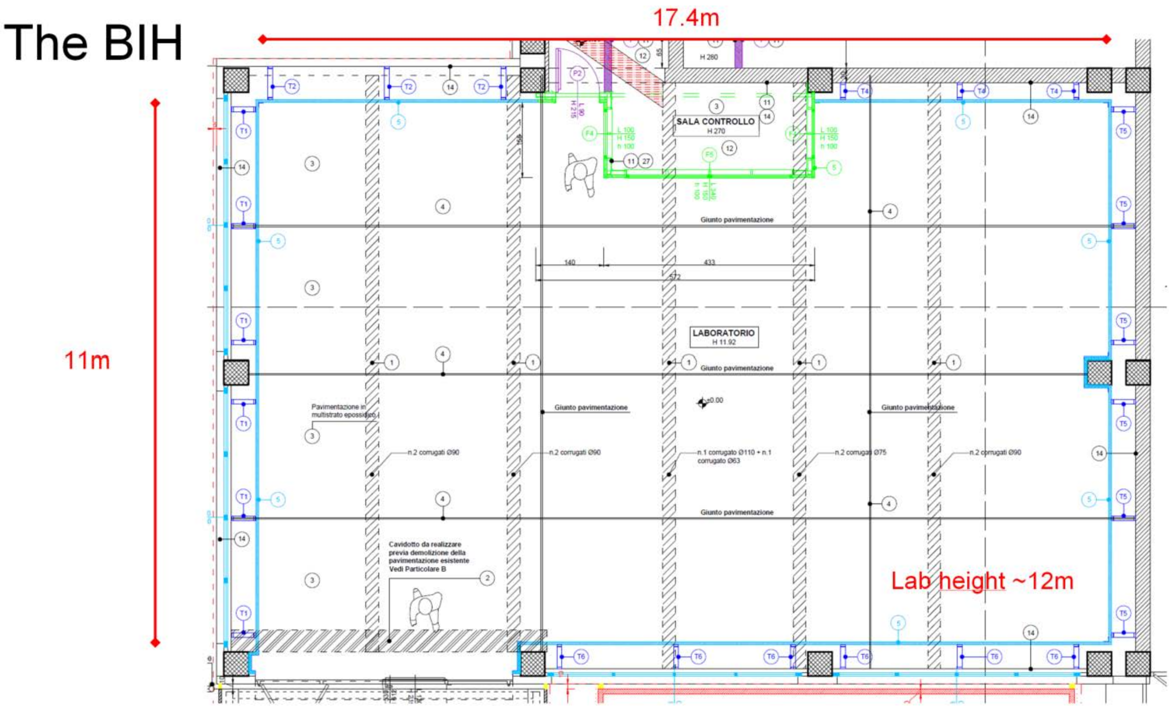


Figure 8: the main integration hall, where MAORY will be assembled and integrated

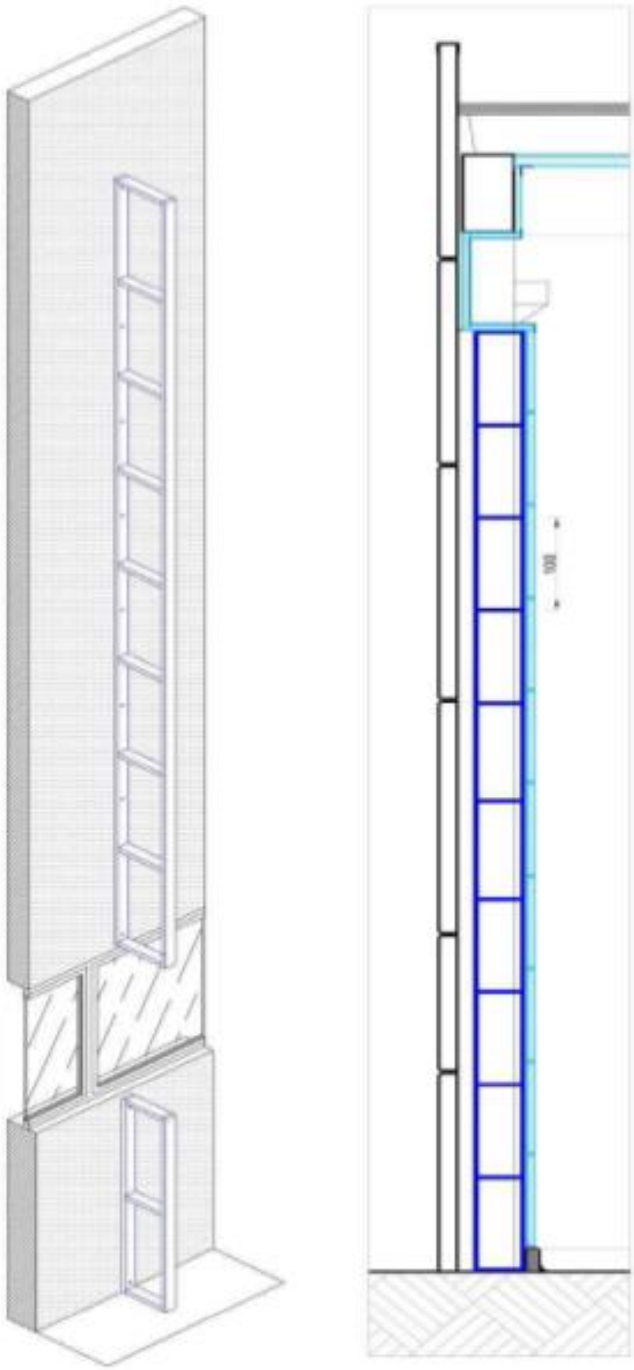


Figure 9: an example of how the insulating panels are kept in position; external windows will be replicated in the inner part of the structure, as shown in the left image. All the windows will have remotely controlled curtains to allow creating a dark environment when needed for test purposes.

5.2.2 Crane

The main integration is equipped with an overhead crane (bridge crane) with a max load capacity of 3.2T.

The useful height below the crane hoist is 10.2m

The overall movement range of the crane hoist are TBC

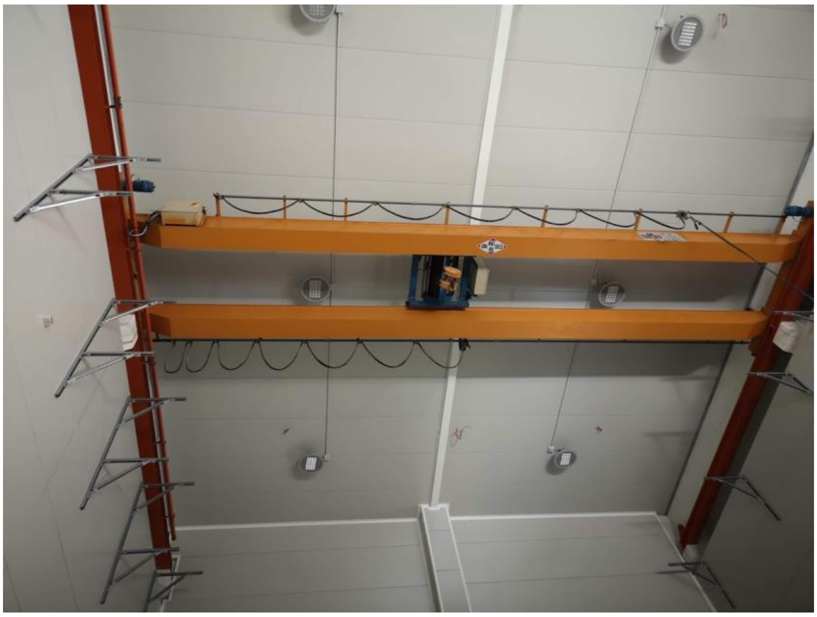


Figure 10: the BIH overhead crane (3.2T maximum load capacity)

5.2.3 Workshops

An electronic workshop and a mechanical workshop will located in the same building, just on the back side of the mein integration hall, allowing to take care of small maintenance/emergency operations.

At the moment of writing, the room is a pretty large single one (about 12x7m, height of about 4m, see Figure 14), but it may be divided in two areas, one dedicated to the mechanical workshop and one dedicated to the electronical lab.

The mechanical WS will be equipped with a lathe and a milling machine, plus a couple of column drills and other standard mechanical tools.

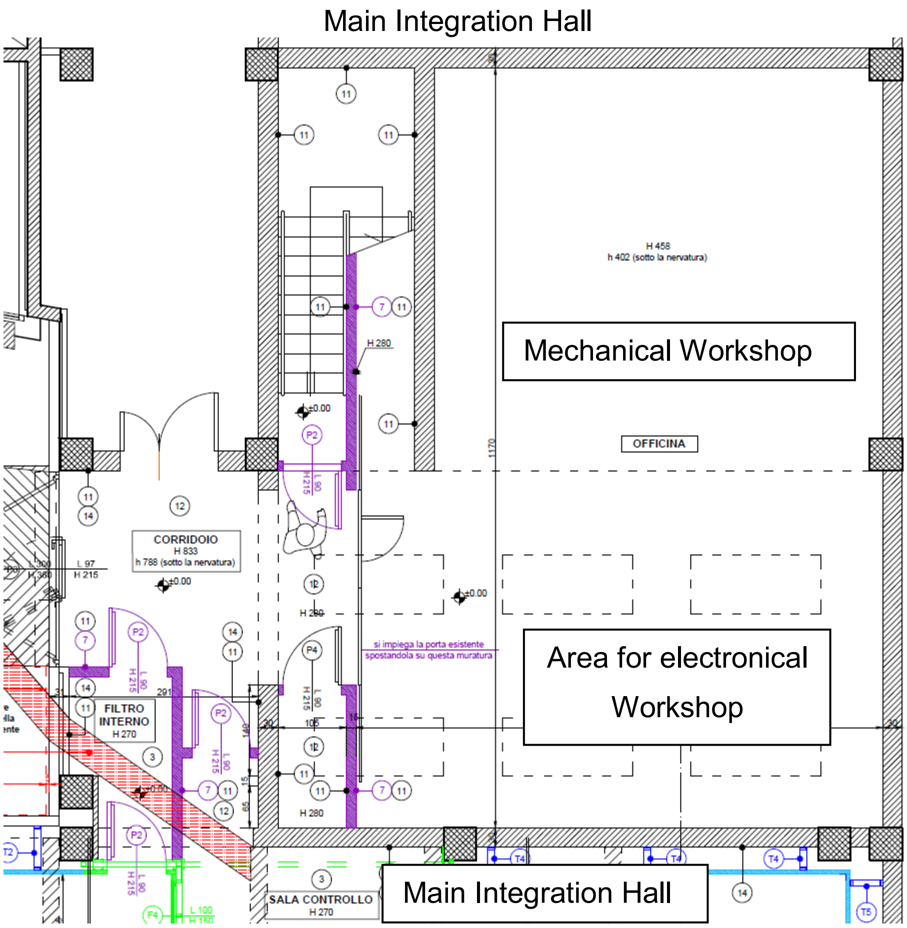


Figure 11: the area dedicated to the mechanical WS, which may be divided in 2 rooms to dedicate an area also to an electronical lab.

A meeting room is also available at the first floor (see Figure 12), with a dimension of about 7x6m and a height of about 3m.

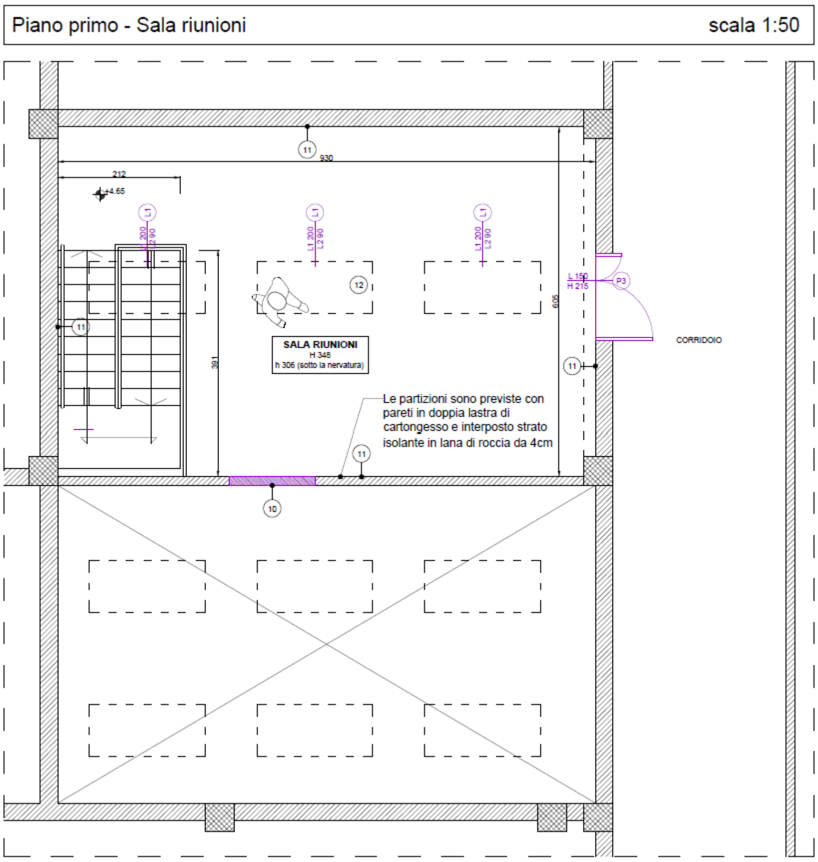


Figure 12: The meeting room at the first floor

5.2.4 Handling devices

For the time being, no commercial handling tools are available at the facility. It is foreseen to buy at least:

- A couple of manual trans-pallet
- One motorized fork lift
- One cherry-picker
- One scissor-lift
- One portable crane
- A few trolleys

Every handling device shall have the CE certification.

5.2.5 Cleanliness

The laboratory ventilation has the purpose to maintain the temperature and humidity conditions foreseen, and to maintain the requested cleanliness class 100000 (ISO 8 following ISO 14644-1). The latter requires a number of total air recirculation corresponding to 10-20 overall lab air volume, which correspond in this case to 20000m^3/h (being the lab volume 1800m^3). The air will be properly filtered with the following sequence: per-filtering with G4 efficiency filters, high-efficiency filtering with F7 filters and then final filters stadium with H12 filters with a global efficiency equal to 99.5%.

5.3 Storage

A dedicated storage area has still to be identified, and we are also evaluating temporary storage solutions, as the one presented in Figure 13.

Figure 13: temporary storage facilities (from CDU presentation at the AIV WS)

5.4 Facilities Summary

Facility code	Description	Notes
SM0-Fac-01	Main Assembly Hall	Safety shoes and helmets required Clean Roon clothes required
SM0-Fac-02	Electronic Lab	
SM0-Fac-03	Mechanical Workshop	
SM0-Fac-04	Control room	
…	…	

To Be further detailed for FDR

6. HANDLING TOOLS

Table 2 gives a complete overview of all Handling Tools in the univocal device code RD16 that are needed during the system AIT

Table 2: list of the handling tools to be used during MAORY AIT

Handling Device code	Description	Notes
SM0-HT-01	Bologna Integration Hall permanent crane (3.2T max load)	Patent needed to operate it Helmet and safety shoes required CE required
SM0-HT-02	Movable Jib Crane (1T max load)	Helmet and safety shoes required CE required
SM0-HT-03	Fork Lift (5T max load)	Patent needed to operate it Helmet and safety shoes required CE required
SM0-HT-04	Trans Pallet (1T max load)	Safety shoes required CE required
SM0-HT-PFK	Schmidt-Plate Assembly and Maintenance Handling Tool	Helmet and safety shoes required
SM0-HT-PFA	M6 Assembly and Maintenance Handling Tool	Helmet and safety shoes required
SM0-HT-PFB	M7 Assembly and Maintenance Handling Tool	Helmet and safety shoes required
SM0-HT-PFC	M8 Assembly and Maintenance Handling Tool	Helmet and safety shoes required
SM0-HT-PDA	DM1 Assembly and Maintenance Handling Tool	Helmet and safety shoes required
SM0-HT-PDB	DM2 Assembly and Maintenance Handling Tool	Helmet and safety shoes required
SM0-HT-PFD_CRANE	Dichroic Assembly and Maintenance Handling Tool to lift up the dichroic	Helmet and safety shoes required
SM0-HT-PFD_BENCH	Dichroic Assembly and Maintenance Handling Tool to make the dichroic sliding into the MSS and to finely position it against its interface points on MSS.	Helmet and safety shoes required
SM0-HT-PFE	M11 Assembly and Maintenance Handling Tool	Helmet and safety shoes required
SM0-HT-	LGS Fold Mirror 1 Assembly and Maintenance	Helmet and safety

PFG_CRANE	Handling Tool to lift up the mirror	shoes required
SM0-HT-PFG_BENCH	LGS Fold Mirror 1 Assembly and Maintenance Handling Tool to make the mirror sliding into the MSS and to finely position it against its interface points on MSS.	Helmet and safety shoes required
SM0-HT-PFH_CRANE	LGS-Objective Assembly and Maintenance Handling Tool to lift it up	Helmet and safety shoes required
SM0-HT-PFH_BENCH	LGS-Objective Assembly and Maintenance Handling Tool to make it sliding into the MSS and to finely position it against its interface points on MSS.	Helmet and safety shoes required
SM0-HT-PFL	LGS Fold Mirror 3 Assembly and Maintenance Handling Tool to lift up the mirror	Helmet and safety shoes required

6.1 M6 Assembly and maintenance Handling Tool (SM0-HT-PFA)

Purpose and functionality

The SM0-HT-PFA has the purpose to perform the assembly of M6 on the MSS. It is equipped with a sliding hoisting point to balance the overall system with and without M6.

Manufacturing

The conceptual design is done within the MAORY consortium, the final design and construction will be out-sourced to an external company.

Description

It is a C-shaped handling. This handling shape allows to interface the crane hook along the projection of the barycentre of M6 + handling. The position of the crane hook hoisting hole with the handling can be finely adjusted as it is mounted on a rail, actuated by an endless screw.

This latter part will be modified in favour of movable masses connected to the handling, keeping the hoist ring fixed. All the images of the handling does not represent this modification yet, still showing the sliding hoist ring.

This is useful when M6 is disconnected from the handling, as the barycentre of the system will move.

In this case, before disconnecting the handling and after M6 is secured to its supporting structure inside MAORY main structure, it is possible to shift the hook hoisting hole to the position where the stand-alone handling would be balanced. In this way, when the handling is disconnected from M6, it will stay well balanced, avoiding dangerous oscillations that could damage the mirror.

At M6 side, the C-shaped handling is constituted by 2 main parts: a fixed part and a movable one. The latter is physically screwed to the 3 branches embracing M6 through six M8 screws (2 per branch), and it is interfaced to the handling fixed part through a heim joint, that allows adjusting its position in 3 DoFs.

The handling can be interfaced to M6 with the mirror protecting cover in place.

3 threaded rods screwed to the fixed part of the handling and pushing on the movable part allow to fine adjust the tip-tilt of M6 during the installation phase. One of the threaded rods is inserted in a small pit in the movable part, to prevent rotation of the mirror around its optical axis.

The handling is designed to keep the mirror with an orientation very close to the one it will have when mounted into MSS. This allows to perform only small mirror position adjustment at the moment of interfacing M6 to its supporting structure inside the MSS.

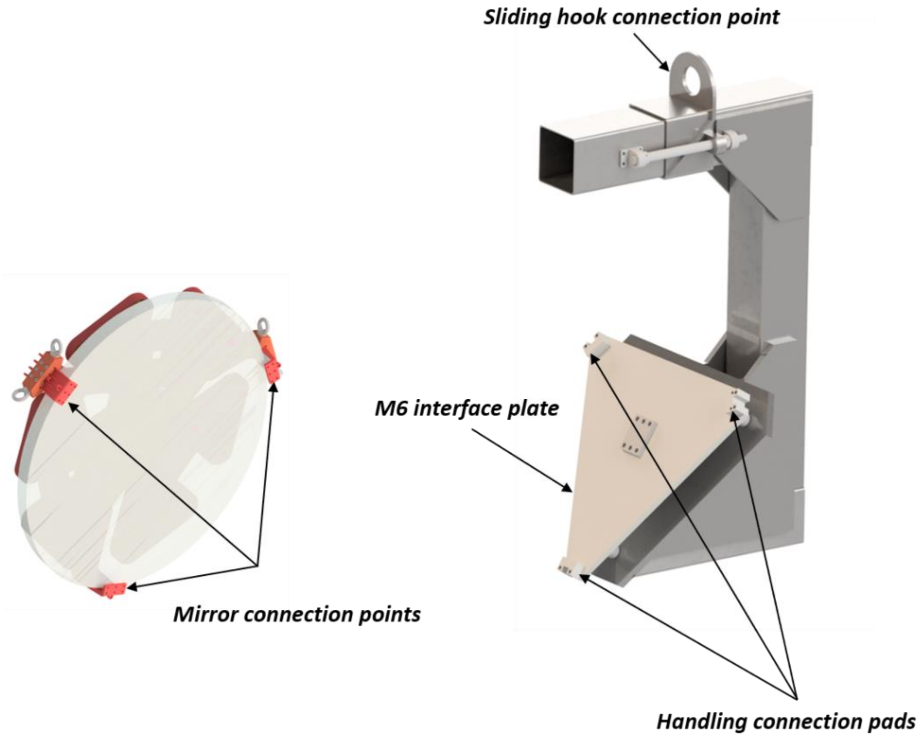


Figure 14: C-shaped handling for M6 installation. The interface between M6 and the handling is between the 3 branches embracing M6 and the 3 connection pads of the handling. The handling is equipped with a hook hoisting connection point having the possibility to slide, in order to have it aligned with the barycentre of the system both when M6 is connected and disconnected.

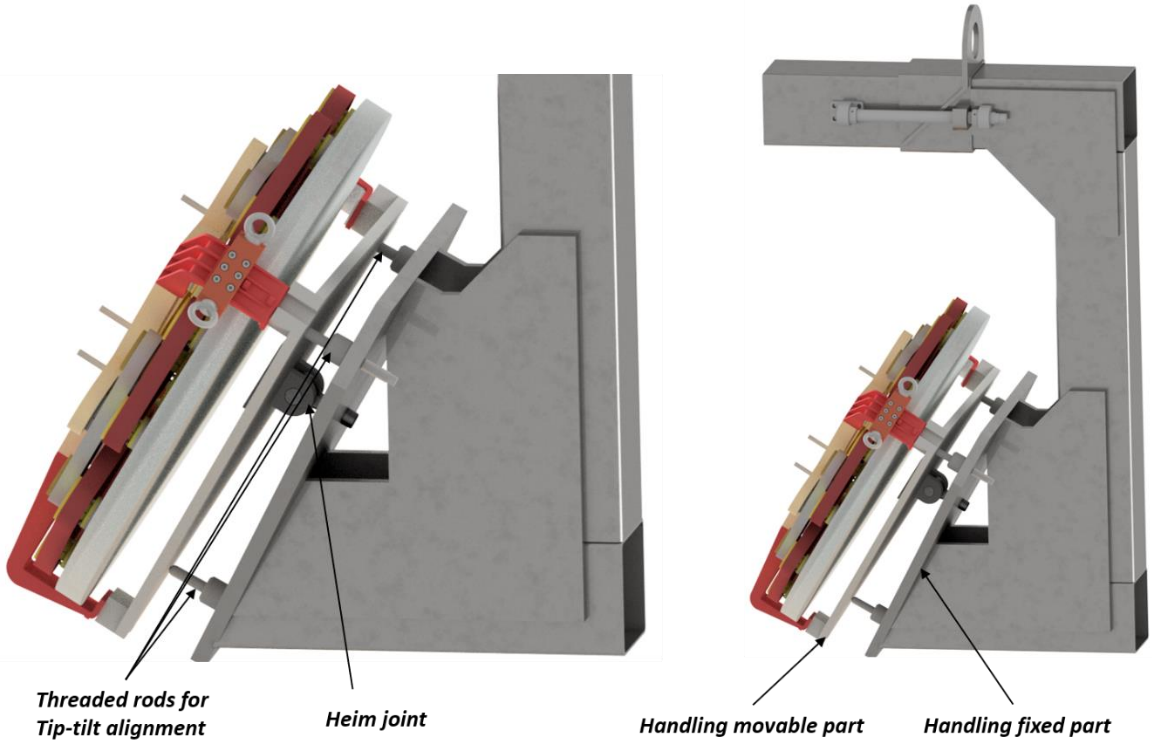


Figure 15: the handling allows to fine adjust tip-tilt of the mirror before installation, thanks to a heim joint and 3 threaded rods pushing against the movable part of the handling.

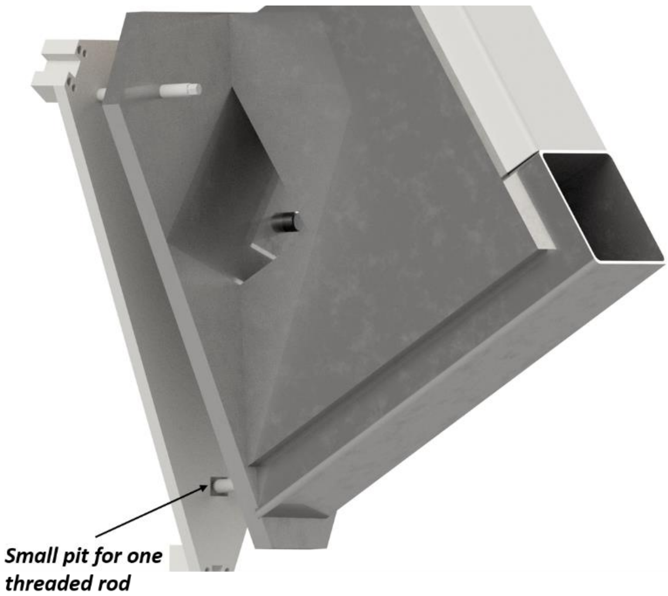


Figure 16: one of the threaded rods allowing tip-tilting of the handling movable part is inserted into a small pit in the movable part, to prevent its rotation around the mirror optical axis.

Way to be operated/procedure

The SM0-HT-PFA must be operated in the following way:

- The cover of M6 must be installed
- A minimum of 2 persons plus the crane operator are necessary for the SM0-HT-PFA handling/movement
- The internal ladders, platform and security harnesses to access M6 on the MSS must be in place

The hoist point on SM0-HT-PFA has to be connected to the crane hook, then the approaches M6 and connects to the fixation points on the mirror opto-mech.. Some bars positioned on M6 branches can be used to ease and guide SM0-HT-PFA approach to M6.

Special tools needed

Normal mechanical workshop tools.

AIT phase when needed

The SM0-HT-PFA is needed for the assembly operations in Bologna and in Chile and for maintenance in Chile.

Deliverable and lifetime

The SM0-HT-PFA is a deliverable to Chile, where it has to be stored to be used for maintenance.

Hazard and Safety issues

The SM0-HT-PFA must be operated in the following way:

- The cover of M6 must be installed
- A minimum of 2 persons plus the crane operator are necessary for the SM0-HT-PFA handling/movement
- The scaffolding or security harnesses to access M6 on the bench must be in place
- The platform allowing to reach M6 area on the bench structure must be in place
- Operators shall ware the helmet, safety gloves and safety shoes
- Every operator shall wear safety shoes, safety gloves and helmet
- When operating on the platform, the harness safely secured is mandatory for each operator

No Major Hazards have been identified, but mirror destruction in case of mis-handling

6.2 M7 Assembly and Maintenance Handling Tool (SM0-HT-PFB)

Purpose and functionality

The SM0-HT-PFB has the purpose to perform the assembly of M7 on the MSS. It is equipped with a fixed hoist ring for the crane hook. Since M7 installation occurs from the top of the MSS, but it is positioned at the bottom, to avoid a very long handling it has been designed to access inside the MSS together with the MSS. This results in a compact handling, but for balancing reasons it must have counterweights, in order to keep the handling hoist ring always “visible” from the crane hook, without colliding with any beam of the MSS.

Manufacturing

The conceptual design is done within the MAORY consortium, the final design and construction will be out-sourced to an external company.

Description

It is a quite stubby C-shaped handling. This handling shape allows to interface the crane hook along the projection of the barycentre of M7 + handling. The position of the crane hook hoisting hole cannot be adjusted, but to keep the system balanced both when M7 is connected and not, a system of sliding counterweights will be used. These are installed on a M30 threaded rod passing through the middle of the long beam of the handling. Two nuts allow to tune the position of the masses on the rod, shifting accordingly the barycentre of the system.

This is useful when M7 is disconnected from the handling, as the barycentre of the system will move.

The rest of the handling is conceptually identical to what described for M7, with the only obvious exception of the handling total dimensions and mirror interface.

At M7 side, the C-shaped handling is constituted by 2 main parts: a fixed part and a movable one. The latter is physically screwed to the 3 branches embracing M7 through six M8 screws (2 per branch), and it is interfaced to the handling fixed part through a heim joint, that allows adjusting its position in 3 DoFs.

The handling can be interfaced to M7 with the mirror protecting cover in place.

3 threaded rods screwed to the fixed part of the handling and pushing on the movable part allow to fine adjust the tip-tilt of M7 during the installation phase. One of the threaded rods is inserted in a small pit in the movable part, to prevent rotation of the mirror around its optical axis.

The handling is designed to keep the mirror with an orientation very close to the one it will have when mounted into MSS. This allows to perform only small mirror position adjustment at the moment of interfacing M7 to its supporting structure inside the MSS.

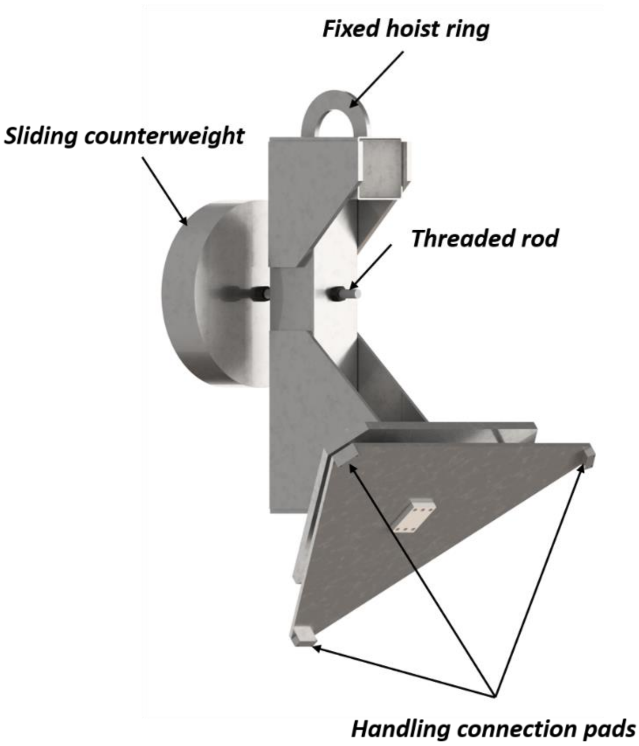


Figure 17: C-shaped handling for M7 installation. The interface between M7and the handling is between the 3 branches embracing M7 and the 3 connection pads of the handling. The handling is equipped with a fixed hoist ring and movable counterweight to tune the position of the barycentre.

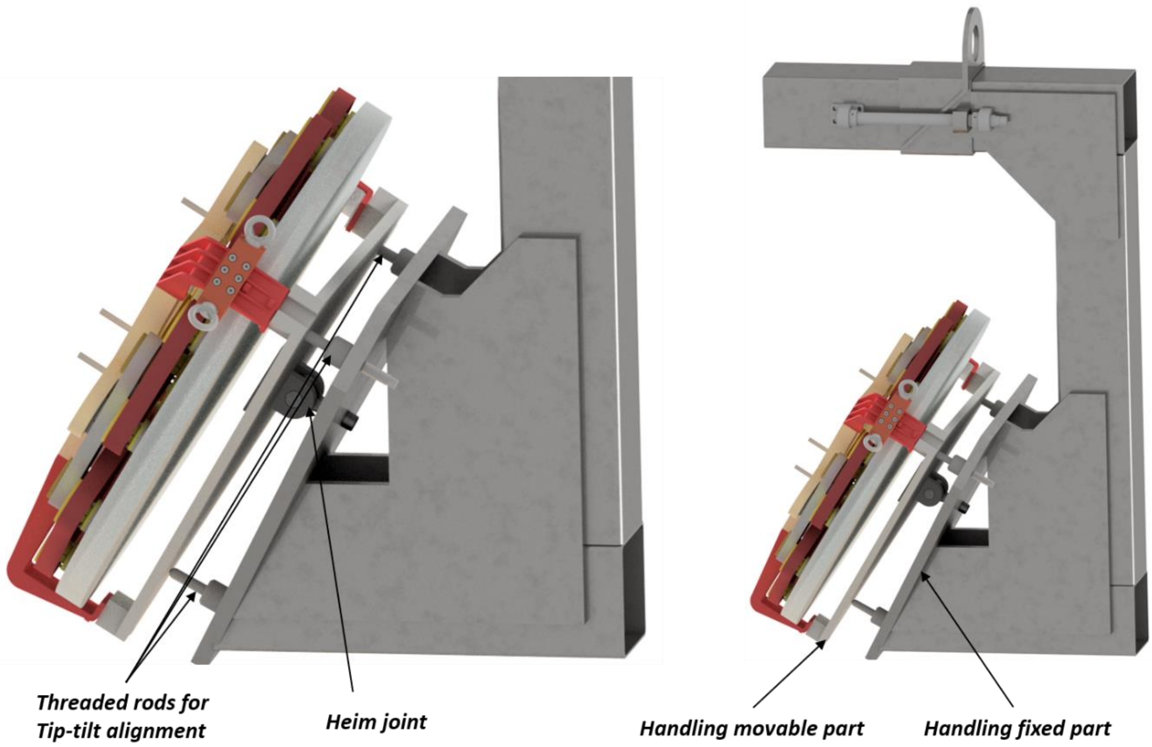


Figure 18: the handling allows to fine adjust tip-tilt of the mirror before installation, thanks to a heim joint and 3 threaded rods pushing against the movable part of the handling.

Way to be operated/procedure

The SM0-HT-PFB must be operated in the following way:

- The cover of M7 must be installed
- A minimum of 2 persons plus the crane operator are necessary for the SM0-HT-PFB handling/movement

The hoist point on SM0-HT-PFB has to be connected to the crane hook, then the approaches M7 and connects to the fixation points on the mirror opto-mech. Some bars positioned on M7 branches can be used to ease and guide SM0-HT-PFB approach to M7.

Special tools needed

Normal mechanical workshop tools.

AIT phase when needed

The SM0-HT-PFB is needed for the assembly operations in Bologna and in Chile and for maintenance in Chile.

Deliverable and lifetime

The SM0-HT-PFB is a deliverable to Chile, where it has to be stored to be used for maintenance.

Hazard and Safety issues

The SM0-HT-PFB must be operated in the following way:

- The cover of M7 must be installed
- A minimum of 2 persons plus the crane operator are necessary for the SM0-HT-PFB handling/movement
- Operators shall ware the helmet, safety gloves and safety shoes
- Every operator shall wear safety shoes, safety gloves and helmet
- When operating on the platform, the harness safely secured is mandatory for each operator
- The crane shall always hold all the weight, also during the shift of the counterweights

No Major Hazards have been identified, but mirror destruction in case of mis-handling

6.3 M8, M9, M10, Dichroic, 1st folding mirror LGSO Assembly and maintenance Handling Tool (SM0-HT-PFC, SM0-HT-PDA, SM0-HT-PDB, SM0-HT-PFD_CRANE, SM0-HT-PFG_CRANE)

Purpose and functionality

These handling are conceptually all the same, and basically identical to the handling shown for M6, differing only for their overall dimensions. They have the purpose to perform the assembly of M8, M9, M10, dichroic and 1st folding mirror LGSO in the MSS. They are equipped with a sliding hoisting point to balance the overall system with and without the mirrors.

Manufacturing

The conceptual design is done within the MAORY consortium, the final design and construction will be out-sourced to an external company.

Description

They are all C-shaped handlings. The handling shape allows to interface the crane hook along the projection of the barycentre of the mirror + handling. The position of the crane hook hoisting hole with the handling can be finely adjusted as it is mounted on a rail, actuated by an endless screw.

This latter part will be modified in favour of movable masses connected to the handling, keeping the hoist ring fixed. All the images of the handling does not represent this modification yet, still showing the sliding hoist ring.

This is useful when the mirrors are disconnected from the handling, as the barycentre of the system will move.

In this case, before disconnecting the handling and after the mirrors are secured to their supporting structure inside MSS, it is possible to shift the hook hoisting hole to the position where the stand-alone handling would be balanced. In this way, when the handling is disconnected from the mirrors, it will stay well balanced, avoiding dangerous oscillations that could damage the mirror.

At mirror side, the C-shaped handling is constituted by 2 main parts: a fixed part and a movable one. The latter is physically screwed to the 3 branches embracing M8 through six M8 screws (2 per branch), and it is interfaced to the handling fixed part through a heim joint, that allows adjusting its position in 3 DoFs.

The handling can be interfaced to the mirrors with the mirror protecting cover in place.

3 threaded rods screwed to the fixed part of the handling and pushing on the movable part allow to fine adjust the tip-tilt of the mirrors during the installation phase. One of the threaded rods is inserted in a small pit in the movable part, to prevent rotation of the mirror around its optical axis.

The handlings are designed to keep the mirrors with an orientation very close to the one they will have when mounted into MSS. This allows to perform only small mirror position adjustment at the moment of interfacing the mirrors to their supporting structure inside the MSS.

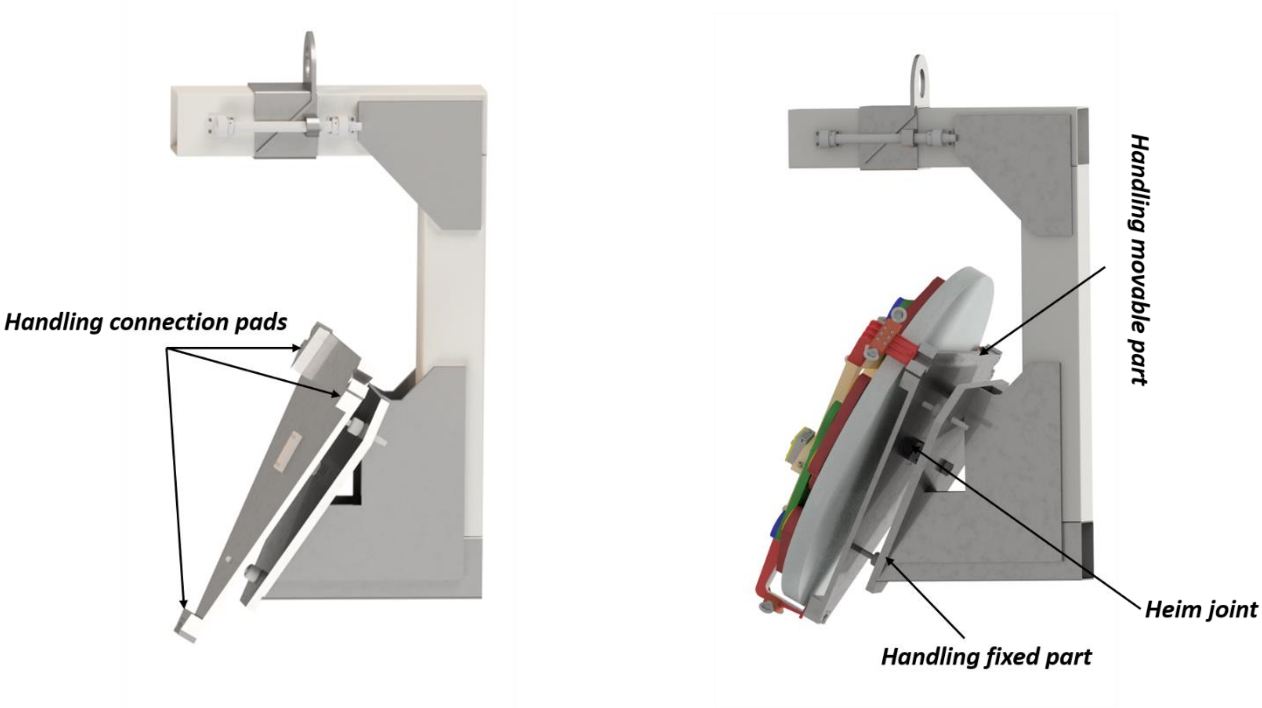


Figure 19: C-shaped handling for M8 installation. The interface between M8 and the handling is between the 3 branches embracing M8 and the 3 connection pads of the handling. The handling is equipped with a hook hoisting connection point having the possibility to slide, in order to have it aligned with the barycentre of the system both when M8 is connected and disconnected.

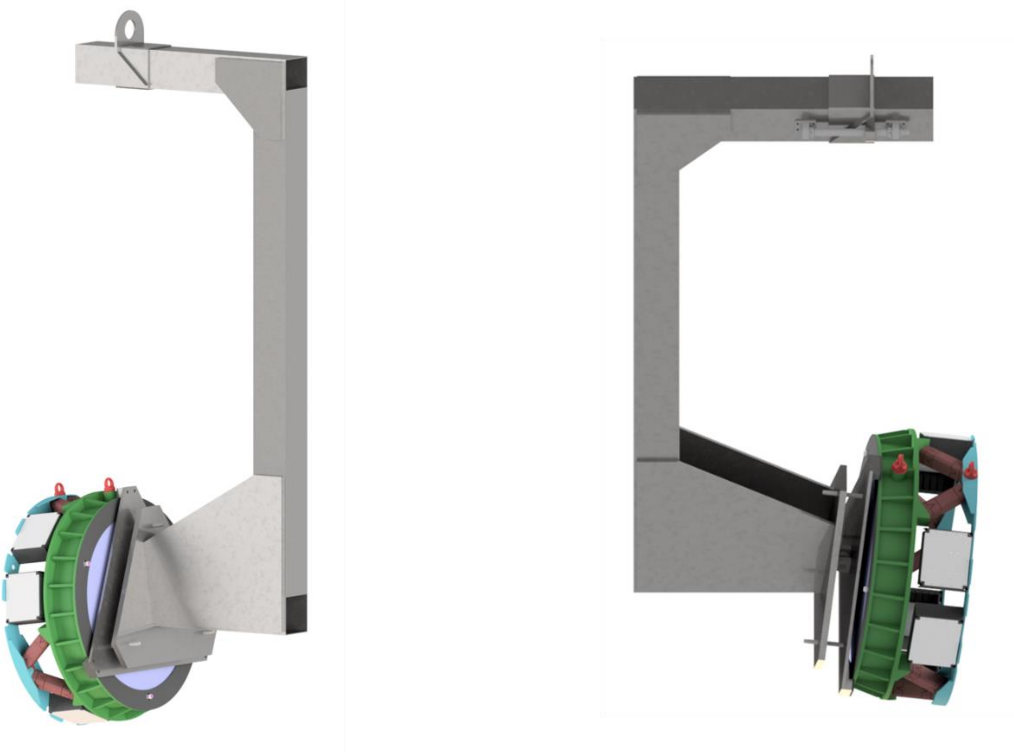


Figure 20: C-shaped handling for M9 installation. The interface between M9 and the handling is between the 3 pads at the front flange (in green) and the 3 connection pads of the handling. The handling is equipped with a hook hoisting connection point having the possibility to slide, in order to have it aligned with the barycentre of the system both when M9 is connected and disconnected.

Figure 21: C-shaped handling for M10 installation. The interface between M10 and the handling is between the 3 pads at the front flange (in green) and the 3 connection pads of the handling. The handling is equipped with a hook hoisting connection point having the possibility to slide, in order to have it aligned with the barycentre of the system both when M9 is connected and disconnected.

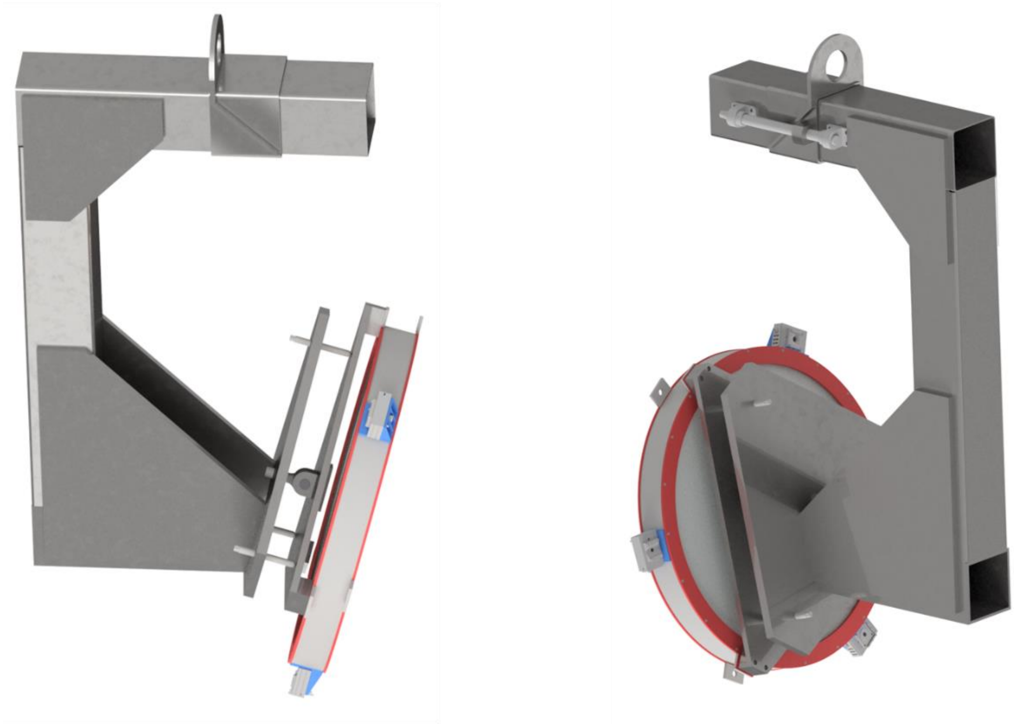


Figure 22: C-shaped handling for dichroic installation. The interface between dichroic and the handling is between the 3 pads at the front flange and the 3 connection pads of the handling. The handling is equipped with a hook hoisting connection point having the possibility to slide, in order to have it aligned with the barycentre of the system both when the dichroic is connected and disconnected.

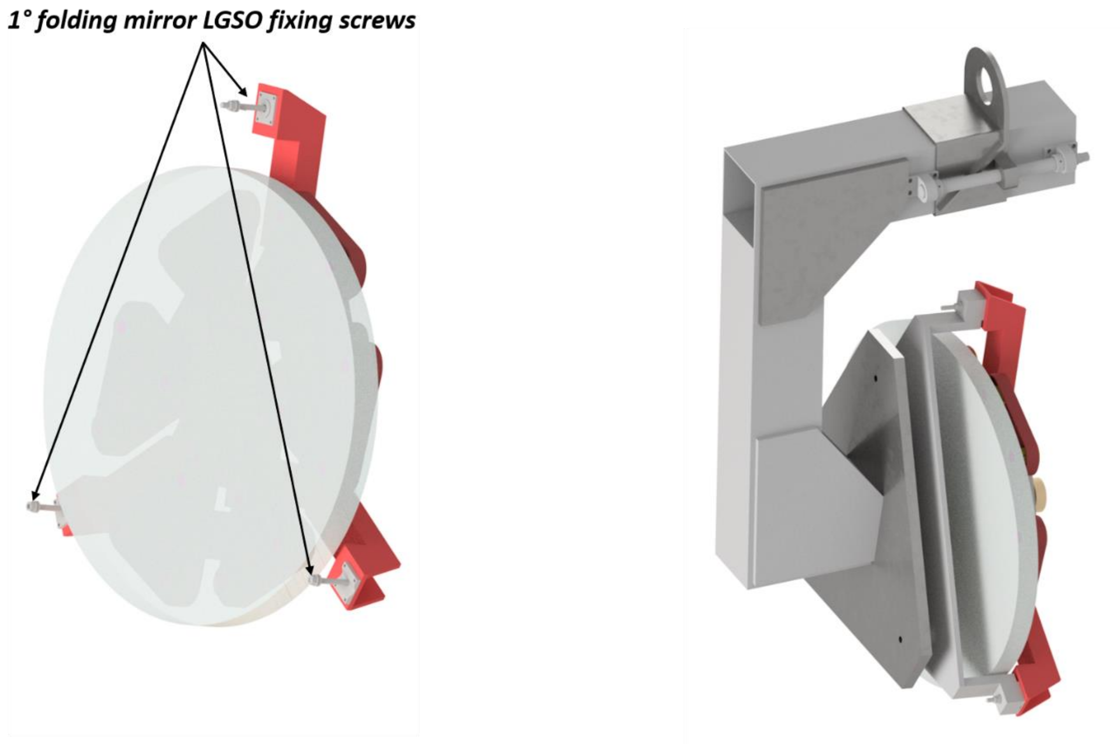


Figure 23: C-shaped handling for 1st folding mirror LGSO installation. The interface between the mirror and the handling is between the 3 branches, which are also the interface of the mirror to its supporting structure inside the MSS, and the 3 connection pads of the handling. The handling is equipped with a hook hoisting connection point having the possibility to slide, in order to have it aligned with the barycentre of the system both when the mirror is connected and disconnected.

Way to be operated/procedure

All these handlings must be operated in the following way:

- The cover of the corresponding mirrors must be installed
- A minimum of 2 persons plus the crane operator are necessary for mirror installation inside the MSS
- The internal ladders, platform and security harnesses to access mirrors in the MSS must be in place

The hoist point on the handlings has to be connected to the crane hook, then the handling approaches the mirror and connects to the fixation points on the mirror opto-mech. Some bars positioned on the opto-mech branches can be used to ease and guide the handlings approaching the relative mirrors.

Special tools needed

Normal mechanical workshop tools.

AIT phase when needed

SM0-HT-PFC, SM0-HT-PDA, SM0-HT-PDB, SM0-HT-PFD_CRANE and SM0-HT-PFG_CRANE are needed for the assembly operations in Bologna and in Chile and for maintenance in Chile.

Deliverable and lifetime

SM0-HT-PFC, SM0-HT-PDA, SM0-HT-PDB, SM0-HT-PFD_CRANE and SM0-HT-PFG_CRANE are deliverables to Chile, where they have to be stored to be used for maintenance.

Hazard and Safety issues

The handlings must be operated in the following way:

- The mirror protection covers must be installed
- A minimum of 2 persons plus the crane operator are necessary for the mirror installation in the MSS
- The temporary platform/scissor lift and internal ladders allowing to reach the mirrors area inside and outside the MSS must be in place
- Operators shall ware the helmet, safety gloves and safety shoes
- Every operator shall wear safety shoes, safety gloves and helmet
- When operating on the platform, the harness safely secured is mandatory for each operator

No Major Hazards have been identified, but mirrors destruction in case of mis-handling

6.4 M11 Assembly and maintenance Handling Tool (SM0-HT-PFE)

Purpose and functionality

The SM0-HT-PFE has the purpose to perform the assembly of M11 in the MSS. It is equipped with a sliding hoisting point to balance the overall system with and without M11.

Manufacturing

The conceptual design is done within the MAORY consortium, the final design and construction will be out-sourced to an external company.

Description

It is a C-shaped handling. This handling shape allows to interface the crane hook along the projection of the barycentre of M11 + handling. The position of the crane hook hoisting hole with the handling can be finely adjusted as it is mounted on a rail, actuated by an endless screw.

This latter part will be modified in favour of movable masses connected to the handling, keeping the hoist ring fixed. All the images of the handling does not represent this modification yet, still showing the sliding hoist ring.

This is useful when M11 is disconnected from the handling, as the barycentre of the system will move.

In this case, before disconnecting the handling and after M8 is secured to its supporting structure inside MAORY main structure, it is possible to shift the hook hoisting hole to the position where the stand-alone handling would be balanced. In this way, when the handling is disconnected from M11, it will stay well balanced, avoiding dangerous oscillations that could damage the mirror.

The opto-mech of M11 is interfaced to MSS in a different way from all the other mirrors, as this is a steering mirror. Thus, also the handling interfaces are different. The handling fixed part is identical to the other C-shaped handlings described till now, with an addition of two plates hosting two other threaded rods acting on the rotation of the mirror. The movable part is still connected to the fixed part through a heim joint, but the interface with the mirror is a kind of a fork entering into some slots in the mirror opto-mech.

3 threaded rods screwed to the fixed part of the handling and pushing on the back movable part allow to fine adjust the tip-tilt of M11 during the installation phase, while two additional rods pushing on the side of the movable part allow to fine adjust the rotation of M11.

The handling is designed to keep the mirror with an orientation very close to the one it will have when mounted into MSS. This allows to perform only small mirror position adjustment at the moment of interfacing M1 to its supporting structure inside the MSS.

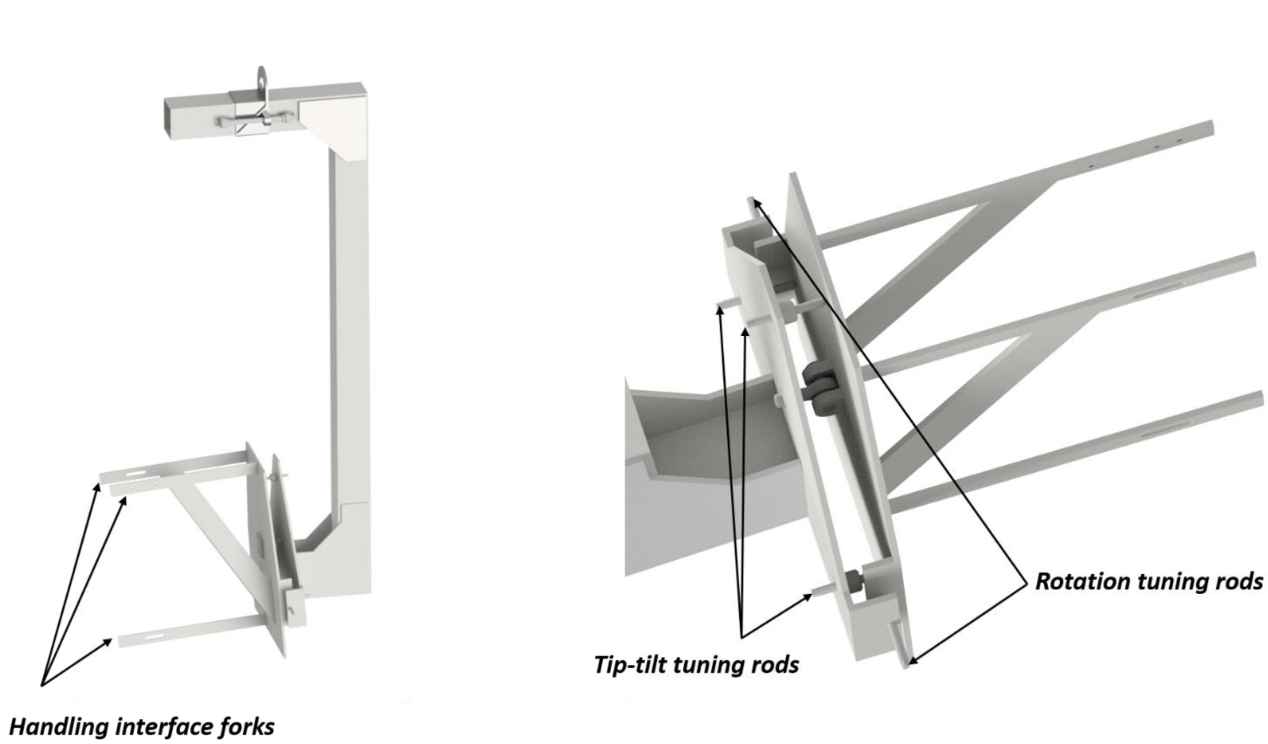


Figure 24: C-shaped handling for M11 installation. The interface between M11 and the handling is between the 3 forks shown here and 3 slots in the mirror opto-mech. This handling allows to control also the rotation of the mirror, using two additional threaded rods acting on the side of the handling movable part. The handling is equipped with a hook hoisting connection point having the possibility to slide, in order to have it aligned with the barycentre of the system both when M11 is connected and disconnected.

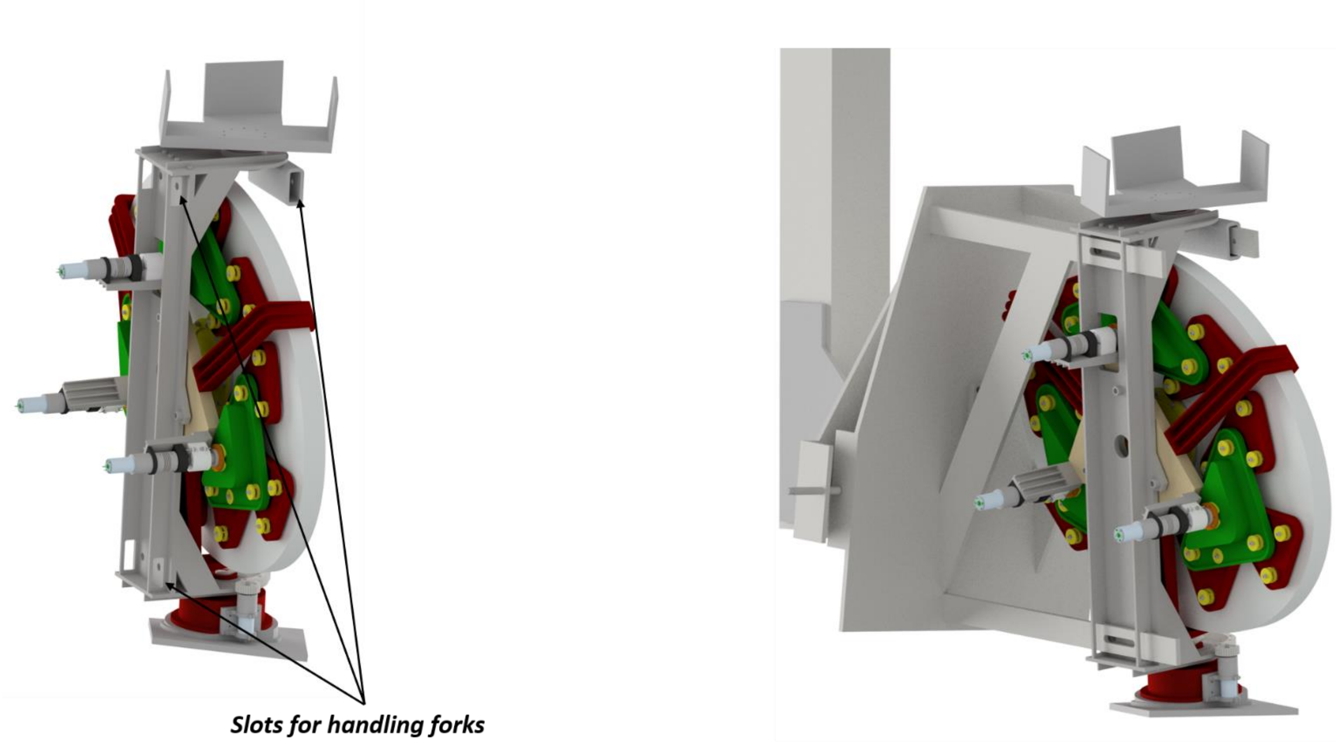


Figure 25: the M11 opto-mech is equipped with 3 slots for the handling forks. Each fork is secured using two M8 screws.

Way to be operated/procedure

The SM0-HT-PFE must be operated in the following way:

- The cover of M11 must be installed
- A minimum of 2 persons plus the crane operator are necessary for the SM0-HT-PFE handling/movement
- The internal ladders, platform and security harnesses to access M11 on the MSS must be in place

The hoist point on SM0-HT-PFE has to be connected to the crane hook, then the approaches M11 and connects to the fixation points on the mirror opto-mech. Some bars positioned on M11 branches can be used to ease and guide SM0-HT-PFE approach to M11.

Special tools needed

Normal mechanical workshop tools.

AIT phase when needed

The SM0-HT-PFE is needed for the assembly operations in Bologna and in Chile and for maintenance in Chile.

Deliverable and lifetime

The SM0-HT-PFE is a deliverable to Chile, where it has to be stored to be used for maintenance.

Hazard and Safety issues

The SM0-HT-PFE must be operated in the following way:

- The cover of M11 must be installed
- A minimum of 2 persons plus the crane operator are necessary for the SM0-HT-PFE handling/movement
- The scaffolding or security harnesses to access M11 on the bench must be in place
- The platform allowing to reach M11 area in the MSS must be in place
- Operators shall ware the helmet, safety gloves and safety shoes
- Every operator shall wear safety shoes, safety gloves and helmet
- When operating on the platform, the harness safely secured is mandatory for each operator

No Major Hazards have been identified, but mirror destruction in case of mis-handling

6.5 Corrective Plate assembly and maintenance Handling Tool (SM0-HT-PFK)

Purpose and functionality

The SM0-HT-PFK has the purpose to perform the assembly of the corrective plate in the MSS. It is equipped with a sliding hoisting point to balance the overall system with and without the corrective plate.

Manufacturing

The conceptual design is done within the MAORY consortium, the final design and construction will be out-sourced to an external company.

Description

It is basically a simplified and light-weighted C-shaped handling. This handling shape allows to interface the crane hook along the projection of the barycentre of the corrective plate + handling. The position of the crane hook hoisting hole with the handling can be finely adjusted as it is mounted on a rail, actuated by an endless screw.

This latter part will be modified in favour of movable masses connected to the handling, keeping the hoist ring fixed. All the images of the handling does not represent this modification yet, still showing the sliding hoist ring.

This is useful when the corrective plate is disconnected from the handling, as the barycentre of the system will move.

In this case, before disconnecting the handling and after the corrective plate is secured to its supporting structure inside MAORY main structure, it is possible to shift the hook hoisting hole to the position where the stand-alone handling would be balanced. In this way, when the handling is disconnected from the corrective plate, it will stay well balanced, avoiding dangerous oscillations that could damage the mirror.

The corrective plate will be mounted with the optical axis perpendicular to the gravity vector, so for its installation we do not devise the need of having a movable part on the handling, allowing to fine tune the tip-tilt position of the plate during the installation. The handling is thus constituted only by a fixed part, interfacing the corrective plate through three pads spaced by 120 degrees. One M8 screw passing through each pad is screwed to a threaded hole on a pad lacated on the corrective plate opto-mech.

The handling can be interfaced to the corrective plate with the mirror protecting cover in place.

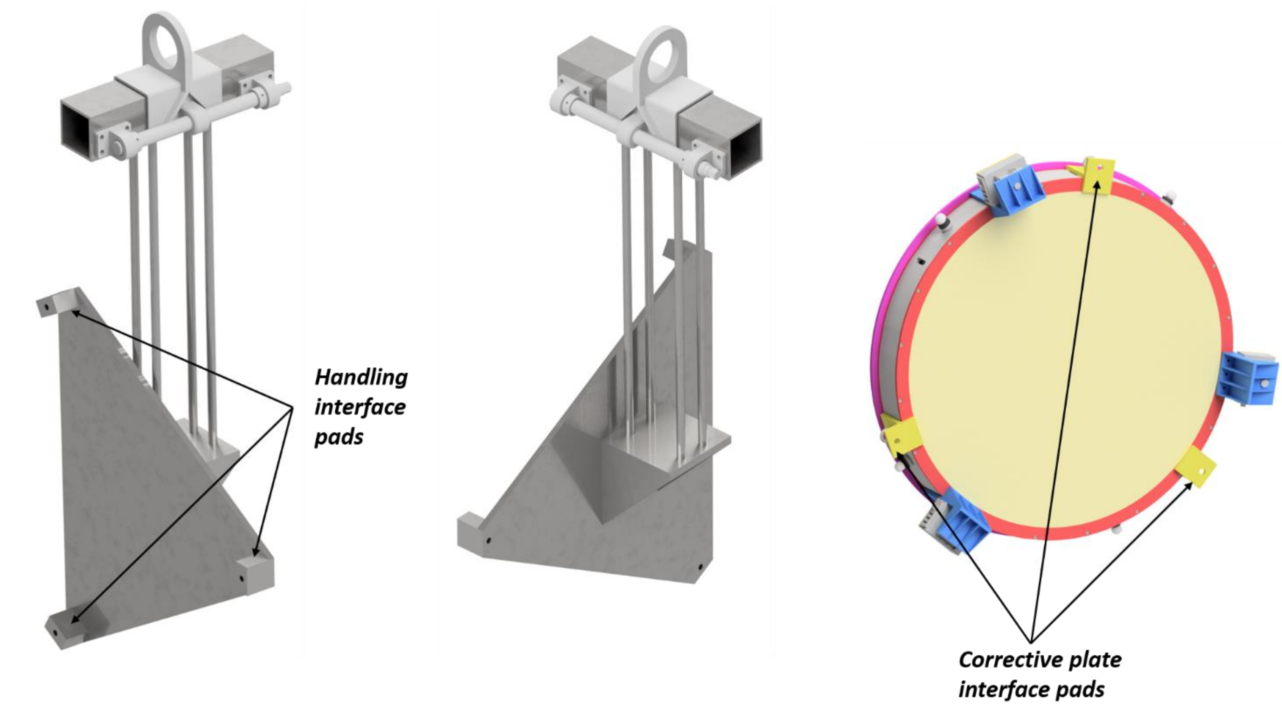


Figure 26: C-shaped handling for corrective plate installation. The interface between the corrective plate and the handling is between the 3 pads on the handling. The handling is equipped with a hook hoisting connection point having the possibility to slide, in order to have it aligned with the barycentre of the system both when M6 is connected and disconnected.

Way to be operated/procedure

The SM0-HT-PFK must be operated in the following way:

- The cover of the corrective plate must be installed
- A minimum of 2 persons plus the crane operator are necessary for the SM0-HT-PFK handling/movement
- The internal ladders, platform and security harnesses to access the corrective plate on the MSS must be in place

The hoist point on SM0-HT-PFK has to be connected to the crane hook, then the approaches the corrective plate and connects to the fixation points on the mirror opto-mech.

Special tools needed

Normal mechanical workshop tools.

AIT phase when needed

The SM0-HT-PFK is needed for the assembly operations in Bologna and in Chile and for maintenance in Chile.

Deliverable and lifetime

The SM0-HT-PFK is a deliverable to Chile, where it has to be stored to be used for maintenance.

Hazard and Safety issues

The SM0-HT-PFK must be operated in the following way:

- The cover of the corrective plate must be installed
- A minimum of 2 persons plus the crane operator are necessary for the SM0-HT-PFK handling/movement
- The platform allowing to reach the corrective plate area on the MSS must be in place
- Operators shall ware the helmet, safety gloves and safety shoes
- Every operator shall wear safety shoes, safety gloves and helmet
- When operating on the platform, the harness safely secured is mandatory for each operator

No Major Hazards have been identified, but mirror destruction in case of mis-handling

6.6 Corrective Plate Assembly and maintenance Handling Tool (SM0-HT-PFL)

Purpose and functionality

The SM0-HT-PFL has the purpose to perform the assembly of the third folding mirror LGSO. It has a fixed hoist point and a system of sliding counterweights to fine tune the barycentre position both when the mirror is connected and disconnected

Manufacturing

The conceptual design is done within the MAORY consortium, the final design and construction will be out-sourced to an external company.

Description

The installation of FM3 LGSO happens from the side of the MSS, and since the mirror is located in the bottom part of the structure a C-shaped handling is not advisable. Due to the light weight of FM3 LGSO, the handling is basically a squared tubular beam, with interface plate to the mirror on one side and a sliding mass at the opposite side. The handling dimensions shall be kept as short as possible, to avoid mechanical interference with MICADO, which is on the same side where the installation take place. At the same time, the handling hoist point shall remain always outside the MSS. This means that the counterweights will be positioned very close to the hoist point. In order to maintain the counterweights at a reasonable mass, the interface plate with FM3 is light-weighted, but it maintains the same principle of three connection pads at 120° seen for all the other handlings. For dimensional constraints tip-tilt fine tuning mechanism has not been included to this handling, so correct inclination of the mirror shall be obtained using shims at the interface between the handling and the mirror.

The handling is secured to the mirror through one M8 screw per each pad.

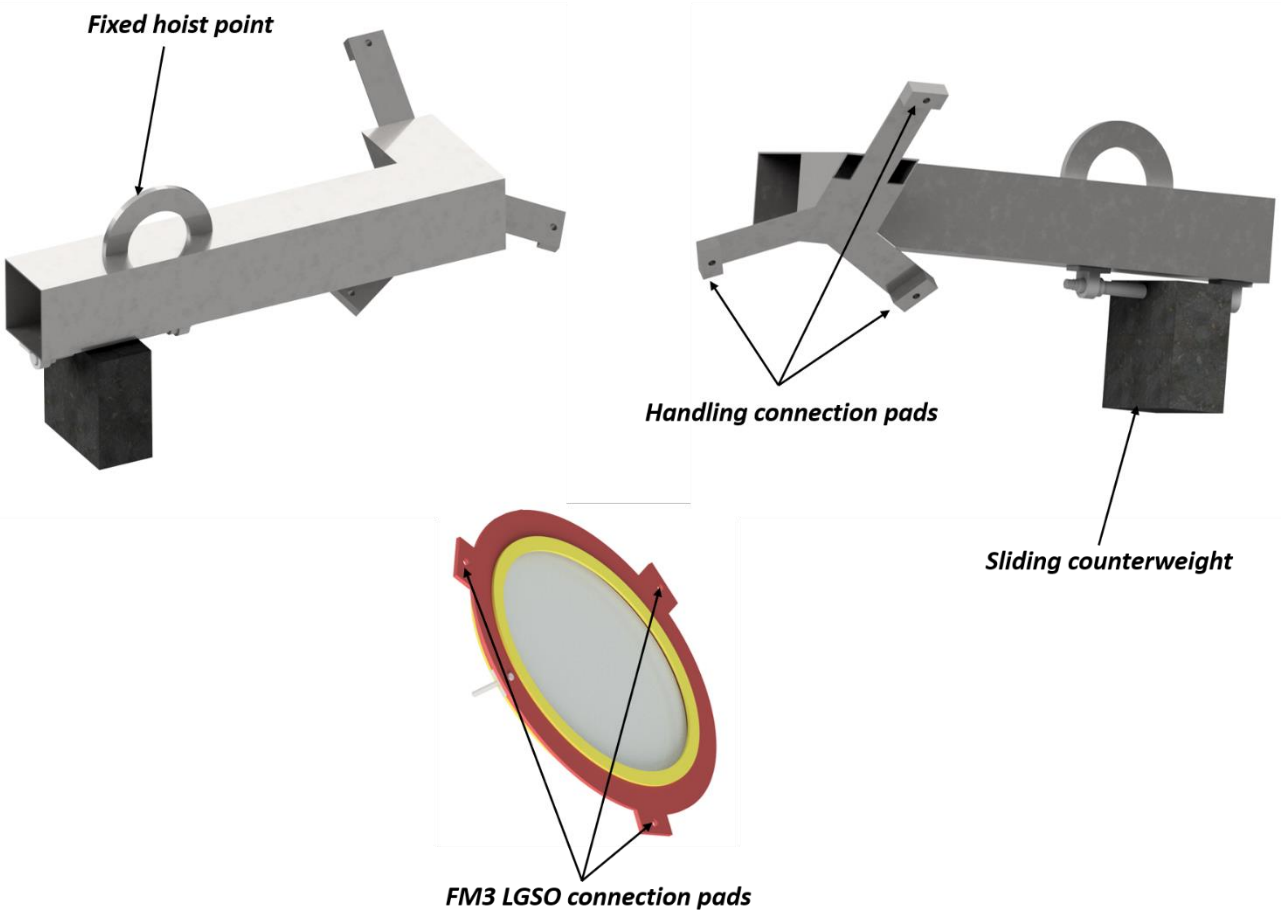


Figure 27: handling for FM3 LGSO installation. The interface between the corrective plate and the handling is between the 3 pads on the handling and the 3 pads on the opto-mech of the mirror. The handling is equipped with a fixed hook hoist point having and a sliding counterweights in order to have it aligned with the barycentre of the system both when FM3 LGSO is connected and disconnected.

Way to be operated/procedure

The SM0-HT-PFL must be operated in the following way:

- A minimum of 1 person plus the crane operator are necessary for the SM0-HT-PFL handling/movement
- The internal ladders, platform and security harnesses to access the corrective plate on the MSS must be in place

The hoist point on SM0-HT-PFL has to be connected to the crane hook, then the approaches FM3 LGSO and connects to the fixation points on the mirror opto-mech.

Special tools needed

Normal mechanical workshop tools.

AIT phase when needed

The SM0-HT-PFL is needed for the assembly operations in Bologna and in Chile and for maintenance in Chile.

Deliverable and lifetime

The SM0-HT-PFL is a deliverable to Chile, where it has to be stored to be used for maintenance.

Hazard and Safety issues

The SM0-HT-PFL must be operated in the following way:

- A minimum of 1 person plus the crane operator are necessary for the SM0-HT-PFL handling/movement
- The internal ladders allowing to reach the corrective plate area on the MSS must be in place
- Operators shall ware the helmet, safety gloves and safety shoes
- Every operator shall wear safety shoes, safety gloves and helmet
- When operating on the platform, the harness safely secured is mandatory for each operator

No Major Hazards have been identified, but mirror destruction in case of mis-handling

6.7 Dichroic Assembly and maintenance Handling Tool (SM0-HT-PFD_BENCH)

Purpose and functionality

The SM0-HT-PFD_BENCH has the purpose to perform the make the dichroic slid into the MMS.

Manufacturing

The conceptual design is done within the MAORY consortium, the final design and construction will be out-sourced to an external company.

Description

The installation of the dichroic happens from the side of the MSS. A handling similar to what presented for FM3 LGSO would require very heavy counterweights, as the dichroic weighs much more than FM3 LGSO and still we have dimensional constraints due to the envelope allocated to the 2nd instrument. For this reason, we studied a system with a rail protruding outside the MSS and entering into it. The rail is oriented in a way that the dichroic will reach its interface points inside the MSS with the correct orientation. The rail is permanently equipped with some sliding carts, and on top of this there is the part of the handling interfacing with the dichroic. It is divided in two parts: a fixed part and a movable one. The dichroic is mounted on the movable part, which has three pads at 120° interfacing to three pads on the dichroic opto-mech. The pads on the opto-mech are located on the opposite side to the one used to interface the dichroic to SM0-HT-PFD_CRANE. The movable part of the handling is secured to the fixed part using screws. These screws are loose, allowing the movable part to slide on the fixed part but preventing it from overturning.

The rail, in fact, bring the dichroic in front of its interface points in the MSS, but at a distance of about 15 mm, to avoid the optical surface of the dichroic being too close to mechanical parts when the handling slides on the rail. Thus, when in position, acting on some screws on the fixed part of the handling and pushing against the movable part, it is possible to push the dichroic against its interface points.

The part of the rail protruding outside the MSS lean on a beam connected to the ground. When the dichroic is secured to the handling on the rail and the handling on the crane is disengaged, the dichroic can slide inside the MSS. Some security blocks at both ends of the rail prevent the carts to slide off the rail.

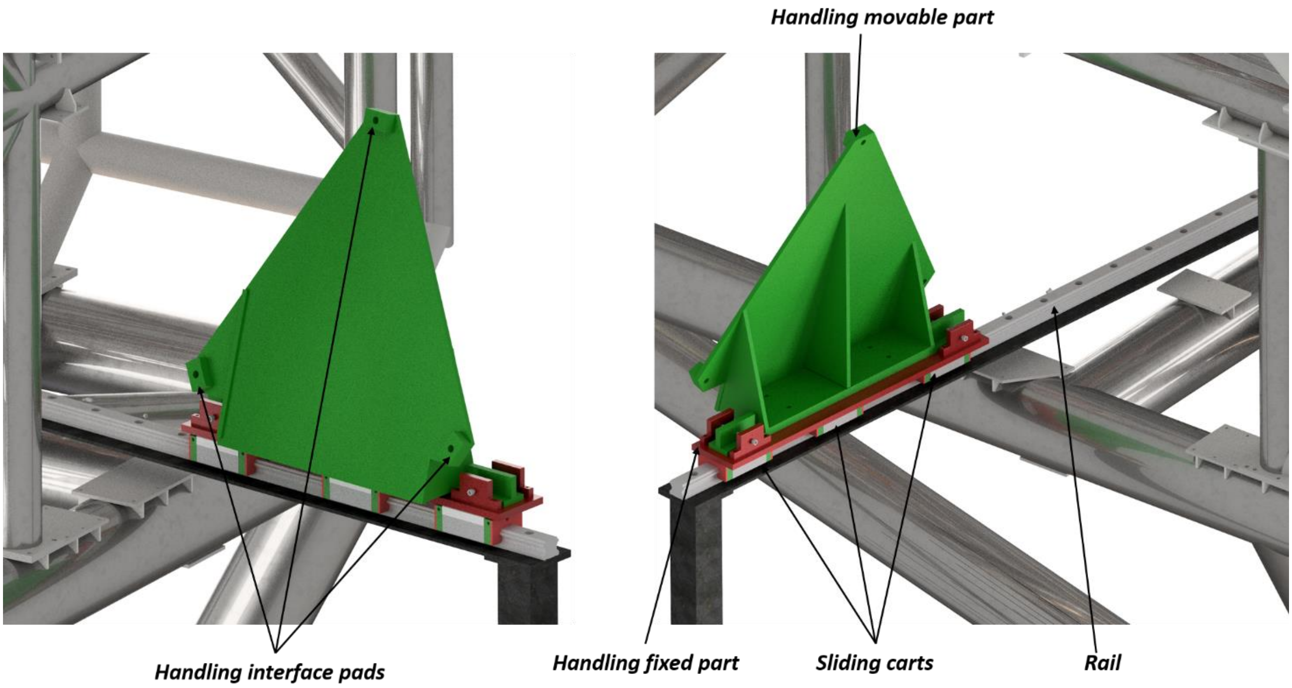


Figure 28: handling for dichroic installation. The fixed part is in red, the movable part in green

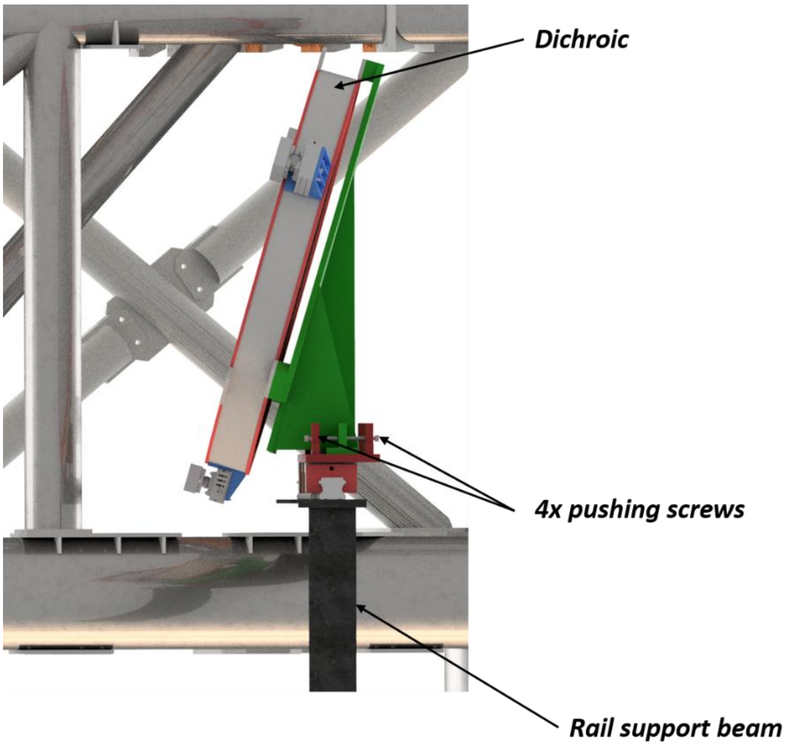


Figure 29: . Four M8 screws pushing against the movable part move it towards (or away) the dichroic interface points in the MSS

Way to be operated/procedure

The SM0-HT-PFD_BENCH must be operated in the following way:

- The cover of the dichroic must be installed
- A minimum of 2 person for the SM0-HT-PFD_BENCH handling/movement
- A small internal ladder to access the dichroic on the MSS must be in place
- Hard stop at both end of the rail must be in place
- Screws between handling movable part and fixed part inserted but not fully tightened

Special tools needed

Normal mechanical workshop tools.

AIT phase when needed

The SM0-HT-PFD_BENCH is needed for the assembly operations in Bologna and in Chile and for extraordinary maintenance in Chile.

Deliverable and lifetime

The SM0-HT-PFD_BENCH is a deliverable to Chile, where it has to be stored to be used for maintenance.

Hazard and Safety issues

The SM0-HT-PFD_BENCH must be operated in the following way:

- A minimum of 2 person are necessary for the SM0-HT-PFD_BENCH handling/movement
- The internal ladders allowing to reach the corrective plate area on the MSS must be in place
- Operators shall ware the helmet, safety gloves and safety shoes
- Every operator shall wear safety shoes, safety gloves and helmet
- When operating on the platform, the harness safely secured is mandatory for each operator

No Major Hazards have been identified, but dichroic destruction in case of mis-handling

6.8 1st folding mirror LGSO Assembly and maintenance Handling Tool (SM0-HT-PFG_BENCH)

Purpose and functionality

The SM0-HT-PFG_BENCH has the purpose to perform the make the 1st folding mirror LGSO slid into the MMS.

Manufacturing

The conceptual design is done within the MAORY consortium, the final design and construction will be out-sourced to an external company.

Description

The installation of the 1st folding mirror LGSO (FM1 LGSO) happens from the side of the MSS. The concept and the reasons for this handling are the same described for the SM0-HT-PFD_BENCH. The rail is oriented in a way that the FM1 LGSO will reach its interface points inside the MSS with the correct orientation. The rail is permanently equipped with some sliding carts, and on top of this there is the part of the handling interfacing with the dichroic. It is divided in two parts: a fixed part and a movable one. The FM1 LGSO is mounted on the movable part, which has three pads at 120° interfacing to three pads on the dichroic opto-mech. The pads on the opto-mech are located on the opposite side to the one used to interface the FM1 LGSO to SM0-HT-PFG_CRANE. The movable part of the handling is secured to the fixed part using screws. These screws are loose, allowing the movable part to slide on the fixed part but preventing it from overturning.

The rail, in fact, bring the FM1 LGSO in front of its interface points in the MSS, but at a distance of about 15 mm, to avoid the optical surface of the dichroic being too close to mechanical parts when the handling slides on the rail. Thus, when in position, acting on some screws on the fixed part of the handling and pushing against the movable part, it is possible to push the FM1 LGSO against its interface points.

The part of the rail protruding outside the MSS lean on a beam connected to the ground. When the FM1 LGSO is secured to the handling on the rail and the handling on the crane is disengaged, the FM1 LGSO can slide inside the MSS. Some security blocks at both ends of the rail prevent the carts to slide off the rail.

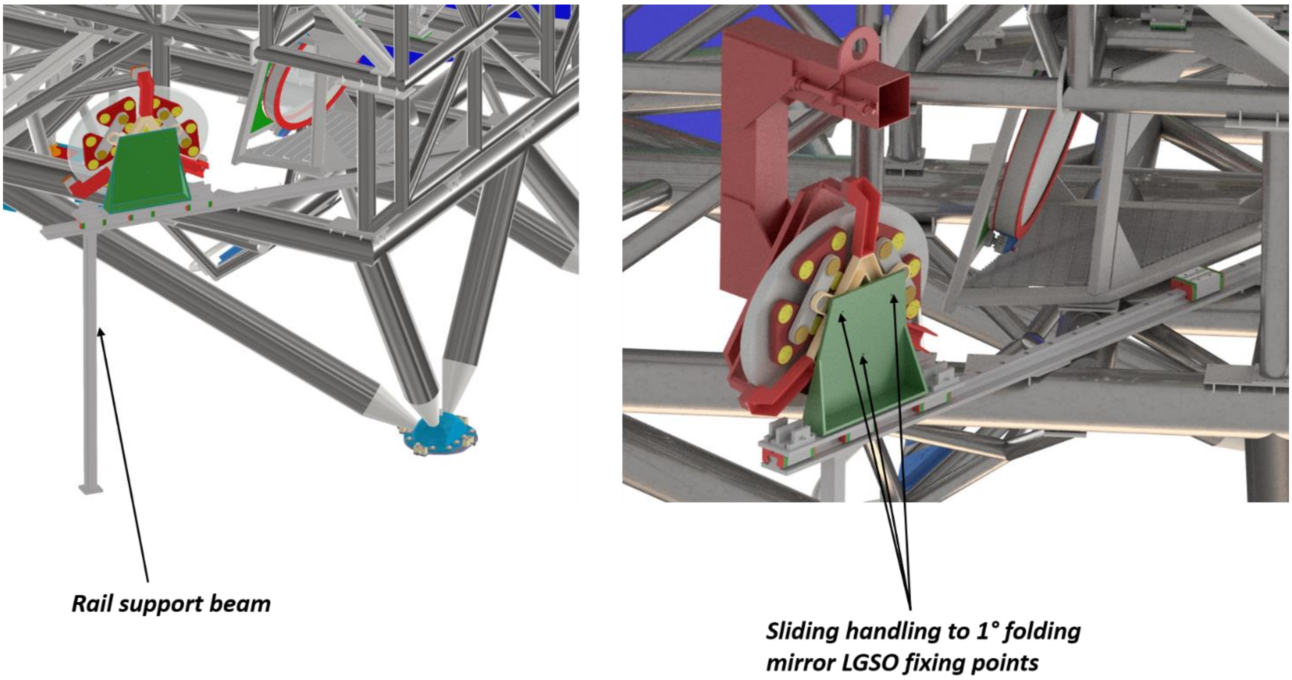


Figure 30: handling for FM1 LGSO installation.

Way to be operated/procedure

The SM0-HT-PFG_BENCH must be operated in the following way:

- The cover of the FM1 LGSO must be installed
- A minimum of 2 person for the SM0-HT-PFG_BENCH handling/movement
- A small internal ladder to access the FM1 LGSO on the MSS must be in place
- Hard stop at both end of the rail must be in place
- Screws between handling movable part and fixed part inserted but not fully tightened

Special tools needed

Normal mechanical workshop tools.

AIT phase when needed

The SM0-HT-PFG_BENCH is needed for the assembly operations in Bologna and in Chile and for maintenance in Chile.

Deliverable and lifetime

The SM0-HT-PFG_BENCH is a deliverable to Chile, where it has to be stored to be used for maintenance.

Hazard and Safety issues

The SM0-HT-PFG_BENCH must be operated in the following way:

- A minimum of 2 person are necessary for the SM0-HT-PFG_BENCH handling/movement
- The internal ladders allowing to reach the corrective plate area on the MSS must be in place
- Operators shall ware the helmet, safety gloves and safety shoes
- Every operator shall wear safety shoes, safety gloves and helmet
- When operating on the platform, the harness safely secured is mandatory for each operator

No Major Hazards have been identified, but dichroic destruction in case of mis-handling

6.9 LGSO Assembly and maintenance Handling Tool (SM0-HT-PFH_CRANE)

Purpose and functionality

The SM0-HT-PFH_CRANE has the purpose to perform the lower the LGSO on the SM0-HT-PFH_BENCH.

Manufacturing

The conceptual design is done within the MAORY consortium, the final design and construction will be out-sourced to an external company.

Description

Due to the shape of the LGSO, whose mechanical structure is equipped with 4 eye-bolts, this handling is basically 4 chains connected to the hook of the crane. The length of the crane must be tuned in order to keep the system balanced.

This handling is only needed to lower the LGSO on the rails of SM0-HT-PFH_BENCH, or to lift it up from the rails, in case of extraordinary maintenance.

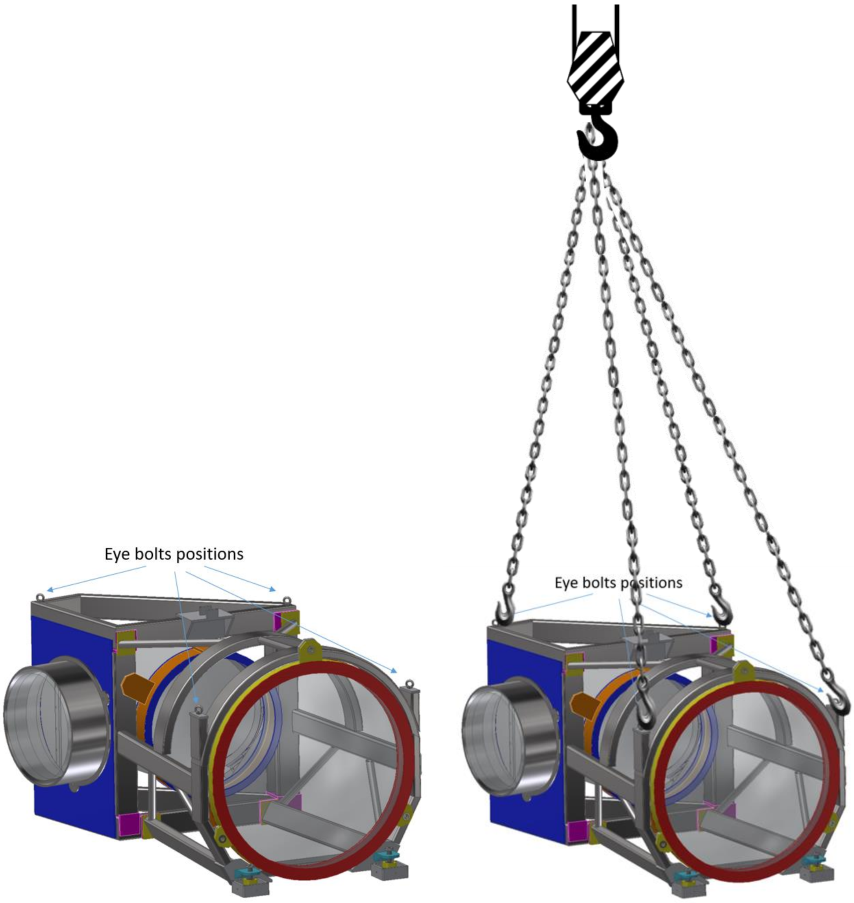


Figure 31: handling for lowering the LGSO

Way to be operated/procedure

The SM0-HT-PFH_CRANE must be operated in the following way:

- The cover of the LGSO must be installed
- The length of the chains must have been tuned to keep the system balanced
- A minimum of 1 person + the crane operator are necessary for the SM0-HT-PFH_CRANE handling/movement

Special tools needed

Normal mechanical workshop tools.

AIT phase when needed

The SM0-HT-PFH_CRANE is needed for the assembly operations in Bologna and in Chile and for maintenance in Chile.

Deliverable and lifetime

The SM0-HT-PFH_CRANE is a deliverable to Chile, where it has to be stored to be used for extraordinary maintenance.

Hazard and Safety issues

The SM0-HT-PFH_CRANE must be operated in the following way:

- A minimum of 1 person + the crane operator are necessary for the SM0-HT-PFG_BENCH handling/movement
- Operators shall ware the helmet, safety gloves and safety shoes
- Every operator shall wear safety shoes, safety gloves and helmet
- When operating on the platform, the harness safely secured is mandatory for each operator

No Major Hazards have been identified, but LGSO damages in case of mis-handling

6.10 LGSO Assembly and maintenance Handling Tool (SM0-HT-PFH_BENCH)

Purpose and functionality

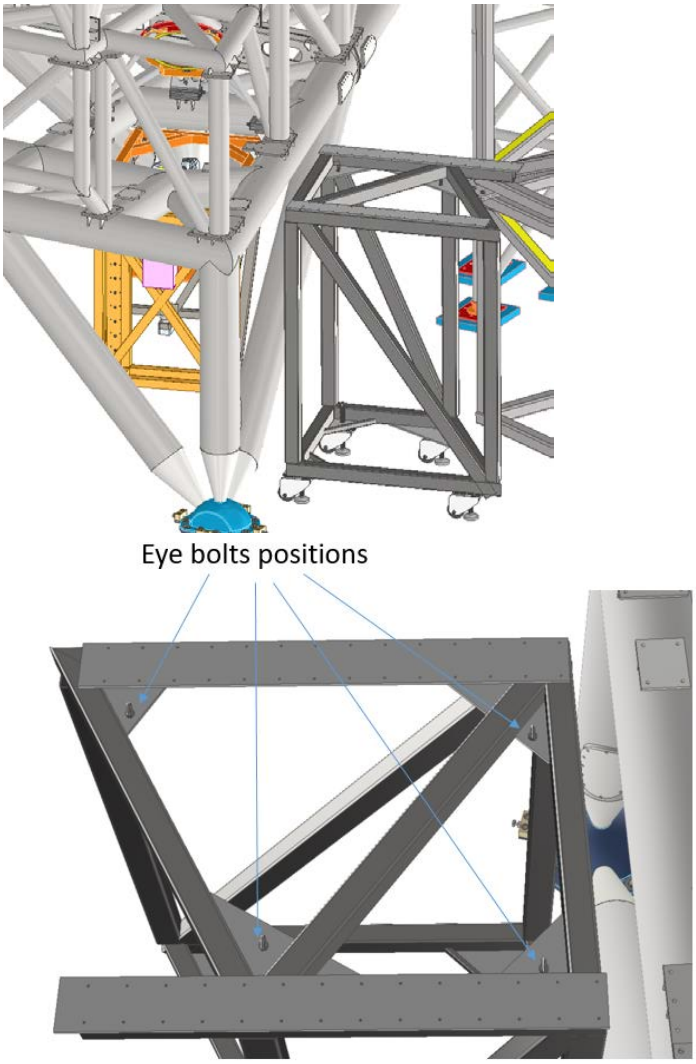
The SM0-HT-PFH_BENCH has the purpose to perform the installation of the LGSO inside the MSS.

Manufacturing

The conceptual design is done within the MAORY consortium, the final design and construction will be out-sourced to an external company.

Description

The LGSO is installed inside the MSS using a rail system, making it sliding in the MSS from the side. Part of these rails will be most likely permanently installed inside the MSS, while the part protruding outside the MSS shall be installed when needed. The rail protruding outside will lean on an external support structure placed next to the aperture in the MSS where the LGSO will enter. The supporting structure can be lowered with the crane thanks to the four eyebolt on the top part of the structure. Once the structure reaches the floor, it can be easily moved as it is equipped with four wheels and aligned to the MSS. The structure can be finally fixed to the ground lowering the feet and screwing it to the floor. On the top part of this structure the missing part of the rails can be installed and screwed by two persons, due to the small size and weight of a single rail.


Eye bolts positions

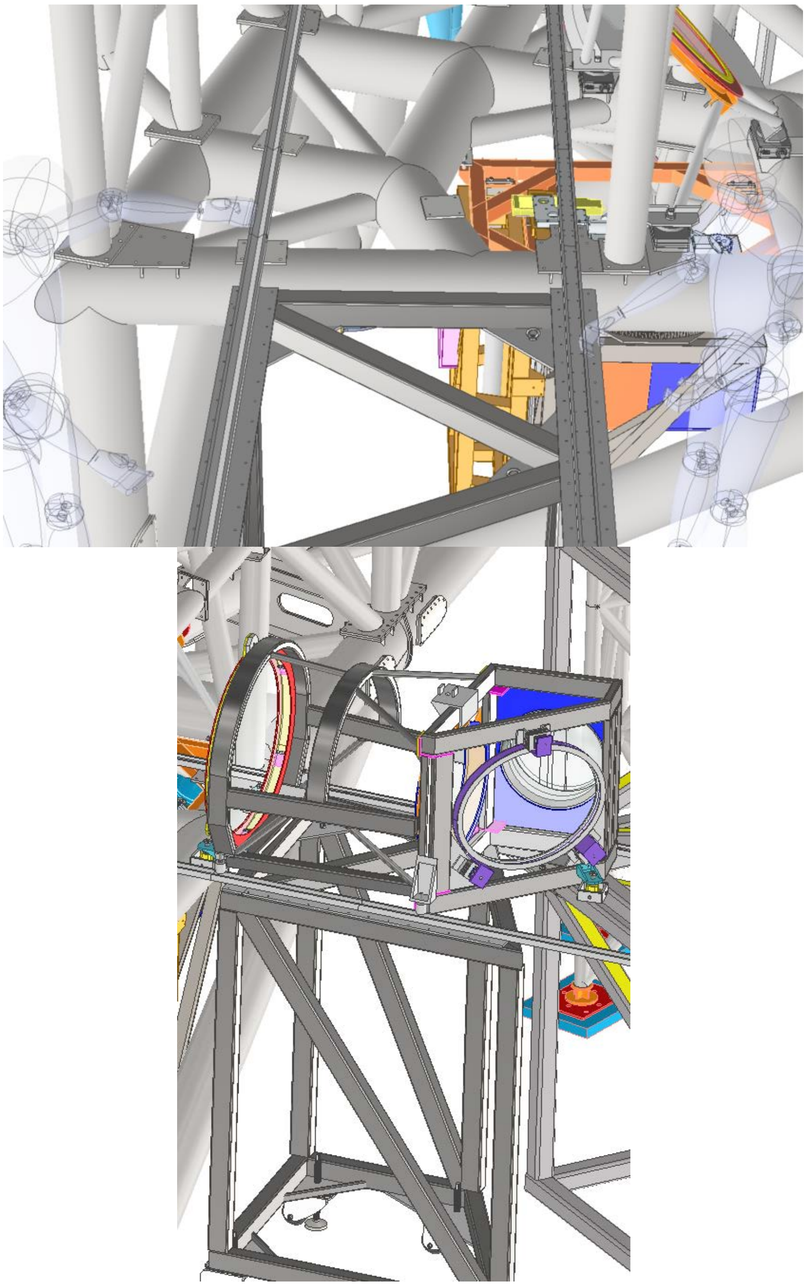


Figure 32: the handling hosting the rails for LGSO installation inside the MSS

Way to be operated/procedure

The SM0-HT-PFH_BENCH must be operated in the following way:

- The length of the chains for lowering the rails supporting structure must have been tuned to keep the system balanced

- A minimum of 1 person + the crane operator are necessary for the supporting structure movement and fixation to the ground when in position.
- Two persons are necessary to fix the rails to the supporting structure

Special tools needed

Normal mechanical workshop tools.

AIT phase when needed

The SM0-HT-PFH_BENCH is needed for the assembly operations in Bologna and in Chile and for maintenance in Chile.

Deliverable and lifetime

The SM0-HT-PFH_BENCH is a deliverable to Chile, where it has to be stored to be used for extraordinary maintenance.

Hazard and Safety issues

The SM0-HT-PFH_BENCH must be operated in the following way:

- A minimum of 1 person + the crane operator are necessary for the supporting structure handling/movement and two person for rail installation on top of the supporting structure
- Operators shall ware the helmet, safety gloves and safety shoes
- Every operator shall wear safety shoes, safety gloves and helmet
- When operating on the platform, the harness safely secured is mandatory for each operator

No Major Hazards have been identified, but mis-handling of the rails and of the supporting structure might damage the items nearby.

7. SUPPORT EQUIPMENT

In this section, we describe all the Support Equipment (SEq) needed for the AIT operations. For every SEq listed, all the relevant information should be reported, such as:

- purpose and functionality
- manufacturing
- description
- way to be operated
- special tools needed
- AIT phase when needed (handling during assembly or necessary for integration or testing or packaging or storage)
- Drawings and/or photos
- Deliverable to Bologna and/or to Chile
- Hazard and Safety issues worth to be underlined

We recall that every support equipment must be listed in the BoM and in the RAMS documents, which have to be referenced for all the issues concerning the Safety and Hazard. A reference directly here for all the support equipment is ok, even if we strongly suggest to recall the main safety and hazard issues related to each Seq also in the correspondent sub-sections describing them, as shown in sec. 0.

All the support equipment which has to be used with a crane and for moving equipment around shall have the CE certification.

7.1 TAC System

7.1.1 Purpose and functionality

The purpose of this system is to have a Test and Alignment Camera (TAC), working in H and J bands, to be used in the BIH for alignment and testing purposes. Due to the impossibility of having a large detector, such camera will be installed on a motorized XYZ system spanning the whole output focal plane. An additional arm may be used to create a pupil image on another detector, positioning a beam splitter just before the OFP and isung a collimating lens, as it is shown in Figure 33 right side.

7.1.2 Manufacturing

They are all off-the-shelf products, but the flanges that will be used to interface them, that will be either manufactured “in house” or outsourced.

7.1.3 AIT phase when needed

The TAC is needed for the alignment operations in Europe.

7.1.4 Deliverable and lifetime

The TAC is a deliverable to Bologna.

7.1.5 Hazard and Safety issues

No particular hazard and safety issues have been identified.

7.1.6 Special tools needed

Normal mechanical WS tools are needed.

7.1.7 Way to be operated

Both for the TAC and for the XYZ we will procure electronics and SW provided by the producers. The SW will possibly be integrated with the MAORY AIV auxiliary SW.

7.1.8 Preliminary description of the Test and Alignment Camera

For the alignment of MAORY in the AIT phase, i.e. in the BIH, a TAC is needed. The procedure is described in detail in 8.4.49.

The main duty of the TAC is the acquisition of the on/off axis MAORY PSFs during the alignment and debugging operations of the instrument. The TAC is used during the AIT operations without MICADO. The TAC shall patrol the MAORY focal plane with Motorized Stages (MS) for the full MICADO field size, diameter 253.25 mm and shall be able to move along the MAORY optical axis with an extension of +/- 37.5 mm along the focal plane position. A possible candidate for the TAC imaging unit is the OWL 1280 1280x1024 with a detector size of 12.8 mm x 10.24 mm and a pixel pitch of 10 µm. From recent discussions the alignment of the pupil of axis of MAORY with the focal plane center would benefit from a Flat Mirror (FTM) deployable by the TAC on a common vessel with the imaging unit. A preliminary conceptual design of the TAC is shown in Figure 33.

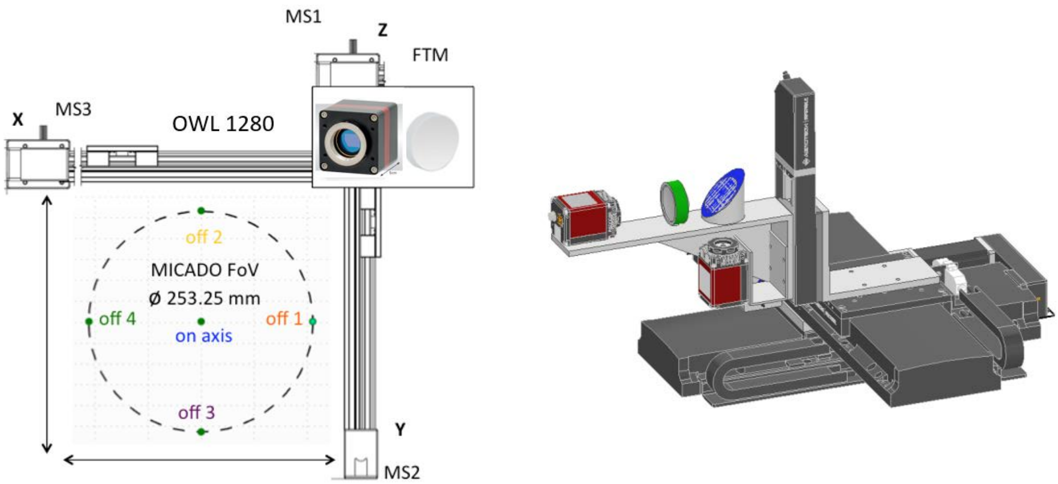


Figure 33 left side: Preliminary concept of the TAC carrying a vessel mounted on a 3D motorized Cartesian system to deploy an imaging unit and a flat mirror (FTM) at the MAORY focal plane. For convention the X and Y axes are tangential to the MAORY focal plane. Right side: the same system with the additional arm to create a pupil image, to be detailed for the FDR.

Link to OWL 1280 datasheet:

https://www.raptorphotonics.com/wp-content/uploads/2021/03/Owl-1280-A4.pdf

The sensitivity and quantum efficiency range of the OWL 1280 is shown in Figure 34.

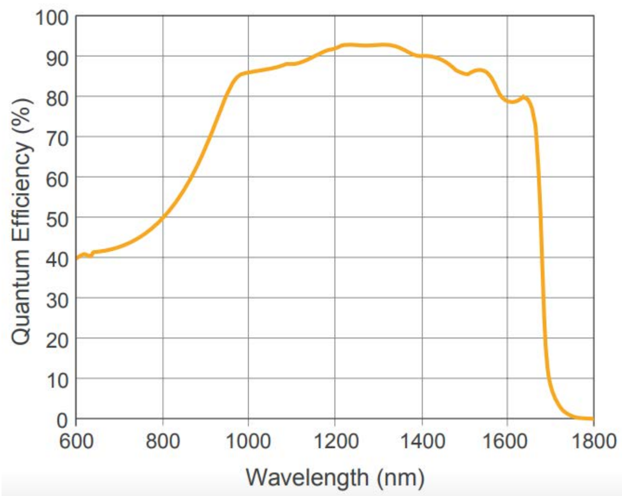


Figure 34 Quantum efficiency of the OWL 1280 camera.

The functional and performance requirements of the TAC are collected in Table 3 and Table 4.

Table 3 TAC functional requirements

Requirement	Verification	Linking
The TAC shall be installed on the MES at the MAORY focal plane.	D	
The TAC shall be capable of patrolling the MAORY focal plane along two independent motorized axes over the MICADO science FoV.	D, T	
The TAC shall be capable of moving through intra and extra focal position wrt the MAORY best focus plane.	D, T	
The TAC shall not have any light source that emits light (in the wavelength range from 0.3 to 3 μm).	D	R-INS-797
The TAC shall be able to operate without any active cooling system.	D	
The TAC might be capable of operating via the MAORY Instrument Control Software. TBC	D	
The TAC shall deploy a flat mirror for the relative	D	

alignment of the pupil to the field (TBC).		
The TAC shall withstand the environmental conditions of the ELT instrument as specified in AD4.	D	

Table 4 TAC performance requirements

Requirement	**Verification**	**Linking**
The TAC shall be sensitive in the 1 µm – 1.6 µm wavelength range.	D	
The TAC shall have a minimum detector size of 5 mm x 5 mm.	D	
The TAC shall have a pixel pitch between 5 µm and 20 µm.	D	
The TAC shall move along two axes at the MAORY focal plane in a range of +/- 127 mm (MICADO field).	D, T	
The TAC shall move along MAORY optical axis in a range of +/- 37.5 mm.	D, T	
The TAC shall move with a minimum step of 100 µm along the three axes.	D, T	
The motorized stage of the TAC shall not wobble (Yaw Pitch Roll, YPR) by more than 35 arcsec (goal 7 arcsec) over 300 mm travel range. Note: YPR of 35 arcsec (goal 10 arcsec) over 300 mm on both stages translates in 70 µm (goal 50 µm) in defocus, compatible with a focus depth of 100 µm.	D, T	

Specification for Owl 1280

Sensor Type	InGaAs PIN-Photodiode
Active Pixel	1280 x 1024
Pixel Pitch	10µm x 10µm
Active Area	12.8mm x 10.24mm
Spectral response[1]	0.6µm to 1.7µm
Readout Noise (RMS)[2] LG = Low Gain HG = High Gain	LG: <180 electrons (160 electrons typical) HG: <50 electrons (47 electrons typical)
Peak Quantum Efficiency	>90% @ 1.3µm
Full Well Depth	LG: 450ke- HG: 10ke-
Pixel Operability	>99.5%
Dark Current (e/p/s)	<19,000 @ 15°C
Digital Output Format	12 bit Camera Link (medium configuration)
Exposure time	LG: 10µs to 92.5ms HG: 10µs to 86.5ms
Shutter mode	Global shutter
Frame Rate	10 to 60Hz
Optical Interface	C mount (selection of SWIR lens avaliable)
Dynamic Range	LG: 69dB, HG: 47dB
Trigger interface	Trigger IN and OUT - TTL compatible
Power supply	12V DC ±0.5V
TE Cooling	Active
Image Correction	3 point NUC (offset, Gain & Dark Current) + pixel correction
Functions controlled by serial communication	Eg. Exposure, intelligent AGC, Non Uniformity Correction, Gamma, Pk/Av, TEC, ROI, etc
Camera Power Consumption[3]	<8W with TEC ON, NUC ON
Operating Case Temperature[4]	-20°C to +55°C
Storage Temperature	-30°C to +60°C
Dimensions (L*W*H)[5]	67.60mm x 50.00mm x 50.00mm
Weight	247g
Raptor Photonics Limited reserves the right to change this document at any time without notice and disclaims liability for editorial, pictorial or typographical errors. This product is under the export control of UK government and maybe subject to an Single Individual export licence before shipment.	

Figure 35 OWL 1280 camera specifications including the electrical and communication interfaces.

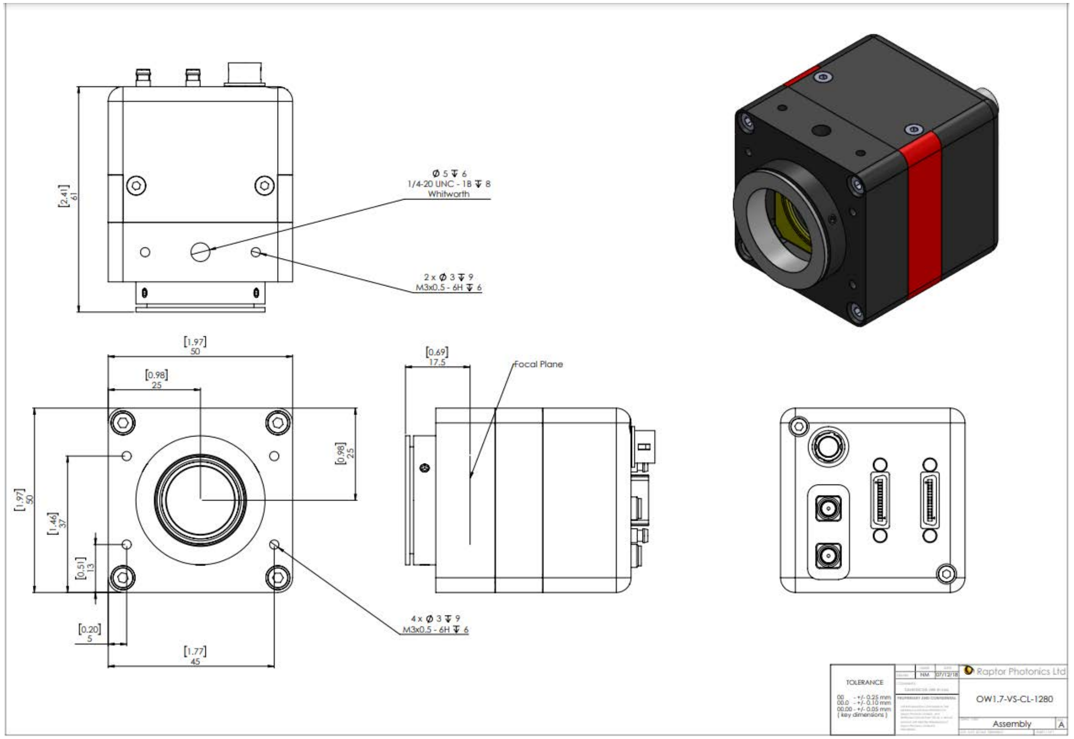


Figure 36 Opto-mechanical interfaces and drawing for the OWL 1280 camera.

The selection of the MS to patrol the MICADO science FoV with the TAC shall take into account the wobble/run out in Yaw, Pitch and Roll (YPR) of the stage translated along the optical axis of the camera. The quadrature sum of the run out of the two MS moving the camera tangentially to the MAORY focal plane to patrol different field points shall be smaller than the focus depth of MAORY, 100 μm-200 μm (Figure 37) to avoid visible defocus of the PSFs.

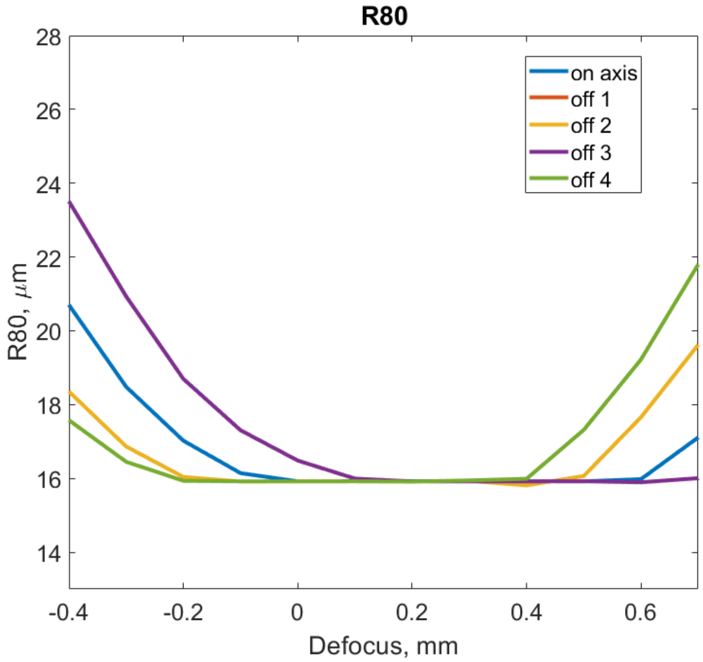


Figure 37 MAORY focus depth using as parameter reference the photometric radius enclosing the 80% of the PSF flux. The focus depth lies between 100 μm and 200 μm.

Some possible MS models and specifications from Aerotech for the 3D Cartesian motorized system of the TAC are reported in Figure 38 and Figure 39.

The suitable travel range for the TAC stages are reported in Table 5.

Table 5 Travel range of the TAC stages required for the MAORY alignment.

Travel range X & Y	300 mm
Travel range Z	75 mm

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Mechanical Specifications		PRO165LM									
Travel		100	150	200	250	300	400	500	600	800	1000
Accuracy[1]	Standard	±4 μm	±6 μm	±8 μm	±9 μm	±10 μm	±12 μm	±14 μm	±15.5 μm	±17 μm	±18 μm
	Calibrated	±1 μm	±1 μm	±1.5 μm	±1.5 μm	±1.5 μm	±1.5 μm	±2 μm	±2 μm	±2 μm	±2 μm
Resolution (Min. Incremental Motion)		5 nm (-E1 Encoder), 10 nm (-E3 Encoder)									
Bidirectional Repeatability[1]		±0.4 μm	±0.4 μm	±0.5 μm	±0.5 μm	±0.5 μm	±0.5 μm	±0.5 μm	±0.5 μm	±0.5 μm	±0.5 μm
Horizontal Straightness[1]		±2.5 μm	±3 μm	±4 μm	±5 μm	±6 μm	±8 μm	±9 μm	±10 μm	±12 μm	±14 μm
Vertical Straightness[1]		±2.5 μm	±3 μm	±4 μm	±5 μm	±6 μm	±8 μm	±9 μm	±10 μm	±12 μm	±14 μm
Pitch		29 μrad (6 arc sec)	29 μrad (6 arc sec)	40 μrad (8.2 arc sec)	46 μrad (9.5 arc sec)	58 μrad (12 arc sec)	70 μrad (14.4 arc sec)	80 μrad (16.5 arc sec)	90 μrad (18.6 arc sec)	100 μrad (20.6 arc sec)	120 μrad (24.7 arc sec)
Roll		29 μrad (6 arc sec)	29 μrad (6 arc sec)	40 μrad (8.2 arc sec)	46 μrad (9.5 arc sec)	58 μrad (12 arc sec)	70 μrad (14.4 arc sec)	80 μrad (16.5 arc sec)	90 μrad (18.6 arc sec)	100 μrad (20.6 arc sec)	120 μrad (24.7 arc sec)
Yaw		29 μrad (6 arc sec)	29 μrad (6 arc sec)	40 μrad (8.2 arc sec)	46 μrad (9.5 arc sec)	58 μrad (12 arc sec)	70 μrad (14.4 arc sec)	80 μrad (16.5 arc sec)	90 μrad (18.6 arc sec)	100 μrad (20.6 arc sec)	120 μrad (24.7 arc sec)
Maximum Speed[2]		2 m/s									
Maximum Acceleration[2]		3 g									
Maximum Force, Continuous		77.7 N									
Load Capacity[3]	Horizontal	45 kg									
	Side	45 kg									
Moving Mass		2.6 kg									
Stage Mass		8.2 kg	9.1 kg	9.9 kg	10.7 kg	11.6 kg	13.3 kg	14.9 kg	16.6 kg	20.0 kg	23.3 kg
Material		Anodized Aluminum									
MTBF (Mean Time Between Failure)		20,000 Hours									

Notes:
1. Certified with -PL1 option.
2. Requires the selection of an appropriate amplifier with sufficient voltage and current.
3. Axis-orientation for on-axis loading is listed.
4. Specifications are for single-axis systems measured 25 mm above the tabletop. Performance of multi-axis systems is payload and workpoint dependent. Contact factory for multi-axis applications.

Electrical Specifications	
Drive System	Brushless Linear Servomotor
Feedback	Noncontact Encoder Incremental – 1 Vpp and TTL (0.1 μm) Output Absolute – EnDat 2.2
Maximum Bus Voltage	340 VDC
Limit Switches	5 V, Normally-Closed
Home Switch	Near Center

Figure 38 A possible MS model from Aerotech for X and Y axes (MS2, MS3) of the TAC, travel range 300 mm. **Stepper motor not available? TBD**

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Mechanical Specifications			MPS75SL-025	MPS75SL-050	MPS75SL-075	MPS75SL-100
Travel			25 mm	50 mm	75 mm	100 mm
Accuracy	Uncalibrated		±2.5 μm	±3.0 μm	±3.5 μm	±4.0 μm
	Uncalibrated with Bellows		±3.5 μm	±4.0 μm	±4.5 μm	±5.0 μm
	Calibrated(1)		±1.0 μm	±1.0 μm	±1.5 μm	±1.5 μm
Resolution (Minimum Incremental Motion)			0.1 μm			
Repeatability (Bidirectional)(1)			±0.75 μm (Standard); ±1.2 μm (with Bellows)			
Straightness			±2.0 μm	±2.0 μm	±3.0 μm	±3.0 μm
Flatness			±2.0 μm	±2.0 μm	±3.0 μm	±3.0 μm
Maximum Speed	1.0 mm/rev Ball Screw	DC Motor (-M1)	50 mm/s	50 mm/s	50 mm/s	35 mm/s
		Stepper Motor (-M2)	30 mm/s	30 mm/s	30 mm/s	30 mm/s
Load Capacity(2)	Horizontal		15 kg			
	Side		15 kg			
	Vertical		4 kg			
Stage Mass			1.7 kg	1.8 kg	1.9 kg	2.0 kg
Material			Anodized Aluminum Body			

Notes:
1. With Aerotech controllers.
2. Payload specifications are single-axis system.
3. Excessive duty cycle may impact stage accuracy.
4. Specifications are for single-axis systems, measured 25 mm above the tabletop.
5. Contact factory for specifications of stages with bellows option.

Electrical Specifications	DC Motor (-M1) (Standard and VAC)	Stepper Motor (-M2) (Standard and VAC)
Drive System	DC Brush Servomotor	24 VDC Bipolar Stepper Motor
Feedback	10,000 lines/rev Rotary Encoder	N/A
Electronic Resolution	0.025 μm	0.025 μm @ 40,000 steps/rev Motor Resolution
Maximum Bus Voltage	48 VDC	48 VDC*
Limit Switches	5V, Normally Closed	

*With Aerotech control system.

Figure 39 A possible MS model from Aerotech for Z axis (MS1) of the TAC, travel range 75 mm. **Stepper motor to be preferred? TBD**

7.2 IFP and alignment flange

7.2.1 Purpose and functionality

The purpose of this system is both to materialize the IFP (by the means of three SMRs representing the IFP plane and centre) and to hold a laser system, which can materialize the optical beam chief ray for alignment purposes.

7.2.2 Manufacturing

It is designed within the MAORY consortium, while the manufacturing will be outsourced.

7.2.3 AIT phase when needed

The IFP flange is needed for the alignment operations in Europe and in the IAA Chile

7.2.4 Deliverable and lifetime

The TAC is a deliverable to Bologna and Armazones, where it has to be stored for possible re-alignment operations to be performed at the telescope.

7.2.5 Hazard and Safety issues

When it is used in its alignment configuration (laser installed), protective glasses have to be worn.

7.2.6 Special tools needed

For its installation at the telescope eyebolts will be provided for the crane lifting and transportation. Otherwise, normal mechanical tools are needed.

7.2.7 Way to be operated

It will be installed instead of the Corrective Plate, using the same interface flanges on the MSS.

In its alignment configuration, the laser needs to be powered through its power supply, which must be temporarily installed in the vicinity of the flange.

7.2.8 Description

The IFP is represented through a flange (planarity < 10μm) with 3 SMRs positioned on a circle at the edge of the IFP, representing the IFP plane and centre. They will be positioned (or charatcerized) on the IFP flange by using a CMM, i.e. with an accuracy <20μm PtV wrt the flange mechanical data (radial displacement and displacement along the mechanical axis). Such a flange will be positioned on the MSS interface using 2 PINs, thus ensuring a positioning accuracy of the order of 10μm PtV.

In Figure 40 the IFP flange is shown as a separate SEq (left side) and installed at the telescope, instead of the Corrective Plate.

When it will be used in its alignment configuration, in its central part an additional system will be installed: a flange holding a manual bearing with a pass-through hole inside which a laser is positioned (see Figure 41). The laser can be aligned in orientation and the whole bearing can be centred wrt the IFP flange. In this way, with a simple laboratory setup, the laser can be aligned to be coincident with the IFP centre and perpendicular to the IFP.

The flange holding this laser system has two pins, to be precisely repositionable on the IFP flange if needed.

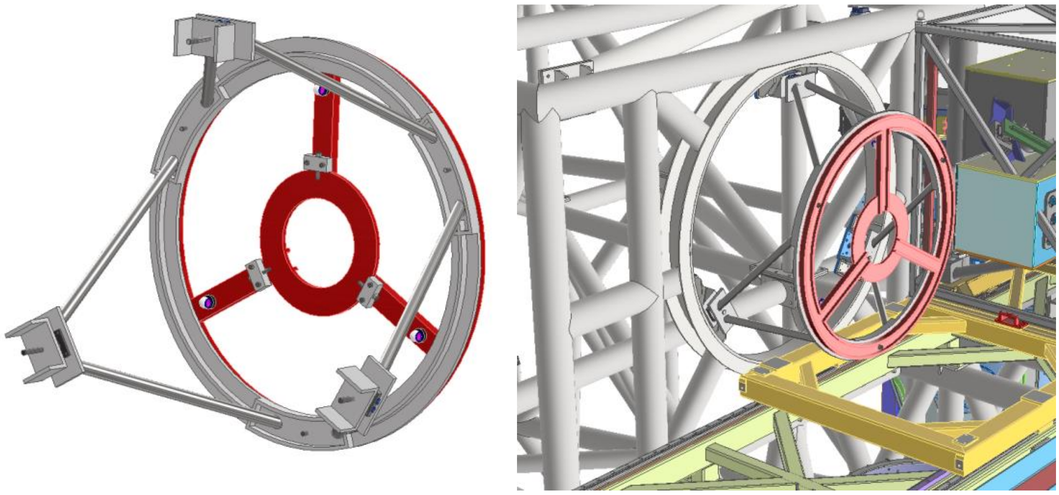


Figure 40: The IFP flange materializing the IFP

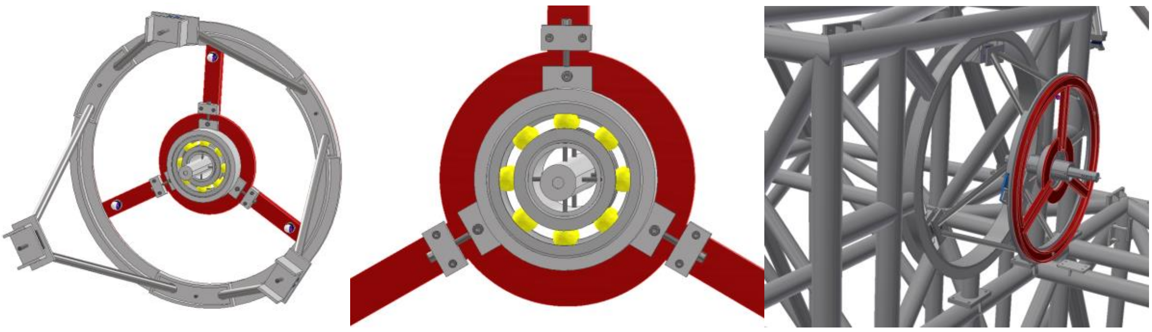


Figure 41: the IFP flange in its alignment configuration, with the laser installed.

7.3 Bearing system

7.3.1 Purpose and functionality

The purpose of this system is to enable the mounting and derotation of the MAORY TACS and LOR and to support various MAORY AIT operations.

7.3.2 Manufacturing

The bearing system is the dummy derotator prototype developed at MPIA for MICADO RD21 and currently in Grenoble at IPAG.

7.3.3 AIT phase when needed

The bearing is required for the alignment operations in Europe

7.3.4 Deliverable and lifetime

The bearing is a deliverable to Bologna.

7.3.5 Hazard and Safety issues

Standing at safety distance (0.5m) during derotation.

7.3.6 Special tools needed

For its installation and movement eyebolts will be provided for the crane lifting and transportation. Otherwise, normal mechanical tools are needed.

7.3.7 Way to be operated

During the alignment operation the derotation will rotated to perform different alignment procedure and LOR alignment and testing. Its control electronic will be provided together with the bearing.

7.3.8 Description

The performance of the MICADO dummy derotator bearing are reported in Figure 42 and a photo of the tool is shown in Figure 43.

Parameter	Test Bearing
Raceway diameter	1094 mm
Axial runout	≤ 50 μm
Radial runout	≤ 60 μm
Gear module	8 mm
Number of teeth	148
Starting friction torque (0 rpm)	1000 Nm
Running friction torque (1 rpm)	900 Nm
Raceway configuration	Spacers
Class quality	5 (worst)

Figure 42 MICADO dummy de-rotator mechanical specifications RD21.

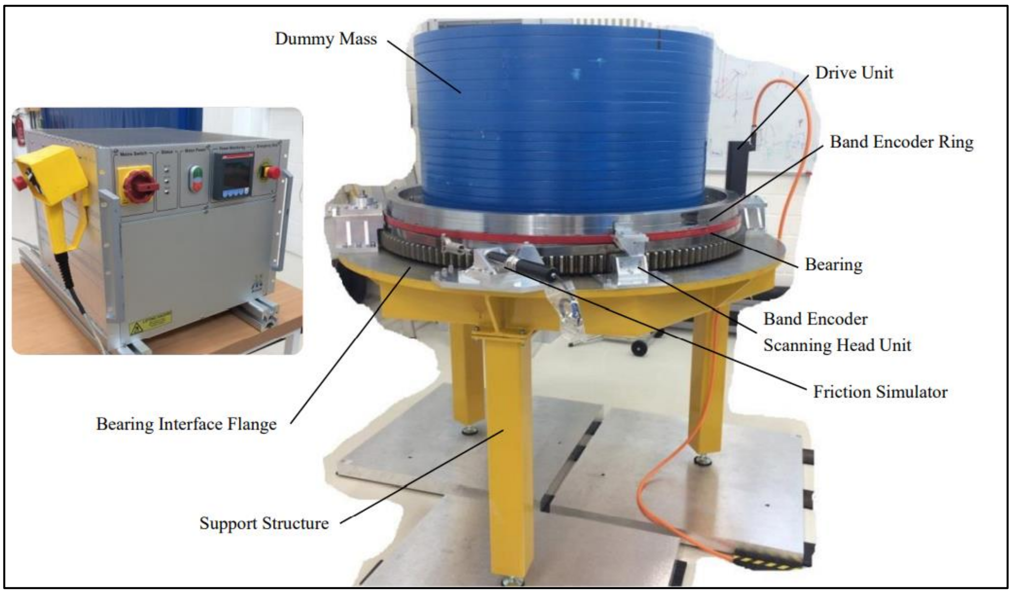


Figure 43 A photo of the MICADO dummy derotor that will be used during the MAORY MAIT RD21. The dummy masses (blue plates) and the friction simulator will be removed before the use with MAORY.

7.4 The MSS Internal Platforms (IP)

7.4.1 Purpose and functionality

The purpose of this system is to enable accessibility to the various opto-mechanics inside the MSS structure

7.4.2 Manufacturing

The design of the MSS IP, will be performed in house, the construction will be outsourced.

7.4.3 AIT phase when needed

The bearing is required for AIT and maintenance operations in Europe and in Chile (both in the IAA and in the Nasmyth)

7.4.4 Deliverable and lifetime

The MSS IP is a deliverable to Bologna and Armazones, where it has to be stored for possible maintenance operations to be performed at the telescope.

7.4.5 Hazard and Safety issues

No particular hazards and safety issues have been identified

7.4.6 Special tools needed

For the installation of the various parts just normal mechanical tools are needed. It is planned to have the parts realized in aluminium, and thus no HTs are needed for their installation.

7.4.7 Way to be operated

During the AIT phase or for maintenance operation, the platforms will be installed at occurrence. Depending on which opto-mechanics need access, only part of the platform may be installed.

7.4.8 Description

The MSS IP is composed of small platforms and stairs/ladders which can be positioned inside the MSS having access from the lower part of the bench using a portable stairs and removing a few enclosure panels.

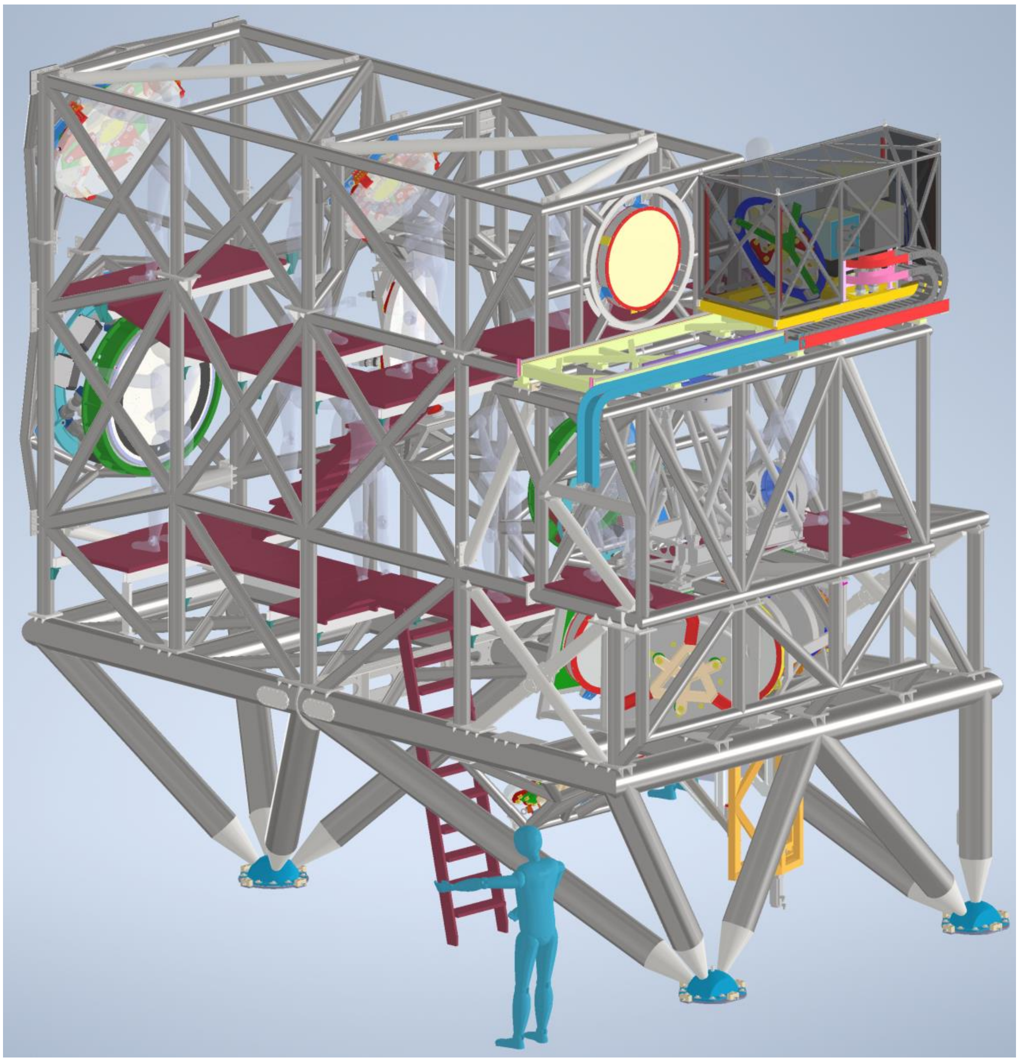


Figure 44: the MSS IP shown in violet colour

In Figure 44 and Figure 45 the MSS IP is shown.

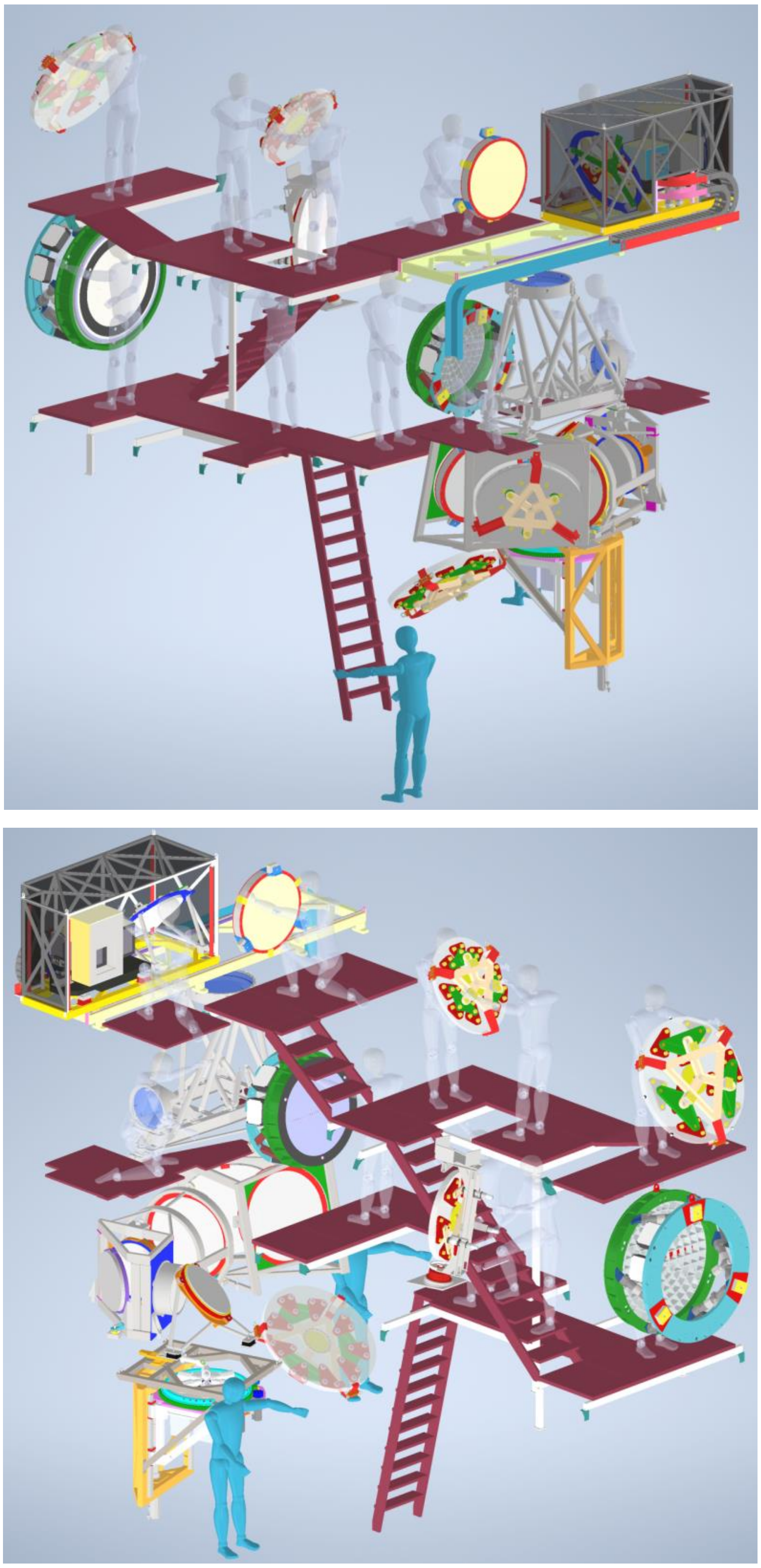


Figure 45: the MSS IP without the bench structure seen from 2 different perspectives

8. THE MAORY MAIT in Europe

In this section, we will describe the Manufacturing (limited to the HT and SEq, as already mentioned in sec. 1.1), Assembly, Integration and Test strategy and the overall process that we will follow in Bologna. We recall in Figure 46 the optical design of MAORY, which develops in 3 dimensions using the volume which is between the ELT output focal plane and the Nasmyth floor.

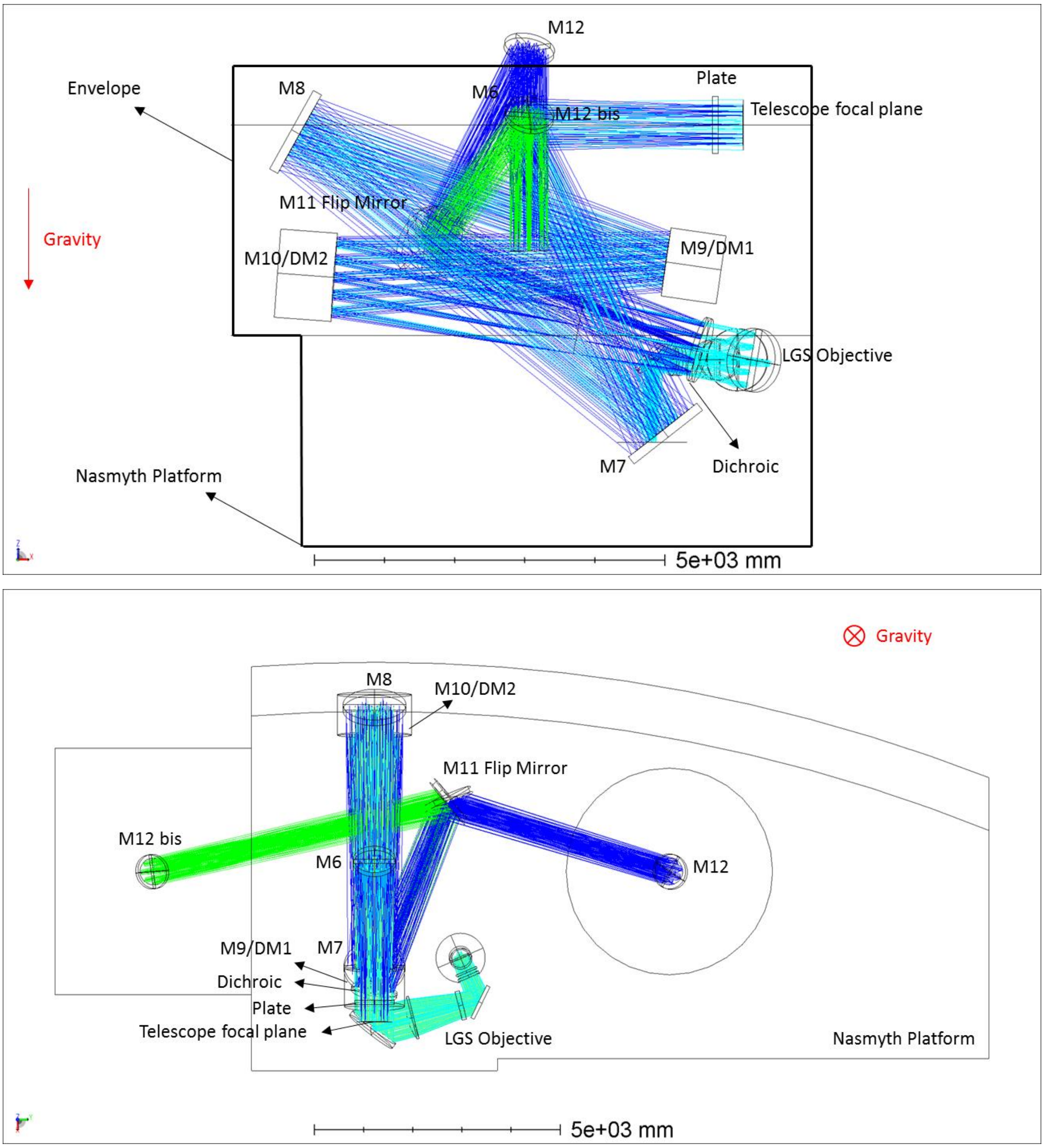


Figure 46. MPO MMS side view layout (top) and top view layout (bottom). Blue rays represent the science and NGS path to MICADO, green rays represent the science and NGS path to second instrument, cyan rays represent the LGS path.

In this way, such a design is using in a very efficient way the available volume, posing on the other side constraints on the orientation of the optical elements, and adding complexity to the AIT operations (in Figure 47 a view of the rather complex and difficult to access opto-mechanical structure is reported). Nevertheless, the smarter feature of this optical design is that it is very “generous” in term of positioning accuracy of all the optical elements but M10, which is the only compensator allowing to fully recover an excellent optical quality to the MICADO camera and to the 2nd port instrument. Adding the correct final positioning of the exit pupil and focal plane on MICADO, the compensators becomes three, since the TT of M11 and M12 (the last two flat folding mirror before the light enters MICADO) can adjust iteratively their positions.

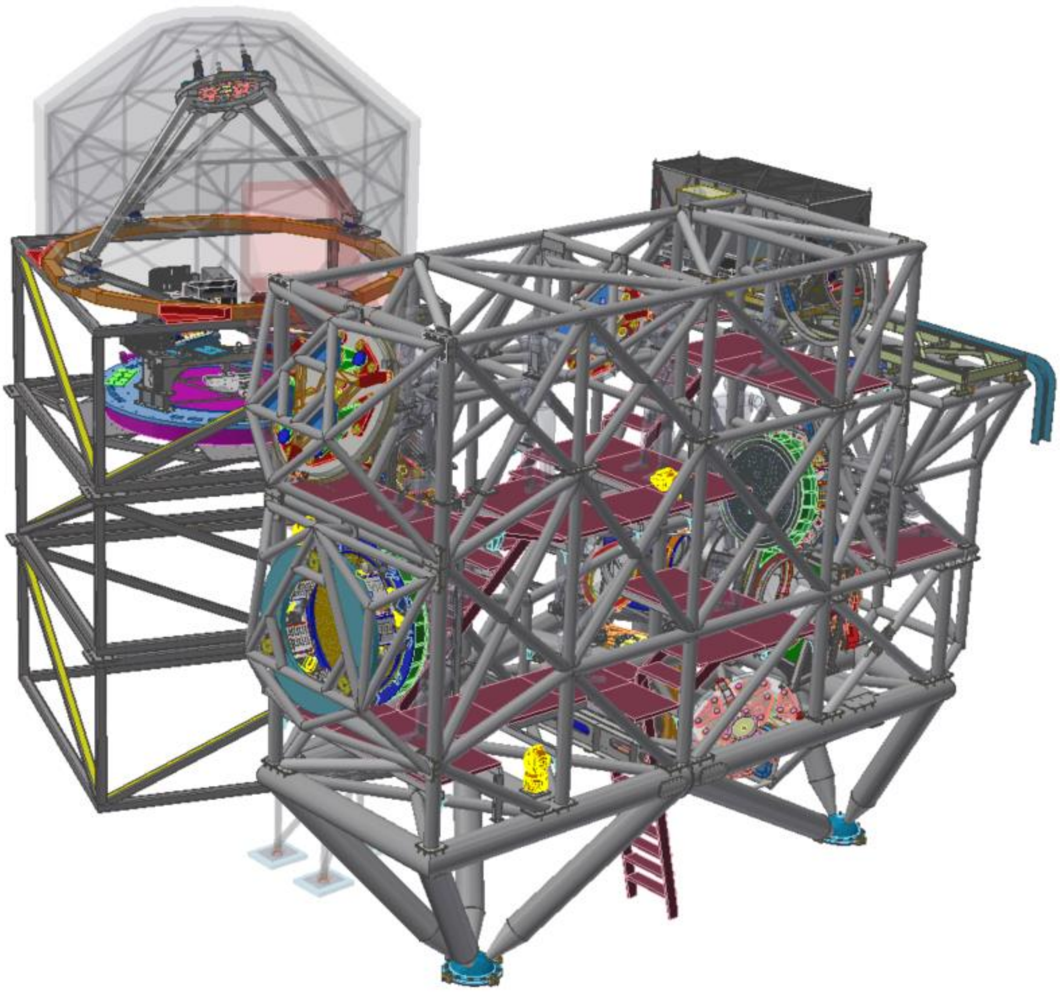


Figure 47: the MAORY bench without the enclosure, with the internal platforms installed and with the MICADO Emulating Structure in background.

The strategy of the MAORY AIT has been briefly introduced in section 3.3, and it is based on these main steps:

1. Main Support Structure (MSS) population with all the opto-mechanics and references for the LT alignment (mainly the IFP, materialized through some SMRs positioned on a plane). Before installing the opto-mechanics, the MSS

will be characterized, measuring all the interfaces wrt the MSS legs interfaces, in a way to bring them within an accuracy smaller than +/-100µm wrt the nominal ones, in case re-machining the plates which are on purpose introduced between the MSS interfaces and the opto-mechanics. Such plates will also compensate all the manufacturing errors, introduced in the “as built” final optical design, in a way that the LT alignment, to be performed in the next step, will be done by acting just on the manual compensators of each opto-mechanics.

2. Laser tracker alignment for all the opto-mechanics to their nominal position (wrt Input Focal Plane (IFP) SMRs), within the accuracy specified by the optical tolerance analysis. A few LTs are installed inside the MSS structure, in strategic positions to target all the opto-mechanics and the IFP, which are all equipped with minimum 3 SMRs, properly characterized wrt the optical element data.
3. Fine tuning of the WFE acting on M10/DM2 tip/tilt and focus, retrieving the correction from the signal coming from a few references (Calibration Unit Fibres) distributed over the FoV; in fact, the MAORY optical design permits loose positioning tolerances on all the optical elements but M10, which is the only compensator needed allowing to recover the final optical quality delivered to MICADO, by moving in TT and focus (actuated with motors remotely controlled).
4. Fine tuning of pupil and exit focal plane position by tip-tilting the last two flat mirrors, M11 and M12. The optical axis coming from the telescope is moving in space together with the ELT movements, and this causes movements of the optical beam footprints on the optics and, consequently, movements of the exit pupil and focal planes, which can be recovered by moving M10 and M11 in TT (actuated with motors remotely controlled); M10, being closer to the pupil, will mostly move the focal plane position while M11, being closer to the focal plane, is mostly moving the pupil. Iterating between the two corrections, the exit pupil and focal plane can be properly positioned on MICADO.
5. Pupil and focal plane alignment within the LGS WFS; M11 and M12 are placed after the dichroic that is transmitting the light to the LGS arm (and reflecting the light toward them). Thus, the LGS arm has to be aligned in a way to be within the alignment tolerances and to provide the focal plane at the entrance of the LGS WFS and the pupil within the sensor in the right positions
6. MAORY to PFS alignment procedure: once in the Nasmyth, the MAORY bench, fully integrated, has to be aligned to the PFS, by acting on the adjustments foreseen between the MSS legs and the Nasmith floor interface. The reference on the MAORY bench to perform this alignment will be three SMRs positioned on the Corrective Plate (CP), characterized wrt the IFP of MAORY, that will be materialized in a way explained in the following sections
7. MAORY testing phase

where steps 3 and 4 will be repeated iteratively, since the alignment of DM2 will affect the position of the pupil and of the exit focal plane. No active corrections are necessary to the optics up to M10/DM2, thus simplifying the Integration procedure.

In the following section we will validate the just presented strategy.

8.1 Validation of the AIT strategy

The main AIT steps described in the previous section require some validation, specifically:

- Item 1 needs to check that the mechanical positioning error of the IFP, which is the reference for the internal MAORY alignment of all the optics, is within the MSS adjustment capabilities wrt the PFS. In fact, such error will cause a rigid shift on the positioning of all the opto-mechanics, which has to be compensated when aligning MAORY to the PFS.
- Item 2 requires a verification that the alignment process using LTs ensures that the required positioning accuracies coming from the tolerance analysis will be achieved.
- Item 3 needs a verification that the procedure adopted to achieve the required WF accuracy is ensured
- Item 4 needs a verification that the procedure selected to align the pupil and focal plane allows to obtain the required accuracy (still under discussion with the MICADO team) and the required positioning range, assuming the foreseen initial positioning MICADO uncertainty
- Item 5 needs a verification that the procedure selected to achieve the required pupil and focal plane positioning accuracy within the LGS WFS is ensured
- Item 6 needs to verify that the foreseen procedure allows to properly align MAORY to the PFS
- Item 7 considering that MAORY will meet major system components like M4 and MICADO only at the telescope, the test phase shall cover all the test which are considered to be necessary to minimize the risks of a late verifications of the performance. To achieve this, a test unit and a “MICADO emulator” have been designed, to allow MAORY to make functional and performance test covering most of the requirements, and allowing to test in advance some procedures that will be used with MICADO.

8.1.1 IFP mechanical positioning accuracy

The position of all the bench sub-systems/components is defined wrt the IFP, which will be materialized through a flange that will be connected to the same interface of the MAORY entrance window (the CP). Such a flange has 3 SMRs, positioned at the edge of the IFP on a circle, representing the IFP plane (Figure 48).

The mechanical positioning error between the IFP flange on the MSS and the IFP nominal position has mainly this effect: a shift/TT of the focal plane would translate in an shift/TT of all the opto-mechanics, which can be compensated with an overall shift/TT of the MAORY bench during the alignment of the MAORY bench to the PFS, provided that we are within the MSS alignment range. To make this check, it has to be considered that there are two error sources:

1. the accuracy foreseen for the positions of the interfaces on the Nasmyth platform (both for MAORY and for the PFS)
2. we have to define what references will be used for the alignment of the MAORY bench to the PFS, in a way to consider the error on their

characterization wrt IFP flange, which is the reference also for the alignment of MAORY wrt the PFS.

We shall thus be sure that the overall error coming these three error sources is within the alignment capabilities of the overall MAORY bench.

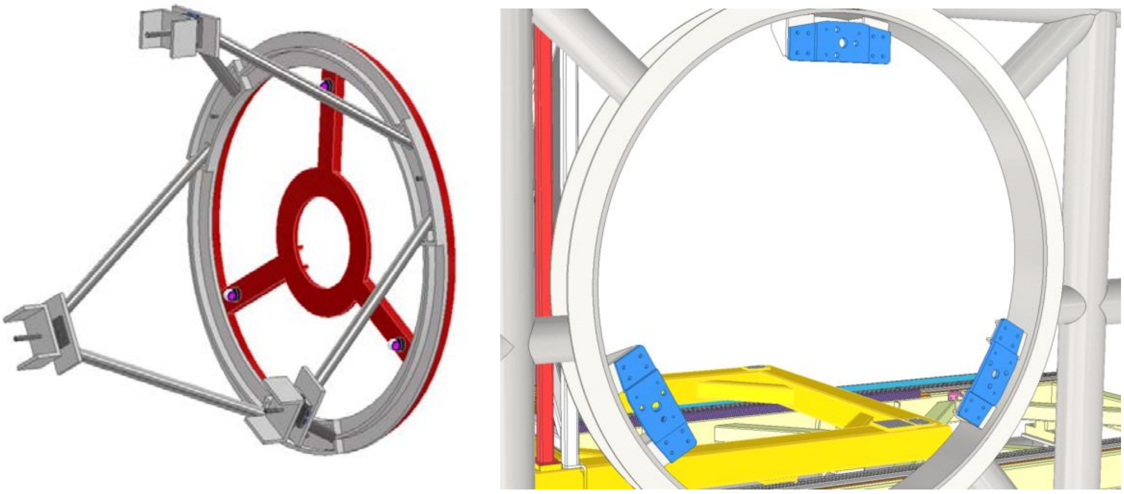


Figure 48: the IFP flange (left side), with the three SMRs on a circle close to the outer diameter of the IFP, on the red spiders; on the right end side, the CP interface flanges, where the IFP flange will be installed (instead of the CP of course)

In the following, we analyse these two issues, recalling some assumptions/design constraints useful for the following analysis:

- As just mentioned, the IFP will be materialized through a flange that will be connected to the same interface of the MAORY entrance window (which is the CP). More details will be given in the following section 8.1.1.1.
- The overall MAORY bench has an alignment range shown in Table 6 (justification given in RD13) .
- The accuracy concerning the positions of the MSS interfaces on the Nasmyth platform (both for MAORY and for the PFS) is ±1mm in X and Y (along the Nasmith floor plane) and ±0.5mm in Z (as specified in AD5 and AD9)
- The references for the alignment of MAORY to the PFS will be placed on the Corrective Plate: three SMRs at 120° on the outer part of the CP diameter, characterized wrt internal SMRs of the CP (the ones used for the alignment of the CP using the internal MSS LTs) with the CMM, thus with accuracies of the order of 20μm PtV in all directions. This choice has been done to allow such references to be targeted by the PFS internal LT, making in this way the alignment procedure as simple as possible.

DoF	Value	Unit of measurement
Decenter z	+/- 2	mm
Decenter (x,y)	+/- 4.5 (TBC)	mm
Tip	+/- 0.67	mrad
Tilt	+/- 0.4	mrad

Table 6: adjustment ranges of the MSS; the axes are given in the ELT coordinate system, in which the z axis points to the zenith.

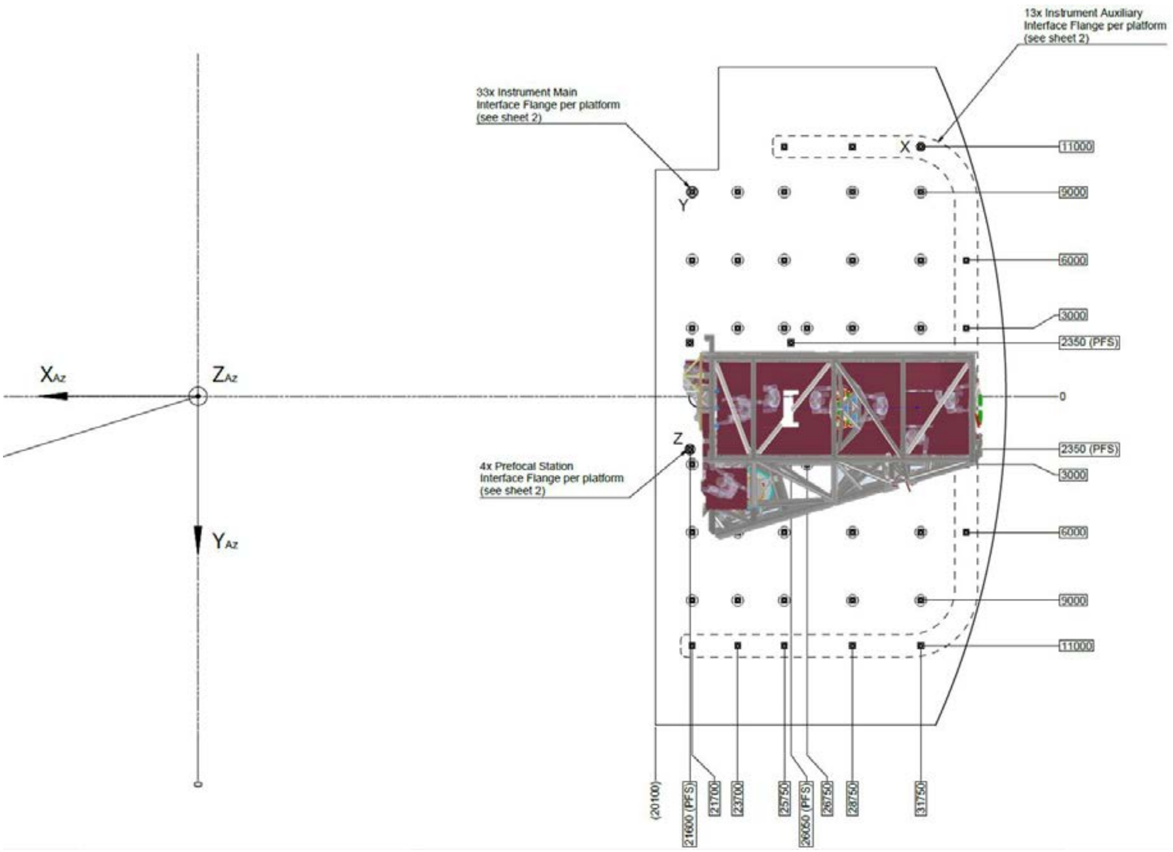


Figure 49: the MAORY MSS on the Nasmyth platform A oriented wrt the Nasmyth co-ordinate system

8.1.1.1 IFP mechanical positioning accuracy

The IFP will be materialized through a flange that will be connected to the same interface of the MAORY entrance window (the CP, as shown in Figure 48).

Such interface on the MAORY MSS will be characterized (and modified if needed, re-machining the three blue interfaces shown in Figure 48 right side) wrt the positions of the three legs interfaces to the Nasmith platform, to ensure that the interface flange is nominally positioned within an accuracy of ±0.1mm (200μm PtV) in all directions, and that the three interface flanges will reach a co-planarity <20μm PtV.

The IFP will be represented through a flange (planarity < 10µm) with 3 SMRs positioned on a circle at the edge of the IFP, representing the IFP plane and centre (see Figure 48). They will be positioned (or charatcerized) on the IFP flange by using a CMM, i.e. with an accuracy <20µm PtV wrt the flange mechanical data (radial displacement and displacement along the mechanical axis).

Such a flange will be positioned on the MSS interface using 2 PINs, thus ensuring a positioning accuracy of the order of 10µm PtV.

The final positioning accuracy of the IFP SMRs wrt legs interface should than be (PtV):

- In X: 10(plan.)+20(co-plan)+20(SMRs)+200(Interfaces2legs)~250µm
- In Y: 10(pins)+20(SMRs)+200(Interfaces characterization)~230µm
- In Z: 10(pins)+20(SMRs)+200(Interfaces characterization)~230µm

while the maximum TT PtV will be:

- T_y: ~250µm over the SMRs diameter (800mm) ~ 65”
- T_z: ~250µm over the SMRs diameter (800mm) ~ 65”

summing linearly the error sources (conservative choice). We emphasize that, for simplicity, we didn’t compute 2 different planes (one identified by the connecting flanges and one identified by the SMRs) to be eventually “summed”, but the TT computation has been conservatively performed considering the inner circle diameter where the SMRs are installed.

The IFP will be installed instead of the CP as first step of the alignment in the BIH, and the PINs will ensure precise re-positioning (~10µm) for future re-installations (if needed).

The IFP position will be measured using the internal MSS LT against the four SMRs of the IFP flange, with the usual accuracy of about 60µm over 5m distance (see sec. 8.1.3.1), bringing the overall accuracy of the IFP materialization to:

- In X_R: 250µm (IFP positioning accuracy)+60µm ~310µm
- In Y_R: 230µm (IFP positioning accuracy)+60µm ~290µm
- In Z_R: 230µm (IFP positioning accuracy)+60µm ~290µm

while the worse TT accuracy PtV will be:

- $T_{y\text{-}R}$: ~310µm over the SMRs diameter (800mm) ~ 80”
- $T_{z\text{-}R}$: ~310µm over the SMRs diameter (800mm) ~ 80”

Where the “$_R$” stands for “Reference” and again summing linearly the errors (conservative choice).

The IFP position characterized with the this procedure and with the accuracy just mentioned is the ***Reference*** with respect to which all the opto-mechanics will be aligned, and the accuracy represent the error of such reference wrt the nominal IFP as built position.

In the next section we will address the impact of such accuracy on the MAORY2PFS alignment procedure and on the opto-mechanics alignment procedure.

8.1.1.2 MAORY 2 PFS alignment capability verification

To address this important issue, we recall that the references for the alignment of MAORY to the PFS will be placed on the Corrective Plate, three SMRs at 120° on the outer part of the CP diameter, characterized wrt internal SMRs of the CP (the ones used for the alignment of the CP using the internal MSS LTs) with the CMM, thus with accuracies of the order of 10µm PtV.

We have now to estimate what is the accuracy of these three references wrt the nominal IFP as built position, and to perform this estimate, we highlight the steps following the IFP position characterization, just explained in sec. 8.1.1.1.

After having characterized the IFP position, which is the reference for the LT positioning of the opto-mechanics, the IFP flange is removed and the CP is installed and aligned (wrt the reference, the IFP position) using LT1, targeting the 3 SMRs of the inner side of the CP, with the usual accuracy of about 60µm over 5m distance (see sec. 8.1.2.1).

At this point, the three SMRs on the outer part of the CP (toward the PFS) represent the MAORY bench position toward the outside world, since they are referenced wrt the nominal IFP as built position, within a certain accuracy, which is straightforward to compute. In fact, such accuracy is the one reported for the IFP position (at the end of the previous section) “plus” the uncertainty of the on the CP alignment operation (60µm in all directions, as just mentioned) “plus” the accuracy of the characterization of the 3 inner SMRs of the CP wrt the 3 outer SMRs of the CP (about 10µm PtV, as explained at the beginning of this section).

Thus, the overall accuracy of the 3 SMRs materializing in space the position of the MAORY instrument is:

- In X_M: 60(LT accuracy)+10(SMRs characterization)+310(X_R)~380µm
- In Y_M: 60(LT accuracy)+10(SMRs characterization)+290(Y_R)~360µm
- In Z_M: 60(LT accuracy)+10(SMRs characterization)+290(Z_R)~360µm

while the worse TT accuracy PtV of the MAORY bench will be:

- $T_{y\text{-}M}$:~380µm over the SMRs diameter (800mm) ~ 98”
- $T_{z\text{-}M}$: ~380µm over the SMRs diameter (800mm) ~ 98”

where M stands for MAORY and summing linearly the error sources. Also in this case, we emphasize that, for simplicity, we didn’t compute 2 different planes (one identified in the previous section and one identified by the outer SMRs) to be “summed”, but the TT computation has been conservatively performed considering the inner circle diameter where the SMRs are installed.

It is fundamental to recall that such accuracy has been computed wrt the MSS legs interfaces, meaning that it is the error on the position of the IFP wrt the interface legs.

Recalling now that the accuracy concerning the positions of the interfaces on the Nasmyth platform (both for MAORY and for the PFS) is ±1mm in X and Y (along the Nasmith floor plane) and ±0.5mm in Z (as specified in AD5 and AD9), the final accuracy PtV that we obtain on the MAORY instrument positioned on the Nasmith platform becomes:

- In X_{M+N}: 380(X_M)+2000(Interface accuracy in X)~2380µm
- In Y_{M+N}: 360(Y_M)+2000(Interface accuracy in Y)~2360µm

- In Z_{M+N}: 360(Y_M)+1000(Interface accuracy in Z)~1360µm

where M+N stands for MAORY+NASMYTH and summing linearly the error sources.

Considering the conservative approach of summing linearly the error contributions, we are within the adjustment range reported in Table 6.

The overall alignment procedure of MAORY to the PFS is described in sec. 8.1.7.

8.1.2 An alternative strategy for the opto-mechanics initial positioning

There is an alternative strategy to the one presented in sec. 8.1.1 concerning the way to position the optics on the bench. We briefly present it here, although additional work may be needed to validate it, which in case will be performed during the FDR phase. This strategy is based on the group heritage in mechanical alignment of optical systems during the projects ESPRESSO@VLT and M4@ELT.

Once the MSS will be manufactured, the structure will be characterized (also using dummies opto-mechanics, to have the full load) to check the positions of all the opto-mechanics interfaces wrt the MAORY legs interfaces. The purpose of this activity is the verification of the positions of the interfaces (used eventually for the bench acceptance) wrt the nominal ones. One or more LTs (even the one installed in the bench for the optics characterization) may be used for this purpose, instead of a large 3D measurement arm (which has a measurement accuracy of ±100µm), to possibly improve the accuracy of the method. Pin, drift and surface magnetic nests (which can host the LT ball probes, see Figure 50) shall be used to characterize the dimensions of the interfaces

Figure 50: pin nests on the top left, drift nests on the bottom left, surface nests (with the lower surface rectified) in the centre and LT ball probes, all magnetic, are shown.

The plates that are foreseen between the MSS interfaces and the optics mounts will be machined, if necessary, such that the discrepancies of the interfaces wrt the nominal values are kept below ±100µm.

The best fit of the as built MSS to the nominal model will also provide information on the position of the input focal plane, the position od which can be adjusted acting on the interfaces between the MSS legs and the basement, considering the MSS as a rigid body. In this way:

the input focal plane will be as close as possible to the nominal one, depending on the accuracy of the LT and the shimming capability

the opto-mechanics interfaces will be as close as possible to the nominal ones, thus reducing the required correction of the kinematic mountings.

By using the MSS internal LTs, we can therefore produce a full map of the MSS structure that will allow, at a later stage, to position all the opto-mechanics without the need of materializing the IFP. If needed for whatever reason (alignment of part of the instrument, for example the LGS WFS arm), the IFP can be materialized using the very same flange described in sec. 8.1.1.1, that can be aligned with LT precision through the 3 SMRs thanks to the XYZ and TT dofs to the input focal plane of the model.

We underline that such strategy will increase the ranges available for the optomechanics alignment, since the MSS interfaces are brought to the nominal position, and that the errors in placing the input focal plane will not propagate to the optomechanics positioning, since the two activity are independent.

We recall that this strategy is the one applied for the alignment of the ESPRESSO Front End Units to the telescope Coudé Trains, and for the alignment of the spectrograph itself, were each optomechanics was characterized by means of CMM and aligned in the spectrograph with a LT. We are also using in these days the very same approach with LT and optical referencing to align the Optical Test Tower of the EELT M4. Nevertheless, further analysis and verifications to better evaluate pro and cons wrt the one presented in sec. 8.1.1 will be performed in the next project phase, including breadbording to simulate this strategy in the MAORY context.

8.1.3 Opto-mechanics alignment accuracy using LTs

The positioning errors (coming from the alignment tolerance process described in the optical design RD9) allowed to each optical element during the alignment process are given in Table 7. The values specified as DoF are the compensators that will be used for the fine tuning of the achieved optical quality and to recover exit focal plane and pupil positions, and they will be of course motorized and remotely controllable.

	dx [mm]	dy [mm]	dz [mm]	tx [deg]	ty [deg]	tz [deg]
Plate	1,000	1,000	1,000	0,0083	0,0083	0,1666
M6	1,000	1,000	0,300	0,0083	0,0083	0,0000
M7	2,000	2,000	0,000	0,0083	0,0083	0,0833
M8	2,000	2,000	0,000	0,0083	0,0083	0,0833
M9	2,000	2,000	0,000	0,0083	0,0083	0,0000
M10	2,000	2,000	DoF	DoF	DoF	0,0000
Dichroic	1,000	1,000	0,300	0,0083	0,0083	0,0000
M11	1,000	1,000	0,300	DoF	DoF	0,0000
M12	1,000	1,000	0,300	DoF	DoF	0,0000

Table 7: Positioning errors allowed to each opto-mechanical element. Values have to be intended as +/- (0,0083 deg corresponds to ~ 1’ PtoV in TT).

Let us underline that the more stringent positioning errors presented in Table 7 are:

- ~ 1’ PtoV in TT (corresponding to 300μm PtoV for a mirror of 1m in diameter)
- ~ 2 mm PtoV in centring
- ~ 0.6 mm PtoV in focus
- ~ 10’ PtoV in clock

We also emphasize that every optical element will be required to be tested assembled in its mount and will have minimum three SMRs (possibly six, to ensure some redundancy) glued at 120 degrees, the position of which must be characterized within a certain accuracy wrt optical data (position of the optical vertex, direction of the optical axis, clock with respect to the optics normal, position wrt the outer radius of the optical surface).

Such positioning errors include both the accuracy of the positioning due to the laser tracker procedure and the uncertainty on the characterization of the optical surfaces with respect to the mechanical references (SMRs).

8.1.3.1 Laser Trackers measurement accuracy

The final position of the LTs to be used within the MSS for the opto-mechanics is shown in Figure 52, showing that 3 LTs are needed to reach all the relevant SMRs installed on the various sub-systems for their correct positioning. Preliminarily, we show in Figure 51 that all the main opto-mechanics may be reachable with a single LT placed in a central position inside the MSS, and in this case all the distances between the LT and the SMRs are smaller than 5m.

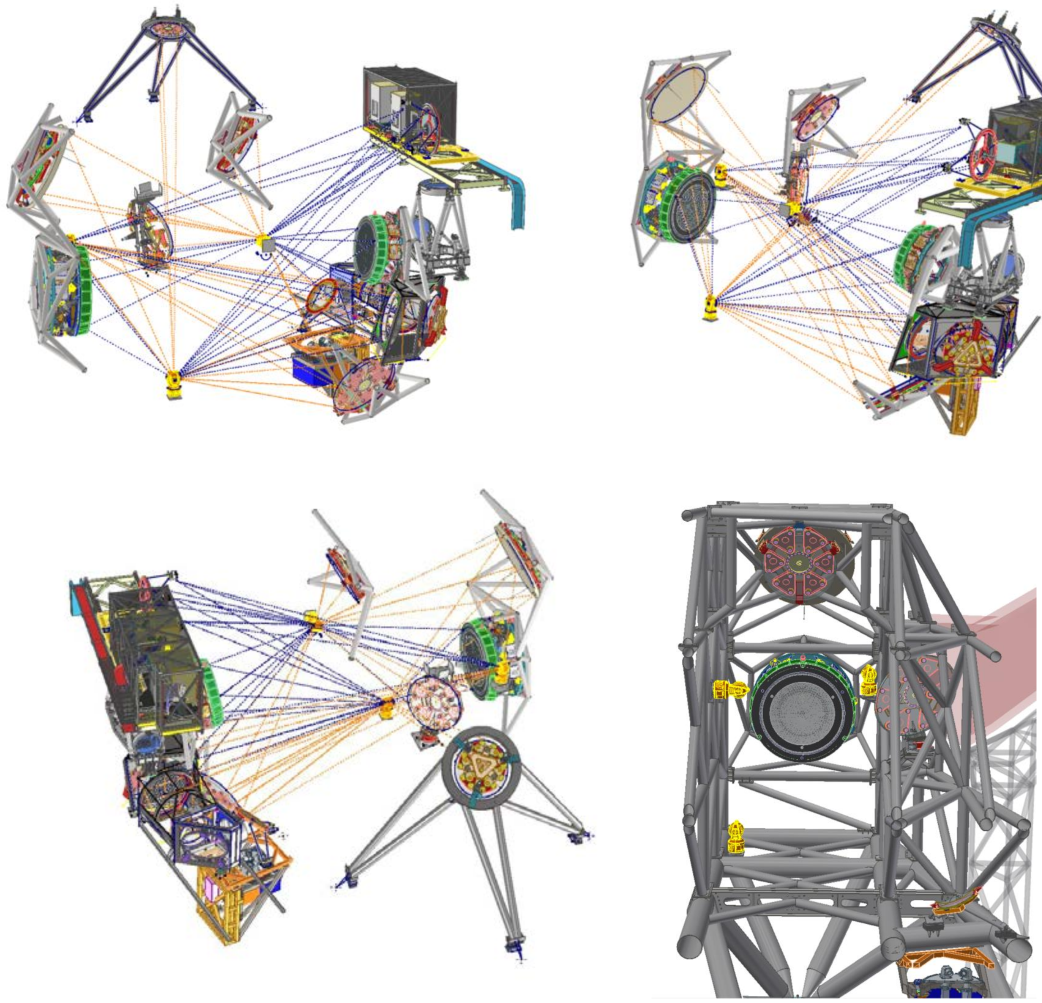


Figure 51: different views of the positions of the LTs inside the instrument, reaching all the MAORY opto-mechanics

In Figure 52 we report the API LT accuracy over the full volume that the LT can span. Similar numbers characterize the performance of the LEICA AT960MR: the volumetric accuracy (XYZ) is of the order of ±15µm+6µm/m, which means 36µm PtoV in the 2m range and 60µm PtoV in the 5m range, comparable to the 28µm (2m range) and to the 49µm (5m range) of the API accuracies shown in Figure 52.

We underline that the typical accuracies claimed by the LT producers are better than the PtoV ones (see column "typical" in Figure 52), but we do consider just PtoV values to be as much conservative as possible.

Considering one LT positioned in the centre of the instrument, we already pointed out that all the distances should be smaller than 5m, thus allowing to consider accuracies of the order of 60µm PtoV, which may be further improved with measurement redundancy when using more LTs to target the same references (possibility that we do not considered here to be conservative).

Horizontal Scale Bar Accuracy**

	PRO				PLUS		CORE	
Range	MPE (ADM)	Typical	MPE (IFM)	Typical	MPE	Typical	MPE	Typical
2m	28µm	14µm	28µm	14µm	35µm	18µm	35µm	18µm
5m	49µm	25µm	49µm	25µm	57µm	29µm	57µm	29µm
10m	85µm	43µm	85µm	43µm	92µm	29µm	92µm	29µm
20m	156µm	78µm	156µm	78µm	163µm	82µm	163µm	82µm
25m	191µm	96µm	191µm	96µm	198µm	99µm	198µm	99µm
30m	226µm	113µm	226µm	113µm	233µm	117µm	233µm	117µm
35m	262µm	131µm	262µm	131µm	269µm	135µm	269µm	135µm
40m	297µm	149µm	297µm	149µm	304µm	152µm	304µm	152µm
50m	368µm	184µm	368µm	184µm	375µm	188µm	375µm	188µm
*60m	438µm	219µm	438µm	219µm	445µm	223µm	445µm	223µm
*80m	580µm	290µm	580µm	290µm	587µm	294µm	587µm	294µm

*Requires 80m range option **2.3m Scale Bar Length

API

Figure 52: API LT accuracy over the full volume that the LT can span (4π steradians)

This is thus the accuracy that we conservatively assign to the LT measurement process, recalling that such 60µm are directly the positioning accuracy in centring and focus while, concerning the tip-tilt, they correspond to about 12" PtoV for a mirror of 1m in diameter.

8.1.3.2 Opto-mechanics SMRs characterization accuracy

Considering what just presented in the previous section, the very good LTs measurement accuracy (~60µm) is living essentially almost the whole 300µm PtoV overall budget (required for the alignment of the tightest tolerance, the TT of a few components, as shown in Table 7) to the error in characterizing the position of the SMRs placed on the optics wrt mirrors optical data (~294µm is the value left, doing the subtraction in quadrature, being the two errors independent).

Is such an accuracy in characterizing the SMRs wrt mirrors optical data achievable? More generally, are the accuracies required in Table 7 compatible with SMRs characterization accuracies?

The accuracy in the knowledge of the references with respect to the optics surface has been evaluated for each optics. In our analysis we considered the possibility to reference the mirrors either:

- using the CMM, i.e., measuring by contact the optical surfaces and the references;

- during the optical testing, by means of dedicated tools (e.g., dedicated CGH patterns and cameras).

A detailed description of the analysis is reported in section 4.1.6.3 of the optical design and analysis document (RD9). A summary of the analysis performed in RD9 is that all the opto-mechanics positioning accuracies required in Table 5 are achievable with at least one technique. In general, when considering interferometric methods for both mirrors and transmissive elements, the achievable accuracies are one order of magnitude better than the requirements, while with the CMM we are in the requirement with margin. For what concern the DMs referencing, we did not see any issue for DM2, which is concave and can be easily referenced with interferometric methods from the center of curvature. Concerning DM1, convex, its referencing during the optical testing via interferometric methods has been evaluated, but the achievable accuracy is pending on the final decision on the mirror test setup; as a backup solution, we evaluated the possibility to reference DM2 via CMM, and we estimated a TT accuracy within the requirement (±30”). To strengthen these analyses, we interacted with companies preliminarily contacted for the optics manufacturing, which are in line with such a required positioning accuracy (further details cannot be reported here for undisclosure reasons).

As a matter of fact, the optics referencing is the limiting factor in the achievable accuracy, but up to now we did not find real showstoppers in the procedure, although further investigations and interactions with the manufacturer are necessary to consolidate these numbers.

8.1.4 Fine optical alignment with DM2

This approach has been verified in RD9 (sec. 4.1.4 step 3) considering 3000 montecarlo occurrences, where we optimized the WFE all over the technical FoV. The movements range for the optical elements introduced in the montecarlo analysis is the one specified in Table 7, while the assumed precision on the measurements of the delivered opto-mechanics (used as offenders in the simulation) are reported in Figure 53.

		RoC [mm]	Z4 RMS [nm]	Z5 RMS [nm]	Z6 RMS [nm]
Plate S1	nominal		0	0	0
	accuracy				
	precision		10	5	5
Plate S2	nominal		0	0	80234
	accuracy				
	precision		20	30	30
M6	nominal		0	0	0
	accuracy				
	precision		10	5	5
M7	nominal	-35094,937		0	13381
	accuracy				
	precision	0,03%		40	40
M8	nominal	38403,193		0	60458
	accuracy				
	precision	0,03%		40	40
M9	nominal	15456,015		0	0
	accuracy				
	precision	0,03%		15	15
M10	nominal	14946,890		0	0
	accuracy				
	precision	0,03%		15	15
Dichroic S1	nominal		0	0	0
	accuracy				
	precision		10	5	5
M11	nominal		0	0	0
	accuracy				
	precision		10	5	5
M12	nominal		0	0	0
	accuracy				
	precision		10	5	5

Plate		
	accuracy	precision
Refractive index		5,00E-05
Abbe number		0%
thickness [mm]		0,1
wedge [arcsec]		2,5

Figure 53: assumed precision on the measurements of the opto-mechanics. Values has to be intended as +/-. Zernike polynomials refer to surface error.

We have also verified over 300 montecarlo occurrences that the WFE can be recovered by applying just TT and defocus of M10/DM2 using a limited number of fields (one at the center and four at the edge in cross configuration), optimizing just the low order aberrations of the WFE (defocus and astigmatisms Zernike polynomials). Results comparing the optimization over the full FoV and over a limited number of fields (Figure 54) do not show significant differences.

Summarizing, the way to recover the tip-tilt and focus signal to be given to the M10/DM2 compensator is currently under study/analysis/simulation and it is presented in the following section (8.1.4.1.), but we emphasize that such a signal will be computed by looking at the wavefront in a few positions over the FoV; the most updated simulations (reported in RD9) are showing that 5 positions in the field (one in the centre and four on a cross, almost at the edge of the diagonal field of MICADO) are enough to recover the necessary information (see Figure 55), and the wavefront analysis on such positions has be limited on to very low orders (defocus and astigmatism).

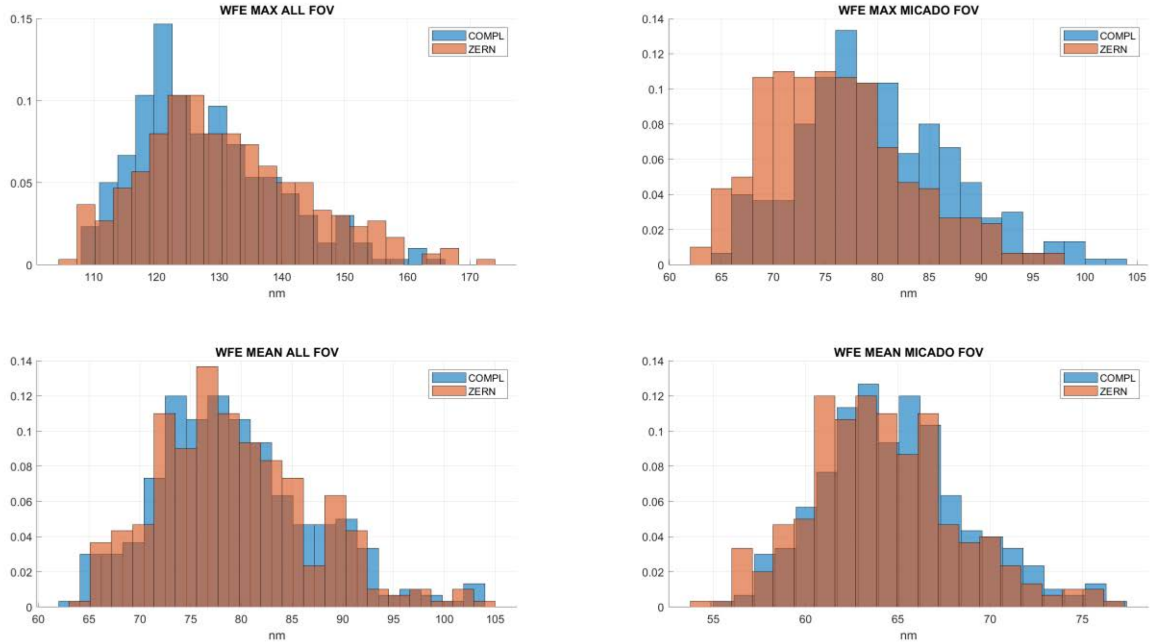


Figure 54: Average value (bottom) and maximum value (top) of the RMS WFE maps in the technical (left) and MICADO (right) FoV after the alignment optimization over the full technical FoV (blue histogram) and over 5 fields on the MICADO FoV limiting the feedback to Zernike polynomials Z4, Z5, Z6 (orange histogram).

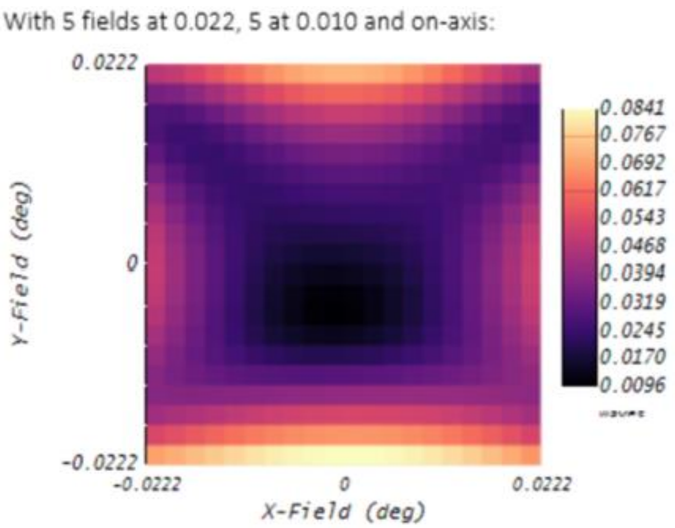


Figure 55: one example of reconstructed WF using 5 positions in the field.

Another result of the simulation are the maximum expected range of the M10/DM2 compensators, which are of the order of ±7mm in focus and ±0.035 deg in TT.

We recall that M10/DM2 has centring capability of ±5mm in X and Y, ±20mm in Z (Focus), and ±0.3° fot Tx and Ty, with resolutions of ±10μm in the translation and ±0.02mrad (±4") in TT.

8.1.4.1 How to retrieve the correction to be done with DM2?

Here we describe the last step of the Optical Alignment (OA) of MAORY once the single optical elements have been placed at laser tracker position in their location within the MAORY bench.

8.1.4.1.1 Internal MAORY Optical Alignment strategy

The MAORY OA (MOA) relies on a iterative loop of consecutive commands uploaded to the relay compensator, the M10 (DM2) and a low order wavefront sensing (WFSensing) technique. The M10 Degree of Freedom (DoFs) are Piston, Tip & Tilt. The alignment strategy is partially inspired to the so-called Donut technique proposed by Tokovinin & Heathcote 2006 RD5, that measures the optical aberrations from a single extrafocal image. This technique has been successfully implemented with LBC @ LBT RD6, SOAR and at the Blanco 4m telescope and it has the advantage of not requiring additional hardware other than a Test and Alignment Camera (TAC) for the first alignment (without MICADO) and the MICADO instrument in imaging mode for the final (re-)alignment at the Nasmyth platform.

The idea behind this method is to use an extrafocal image (Donut) of the instrument PSF as proxy for the instrument pupil. The donut image is used to WFSensing and extracting the amplitude of the Zernike terms correctable with the MAORY DoFs. The internal MOA is sensitive to the Piston, Tip & Tilt of M10 (DM2) and the tolerance analysis reported in RD9 has proven the ability to suppress the WFE using these three DoFs. While in the ray tracing software the optimization is performed by means of a built-in Merit Function (MF), in real life one needs to link the alignment strategy to some measurable observables and cope with finite resolution and WFSensing limitations. In practice the method requires the creation of a poke matrix of the M10 DoFs and the instrument WFE, as mathematical tool that converts the DoFs commands into specific wavefront modes to be applied during the iterative alignment loop.

In the typical alignment workflow (Figure 56) starting from a MonteCarlo (MC) random realization of MAORY with alignment and manufacturing tolerances, a poke matrix for the DoFs of M10 is built by mapping the effect of a DoF change onto the measured WFE decomposed in a Zernike basis. Once the poke matrix is derived, its inverse expression is used to calculate the DoF commands to upload on M10 to suppress the observed WFE as extracted from 3 to 5 field points in a iterative loop that is interrupted once the DoFs changes are negligible and the WFE reaches a minimum value.

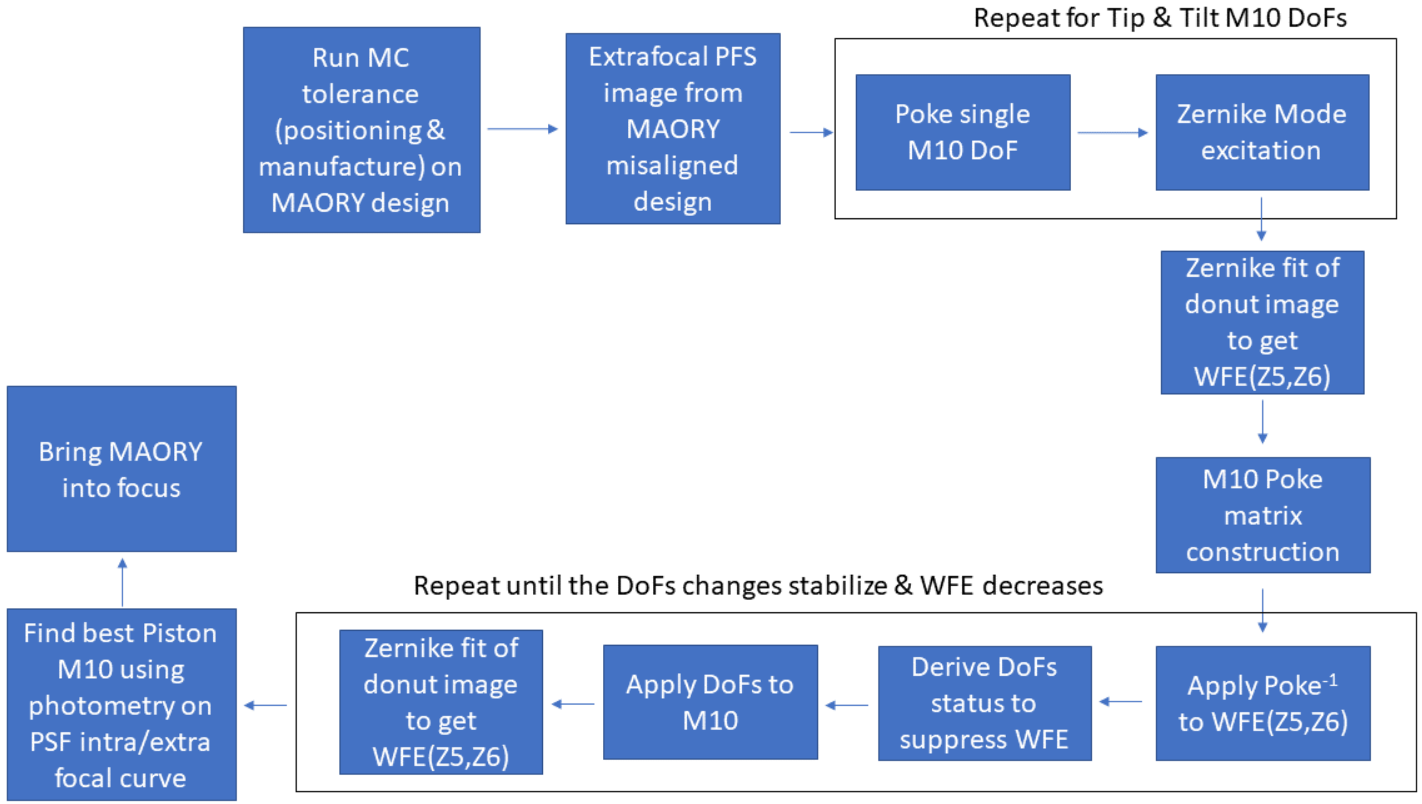


Figure 56 Flowchart of the fine-alignment technique assessed for the MAORY WFE minimization using the DoFs of M10.

The poke matrix includes only the two astigmatic terms (Z5, Z6) in Noll/Zemax notation since tip & tilt of M10 mainly develops astigmatism, while the piston term, having a degeneracy with the Donut defocused image, it is left apart to avoid instability in the iterative loop. Once a satisfactory solution is achieved, the best focus position of M10 is estimated by scanning a focal sequence of on-axis PSFs and calculating their reference photometric radius. Typical photometric radii R80/R90, enclosing the 80%/90% of the PSF light, are calculated with aperture photometry to find the piston position that minimizes the PSF size, i.e. the best focus. The method here described departs from the original Donut technique for two main aspects:

i) the Donut is meant to align telescopes with starlight and it is based on an iterative loop to estimate the WFE aberration terms against the time-variant seeing distortions that uses an interaction matrix between the real donut image and a model of it;

ii) ii) the Donut exploits a series of terms called moments of light to parametrize the main low order Zernike terms (defocus included) to build with an iterative loop a faithful image model of the real one and extract the aberration content. In the current developed code for MAORY, the algorithm performs a single, direct least square fitting of the WFE on a Zernike basis without any iterative sequence to retrieve a model of the donut and excluding the defocus that is addressed independently using the PSF photometry. The Zernike coefficients are commonly used to fit a wavefront $U(x,y) = A(x,y)e^{j\varphi(x,y)}$ where the phase information φ is available. Using an optical/NIR detector the phase is lost and therefore only the intensity distribution of the wavefront is retrieved $A(x,y) = \sqrt{I(x,y)}/I_0$. The moments of light used by Tokovinin parametrize the defocus and astigmatic terms in the context of having only an intensity distribution available of the donut. We deliberately chose to start with a direct (single) least square fit of the PSF donut using a Zernike basis accepting that part of the spatial information is not represented. Now that the first round of simulations and the general code algorithm has been developed and tested as reported in the following paragraphs we will implement also the moments of light parametrization to fully exploit the potential of the method.

In a real-life scenario of MAORY (re-)alignment operations, the technique uses the Calibration Unit (CU) point-like sources to probe the WFE in the instrument optical path without the need to get the starlight (and therefore seeing) from the telescope. The required defocus to observe the PSF donut can be achieved by pistoning M10 and/or by offsetting along the optical axis the detector at the MAORY output focal plane when MAORY is integrated in Bologna without MICADO.

More details on the hardware required and the step-by-step procedure is given in section 7.1. Hereafter we present the simulation results of a pathfinder study to assess the efficiency of this technique applied to MAORY.

8.1.4.1.2 Optical alignment simulations backbone

The simulations to assess the reliability of the MAORY OA (MOA) based on the technique described in the previous section are developed in a Zemax ZOS-API & Matlab environment for computational optimization. The skeleton of the code resembles the workflow chart reported in Figure 56 and as explained above, it relies on the same observables that will be used for the real alignment procedure:

- Amplitude of the Zernike astigmatic (Z5, Z6) terms for 3 to 5 field points in the MAORY FoV
- DoF status and history (during loop) of M10
- On axis PSF photometric radius

The value of the WFE as derived from the Zemax default MF provides a virtually perfect WFSensing and it is therefore logged at each loop iteration for the algorithm sanity check and performance comparison. These simulations have been performed using a MAORY 'standalone' configuration, i.e. without MICADO, thus reproducing the alignment sequence of the relay with a Test and Alignment Camera (TAC, see section 7.1) at the instrument output focal plane in Bologna and at Armazones integration hall before the mating with MICADO. An example of the PSF Donut simulated image as seen by the TAC (13 µm pixel pitch) for a defocus position of 15 mm before alignment is given in Figure 57. On such images the MOA algorithm runs a Zernike fit with typically the first six terms (max 231) and build up the poke matrix for M10. The intensity distribution of the PSF Donut is the quantity that is fitted (section ii)).

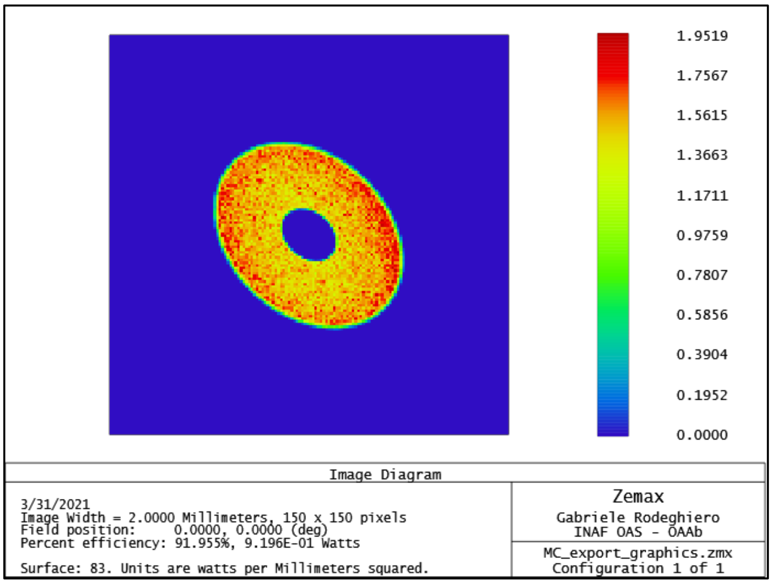


Figure 57 Simulated image, 2mm x 2mm & 150pix x 150pix, of a PSF donut for a 15 mm defocus position of the TAC indicating the presence of astigmatism. On this image the MOA algorithm runs a Zernike fit to extract Z5 and Z6.

The aberrated PSFs in five MAORY field points at the instrument focal plane shown in Figure 58 indicate the presence of astigmatism and defocus as predominant aberrations.

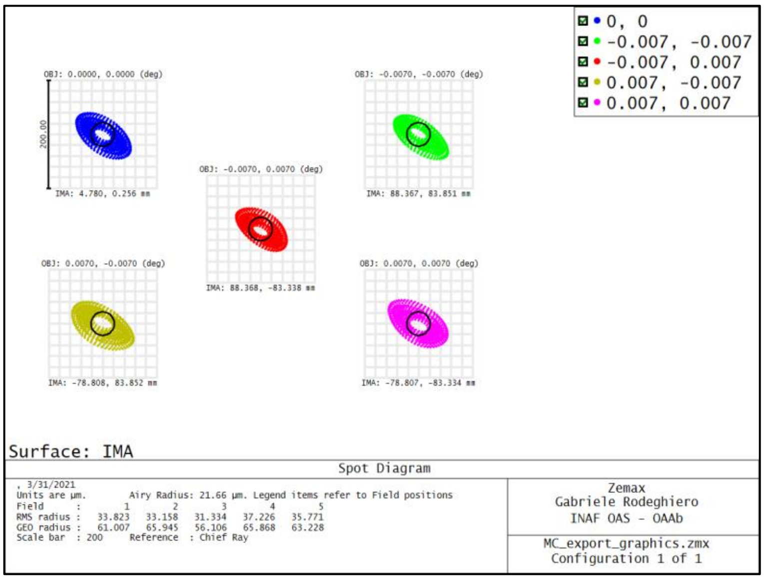


Figure 58 Aberrated PSFs in five MAORY field points, one on-axis and four off-axis, before the MOA sequence at the MAORY nominal focal plane. The black circle represents the Airy disk.

The M10 poke matrix (Equation 3) is computed for the Z5,Z6 Zernike terms evaluated over 3 to 5 field points as response to the Tip & Tilt perturbations of M10:

$$Tip^{+} = \begin{bmatrix} Z_5^{+}|_1 & Z_5^{+}|_2 \\ Z_6^{+}|_1 & Z_6^{+}|_2 \end{bmatrix}$$

Equation 1 System response to a M10 positive Tip poking in terms Zernike Z5,Z6 over fields 1 and 2.

$$ZTip = \frac{[Tip^{+} - Tip^{-}]}{\Delta Tip} / 2$$

Equation 2 The response to a Tip/Tilt poke is averaged among positive and negative perturbation, halved and divided by the amplitude of the perturbation.

$$M = \begin{bmatrix} Ztip_1 & Ztilt_1 \\ Ztip_2 & Ztilt_2 \end{bmatrix}$$

Equation 3 The size of the poke matrix M is (N_Z x N_{field}) x N_{DoF} and it is built putting together the responses to all the perturbations over all the fields expressed in Zernike terms.

Using a single value decomposition algorithm we can derive the inverse of the poke matrix R such that *M x R = Id* is the identity matrix. This matrix allows to retrieve the amplitude of the DoFs to be uploaded at M10 to suppress the WFE terms of the misaligned instrument:

$$\Delta DoF = G \cdot WFE(Z5, Z6) \times R$$

Equation 4 The differential command to be uploaded to M10 for damping the WFE(Z5,Z6) is derived by R, the inverse matrix of M.

The term *G* in Equation 4 is a gain factor < 1, typically 0.6 < *G* < 0.9, to upload a fraction of the DoF and not the exact value to make the convergence of the loop more robust. Subsequently to the command upload the WFE is evaluated again with the Zernike fit and a new estimate for WFE(Z5,Z6) is derived and inserted in Equation 4 to recalculate the ΔDoF for the consecutive loop iteration. In the best case the loop breaks automatically if the WFE(Z5,Z6) changes stabilize and the ΔDoF changes are negligible as shown in Figure 59 and Figure 60. If the loop is unstable, not converging or diverging, after a certain number of iterations (min 15) the algorithm searches in the history of the loop for the minimum value of the WFE and picks that up as best solution.

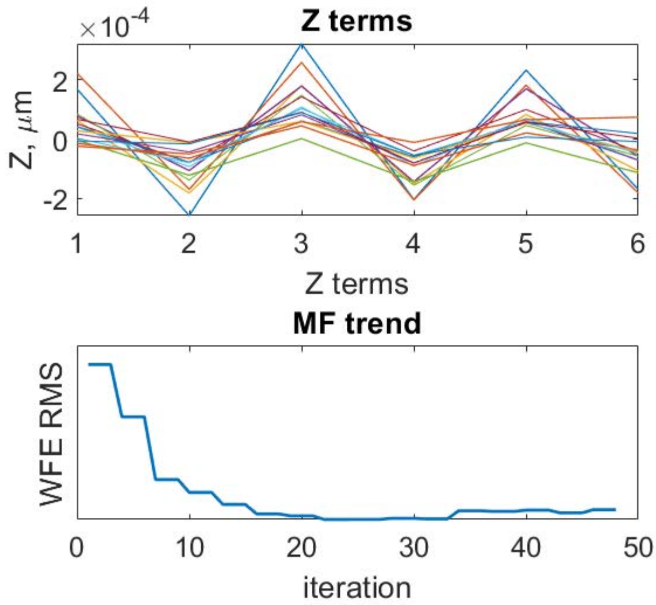


Figure 59 Top: amplitude of the Z5,Z6 terms for the different field points during the loop; in a converging loop the lines flatten progressively. Bottom: trend of the Zemax MF during a converging loop of suppression of the Z5,Z6 terms.

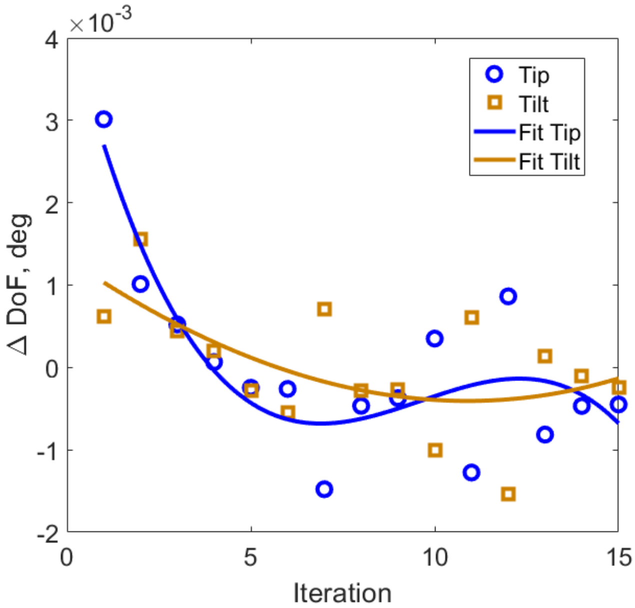


Figure 60 Decreasing trend of the Tip & Tilt DoFs within the iterative loop towards convergence to the solution. The large initial variation damps progressively with the number of loop iterations.

Once the astigmatic terms are minimized following the above-mentioned criteria the last parameter to be minimized is the defocus; an image of the donut with minimized astigmatic terms at the end of the loop is given in Figure 63. The best focus position is determined scanning different intra/extra focal positions acting on the piston of M10 and estimating the PSF size using the aperture photometry. An example of extrafocal PSFs sequence is given Figure 62. The size of the PSF is measured using the R80 or R90 as figure of merit; these are respectively the radii enclosing the 80% and 90% of the PSF energy. An example of the PSF focal curve from a MC realization is reported in Figure 61, the photometric curve is fitted with a parabolic function and the minimum is used as best focus position of M10.

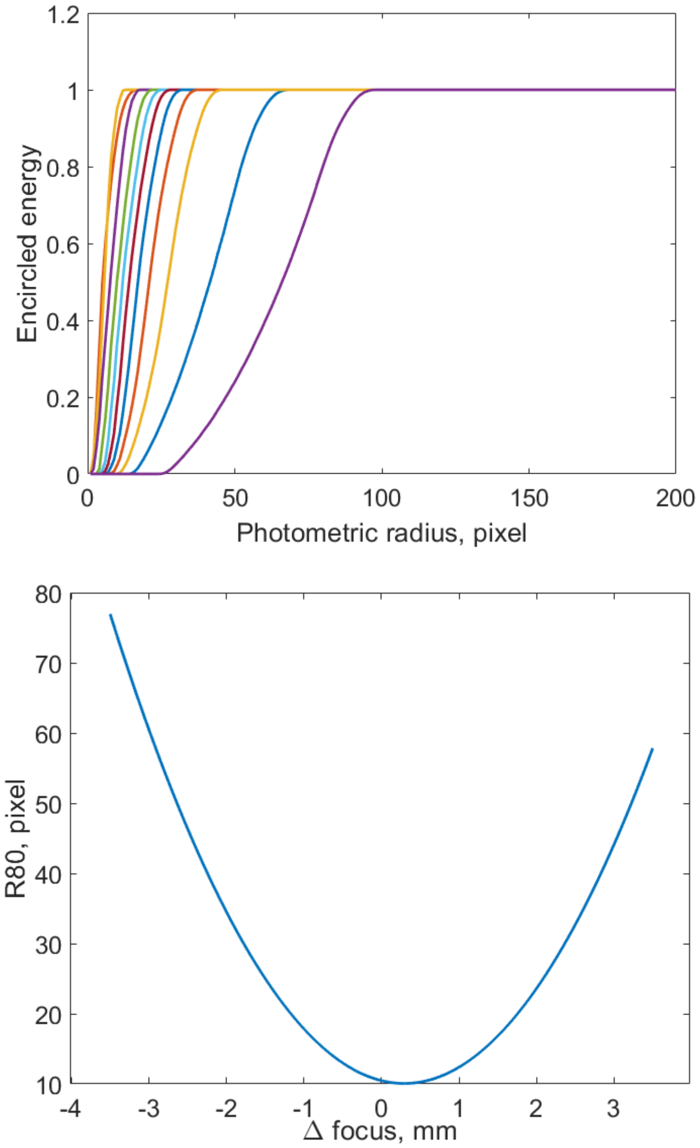


Figure 61 Top: aperture photometry curves for on-axis PSF at different extra/intra focal positions (color scale), the reference radii generally used are those enclosing the 0.8 and 0.9 of PSF energy; bottom: extra/intra focal scan of the MAORY on-axis PSF to recognize the best focus position using the radius of the PSF that encloses the 80% of the flux. The points are fitted with a parabolic function and the minimum of the curve tells the amplitude of the piston command to be uploaded at M10.

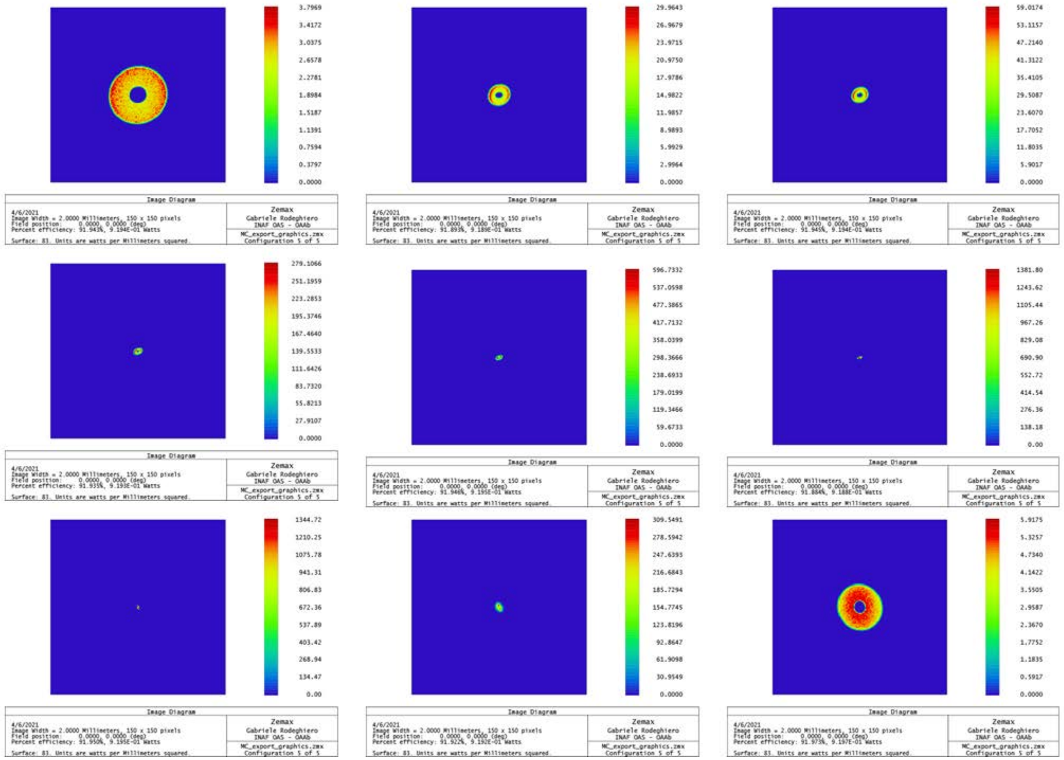


Figure 62 Simulated Donuts at different extrafocal positions of the TAC; these images are analysed with aperture photometry routines to estimate the size of the PSF and locate the best focus position.

At the end of the MOA sequence the Donut is round (no astigmatism) and the PSFs are diffraction-limited, see Figure 63 and Figure 64.

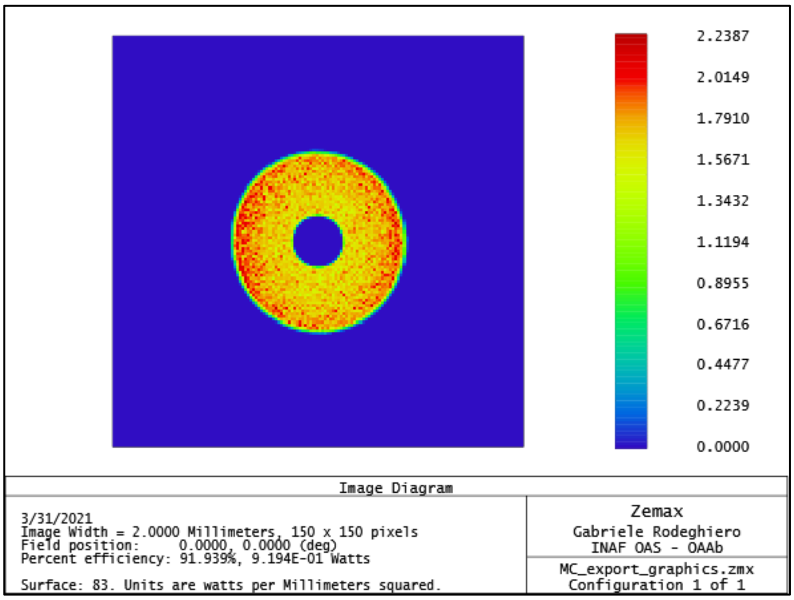


Figure 63 Simulated image of the Donut after the astigmatic terms Z5,Z6 have been minimized by the iterative loop. The Donut is now round.

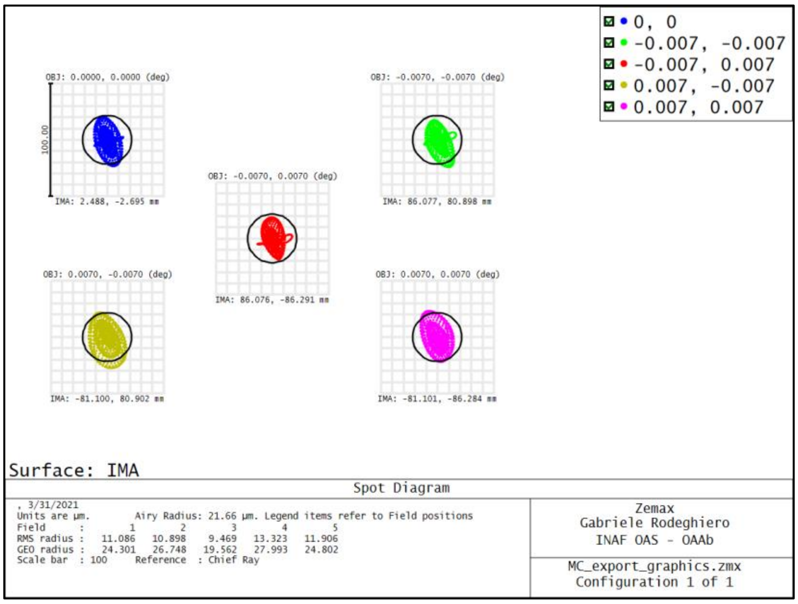


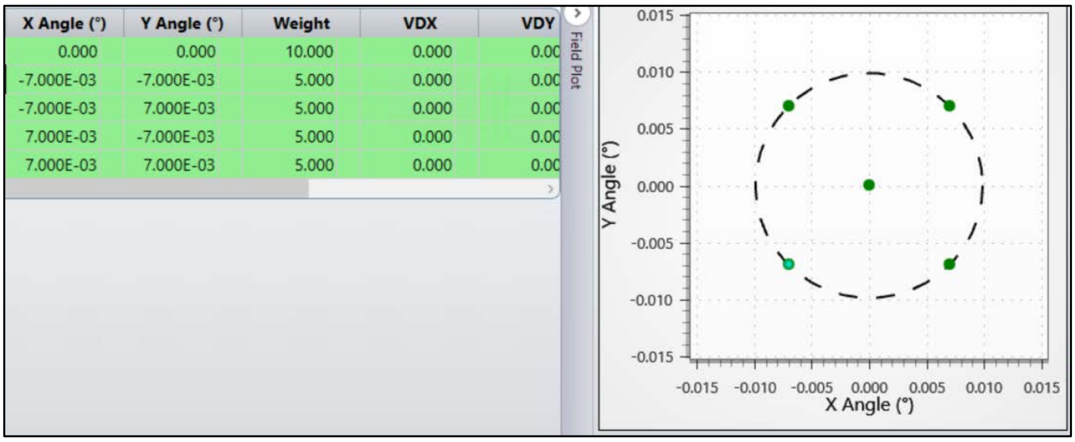
Figure 64 Diffraction-limited PSFs in five MAORY field points, one on-axis and four off-axis at the MAORY focal plane, at the end of the alignment procedure. The aberrated counterpart is reported in Figure 58. The black circle represents the Airy disk.

Following the steps described in this section a ZOS-API code has been applied to a series of 50 MC tolerance realizations of the MAORY instrument.

A collection of different simulations has been run to explore the envelope of the problem and the reliability and the convergence of the method against different systematic errors and system configurations:

- Number of field points observed for WFSensing
- Different positioning tolerances, class I (+/-1mm, +/-0.01deg) and class II (+/ 2mm, +/-0.01deg)
- Different Zernike orders of manufacturing tolerances up to 37 and 100 aberration terms including positioning tolerances class I & class II.

The field points used for the simulations are reported in Figure 65 and correspond to an on-axis PSF and up to four off-axis PSFs placed close to the edge of the MICADO FoV.



X Angle (°)	Y Angle (°)	Weight	VDX	VDY
0.000	0.000	10.000	0.000	0.00
-7.000E-03	-7.000E-03	5.000	0.000	0.00
-7.000E-03	7.000E-03	5.000	0.000	0.00
7.000E-03	-7.000E-03	5.000	0.000	0.00
7.000E-03	7.000E-03	5.000	0.000	0.00

Figure 65 Field points used for the MOA MC simulations.

The simulations are run for a polychromatic light made of 1 µm, 1.65 µm and 2.2 µm wavelengths. The results in terms of residual WFE extracted by the MOA algorithm are expressed as the RMS sum of the five field points considered in Figure 65 calculated from the Zemax default MF for wavefront errors (3 rings 6 arms). The MAORY WFE requirement calculated as average value over the full FoV is 150 nm over the MICADO FoV and 200 nm over the MAORY technical field. A more direct linking between the two quantities is discussed in section 8.1.4.1.10.

8.1.4.1.3 Optical alignment simulations results

The results of the simulation campaign using the MOA in different MAORY tolerance conditions are collected in Table 8. The following four different contributions have been evaluated singularly and in combination:

- Class I tol: positioning tolerances [+/-1mm, +/-0.01deg]
- Class II tol: positioning tolerances [+/-2mm, +/-0.01deg]
- 37Z Manufacturing Errors (ME): manufacturing tolerances from optics up to 37th Zernike term
- 100Z ME: manufacturing tolerances from optics up to 100th Zernike term

Different construction methods of the poke matrix and the Donut Zernike fit are also evaluated:

- Nm PM: Poke matrix built from the nominal, unperturbed MAORY optical design
- MC PM: Poke matrix built from each MC realization
- 6Z fit: Donut Zernike fit up to the 6th Zernike term (up to astigmatism)
- 100Z fit: Donut Zernike fit up to the 100th Zernike term

Table 8 Summary of the WFE after the OA of MAORY: the results are retrieved using three fields in the MICADO FoV and the mean and median WFE over 50 MC simulations are adopted as representative parameters.

Tolerance type	**WFE residual** **Mean & standard dev.**	**WFE residual Median**	**Comment**
Class I tol	54 ± 34.3	35.4	100Z MC PM
Class II tol	72 ± 53.2	55.7	100Z MC PM
Class I tol	36.4 ± 12.4	32.9	6Z MC PM
Class I tol	36.41 ± 12.9	30.9	6Z Nm PM
37Z ME + class I tol	63.2 ± 6.4	61	100Z MC PM
100Z ME + class I tol	71.4 ± 19.9	64.8	100Z MC PM
37Z ME + class II tol	72.6 ± 20.6	67.4	100Z MC PM
100Z ME + class II tol	105.4 ± 65.8	76.6	100Z MC PM
100Z ME + class II tol	84.6 ± 48.9	71.4	100Z MC PM
37Z ME + class II tol	67.2 ± 21	55.6	6Z M6 & M9 class I tol, MC PM
37Z ME + class II tol	66.1 ± 37.8	54.4	6Z M6 & M9 class I tol, Nm PM
100Z ME + class II tol	93.5 ± 27.5	88.2	M6 & M9 class I tol,

			6Z MC PM
100Z ME + class II tol	87 ± 20.1	83.1	M6 & M9 class I tol, 6Z Nm PM

A graphical summary of the simulations results is reported in the next pages.

8.1.4.1.4 Number field points observed for WFSensing

From the tolerance study of MAORY reported in RD9 the optimum number of field points to constrain the alignment of the relay is five. The current seems to be less sensitive to the number of field points considered for the WFSensing although the WFE residual mildly decreases for a higher number of field points observed. A good compromise among WFE residual and computational time indicates that three field points, one on-axis and two off-axis is a good compromise (Figure 66). Although the single field point shows a small WFE (Table 9) we believe it is better to always observe also one or more fields off-axis to avoid unconstrainted/unprobed regions in the field.

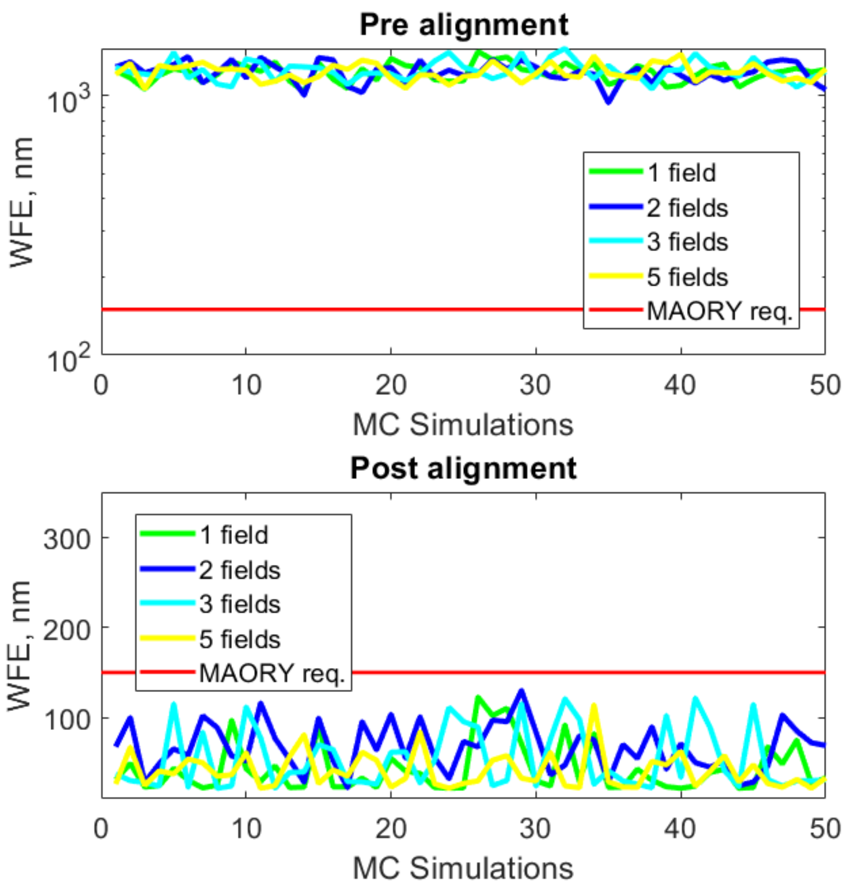


Figure 66 The efficiency of the MOA algorithm for different reference field points number. Using several fields increases the precision of the WF reconstruction.

Table 9 Average WFE residuals for different field points number.

Field points number	Mean, nm	Standard deviation, nm
1	0.0426	0.0271
2	0.0669	0.0263
3	0.0540	0.0343
5	0.0409	0.0195

8.1.4.1.5 Different positioning tolerances amplitude (NO manufacturing tolerances)

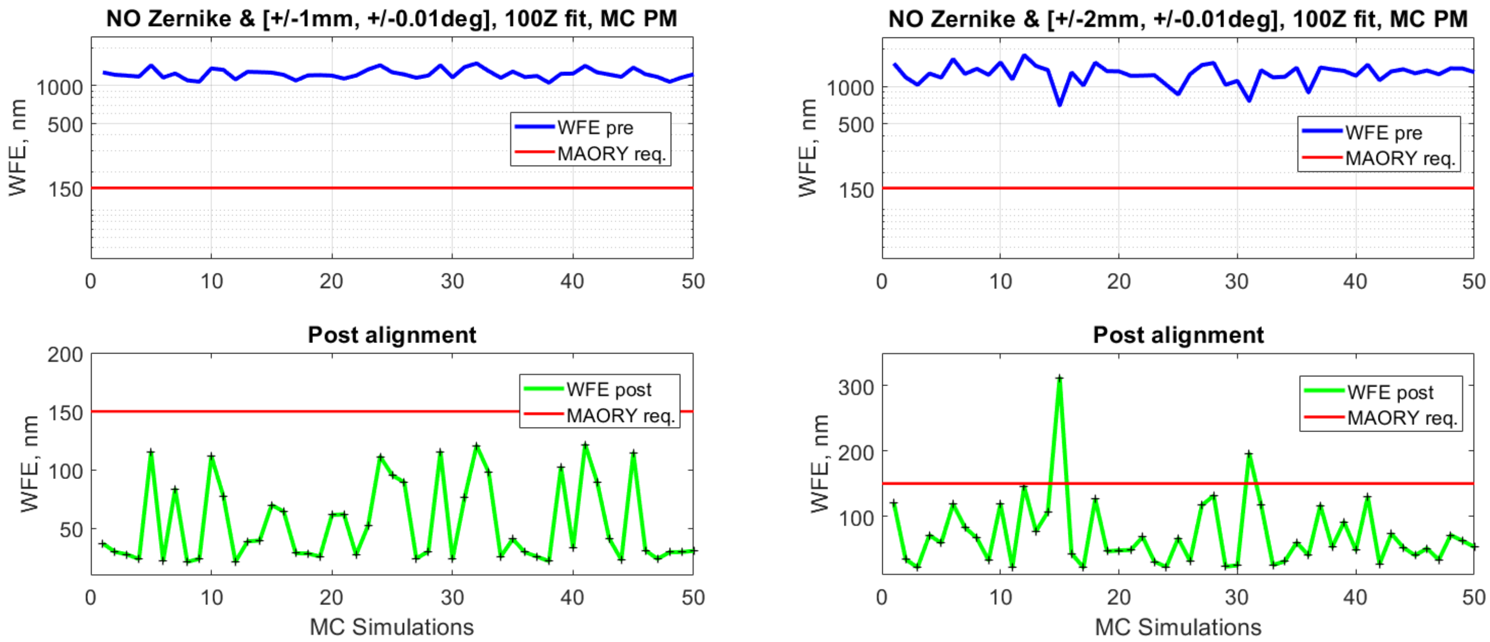


Figure 67 WFE pre alignment (top) & post (bottom) for 50 MC simulations. WFE for class I positioning tolerances (left) and class II (right). The decenter of the optics for class II tolerances is in average twice that one of class I. In both the samples the Donuts were fitted with 100 Zernike terms.

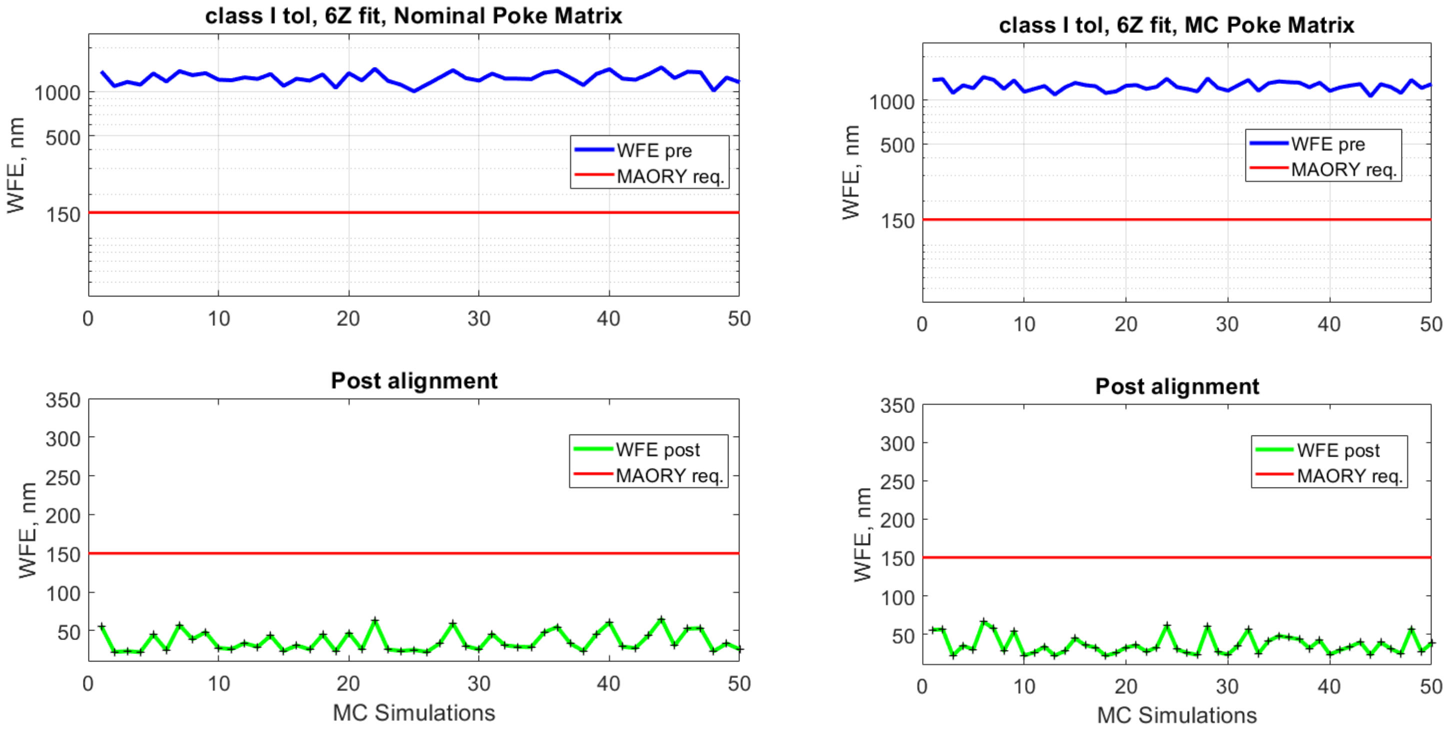


Figure 68 WFE pre alignment (top) & post (bottom) for 50 MC simulations for class I positioning tolerances corrected with a poke matrix retrieved from the nominal MAORY design (left) and for poke matrices built for each MC realization (right). In both the samples the Donuts were fitted with 6 Zernike terms.

8.1.4.1.6 Different Zernike orders of manufacturing tolerances (including positioning tolerances class I)

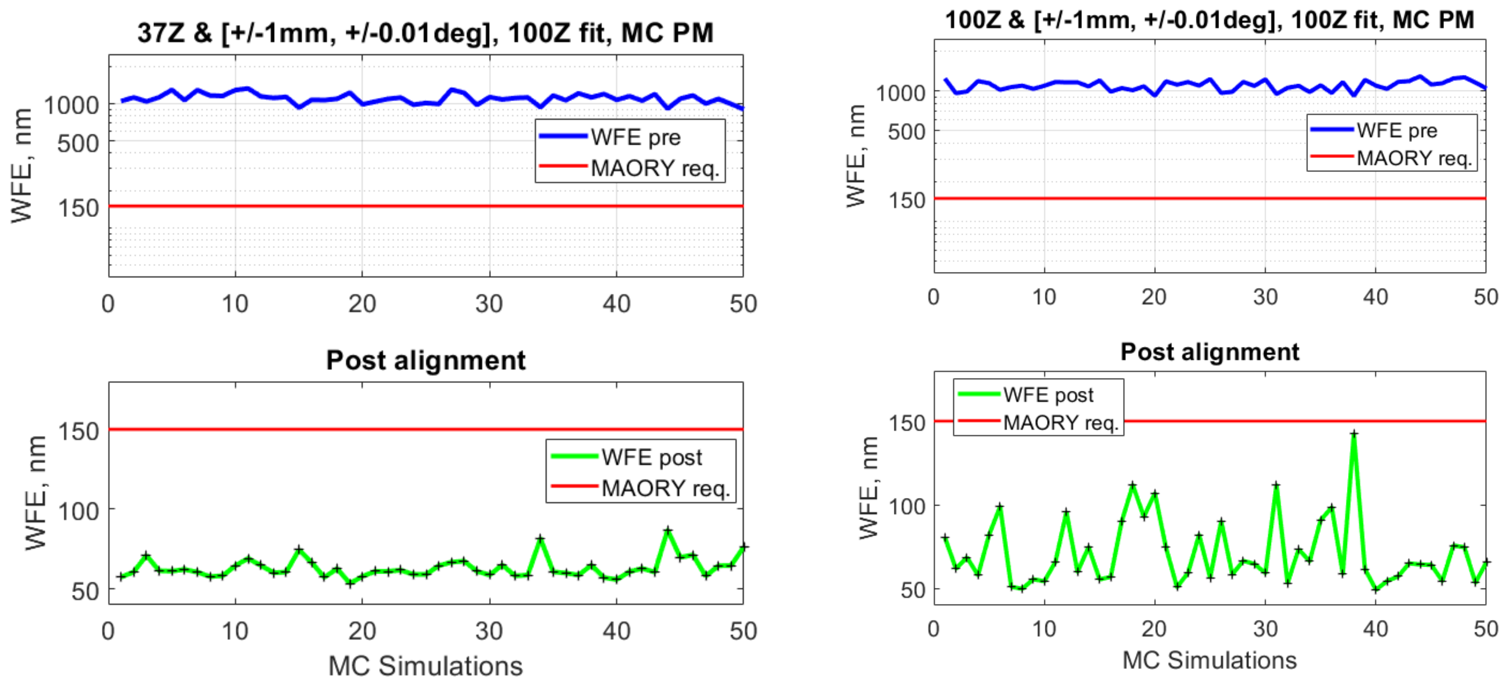


Figure 69 WFE pre alignment (top) & post (bottom) for 50 MC simulations. In addition to class I positioning tolerances the first 37 (left) and 100 (right) Zernike Manufacturing Error (ME) terms are added to account for the manufacturing tolerances of the optics. In both the samples the Donuts were fitted with 100 Zernike terms.

8.1.4.1.7 Different Zernike orders of manufacturing tolerances (including positioning tolerances class II)

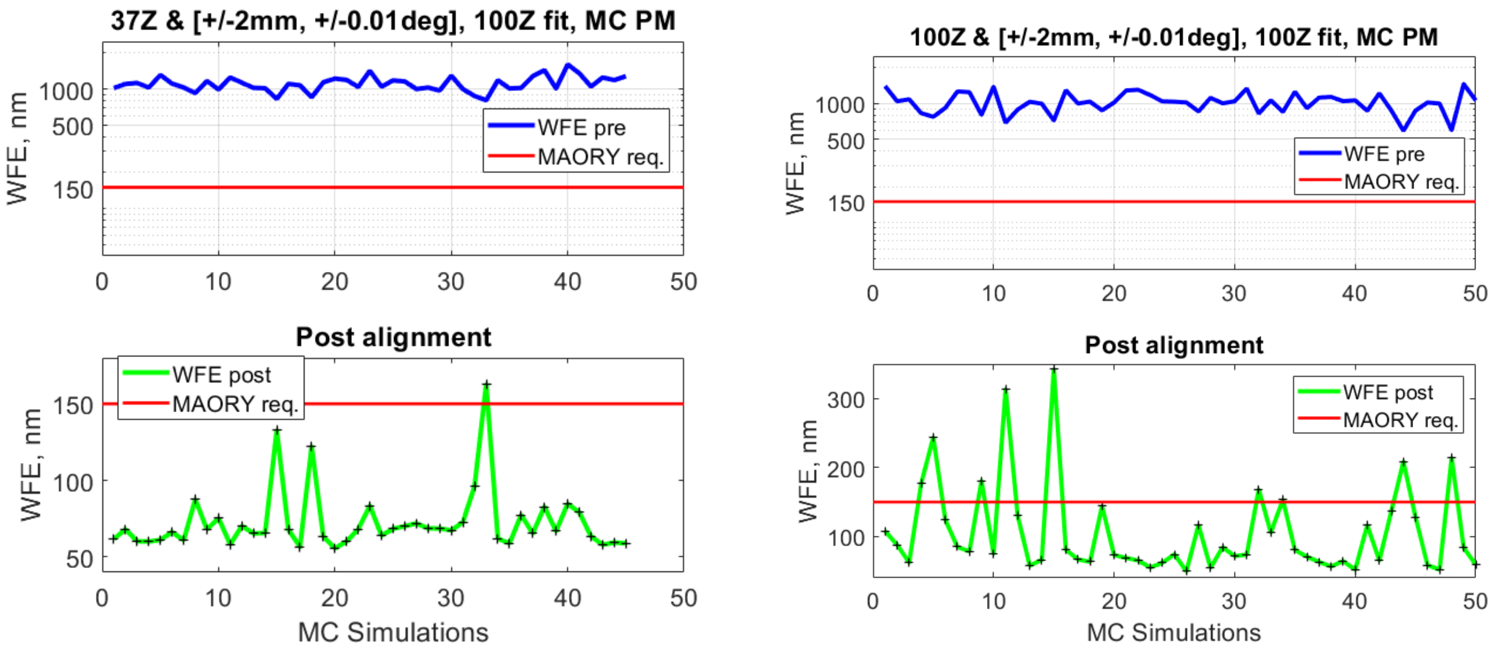


Figure 70 WFE pre alignment (top) & post (bottom) for 50 MC simulations. In addition to class II positioning tolerances the first 37 (left) and 100 (right) Zernike ME terms are added to account for the manufacturing tolerances of the optics. In both the samples the Donuts were fitted with 100 Zernike terms.

This pilot study has pointed out M6 and M9 as potential worst offender to the MOA precision and convergence. The number of MC realizations non-compliant with the MAORY WFE requirement over the MICADO FoV (150 nm) can be decreased tightening the positioning tolerances of M6 and M9 to class I (see Figure 71).

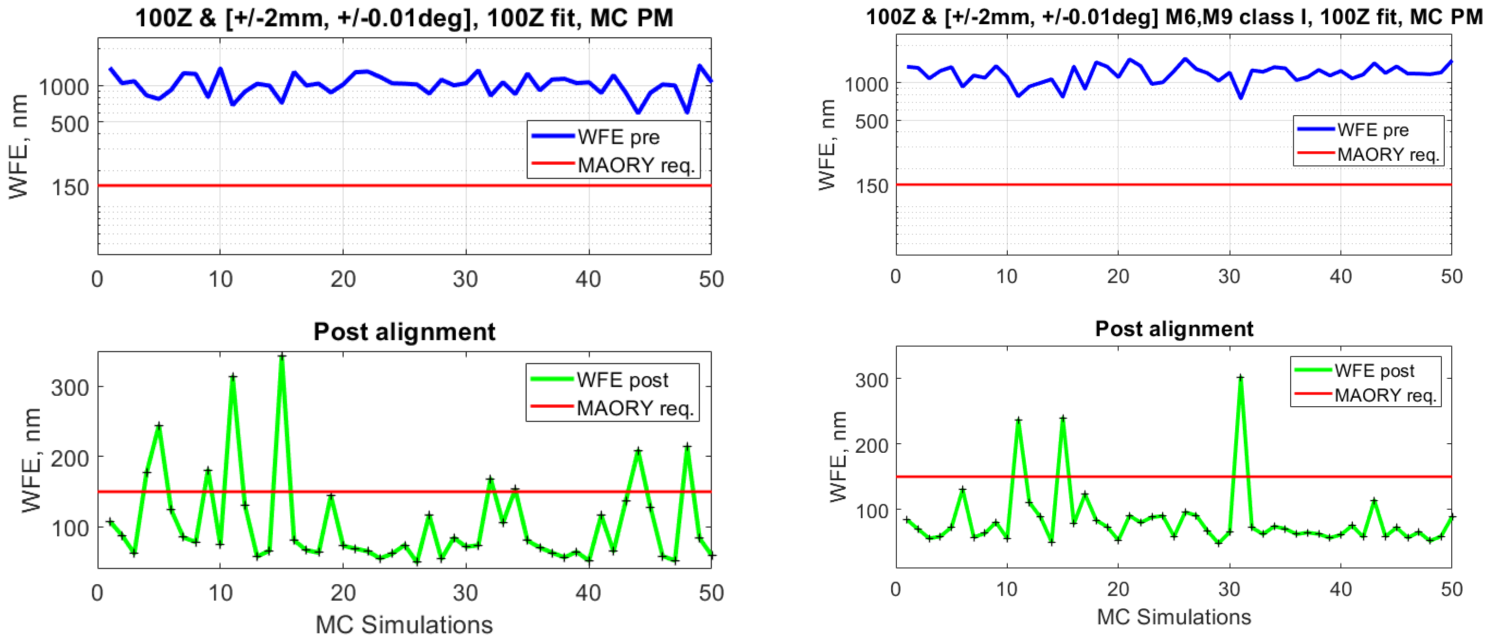


Figure 71. Left: 100 Zernike ME terms and class II positioning tolerances; right: fewer non-compliant MC realizations for 100 Zernike terms, class II positioning tolerances and class I for M6 and M9 that are the worst offenders for the precision of the MOA algorithm. In both the samples the Donuts were fitted with 100 Zernike terms.

8.1.4.1.8 Different poke matrix terms positioning and manufacturing tolerances

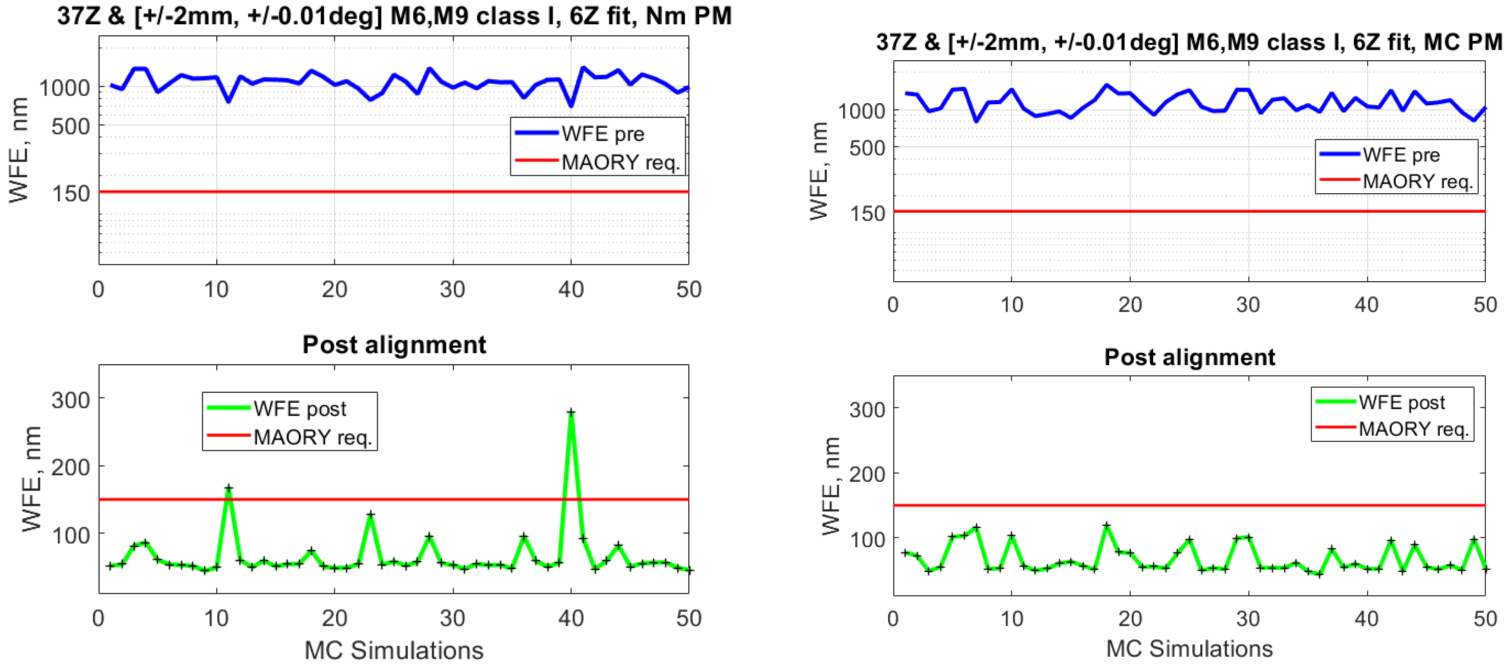


Figure 72 Left: 37 Zernike ME terms and class II positioning tolerances with a poke matrix derived from the unperturbed ideal MAORY design; right: 37 Zernike terms and class II positioning tolerances with a poke matrix derived from each MC realization. There are no realizations exceeding the 150 nm threshold and the average WFE over 50 MCs is comparable to the case on the left. In both the samples the Donuts were fitted with 6 Zernike terms.

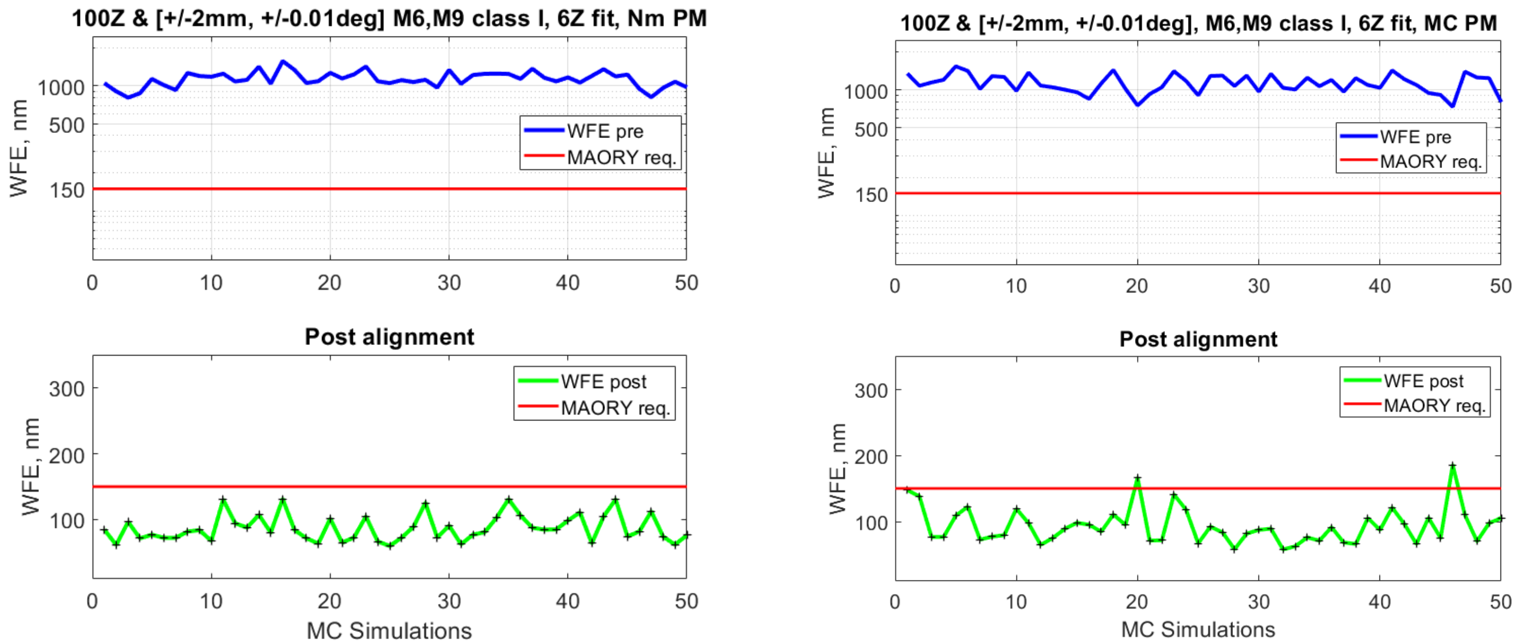


Figure 73 Left: 100 Zernike ME terms and class II positioning tolerances with a poke matrix derived from the unperturbed ideal MAORY design; right: 100 Zernike terms and class II positioning tolerances with a poke matrix derived from each MC realization. The situation is reversed with respect to the case reported in Figure 72 (37 Zernike ME), the poke matrix built for each MC realization returns slightly higher WFE and two cases above 150 nm WFE. In both the samples the Donuts were fitted with 6 Zernike terms.

8.1.4.1.9 M10 DoF inferred strokes from MOA simulations

From the MOA simulations we evaluated the required stroke for the M10 Tip & Tilt DoFs over each iteration of the loop for 50 MC simulations. Figure 74 reports the distribution of the variation of the DoFs with respect to the nominal M10 orientation for a scenario with 100 Zernike terms (manufacturing) and class II positioning tolerances.

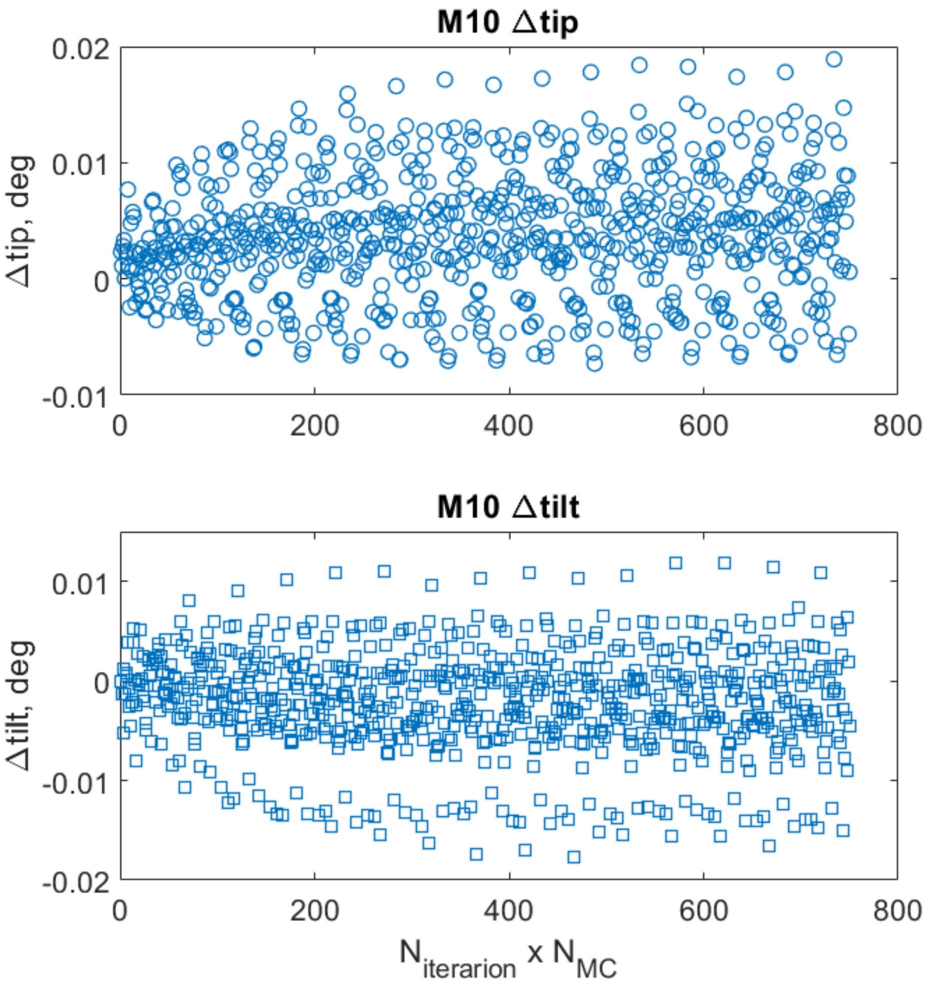


Figure 74 Distribution of the variation of the Tip & Tilt DoFs with respect to the nominal M10 orientation required by the MOA over 50 MC simulations. Scenario 100 Zernike terms (manufacturing) and class II positioning tolerances.

The M10 required stroke for the piston DoF is +/- 5 mm, 3.5 mm from simulations plus contingency.

The Tip-Tilt actuation of M10 induces a lateral shift of the FP at the TAC FP. Assuming the numbers of the ΔDoF reported in Figure 74 the PSFs motion span a field that is about

2x2 times the sensed field of the OWL 1280 detector envisaged for the TAC (sec. 7.1) as shown in Figure 75. To pick-up the PSF Donuts for any M10 PTT configuration the OWL 1280 needs to be patrolled along the focal plane using the 2D linear stages available on the TAC.

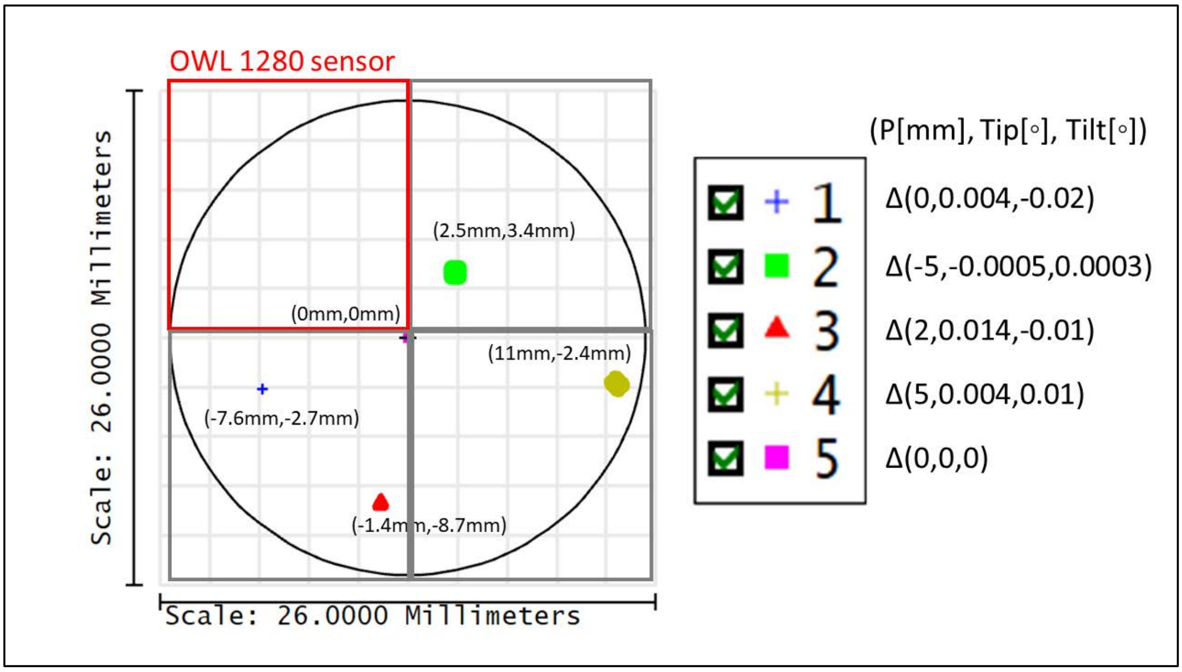


Figure 75 Simulated PSF motion for different Piston, Tip & Tilt variations of M10; the motion is about 2 times larger than the sensed field using the OWL 1280 as detector for the TAC.

For the MAORY standalone internal alignment the focal plane shift (Figure 75) does not represent an issue as long as the PSF shift falls within the sensed field by the TAC. When this procedure is applied to the (re-)alignment of MAORY with MICADO at the Nasmyth platform an additional alignment step needs to be carried out. The TT of M10 induces both a focal plane and a pupil shift with respect to the downstream optics of MICADO. At the end of the WFE minimization process the MAORY focal plane needs to be stacked to the input focal plane of MICADO and the MAORY pupil to be re-aligned to the MICADO cold stop pupil. This is achieved by tip-tilting M11 that however influences also the pupil position and requires the compensation with M12. The mutual dependence of the focal plane and pupil position on the actuation of the active mirrors and the alignment strategy of the optical interface between MAORY and MICADO is described in section 8.1.5.

8.1.4.1.10 MOA WFE linking to MAORY WFE requirement

As previously discussed, the MOA simulations are run for a polychromatic light made of 1 μm, 1.65 μm and 2.2 μm wavelengths. The results in terms of residual WFE extracted by are expressed as the RMS sum of five field points (Figure 65) calculated from the Zemax default MF for wavefront errors (3 rings 6 arms). In order to link the obtained results to requirements MAO-SF0-1.2.4.4 and MAO-SF0-1.2.4.3, i.e. to the average value of the RMS WFE in the MICADO FoV and in the Technical FoV at wavelength 1 µm, we have considered a few representative MC cases: MC22, MC41, M43. The different fitting Zernike order experimented in the MOA algorithm are labelled as follows:

- Method 1: 100 Zernike terms donut fit
- Method 2: 6 Zernike terms donut fit up to astigmatism

MC22 has ‘good’ convergence with both the first and second method; MC41 has ‘bad’ convergence with the first method and ‘good’ convergence with the second method; MC43 has ‘bad’ convergence with the first method and ‘bad’ convergence with the second method. For each MC, we have set the wavelength to 1 µm (compensating the chromatic focal shift) and compared the RMS WFE map on the MICADO FoV and Technical FOV for the first method, for the second method, and by re-optimizing the system using a ZEMAX Merit Function (MF) based on the minimization of Z4, Z5, Z6 for the 5 fields. The latter is considered as the theoretical correction one could achieve. The results are shown in Figure 76, Figure 77 and Figure 78. For each cases we have computed the average RMS WFE over the MICADO FoV and over the Technical FoV, and the value of the Zemax MF RMS WFE over the 5 fields. Results are reported in Table 10.

Table 10. Average RMS WFE and Zemax MF vale based on RMS WFE over the 5 fields using method 1, method 2 and Z4 Z5 Z6 Zemax optimization for MC cases 22, 41 and 43.

		Method 1 100Z fit donut		**Method 2 6Z fit donut**		**Zemax MF Z4 Z5 Z6**
		average RMS WFE, nm	**MF WFE 5 fields, nm**	**average RMS WFE, nm**	**MF value WFE 5 fields**	**average RMS WFE, nm**
MC22	MICADO FoV	59,1	0,049	64,6	0,057	57,9
	Technical FoV	79,5		85,6		73,4
MC41	MICADO FoV	101,6	0,102	57,8	0,052	53,8
	Technical FoV	93,0		70,9		68,1
MC43	MICADO FoV	128,3	0,131	93,1	0,090	60,0
	MICADO FoV	121,0		116,9		78,2

The reader can observe how the MC22 and MC41 residual WFE is close to the theoretical value given by the Zemax MF when the MOA is run with a 6 terms Zernike fit of the donut (method 2). The MC43 experiences also an improvement using the method 2 although the WFE remains still significantly higher than the theoretical value.

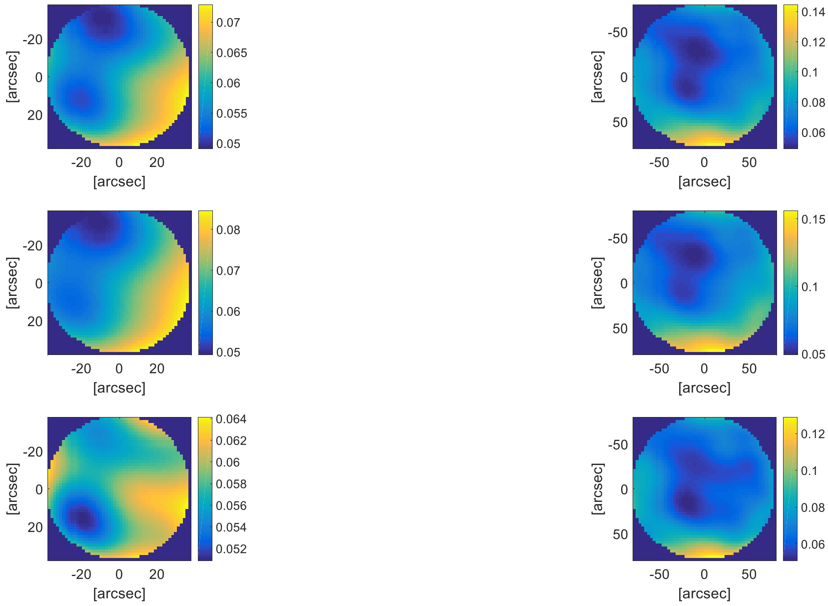


Figure 76: RMS WFE maps In the MICADO FoV (left) and on the Technical FoV (right) using the first method (top), the second method (middle) and Zemax Z4, Z5, Z6 merit function (bottom) for the case 22.

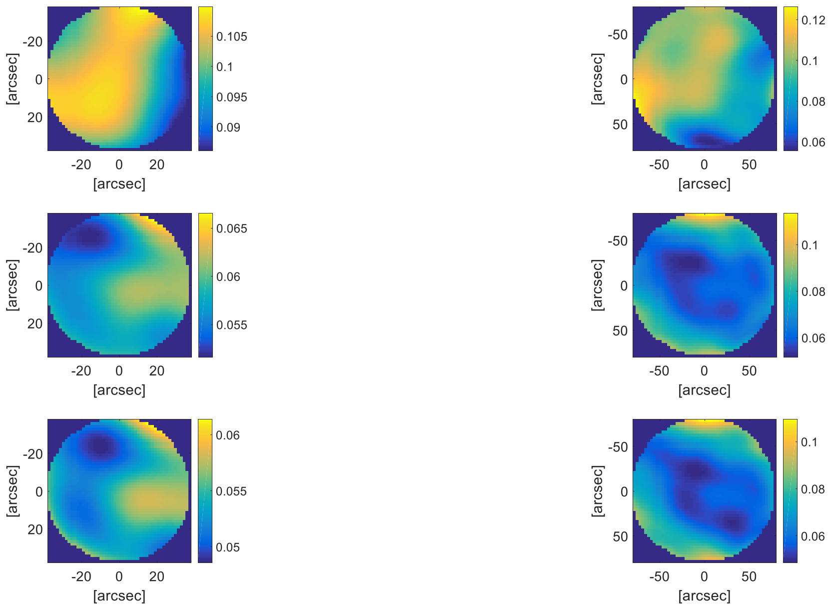


Figure 77: RMS WFE maps In the MICADO FoV (left) and on the Technical FoV (right) using the first method (top), the second method (middle) and Zemax Z4, Z5, Z6 merit function (bottom) for the case 41.

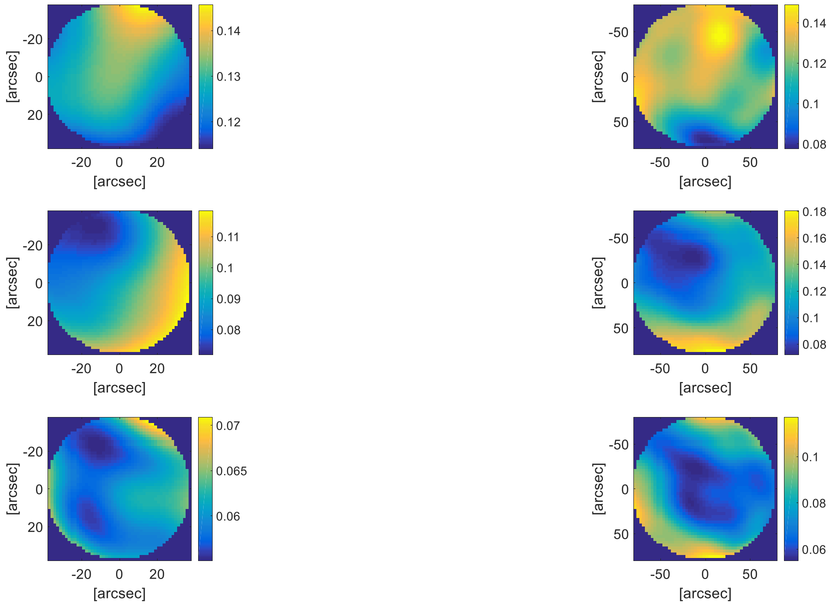


Figure 78: RMS WFE maps In the MICADO FoV (left) and on the Technical FoV (right) using the first method (top), the second method (middle) and Zemax Z4, Z5, Z6 merit function (bottom) for the case 43.

8.1.4.1.11 Optical alignment remarks

The capabilities and limitations of the MOA development code (section 8.1.4.1.1) have been assessed with a series of exploratory simulations with different boundary conditions (section 8.1.4.1.3) described in the previous sections.

A large fraction of the 50 MC simulations for each category of errors and their multiple combinations has been assessed as compliant with the MAORY WFE requirement of 150 nm rms over the MICADO FoV (Table 8 & Table 10). Using a poke matrix built for every MC realization and a Zernike fit of the Donut with 100 terms, the 16% (Figure 71 - left) of the MC simulations accounting for the manufacturing tolerances (up to Zernike 100) and class II positioning tolerances (+/-2mm, +/-0.01deg) has been found non-compliant with the WFE requirement. Further analyses have pointed out the role of worst offenders for the MOA the positioning tolerances of M6 and M9. By constraining M6 and M9 to class I (+/-1mm, +/-0.01deg) the fraction of the MC realizations non-compliancy reduces to 6% (Figure 71 - right). Using a Donut Zernike fit with the first 6 Zernike terms (up to astigmatism) the number of non-compliant MC realizations decreases (Figure 72 and Figure 73) with some small oscillations depending on the construction method of the poke matrix: either retrieved from the nominal design with no tolerances or built for each single MC realization. The effectiveness of the use of a low order Zernike fit for the Donut has been proven also for MC realizations affected by only positioning tolerances (Figure 68 vs. Figure 67) while there is no clear benefit (so far) in using a nominal-born vs. MC-born poke matrix.

The MOA still requires some ameliorations and verifications that will be developed and provided by FDR:

- Add the calculation of the moments of light to parametrize the low order Zernike terms in combination with the use of a phase-insensitive optical/NIR detector as it will be for MAORY.
- Add a morphology check for the extremely astigmatic MC realizations in which the donuts look likes cigars and the Zernike fit cannot be directly applied. In this case a pre-set of commands of M10 needs to be uploaded to increase the roundness of the donut before starting with the iterative loop.
- Study in more detail the sample of un-converged MCs to understand what prevented the MOA to restore the expected WFE. These realizations go to convergence if optimized using the Zemax MF and the three M10 DoFs, meaning that the relay is always alignable within the optical standard optimization framework even if the algorithm fails. One additional feature that will be added in this context is the injection of a lager perturbation of M10 to move the system away from the local 'un-convergence zone'. An alternative action that we might adopt after PDR is the PSF Donut spatial filtering to remove the high order features and isolate low order (astigmatic) terms.
- Evaluate the effective of vibrations on MOA. In a operative scenario the system will suffer the presence of a background of vibrations that can induce a PSF jitter of 5 mas (PV) at the MAORY focal plane. These vibrations will smear/filter out the highest spatial features of the PSF/Donut without a significant impact on the WFSensing of the MOA that looks for the astigmatic predominant terms.
- Add MICADO to the ray tracing model to account for the additional static aberrations of the cold optics through which the donuts are seen when the MICADO detector is used for the MOA. These additional aberrations could challenge the WFSensing precision of the MOA and it therefore important to repeat the MC analysis with the whole optical train.

Alternative methods to the MOA might be assessed by FDR. At the moment two possible techniques at a primitive stage could be further analysed:

- Using the MICADO Pupil Imager (PIM) for WFSensing the aberrations of the MAORY beam. This possibility has not yet been discussed with MICADO and the impact of the PIM WFE by design on the WFSensing shall be evaluated if this strategy will be pursued.
- Injecting known aberrations with the MAORY DMs or the CU DM, if available beyond the Test Unit phase, while looking at the PSFs sharpness at the MAORY/MICADO FP. When in the relay a certain Zernike term is present and the DM injects the negative corresponding term the Strehl of the PSF is maximized. This technique has been used successfully in SHARK VIS @ LBT (RD6).

Perform WFSensing on the MAORY WFSs and applying a similar M10 poke matrix approach. The weak point of this method are the NCPAs unsensed downstream the WFSs. Among the most critical sources of error the opto-mechanical interface tolerances between the M12 and the MICADO cryostat are probably the largest. These tolerances however will be sensed by the WFSs and compensated by the MOA eventually involving the use of M11 and M12 for the repositioning of the MAORY exit pupil and focal plane position.

8.1.5 Pupil and Focal Plane positions adjustment

The aim of this section is to verify that the procedure selected to align the pupil and focal plane allows to obtain the required accuracy (still under discussion with the MICADO team) and the required positioning range, assuming the foreseen initial positioning MICADO uncertainty

The fine tuning of pupil and exit focal plane position is performed by tip-tilting the last two flat mirrors, M11 and M12. If necessary, the last two steps will be repeated iteratively, since M11 will move mostly the focal plane but also slightly the pupil plane and vice versa M12 will move mostly the pupil plane but also slightly the focal plane. Also, since the alignment of DM2 will affect the position of the pupil and of the exit focal plane, what described here may be iterated with the previous step “fine optical alignment with DM2”. We note that no active corrections are necessary to all the optics before M10/DM2, simplifying the AIV procedure.

The Pupil and Focal Plane positions adjustment accuracy and positioning range are addressed in the next 2 sections.

8.1.5.1 Pupil and Focal Plane positions adjustment accuracy

We emphasize that the way to recover the tip-tilt to be given to M11 and M12, in order to compensate the positions of the exit focal plane and pupil, is currently being studied/evaluated together with the MICADO team. Also, the required accuracy necessary for the pupil and focal plane alignment is under discussion. What we want to mention is that such an operation looks to be almost straightforward once MAORY will be operated with MICADO, since:

- both the pupil plane (inserting the MICADO pupil re-imager) and the final focal plane will be of course available, one at a time, and the process may be iterated by alternatively checking their positions and acting on M12 and M11 (TBC the time needed to switch between pupil and focal plane in MICADO)
- furthermore, inserting the pupil viewer of the SCAO WFS, pupil plane (even though not the MICADO one, but being the instrument gravity invariant the relative movement between the two should be minimum, TBC) and focal plane could be visible at the same time, thus simplifying and speeding up the iterative procedure (note that, in this second option, only open loop operations can be performed)

A little trickier is how to perform this operation in Bologna without MICADO, although a verification of the procedure to correctly move and position focal and pupil plane within a certain range may be enough for the purpose of the Bologna AIT. Such a verification should include:

- travel range (±0.15° by design) and accuracy (<1” by design) of M11 and M12 TT adjustments; we emphasize that such an accuracy by design corresponds to a pupil shift on MICADO of about 2μm (that should be compatible with whatever required accuracy will be agreed upon with the MICADO team), while it corresponds to a focal plane movement on MICADO of about 50μm, which corresponds to about 3 pixels of the camera (15μm square pixel size) and to about 12mas on sky for the full field imager (~5mas for the zoom mode), which looks to be a reasonable field centring accuracy, but it has to be agreed upon with the MICADO team.

- achievable accuracy on the observables of the pupil and focal planes, which is dependent on the procedure that will be identified with the MICADO team (using the MICADO pupil re-imager? Or the SCAO pupil re-imager?) while it is totally independent from the AIT in Europe, and can be independently checked on MICADO. Essentially, the process should consist in acquiring a pupil image and characterize its position down to a certain accuracy (still under discussion - a pixel? A fraction of a pixel?). The verification of this part of the process can be done in parallel to the AIT related activities.

What is important to underline is that the overall MAORY AIT procedure described in this document allows for movements of the pupil within MAORY which don't need any adjustment but the final compensation of its position within MICADO, performed using M11 and M12.

Of course, whenever the instrument will undergo major changes (first installation in the BIH and/or in the IAA and/or transportation to the Nasmyth platform at the telescope), the pupil, and the focal plane too, have to be aligned within the LGS wavefront sensor.

8.1.5.2 Pupil and Focal Plane positions adjustment range

The alignment of the external optical interface of MAORY towards MICADO is managed with the active Piston, Tip & Tilt (PTT) mirrors M10, M11 and M12. In this analysis we assume that the MICADO instrument will be installed at Nasmyth platform within the positioning uncertainty ranges reported in Table 11 and still under discussion at the I/F level between the two systems. To absorb the relative MICADO-MAORY misalignment arising from these opto-mechanical interface tolerances the three active mirrors M10, M11 and M12 are repositioned in their PTT DoF to enable to recollimation between the two instruments. The reader should bear in mind that the MSS has been previously aligned to the PSF following the procedure in section 8.1.7.

Table 11 Positioning uncertainty ranges of MICADO at the first installation on the Nasmyth platform.

DoF	Value	Unit of measurement
Decenter (x,y,z)	+/- 5	mm
Tilt & Tilt	+/- 0.58	mrad
Rotation	NA	mrad

The tip-tilt actuation of M11 and M12 allows to steer simultaneously both the MAORY exit pupil and focal plane with respect to MICADO. The goal of the alignment operations is to co-align the MAORY exit pupil with the MICADO cold stop and the MAORY output focal plane with the MICADO input focal plane. The observables of the alignment procedure are therefore the position of at least two PSFs at the MICADO focal plane, one on-axis and one off-axis and the position of the pupil as seen either by the SCAO pupil viewer or the

MICADO Pupil Imager (PIM). A graphical overview of the DoFs and observables involved in the alignment procedure is given in Figure 79.

Since the actuation of one of the PTT mirrors influences both the focal plane and pupil position it is desirable to observe both the observables in parallel during the alignment procedure. For a simultaneous monitoring the ideal configuration is to observe the PSFs at the MICADO focal plane with the low resolution imager mode of the instrument and the MAORY pupil with the SCAO pupil viewer. The SCAO and MICADO system are aligned one with each other so the use of the SCAO pupil viewer is equivalent to the use of the PIM to image the pupil at the MICADO cold stop. The MAORY calibration unit, previously aligned to the MAORY main path, is used to materialize two point-like sources in the MAORY and MICADO instrument. One PSF is on-axis and the other off-axis close to the edge of the MICADO FoV; the measurement of the PSFs position retrieved by their centroids measurement is used to track the focal plane position. For what concerns the pupil at the SCAO pupil viewer, either the external rim of or the central hole of the pupil can be recognized and fit to locate the pupil position. The M11 being farther away from the focal plane shall be privileged to steer the field whereas the M12 being closer to the focal plane shall be used to move the pupil. The procedure must be necessarily recursive among the measurement of the observables and the actuation of the PTT mirrors. If the LOR stabilization by MAORY is required/preferable, the pupil alignment shall be executed relying on the MICADO PIM. In this case the use of the PIM and the low resolution imager shall be alternated during the alignment procedure. The defocus can be compensated either acting on the piston of M11 and M12 or M10 with the latter being the preferred DoF for this procedure due to its large sensitivity on the system. In addition, the current opto-mechanical baseline of MAORY foresees to actuate only the DoFs TT of M11 and M12 with a motorized and remote control. The piston term of M11 and M12 can be actuated manually during the AIT operations, but it is not in the baseline for the re-alignment operations at the Nasmyth platform.

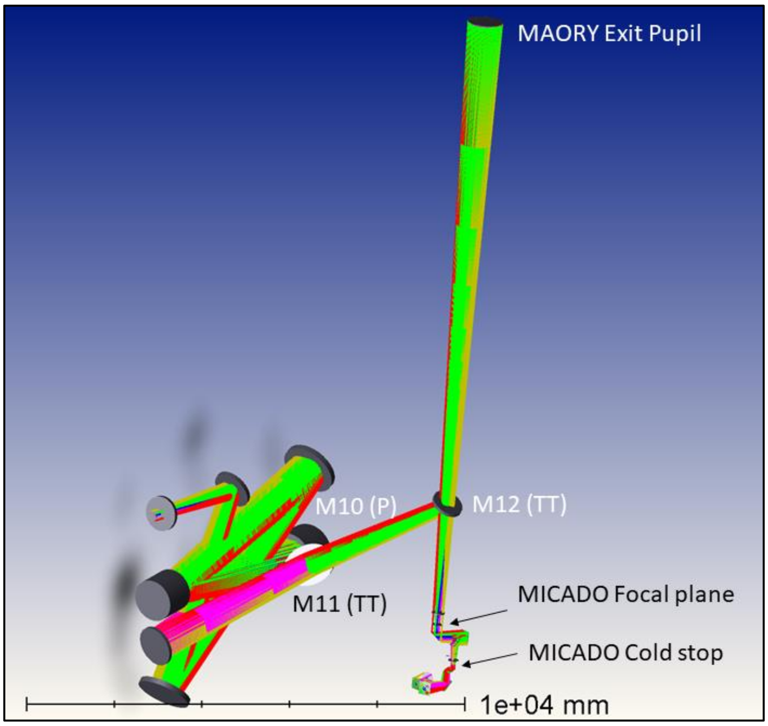


Figure 79 Active DoFs and observables involved in the alignment procedure between MAORY and MICADO.The system sensitivity to the M10, M11 and M12 TT actuation is reported in Table 12.

In the following we present the main results of 100 Monte Carlo (MC) simulations proving the effectiveness of M10, M11 and M12 for addressing the opto-mechanical interface tolerances between MAORY and MICADO. The statistics used to build up the random positioning error realizations of the MICADO focal plane (Table 11) is parabolic to assume a more conservative/pessimistic scenario. The simulations do not include neither the positioning tolerances of the optical elements of MAORY and MICADO nor the manufacturing tolerances at the surfaces. The unique tolerance component is the interface misalignment between the two instruments.

Table 12 TT DoFs steering power on the MAORY focal plane and pupil at the MICADO cold stop. The normalized shift columns highlight the most powerful element DoF.

DoF	**DoF change, deg**	**Focal plane shift, mm**	**Normalized FP shift to max DoF**	**Pupil shift @ cold stop, mm**	**Normalized Pupil shift to max DoF**
Tip M10	0.05	31.28	1.0000	0.59	0.8429
Tilt M10	0.05	31.06	0.9930	0.58	0.8286
Tip M11	0.05	9.16	0.2928	0.7	1.0000
Tilt M11	0.05	12.49	0.3993	0.38	0.5429
Tip M12	0.05	4.87	0.1557	0.42	0.6000
Tilt M12	0.05	3.85	0.1231	0.18	0.2571

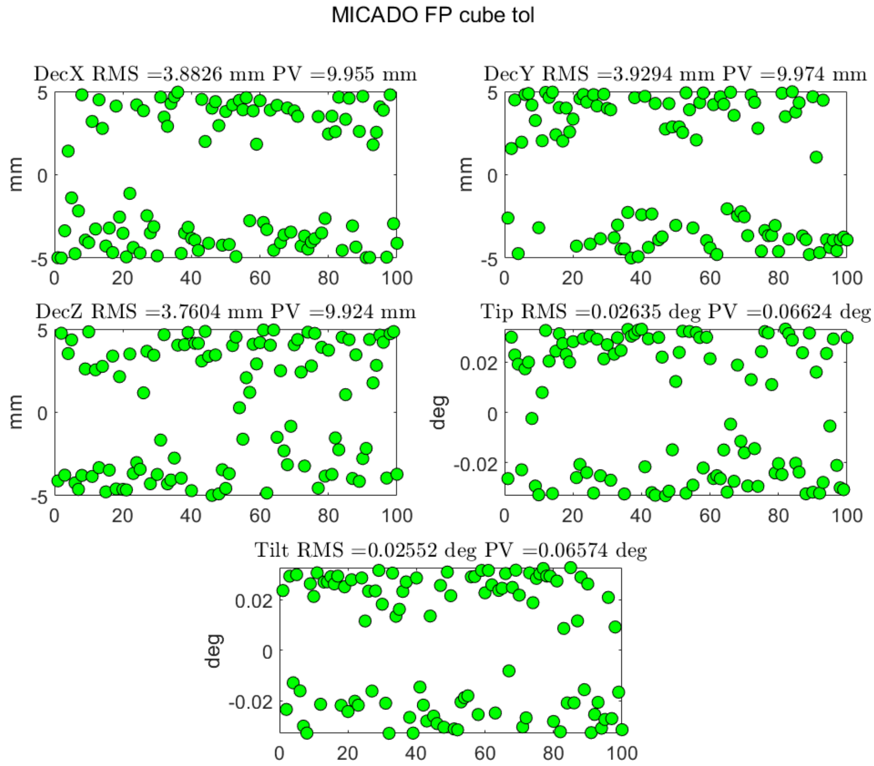


Figure 80 Random distribution of the MICADO focal plane position in the 100 MC simulations. Well visible is the parabolic statistics that prefers extremal values.

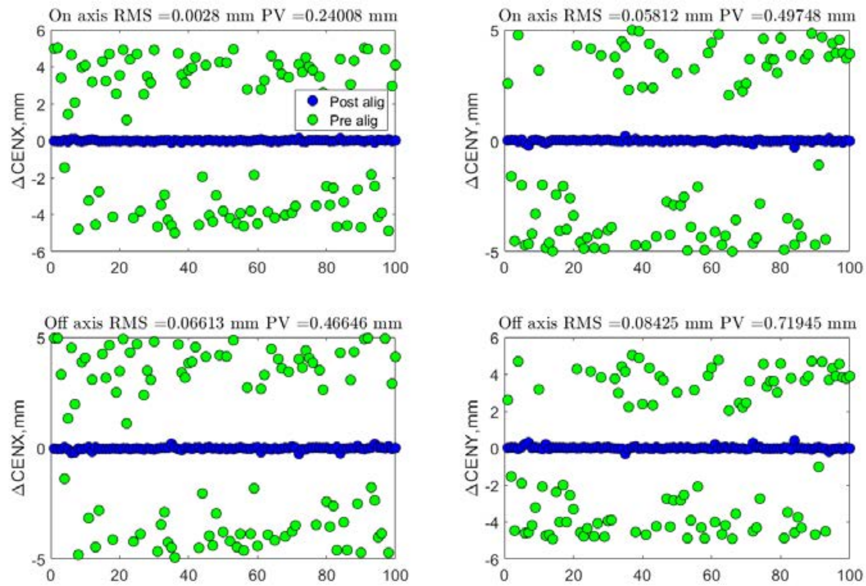


Figure 81 Centroids of on-axis (top) and off-axis (bottom) PSFs at the interface focal plane between MAORY and MICADO before (green) and after (blue) alignment.

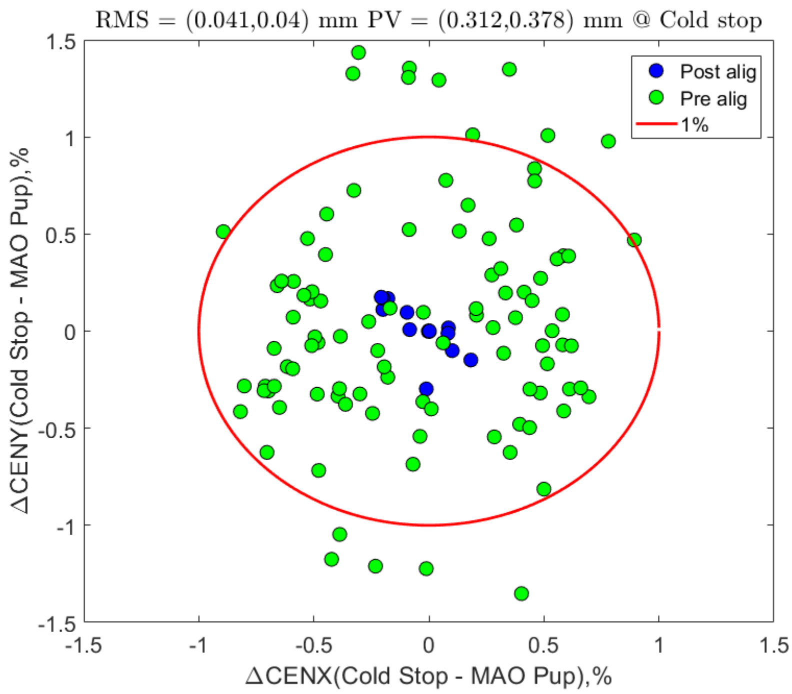


Figure 82 Pupil scollimation between the MAORY pupil and the MICADO cold stop before (green) and after (blue) alignment. The data are given in percentage of the pupil diameter.

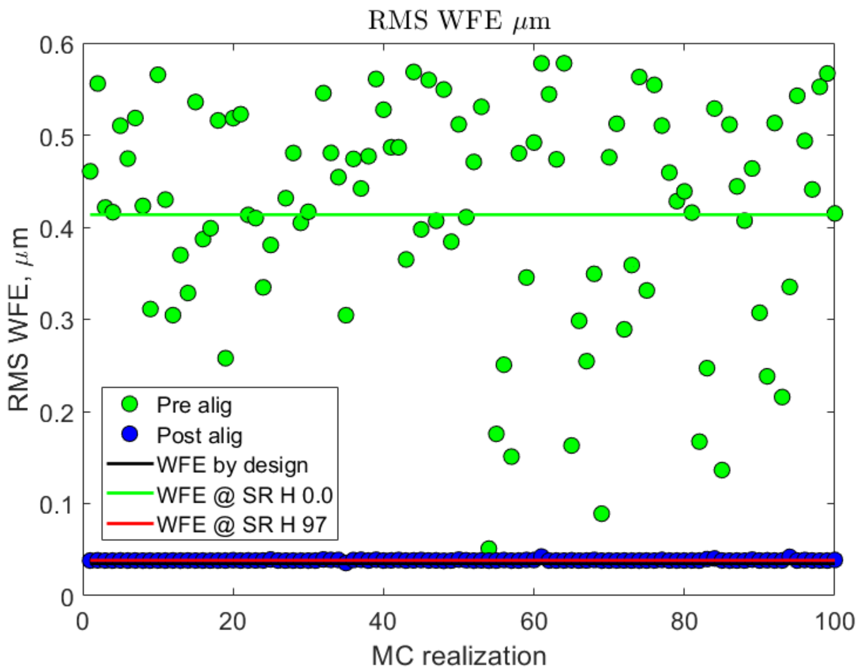


Figure 83 MAORY+MICADO WFE before (green) and after (blue) alignment. The average WFE from 100 MC after alignment translates in a Strehl ratio of 0.97 in H band.

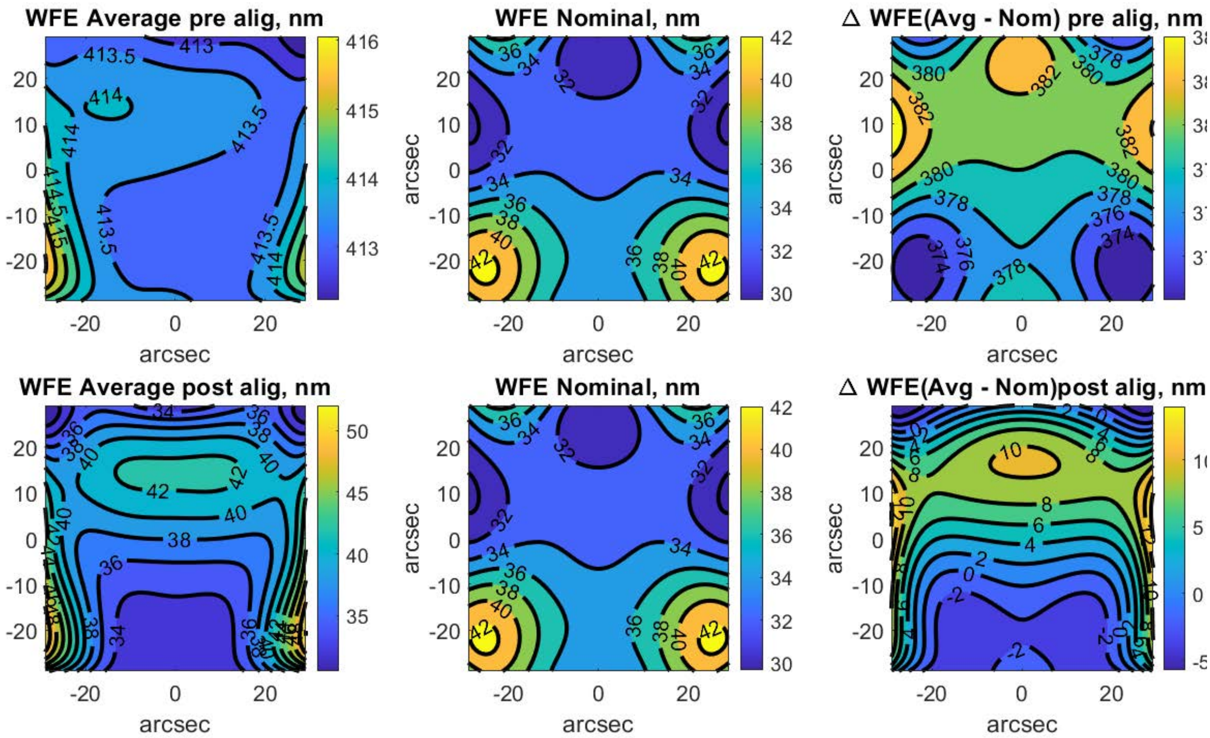


Figure 84 MAORY+MICADO WFE over the MICADO FoV from a single MC before (top) and after (bottom) alignment; the residual WFE is < 10 nm over the MICADO FoV.

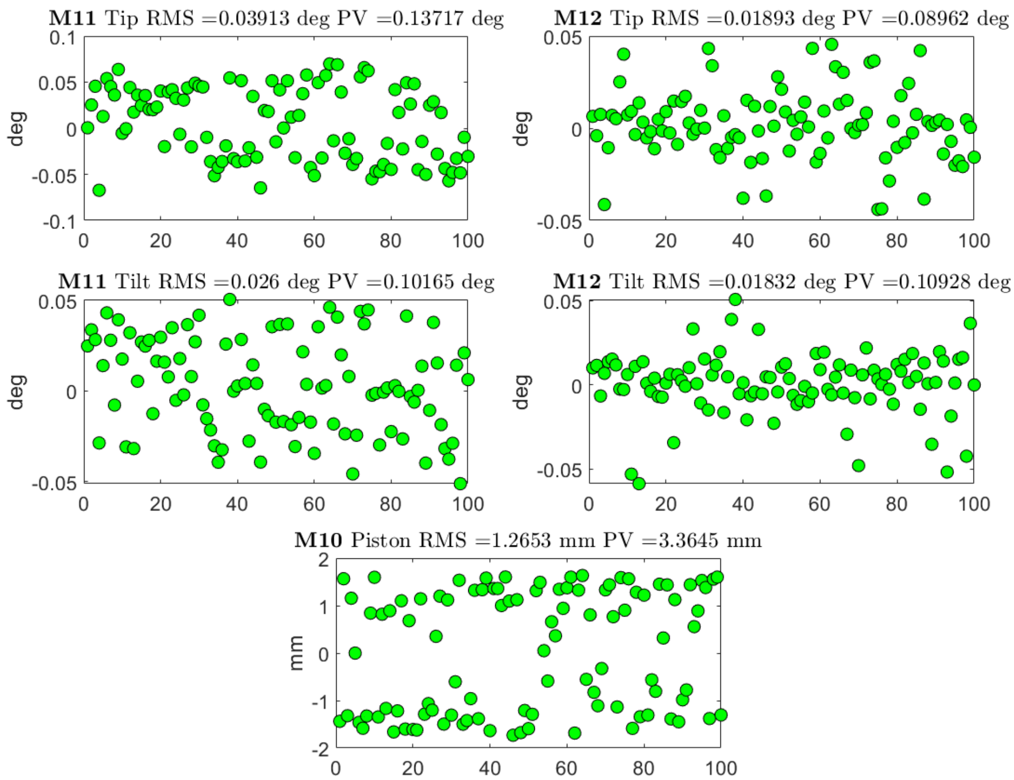


Figure 85 Required TT strokes for M11 (left) and M12 (right) and Piston for M10 (bottom) to cope with the MICADO positioning errors reported in Figure 80.

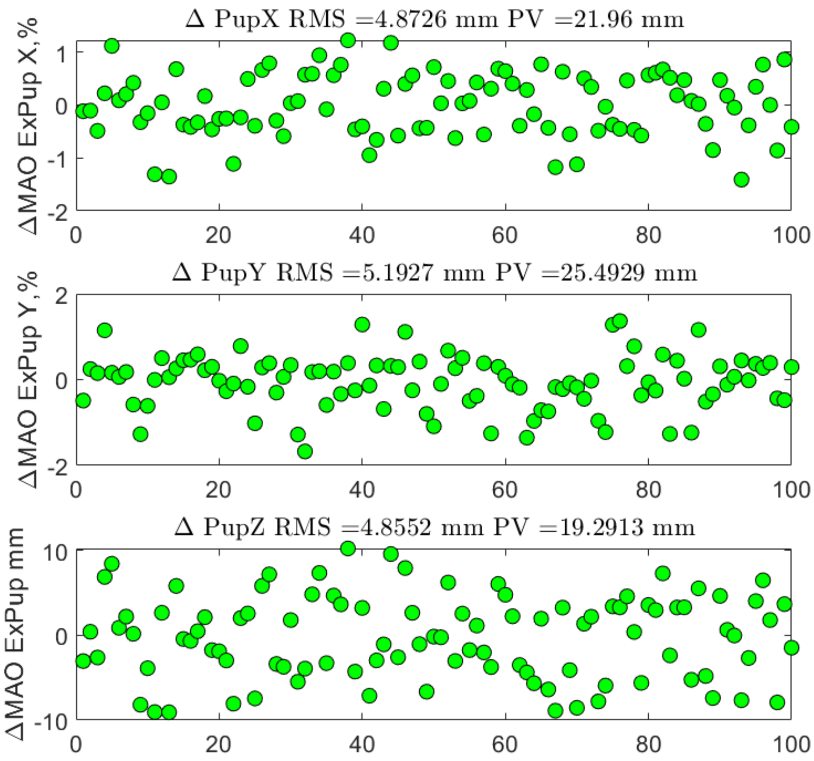


Figure 86 MAORY exit pupil motion (x,y,z) with respect to its nominal position by design subsequently the alignment with MICADO acting on M11 and M12.

These simulations have been carried out using the feedbacks from the Zemax merit function in terms of PSF and pupil centroids. For each MC a short optimization cycle has been run to damp the residual PSF and pupil offsets and to minimize the MAORY+MICADO WFE. In real life the pupil position will be derived from a fit of the internal/external rim of the pupil image as well as finding the best focus position will be carried out using the aperture photometry technique described for the MAORY internal alignment fine tuning in section 8.1.4.1.1. The defocus compensation can be achieved either acting on the piston terms of M11 and M12 or on the piston term of M10 with a preference for the latter that has a higher focusing power. The commands to be uploaded at M11 and M12 will be driven by an interaction matrix previously built following the standard approach to link the poking of a certain DoF and its effect on the observables. The simulation upgrade to the real conditions will be provided by FDR.

In conclusion, by looking at Table 12, the adjustment range coping with the MICADO initial displacement, reported in Table 11, is of the order of 0.02° for M11 and M12 TT, well within their foreseen travel ranges (±0.15°); Additionally, this contribution is static, allowing in principle to compensate for that by shimming M11 and M12, without reducing the travel range of their motors. Furthermore, after the alignment of the pupil and focal planes on MICADO, the average WFE over 100 MC is always below 10nm.

8.1.6 Pupil and focal plane alignment within the LGS WFS

First of all, we present the optical design of the LGS arm, which is shown in Figure 87. After the dichroic, there is a flat folding mirror, LGS FM1, re-directing the light toward 2 lenses, LGS L1 and LGS L2; just after the latter, another flat folding mirror, LGS FM2, is sending the light to other two lenses, LGS L3 and LGS L4. The last flat folding mirror LGS FM3 is folding the light to the LGS WFS.

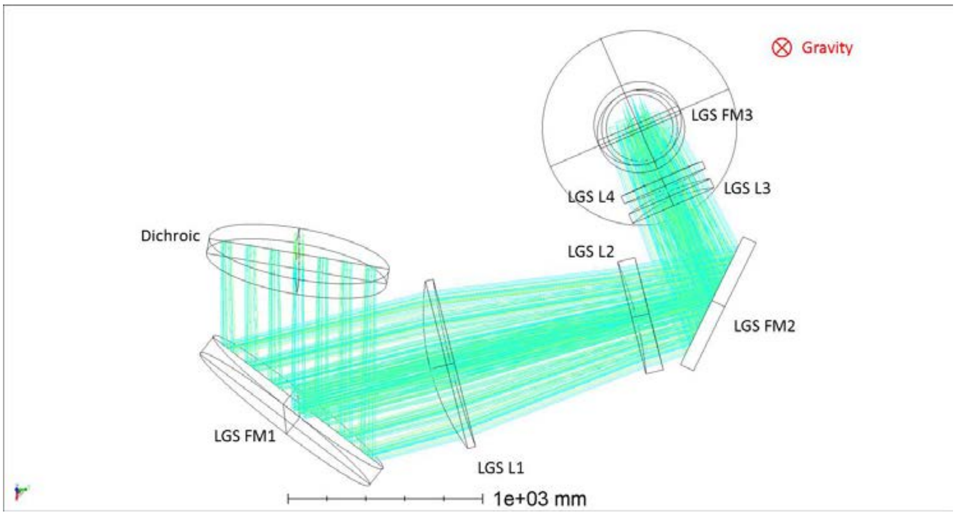


Figure 87. LGS arm top view layout.

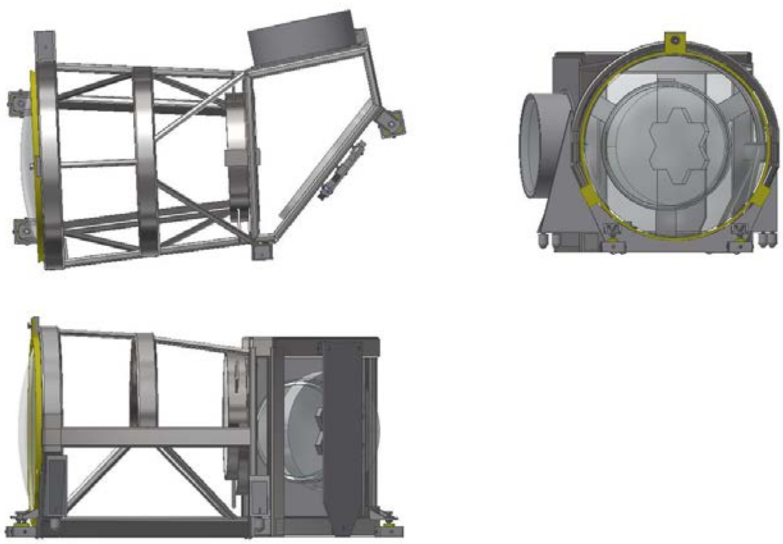


Figure 88: 3 different views of the LGSO

We foresee to group LGS L1, L2, FM2, L3 and L4 in a common subsystem, that we call LGS Objective (LGSO, shown in Figure 88). The baseline is to outsource the manufacturing, integration and test of the LGSO as a whole, foreseen a mechanical method for the alignment, as it will be explained in the following section (8.1.6.1). In section 8.1.6.2 we outline instead how we will align the LGSO arm, considering the LGSO as a sub-system already integrated.

8.1.6.1 Internal alignment of the LGSO

The following analysis regards the possibility to align the LGSO (from L1 to L4) as a whole system, by using mechanical methods, i.e, the CMM. Even if the baseline is to procure the LGSO as an already integrated system (referenced with few SMRs in order to mechanical align the subsystem in the instrument by using the LT) we would like to verify that the subsystem itself can be aligned.
The procedure consists in the measurement with the CMM of few points on each surface of the optics. For curved surfaces, by fitting the position of the points with a sphere, we can retrieve the surface RoC and its position in space. With this method, given a certain CMM accuracy, the smaller the sphere radius and the wider the optics, the more precise is the surface fit and therefore the better is the determination of the position of the center of curvature. For flat surfaces, we retrieve the position of the surface along the optical axis and its inclination.
The simulations consider 20 points acquired for each surface, probed with a 50 mm head in horizontal configuration, to an accuracy derived on measurement campaign on the CMM of the INAF-OA Brera (Coord3 Universal 15.8.6). For comparison, the values considered in the tolerance analysis are summarized in Table 13. An example of the analysis is reported in Figure 89, and the results in Table 14, where we considered a 3 sigma level of confidence. Tilt and centration are very well detected, as well as the elements thickness. In general, we also verified an accuracy in the knowledge of the radius of curvature within the allocated budget.
Given the measurement procedure, the knowledge on the radius of curvature turns into an indetermination in the z position of the elements, which was probably over constrained in the tolerance analysis. In fact, supposing a perfect knowledge of the RoC, the z position of each element can be determined to an accuracy lower than 10um.
A number of retroreflectors placed on the LGSO mountings may also be characterized with the CMM and referenced to the optics, such that the whole subsystem may be mechanically aligned with the LT inside the instrument.
In conclusion, the mechanical alignment of the LGSO with the CMM appears feasible, a further step in the tolerance analysis may be required to finely tune the alignment requirements.

Table 13: tolerances of the LGSO, as per RD9. Values have to be intended as +/-. dR is the accuracy in the RoC, dt in the thickness, dx, dy in centering, dz in the axial position and tx, ty in the surface tilt.

Element	dR_1 (um)	dR_2 (um)	dt (um)	dx, dy (um)	dz (um)	tx, ty (asec)
L1	600	5600	1000	100	100	20
L2	2100	-	1000	100	100	20
FM2	-	-		-	-	20
L3	700	1000	1000	100	100	20
L4	1800	4900	1000	100	100	20

Table 14: expected CMM alignment errors. Values have to be intended as … . The values in bracket consider the perfect knowledge of the radius of curvature of the surfaces.

Element	dR1 (um)	dR2 (um)	dt (um)	dx, dy (um)	dz (um)	tx, ty (asec)
L1	87.0 (0)	2088.0 (0)	6.0	15.0	1045.5 (4.5)	9.0
L2	484.5 (0)	-	7.5	28.5	7.5 (7.5)	9.0
FM2	-	-	9.0	-	-	9.0
L3	117.0 (0)	229.5 (0)	9.0	63.0	130.5 (7.5)	16.5
L4	688.5 (0)	4969.5 (0)	9.0	37.5	2515.5 (7.5)	9.0

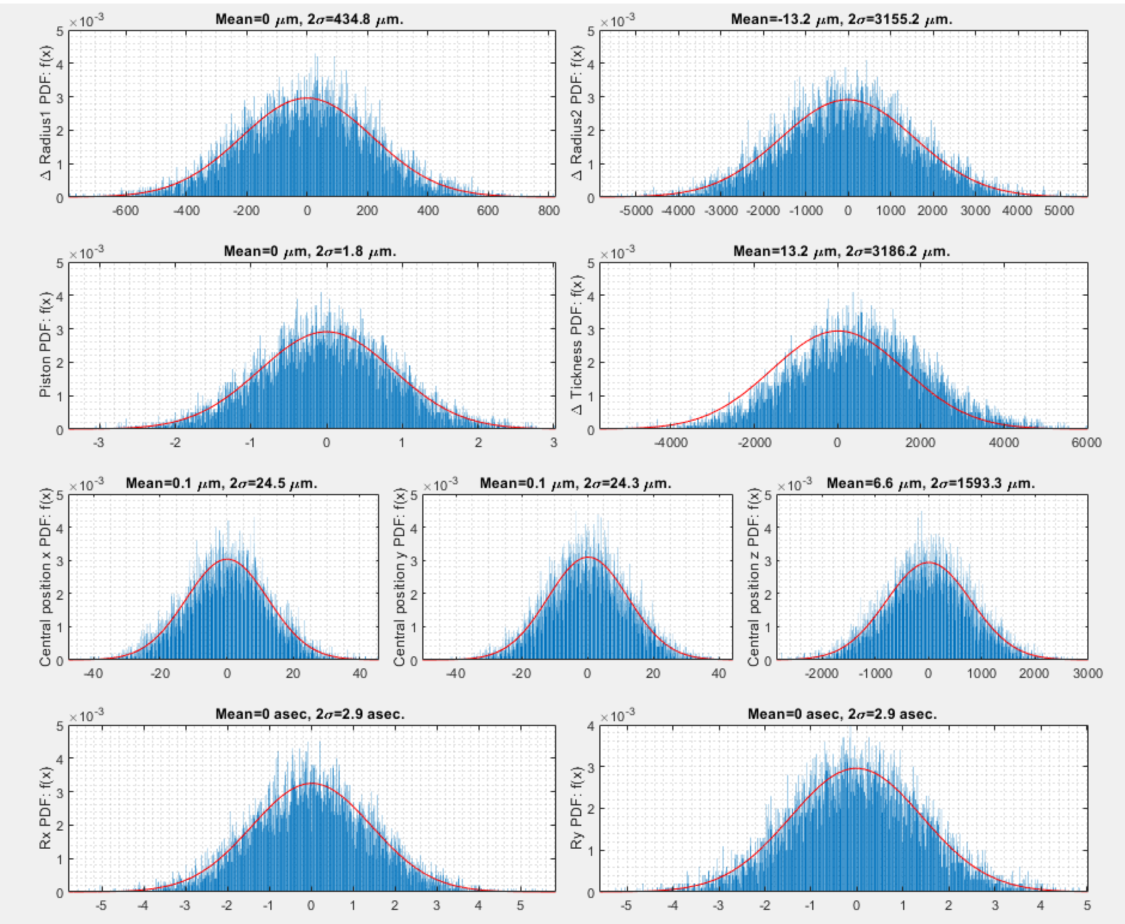


Figure 89: example of the results obtained as part of the CMM simulation. The graphs show the uncertainties related to the CMM probing system during the measurement of one optical element. Those values, once combined with the thermal and the geometric simulation of the CMM (not shown here), generate the uncertainties presented in Table 14.

8.1.6.2 Alignment of the LGS arm

The baseline procedure for the alignment of the LGSO to the Main path and LGSWFS module to the LGSO takes advantage of a laser (the IFP flange in its alignment configuration, see SEq 7.2) and the CU as reference sources. It is based on two phases:

1) Alignment of the LGSO to the Main Path
2) Alignment of the LGSWFS module to the LGSO focal plane and exit pupil

As first step, the laser is positioned in order to materialize the chief ray of the central field of the optical system (system previously aligned in the lab). The laser beam has the aim to visualize the intermediate pupil position of the as-aligned main path. Given that the laser has to be transmitted by the dichroic, its wavelength has to be close to 589 nm. We have preliminarily selected N-LYP-173 Yellow HeNe Laser (https://www.newport.com/p/N-LYP-173), working at 594.1 nm. The technical specifications of the laser are reported in Table 15.

Table 15: technical specifications of N-LYP-173 Yellow HeNe Laser.

Technical Specs

Operating Wavelength	594.1 nm	CDRH Class	IIIa
Polarization	500:1	Size	455.9 x Ø44.5 mm
Output Power	2.0 mW	Noise	≤2.8% P-P
Longitudinal Mode	373 MHz	Spatial Mode	>90% TEM_{00}
Beam Diameter ($1/e^2$)	0.83 mm	Power Requirements	120/240 VAC 50/60 Hz
Beam Divergence Full Angle	0.91 mrad	Power Supply Size	128.3 x 60.9 x 133.4 mm
Beam Drift, Long Term	<0.03 mrad		

After the LGSO internal alignment, we foresee to accommodate another couple of irises, one in front of L1 and one in the rear of L4, centered on the lenses at laser tracker precision (the SMRs positioned at the mountings of the lenses can be used as references for such operation).

The LGSO (including the two irises) is then coarsely mounted into the structure on its nominal position. The laser passes through the LGSO lenses. Accounting for the divergence angle, we have estimated the laser footprint size on each surface. The results are shown in Table 16.

Table 16: Laser footprint size on the LGSO surfaces.

	RMS Spot Diameter [mm]	Geometrical Spot Diameter [mm]
DICH	9.4	12.4
FM1	10.0	14.4
L1S1	8.2	10.6
L1S2	7.8	10.2
L2S1	4.6	6.2
L2S2	4.6	6.0
FM2	4.4	6.6
L3S1	2.6	3.4
L3S2	2.6	3.4
L4S1	2.6	3.4
L4S2	2.4	3.2

The LGSO is then aligned to the laser beam, by acting on the FM1 tip/tilt and decentering the whole LGSO along X-Y direction (local coordinates system in L1), so that the laser passes through the two irises. A possibility is to use the target on L1 to centre the LGSO with the laser beam and the target on L4 to for the tilt FM1. In such way, the optical axis of the LGSO is aligned to the laser, i.e. to the chief ray of the central field.

At this working level, we have assumed that the combination of the errors due to laser source positioning, positioning accuracy of the irises on the L1 and L4 and the accuracy on the determination of laser spot centre is less than +/-2 millimetres.

The impact on the performance is a worsening of the average WFE less than 10%, while the LGSO focal plane maximum displacement is less than +/-5 mm in X, Y, Z direction with respect to the nominal position.

For this LGSO installation and alignment to the Main Path phase, we are also exploring two alternatives: one based on the back-reflected laser spots (if a more precise alignment will be required) and one based on LGSO installation at nominal position (if a less precise alignment will be required) avoiding the use of the laser.

The first alternative LGSO alignment uses as set of observables the back reflected laser spots of the lenses faces: co-aligning different back reflection coming from the several lenses faces it would be possible to align the LGSO with respect to the MPO, exploiting the interference effect and, in principle, obtaining an high accuracy. The evaluation of this methods is ongoing but spot size and irradiances of reflected spots are promising: assuming a detector with 10 µm pixel size positioned at 300 mm before L1 the expected spot size and the flux per pixel is given in Table 17.

Table 17: Laser footprint size and flux of back-reflected spots on a detector with 10 µm pixel size positioned at 300 mm before L1.

lens	surface	Geometrical Spot Radius [mm]	Irradiance ratio wrt laser	Flux (10 µm pixel) [ph/pixel/s]
L1	S1	7.8	1.15E-04	2.19E+07
	S2	4.6	3.27E-04	6.23E+07
L2	S1	3.7	5.02E-04	9.55E+07
	S2	1.7	2.41E-03	4.59E+08
L3	S1	12.3	4.12E-05	7.83E+06
	S2	8.3	8.93E-05	1.70E+07
L4	S1	4.2	3.34E-04	6.36E+07
	S2	4.8	2.49E-04	4.73E+07

The second alternative LGSO alignment assumes to mechanically mount the LGSO to its nominal position by mean of the SMRs and laser tracker procedure. In this case, we are not trying to compensate the intermediate pupil displacement (due to the as-built Main Path) causing a deterioration of the WFE and a displacement of the LGSO focal plane.

We have simulated the effects by analysing 300 MC occupancies accounting for Main path tolerances (manufacturing and alignment) and an ideal LGSO. These mean that the errors include not only the LGSO to Main Path alignment contribution but also the Main Path realization error. The expected deterioration of the WFE is about 300 nm in the worst case (the nominal value is about 100 nm) while the LGSO focal plane is displaced by +/-5 mm in X, Y, Z direction with respect to the nominal position. By accounting the LGSO manufacturing and internal alignment error (WFE deterioration of about 100 nm and FP displacement of about 5 mm), the overall WFE is noncompliance (about 400 nm with respect to 300 nm) while the FP displacement is marginally compliant (10 mm, i.e. the maximum range on LGSWFS module compensation in X and Y direction). Such alternative method will require a relaxation on the WFE requirement and LGSWFS module adjusting range but it will simplify the AIV procedure. We will study it in the next phase.

After the integration and alignment of the LGSO to the Main Path, the LGSWFS module (including FM3) is installed initially on its nominal position. For its alignment, the laser will be dismounted and the reference sources will be provided by the CU, and in particular a set of sources mimicking the 45 arcsec LGS asterism at different conjugation altitudes (see RD18).

As first step the focal plane de-center and pupil de-center will be minimized by acting on FM3 tip/tilt and LGSWFS module X-Y displacement. The observables are in this case the illumination of the common illumination of the SHs sub-apertures and the common tip/tilt signal of the SH wavefront sensor. The impact on the focal plane X-Y displacement with respect to the nominal position has been estimated to be about +/-3 mm in the worst case.

As second step the F number is optimized by acting on the L4 displacement along the optical axis and on the LGS WFS module displacement along the gravity (Z-direction). The observable is the illumination of the sub-apertures at the edge of the SH.

After the integration and alignment of the LGSO to the Main Path and of the LGSWFS module to the LGSO focal plane, we expected a deterioration of the RMS WFE of about

10%. The LGS WFS module will be displaced in X-Y direction with respect to its nominal position by +/-8 mm in the worst case (linear sum), within the current foreseen compensation range that is +/-10 mm (see RD19) (note that in Z direction the margin is > 100 mm)

8.1.7 MAORY2PFS alignment verification

The procedure to align the MAORY bench as a whole to the PFS is introduced here. The Corrective Plate (CP) has 3 SMRs looking toward the PFS (see Figure 90), and characterized wrt the 3 SMRs looking toward the inner part of the bench (used to perform its alignment to the IFP reference). The characterization shall be performed using a CMM, and the accuracy foreseen is <20µm PtV. In this way, they are also characterized to the IFP reference, to which the CP is aigned.

The alignment of the external optical interface of MAORY towards the ELT is performed by referencing the MAORY MSS (using the 3RRs on the external side of the CP) to the ELT Pre Focal Station (PFS). After the installation of the MSS at the Nasmyth platform the MSS can be repositioned in decentre and tip-tilt acting on a dedicated adjustment system located at the interface between the MSS bench legs and the Nasmyth platform floor.

We envision (upon ESO confirmation of availability) to rely on the use of the ESO PFS Laser Tracker (LT) installed into the PFS to fine tune the mechanical alignment of the MSS with respect to the PFS. As shown in Figure 91, the PFS hosts a series of Laser Tracker Spherically Mounted Retroreflectors (SMRs) around the output beam port and/or on the PFS sensor arm metrology system (Figure 93).

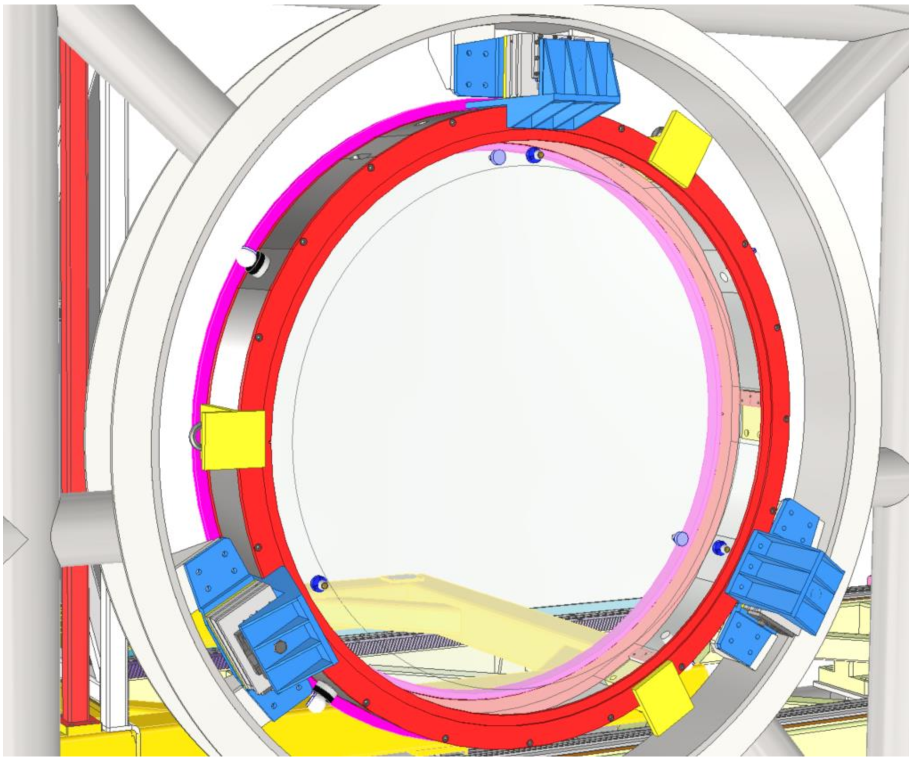


Figure 90: the corrective plate seen from the PFS side; the three SMRs are visible in the transparent ring just inside the “salmon colour” ring. In background, on the same radius, two of the three inner SMRs are also visible in transparency.

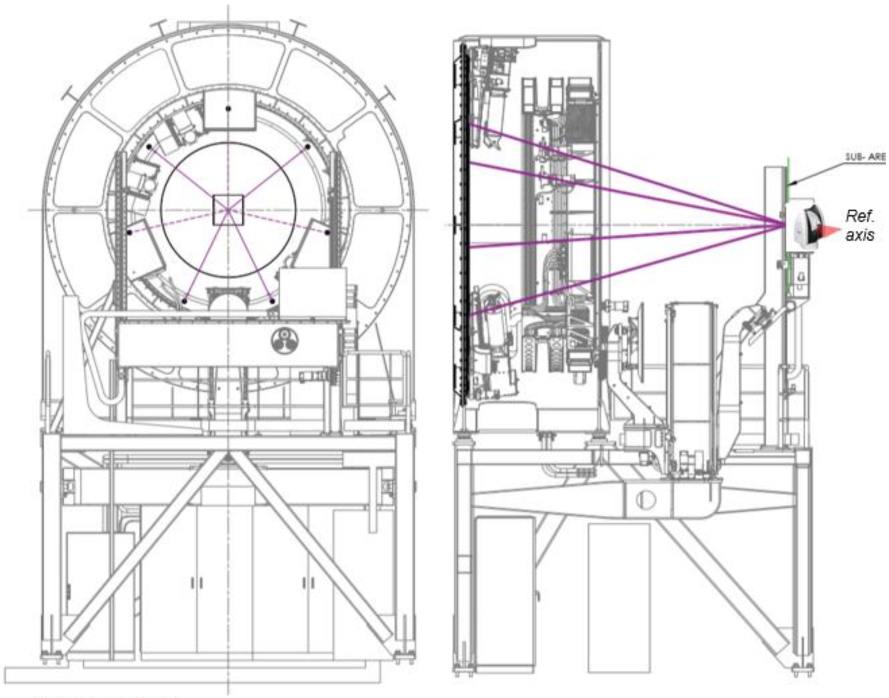


Figure 91 Laser tracker and SMRs position into the ELT-PFS, taken from RD14.

The idea is that the observation of at least three (3) SMRs with the PFS LT lead to build a reference plane that can be used to perform the alignment between the PFS and the MSS.

With the same PFS LT, the observation of the three (3) SMRs in the outer part of the CP permits to precisely locate the MSS at the Nasmyth platform. The visibility of the SMRs around the CP is guaranteed by the large Clear Aperture (CA), radius > 1 m, of the PFS. The SMR position on the PFS sensor arm metrology system can be deployed between radii of 400 mm and 1000 mm from the centre of the ELT focal plane (Figure 93). The SMRs on the CP are positioned at a radius of 420 mm and 500 mm from the centre of the MAORY/ELT focal plane. In case the accuracy of the MAORY IFP through the SMRs located on the CP is poor, we may consider to target the three M6 SMRs, in order to have two coaxial Line-of-Sight (LoS) between the PFS LT and MAORY (green and blue lines in Figure 92, where a schematic of this procedure is shown).

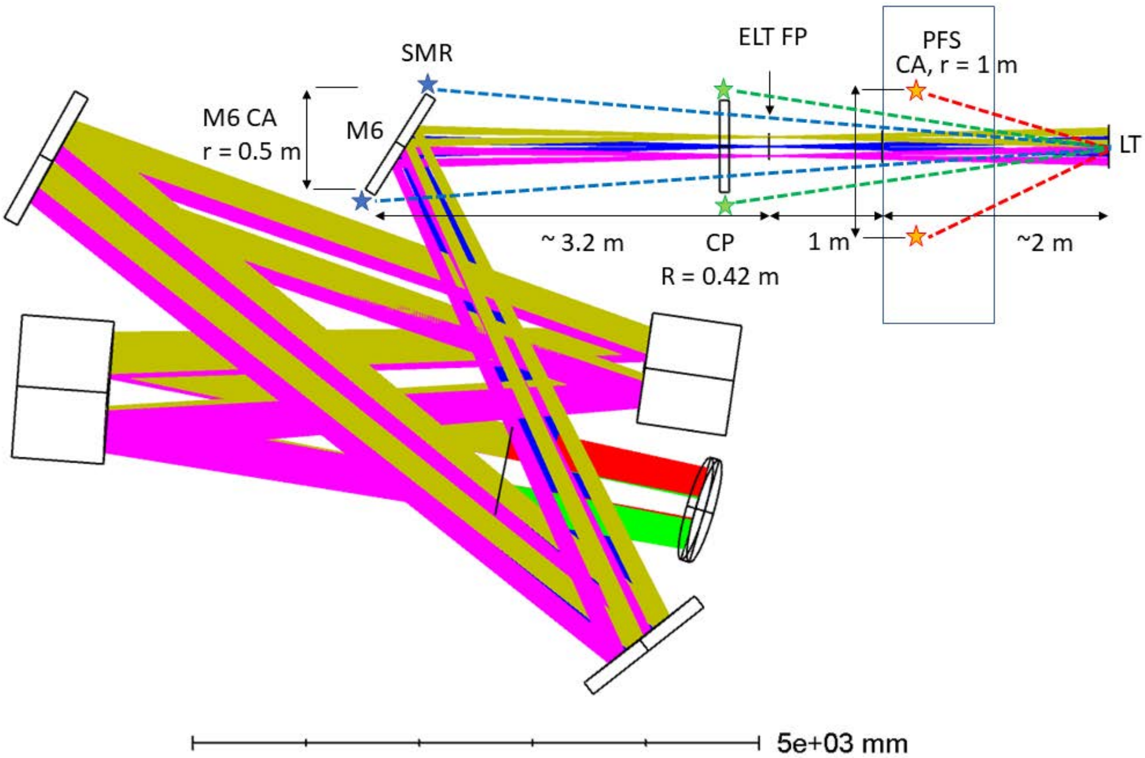


Figure 92 Side view of the MAORY and PFS schematics for the instrument external alignment towards the ELT. The red LoS trace the positions of the PFS SMRs mounted on the PFS sensor arm metrology system; the position of the SMRs around the MAORY CP (and M6 if needed) are linked to the PFS references through the green and blue LoS.

In principle either the CP or M6, but not necessarily both, are needed for the alignment. To maximize the optical leverage, the most suitable element is M6, being the furthermost optic along the LoS of the LT. However the impact of the CP optical power on the LT beams has not been assessed yet; so, precautionary, we do initially foresee to use only the CP.

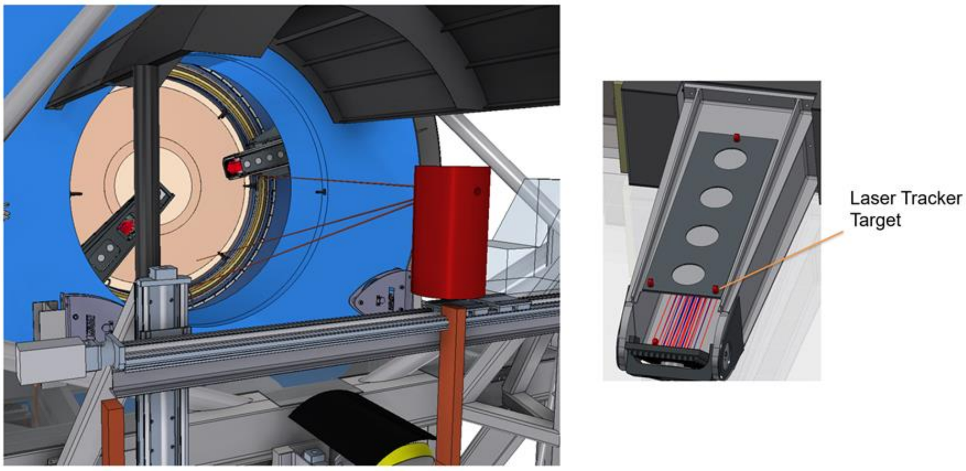


Figure 93 Images of PFS sensor arm metrology system, adopted from RD14. The arm can deploy the SMRs between a radius of 400 mm and 1000 mm.

The verification of the procedure just presented is going through the following steps:

- To assess the accuracy of the MAORY IFP characterization
- Also, to evaluate the accuracy of the ELT OFP characterization
- Finally, to estimate the accuracy of the MAORY alignment system acting on the MSS legs interfaces.

These aspects are covered in the following sections.

8.1.7.1 The Accuracy of the MAORY IFP characterization

As we mentioned in sec. 8.1.7, the accuracy of the characterization of the CP outer SMRs wrt the inner ones is of the order of 20µm PtV in every direction for each SMR.

Since the SMRs are applied on a diameter of about 800mm, the maximum TT is 5” PtV, while the accuracy of the centre of the reference plane is of the order of 20µm PtV in all directions.

Additionally, the PFS LT will also performance measurements within a certain accuracy. From Figure 92, we estimate the distance between the PFS LT and the CP SMRs to be below 5m, thus allowing to consider an accuracy on the single point measurement in space of ~60µm PtV (see sec. 8.1.3.1). Thus, the accuracy of the TT is 15” PtV, while the accuracy of the centre of the reference plane is of the order of 60µm PtV in all directions.

Summing linearly the two contributions just estimated, we come with an overall accuracy of ~20” PtV for the $TT_{IFP-MAORY}$ and ~80µm PtV for the centre of the IFP.

We note that the CP position is not giving directly the IFP position, but the CAD model of the as built system (obtained with the LT measurements) knows where the IFP is wrt the inner and outer SMRs positioned on the CP.

8.1.7.2 The Accuracy of the ELT OFP characterization

The ELT OFP is defined looking at the PFS SMRs with the PFS LT. Also in this case, we make some assumptions, not having yet available final drawings of the PFS. From Figure 92, we estimate the distance between the PFS LT and the SMRs to be ~2m, thus allowing to consider an accuracy on the single point measurement in space of ~45µm PtV (see sec. 8.1.3.1). Also, we estimate the SMRs to be on a diameter of ~1m (see Figure 93).

Thus, , the accuracy of the $TT_{OFP-ELT}$ is ~10” PtV, while the accuracy of the centre of the reference plane is of the order of 45µm PtV in all directions.

8.1.7.3 The accuracy of the MAORY2ELT alignment system

After the installation of the MSS at the Nasmyth platform the MSS can be repositioned in decentre and tip-tilt, as it is shown in Figure 94, and with the travel ranges reported in Table 18. The screws performing the adjustments are M20 1.5mm step. We assume to have a coarse manual minimum step of 1/12th of the DoF ranges by turning around the screw thread of about 30° (if needed, monitoring the travel range with Linear Variable Displacement Transducer (LVDT)).

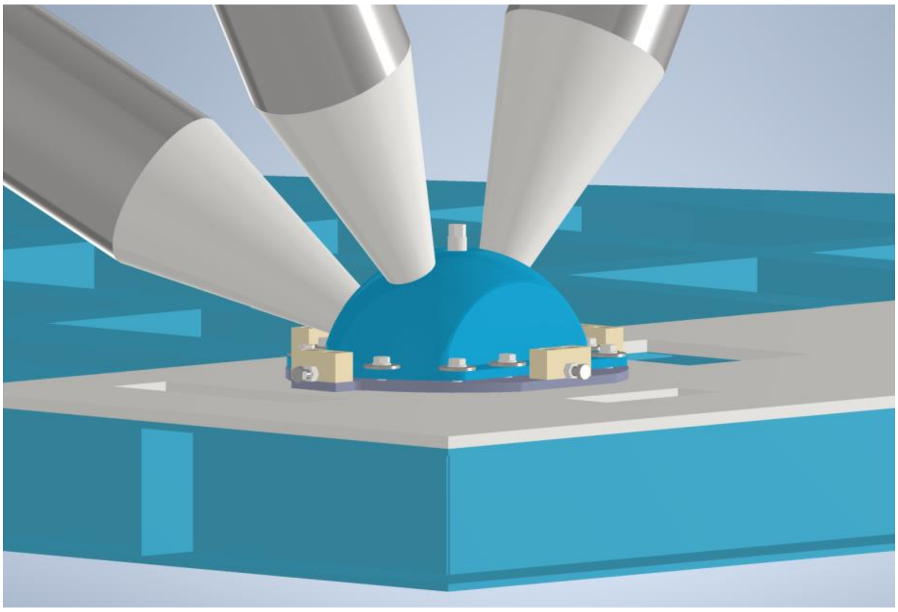


Figure 94: the legs adjusting system on the interfaces between MAORY and the Nasmith

With this assumption, the accuracy in X, Y and Z is of the order of 120µm. More difficult is to evaluate the effect of such a minimum incremental step at the level of the IFP tilt, but in the worst case such a minimum incremental step should translate in a tilt of about 4”.

Table 18 Adjustment ranges of the MSS DoF. The axes are given in the ELT coordinate system in which the z axis points to the zenith.

DoF	Value	Unit of measurement
Decenter z	+/- 2	mm
Decenter (x,y)	+/- 4.5 (TBC)	mm
Tip	+/- 0.67	mrad
Tilt	+/- 0.4	mrad
Rotation	+/- 0.1	mrad

8.1.7.4 Impact of the overall accuracy of the MAORY2ELT alignment

With the procedure described in the previous sections, we did evaluate the following accuracies:

- Definition of the MAORY IFP: accuracy of ~20” PtV for the $TT_{IFP\text{-}MAORY}$ and ~80µm PtV for the centre of the IFP in all directions
- Definition of the ELT OFP: accuracy of $TT_{OFP\text{-}ELT}$ is ~10” PtV, and ~45µm PtV for the centre of the OFP in all directions.
- MSS adjustment system: accuracy of ~4” PtV for the TT and ~120µm PtV for the MSS centring in all directions

Summing them linearly (conservative approach), we obtain an overall MAORY2PFS alignment accuracy of **~34” PtV** for the TT and **~250µm PtV** for the centring in all directions, that will correspond to a misplacement between MAORY and the PFS.

We now evaluate the effect of such a rigid body motion between MAORY and the ELT, in terms of shift of the exit focal and pupil planes and in terms of the final optical quality delivered to MICADO (of course always considering the possibility to recover these effects with M10, M11 and M12).

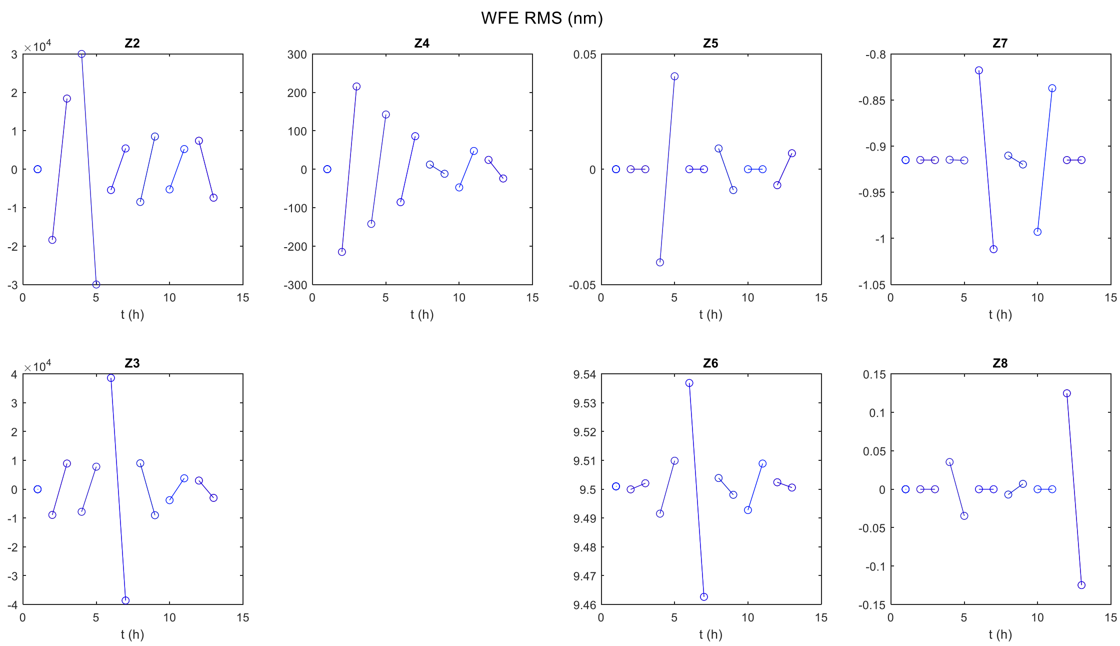


Figure 95: WFE decomposition in Zernike polynomials for the central field in the different cases.

We emphasize that such analysis has been already carried out in RD9 sec. 5.1, considering:

- Displacements in X, Y and Z of ±1.5mm, more than 10 times larger than the ones we are considering here

- TT of ±0.05mrad (21" PtV), about 30% less than the one we are considering here.

We report here a summary of the results of the analysis performed in RD9 sec. 5.1.

In terms of effect on the wavefront, in Figure 95 it is shown the effect on the first 8 Zernike polynomials of decentre and TT (the latter being cases from 7 to 12, 21"PtV). It is clear that the effect of the TT is nearly negligible, but for the effect on the defocus term (Z4), meaning that it is essentially defocus. Even adding 30% (it scales linearly) to the WFE shown for the cases from 7 to 12, the worst WF degradation (case 7) becomes ~120nm, still smaller of about a factor 2 with respect to the cases concerning the decentre (for example 2 and 3), for which the same analysis is showing that 0.82mm of defocus applied to M10 will recover completely this effect.

The same study shows that there is an effect also on the pointing and on the exit pupil displacement. Again, considering an increase of 30% on the simulated tilt will not impact the analysis conclusion, which is that applying a TT of about 0.05° to M11 and to M12, the footprint on M12 is almost nominal.

Therefore, the conclusion is that the accuracy of the MAORY2PFS alignment is having an effect on the wavefront (essentially adding only defocus) and on the exit focal and pupil planes, all of which can be recovered with our compensators (M10 defocus, M11 and M12 TT) with movements within their foreseen travel ranges (±0.15°). Additionally, this contribution is static, allowing in principle to compensate for that by shimming M11 and M12, without reducing the travel range of their motors.

8.1.8 The MAORY Testing Phase

In the following sections we describe the two SEqs that will allow to perform several test at system level of the MAORY instrument, the Test Unit (TU) and the MICADO Emulating System (MES). The test unit, which shares the design with the CU, will provide a set of suitable calibration light sources (which vary in number, geometry, size and wavelength):

- 6 LGS sources (589 nm) feeding the LGS WFS
- >36 NGS-REF sources (R-band) feeding the REF WFS (on a regular grid)
- 9 NGS-LO sources (H-band) feeding the LO WFS (3 asterisms)
- >9 NGS-MIC sources (H-band) feeding MICADO (on a regular grid)

They will be used to provide references for the two wavefront sensors (the LOR NGS WFS and the LGS WFS) closed loop operations, and also to probe the scientific field of MICADO, to check the achieved correction.

The MES is instead a structure holding a bearing (originally designed to hold MICADO, see RD21), to which both the LOR GWS and e Test and Alignment Camera (TAC) System (see 7.1) are connected. The same structure is also holding the M12 sub-system and the part of the enclosure covering M12. The TAC can be moved on a XYZ system, to move over the full MICADO FoV.

In the following two sections we describe these two systems, which are fundamental to exploit functional and performance test, although it is clear that it is impossible to recreate all the optical effects which will be present at the telescope, and that such a system is a compromise between cost and complexity of the TU system.

8.1.8.1 Test Unit (TU)

The TU shall be described in sec. 7 Support Equipment, it will be done for the FDR.

The TU is as a SEq to allow the test of MAORY in Europe. It should provide confidence that the whole MAORY system will perform as specified when re-assembled and installed at the ELT. At the beginning of the design phase, considering the similarities with what required to the Calibration Unit, it has been decided to go for a common optical design, in which a flat mirror present on a pupil plane in the optical path of the CU can be exchanged with a DM.

It will provide optical beams to MAORY which are optically the same as the beams from the ELT i.e. the same f-number, focus position and field aberrations. These beams should emulate the beams coming from both Laser and Natural Guide Stars. It is clear that an exact emulation of all the optical effects which will be present at the telescope is not possible, and there is a balance between cost and complexity of the emulator against the precision of the optical emulation.

Additionally, a system to check the quality (using one or more test cameras) in the OFP will also be provided.

In Figure 96 only the NGS path of the TU is shown, consisting in an optical system generating an array of NGSs across a 160 arcsec field of view in the R band. Turbulence will be injected into MAORY software-wise, by applying it directly on the DM.

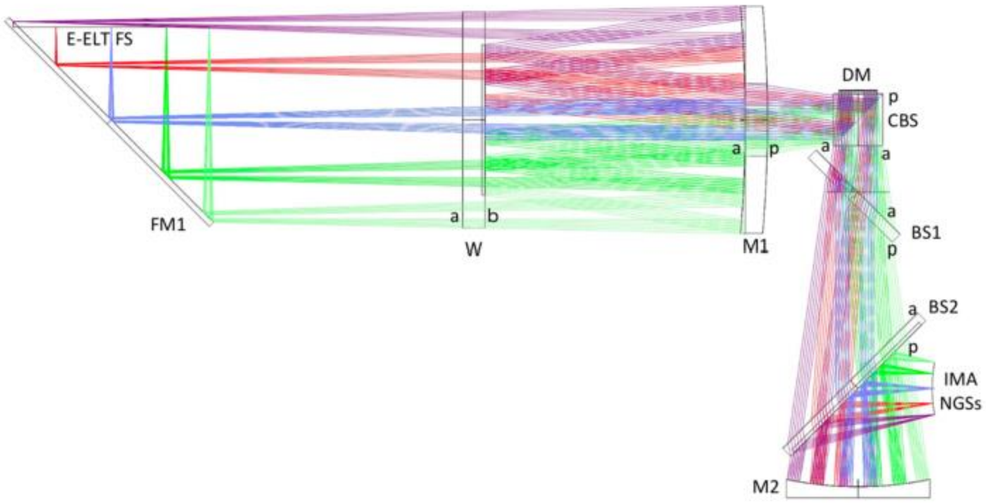


Figure 96: The NGS path on the TU

8.1.8.2 MICADO Emulating System (MES)

The MES shall be described in sec. 7 Support Equipment, it will be done for the FDR.

The MICADO Emulating System (MES, Figure 97) is essentially a structure which is holding:

- a bearing, simulating the one that will be used at the telescope by MICADO and by the LOR WFS
- a test camera (working in J and H bands), connected to the bearing, and spanning the whole MICADO FoV on a XYZ motorized system

- the LOR WFS, also connected to the bearing
- the M12 sub-system
- the cover

The main structure supporting the just mentioned sub-systems includes an assembly of sub-structures, mounted one above other. There are 3 sub-structures with the same shape, but different interfaces with the different sub-systems; they are named FLOOR 1, FLOOR 2, and FLOOR 3, from ground to the top.

FLOOR 1 and 2 are almost identical, while FLOOR 3 integrates the LOR and the M12 interfaces.

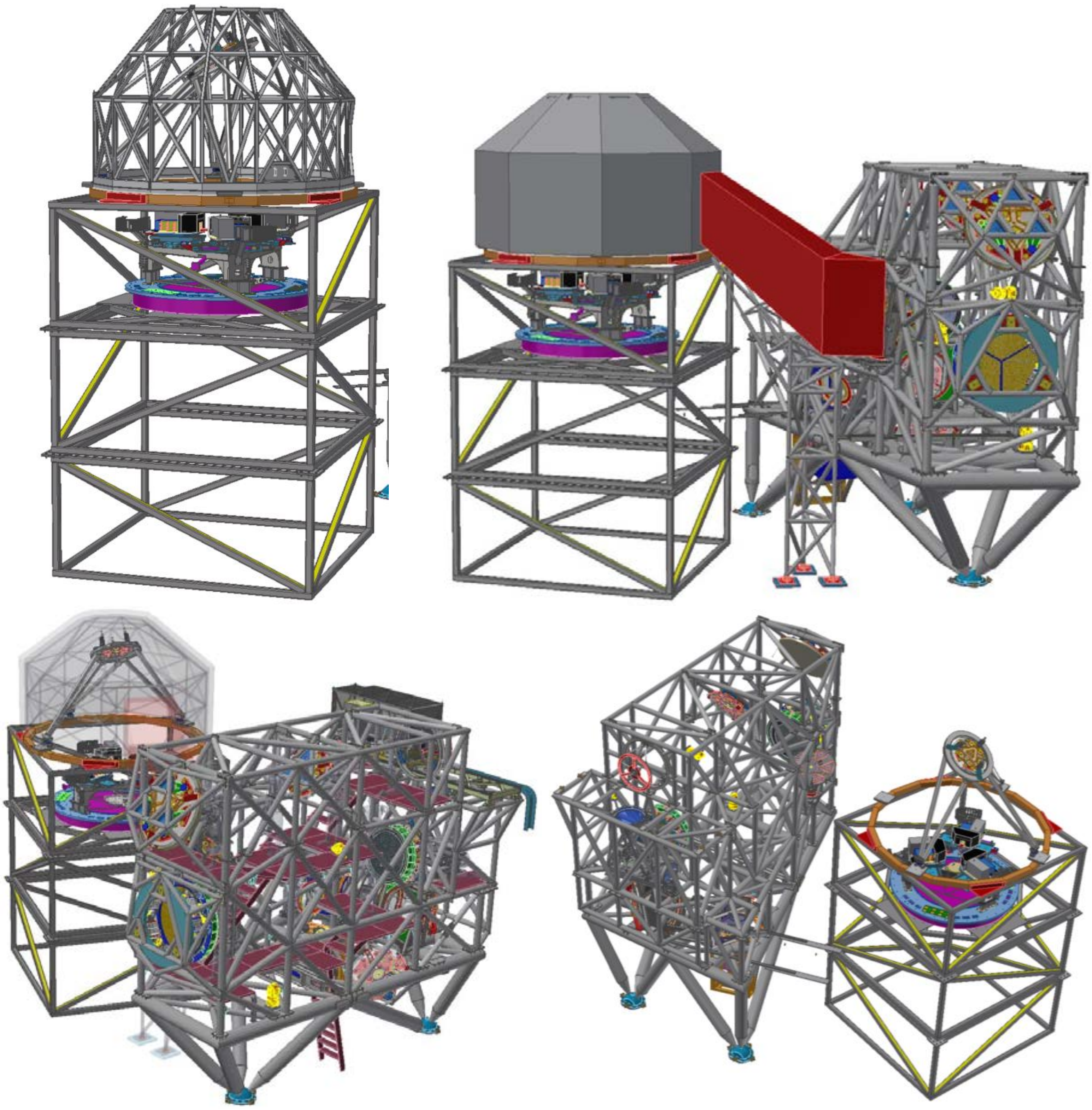


Figure 97: The MES: stand alone in the top left view, with MAORY and the cover in the top right view, with MAORY and the cover (in transparency, to see M12 too) in the bottom left view and with MAORY nwithout the cover in the bottom right view.

LOR sub-system includes LOR itself, an axial Bearing, Goldeye G-033 TECless camera, and a set of 3 Stages to precisely control the positioning of it, and some frames and structures.

The M12 sub-system includes M12 and the Enclosure.

8.1.8.2.1.1 Sizes

The maximum height of the structure reaches 1800mm from the XY Plan of the reference system or 7800mm to the ground.

The main structure is square-shaped, with a side length of 3700mm.

To provide enough space during the assembly movings, it requires a minimum lifting capability of the crane of 8000mm.

Each FLOOR is about 1710mm tall.

8.1.8.2.1.2 Weight and Loads

The crane must be able to lift the weight of each of the sub-systems to ensure the proper mounting sequence.

ELEMENTS	MASS [Kg]	WEIGHT [N]
GENERIC "FLOOR" FRAME	1503	14740
LOR'S FRAME	818	8029
M12 and MICADO ENCLOSURE	1130	11085
LOR	1116	10948
BEARING (estimation)	2500	24525
CAMERA'S SETUP AND FRAME	100	981
SUB-SYSTEMS		
FLOOR 1	1503	14740
FLOOR 2	1503	14740
LOR SUB-SYSTEM	4534	44483
FLOOR 3 + LOR's FRAME	2321	22769
M12 and MICADO ENCLOSURE	1130	11085

Table 19: the mass/weight budget of the MICADO Simulating System

According to Table 19, the crane must be able to lift at least 4500 Kg (considering that the Bearing’s weight is just an estimation, so the actual capacity required is about 2000 Kg + Bearing’s weight).

8.1.8.2.1.3 LOR, Camera, and Bearing Assembly

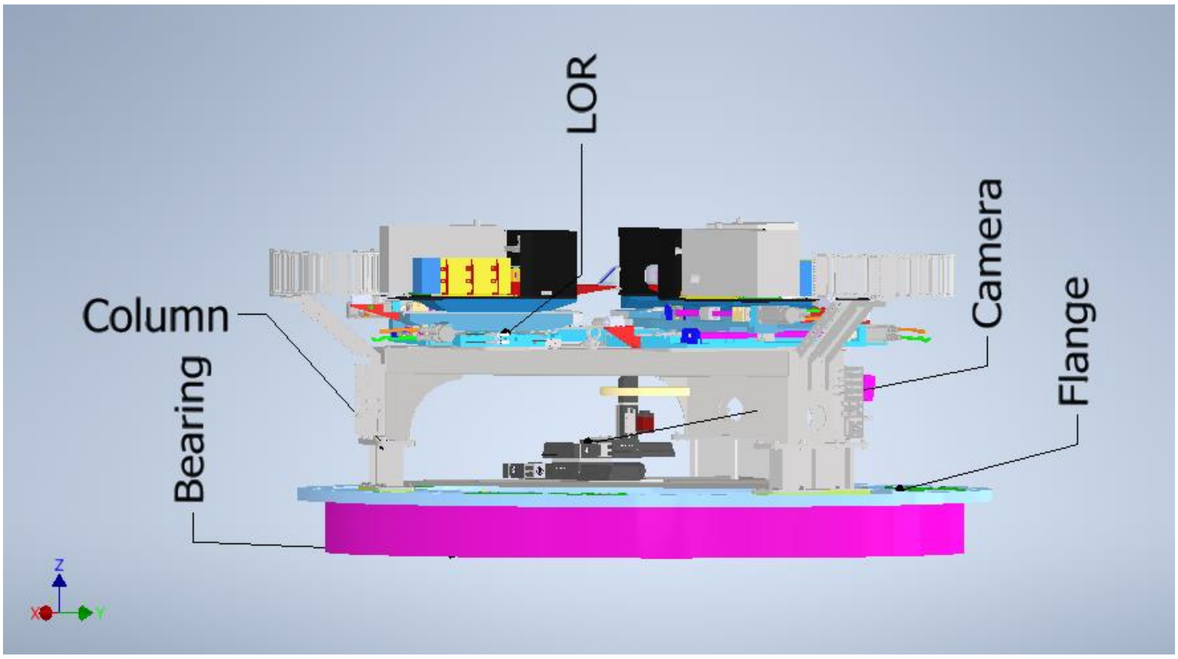


Figure 98: The assembly consisting of the bearing, the test camera system and the LOR WFS

The assembly shown in Figure 98 is connected with FLOOR 3 by a frame, bolted to the Bearing. The core of the structure, however, is the blue Flange that supports the whole Stages-Camera system (and its frame), and the main LOR instrumentation. Note that the original LOR's frame has been extended by 3 customized columns, bolted on the Flange. Moreover, these columns provide the base to the Camera-System's frame.

8.1.8.2.1.4 Camera-System

This system can precisely control the XYZ position of the Camera. The main components are two Aerotech PRO 165 LM with a travel of 300mm for X and Y axes, one Aerotech MPS75SL-025 with a travel of 25mm for the Z axis and a test camera (most probably the OWL 1280, a VIS-SWIR camera 1280x1024 with 10µm square pixel size). The whole structure is thought to guarantee the coincidence of the point of focus with the center of the camera sensor when stages are in the middle of their travel.

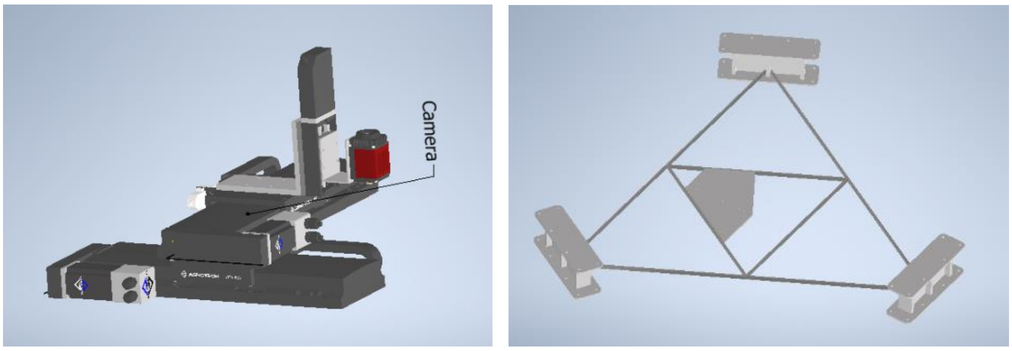


Figure 99: the camera system (left) and the frame supporting it

In Figure 99 it is shown the camera systemand the frame supporting it, which should provide the right balance of stiffness and lightness, and a custom plate guarantees the best load distribution on the frame.

8.1.8.2.1.5 M12 and Enclosure

The enclosure (included M12, not shown in Figure 100) must be assembled on the ground and lifted up with the crane all at once.

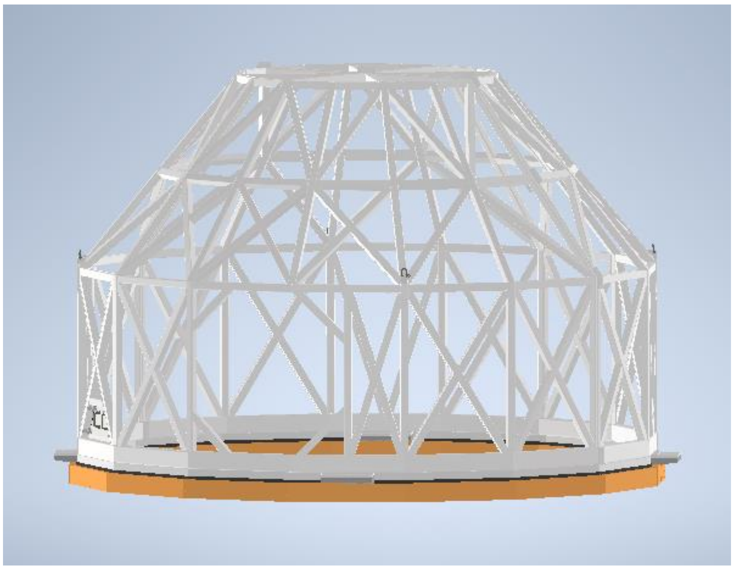


Figure 100: the M12 enclosure

8.2 MAORY in the BIH

In Figure 101 we show two possible disposition of the MAORY bench and of the Micado Emulating Structure in the BIH. These are only preliminary studies, that will be analysed in details during the FDR phase.

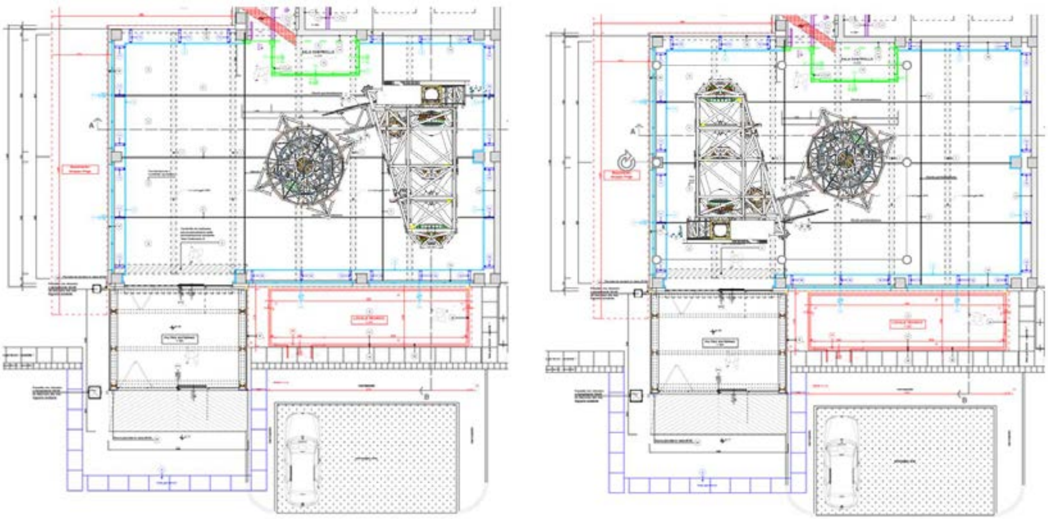


Figure 101: two possible positions of MAORY+MES in the BIH

In both images, the space between the MSS and the wall is never less than the space that will be available on the Nasmyth platform. The cabinets may be located below the MES, although care should be given to the heat that might affect the OFP, and thus an insulation of the lower level of the MES might be required (see).

8.3 The HTs and SeQs Manufacturing

As already mentioned in sec. 1.1 and 4.6, the manufacturing of the various parts/components of the MAORY instrument is addressed at sub-system level in the related MAIT plans. In this document we address only the manufacturing of the Handling Tools and Support Equipment necessary for the AIT of the overall MAORY instrument.

The conceptual and preliminary design of the HTs and SEqs will be performed by the AIV team, while the final design and manufacturing will be given to external companies.

For every part to be manufactured, a “SoW and Technical Specification” document will be issued.

Also, dummies of all the opto-mechanical subsystems (specified in sec. 3.2.1) will be designed and manufactured. The dummies should have same CoG, same weight, similar volumes and same interfaces of the correspondent sub-system. Only in areas of the instrument where the accessibility is critical (for space/volume constraints), also the volume should be the same of the correspondent sub-systems. The manufacturing of the dummies will be possibly given to the same company providing the HTs of the correspondent sub-system, in a way that the interfaces and the HT shall be tested at the companies premises during the acceptance test.

8.4 The overall AI process

In this section we describe the Assembly and Integration steps foreseen in Bologna as a sequence of activities to be performed. We emphasize that such a sequence is not a schedule, and thus does not consider activities parallelization and when the sub-systems will be available. Also, we underline that the estimated duration of each step (above all for some procedures, still currently under development/study) has to be more carefully reviewed/updated. A contingency of 20% at this project phase and with the current maturity level seems to be appropriate.

We recall that after having successfully undergone the ARR, the sub-systems can be shipped to Bologna, where the instrument AIT will take place. The first sub-system to be assembled is of course Main Support Structure (MSS), followed by the opto-mechanics and by all the other main sub-systems, such as the Calibration Unit, the LGS system, the LOR system, and so forth.

Then, the overall assembly and integration process will be carried on, and we detail in the following the main steps of the AI procedure.

Please consider that all the images describing the installation procedure of the optical elements inside the MSS are merely conceptual sketch and are not representing the final design of the handlings, which will be optimized and finalized in the next phase of the project. Their aim is mainly to present a possible installation/removal procedure for all the sub-systems at BIH.

All the optics coated side will be protected by a light cover during the whole installation process, which will be removed only at the end of the installation. In case of removal of the optics, the cover will be installed before any other operation.

The vast majority of the subsystem described hereafter are:

- Interfaced to the MSS structure through interface flanges, which can be re-machined to compensate for large deviations from the nominal positions and to recover manufacturing errors of the opto-mechanics (Figure 102)
- Connected to the interface flanges of the MSS (the blue ones shown in Figure 102) through 3 kinematics (Figure 103) displaced by 120deg, half of the kinematic being connected the MSS and the other half to the opto-mech of the subsystem. This ensures fine tuning of the alignment in TT and focus, discrete centring alignment using shims and repeatability of the sub-system repositioning. The centring range is ±2mm and the accuracy is 5μm (shim smallest thickness), while the TT/Focus range is ±2mm corresponding to about ±1' for a 1m diameter mirror and wedges of 7°, with the kinematics applied to about 0.6 of the radius, and the accuracy is ~2".

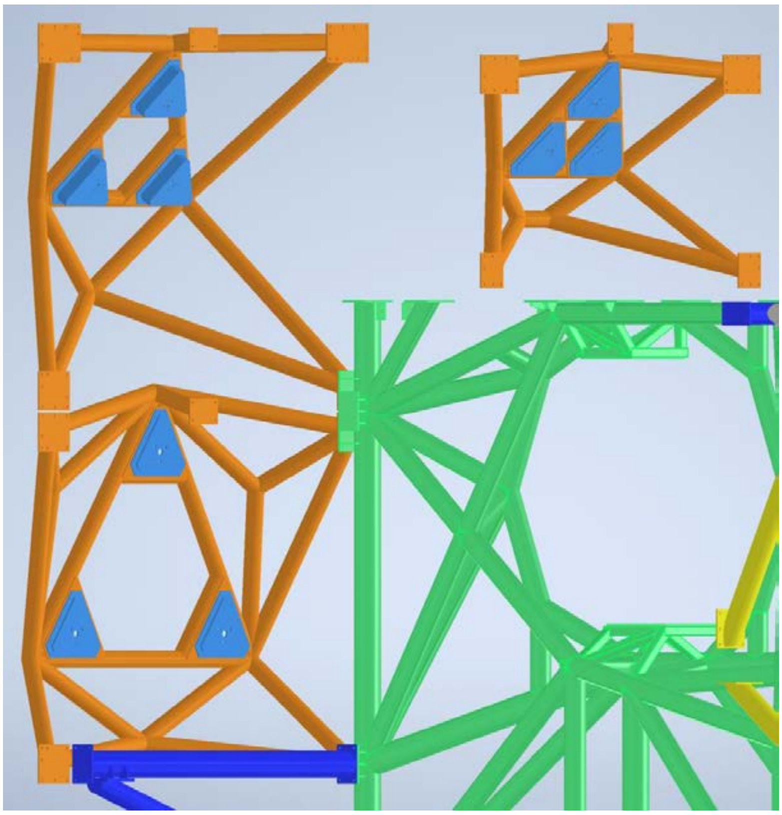


Figure 102: three mechanical structures for the opto-mechanics (top left is the one of M6, bottom left is the one of M10/DM2, top right is the M8 one) are shown (in orange colour), with the interfaces flanges to the opto-mechanics shown in blue colour.

Each subsystem is fixed to its interface using 3 screws M12, passing through the kinematic. Depending on the subsystem, the fixing screws are locked from the front (coated side of the optics) or from the back. Whatever is the case, the screw is always a trapped screw (in the opto-mech or in the MSS, depending on the case) and it is locked with a nut at the opposite side.

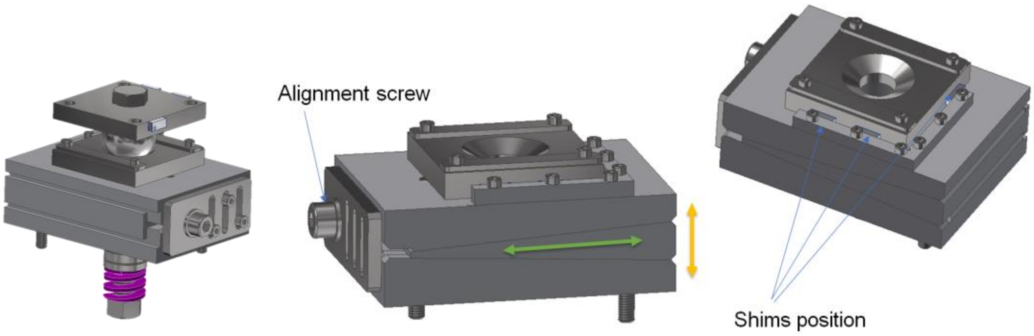


Figure 103: the kinematics interfaces, which allow tip-tilt adjustment through a wedge system

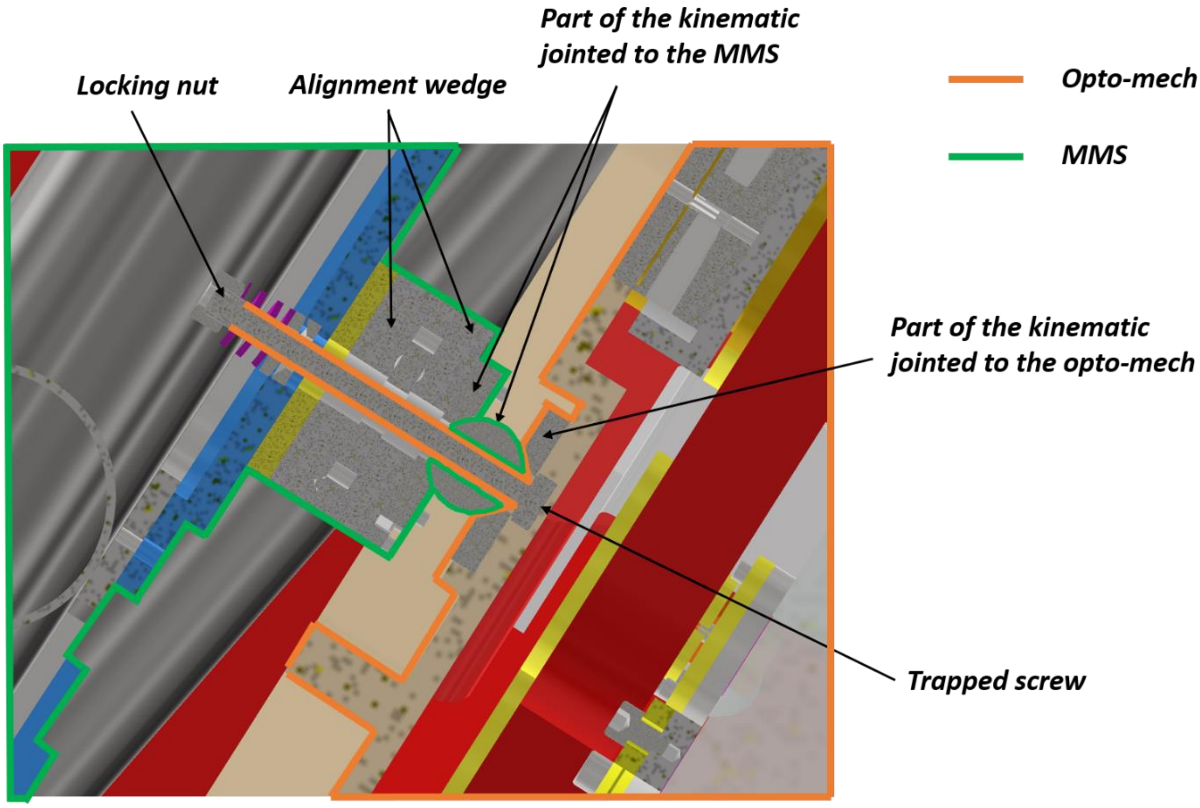


Figure 104: section view of one kinematic mount on the back surface of a subsystem (M6 in this case). The fixing screw is trapped in the opto-mech, and it is locked by a nut at the opposite edge of the screw. Bordered in green, the parts mechanically jointed to the MSS (fixed), bordered in orange the parts jointed to the subsystem (movable). The nut is positioned by an operator when all the 3 fixing screws are inside their kinematics.

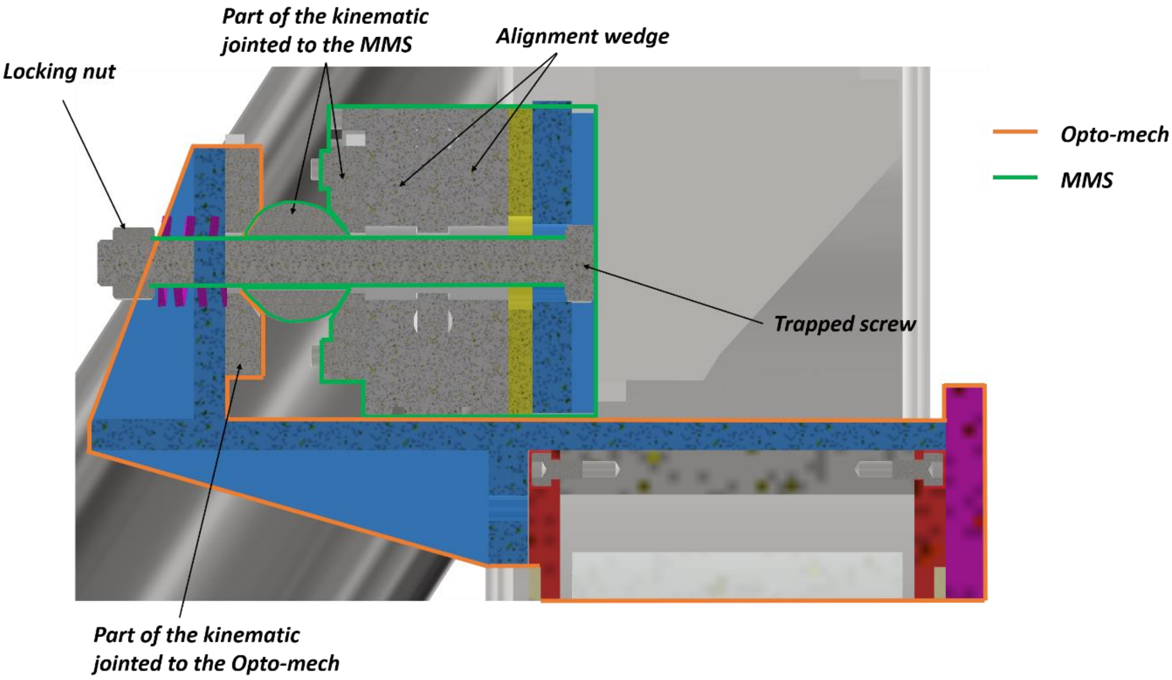


Figure 105: section view of one kinematic mount on the front surface of a subsystem (Schmidt Plate in this case). The fixing screw is trapped in the MSS, and it is locked by a nut at the opposite edge of the screw. Bordered in green, the parts mechanically jointed to the MSS (fixed), bordered in orange the parts jointed to the subsystem (movable). The nut is positioned by an operator when all the 3 fixing screws are inside their kinematics.

8.4.1 The Nasmith Interface Plate (NIP) installation

Purpose and functionality

An interface plate simulating the Nasmith floor is installed and fixed to the Lab floor. On such a plate, some references to be targeted with the Laser Trackers (LTs) have to be positioned (above all the ones needed to simulate the PFS), in a way that every large sub-systems that have to be positioned through the LTs will reference to them (mainly the bench legs, the input focal plane reference to be installed on the bench structure, the tower supporting the LOR and M12 and the output focal plane reference whih has to be installed on the latter).

Responsible: VDC, VCI, JFA, ERE, LMA, GRO, ECA

HTs/SEq needed: Forklift, Bridge Crane, Portable Crane

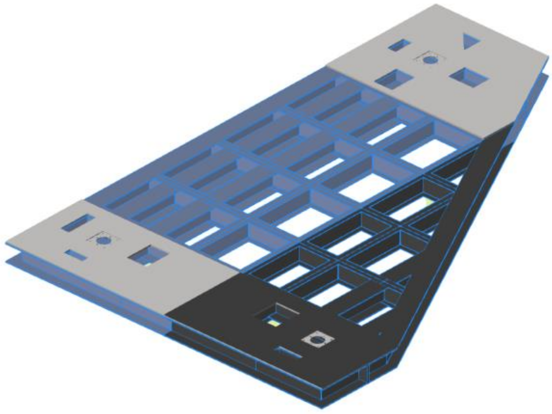
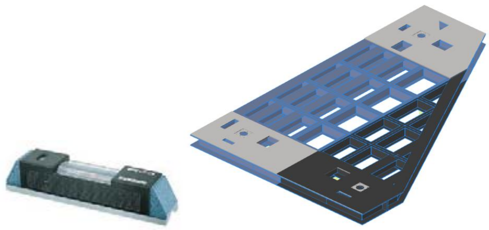
Success Criteria: NIP Properly installed

Duration: 3 days

Prerequisites: BIH ready and charaterized

Procedure:

Interface Structure for BIH floor (IS-BIH)

Bring both the pieces of the base structure in the assembly position (using a Forklift or a crane) and couple them by means of the dedicated bolts.	
Check the flatness of the three support points of the Nasmith Flanges and insert the fork shims (specially prepared) below the Interface Structure, until there is an error smaller than 0.5 mm on the three top flanges and all the fixing points to the floor are in contact with the floor.	
Dowel them with threaded rods M16 and chemical anchor Hilti HIT Re 500.	
Once the resin has hardened: - Lock the nuts; - Verify the permanence of the plane/level specifications, otherwise correct it.	

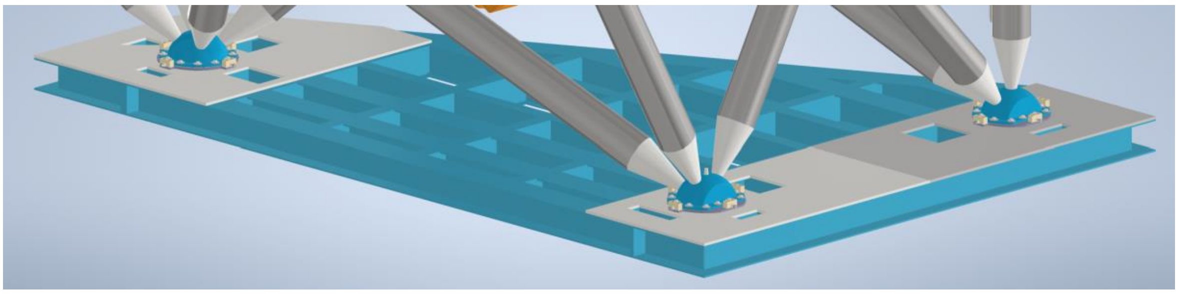


Figure 106: The Nasmith Interface Plate concept

Notes:

8.4.2 Main Support Structure (MSS) installation

Purpose and functionality

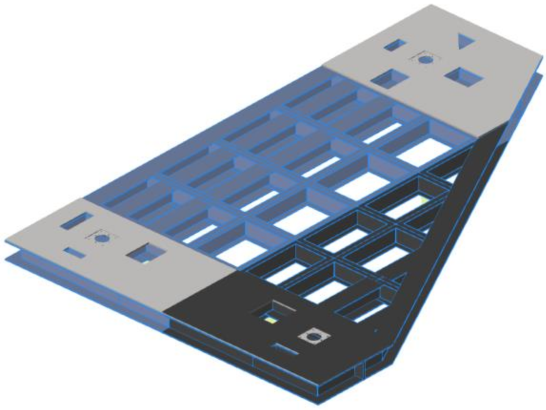
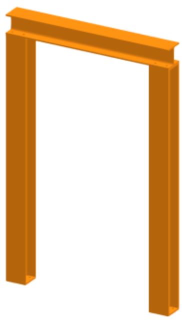
The MSS is divided into several parts (7 main parts in the current design, plus the optoi-mechanics holding structures) which are transported on a few trucks (TBD). The parts are unloaded from the trucks, carried inside the BIH and then positioned and connected together.

To avoid the truck entering the lab, a telescopic crane (or the crane of a truck equipped with its own telescopic crane) might unload the legs on a motorized transporter positioned in front of the main lab entrance door, and then the transporter can be driven inside the lab, where the BIH crane can take the MSS parts and position them on the NIP.

Responsible: VDC, VCI, JFA, ERE, LMA, GRO, ECA

HTs/SEq needed: BIH Crane, HTs TBD, Truck with telescopic crane or separate telescopic crane (rented?), Motorized transporter, Scissor lift, Cherry picker

CODE/DWG ID	Description	Deliverable to Bologna (yes/no)	Deliverable to ESO (yes/no)
	Interface Structure for the assembly hall floor. The frame is composed by different steel beams kind: • HE240A standard beams. • Other ones are designed (and welded together) to fit the HE240A same height (230mm). The support base is made of 2 main modules (to bolt and leveling before use the Structure).	Yes	TBC

			
TBD	Special tool A1/A2 for supporting base structures (structure A1 and A2), to be fixed on the Interface Structure. It must be made of HEA 120 profile, divided into three pieces, as sketched (in orange) in the image below. Each piece is handled by two people. Max 20 kg / piece (max 15 kg per person). 	Yes	Yes
TBD	Manual hydraulic jacks – N°02 – (type as in the image below) capacity 4t.	Yes	TBC

			
TBD	Lifting harness - different lengths and carrying capacities - (type as in the image below). 	Yes	TBC
TBD	Laser tracker “FARO” type or similar. 	No, Rent	--
TBD	Precision bubble level. 	Yes	TBC
TBD	Set of shims for temporary leveling of components.	Yes	TBC

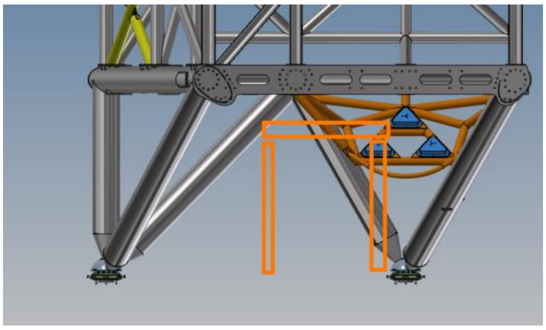
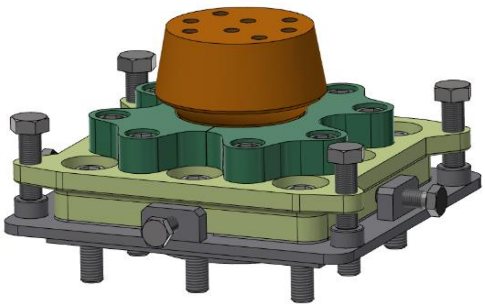
TBD	Modular scaffolding, aluminum support walkable surfaces, and stairs.	No, Rent	--

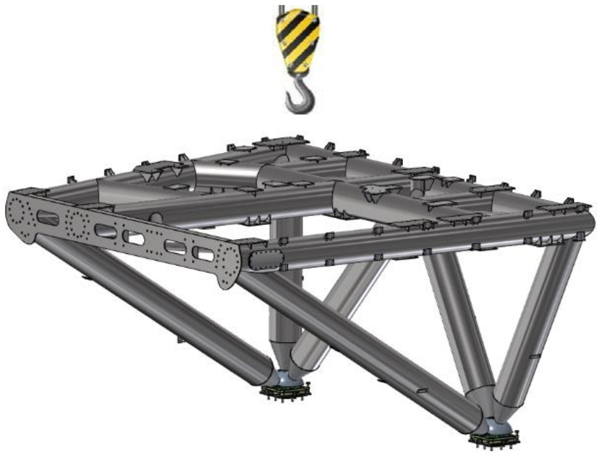
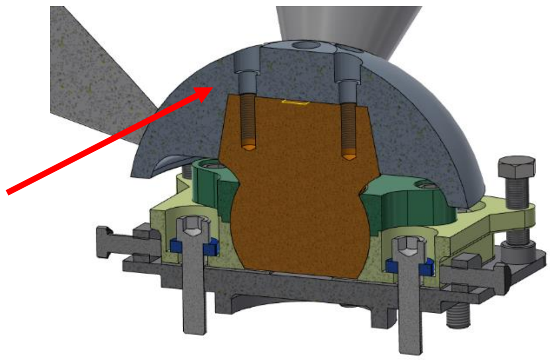
Success Criteria: MSS properly installed and connected to the NIP

Duration: 10 days

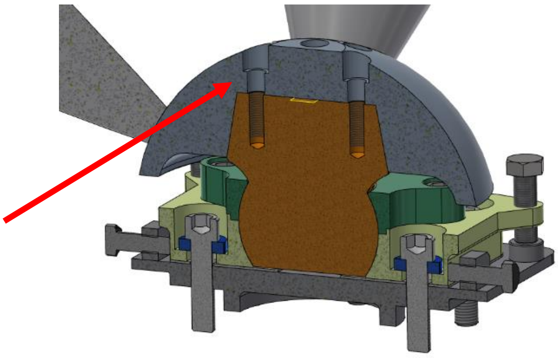
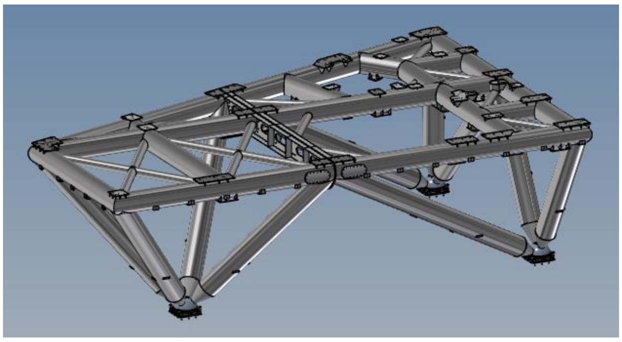
Prerequisites: 8.4.1 NIP installed

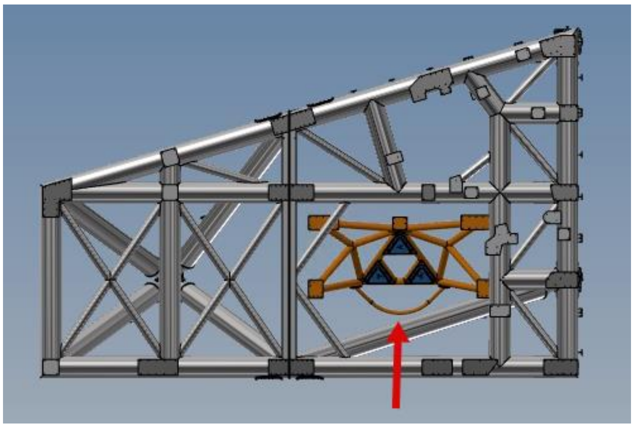
Procedure:

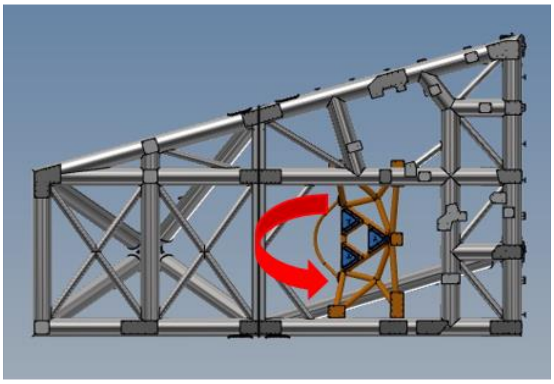
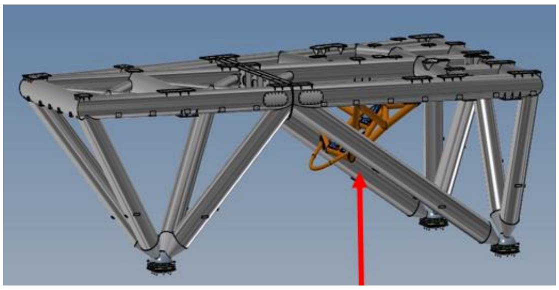
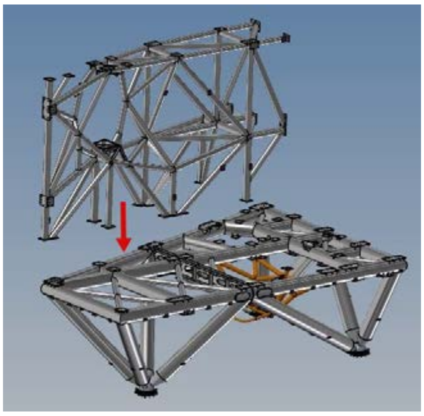
A1 Structure	
Mount the A1/A2 Special tool on the Interface Structure.	
Mount the two flanges on the Interface Structure.	FIGURE - TBD
Position the jack at the foreseen height.	
Mount all the spherical joints of the MSS on the Interface Structure.	

Lift the A1 structure with the crane and put it in position.	
Mount the screw of the top flange, as shown in the side figure.	
Pre-leveling the A1 Structure.	

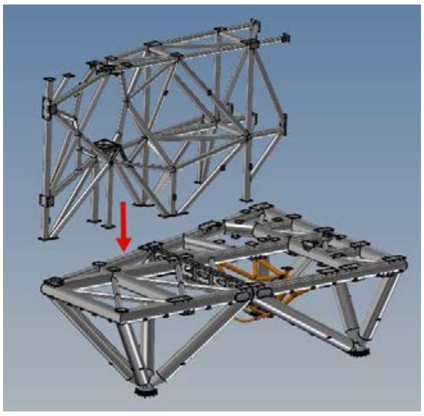
A2 Structure	
Lift the A2 structure with the crane and put it in position.	

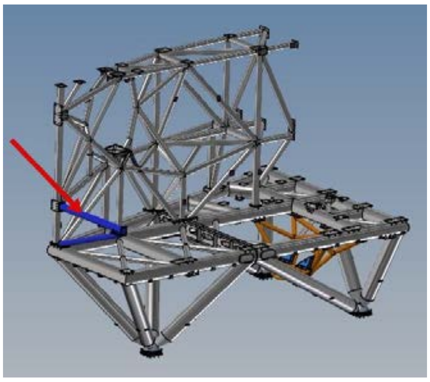
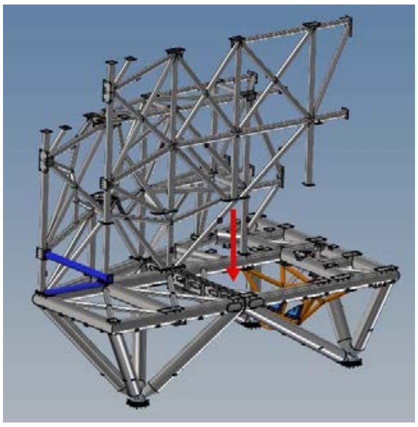
Mount the screw of the top flange, as shown in the side figure.	
Pre-level the A2 Structure.	
Couple the structures through their coupling flanges and screw the connecting bolts.	
Check the level of the coupled A1 and A2 structures and correct it if/when required.	

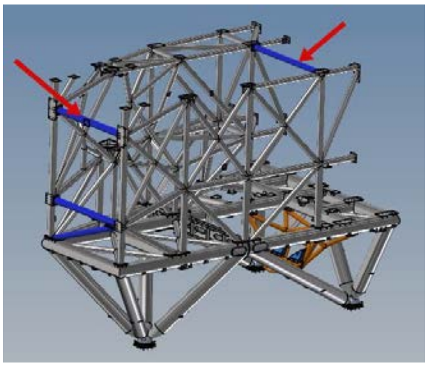
M7 Holder	
Place the M7 Holder under the bench via a pallet truck, positioned as indicated on the side figure.	

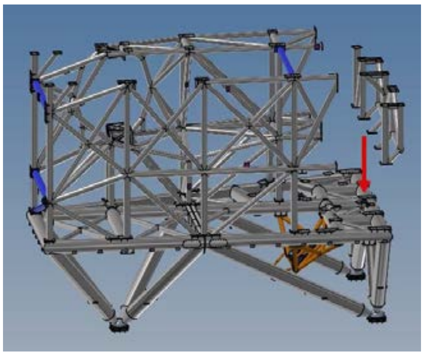
Bridle it by the lifting harness, and lift it to exceed the height of the leg, so rotate it as shown in the side figure.	
Lift it again, to the final mounting position.	
A5 Structure	
Bridle it, so lift it with the crane and place it above the previously assembled structure.	

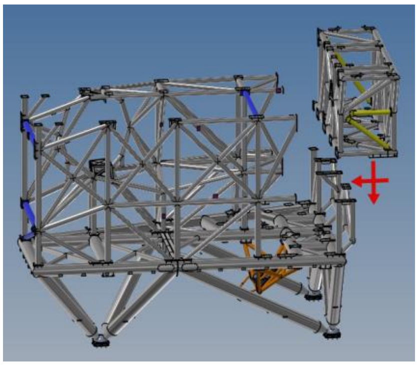
A5 Structure

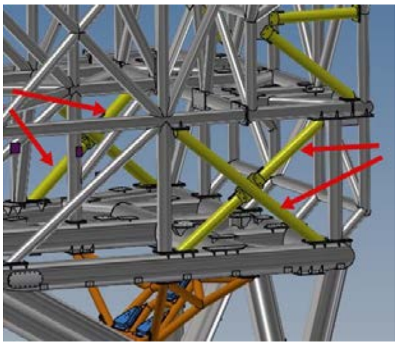
Bridle it, so lift it with the crane and place it above the previously assembled structure.	

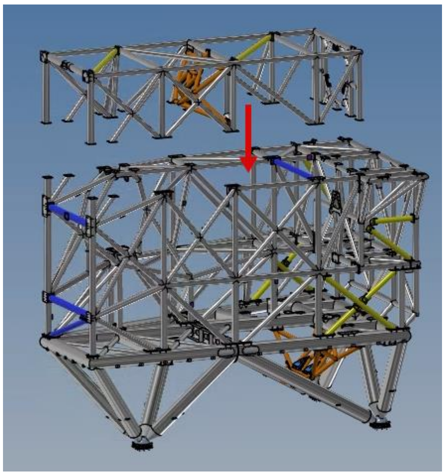
A4 Structure	
Mount preliminarily the A12 TUBE and the C3 TUBE, as shown in the side figure.	
Place the A4 Structure with the crane, as shown in the side figure, and bolt it to the base structure and to the A12 TUBE.	

Keeping the A4 Structure still harnessed to the crane, mount the A11 TUBE and A10 TUBE be using the scissor lift.	

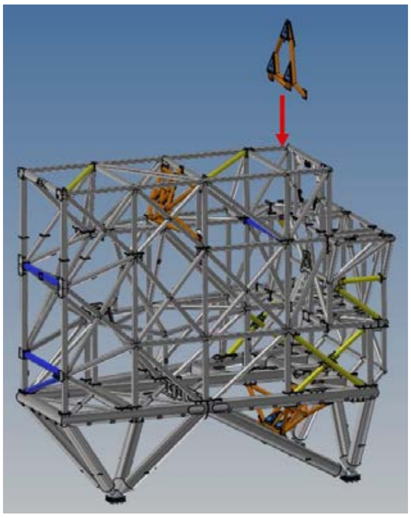
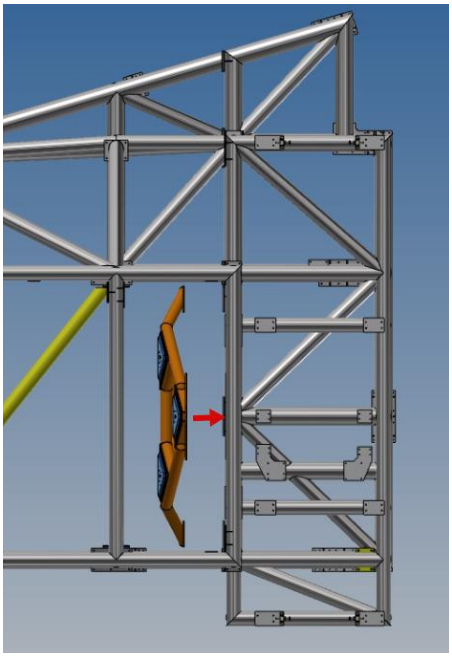
A6 Structure	
Bridle it, so lift it with the crane and place it above the previous assembled structure.	

A3 Structure	
Place the A3 Structure with the removable tubes already mounted onboard. Lift the assembly with the crane and put it down in place, next to the flanges of the A5 and A4 Structures.	

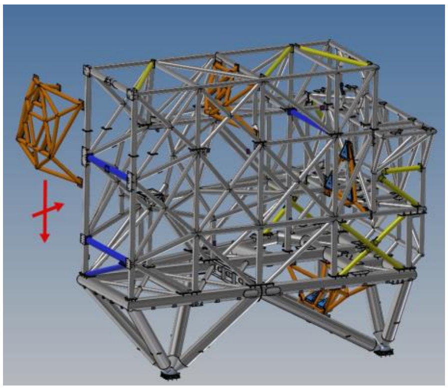
Bolt it with the other structures and then position the TUBES of the first level A8-1,2 and 3 and A9-1,2 and 3.	

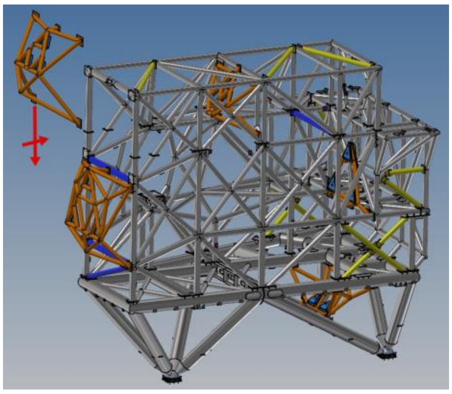
A7 Structure – Holder M6	
Transport the A7 structure already equipped with M6 Holder and the A15, A16, and A17 TUBES. The A15 TUBES, shown in the side figure, must be removed before lifting the A7 Structure.	
Carry it in position and lower it with the crane, as shown in the side figure, so bolt it to the other parts of the structure.	

Holder M9/DM1

Lift the frame vertically with the crane, as shown in the side figure, and lower it from above.	
The frame must be lowered in the central position of the lattice structure and pulled in position as shown in the side figure.	
Remount the removable A15 TUBE.	

Holder M10/DM2

<table>
<tr><td>Put it in position with the crane, as in the side figure, and screw it.</td><td></td></tr>
</table>

<table>
<tr><th colspan="2">Holder M8</th></tr>
<tr><td>Put it in position with the crane, as in the side figure, and screw it.</td><td></td></tr>
</table>

After completing the whole assembly of the MSS, check the tightening of all the screws and then carry out a general dimensional check of the assembled structure, using the laser tracker and other measuring and level checking instruments.

If required, correct the MSS level by acting on the base flanges of the spherical joints and then tighten them.

Notes: a more detailed description can be found in RD13. In the IAA Chile, this procedure has to be slightly modified due to the limited height below the crane hoist (7.5m), such as for example the installation of M9 that cannot come from above, and should be pre-installed in the A7 structure, as it is done for M6. Also, again due to the limited crane hoist height, some handlings will have to be used to position some parts of the MSS, such as A5, A4, A3 and A7.

8.4.3 Installation of the LTs on the MSS

Purpose and functionality

The MSS LTs (3) shall be installed on the main structure in the selected areas

Responsible: JFA, VDC, ERE

HTs/SEq needed: Scissor lift, Cherry Picker, movable ladders, internal platforms

Success Criteria: LTs properly installed

Duration: 1 day

Prerequisites: 8.4.2 MSS installed

Procedure: depending on the position of the LTs (see Figure 107), by using portable ladders, the cherry picker and or the internal platforms the 3 LTs will be installed to the dedicated flanges on the selected locations.

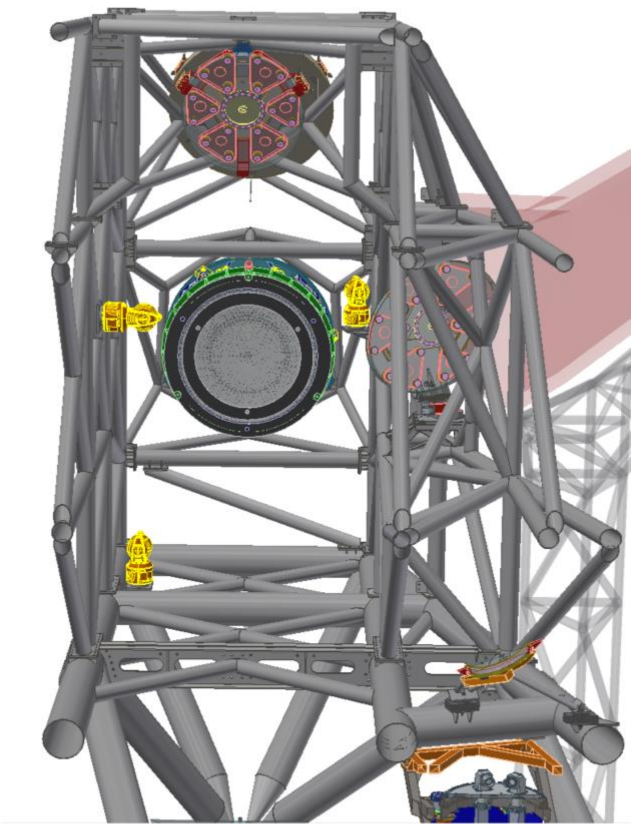


Figure 107: the three inner LTs of the MSS

Notes:

8.4.4 IFP flange installation, measurement and dis-installation

Purpose and functionality

The IFP flange is installed at the CP interface. PINs will allow to position it with an accuracy of about 10µm wrt its nominal position on the interface flanges. It will be measured to be used as reference for the opto-mechanics alignment. After measuring the IFP flange SMRs with the MSS LTs, it will be dismounted.

Responsible: JFA, ERE

HTs/SEq needed: BIH Bridge crane, Internal platforms

Success Criteria: IFP properly measured

Duration: 1 day

Prerequisites: 8.4.3 LTs installed

Procedure: The IFP flange (Figure 108 left side) will be installed at the CP interface (Figure 108 right side) carrying it with the crane in position and fixing the screws on the interfaces accessing them from the inner side of the bench, using the dedicated platforms.

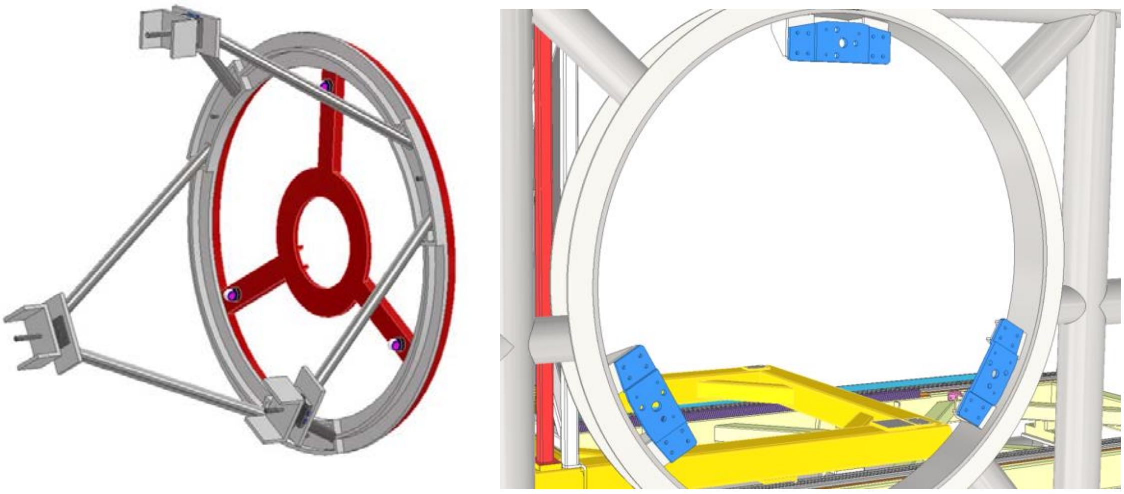


Figure 108: the IFP flange (left side), with the three SMRs on a circle close to the outer diameter of the IFP, on the red spiders; on the right end side, the CP interface flanges, where the IFP flange will be installed (instead of the CP of course)

Two PINs will allow its precise positioning wrt the interfaces (shown in blue colour in Figure 108 right side). Once in position, the three SMRs in the inner side of the IFP flange will be measured with the inner MSS LTs, and the "as built" IFP represented by the three SMRs will be used for the alignment of all the opto-mechanics to be after installed.

Just after the measurement, the IFP flange will be dismounted using the crane.

Notes:

8.4.5 Dummies installation and interfaces measurements

Purpose and functionality

The dummies of all the opto-mechanics are installed, including the LGS, LOR, LGS-O and CU ones. SMRs on the dummies (if any, still TBD if every dummy will be equipped with SMRs, characterized with respect to the mounting interfaces) have to be measured with the MSS and BIH LTs. If the dummies won't have the SMRs, we will use nests of various types with magnetic SMRs to characterize the interfaces positions, again using the MSS and BIH LTs.

Responsible: JFA, ERE, LMA, ECA, GRO

HTs/SEq needed: BIH Crane, Scissor Lift, Cherry Picker, Portable Ladders and all opto-mechanics HTs

Success Criteria: Dummies properly installed, all handlings properly working and all dummies interfaces measured

Duration: 15 days

Prerequisites: 8.4.3 MSS LTs installed

Procedure: The same procedures described (in the following sections) for the various sub-systems installation will be applied.

Notes: Dummies will have similar volume (when needed same volume), same weight, same CoG and same interfaces of the final subsystems.

This step will allow to test in advance (and moreover not on the real sub-systems) all the installation procedures and the HTs in a way to identify and solve possible problems. It will be also a double-check of the opto-mechanics positions after dismounting and remounting the MSS, since the same measurements has been previously performed also at the company premises before MSS acceptance. Finally, it will allow to re-machine the interface plates between the MSS and the opto-mechanics based on the current measurements of the interfaces positions and on the update of the optical design with the "as built" opto-mechanics data.

8.4.6 Dummies dis-installation

Purpose and functionality

For every opto-mechanical component, the dis-installation procedure shall be tested with the dummies doing the complete dismounting procedure. This step will allow to test in advance (and moreover not on the real sub-systems) all the dis-installation procedures and the HTs in a way to identify and solve possible problems. This step in necessary for the re-machining of the interface plates between the MSS and the opto-mechanics.

Responsible: JFA, ERE, GRO, LMA, ECA

HTs/SEq needed: BIH Crane, Scissor Lift, Cherry Picker, Portable Ladders and all opto-mechanics HTs

Success Criteria: opto-mechanical components properly and safely removed

Duration: 10 days

Prerequisites: 8.4.6 Dummies interface measurements

Procedure: The dis-installation procedures will be described for the FDR.

Notes:

8.4.7 Opto-mechanics interface plates dismounting and re-machining

Purpose and functionality

After having updated the optical design with the "as built" opto-mechanics data and having measured all the opto-mechanics positions on the bench, the "as built" nominal positions of all the opto-mechanics will be computed, and all the interfaces which need re-machining will be dismounted.

Responsible: JFA, ERE, ECA

HTs/SEq needed: BIH Crane, Scissor Lift, Cherry Picker, Portable Ladders

Success Criteria: opto-mechanics interfaces properly and safely removed

Duration: 1 day

Prerequisites: 8.4.14 and 8.4.13

Procedure: depending on the position of the interface plates, by using portable ladders, the cherry picker and or the internal platforms the interface plates will be uninstalled and sent to the mechanical WS for re-machining.

Notes:

8.4.8 MES installation

Purpose and functionality

The MES will be installed in the BIH. The MES includes the supporting structure, the bearing, the Test Camera System, the LOR WFS and M12. The purpose of the MES is to provide a system which emulates the MICADO camera, which essentially consists of a Technical Alignment Camera (TAC), an XYZ motorized system to position the camera over the full MICADO FoV, a bearing simulating the MICADO bearing, the LOR WFS and the M12 sub-system. The enclosure of the thermal system can also be installed on the MES upper part of the supporting structure, allowing to make functional test of such a system.

Responsible: ERE, JFA, MRI, GRO, LMA, ECA

HTs/SEq needed: BIH Bridge crane, Scissor lift, Cherry picker, portable ladders.

Success Criteria: MES structure and sub-systems installed and interfaced properly in their nominal position when measured with the BIH LTs wrt the MAORY SMRs

Duration: 5 days

Prerequisites: no real prerequisites apply here, but for the NIP, which should include an extension to allow the installation of the MES (TBD for FDR).

Procedure: No special handlings are required for the installation of the MES. The procedure is the following:

1. We assemble the 1st floor in its foreseen position, removing one diagonal flange and one “floor bar” (on the same side of the diagonal one) to allow to position the LOR cabinets within its base.
2. We position the cabinets and re-install the diagonal and the floor bars.
3. We install floor 2 + floor 3 already assembled
4. We install the bearing, with a flange connected to it where 3 SMRs on a circle are placed, at the edge of the FoV, positioned in Z where the OFP should be. Such flange materialize the OFP, and should be characterized in advance using a CMM, to relatively loose tolerances wrt the bearing plane and focus position (We recall that the MICADO positioning accuracy is ±5mm in XYZ and ±0.58mrad in TT). On this flange, the XYZ system holding the TAC is also placed.
5. We check the bearing position (using the BIH LTs against the SMRs on the MSS/M11 and on the OFP flange) and, in case the bearing position is outside the MICADO positioning accuracy, we adjust it (using shims for TT and focus, and a coarse adjustment with screws pushing on the 4 sides of the bearing)
6. We install the LOR

7. We install M12 on floor 3 and we align it to the bearing using the BIH LTs against the M12 SMRs and the MSS SMRs

In Figure 109 we report the installation sequence just presented, which in this step will end without the installation of the enclosure.

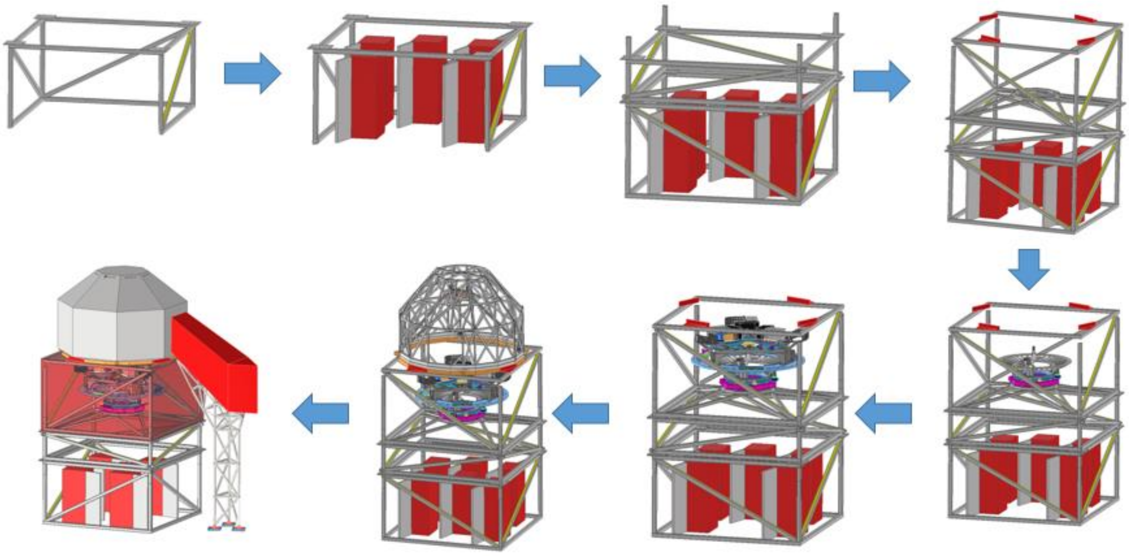


Figure 109: the MES installation sequence

Notes: a possible position for the cabinets in the BIH is at the level of floor 1, as it is shown in Figure 109. Of course, care should be given to the heat that might affect the OFP, and thus an insulation of floor 1 might be required.

8.4.9 MSS characterization (optional)

Purpose and functionality

The MSS stability over time and vs temperature (and vs vibrations?) without load will be characterized.

Responsible: JFA, GRO, LMA, ECA

HTs/SEq needed: All LTs (BIH and MSS), a few PT100 sensors and the electronics to read them out and record the data

Success Criteria: All the measured shifts of the SMRs within the expected ones (obtained by analysis) in the measured T range

Duration: 5 days

Prerequisites: 8.4.8 MES installation

Procedure: The BIH LTs and the MSS LTs will target and measure/record the positions of the SMRs positioned on the MSS and on the NIP; The position of the references will be monitored continuously for a time scale of the order of two weeks, and the lab temperature has also to be monitored and recorded to be referenced and studied against the recorded positions of the spheres.

Notes: this step will be performed only if the re-machining of the interface flanges will take more than 5 days (time estimated to install the MES).

Temperature changes to the lab may be induced (within the adjustment range) to characterize references shifts vs temperature variation

TBD if accelerators may be installed to check environmental vibrations to refer MSS stability also to them.

8.4.10 Opto-mechanics interface plates re-installation

Purpose and functionality

After having re-machined the interface plates dismounted in 8.4.7, they will be re-installed in the proper positions.

Responsible: JFA, ERE, GRO, ECA

HTs/SEq needed: BIH Crane, Scissor Lift, Cherry Picker, Portable Ladders

Success Criteria: opto-mechanics interfacse properly and safely removed

Duration: 1 day

Prerequisites: 8.4.7

Procedure: depending on the position of the interface plates, by using portable ladders, the cherry picker and or the internal platforms the interface plates will be re-installed in the proper position.

Notes:

8.4.11 Dummies re-installation and interfaces measurement

Purpose and functionality

The dummies of all the opto-mechanics are re-installed. The aim is to check if the dummies are in the "as built" nominal position after re-machining the interface flanges.

Responsible: JFA, ERE, LMA, GRO, ECA

HTs/SEq needed: BIH Crane, Scissor Lift, Cherry Picker, Portable Ladders and all opto-mechanics HTs

Success Criteria: Dummies properly installed, all handlings properly working and all dummies in the nominal positions (within their adjustment ranges)

Duration: 15 days (TBC)

Prerequisites: 8.4.10

Procedure: The same procedures described (in the following sections) for the various sub-systems installation will be applied. All the interfaces will be measured again, to double-check that they are in the "as-built" foreseen positions, within the adjustment range provided at each opto-mechanics.

Notes:

8.4.12 Thermal enclosure installation

Purpose and functionality

The thermal cover panels shall be installed on the MSS and on the MES. Also, all the necessary electronics has to be installed and functionally checked.

All the electronic to control the thermal system shall be installed

Responsible: VDC, VCI, MAL, JFA, ERE, LMA, GRO, ECA, IFO, ECA. CER

HTs/SEq needed: BIH Crane, Scissor Lift, Cherry Picker, Portable Ladder

Success Criteria: Panels of the thermal enclosure properly positioned and tightened

Duration: 5 days

Prerequisites: 8.4.9 MSS characterization

Procedure: Still TBD, it will be specified for the FDR

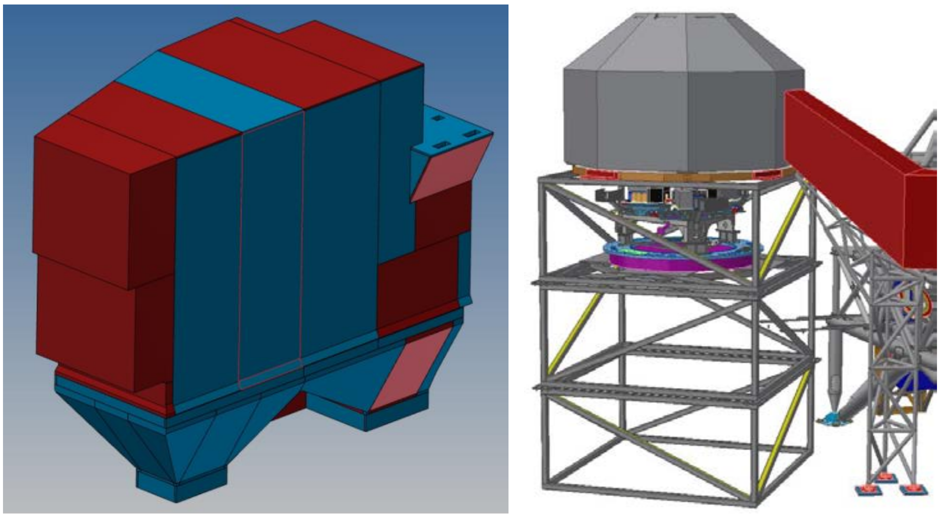


Figure 110: the thermal enclosure installed on the MSS (left side) and on the MES (right side)

Notes:

8.4.13 MSS and MES Thermal test

Purpose and functionality

The MSS stability over time and vs temperature (and vs vibrations?) with the dummies installed will be characterized. Time needed for the thermalization will be measured too over a few cycles. This test will also allow to check the MSS stability vs environmental conditions, by continuously monitoring SMRs on the MSS witl the MSS LTs.

Responsible: VDC, VCI, MAL, JFA

HTs/SEq needed: MSS LTs, a few PT100 sensors and the electronics (lakeshore+PC) to read them out and record the data

Success Criteria: Measured MSS temperature within the expected range (T=X°±?)

Duration: 30 days

Prerequisites: 8.4.12 Thermal Enclosure Installation

Procedure: The MSS LTs will target the SMRs of the MSS; The position of the references will be monitored continuously for a time scale of the order of one month, and the lab temperature has also to be monitored (T air aoutside, T air inside, T MSS in various positions) and recorded to be referenced and studied against the recorded positions of the SMRs. Time needed for the thermalization will be measured too over a few cycles.

Notes: Temperature changes to the lab may be induced (within the adjustment range) to characterize references shifts vs temperature variation

TBD if accelerators may be installed to check environmental vibrations to refer MSS stability also to them.

8.4.14 Alignment of the MSS to the PFS

Purpose and functionality

The alignment capability of the MSS is checked in term of achievable travel range and accuracy

Responsible: GRO, VDC, VCI, JFA

HTs/SEq needed: Dedicated tools for the legs movement, BIH LTs

Success Criteria: Travel range and accuracy in specifications, as specified in Table 20.

DoF	Value	Unit of measurement
Decenter z	+/- 2	mm
Decenter (x,y)	+/- 4.5 (TBC)	mm
Tip	+/- 0.67	mrad
Tilt	+/- 0.4	mrad
Rotation	+/- 0.1	mrad

Table 20: adjustments ranges of the MSS

Duration: 1 day

Prerequisites: 8.4.12 Thermal Enclosure Installation

Procedure: The system to move the overall MSS is tested, measuring the MSS SMRs wrt to the BIH SMRs (Bologna world) and wrt PFS SMRs to evaluate the MSS movement; the movement of the MSS will be also measured with LVDT and/or mechanical gauges.

Travel range and accuracy are characterized in the three axis using also the BIH LTs against the MSS external references.

Notes: done at MSS company premises also, If not really needed, we can skip

8.4.15 Thermal enclosure dis-installation

Purpose and functionality

All the panels have to be removed, to allow proper access to all the MSS areas for the following operations foreseen, above all for the electronics and cables installation and routing

Responsible: VDC, VCI, JFA, MAL

HTs/SEq needed: BIH Crane, Scissor Lift, Cherry Picker, Portable Ladders

Success Criteria: Procedure safely working

Duration: 2 days

Prerequisites: 8.4.13 MSS and MES Thermal Test

Procedure: Still TBD, it will be specified for the FDR

Notes: The thermal enclosure has to be uninstalled at this stage to allow proper cables and pipe installation and routing

8.4.16 CP dummy dis-installation

Purpose and functionality

The CP dummy will be dismounted, to allow the installation of the IFP flange.

Responsible: JFA, ERE

HTs/SEq needed: BIH Bridge crane, dedicated HT, Internal platforms

Success Criteria: CP safely dismounted

Duration: 1 day

Prerequisites: 8.4.15 Thermal enclosure dis-installation

Procedure: The CP flange will be un-installed using the crane.

Notes:

8.4.17 IFP flange installation and measurement

Purpose and functionality

The IFP flange is installed at the CP interface. PINs will allow to position it with an accuracy of about 10µm wrt its nominal position on the interface flanges. It will be measured to compare the measurement carried out in step 8.4.4, where the MSS had no load. After measuring the IFP flange SMRs with the MSS LTs, it will be dismounted.

Responsible: JFA, ERE

HTs/SEq needed: BIH Bridge crane, Internal platforms

Success Criteria: IFP properly measured

Duration: 1 day

Prerequisites: 8.4.16 CP dummy dis-installation

Procedure: The IFP flange will be installed at the CP interface with the same procedure described in step 8.4.4.Two PINs will allow its precise positioning wrt the MSS interfaces. Once in position, the three SMRs in the inner side of the IFP flange will be measured with the inner MSS LTs.

Just after the measurement, the IFP flange will be dismounted using the crane.

Notes:

8.4.18 Dummies dis-installation

Purpose and functionality

All the opto-mechanics dummies will be uninstalled.

Responsible: ERE, JFA, LMA, GRO, ECA

HTs/SEq needed: BIH Crane, Scissor Lift, Cherry Picker, Portable Ladders and all opto-mechanics HTs

Success Criteria: opto-mechanical components properly and safely removed

Duration: 10 days

Prerequisites: 8.4.17 IFP flange installation and measurement

Procedure: The dis-installation procedures will be described for the FDR.

Notes:

8.4.19 Electronic cabinets installation

Purpose and functionality

Installation of the cabinets in their BIH foreseen position (on the floor below the MES) and functional test will be performed.

Responsible: IFO, ECA, CER, JFA

HTs/SEq needed: BIH crane, fork lift

Success Criteria: No damage to the cabinets, functional test all working

Duration: 10 days

Prerequisites: 8.4.18 Dummies dis-installation

Procedure: All the cabinets are fixed in their foreseen position and functional power test are executed.

Notes: a possible position for the cabinets in the BIH is at the level of floor 1 (as also reported and shown in step 8.4.8). Of course, care should be given to the heat that might affect the OFP, and thus an insulation of floor 1 might be required.

8.4.20 Cables and pipes routing

Purpose and functionality

Cables and pipes installation and functional test

Responsible: IFO, ECA, CER, JFA

HTs/SEq needed: Scissor lifts, Cherry picker, portable ladders

Success Criteria: all cable and pipe are safely deployed, pin to pin test all working

Duration: 10 days

Prerequisites: 8.4.15 Thermal Enclosure dis-installation

Procedure: Cable and pipe trays are installed, cables and pipes are routed from the cabinets to the opto-mechanical sub-systems locations. Cables for power and network delivery are routed from the Power Distribution Cabinet to all the other cabinets.

Notes:

8.4.21 Engineering ICS SW installation and test

Purpose and functionality

The SW needed to move to motorized functions of the opto-mechanic sub-systems is installed and tested by moving the motorized axis of the installed opto-mechanics (elevator, CU, M10 TT and focus, M11 TT) and fine tuning the motor controller parameters;

Responsible: JFA, BSA

HTs/SEq needed: Floppy Disk(s) (“s” in case more than one will be needed)

Success CriteriaCriteria: data transfer, communication and functional test working

Duration: 5 days

Prerequisites: 8.4.20 Cables and Pipes routing

Notes:

8.4.22 IFP flange installation and measurement

Purpose and functionality

The IFP flange is installed at the CP interface. PINs will allow to position it with an accuracy of about 10µm wrt its nominal position on the interface flanges. After measuring the IFP flange SMRs with the MSS LTs, it will be dismounted.

Responsible: JFA, ERE

HTs/SEq needed: BIH Bridge crane, Internal platforms

Success Criteria: IFP properly measured

Duration: 1 day

Prerequisites: 8.4.18 dummies dis-installation

Procedure: The IFP flange will be installed at the CP interface with the same procedure described in step 8.4.4.Two PINs will allow its precise positioning wrt the MSS interfaces. Once in position, the three SMRs in the inner side of the IFP flange will be measured with the inner MSS LTs.

Just after the measurement, the IFP flange will be dismounted using the crane.

Notes: This step makes sense only if the measurements performed in steps 8.4.4 and 8.4.17 didn’t show relevant differences in the IFP position measurements, meaning that the MSS load effect is negligible. Otherwise, the IFP flange must be measured just once all the opto-mechanics will be installed, meaning that also the opto-mechanics LT positioning will have to be performed on a second stage.

8.4.23 Corrective Plate Installation

Purpose and functionality

The CP is installed on the MSS; its position is adjusted by acting on its TT and focus manual adjustments using the BIH LTs against the CP internal SMRs.

Responsible: LMA, ERE, JFA, GRO, ECA

HTs/SEq needed: BIH Bridge crane, Dedicated HTs, Internal platforms

Success Criteria: CP properly installed and in the nominal position given by the LTs

Duration: 1 day

Prerequisites: 8.4.22 IFP flange installation

Procedure:

The Schmidt Plate is located at the edge of MAORY Support Structure (MSS). Since its interface points are on the internal side of the main structure, this plate should be installed/removed from that side.

The Schmidt Plate assembly structure is basically a double metal ring clamping the glass. On the circumference of the metal ring we have both the interfaces with the main structure and with the handling for installation/removal (see Figure 111)

Due to its relative light weight and orientation in space when installed on the main structure (surface normal is perpendicular to gravity vector), the handling for its installation/removal is quite simple.

The handling is basically a plate interfacing with the Schmidt Plate ring and some threaded rods ending with a small plate and hoisting points for the crane. The hoist ring has the possibility to slide to account for barycentre shift when the Schmidt Plate is disengaged

The easiest way to install it would be from the top of the main structure. This would be require to remove the yellow beam shown in Figure 112 and the thermal cover panel on top of it.

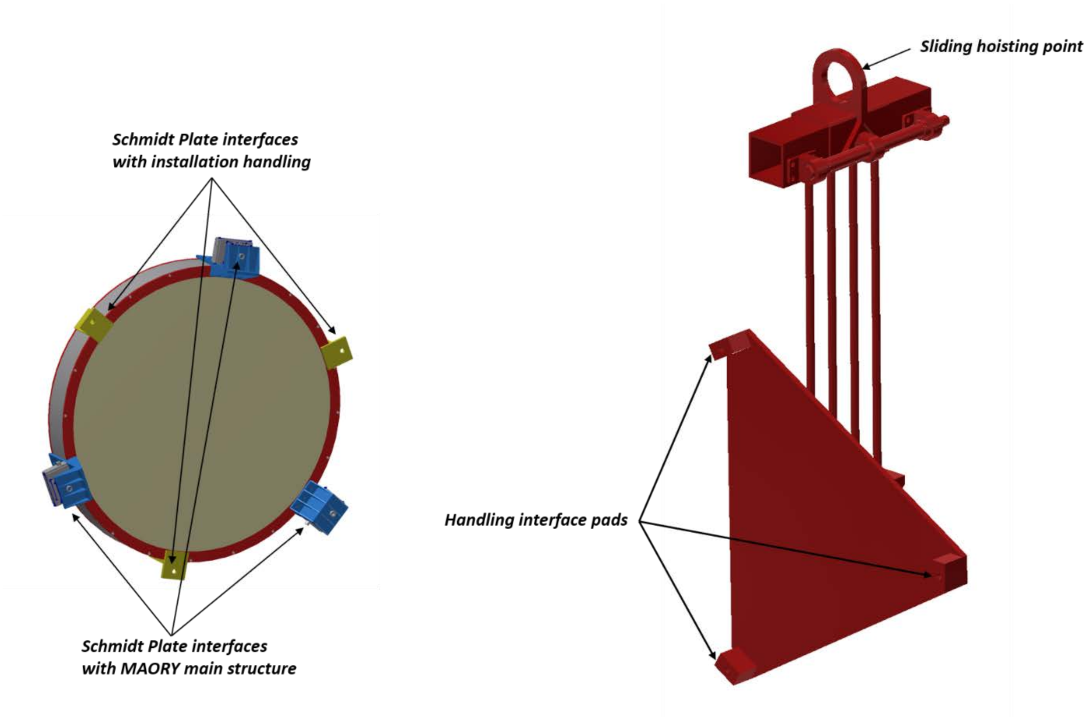


Figure 111: on the left the Schmidt Plate assembly, with its interface points. On the right, the handling for its installation from the top.

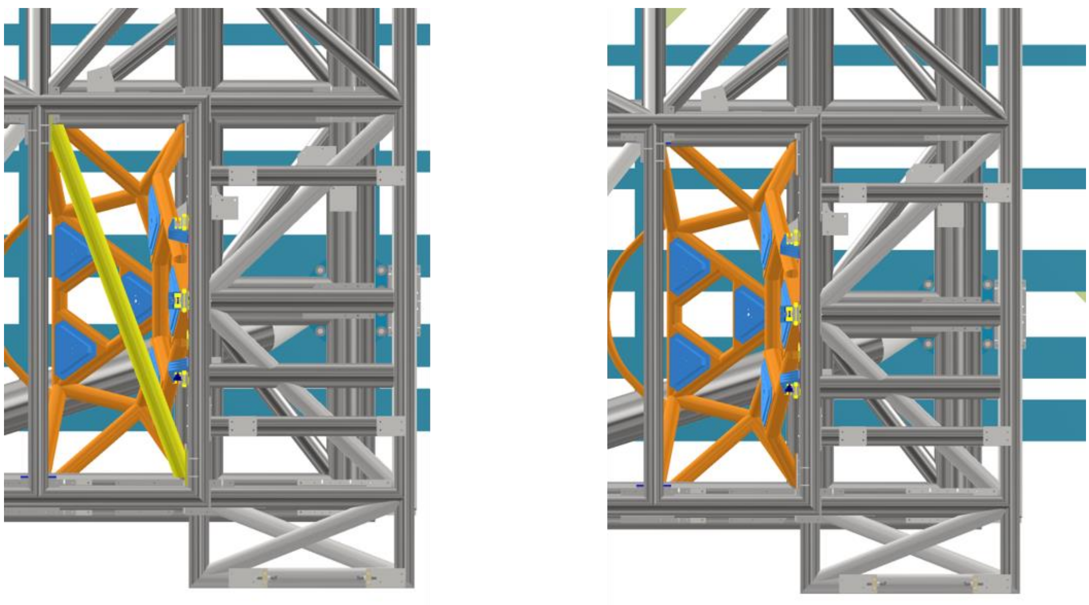


Figure 112: the yellow beam highlighted in left panel shall be removed to allow Schmidt Plate installation/removal from the top.

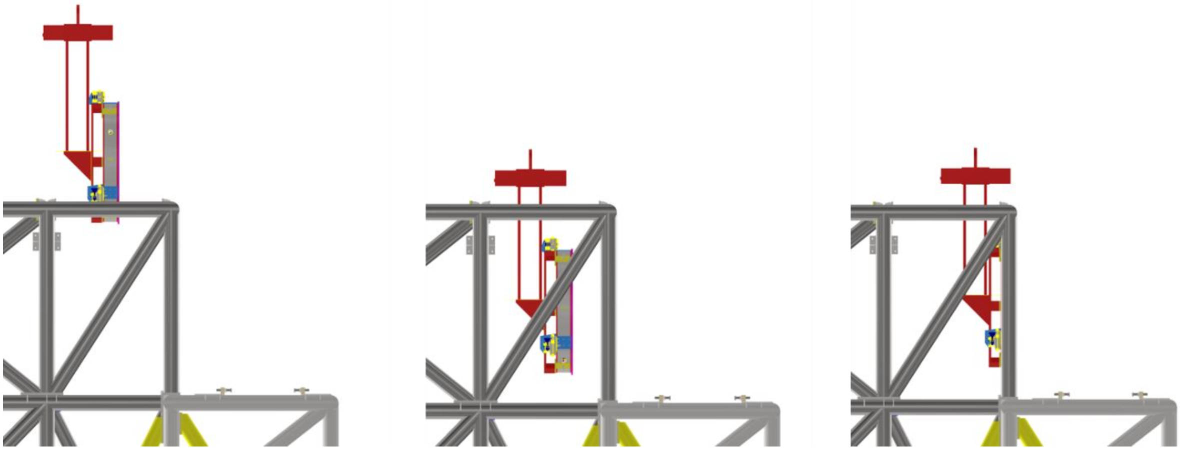


Figure 113: once the beam has been removed, the crane can simply lower the Schmidt Plate inside MAORY main structure and shift it towards its interface points.

The installation of the CP to its interface points on MSS requires a person in front of it, to perform several activities: remove the screws from the yellow beam that must be removed, tighten the 3 locking nuts and release the handling from the Schmidt Plate. Access to that location is provided by a modular system of internal ladders that can be mounted/dismounted inside the MSS at the occurrence.

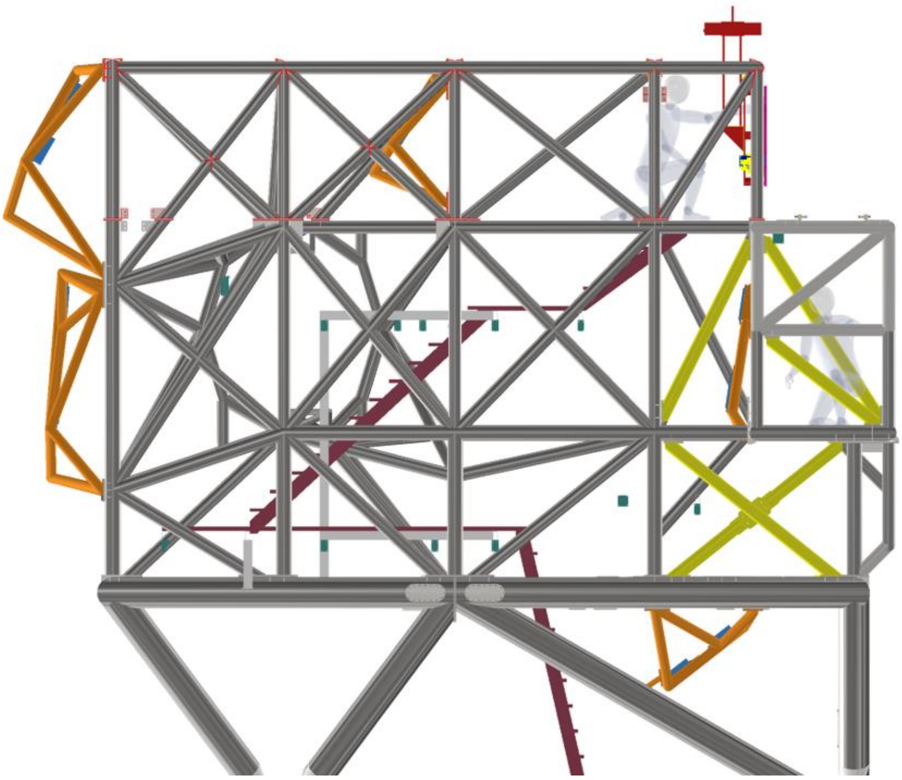


Figure 114: Internal ladders (in garnet) to reach the Schmidt Plate position

Notes:

8.4.24 M6 Installation

Purpose and functionality

M6 is installed on the MSS; its position is adjusted by acting on its TT and focus manual adjustments using the BIH LTs against M6 reference SMRS.

Responsible: LMA, ERE, JFA, GRO, ECA

HTs/SEq needed: BIH Bridge crane, Dedicated HT, Scissor lifts, internal platforms

Success Criteria: M6 properly installed and in the nominal position given by the BIH LTs

Duration: 1 days

Prerequisites: 8.4.23 CP installation

Procedure

Its position into MAORY main structure suggests to install this mirror from the top. This can be performed by removing the yellow beam shown in Figure 115 and the thermal cover panel on top of it.

In this way we create an access at the top of the main structure wide enough to insert M6 using a C-shaped handling. The handling shape allows to interface the crane hook along the projection of the M6 + handling barycentre. The position of the crane hook hoisting ring with the handling can be finely adjusted as it is mounted on a rail, actuated by an endless screw.

This is useful when M6 is disconnected from the handling, as the barycentre of the system will move.

In this case, before disconnecting the handling and after M6 is secured to its supporting structure inside MSS, it is possible to shift the hook hoisting hole to the position where the stand-alone handling would be balanced. In this way, the handling will not swing when M6 is released. This operation will require extreme attention and sensitivity in moving together the crane hook and the hoisting point on the handling, to avoid transferring torque to the mirror. **For this reason, a solution with moving masses rather than moving the hook interface on the handling is currently under study.**

At M6 side, the C-shaped handling is constituted by 2 main parts: a fixed part and a movable one. The latter is physically screwed to the 3 branches embracing M6 using M8 screws, and it is interfaced to the handling fixed part through a heim joint, that allows adjusting its position in 3 DoFs (tip-tilt-rotation, even though rotation around mirror optical axis will be mechanically constrained).

3 threaded rods screwed to the fixed part of the handling and pushing on the movable part allow to finely adjust the tip-tilt of M6 during the installation phase. Centering of the mirror with respect to its interfaces on the MSS will be done maneuvering the crane (a precision of ±2 mm is required to engage the kinematic mount).

The handling is designed to naturally pick M6 with the same orientation it will have when mounted into the MSS, even though the handling movable part allows some tip-tilt adjustment.

Two people, one at the front and one at the back of M6 inside the MSS, are necessary to secure the mirror to its supporting structure and to release the handling. Access to that location is provided by a modular system of internal ladders that can be mounted/dismounted inside the MSS at the occurrence (see Figure 119).

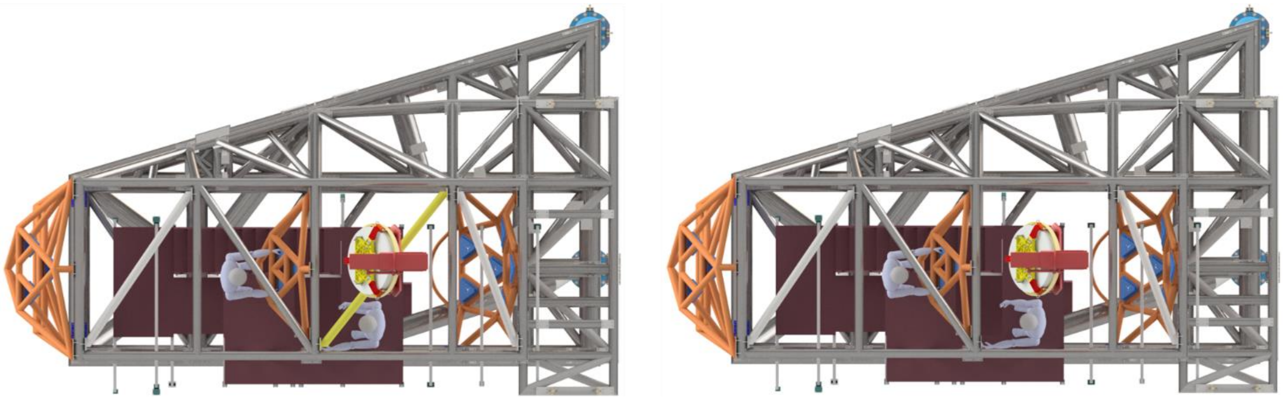


Figure 115: yellow beams shall be removed to allow handling accessing into MAORY main structure.

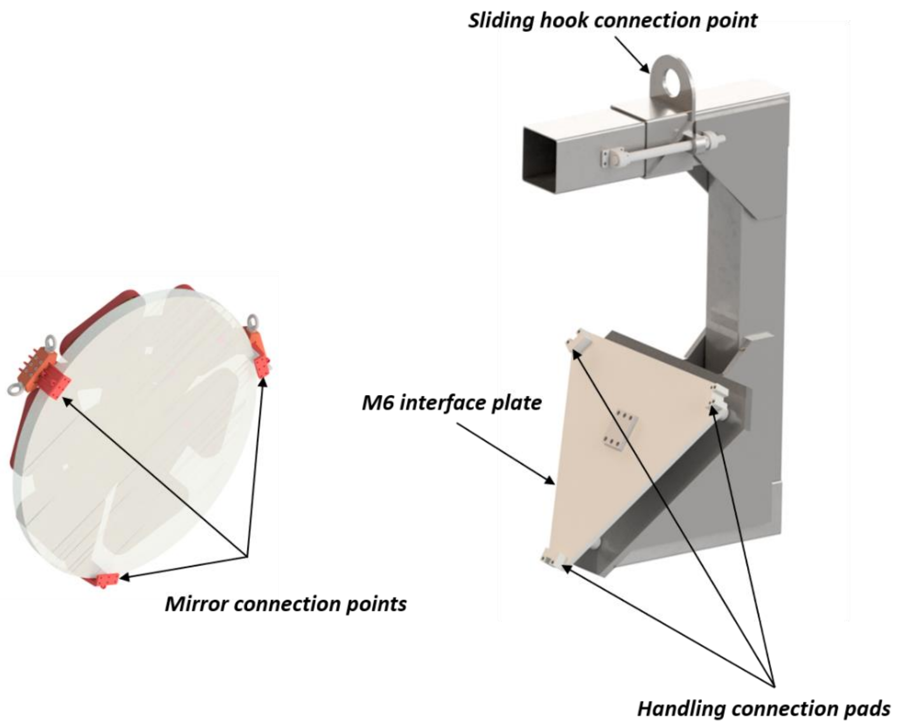


Figure 116: C-shaped handling for M6 installation. The interface between M6 and the handling is between the 3 branches embracing M6 and the 3 connection pads of the handling. The handling is equipped with a hook hoisting connection point having the possibility to slide, in order to have it aligned with the barycentre of the system both when M6 is connected and disconnected.

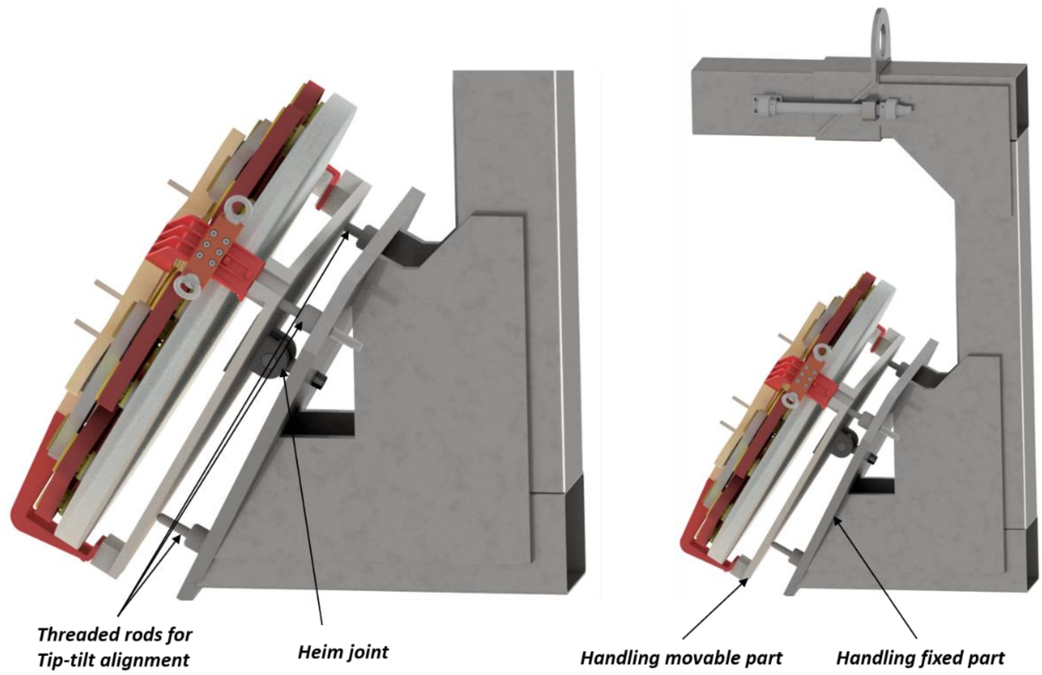


Figure 117: the handling allows to fine adjust tip-tilt of the mirror before installation, thanks to a heim joint and 3 threaded rods pushing against the movable part of the handling.

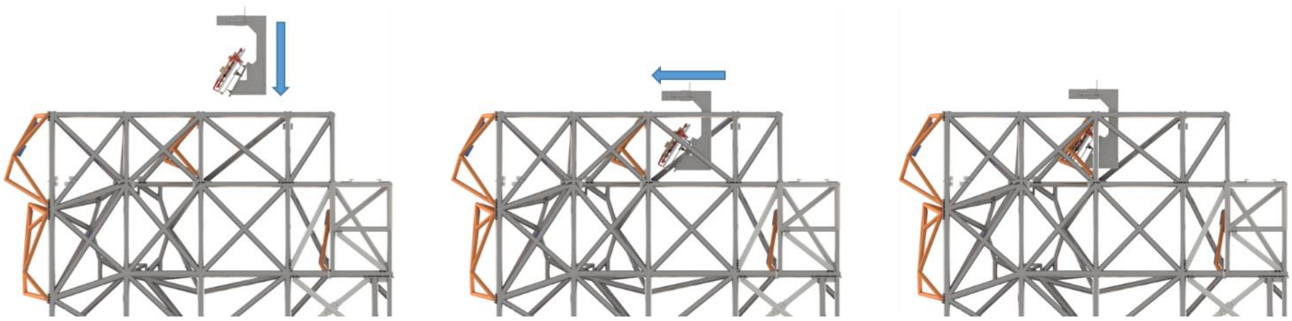


Figure 118: installation of M6 inside MAORY main structure. The hoisting point is always above the top part of MAORY main structure, so to avoid interferences between the crane wire rope and the beams of the main structure.

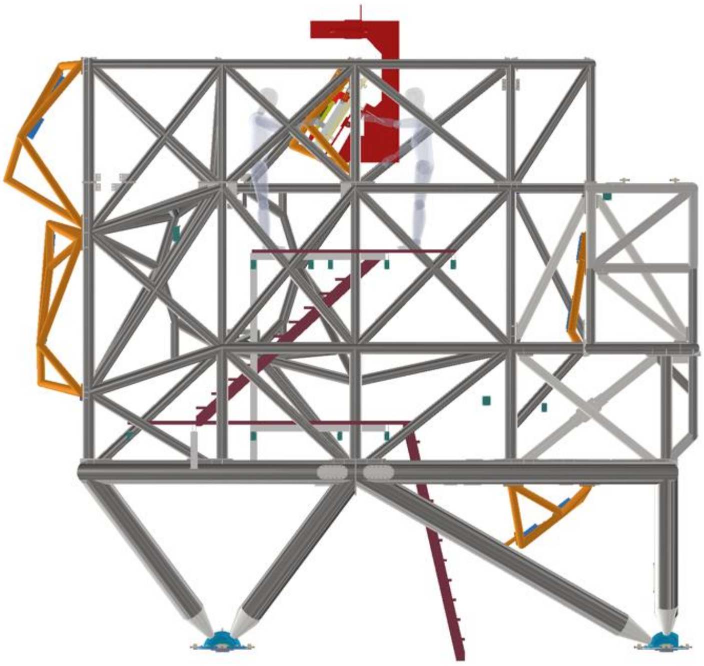


Figure 119: Internal ladders (in garnet) to reach the M6 position

Notes: The pre-requisites here are more due to the procedure sequence and to the necessity/wish to install just one main subsystem at a time

8.4.25 M7 Installation

Purpose and functionality

M7 is installed on the MSS; its position is adjusted by acting on its TT and focus manual adjustments using the BIH LTs against M7 reference SMRS.

Responsible: ERE, JFA, LMA, ECA, GRO

HTs/SEq needed: BIH Bridge crane, Dedicated HT

Success Criteria: M7 properly installed and in the nominal position given by the BIH LTs

Duration: 1 days

Prerequisites: 8.4.24 CP installation

Procedure:

Due to its location, at the bottom part of MAORY main structure, a C-shaped handling with the hoist ring above the top of the MSS is not an optimal solution as it would result in a very long handling.

Still the installation can be done from the top, using the same access used for M6. The handling is still C-shaped, even though the short sides of the C must be really short, as the whole handling must enter into the MSS. For this reason, it is not possible to locate the hoist ring along the projection of the barycenter of M7 + handling, thus a counterweight is required. The counterweight constitutes of some metal disk inserted in a threaded rod fixed to the long side of the C-shaped handling. Two nuts allow to move the counterweight along the threaded rod, in order to adjust its position when M7 is removed.

Other than this, the concept of the M7 handling is the same shown for M6, thus the handling is physically connected to the 3 branches embracing M7 by using M8 screws.

The mirror is then lowered all the way down the MSS and brought in position. Being in a quite low position (highest interface point with its supporting structure being less than 1.8 meter from the ground), the operator does not need any special SEq to fix M7 to its interface points nor to disengage the handling from M7, while a small portable ladder might be needed to move the counterweight before releasing the handling.

When M7 is secured to its supporting structure and the handling, after rebalancing, is disengaged, it is extracted from the top of MSS.

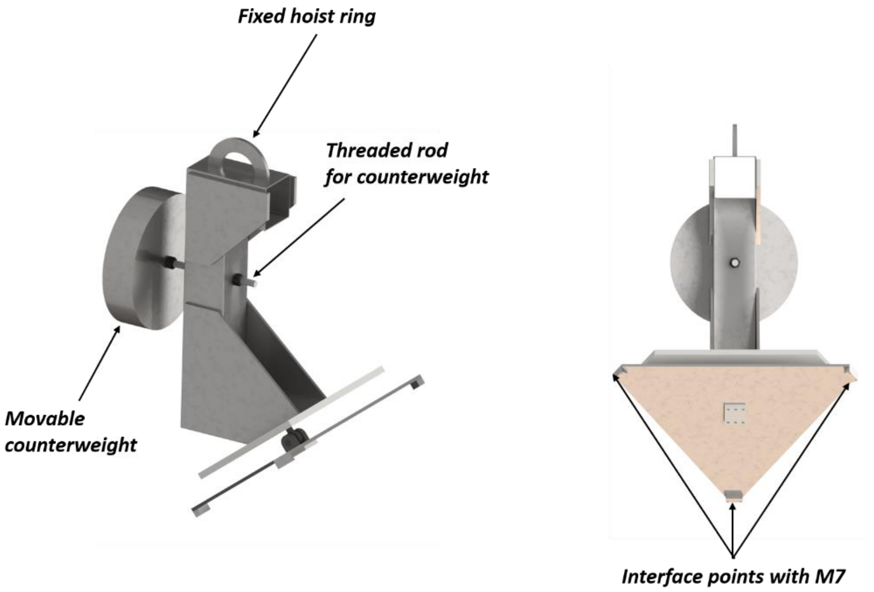


Figure 120: the C-shaped handling for M7 installation.

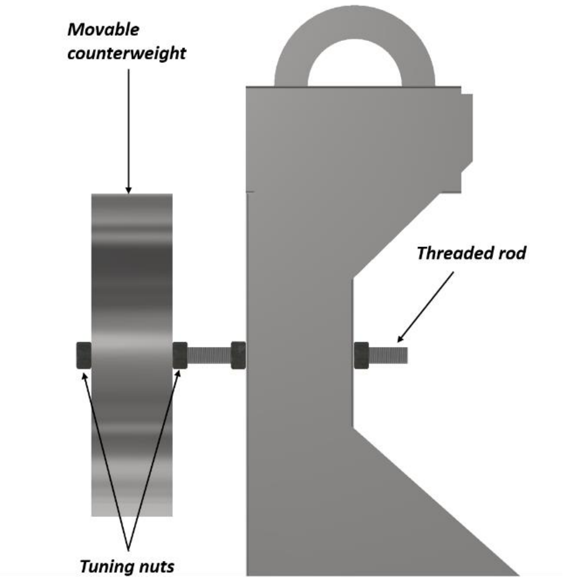


Figure 121: Two nuts allow to tune the position of the counterweight on the threaded rod.

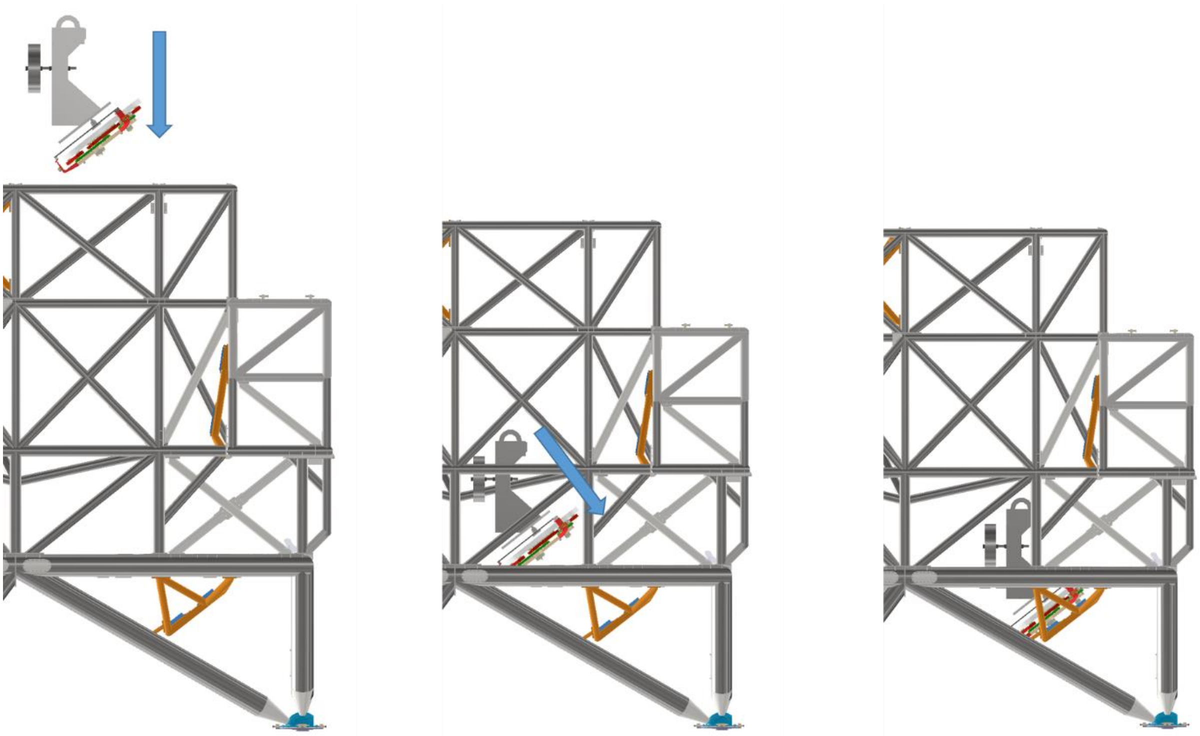


Figure 122: installation of M7 inside MAORY main structure. To avoid a very long handling, the hoist ring during the installation is inside the MSS. This poses handling dimensioning constraints and the use of counterweights.

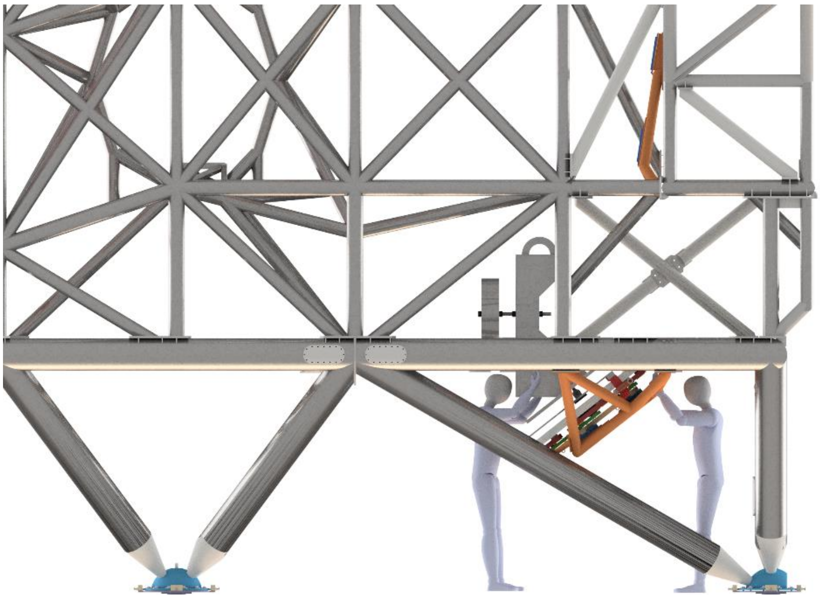


Figure 123: persons standing on the ground can easily secure M7 to its supporting structure and remove the handling. Fine tuning of the counterweight position might require a small ladder.

Notes: The pre-requisites here are more due to the procedure sequence and to the necessity/wish to install just one main subsystem at a time

8.4.26 M8 installation

Purpose and functionality

M8 is installed on the MSS; its position is adjusted by acting on its TT and focus manual adjustments using the BIH LTs against M8 reference SMRS.

Responsible: ERE, JFA, LMA, ECA, GRO

HTs/SEq needed: BIH Bridge crane, Dedicated HT, Scissor lifts, internal platforms

Success Criteria: M8 properly installed and in the nominal position given by the BIH LTs

Duration: 1 days

Prerequisites: 8.4.25 M6 installation

Procedure: The idea is to use a C-shaped handling, which is exactly the same described for M6, connected to the crane of the dome. The only difference will be the movable part of the handling, which has slightly different dimensions. This handling should enter into MAORY main structure through the hatch that will be obtained removing a beam at the top of the structure (yellow beam in Figure 124).

The handling will be interfaced to the mirror using threaded holes in the three branches embracing the mirror, in the same way described for M6, and then lowered into the MSS through the hatch at the top.

Similarly to M6, two people are required, one in front and one at the back of M8, to interface it to its supporting structure and to release the handling. The person at the front can reach the position via the internal ladders, the person at the back uses a scissor lift or a temporary scaffolding to be mounted in the relevant position.

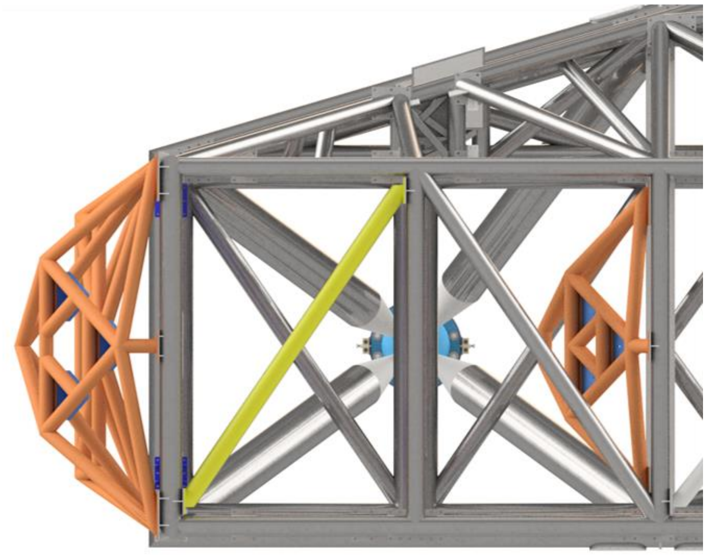


Figure 124: the yellow beam at the top of MAORY main structure shall be removed to allow M8 maintenance handling to access into the structure

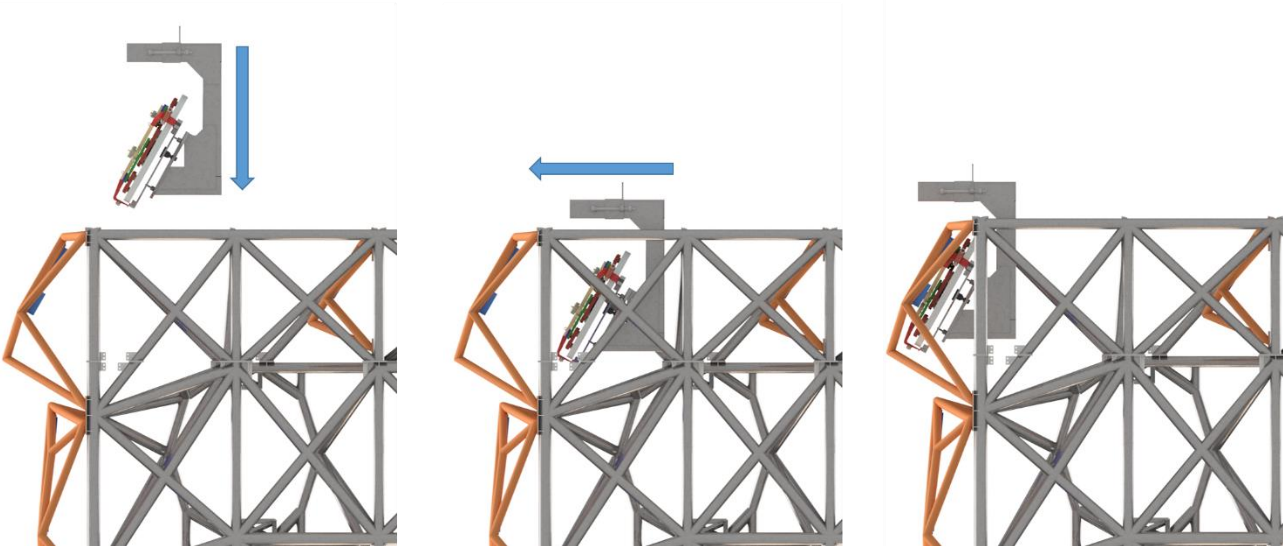


Figure 125: installation of M8 inside MSS in BIH and Nasmyth Platform. The hoisting point is always above the top part of MAORY main structure, so to avoid interferences between the crane chain and the beams of the main structure.

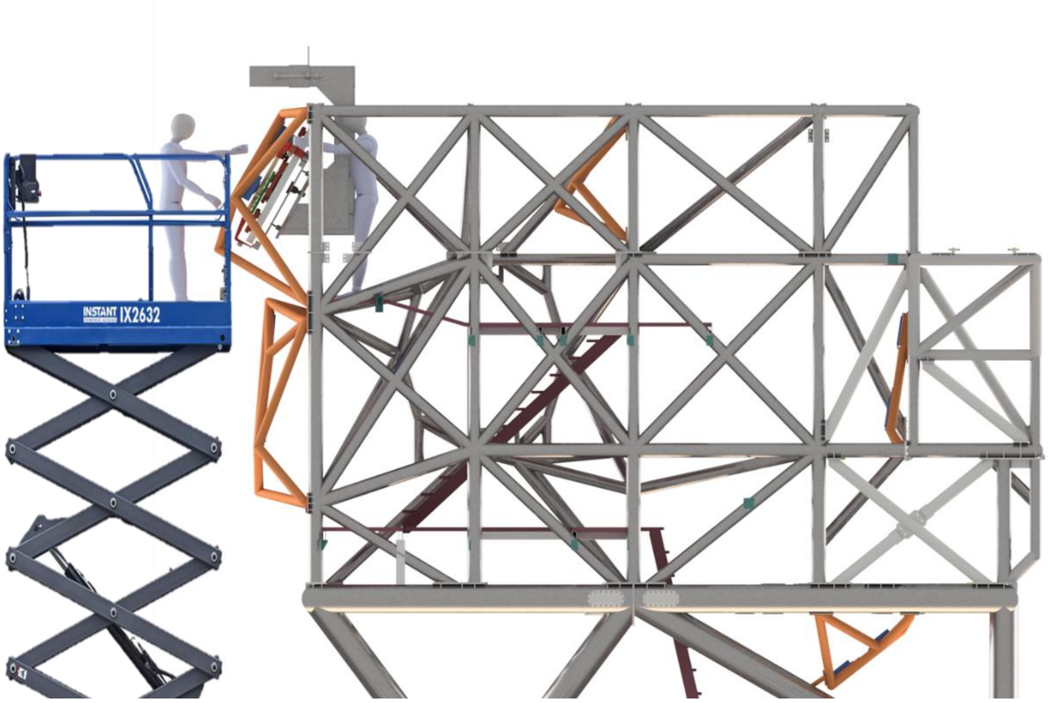


Figure 126: internal ladders (in garnet) to reach M8 front position and a scissor lift (that might be replaced by a temporary scaffolding) to reach M8 back position.

Notes: The pre-requisites here are more due to the procedure sequence and to the necessity/wish to install just one main subsystem at a time

8.4.27 M9/DM1 Installation

Purpose and functionality

M8 is installed on the MSS; its position is adjusted by acting on its TT and focus manual adjustments using the BIH LTs against M8 reference SMRS.

Responsible: MXO, JFA, GRO, ECA, LMA

HTs/SEq needed: BIH Bridge crane, Dedicated HT, Scissor lifts, internal platforms

Success Criteria: M9 properly installed and in the nominal position given by the BIH LTs

Duration: 2 days

Prerequisites: 8.4.26 M8 installation

Procedure: The mirror is installed/removed from the top, removing the same bar removed for M6 and M7.

The handling concept is the same seen for the installation of M6 and M8 in BIH and Nasmyth Platform, just longer due to the position of M9, deeper inside the MSS.

Its installation thus follow the same steps described for M6 and M8, so the handling is interfaced to 3 points at 120deg at the mirror front flange, and it holds the mirror with the same orientation it will have when mounted in the MSS. The hoist ring for the crane hook is movable, to compensate for the shift of the barycentre when the mirror is disengaged, and it is always above the top part of the MSS.

The handling with M9 is lowered through the aperture at the top of the MSS and then maneuvered with the crane till the mirror fixing screws enters into the kinematic mount on its support structure.

In order to secure the mirror to its supporting structure and to release the handling, two persons are needed, one at the front of the mirror and one at the back.

The front position can be reached using the MSS internal ladders, while the position at the back require access to the CU area using a cage ladder to be mounted outside the MSS, which is the same ladder used for the CU installation. If the CU is installed, the person should operate lying down.

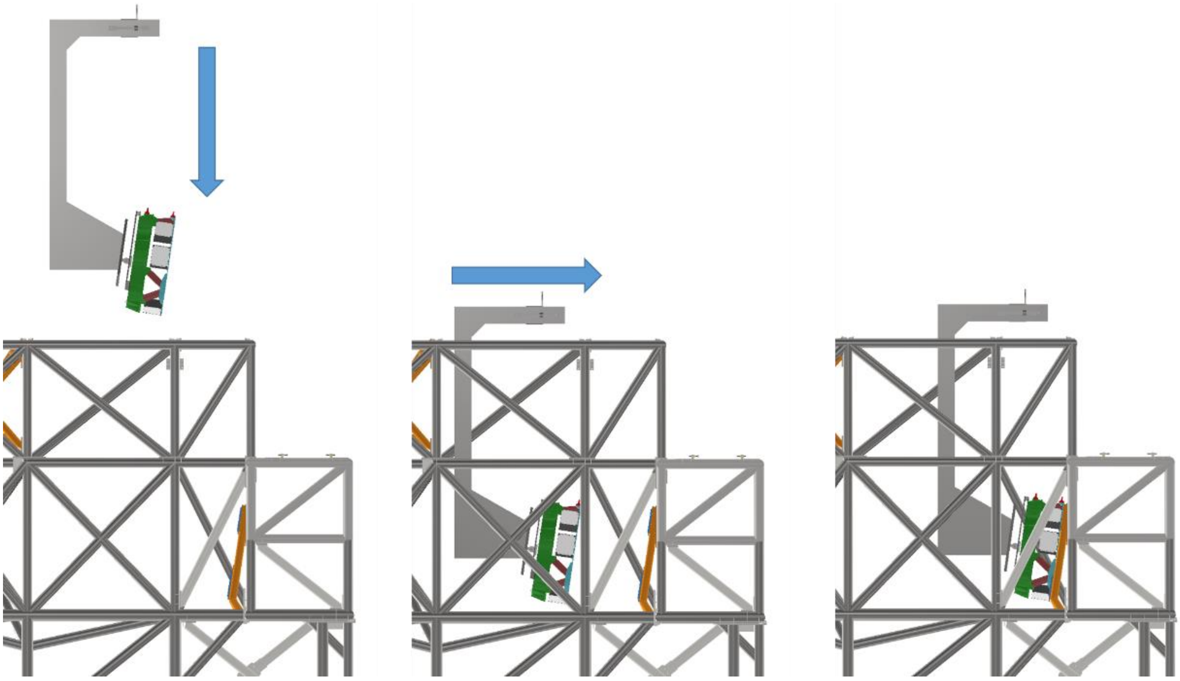


Figure 127: installation of M9 from the top of the MSS.

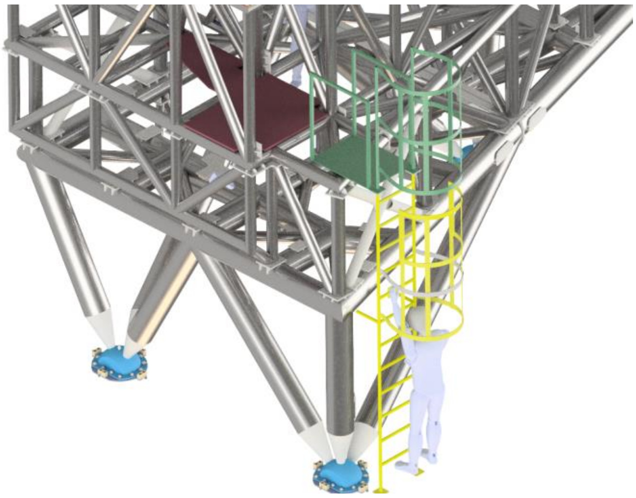


Figure 128: access to the back of M9, needed to secure M9 to its supporting structure, is done using a cage ladder outside the MSS, on MICADO side. The person should then enter into the CU area, where it can reach the interface point of M9.

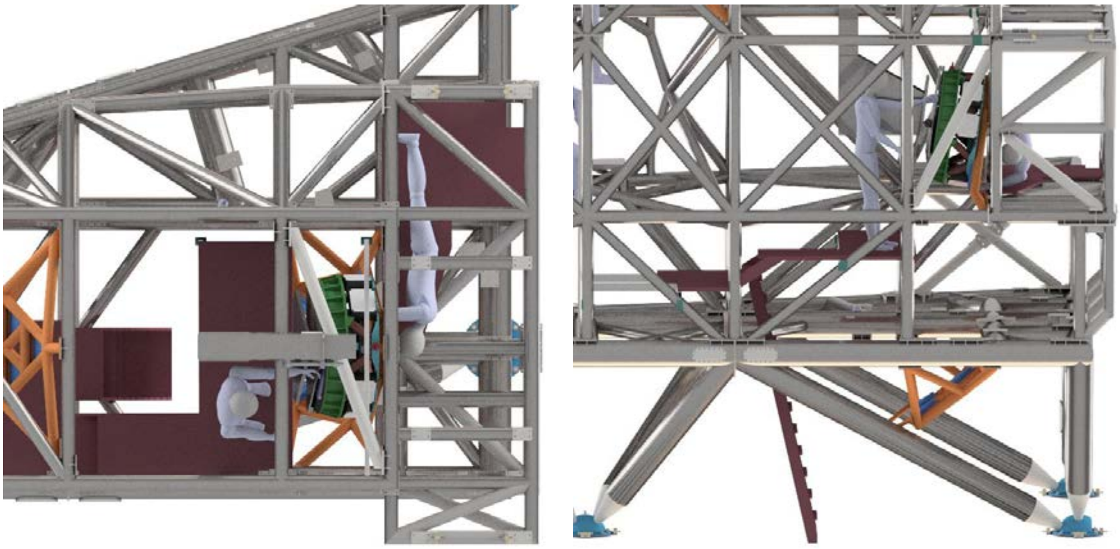


Figure 129: two persons are required to fix M9 to its supporting structure and to release the handling, one at the front and the other one at the back of the mirror. Left panel: MSS top view. Right panel: MSS side view.

Notes: if DM1 will not be available at this time, a solid mirror will be installed

The pre-requisites here are more due to the procedure sequence and to the necessity/wish to install just one main subsystem at a time

8.4.28 M10/DM2 installation

Purpose and functionality

DM2 is installed on the MSS; its position is adjusted by acting on the DM2 alignment manual adjustments using the BIH LTs against DM2 reference SMRS.

Responsible: MXO, JFA, GRO, ECA, LMA

HTs/SEq needed: BIH Bridge crane, Dedicated HTs, Scissor lifts

Success Criteria: M10/DM2 properly installed and in the nominal position given by the BIH LTs

Duration: 2 days

Prerequisites: 8.4.27 M9/DM1 installation

Procedure: Also for this mirror, the approach for its installation/removal in the MSS is the access from the top, removing the same beam (and thermal panel) removed for M8 installation, shown in Figure 124.

The handling concept is exactly the same shown for M6-M7-M8, while the dimensioning of the handling is of course different, due to the position of M10, deeper into the MSS.

Similarly to M8, two people (1 in front and 1 at the back of the mirror) are required for mirror installation/removal. The person in front of the mirror, who can reach there using the internal ladders, has the deputy of releasing the handling when M10 is secured to its supporting structure. The person at the back will fix the mirror to the supporting structure, in the same way shown for M6. Both are then necessary to drive the crane operator during installation/removal.

Figure 130: C-shaped handling for the installation of M10 in the MSS

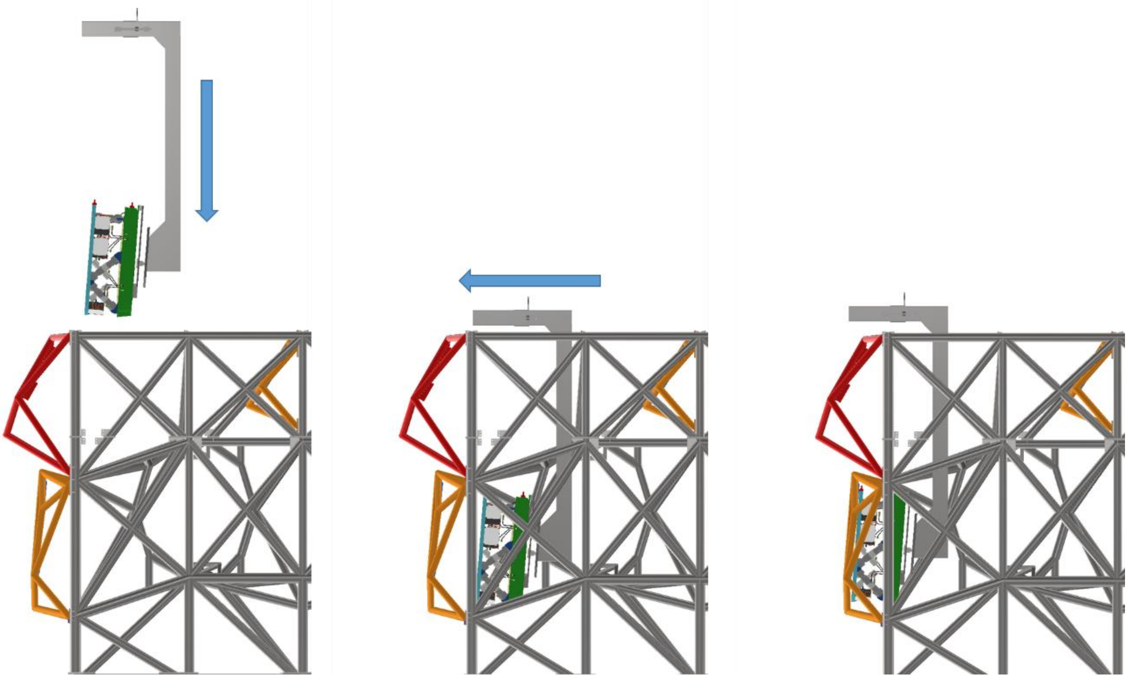


Figure 131: installation of M10 inside MSS in BIH and Nasmyth Platform. The hoisting point is always above the top part of MAORY main structure, so to avoid interferences between the crane chain and the beams of the main structure.

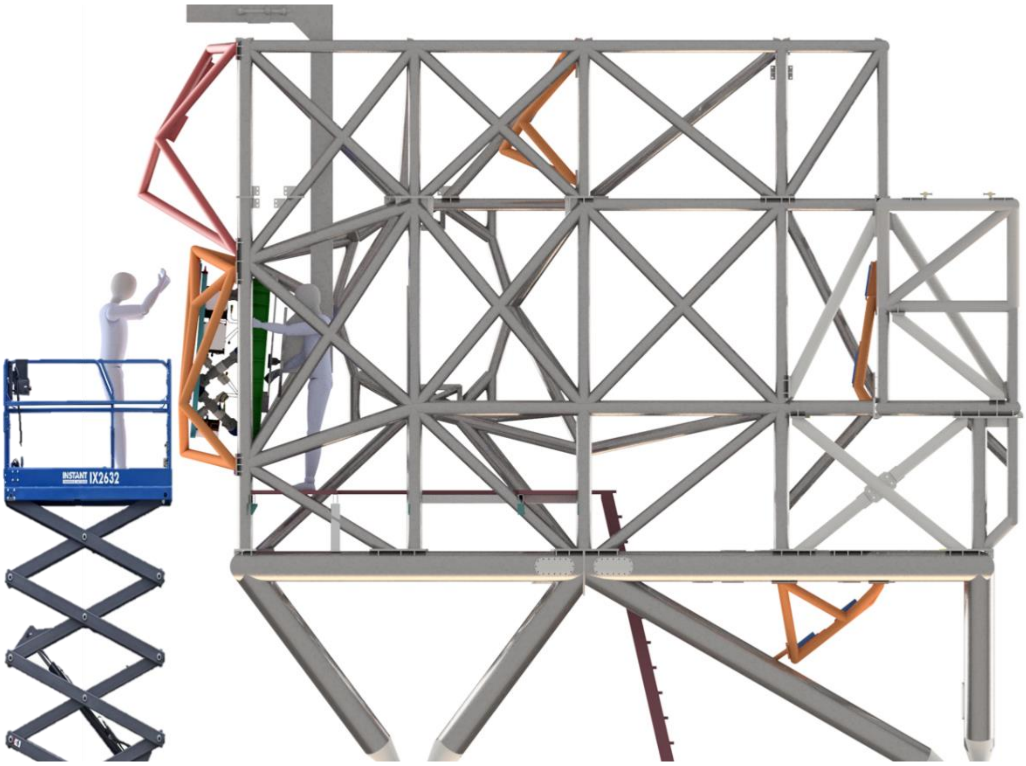


Figure 132: internal ladders (in garnet) to reach M10 front position and a scissor lift (that might be replaced by a temporary scaffolding) to reach M10 back position.

Notes: The pre-requisites here are more due to the procedure sequence and to the necessity/wish to install just one main subsystem at a time

if DM2 will not be available at this time, a solid mirror will be installed

8.4.29 M11 Installation

Purpose and functionality

M11 is installed on the MSS; its position is adjusted by acting on its TT and focus manual adjustments using the BIH LTs against M11 reference SMRS.

Responsible: JFA, ERE, LMA

HTs/SEq needed: BIH Bridge crane, Dedicated HT, Scissor lifts, internal platforms

Success Criteria: M8 properly installed and in the nominal position given by the BIH LTs

Duration: 1 days

Prerequisites: 8.4.28 M10/DM2 installation

Procedure: This mirror is not installed from the top of the MSS, thus it has the same mounting/dismounting procedure at BIH, IAA and Nasmyth Platform.

M11 has a mounting frame different from the ones we have seen in the previous sections, as it is equipped with motorized actuators and rotary base.

The idea for this mirror is to install/remove it together with the motors. This means that the mirror will be extracted together with its interface assembly, thus it is possible to interface the handling to the interface assembly rather than on the branches holding the mirror cover.

The handling has 3 forks to be inserted into 3 slots in M11 interface assembly, and they are secured by screws. A heim joint rod end on the handling allows tuning the position of the mirror in 3 DoFs, using some threaded rods on the fixed part of the handling. When the mirror has the correct orientation in the space, the interface assembly can be fixed to the MAORY main structure. Since the barycentre of the system moves by several centimetres, and mostly in one direction, with and without M11 connected to the handling, to avoid unwanted oscillations of the handling when releasing M11, the handling interface hook with the crane is mounted on a sliding system. Thus, when M11 is secured to MAORY main structure, before releasing the handling, the hook is slid to the position where the stand-alone handling is balanced, and only after this operation the handling is decoupled from M11.

One person is needed to fix M11 to the MSS and to engage/disengage the handling from M11. This person shall be on a scissor lift or a temporary platform located between MAORY and MICADO, in a position not interfering with the tower duct.

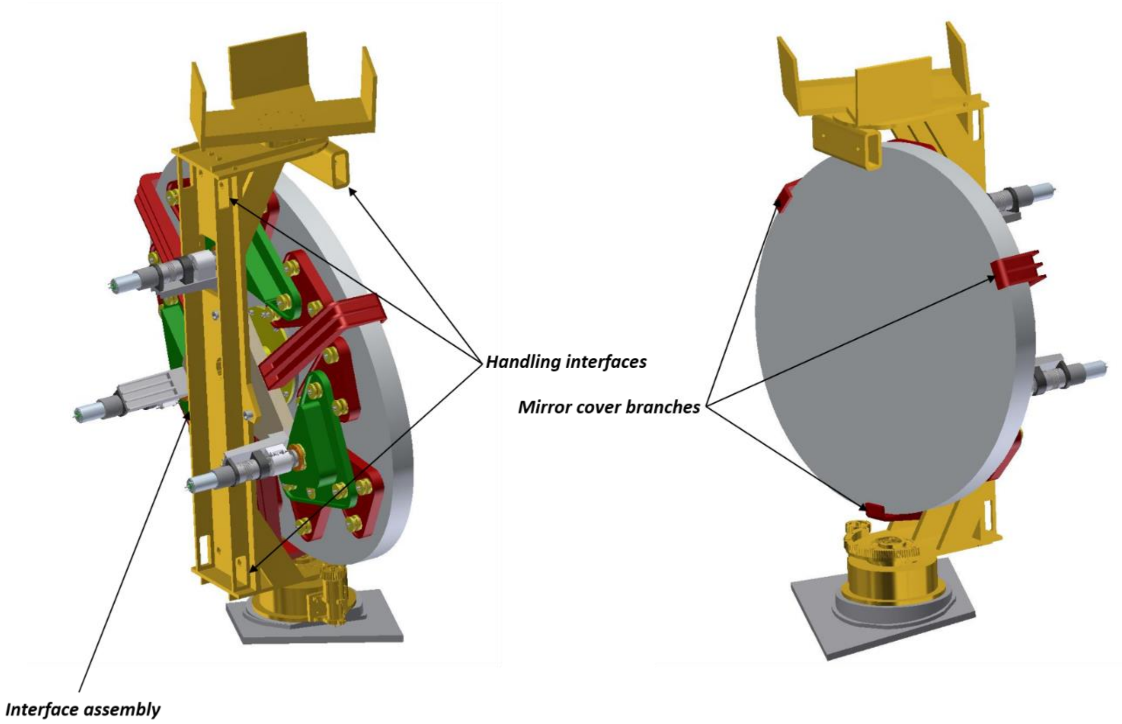


Figure 133: M11 assembly that will be inserted/extracted from the MAORY main structure.

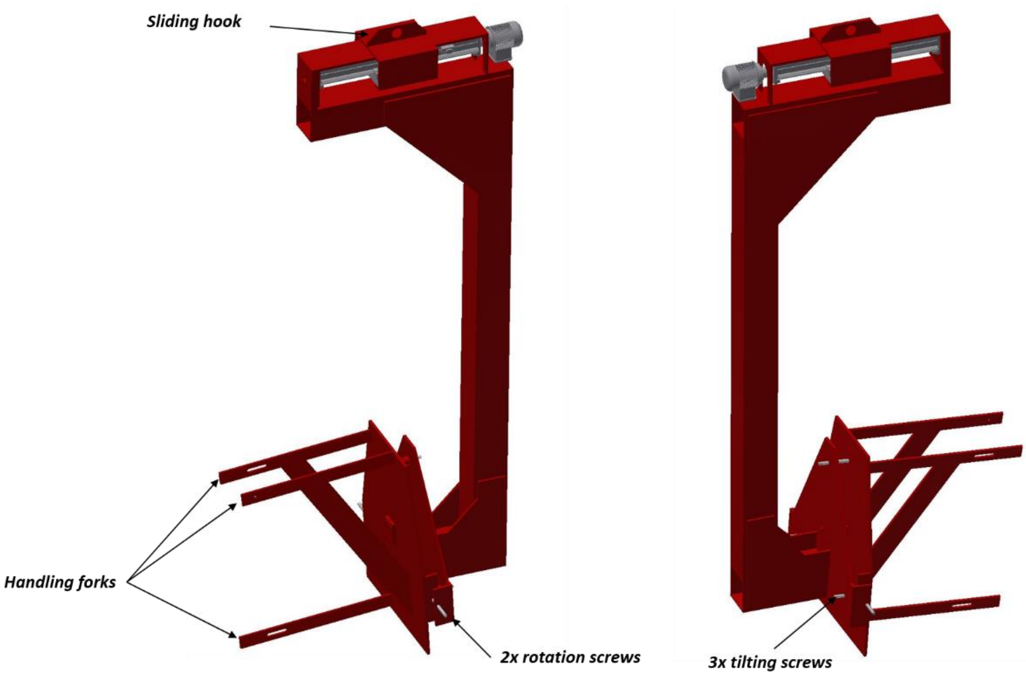


Figure 134: M11 installation/removal handling. The interface will be on the 3 forks. The handling will allow to fine tune the tip-tilt-rotation of the mirror during the installation. A sliding interface hook allows to re-balance the system when M11 is engaged/dis-engaged.

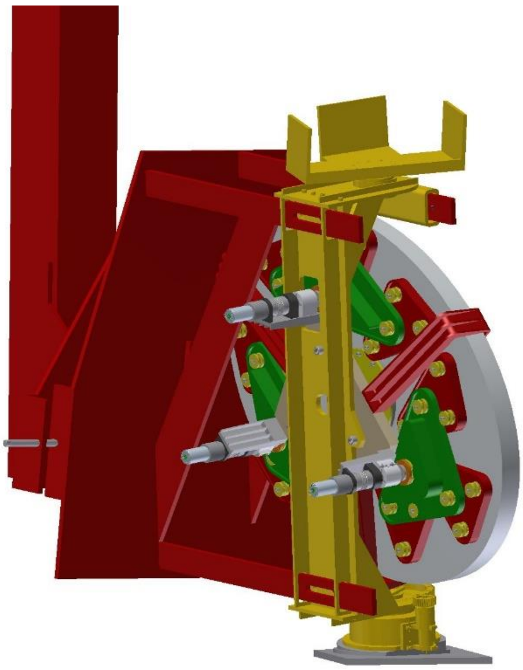


Figure 135: handling engaged to M11.

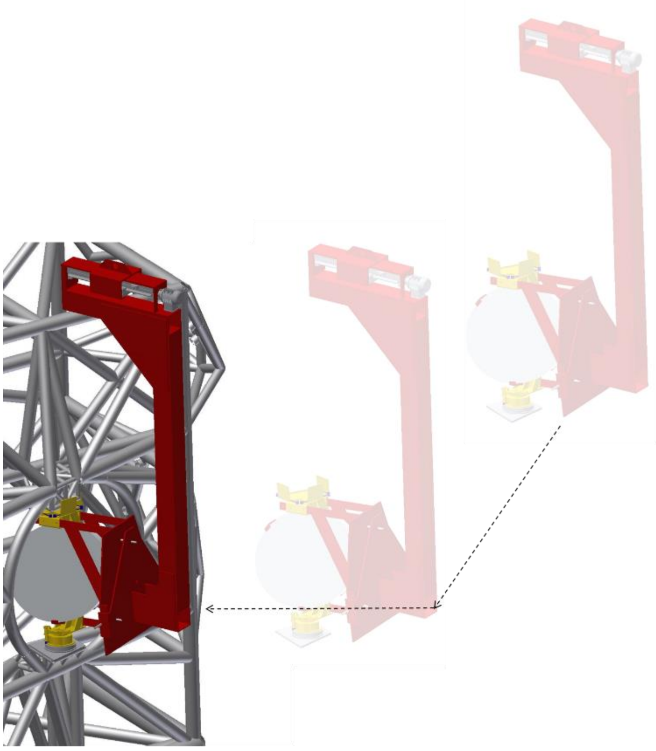


Figure 136: possible M11 installation path into MAORY main structure.

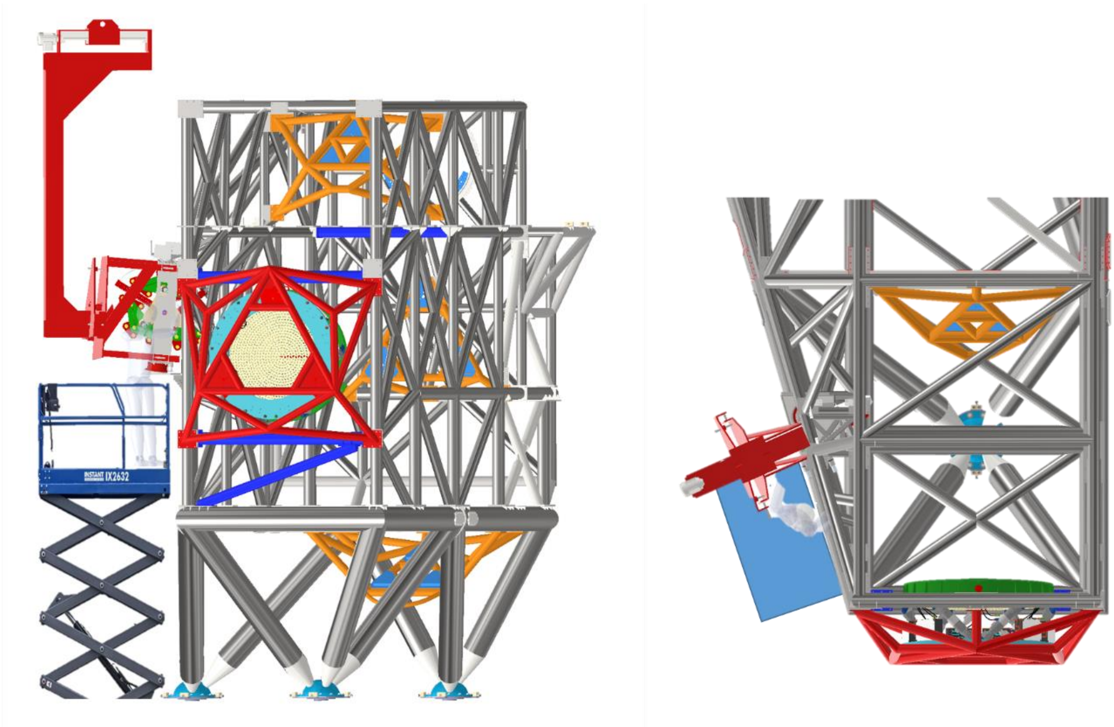


Figure 137: a single person, on a scissor lift or on a temporary platform, is sufficient for installation/removal of M11.

Notes: The pre-requisites here are more due to the procedure sequence and to the necessity/wish to install just one main subsystem at a time

8.4.30 CU selector and CU folding mirror installation

Purpose and functionality

The CU selector is installed on the MSS together with the dummy of the MCA and with the CU folding mirror assembled and integrated on it, motors are plugged and functional test are performed. The CU Selector will be delivered in Bologna fully assembled (without the two units needed for calibration) from Factory.

Responsible: VDC, VCI, GDR, GRO, JFA

HTs/SEq needed: BIH Bridge crane, Dedicated HTs, Scissor lifts

Success Criteria: Selector and CU properly installed and functional test all working

Duration: 2 day

Prerequisites: 8.4.29 M11 installation

Procedure: Before mounting the subsystem on the MSS we shall:

- Remove the enclosure of the subsystem (Figure 138 left side)
- Mount the Folding Mirror of the CU (FMCU) assembly and the MICADO MCA dummy on the sliding part of the CU Selector (Figure 138 right side)

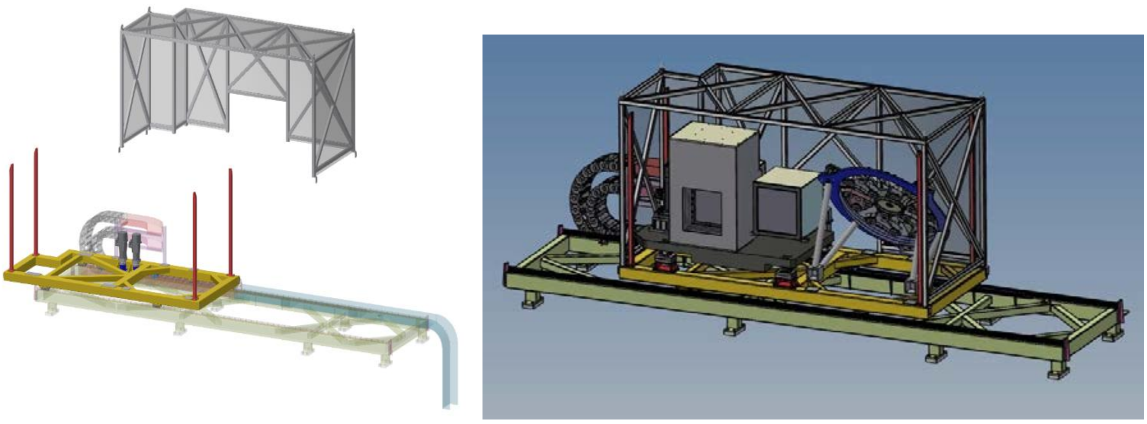


Figure 138: the CU selector with the enclosure removed for the installation of the MCA dummy and of the FMCU (left end side), and the CU selector fully assembled (right end side)

- Test and pre-align the FMCU
- Re-Install the enclosure of the CU sub-system
- Assemble the Enclosure on the MSS bottom part of the CU Selector and in the MSS front side adjacent to the CU selector location, before mounting the CU Selector (Figure 139 left side)

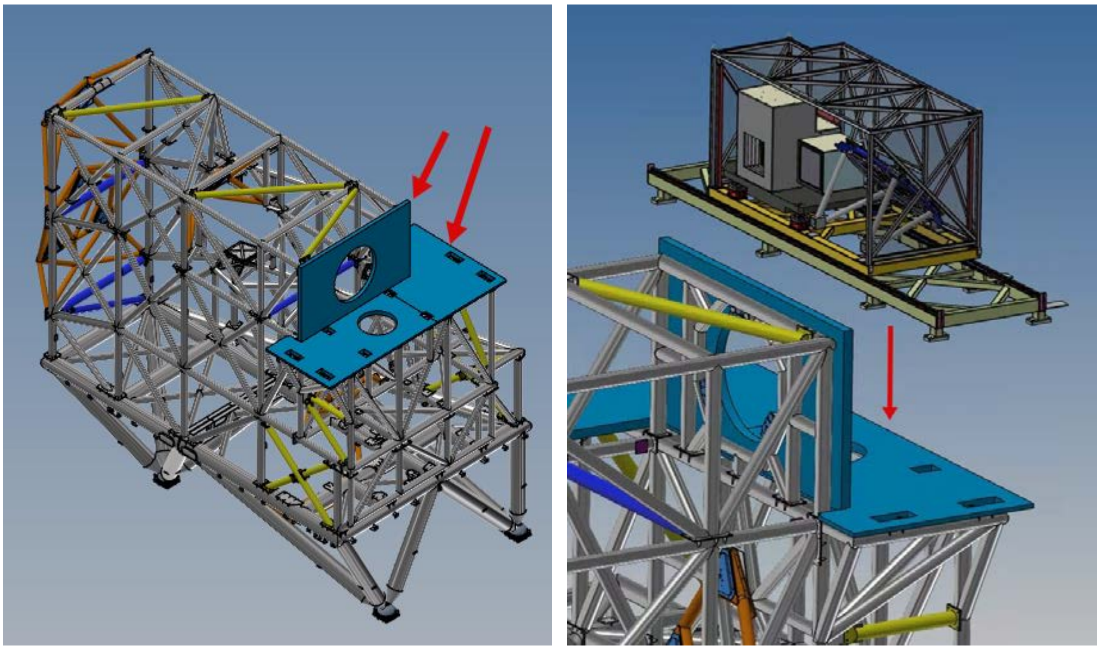


Figure 139: installation of the part of the cover below and adjacent to the CU sub-system (left end side) and craining of the CU selector and CU sub-system on the MSS (rught end side)

- The cable chain must be partially disassembled for the part where the cables are not present.
- Cables must be collected and provisionally secured.

Then, using four slings connected at the ends of the fixed frame, the Calibration CU selector will be position using the BIH crane and screw it on the MSS ((Figure 139 right side).

Notes:

8.4.31 Calibration Unit installation

Purpose and functionality

The CU is installed on the MSS; its position is adjusted by acting on the CU alignment manual adjustments using the BIH LTs against the CU reference SMRS.

Responsible: GDR, IDA, GRO, JFA

HTs/SEq needed: BIH Bridge crane, Dedicated HTs, Scissor lifts, Cherry picker

Success Criteria: CU properly installed and in the nominal position given by the BIH LTs

Duration: 2 days

Prerequisites: 8.4.30 CU Selector installation

Procedure: The MAORY Calibration Unit sources box will be integrated onto MAORY main structure as a single piece, once internally fully aligned.

The concept is quite similar to the one devised for the LGS-o, i.e. lowering with the crane the CU box onto two rails defining the path inside MAORY main structure, and when the CU box is leaning on the rails, push it towards its working position.

The first step is to create an access in the MSS for the CU, and this is done by removing the beam shown in Figure 140. The beam shown in the left panel of Figure 140 (MICADO side) is the one to be removed to actually install/remove the CU, while removing the beam on the opposite side is necessary to allow a person enter into the MSS to fix the CU to its interface points later in the procedure.

Due to the dimensions of the CU, part of the rails will protrude out of the MSS (as for the dichroic and 1st folding mirror), thus a support is required. Also, the rails will be located at 3.5 meters above the ground, so some persons are required at this height to both mount the rails to their supports and, in a second moment, to release the handling lowering the CU on the rails.

Some caged ladders, to be mounted temporarily at both the relevant (for CU installation) sides of MSS, allow to the operators to enter into the MSS and to remove the aforementioned beams. At the MICADO side two small platform, fixed to the ground, have a double scope:

- Providing a working area for two persons, who have to fix the protruding part of the rails to the support beams, to disengage the handling lowering the CU once it is secured to the rails and to release the rails from the supporting beams when CU installation is over.
- Provide support to the rails protruding parts.

A view of the SEq required for CU installation is shown in Figure 141.

The rails are lowered by the crane and then inserted into MSS. Most likely, part of the rails will permanently live inside the MSS, and only a shorter pair of rails will be mounted when necessary. As an alternative, the rails will be anyhow divided in more pieces, to avoid dealing with the installation of very long rails. Two people inside the MSS fix the rails to the supporting plates, while two people on the temporary scaffolding at the MICADO side fix the protruding part of the rails to the supporting beams, that are integrating part of the scaffolding.

For installation, the CU is mounted on a trolley which can slide on the rails, by means of 4 M20 screws. Another handling embraces the CU and is connected to its base frame through 4 others M20 screws. The latter handling allow to pick-up the calibration unit together with the trolley and to position it on the rails. At the top of the handling there is a hoist ring for the crane hook.

When the CU lies on the rails, the two persons on the temporary scaffolding fasten the 4 security clamps on the trolley to the rails (Figure 145). Now, the hoist ring position can be tuned to the handling barycenter position without the CU and the handling is released by removing the 4 M20 screws.

The CU now can slide inside the MSS (Figure 146). Due to its weight, a system using steel cables and a winch is under study.

CU shall slide inside the MSS till the 3 guiding screws on the CU are aligned to the spherolinder (previously aligned) in the MSS (Figure 147). The two persons working inside the MSS now insert the guiding screws in the spherolinder and also the 2 screw jacks (next to the guiding screws) into their seats (Figure 148).

The 4 M20 screws fixing the CU to the handling can now be removed (Figure 149), and screwing more the 2 screw jacks, one side of the CU is lifted up by ~ 24 mm so to free the trolley, which can now slide out the MSS, where it can be removed with the crane (Figure 150)

At this point, unscrew the screw jacks so that the CU is lowered, remove the guiding screws and replace them with the locking screws, equipped with cup springs (Figure 151).

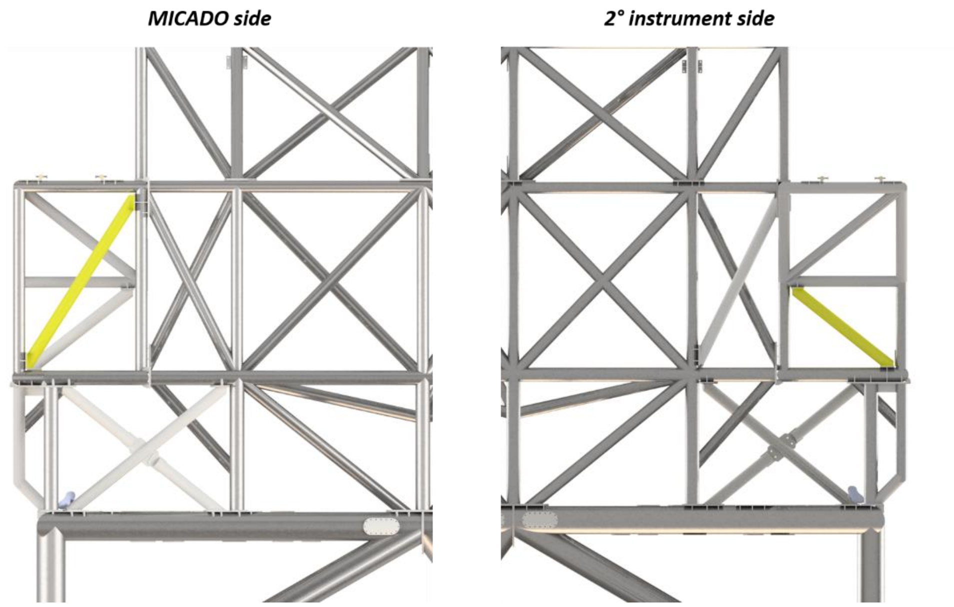


Figure 140: yellow beams shall be removed to allow installation of Calibration Unit box.

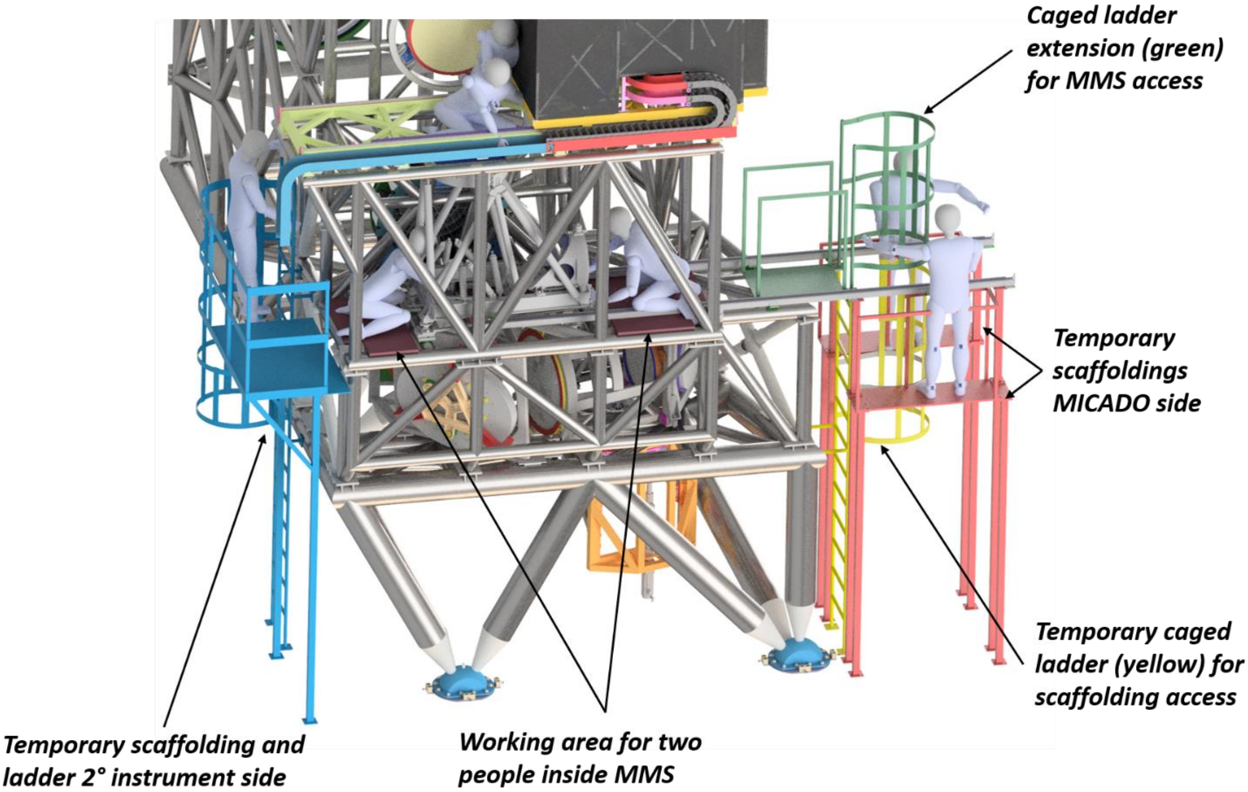


Figure 141: temporary scaffolding mounted at both relevant side of MSS to allow all the operations necessary for CU installation/removal. The blue caged ladder on the left is needed to access the MSS from the 2nd instrument side, while the yellow caged ladder + its green extension allows accessibility into MSS from MICADO side. The green extension shall be removed before lowering the CU on the rails, of course. The yellow caged ladder stand-alone, provide accessibility to the red temporary scaffoldings.

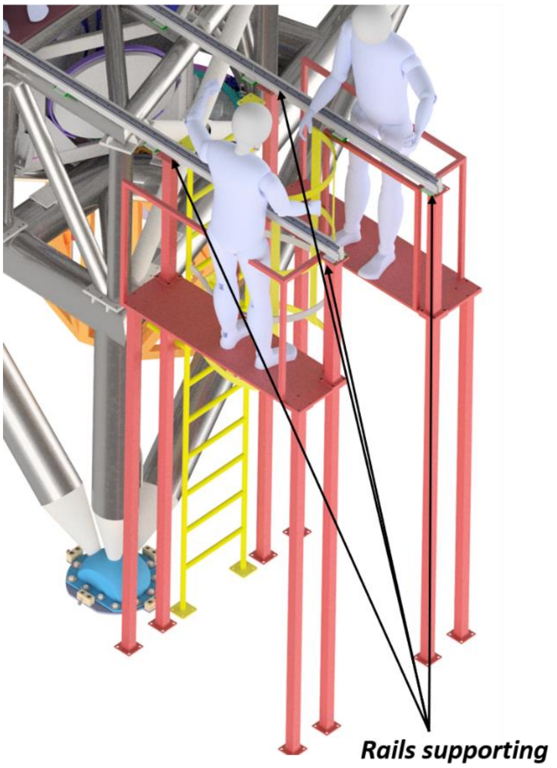


Figure 142: red scaffoldings provide a working area to 2 people and support to the protruding part of the rails.

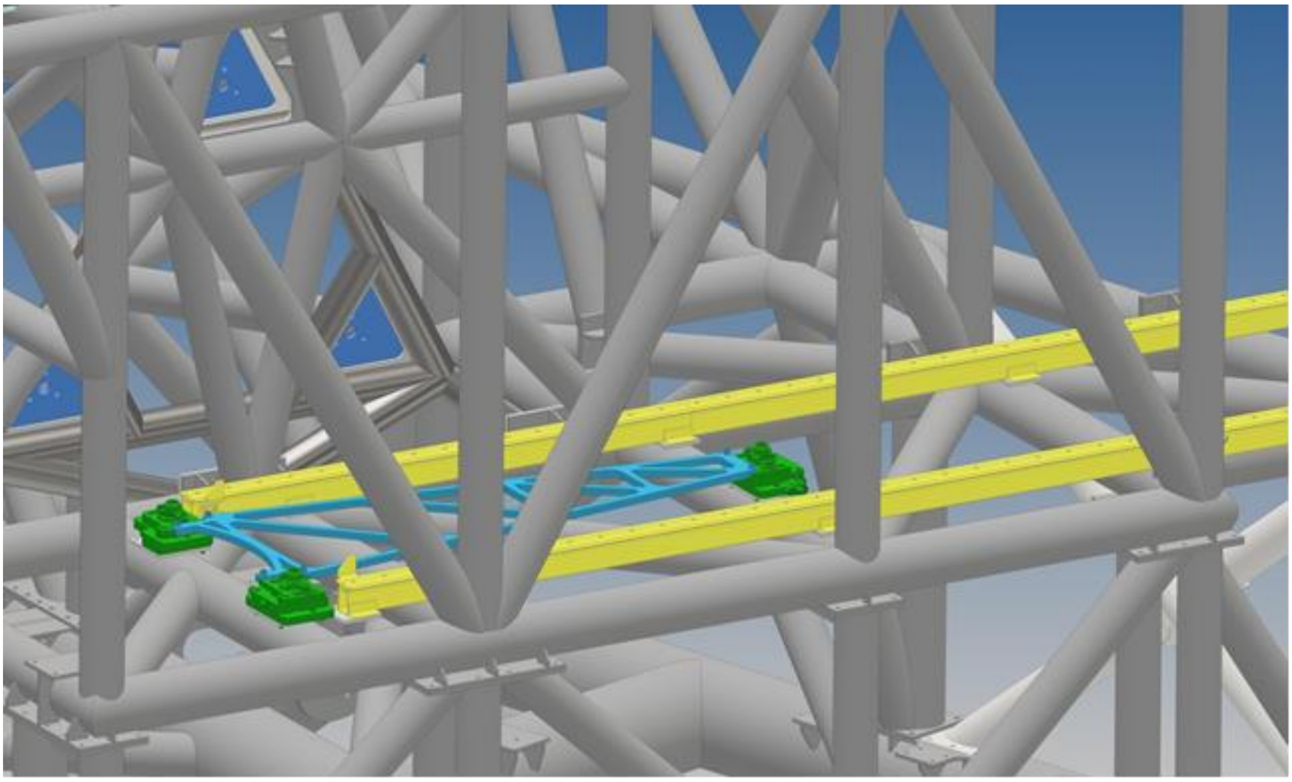


Figure 143: CU rails installed inside MSS (in yellow).

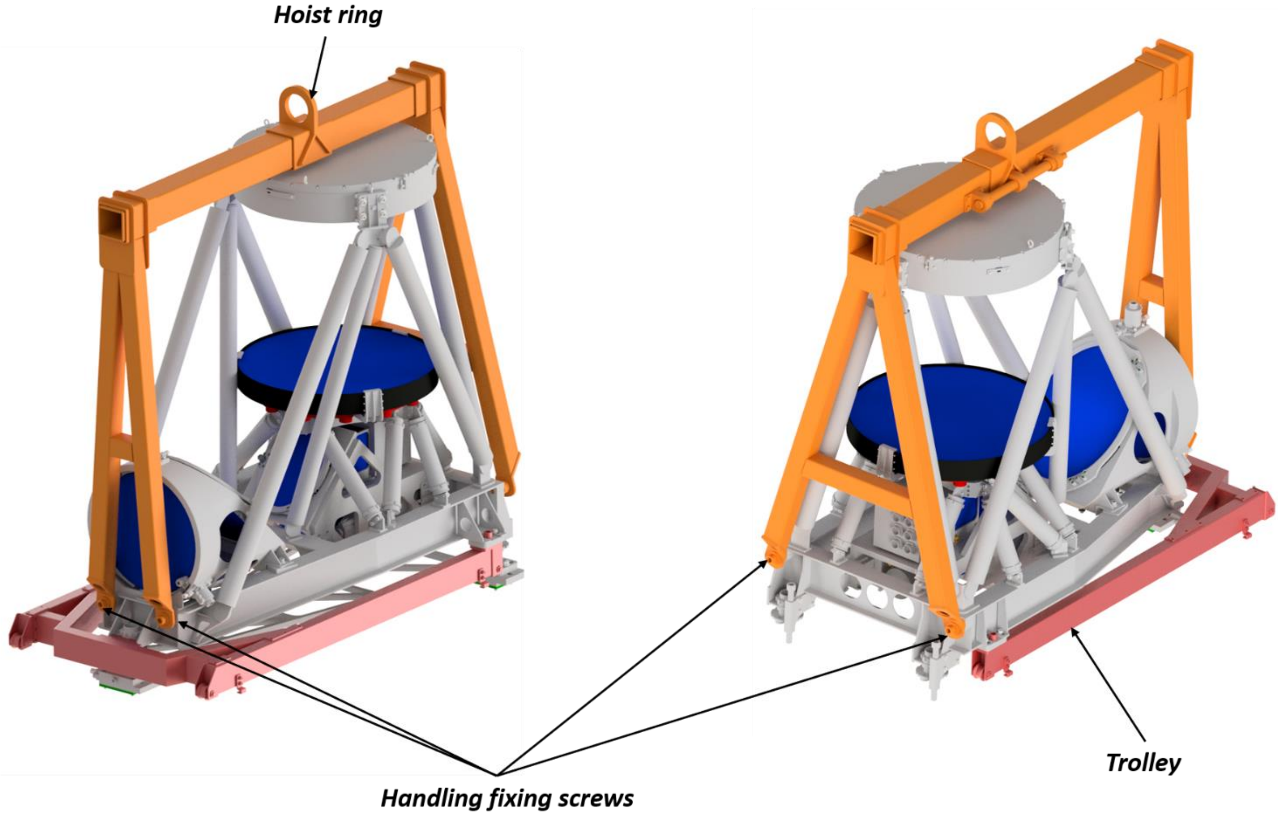


Figure 144: in orange, the handling to pick-up and lower the CU on the rails. It is fixed to the CU base frame with 4 M20 screws. In red, the trolley that will allow the CU to slide on the rails to its nominal position inside the MSS.

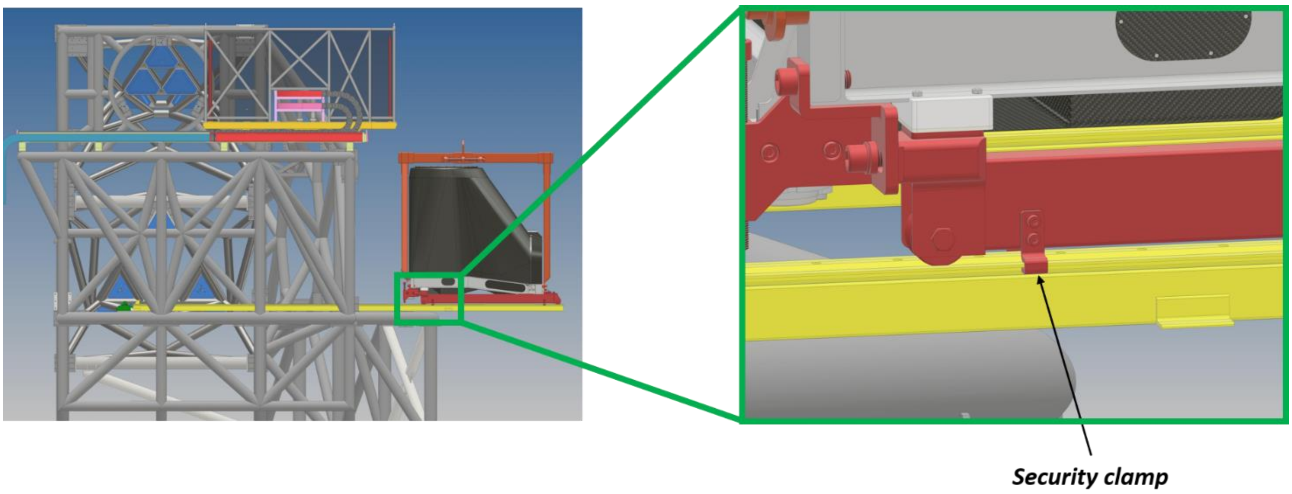


Figure 145: 4 security clamps shall be engaged to the rails before sliding the CU inside the MSS.

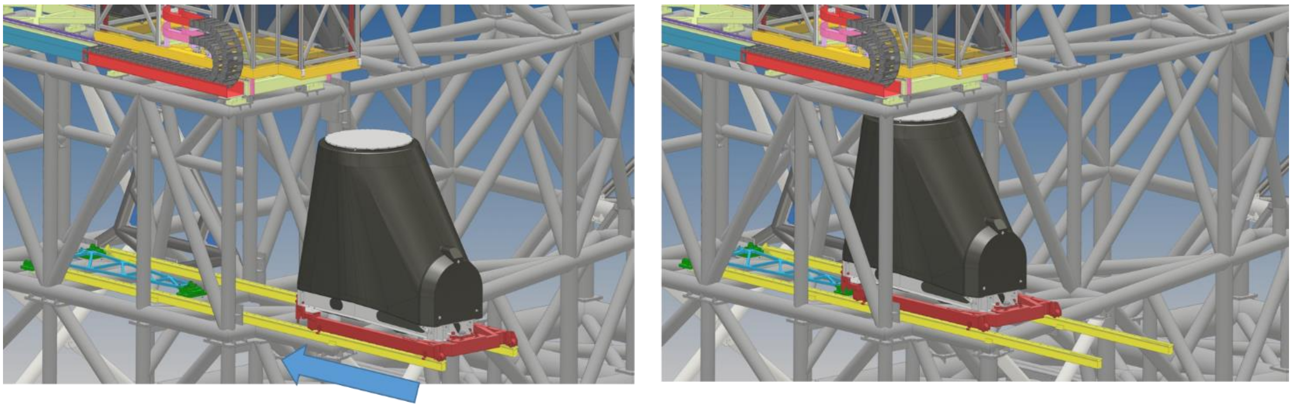


Figure 146: the CU slides inside MSS.

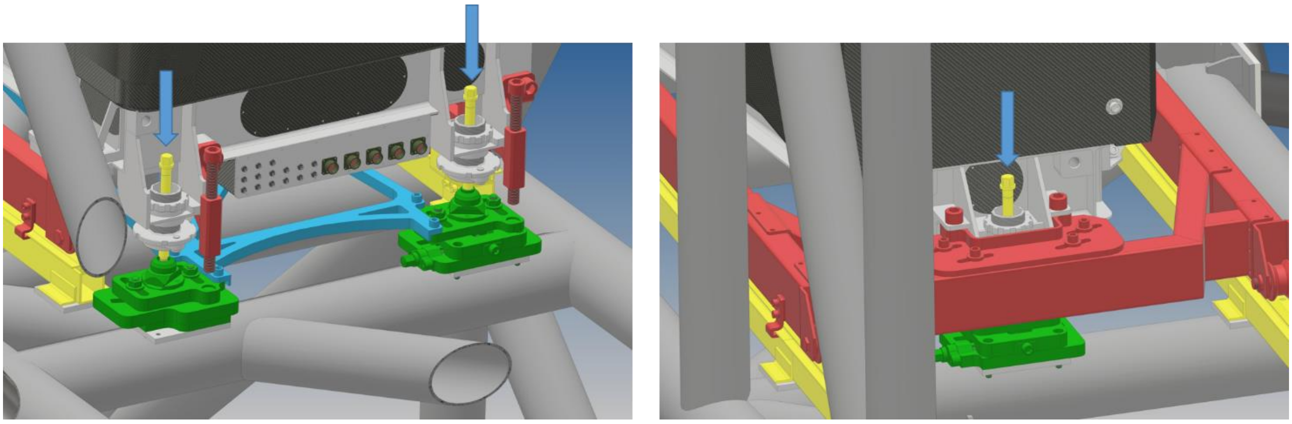


Figure 147: in yellow and pointed by the blue arrows, the guiding screws that must be aligned to the spherolinder (in green)

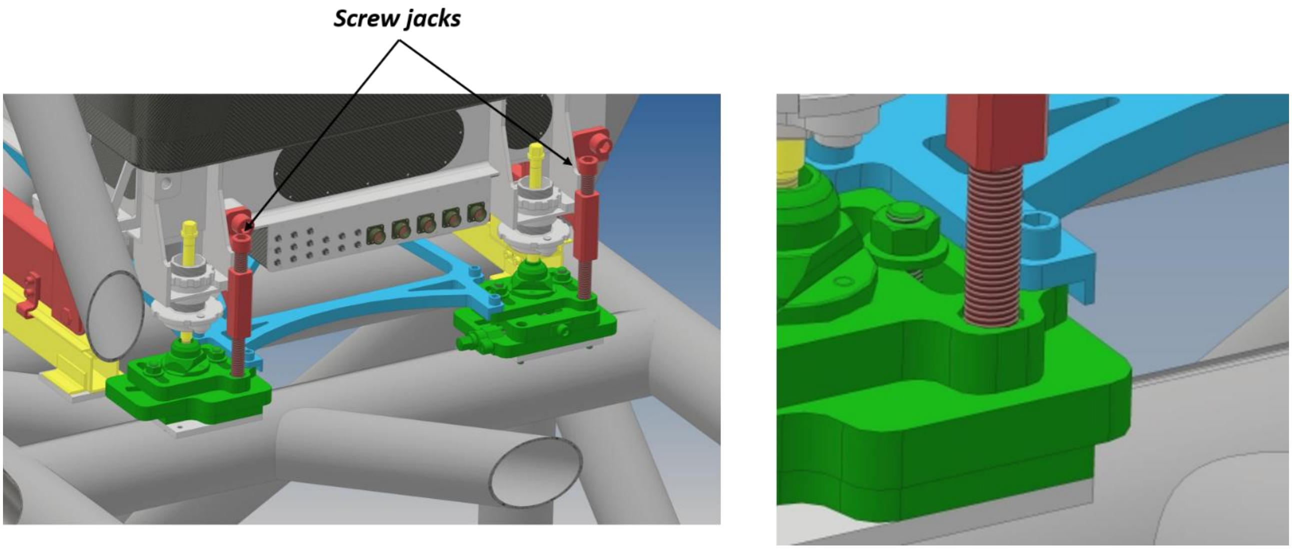


Figure 148: in red, the 2 screw jacks that shall be screwed all the way down till they enter into their seat in the green plate.

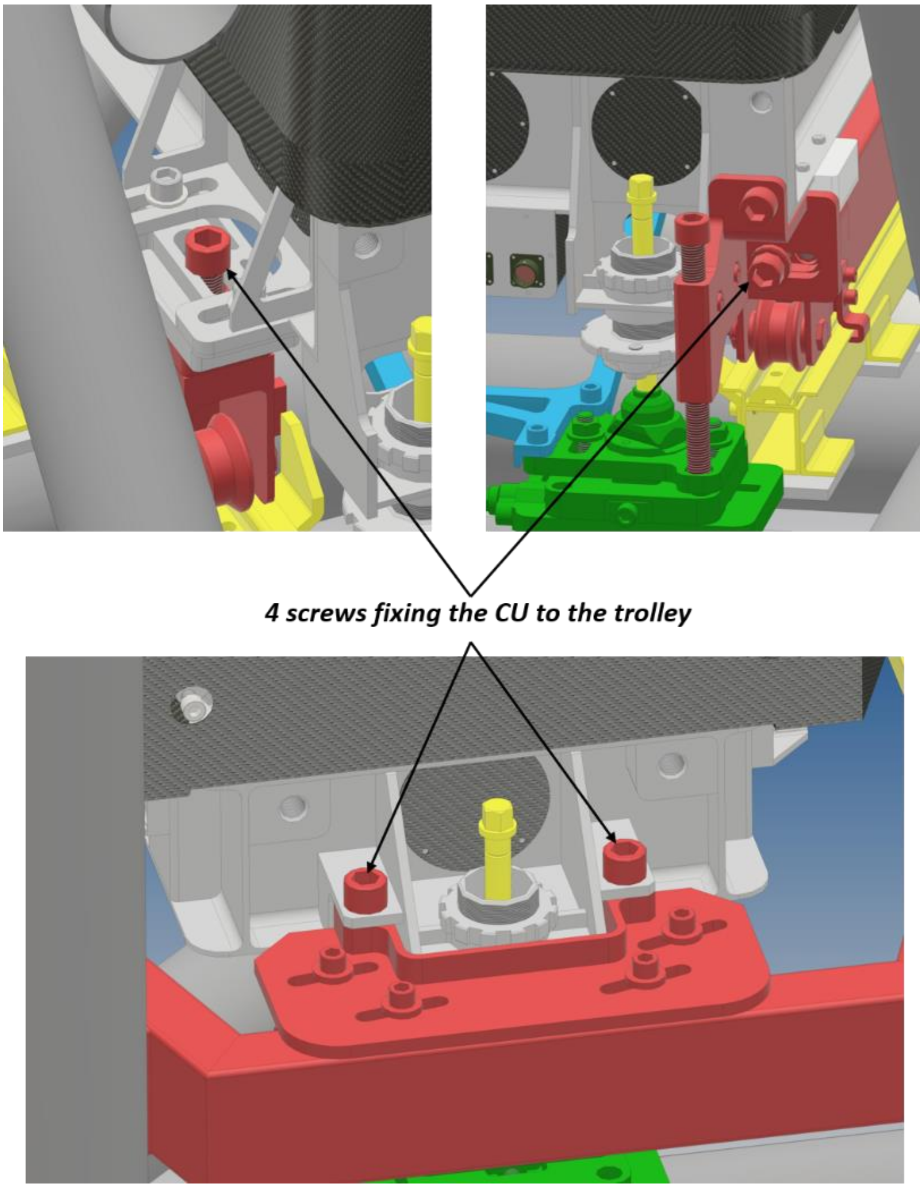


Figure 149: the 4 M20 fixing screws to be removed to free the trolley

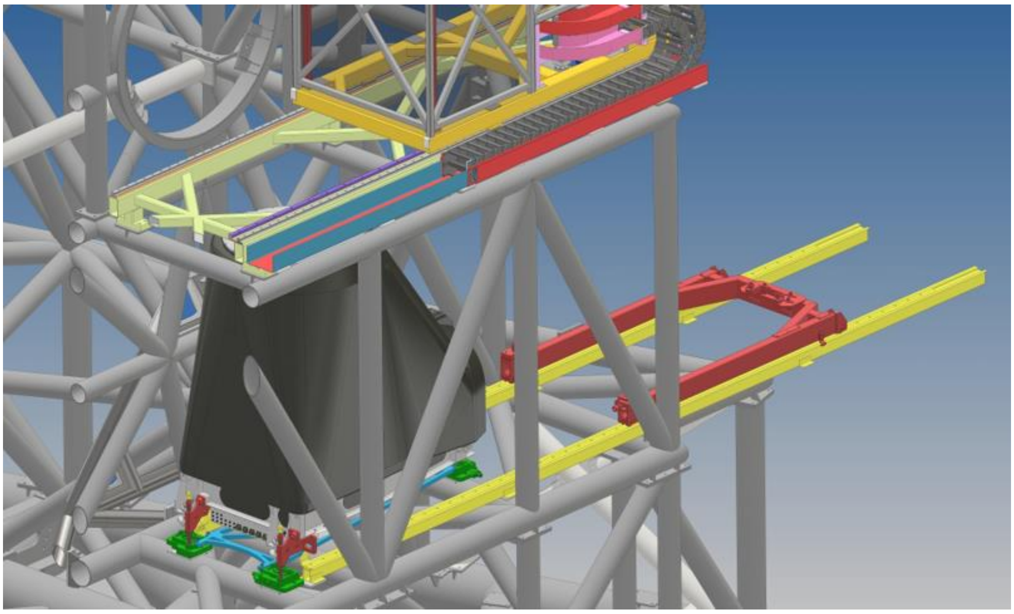


Figure 150: trolley slides out

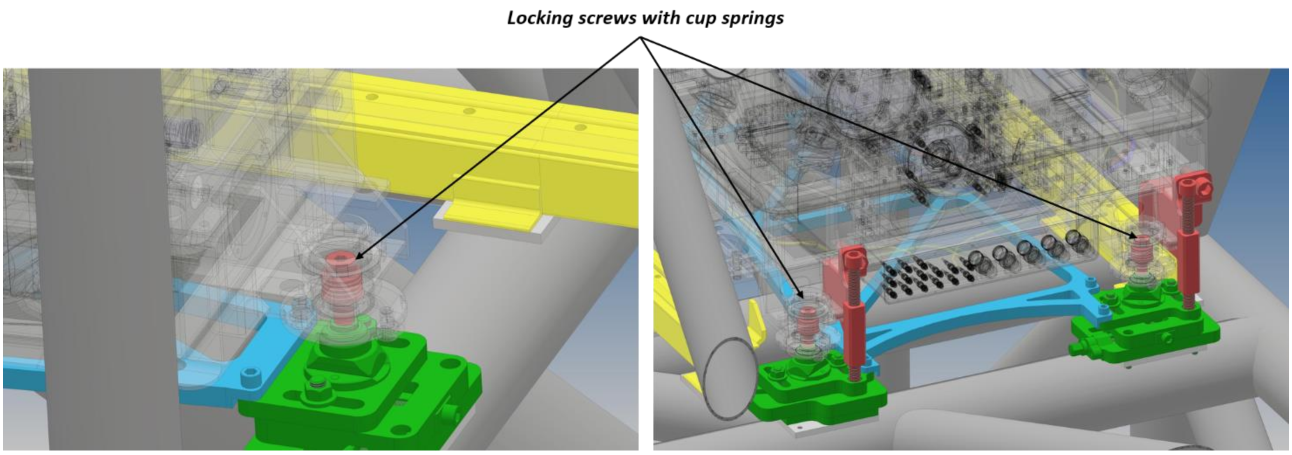


Figure 151: replace the guiding screws with the locking screws and tightnen them.

Notes:

8.4.32 Dichroic Installation

Purpose and functionality

The Duchroic is installed on the MSS; its position is adjusted by acting on its TT and focus manual adjustments using the BIH LTs against its reference SMRs.

Responsible: LMA, ERE, VDC, VCI, JFA

HTs/SEq needed: BIH Bridge crane, Dedicated HT, internal platform

Success Criteria: Dichroic properly installed and in the nominal position given by the BIH LTs

Duration: 1 days

Prerequisites: 8.4.31 CU installation

Procedure: Also in this case, the installation/removal procedures are the same in BIH, IAA and Nasmyth Platform.

The Dichroic is installed using a rail system that allows to slide it in its final position. For its installation, an opening on the side of MSS is required, and this is obtained by removing the beams shown in Figure 152.

After removal of the beams and of the corresponding thermal panel, the rail shall be mounted inside the MSS. The rail orientation is optimized to transfer the dichroic from outside the MSS just in front of its interface points inside MSS. To ease the process, it is under evaluation to split the rail in two parts, keeping a part always mounted into the MSS, and having only a short piece of rail to be mounted at the occurrence.

The part of the rail protruding from the MSS unload part of the weights to a beam connected to the ground, while the part inside the MSS is attached to the MSS itself..

When the rail is in place, a special handling is mounted on the carts sliding on the rail. The scope of this handling is to keep the dichroic with the same orientation it will have when mounted in the MSS

In order to position the dichroic on the sliding handling, the plan is to use a C-shaped handling, interfaced to 3 points on the dichroic opto-mech, as for most of the other optical elements in MAORY.

The dichroic connected to the C-shaped handling approaches the sliding handling on the rail, to which it is connected using 3 other points on the opposite side of the opto-mech. When the dichroic is secured to the second handling, the C-shaped handling can be removed and taken away by the crane.

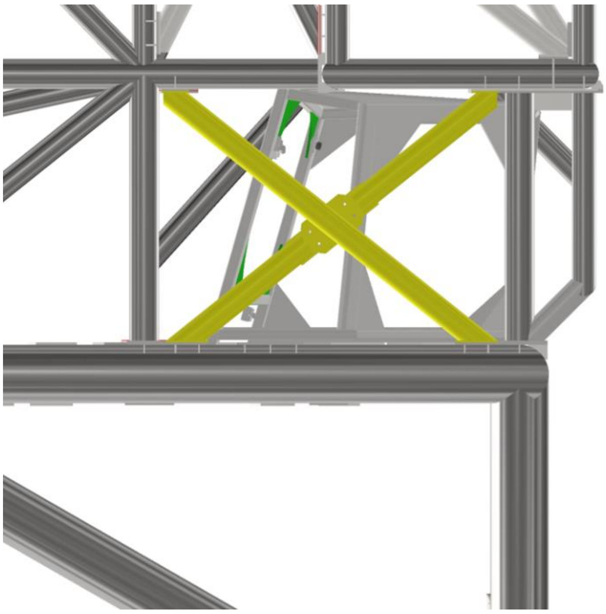


Figure 152: beams to remove to permit installation of dichroic

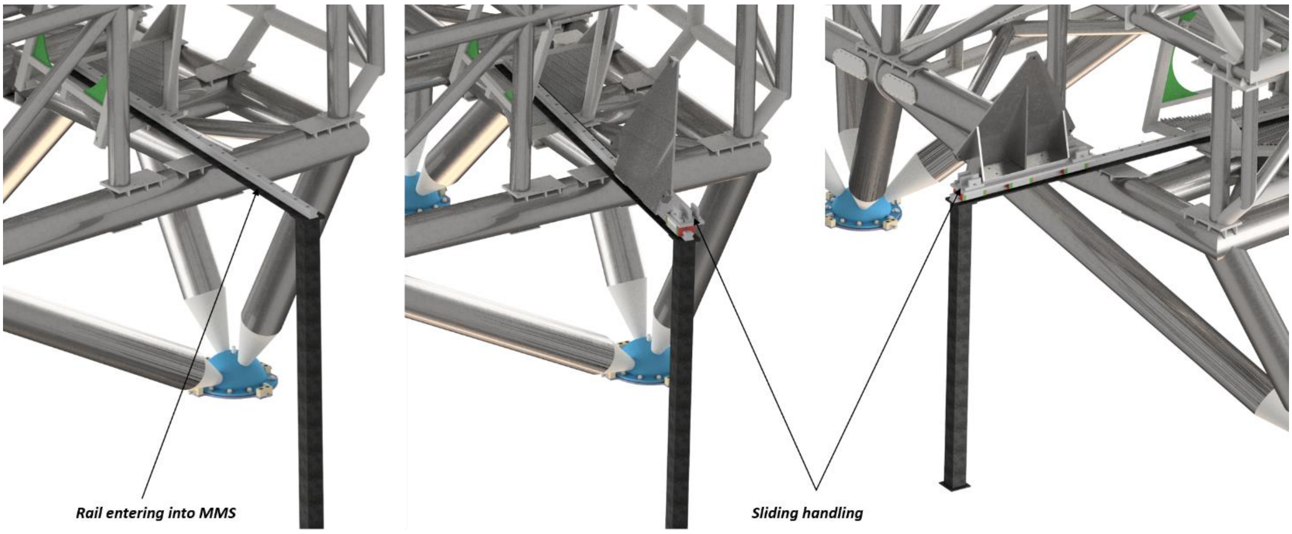


Figure 153: the rail and sliding handling to be used for the installation of the dichroic.

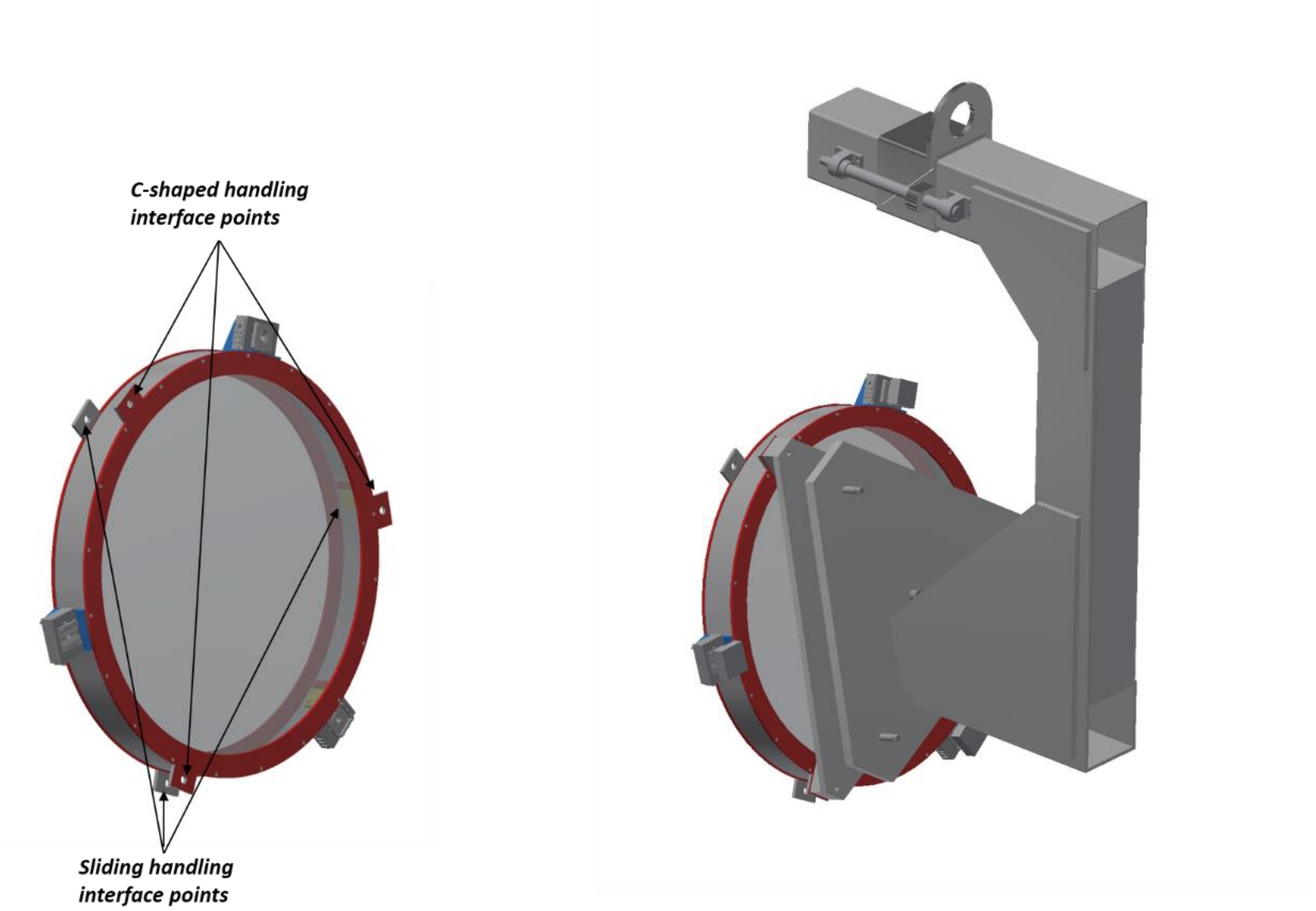


Figure 154: the C-shaped handling used to position the dichroic on the rail system

To allow the right positioning of the dichroic assembly on the cart and to properly connect it to the cart itself, normal portable ladders are used by two persons, positioned one per side of the rail.

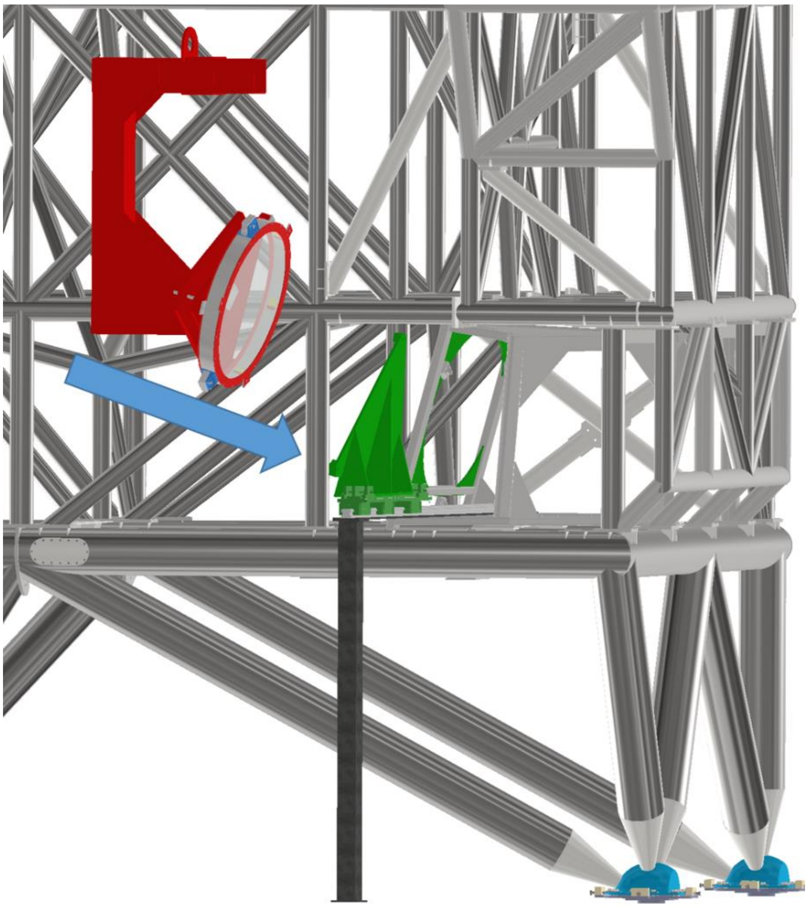


Figure 155: dichroic is installed to the sliding handling (in green in the figure). This handling is on carts which can slide into MAORY main structure.

At this point, the dichroic can be manually slid on the rail toward the mount. Some security blocks on the rail prevent the dichroic to slide off the rail.

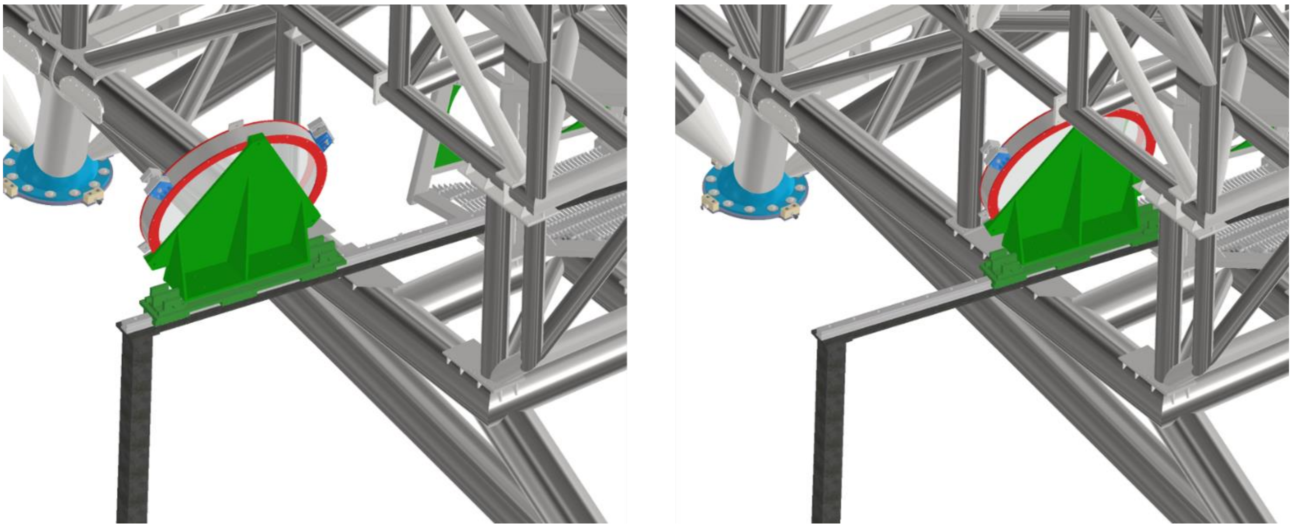


Figure 156: the dichroic assembly connected to the cart sliding on the rail system.

The cart has the possibility to move in the direction of the dichroic optical axis, by acting on two set of screws positioned at the two cart sides, with a total travel of about ±15mm. Thus, the system will be nominally kept at distance of about 10mm with respect to the interfaces where it has to be fixed, and only after reaching the correct position, it will be pushed toward the interfaces, where it will be connected using the dedicated screws.

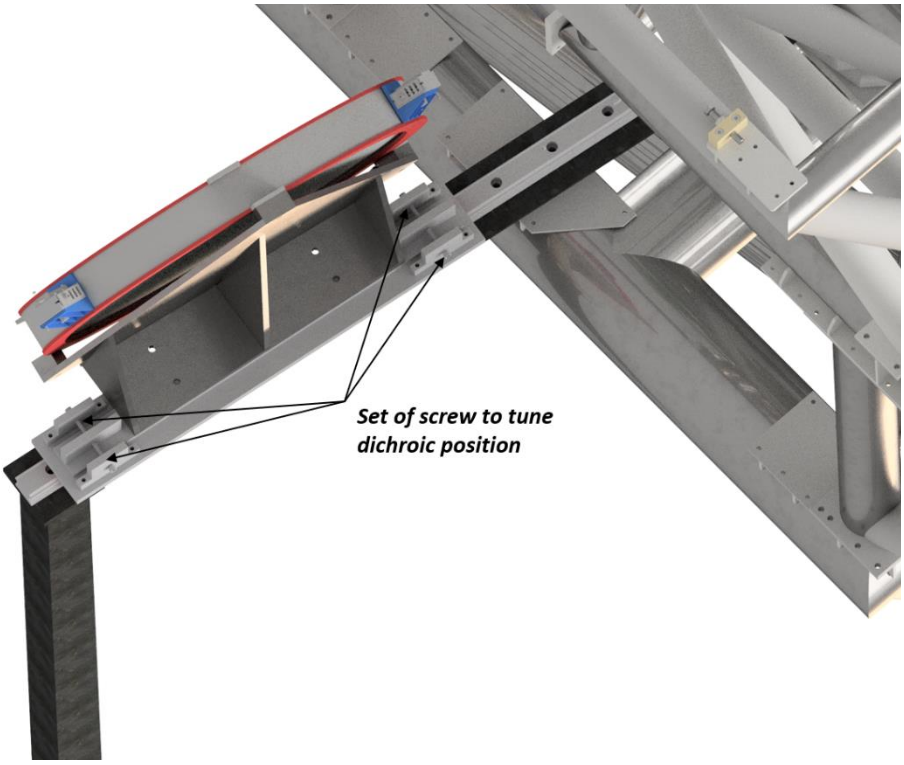


Figure 157: set of screws to adjust dichroic position with respect to its interface to MAORY main structure

One person on a platform positioned on the back side of the dichroic (see Figure 158) can perform this operation, and access to such platform on the bench structure is ensured using a normal portable ladder, due to the low position of the dichroic in the MSS.

For accessibility reasons, the installation of the dichroic will take place before installing the 1st LGSO folding mirror.

All the described operations will not invade the 2nd instrument allocated volume.

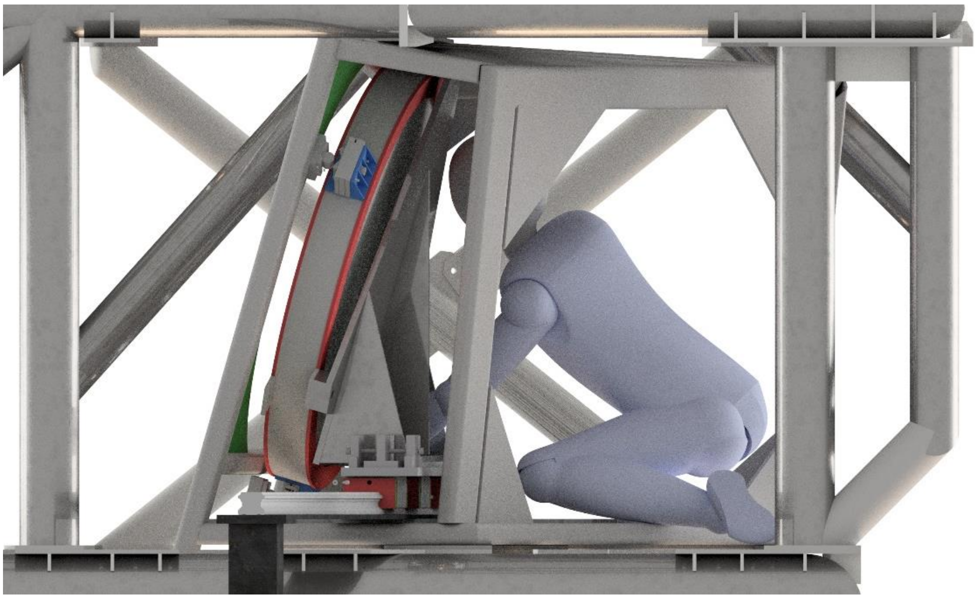


Figure 158: a person will access into the dichroic+1st LGSO folding mirror supporting structure to fix the dichroic to its interfaces and release the sliding handling.

Notes:

8.4.33 First Folding Mirror LGSO Installation

Purpose and functionality

The first folding mirror of the LGSO is installed on the MSS and its preliminary alignment is carried on using the MSS LTs and the SMRs positioned on the mirror

Responsible: ERE, JFA, LMA, ECA, GRO

HTs/SEq needed: BIH Bridge crane, Dedicated HT, internal platform

Success Criteria: Mirror properly installed in its nominal position

Duration: 1 day

Prerequisites: 8.4.32 Dichroic installation

Procedure: The 1st folding mirror LGSO is installed using a rail system that allows to slide it in its final position. For its installation, an opening on the side of MSS is required, and this is obtained by removing the beams shown in Figure 152.

After removal of the beams and of the corresponding thermal panel, the rail shall be mounted inside the MSS. The rail orientation is optimized to transfer the dichroic from outside the MSS just in front of its interface points inside MSS. To ease the process, it is under evaluation to split the rail in two parts, keeping a part always mounted into the MSS, and having only a short piece of rail to be mounted at the occurrence.

The part of the rail protruding from the MSS unload part of the weights to a beam connected to the ground, while the part inside the MSS is attached to the MSS itself.

When the rail is in place, a special handling is mounted on the carts sliding on the rail. The scope of this handling is to keep the 1st folding mirror LGSO with the same orientation it will have when mounted in the MSS

In order to position the dichroic on the sliding handling, the plan is to use a C-shaped handling, interfaced to 3 points on the dichroic opto-mech. In this mirror, the kinematics are mounted at the mirror coated side, differently from all the other mirrors, which have the kinematics at the back side and it is not equipped with any security branch at the front. For this reason, the C-shaped handling will be interfaced to the three M12 fixing screws that will be later inserted into the kinematics Figure 159).

The 1st folding mirror LGSO connected to the C-shaped handling approaches the sliding handling on the rail, to which it is connected using 3 other points and 3 other screws on the opposite side of the opto-mech (Figure 162). When the dichroic is secured to the second handling, the C-shaped handling can be removed and taken away by the crane.

To allow the right positioning of the 1st folding mirror LGSO on the cart and to properly connect it to the cart itself, normal portable ladders are used by two persons, positioned one per side of the rail.

At this point, the 1st folding mirror LGSO can be manually slid on the rail toward the mount. Some security blocks on the rail prevent the dichroic to slide off the rail.

The cart has the possibility to move in the direction of the dichroic optical axis, by acting on two set of screws positioned at the two cart sides, with a total travel of about ±15mm. Thus, the system will be nominally kept at distance of about 10mm with respect to the interfaces where it has to be fixed, and only after reaching the correct position, it will be pushed toward the interfaces, where it will be connected using the dedicated screws. One person at the back of the 1st folding mirror LGSO is necessary to secure it to its interface inside the MSS and to disengage the handling.

All the described operations will not invade the 2nd instrument allocated volume.

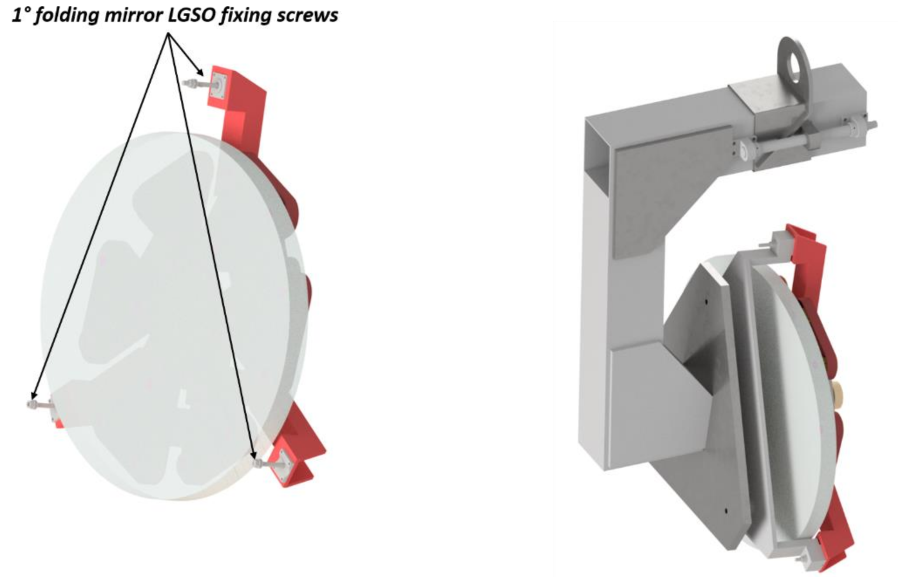


Figure 159: : the C-shaped handling used to position the 1st folding mirror LGSO on the rail system.

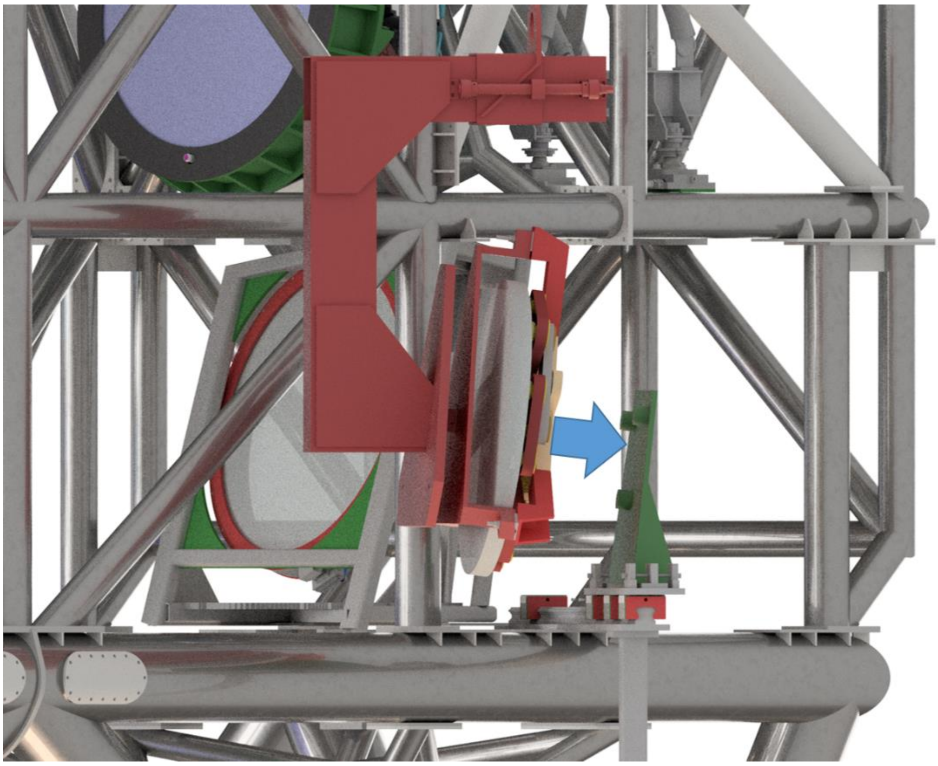


Figure 160: 1st folding mirror LGSO on C-shaped handling approaching the sliding handling on the rail.

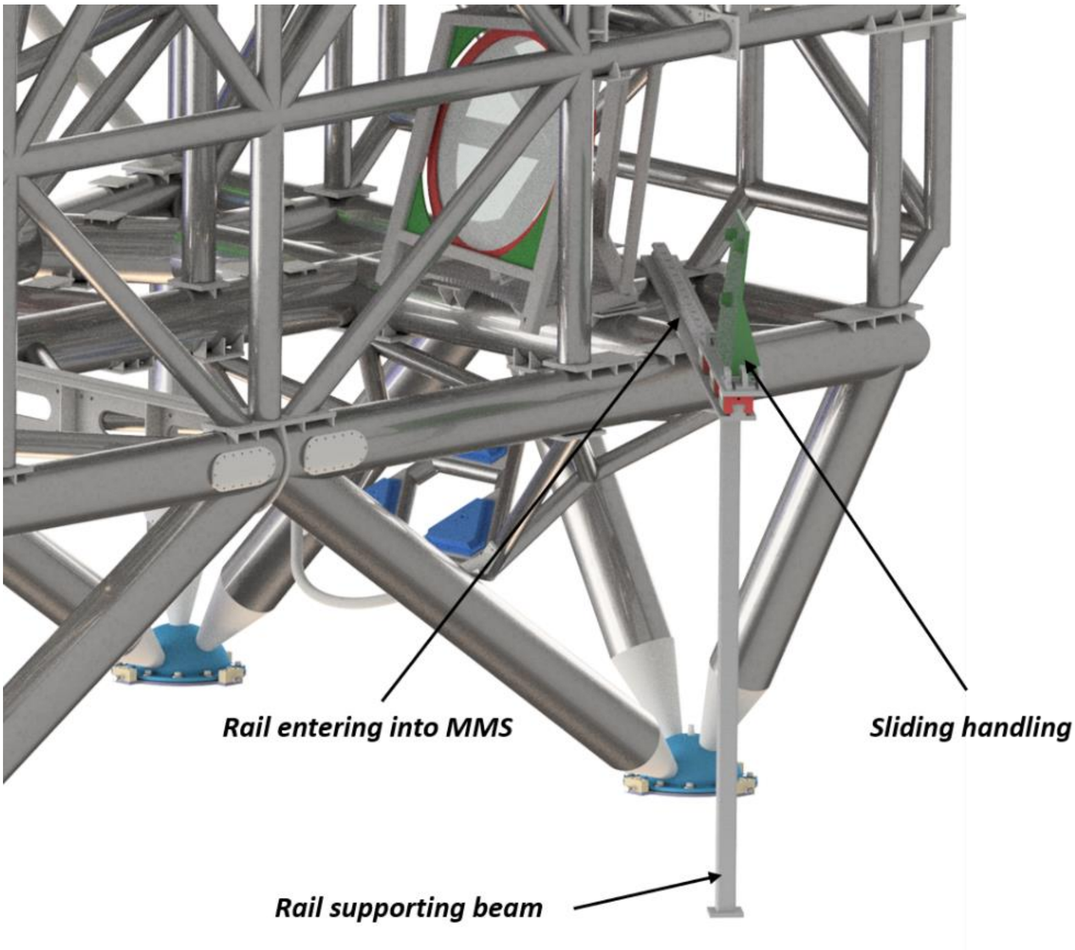


Figure 161: the rail and sliding handling to be used for the installation of the 1st folding mirror LGSO.

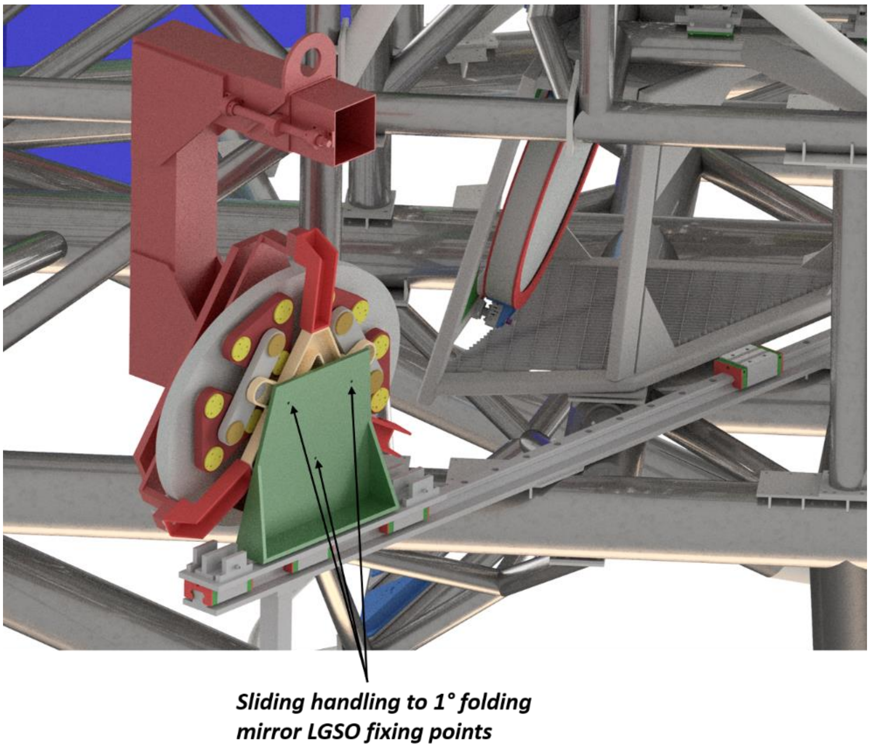


Figure 162: the 1st folding mirror LGSO is interfaced to the sliding handling through 3 screws at the back of its opto-mech.

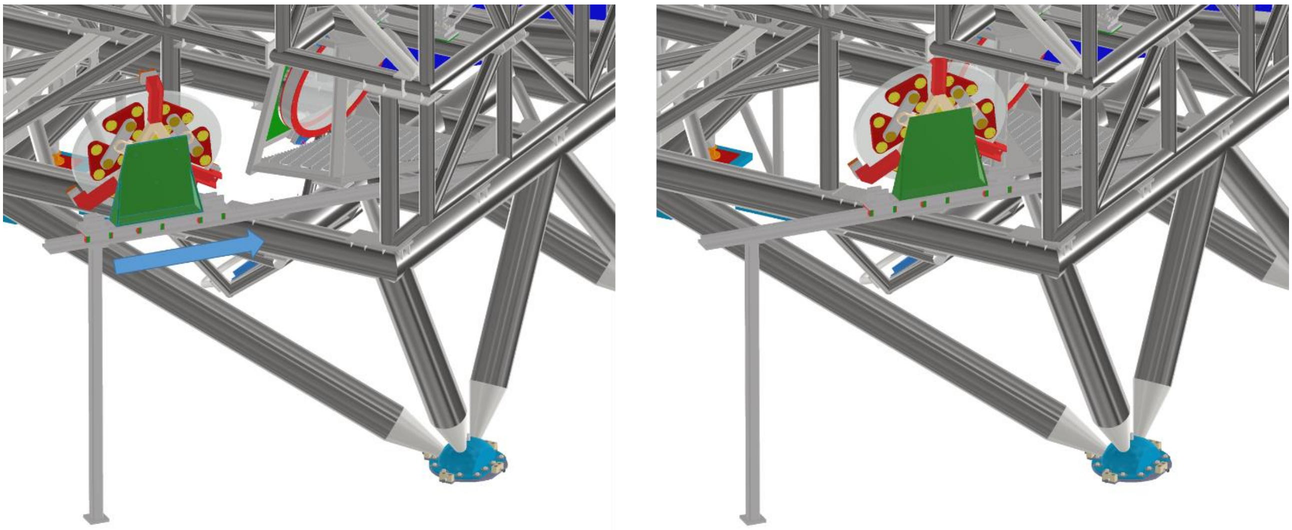


Figure 163: the 1st folding mirror LGSO assembly connected to the cart sliding on the rail system.

Notes:

8.4.34 LGSO installation

Purpose and functionality

The LGSO is installed on the MSS; its position is adjusted by acting on the LGS-O alignment manual adjustments using the BIH LTs against the LGS-O reference SMRS. The accuracy achievable through the SMRs won't be enough to properly align the LGS-O, that will thus need a dedicated alignment procedure. The following procedure is TBD and TBC with MICADO team, as the LGS-o would be very close to MICADO volume in some parts of this procedure.

Responsible: ERE, LMA, JFA, ECA, GRO

HTs/SEq needed: BIH Bridge crane, Dedicated HTs and SEqs, Scissor lifts, Portable ladders

Success Criteria: LGS-O properly installed

Duration: 2 days

Prerequisites: 8.4.33 First LGSO folding mirror installation

Procedure:

The LGSO structure is composed by four lenses and three mirrors. These elements are separated in three different groups: the first folding mirror FM1 is attached to the structure that hold at the same time the dichroic. The third folding mirror FM3 is mounted on a separate structure above the LGS module. The other elements (all the lenses and the second folding mirror) are mounted inside a structure that has been previously assembled in a lab or by the manufacturer.

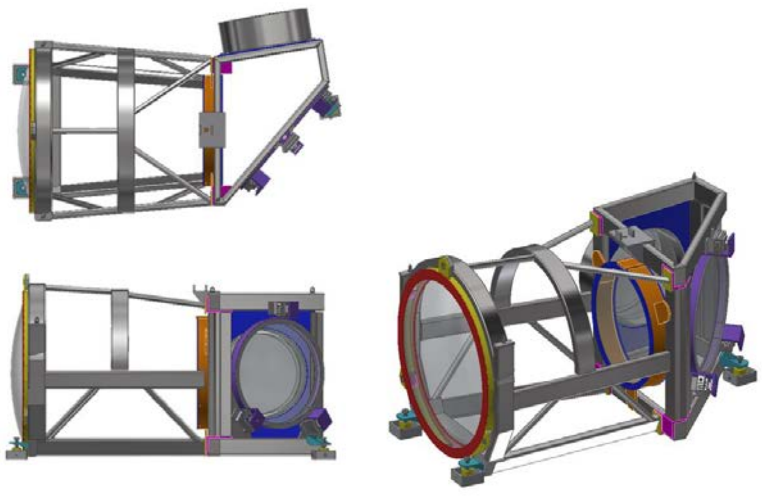


Figure 164 LGSO scheme after the manufacturer integration

In order to insert the LGSO inside the MAORY main structure the first operation is to remove the two beams that block the entrance for the LGSO, at the MICADO side of the MSS. Then, in order to have the possibility to move the objective inside the MSS, guide rails must be installed. These consist in two rails of different shapes (v-groove and Plane). The position where the rails are fixed inside the MSS is reported in Figure 165. Figure 166 shows the beams, in yellow, that shall be removed to allow LGSO installation. They can be unscrewed from the outside.

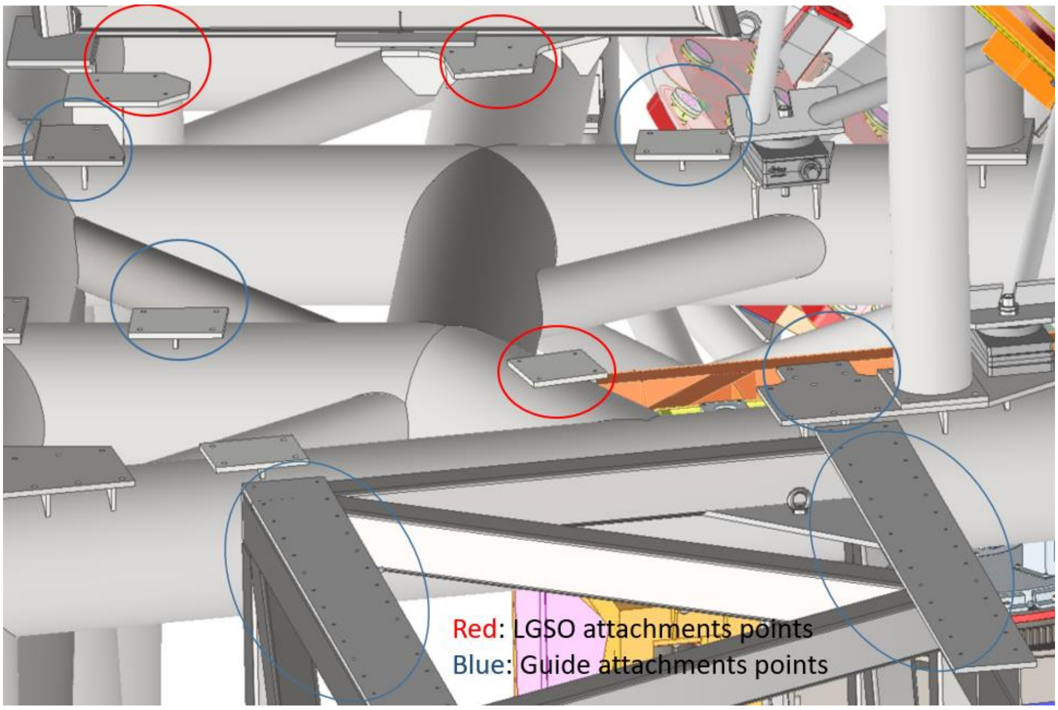


Figure 165 LGSO and Guide attachments points

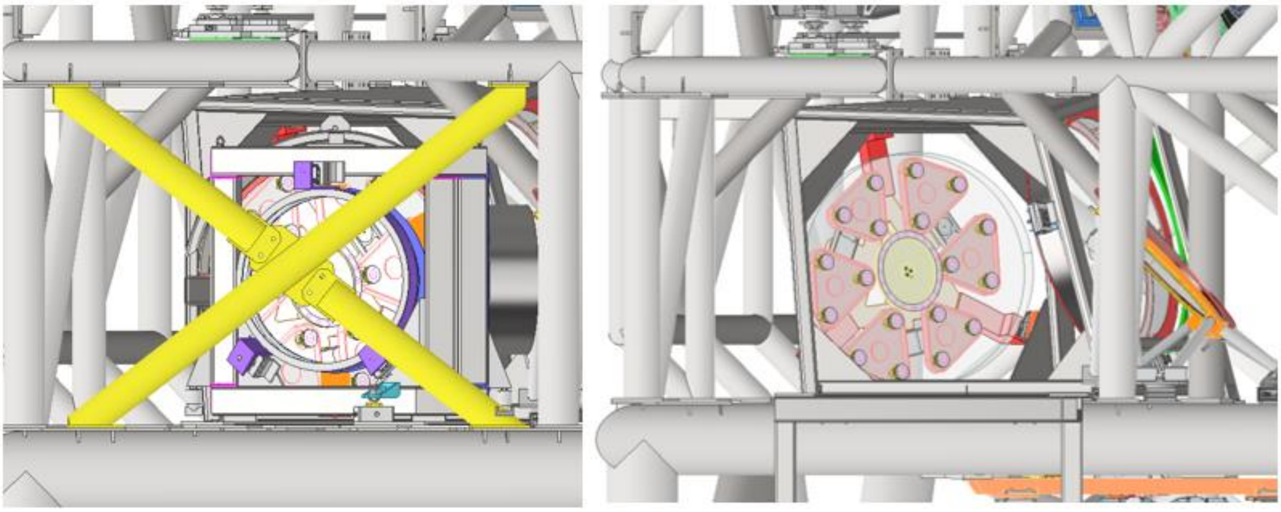


Figure 166 1st operation: MSS beams that must be removed in order to insert the objective

Since part of the rails protrude outside the MSS, before installing them, an external support structure shall be placed next to the aperture obtained in the MSS. This can be lowered with the crane thanks to the four eyebolt on the top part of the structure. Once the structure reaches the floor, it can be easily moved as it is equipped with four wheels and aligned to the MSS. The structure can be finally fixed to the ground lowering the feet and screwing it to the floor.

Figure 167 2nd operation: lower the external support structure

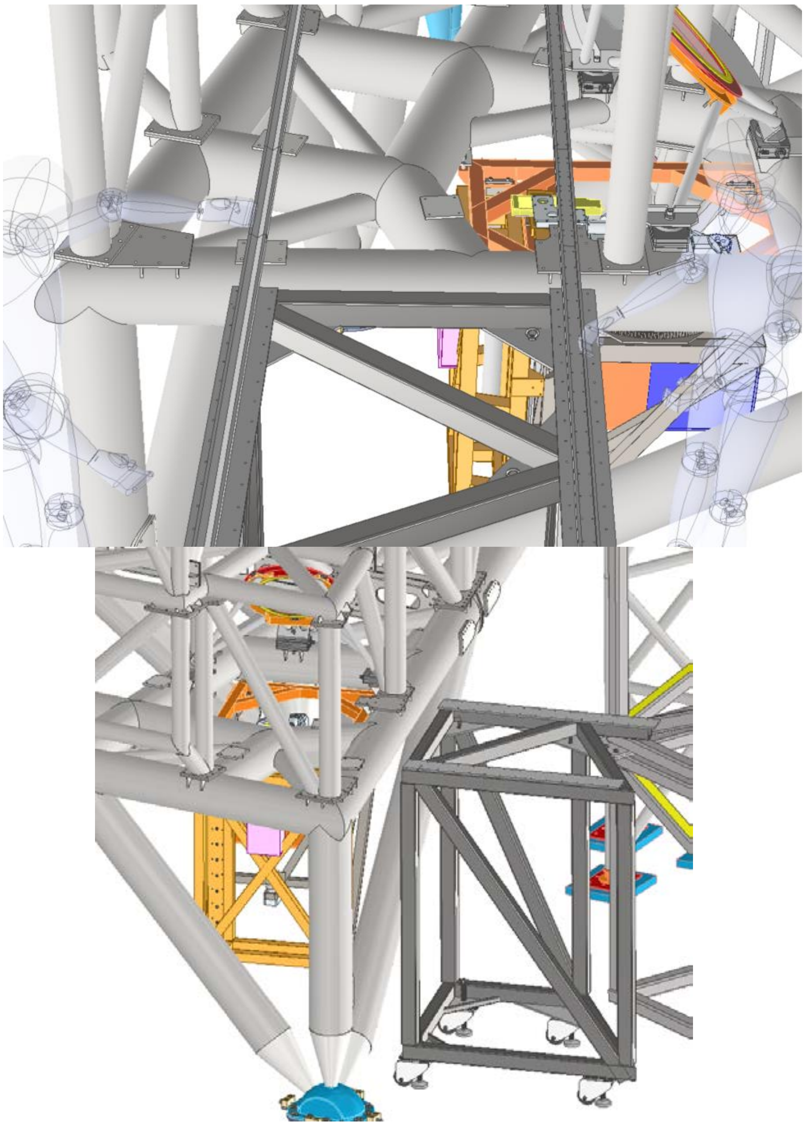


Figure 168 3rd operation: align the external structure the MS and guide rails installation

Figure 168 shows the structure aligned to the MSS. The rails are installed on top of the support structure. To avoid very long rails, each rail is split in two parts, one living permanently into the MSS and the second part installed on the support structure. When the rails are in position and fixed, the objective can be lowered on top of them. Figure 170 shows the LGSO lying on the guide rails outside of the MSS. The guide rails are joined in correspondence of the most external interface plates on the MSS, and the second part of the rails is aligned to the guides already installed in the MSS. The size and weight of these guide rails allow transportation from a single man. The shape of the guide rails avoid to the spherical wheel to fall outside of the rails. Furthermore, at the end of the guide there will be a mechanical hard end stop preventing the LGSO to slide off the rails.

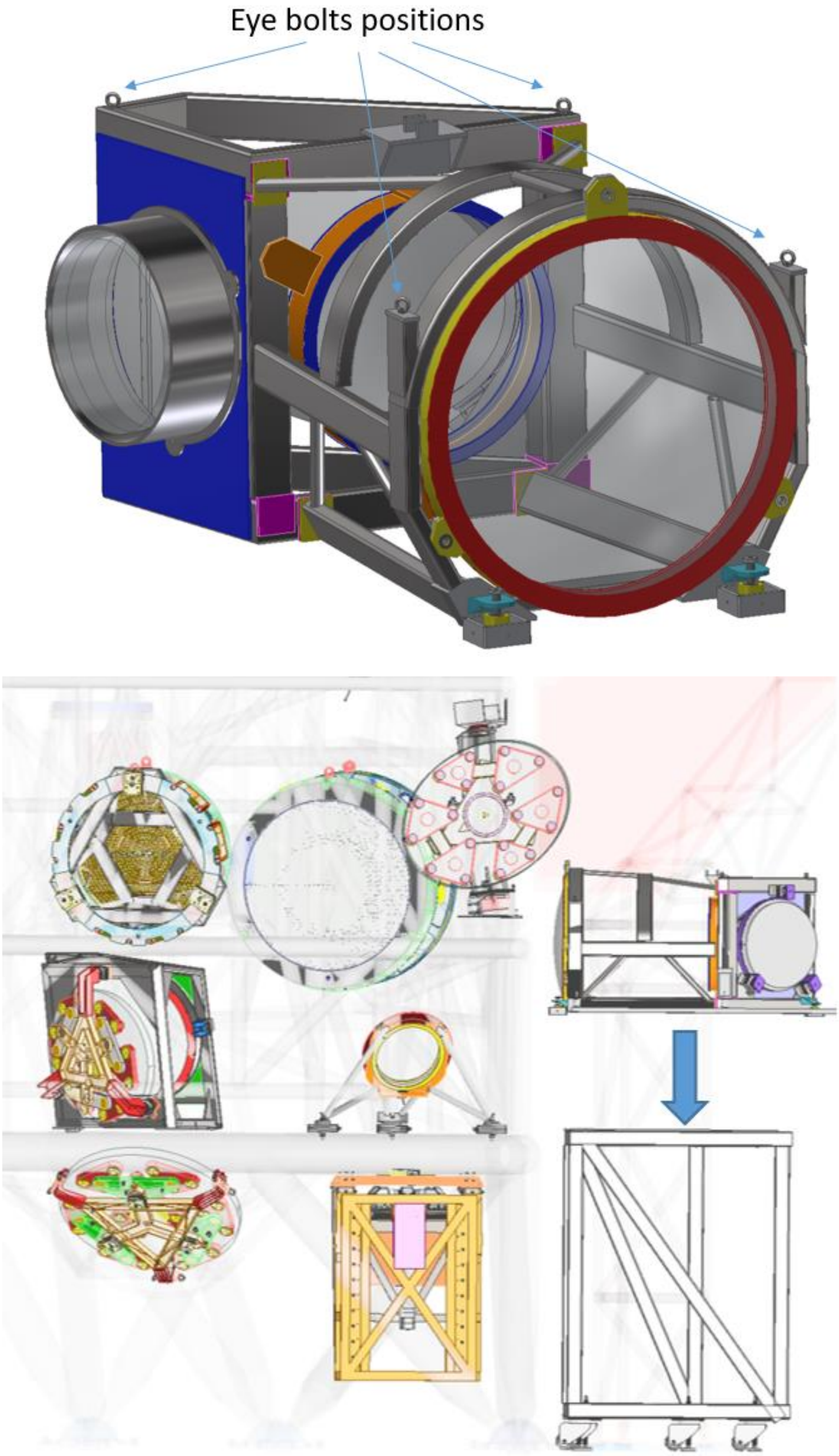


Figure 169 4th operation: lowering the objective

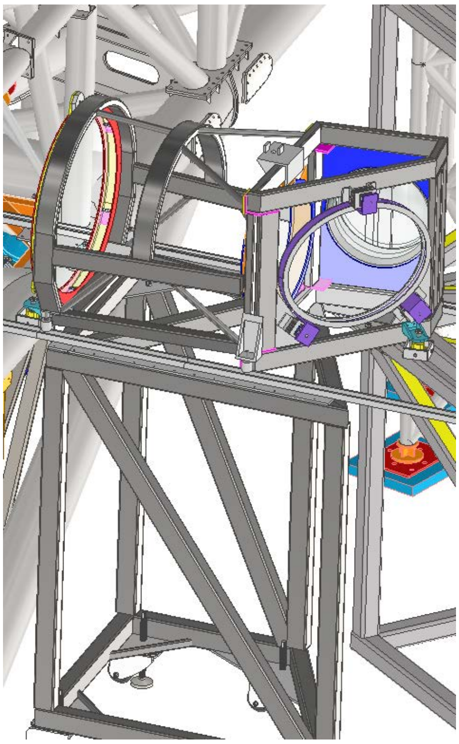


Figure 170 Position of the LGSO on top of the integration structure

The LGSO is manually slid inside the MSS. When the final position of the LGSO is reached inside the main structure, the threaded rod holding the spherical wheels of the LGSO are unscrewd. In this way, the whole LGSO is lowered till its feet lie in their seats in the MSS. Retroreflector mounted on the outer part of the LGSO can be now seen from the LT mounted inside the MSS and used for alignment purposes. The fine tuning of the LGSO position is done acting on the screw pushing against the LGSO feet shown in Figure 172.

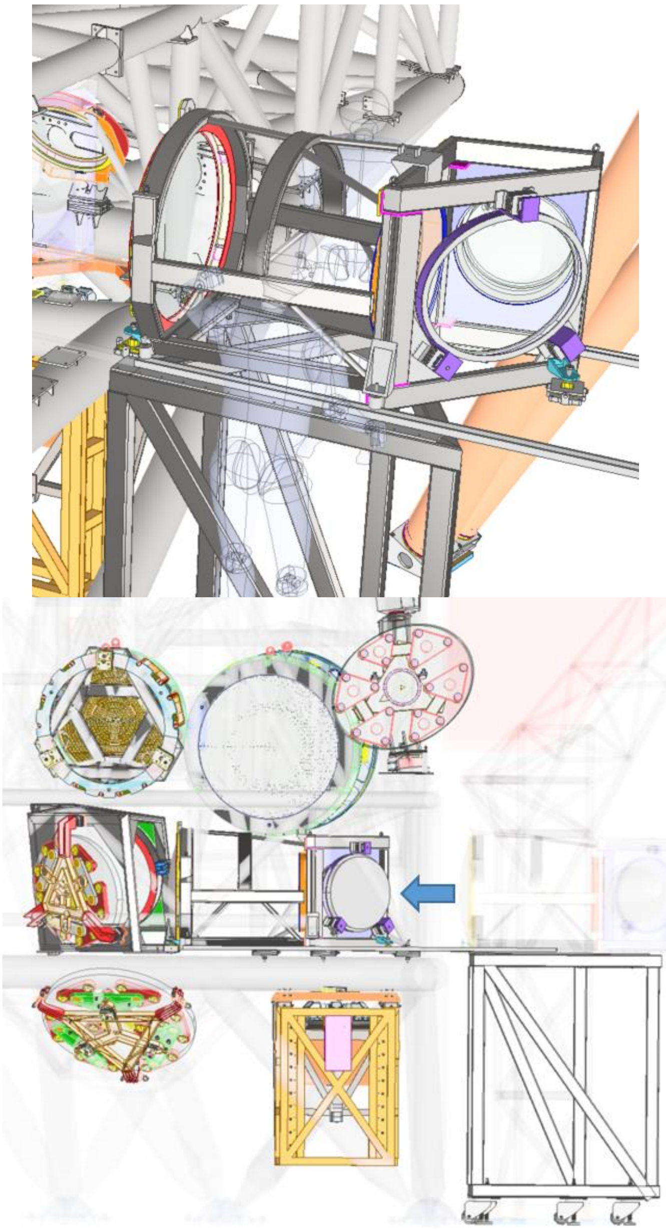


Figure 171 5th operation: move inside of the main structure the LGSO

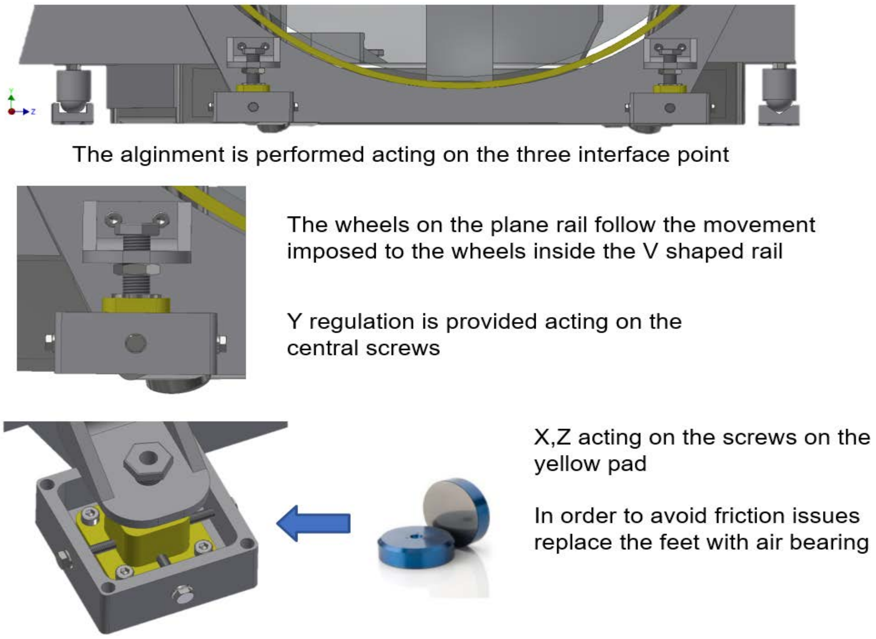


Figure 172 6th operations: final alignment

To reduce the friction between the LGSO feet moving part (yellow Figure 173, left panel) and the LGSO feet fixed part (grey in Figure 173, right panel) and to make the alignment of the LGSO smooth, each LGSO foot movable part will move on an air bearing. Acting on the frictionless feet the resolution is increased since there isn't the problem to overpass the friction between the static and the moving part. In Table 21 are reported all the estimated number foreseen for the alignment of the LGSO. In Figure 173, left panel, is possible to see the 4 feet of LGSO. When the alignment of the LGSO is completed, all the feet are locked using four M8 screws per foot. The first operation to do when the LGSO is close to its nominal position is to screw the grey pads to the MSS, then acting on the alignment screws that moves the yellow part finely tune the LGSO position and finally lock it using four M8 screws securing the yellow part to the grey pad.

The yellow part in Figure 173 will be updated in the next phase in order to integrate an air bearing in order to reduce the friction between the parts. The Y regulation (Figure 172) is used for two reasons:

- When the LGSO is inserted the feet are in a higher position respect to the guide in order to avoid the collision with the main structure. When the fixing point are reached the feet will be lowered.
- the alignment in Y, pitch and roll regulation are provided by the central vertical screw that has a bilateral joint (spherical connection wrt the yellow part). When the alignment is reached a nut fix the position of the system as is possible to see in Figure 172

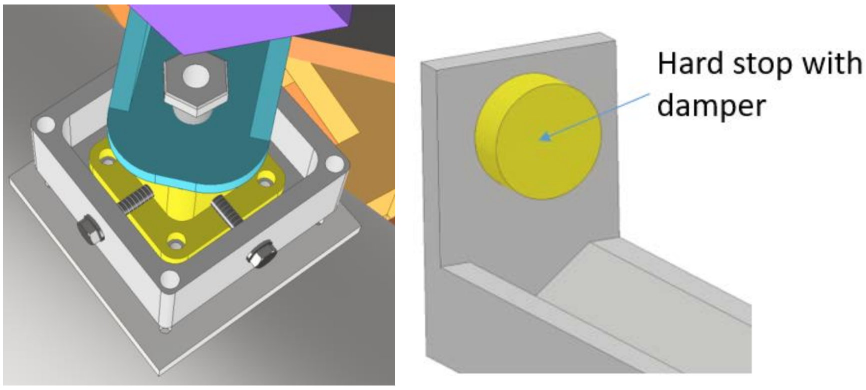


Figure 173 The LGSO foot is screwed to the main structure and guide hard stop

Table 21 Estimated alignment ranges and resolutions

ID	Components used as compensator	Range	Resolution	Foresee accuracies from sensitivity*	How
1	Whole LGSO	+/- 10 mm	0.1 mm	+/- 0.3 mm	Regulation at the feet level
2	FM1	+/- 1°	2 arcsec	+/- 10 arcsec	wedges
3	FM3	+/- 1°	2 arcsec	+/- 20 arcsec	wedges
4	L4	+/- 10 mm	0.1 mm	+/-1 mm	Shims

*Assuming such accuracies, the impact on the LGSO budget (WFE, telecentricity, WFNO, focal plane position) is about 10% of the overall budget

In Figure 174 is possible to see the space around the LGSO and the other elements.

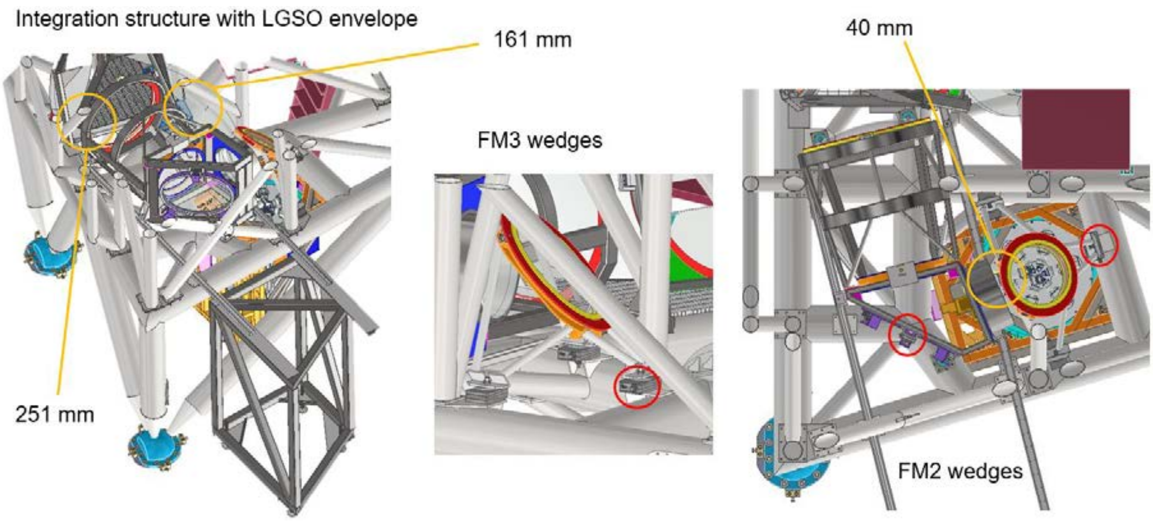


Figure 174 Space around the LGSO volume

Notes:

8.4.35 Third folding mirror LGSO Installation

Purpose and functionality

The third folding mirror of the LGSO is installed on the MSS and its preliminary alignment is carried on using the MSS LTs and the SMRs positioned on the mirror

Responsible: ERE, LMA, ECA

HTs/SEq needed: BIH Bridge crane, Dedicated HT

Success Criteria: Mirror properly installed in its nominal position

Duration: 1 day

Prerequisites: 8.4.34 LGSO installation

Procedure: This mirror can be inserted/removed from an opening on the side of the MSS (MICADO side). Due to its relatively small dimension, it only requires dismounting the relative thermal panel, but no beams from the structure. Due to its small weight and position inside the MSS, a C-shaped handling is not an optimal solution for its installation/removal, as it would result in a very long and heavy handling.

For this mirror, the handling is a simple squared tubular beam with an interface plate for the mirror at one edge, a hoist ring for the crane hook and a movable counterweight at edge opposite to the mirror. Since the hoist ring for the crane shall remain outside of the MSS during the whole process, the part of the handling on mirror side is light-weighted (but maintaining 3 contact points at 120deg with the mirror), while on the opposite side a counterweight is required. The counterweight is mounted on a threaded rod, and 2 nuts allow to fine tune its position to compensate for the barycenter shift when the mirror is disengaged.

The mirror is inserted/removed from MICADO side. The handling does not interfere with MICADO volume, but the MICADO temporary platform shall not be in place during this phase.

When the mirror is secured to its supporting structure inside the MSS, the handling is removed, after readjustment of the movable counterweight position.

In order to secure the mirror to its support structure and to disengage the handling one person inside the MSS, with a small ladder close to M7 position, and one person outside, next to the handling, are necessary.

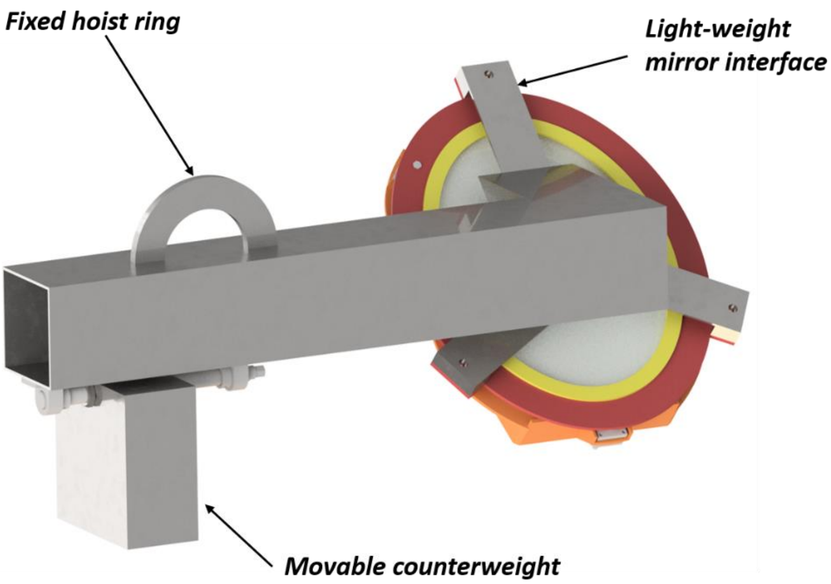


Figure 175: the handling for LGSO FM3 installation/removal.

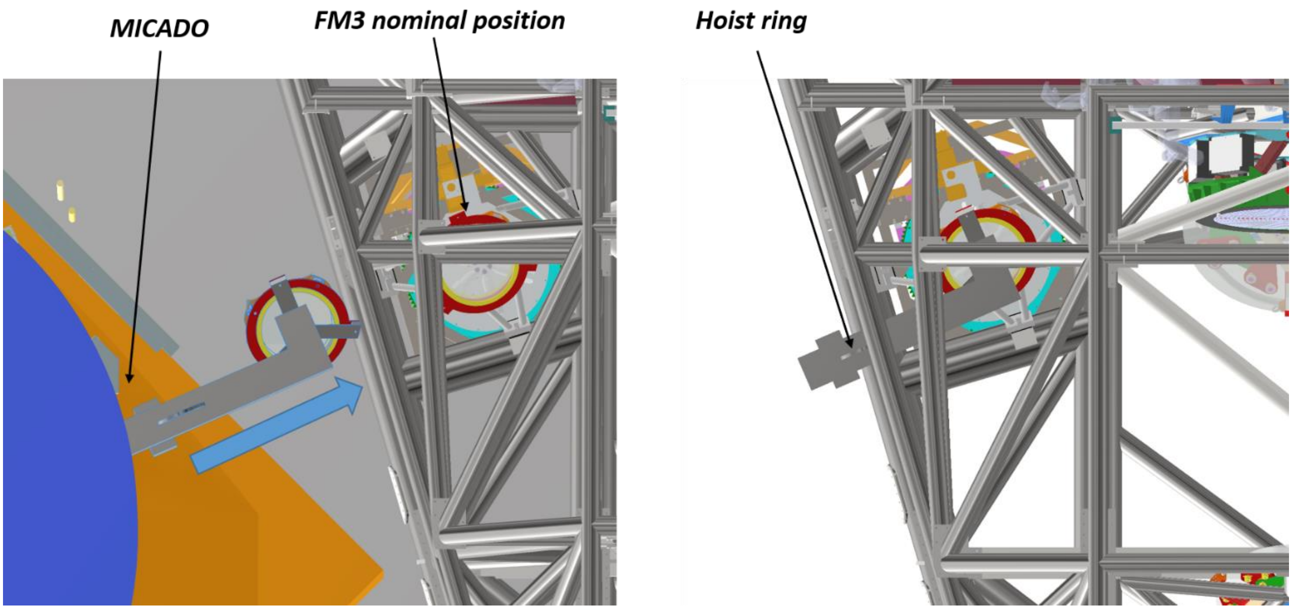


Figure 176: in the left panel, the handling with FM3 totally extracted from the MSS. There is no interference with MICADO volume, but its temporary platform shall not be in place for this operation. In the right panel, FM3 in its nominal position. The hoist ring for the crane is still outside the MSS.

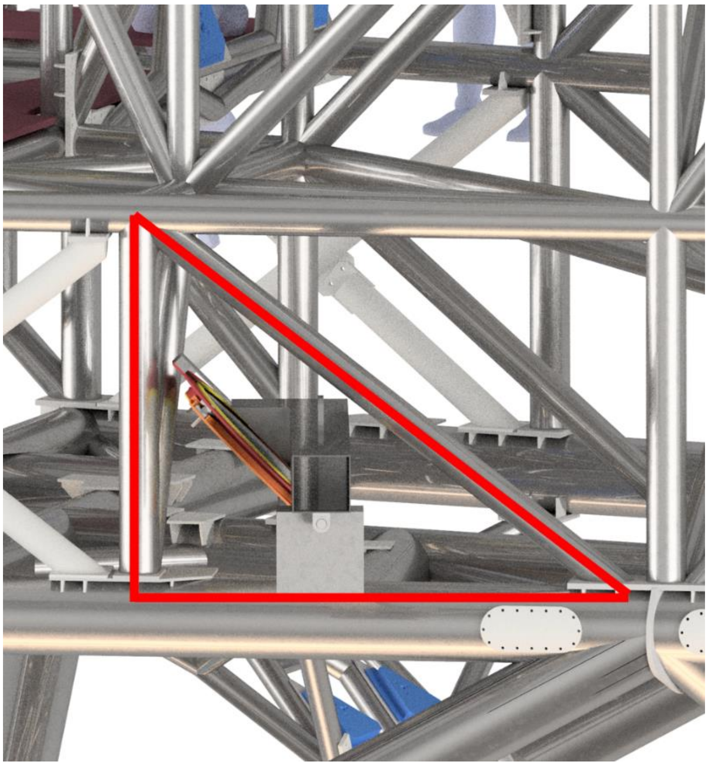


Figure 177: FM3 is mounted/dismounted using the aperture marked by the red triangle, which provide enough room for the procedures even without removing the diagonal beam.

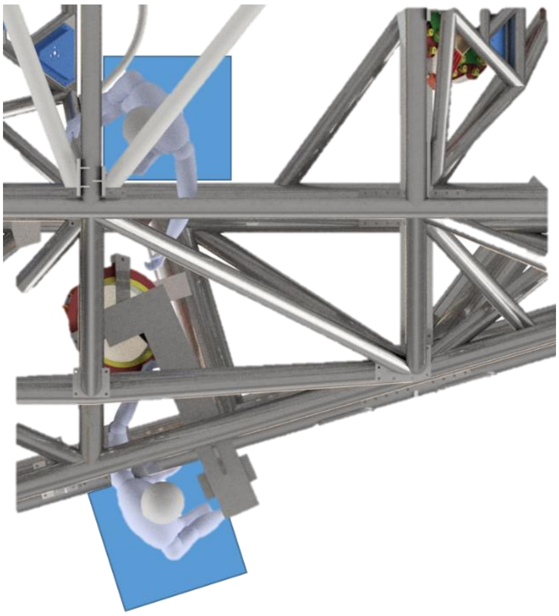


Figure 178: two persons on small portable ladders can fix LGSO FM3 to its support structure and release the handling.

Notes:

8.4.36 LGS WFS installation

Purpose and functionality

The LGS is installed on the MSS and its preliminary alignment is carried on using the MSS LTs and the LGS SMRs. Also the control electronics of the LGS will be installed and the cables routed and connected, and functional test will be perfomed on the system.

Responsible: ZHU, TMO, JFA, LMA

HTs/SEq needed: LGS HTs, BIH LTs

Success Criteria: LGS properly installed in its nominal position

Duration: 3 days

Prerequisites: 8.4.35 LGSO third folding mirror installation

Procedure: It will be installed from the bottom, using a special handling allowing to rotate and lift up the LGS. The rotation is necessary as the physical dimensions of the LGS do not allow it to pass through the legs of the MSS with its final orientation, but only rotated. This handling is still under study, to define the optimal rotation angle and where to place the pivot point, considering the mechanical constraints of the MSS. Once the LGS passed through the MSS legs, it can be rotated vertical, in the area in front of M7, then moved towards its interface points on the MSS and finally lifted up. Since it is installed at a very low height, the operators do not need any particular SEq for its installation.

Being an installation from the bottom, the procedure is the same in BIH, IAA and Nasmyth Platform.

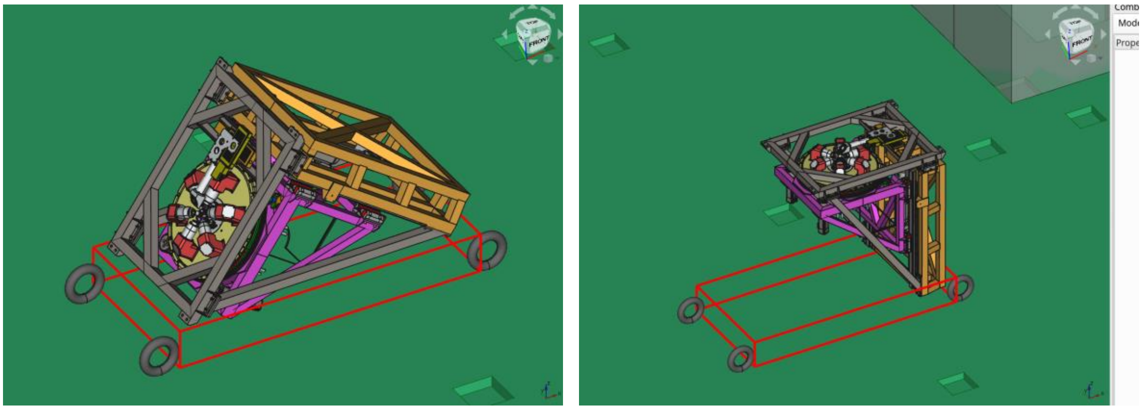


Figure 179: The cart allowing to transport the LGS WFS with the right angle to fit into the structure; the same cart allows to rotate the LGS WFS in the right orientation to lift it up and install it on the MSS

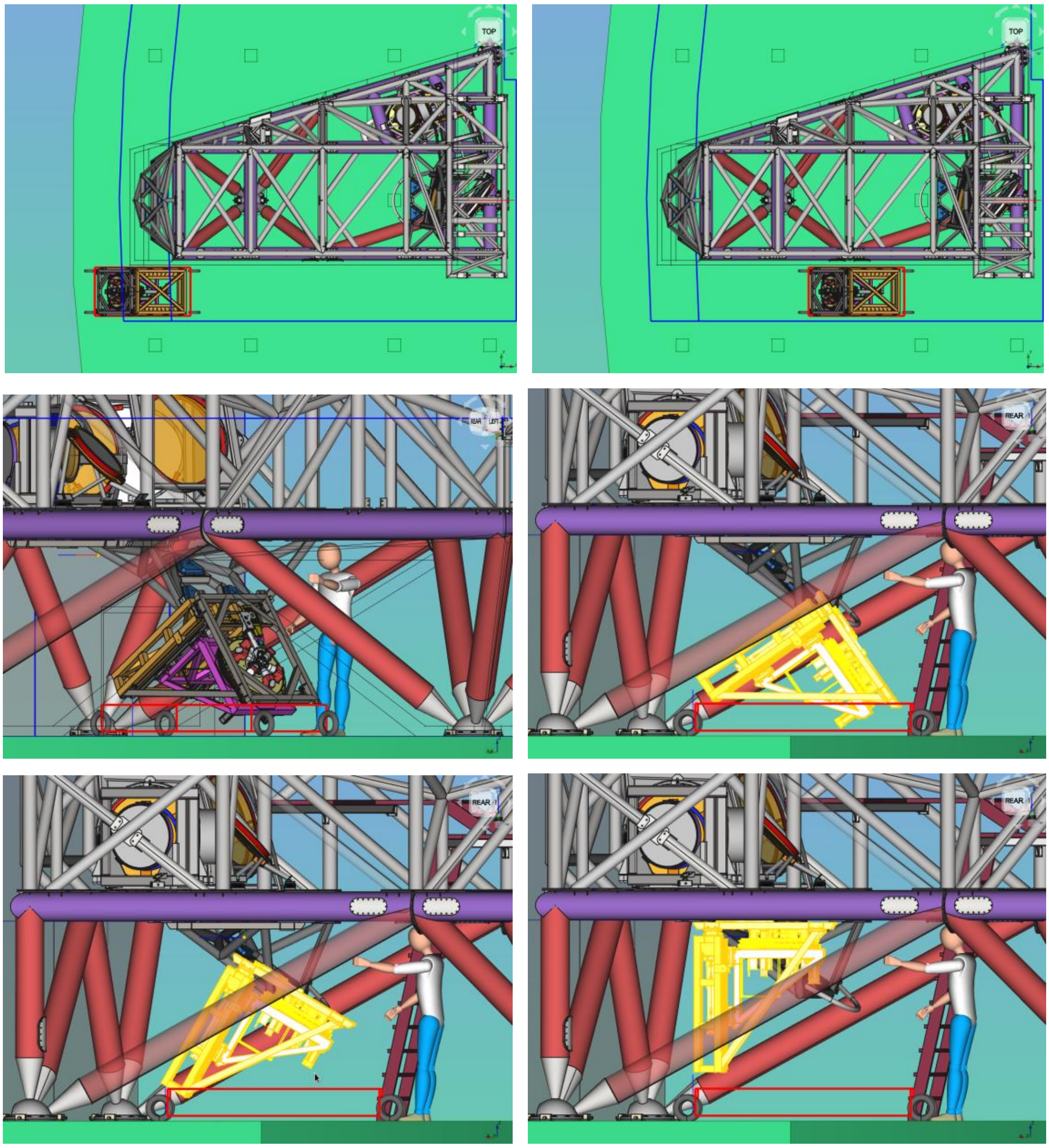


Figure 180: sketch of the installation of the LGSWFS inside the MSS.

Notes:

8.4.37 Electronics functional test

Purpose and functionality

All the motorized axis of the sub-systems previously installed are functionally tested

Responsible: IFO, ECA, CER, JFA

HTs/SEq needed: BIH Bridge crane, Dedicated HTs, Scissor lifts, Cherry picker

Success Criteria: functional test all working

Duration: 2 days

Prerequisites: 8.4.21 Engineering ICS SW installation and test

Procedure:

- The TT and focus motorized axis of the M10 system will be tested checking the range and accuracy
- The TT motorized axis of the M11 system will be tested checking the range and accuracy
- The TT motorized axis of the M12 system will be tested checking the range and accuracy

Notes:

8.4.38 ICS SW installation and test

Purpose and functionality

The full SW to control the instrument is installed and tested

Responsible: BSA, JFA

HTs/SEq needed:

Success Criteria: functional test all working

Duration: 10 days

Prerequisites: 8.4.37 Electronics functional test

Procedure: the MAORY ICS SW will be integrated with the instrument and test it

1. Install SW in target system
2. Perform functional tests
3. Produce installation and test report
4. Report issue through tracking system

Notes: More details will be provided for the FDR.

8.4.39 RTC installation and test

Purpose and functionality

The RTC is installed and functionally tested

Responsible: ABA, JFA

HTs/SEq needed:

Success Criteria: functional test all working

Duration: 10 days

Prerequisites: 8.4.38 ICS SW installation and test

Procedure: the RTC is integrated in the ICS and with the Instrument Hardware (LOR and LGS WFSs cameras, DMs). The external contractor will provide support for the H-RTC and Telemetry Recorder.

More details will be provided for the FDR.

Notes: More details will be provided for the FDR.

8.4.40 MES functional test

Purpose and functionality

All the MES sub-systems are functionally tested

Responsible: ERE, JFA, GRO, ECA

HTs/SEq needed:

Success Criteria: functional test all working

Duration: 1 day

Prerequisites: 8.4.38 ICS installation and test

Procedure: Being the LOR functionally tested in step 8.4.41 and M12 in step 8.4.42, the activities here will be:

- Perform functional test of the bearing
- Perform functional test of the XYZ system moving the TAC
- Perform functional test of the two cameras of the TAC system

Notes:

8.4.41 LOR functional test

Purpose and functionality

The LOR system is extensively functionally tested

Responsible: MBO, LBU, GRO, LMA, ECA, JFA

HTs/SEq needed:

Success Criteria: functional test all working

Duration: 2 days

Prerequisites: 8.4.39 RTC installation and test

Procedure: the motors and the detectors of the LOR WFS will be functionally tested.

Notes:

8.4.42 Motorized opto-mechanics functional test

Purpose and functionality

The purpose is to perform functional test on M10, M11 and M12.

Responsible: MBO, LBU, GRO, LMA, ECA, JFA

HTs/SEq needed:

Success Criteria: functional test all working

Duration: 1 days

Prerequisites: 8.4.38 ICS installation and test

Procedure: M10 (TT and focus), M11 (TT) and M12 (TT) are functionally tested.

Notes:

8.4.43 MSS to MES Alignment

Purpose and functionality

The purpose of this procedure is to align the MSS to the MES (in terms of position of the OFP and of the output pupil), by using just the TT of M11 and M12, as it is foreseen and explained in sec. 8 item 5. Such procedure is assuming that the bearing mechanical axis is the reference of the alignment, as discussed/agreed with the MICADO team. Also, this procedure is NOT assuming any movement of MICADO/Bearing, we are only assuming that the Bearing is positioned within the same initial positioning accuracy of MICADO, which is ±5mm in XYZ and ±0.58mrad in TT (being this ensured when the MES will be installed, see step 8.4.8). In short, we are simulating the same procedure, from the conceptual point of view, that will be implemented with MICADO on the Nasmyth platform, where the bearing will be positioned within a certain accuracy and the OFP will be adjusted to match this position.

Responsible: JFA, GRO, LMA, ECA

HTs/SEq needed: BIH Bridge crane, internal platforms, IFP flange SEq, OFP flange SEq, TAC system, MES

Success Criteria: MES and MSS aligned within TBD in OFP position and TBD in pupil plane position.

Duration: 3 days

Prerequisites: 8.4.42 Motorized opto-mechanics functional test

Procedure:

- We remove the Corrective Plate
- We insert the IFP flange, in its configuration with the laser installed (see SEq 7.2) (Laser will be pre-aligned in the lab to be concentric with the flange and orthogonal to the bearing rotating plane). The laser will deliver on the OFP a spot of about 1mm size (plus size increase due to the laser beam divergence, to be evaluated once the laser will be selected).
- We install the TAC system (previously aligned in the lab in a way that the XY stages move on planes parallel to each other and parallel to the flange plane too, and the Z move perpendicular to the previous planes)
- We move XYZ to have the TAC more or less in the OFP
- We align M11 and M12 to the OFP flange (simulating the MICADO+Bearing system) in this way:
    - M11 TT will be tuned to minimize the dimension of the circle on the TAC obtained by rotating the bearing (alignment of the focal plane position)
    - Concerning the M12 TT adjustment (moving mainly the output pupil), there may be two observables:
        - We minimize the spot shift moving the TAC along Z (optical axis)

  - We minimize the pupil wobble observed by rotating the bearing, by looking at a pupil image created using an additional arm on the TAC system with a BS positioned just before the OFP, a small pupil re-imager (objective) and an additional camera

  These two steps must be iterated, since both M11 and M12 are moving both the focal and the pupil plane.

- We centre the TAC on the aligned beam, and we record the stages position and the spot centroid on the TAC.
- We remove the IFP flange
- We install the CP

Notes:

By adjusting the pupil position shifting the TAC in Z, considering 75 mm of travels and assuming that we can compute centroids on the spots with an accuracy of 20µm PtV (2 pixels of the TAC camera which has 10µm square pixel size), the accuracy on the direction of the pupil chief ray should be of the order of 1' PtV, while the accuracy of the OFP positioning should be of the order of 20µm PtV, again assuming that we can compute centroids on the spots with an accuracy of about 2 pixels PtV on the TAC camera.

The Laser beam divergence (about 1mrad) and the diffraction are causing negligible effects on the beam at the OFP.

8.4.44 CU Alignment

Purpose and functionality

The purpose of this procedure is to align the CU to MAORY.

Responsible: MBO, JFA, GRO, LMA, ECA

HTs/SEq needed: Scissor lifts, cherry picker, portable ladders, OFP flange SEq, TAC System

Success Criteria: CU properly aligned to the MSS and OFP

Duration: 3 days

Prerequisites: 8.4.43 MSS to MES alignment

Procedure:

- We insert the CU folding mirror in front of the CP and switch on the CU fibres which are diffraction limit
- By looking at the central fibre spot created in the TAC, we align the CU in focus (by acting on acting on the XYZ adjustments foreseen, see RD18) till having a focussed image on the TAC.
- We align the CU in centring (acting on the XYZ adjustments foreseen, see RD18) till having the spot in the field centre of the TAC (defined in step 8.4.42).
- We align the CU in TT (by acting on the TT of the CU folding mirror) with two possible observables:

- We minimize the spot shift moving the TAC along Z (optical axis)
- We minimize the pupil wobble observed by rotating the bearing, by looking at a pupil image created using an additional arm on the TAC system with a BS positioned just before the OFP, a small pupil re-imager (objective) and an additional camera

A few iterations between focussing, centring and TT steps will be required.

Notes:

- the accuracy achievable with this procedure in the CU centring should be very good, of the order of 10µm assuming that we can compute centroids on the spots with an accuracy of 10µm PtV (1 pixels on the TAC camera), that shoud be easily feasible considering that the spot image will be diffraction limit.
- the accuracy achievable with this procedure in the CU TT is depending on which of the two proposed procedure we will use. We envisage that the accuracy achievable by moving the TAC will be worse than estimated in step 8.4.42, due to the bad quality of the out-focus images, that will probably cause low accuracy in the centroiding operations. Supposing to compute centroids on the out-of-focus spots with an accuracy of 60µm PtV (6 pixels of the TAC camera), the accuracy on the direction of the pupil chief ray should be of the order of 3’ PtV.

  Checking instead the wobble of the pupil, the accuracy will be limited by the bearing runout (60µm) and by the accuracy in estimating the pupil position (2 pixel on the diameter, ~20µm). The pupil is about 8.6mm, it means 860 pixels on the diameter. Thus, ~80µm of accuracy (summing the 2 contributions linearly) would correspond to about 0.9% wrt the pupil diameter, corresponding to about 2’ of accuracy on the direction of the pupil chief ray, which is comparable with the previous one.

8.4.45 LOR WFS Alignment

Purpose and functionality

The purpose of this procedure is to align the LOR WFS to the bearing axis.

Responsible: MBO, JFA, GRO, LMA, ECA

HTs/SEq needed: Scissor lifts, cherry picker, portable ladders, OFP flange SEq

Success Criteria: LOR WFS aligned

Duration: 3 days

Prerequisites: 8.4.44 CU Alignment

Procedure: the LOR WFS will be aligned to the bearing with the following procedure:

- Insert the CU and switch on the diffraction limit fibres
- Position one probe on the fibre at the centre of the field
- TT of the LOR should be corrected by minimizing the pupils wobble on the probe detector (within the bearing runout) when rotating the bearing
- Position the probes on three fibres at the edge of the field

- Decentre of the LOR WFS should be corrected by minimizing the common TT on the three probes
- Defocus of the LOR WFS should be corrected by minimizing the common defocus on the three probes

Notes:

8.4.46 LGS arm alignment

Purpose and functionality

The purpose of this procedure is to align the LGS ARM to the Main Path optical beam.

Responsible: JFA, GRO, LMA, ECA

HTs/SEq needed: portable ladders, internal platforms, IFP flange SEq, 2 plates with targets

Success Criteria: LGS ARM aligned

Duration: 3 days

Prerequisites: 8.4.45 LOR WFS alignment

Procedure: (also explained in sec. 8.1.6.2 more in detail)

- Install the IFP flange in its alignment configuration, see SEq 7.2
- The laser is positioned in order to materialize the chief ray of the central field of the optical system (system previously aligned in the lab). The laser beam has the aim to visualize the intermediate pupil position of the as-aligned main path. Given that the laser has to be transmitted by the dichroic, its wavelength has to be close to 589 nm.
- we foresee to position two irises, one before L1 and one after L4, centered on the lenses at laser tracker precision (the SMRs positioned at the mountings of the lenses can be used as references for such operation), or otherwise pre-aligned and positioned by the company which will align internally the LGSO.
- The LGSO (including the two irises) has been previously installed into the structure in its nominal position (by using LTs against 3 SMRs coarsely placed on the LGSO structure. The laser will go across the LGSO lenses. Accounting for the divergence angle, we have estimated the laser footprint size on each surface. The results are shown in Table 16.

Table 22: Laser footprint size on the LGSO surfaces.

	RMS Spot Diameter [mm]	Geometrical Spot Diameter [mm]
DICH	9.4	12.4
FM1	10.0	14.4
L1S1	8.2	10.6
L1S2	7.8	10.2

L2S1	4.6	6.2
L2S2	4.6	6.0
FM2	4.4	6.6
L3S1	2.6	3.4
L3S2	2.6	3.4
L4S1	2.6	3.4
L4S2	2.4	3.2

- The LGSO is then aligned to the laser beam, by acting on the FM1 tip/tilt and decentering the whole LGSO along X-Y direction (local coordinates system in L1), so that the laser passes through the two irises. A possibility is to use the target on L1 to centre the LGSO with the laser beam and the target on L4 to for the tilt FM1. In such way, the optical axis of the LGSO is aligned to the laser, i.e. to the chief ray of the central field.

At this working level, we have assumed that the combination of the errors due to laser source positioning, positioning accuracy of the irises on the L1 and L4 and the accuracy on the determination of laser spot centre is less than +/-2 millimetres.

The impact on the performance is a worsening of the average WFE less than 10%, while the LGSO focal plane maximum displacement is less than +/-5 mm in X, Y, Z direction with respect to the nominal position.

Notes: There are two alternative procedures that we are exploring (see sec. 8.1.6.2 for details), which will be studied in more detail for the FDR:

- A fully mechanical alignment, that would lead to a worse result in term of WFE (30% instead of 10%)
- An alignment performed by looking at the back-reflections of the lenses, which should perform more or less as the baseline here presented

8.4.47 LGS WFS alignment

Purpose and functionality

The LGS is functionally tested with its SW and Electronics. Also, the focal plane and the pupil plane have to be placed in the correct positions within the WFS.

Responsible: JFA, ZHU, GRO, LMA, ECA

HTs/SEq needed: portable ladders, internal platforms

Success Criteria: functional test all working, pupil and focal planes aligned within tolerances

Duration: 4 days

Prerequisites: 8.4.46 LGS arm alignment

Procedure: Perform functional test all the motorized functions and all the detectors.

The LGS WFS will be aligned to the bearing with the following procedure:

- Insert the CU and switch on the LGS fibres, in a way that each probes is looking at one fibre
- TT of the LGS WFS should be corrected (by acting on the 3rd LGSO folding mirror TT) by minimizing the differential defocus on the probes. Alternatively, the TT of the LGS WFS should cause a shift of all the pupils on the pupil probes, that should be visible by checking illumination of the SHs sub-apertures, that at the edge should be different (and equal for every probe) depending on the shift direction; TT of the LGS WFS should be tune to have all the sub-apertures at the edge radially equally illuminated.
- Decentre of the LGS WFS should be corrected by minimizing the common TT on the probes (by moving the whole LGS WFS)
- Adjust the F# by observing the illumination of the sub-apertures at the edge of the SH; if there is a radial variation of the light, move L4 along the optical axis to minimize the radial illumination variation
- Defocus of the LGS WFS should be corrected by minimizing the common defocus on the probes (by moving along the optical axis the whole LGS WFS)

Notes:

8.4.48 Thermal enclosure installation and test

Purpose and functionality

The thermal enclosure is installed, including the part of the MES and the ""bridge"" between MAORY and the MES; the system is then tested, in term of T stability and a few cooling cycle are performed

Also, the mechanical stability of MAORY and MES is checked using the BIH LTs against the external SMRs on the MAORY and MES structure

Responsible: JFA, MAL

HTs/SEq needed: BIH Bridge crane, Dedicated HTs, Scissor lifts, Cherry picker, portable cranes, BIH LTs, T sensors PT100, Lakeshore electronics

Success Criteria: Thermalization within requirements

Duration: 20 days

Prerequisites: 8.4.47 LGS WFS Alignment

Procedure:

Notes:

8.4.49 Fine tuning of the optical quality

Purpose and functionality

The MAORY Optical Alignment (MOA) has the purpose to bring the MAORY WFE close to the as-built prescription, minimizing the residual aberrations coming from the alignment and low-order aberrations of the relay.

Responsible: JFA, GRO, LMA

HTs/SEq needed: TAC, MES.

Success Criteria: MAORY WFE minimized at the end of procedure.

Duration: 2 days first time. Nominal re-alignment sequences 10-15 min (TBC).

Prerequisites: 8.4.48 Thermal enclosure installation

Procedure: the procedure is described in detail in sec. 8.1.4., and the man steps are here reported:

1. Engage the MAORY CU
2. Turn ON the light sources diffraction limit at the MAORY input focal plane; 5 references are needed, one in the centre and four at the edge of the FoV, possibly in the diagonal of the field
3. Turn ON the TAC on the MES
4. Establish communication with M10
5. Move TAC on the five fibres and acquire an image of the PSFs out of focus
6. Perform the WFSensing on the PSFs running the MOA algorithm, as described in sec. 8.1.4.1.1
7. Find best TT and set M10
8. Repeat steps from 5 to 7 till converging
9. Perform a focus sweep (by pistoning M10 or moving axially the TAC) on the on-axis PSF to find the best focus
10. Move the TAC to acquire the 5 PSFs to check the optical quality achieved (PSFs FWHM? TBD)

Notes: future upgrade of the MOA will include the computation of the best focus using the wavefront sensing procedure, as for the astigmatism

8.4.50 Test Unit (TU) installation and test

Purpose and functionality

The test unit is installed, and functional test will be performed to ensure the TU functionality

Responsible: NDE, SGO, LBU, MBO, JFA

HTs/SEq needed: Scissor lift, dedicated stairs.

Success Criteria: DM properly aligned; the position in the field with the CU folding mirror and with the DM flattened should be the same within a certain accuracy

Duration: 10 days

Prerequisites: 8.4.49 fine tuning of the optical quality

Procedure:

The DM should be installed inside the CU, replacing the CU internal flat mirror (see 8.1.8.1. After the DM is installed and connected to the high voltage amplifiers (that should be temporarily positioned in the vicinity of the CU), functional test on the DM will be performed.

Notes:

8.5 MAORY Testing Phase

For the time being, we do not consider any test inherent to the interface with MICADO, since the ICD is still under discussion. They will be added once the requirements will be clarified/agreed.

The test are grouped depending on the ESO requirement document which originates them. Please, consider this part very preliminary, a draft to be of course completed for the FDR (we left on purpose our notes . We also note that the AO related system test are covered in RD15. Only the test originated by a requirement are described in both documents.

TEST_1, test_ESO-254311

AD3 MAORY (E-ELT MCAO) Technical Specification
ESO-254311 Version 1

8.5.1 TEST_1.1: R-MAO-60 Unvignetted FOV (Primary port)

Requirement description:

R-000-1.2.3.5

MAORY shall deliver an unvignetted field of view of at least 70 arcsec diameter (TBC) at the MICADO instrument port.

Test Description

Insert the CU, switch on the fibers, move the test camera on each of the fibers in the FoV, record a few images to be after averaged, compute the flux of each fiber and check the unvignetted FoV. OL test.

Responsible:

HTs/SEq needed: TAC System

Success Criteria:

Duration:

Prerequisities:

Notes: *Optical description is in E-MAO-000-INA-ANR-007 doc optical section*

What uniformity we have in the CU fibers? What is the geometry of the fibers in the CU? Do we have fibers at the edge of the FoV?

Is there a requirement in term of light loss % at the edge of the FoV, to define a success criteria?

8.5.2 TEST_1.2: R-MAO-60 Corrected FOV (Primary port)

Requirement description:

R-000-1.2.3.6

MAORY shall deliver a corrected field of view of at least 70 arcsec diameter (TBC) at the MICADO instrument port.

Test Description

Pending all the comments on the notes, a possible procedure is the following. Insert the CU, switch on the fibers, move the test camera on each of the fibers at the edge of the FoV, record a few images and analyze them to check the psf size. Move the LOR probes on the selected ("most suitable for the test") references, Close the AO loop, move the test camera on each of the fibers at the edge of the FoV, record a few images and analyze them to check the psf size.

Responsible:

HTs/SEq needed: TAC System

Success Criteria:

Duration:

Prerequisities:

Notes: *Optical description is in E-MAO-000-INA-ANR-007 doc optical section*

What do we have to test here? Isn't by design/analysis? It depends on the position of the LGS (chosen to achieve this requirement) and of the NGS (variable depending on the target). If in a certain field we have no NGS, the requirement is not fulfilled. Thus, we can only say that by design/analysis we are compliant. How many asterisms do we have in the CU to simulate NGSs for the LOR? I remember 3 + a grid of fibres?

8.5.3 TEST_1.3: R-MAO-62 Unvignetted FOV (Secondary port)

Requirement description:

R-000-1.2.3.8

The unvignetted field of view at the second instrument port shall be 2.5 arcmin diameter (TBC).

Test Description

Test with cartoncin at the thermal cover second port side, tech field shall be 2,5 arcmn (note that 1st port is 2,6 arcmin).

Add wavefront error with dm corresponding to M11 wfe different oreintation (TBC)

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: *Optical description is in E-MAO-000-INA-ANR-007 doc optical section*

Do we have to test it? I would strongly push do remove it from the test and change the verification in "by design".

8.5.4 TEST_1.4: R-MAO-64 Offsetting in MCAO mode

Requirement description:

Observations in MCAO mode shall support the offsetting, dithering or nodding requirements arising from the MICADO operational concept.

Test Description

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes:

8.5.5 TEST_1.5: R-MAO-63 1 to 1 relay

Requirement description:

The MAORY optics should, as a design goal, provide a 1:1 relay of the beam at both ports.

Test Description

A plate with characterized (in position) holes positioned on the input focal plane (or calibrated - in term of distance - fibers of the CU), movable in various position over the field (to account for field distorsion), may be used. A camera on the output focal plane, movable in the corresponding position on the plate, shall record images of the spot on which accurate centroids measurements shall be performed. Effect of diffraction? TBD

Responsible:

HTs/SEq needed: TAC System

Success Criteria:

Duration:

Prerequisities:

Notes: *Optical description is in E-MAO-000-INA-ANR-007 doc optical section*

Accuracy?

Reverse engineering on characterization accuracy of position of cu fibres

mapping of the CU focal plane (output or input)

8.5.6 TEST_1.6: R-MAO-70 Moon distance

Requirement description:

R-000-1.2.4.4 Moon distance

MAORY shall be able to deliver the required performance as close as 25 degrees from the full moon centre

Test Description: covered in RD15

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: *Is the req referring to the effect of the sky bkg? Can we artificially increase the sky bkg during our MCAO test?*

8.5.7 TEST_1.7: R-MAO-71 Operational range of zenith angles

Requirement description:

R-000-1.2.4.5

MAORY shall be capable of observing at zenith angles greater than 1.5 degrees and smaller than 70 degrees. Operation with lasers is restricted to zenith angle < 60.

Test Description: covered in RD15

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes:

8.5.8 TEST_1.8: R-MAO-72 Performance at zenith 30 degrees

Requirement description:

R-000-1.2.4.6

MAORY shall be able to deliver the required performance at zenith distance of 30 degrees.

Test Description: covered in RD15

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes:

8.5.9 TEST_1.9: R-MAO-73 Stability

Requirement description:

Assuming stable atmospheric conditions, MAORY shall be able to deliver the required performance when measured as integrated performance over a continuous 60 minute observing block.

Test Description: covered in RD15

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: *Supposed to be done by analysis, it may be done in BO. It depends on the SW which introduces the turbulence on the DMs. Anyhow, the "stable atmospheric conditions" are not defined. How much can the seeing vary in 60 minutes? May be the answer is in what specified in R-MAO-85 reported a few lines below?*

8.5.10 TEST_1.10: R-MAO-74 Sky coverage

Requirement description:

R-000-1.2.4.9 Sky coverage

MAORY shall be able to deliver the required performance over the sky observable by the E-ELT with 50% probability unless otherwise specified.

Test Description

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: *The only thing we can (probably) verify by test are (may be) how realistic are certain assumptions made on the simulations to validate them somehow, but anyhow it will be done by analysis.*

Define the benchmark test configuration?

Worst case?

8.5.11 TEST_1.11: R-MAO-75 Wind conditions

Requirement description:

MAORY shall be able to deliver the required performance in median atmospheric wind conditions.

Test Description: covered in RD15

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: *Similar comment of above, although the median atmospheric wind condition may be simulated with the frequency of the turbulence introduced with the DM.*

8.5.12 TEST_1.12: R-MAO-77 Observing efficiency

Requirement description:

MAORY shall be able to deliver the required performance within 3 minutes of the completion of the telescope preset (TBC: AOF requires 5mins).

Test Description:

No procedure defined yet, but the TAC system will be probably required to check the achieved optical quality.

Responsible:

HTs/SEq needed: TAC System

Success Criteria:

Duration:

Prerequisities:

Notes: *It is depending on several factors:*

1) how often we will have to perform the fine tuning of the optical quality? (up to the actual knwoledge this is needed only once at the beginning of the night)

2) how long is the optimization time of the AO, including the reference acquisition?

3) …

I would write a sentence like: "The duration of each of this phase is still to be studied in detail, and it will be performed during the PDR phase."

Probably the final verification in BIH will be "Analysis/Test", a combination of the two

8.5.13 TEST_1.13: R-MAO-79 SCAO-MCAO switching

Requirement description:

It shall be possible to switch between the SCAO mode and MCAO mode within 255 sec (TBC).

Test Description: covered in RD15

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes:

8.5.14 TEST_1.14: R-MAO-80 Performance in best conditions

Requirement description:

Under the best conditions, the MAORY System (including the telescope) shall deliver a Strehl ratio of 0.50 (TBC) at 2.2 μm wavelength and should, as a goal, deliver a Strehl ratio of 0.60 at 2.2 μm wavelength. This requirement is assumed to be met under Quartile 1 (Q1) seeing and wind conditions (from AD3) and over a 20 arcsec diameter FoV. Sky coverage requirements do not apply. These Strehl ratio values assume a contribution of 145 nm RMS from the telescope to the overall wavefront error budget. The contribution from the telescope is TBC.

Test Description: covered in RD15

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: *see performance section of E-MAO-000-INA-ANR-007 and for details M-ANA 1.4 shown in E-MAO-IA0-INA-DER-0001 AO description document*

Are the "best seeing conditions" defined in the above mentioned document? How can we simulate it in a realistic way? It would be probably better to specify the strehl as SR of XX+/-YY.

8.5.15 TEST_1.15: R-MAO-82 Performance in median conditions

Requirement description:

Under median conditions (from AD3) the MAORY System (including the telescope) shall deliver a Strehl ratio of 0.30 (TBC) at 2.2 μm wavelength with a goal of 0.50 (TBC) at 2.0 μm wavelength. This requirement is assumed to be met under median seeing conditions, as close to zenith as permitted by the zenith avoidance zone and over a 1 arcmin diameter FoV. These Strehl ratio values assume a contribution of 145 nm RMS from the telescope to the overall wavefront error budget.

Test Description: covered in RD15

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: *see performance section of E-MAO-000-INA-ANR-007 and for details M-ANA 1.4 shown in E-MAO-IA0-INA-DER-0001 AO description document*

Same comment of R-MAO-82.

8.5.16 TEST_1.16: R-MAO-83 Performance in sub-optimal conditions

Requirement description:

Under Q3 seeing conditions (from AD3) over a 2 arcmin diameter FoV the MAORY System (including the telescope) shall deliver: at 2.2 μm wavelength a Strehl ratio of 0.15 (TBC, requirement) with a goal of 0.30 (TBC). The degradation of Strehl ratio with wavelength shall follow [R-MAO-84]. These Strehl ratio values assume a contribution of 145 nm RMS from the telescope to the overall wavefront error budget.

Test Description: covered in RD15

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: *see performance section of E-MAO-000-INA-ANR-007 and for details M-ANA 1.4 shown in E-MAO-IA0-INA-DER-0001 AO description document*

Same comment of R-MAO-82.

8.5.17 TEST_1.17: R-MAO-84 Peak Strehl

Requirement description:

The degradation of Strehl ratio with wavelength shall degrade approximately according to the expected relationship i.e. SR2 = SR1^((lambda1/lambda2)^2).

Test Description:

No procedure defined yet, but the TAC system will be probably required to check the SR changing the wavelength of the sources in the CU (check if J and H sources are available).

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: *M-ANA 1.4 is shown in E-MAO-IA0-INA-DER-0001 AO description document*

8.5.18 TEST_1.18: R-MAO-85 Uniformity of PSF

Requirement description:

The variation in Strehl ratio measured on any two point sources anywhere over the full corrected field at the MICADO port must be less than 10% (TBC; peak-to-valley absolute variation i.e. between 0.25 and 0.35 Strehl in median conditions as specified in [R-MAO-

82]. The requirement applies for all wavelengths > 1 µm and for zenith distances less than 60 degrees.

Test Description: covered in RD15

This should be easily feasible with the TU, moving the test camera in the various field positions and applying with the DMs the requested turbulence conditions

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: *M-ANA 1.4 is shown in E-MAO-IA0-INA-DER-0001 AO description document*

Does this req (less than 10% variation SR) answer to the questions above? Has the TBC been clarified?

8.5.19 TEST_1.19: R-MAO-87 Astrometric Accuracy

Requirement description:

MAORY shall permit observations such that the relative position on the sky of an unresolved, unconfused source of optimal brightness with respect to an optimal set of reference sources must be reproducible to within 50 µas (goal: 10 µas) over a central, circular field of 20 arcsec diameter (goal: across the entire field of view) and over all timescales in the range of 1 hour to 5 years.

Test Description

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: Optical description is in E-MAO-000-INA-ANR-007 doc optical section

50 muas is the final result, no budget provided. It is an astrometric req.

8.5.20 TEST_1.20: R-MAO-89 Photometric accuracy

Requirement description:

MAORY shall permit observations with MICADO such that the relative flux of an unresolved, unconfused source of optimal brightness with respect to an optimal set of reference sources must be reproducible to within 0.02 mag (goal: 0.01 mag) across the entire field of view and over all timescales in the range of 1 hour to 5 years.

Test Description:

No procedure defined yet, but the TAC system will be required for such a test (with adequate dynamic range).

Responsible:

HTs/SEq needed: TAC System

Success Criteria:

Duration:

Prerequisities:

Notes:

8.5.21 TEST_1.21: R-MAO-91 Transmission I

Requirement description:

MAORY optics from the entrance focal plane to the output port(s) shall have transmission over the science fields of view greater than 65% (TBC) at all wavelengths in the range 1.0-2.5 μm.

Test Description

Using the CU infrared light sources, we may think to perform a test by using the test camera (or a characterized NIR photodiode) positioned at the input and output focal plane to perform relative measurement.

Responsible:

HTs/SEq needed: TAC system or calibrated infrared photodiode

Success Criteria:

Duration:

Prerequisities:

Notes: *Throughput budget is described in optical session of E-MAO-000-INA-ANR-007 and managed in E-MAO-SE0-INA-DER-001 and descirbed in …*

8.5.22 TEST_1.22: R-MAO-92 Transmission II

Requirement description:

MAORY optics from the entrance focal plane to the output port(s) shall have transmission over the science fields of view larger than 50% (TBC) at all wavelengths in the range 0.8-1.0 µm.

Test Description

If we light sources in the range 0.8-1.0 µm, we may think to perform a test by using the test camera (or a characterized NIR photodiode) positioned at the input and output focal plane to perform relative measurement.

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: *Throughput budget is described in optical session of E-MAO-000-INA-ANR-007 and managed in E-MAO-SE0-INA-DER-001 and descirbed in …*

Same comment of the previous transmission requirement (R-MAO-91), but with vis light.

8.5.23 TEST_1.23: R-MAO-96 Performance under worst conditions I

Requirement description:

MAORY shall be able to close the loop and to keep the loop closed stably (stable PSF) up to 1.5 arcsec seeing at 500 nm along the line of sight for bright stars. (TBC)

Test Description: covered in RD15

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: *See performance section of E-MAO-000-INA-ANR-007 and for details M-ANA 1.4 shown in E-MAO-IA0-INA-DER-0001 AO description document*

Performance test, to be discussed with Lorenzo/Marco/Nicholas

8.5.24 TEST_1.24: R-MAO-97 Performance under worst conditions II

Requirement description:

For short (e.g. <1 min) excursions above 1.5 arcsecs but below TBD arcsecs and assuming that the telescope control loops are stable, the MCAO system shall remain stable in the sense that the AO correction continues without re-acquisition when the seeing returns below that threshold. A short period of re-optimisation of the loop is permitted. The upper limit of the seeing is set by the point at which the NGS tip-tilt signal is lost.

Test Description: covered in RD15

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: *See performance section of E-MAO-000-INA-ANR-007 and for details M-ANA 1.4 shown in E-MAO-IA0-INA-DER-0001 AO description document*

Performance test, to be discussed with Lorenzo/Marco/Nicholas, in principle possible to be tested by changing the turbulence introduced with the DM.

8.5.25 TEST_1.25: R-MAO-102 Mass R-INS-1137

Requirement description:

The total mass of the instrument elements located on the Nasmyth platform shall not exceed 25000 kg.

Test Description

This will be tested by weighting all the sub-systems individually, fully assembled. In Naple the whole thermal cover will be installed and the overall bench + thermal cover may be tested.

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes:

8.5.26 TEST_1.26: R-MAO-104 Computer Room Volume

Requirement description:

The volume of the instrument elements located in the computer room shall not exceed 19"x31.5"x 48 U.

Test Description

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: *[]*

8.5.27 TEST_1.27: R-MAO-107 Cooling power limit

Requirement description:

The cooling power consumption of the instrument shall not exceed the following values:

Power from the Nasmyth SCP:

Average (over 24hours): 10.4 kW

Peak: 14.8 kW

Warming-up and pumping down shall not be considered in the average power supply but shall be within the peak.

Test Description

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes:

8.5.28 TEST_1.28: R-MAO-109 Heat dissipation limit

Requirement description:

The average (in 10 minutes) heat dissipation of the active elements of the instrument located in the Nasmyth platform shall not exceed the following values:

Day-time: ±1050 W

Night-time: ±210 W

Test Description

measure the heat with the thermocamera, mapping all the temperatures and multiplying for the area to obtain the heat dissipation

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: *[]*

8.5.29 TEST_1.29: R-MAO-129 Electrical power limit

Requirement description:

The electrical power consumption of the instrument shall not exceed the following values:

Power from the Nasmyth SCP:

Average (over 24hours) normal power: 10.4 kW

Peak normal power: 25 kW

Average (over 24hours) safety power: 0.5 kW

Power from the Computer Room:

Average (over 24hours) normal power: 25 kW

Peak normal power: 35.7 kW

Test Description

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes:

TEST_2 ,test_ESO-254547

AD4 Common Requirements for E-ELT Instruments
ESO-254547 Version 2

8.5.30 TEST_2.1: R-INS-744 Calibration independency

Requirement description:

Maory shall be designed and built to be insensitive to outside illumination (see #743) so that all calibration procedures needed by Maory can be performed without affecting or being affected by routine observatory operations (including also the operation of other Maory).

Test Description

Calibration run with Assembly Hall lights on

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: *[]*

8.5.31 TEST_2.2: R-INS-749 Calibration sources intensity

Requirement description:

R-000-2.2.3.4.3

The intensity of the provided calibration sources shall be high enough to keep exposure times for calibration reasonably short while meeting the requirements given in section 8.12. What is regarded as “reasonably" shall be agreed by ESO and the consortium on a case-by-case basis at latest by FDR.

Test Description

Perform calibration run and confirm that the expected time is respected

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes:

8.5.32 TEST_2.3: R-INS-711 Night time operation preparation time

Requirement description:

R-000-2.2.4.2

Maory preparation for night time operation shall take less than 15 minutes per day, and shall be limited to one single observatory technician.

Test Description

Perform night time operation procedure and check the time constraint

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes:

8.5.33 TEST_2.4: R-INS-911 stand-by/operational switch time

Requirement description:

R-000-2.2.4.10

The transition from stand-by to operational and vice versa shall require less than 10 minutes.

Test Description

Perform the transition from non-operational (stand-by) to operational and procedure and check the time constraint

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: *I don't know what it is meant with "stand-by" and "operational" but I believe it may be tested*

8.5.34 TEST_2.5: R-INS-921 full correction time budget

Requirement description:

R-000-2.2.4.14

After target acquisition by the telescope, the adaptive optics capabilities shall acquire the guide stars and provide full image correction in less than 3 minutes.

Test Description

redundant with R-Mao-77

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: *[]*

8.5.35 TEST_2.6: R-INS-1211 Control system off/stand-by switch time

Requirement description:

R-000-2.2.4.15

The control system shall be capable to switch from off to stand-by and vice versa within less than 10 minutes.

Test Description

Perform the transition from off to non-operational (stadn-by) and procedure and check the time constraint

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: *[]*

8.5.36 TEST_2.7: R-INS-677 Electrical bonding

Requirement description:

R-000-2.5.5.1

Maory shall be electrically bonded. The bonding shall be compliant with ESO-262825 (see in particular RD3 of ESO-262825).

Test Description

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes

8.5.37 TEST_2.8: R-INS-1154 General electromagnetical requirements

Requirement description:

R-000-2.5.6.1

Maory shall conform to the electromagnetic compatibility requirements specified in ESO-262825.

Test Description

test with ESO equipoment

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: *Design?*

Up to my experence arriva l'omino ESO con la macchinetta che fa il test

8.5.38 TEST_2.9: R-INS-760 Induced vibration limit

Requirement description:

R-000-2.5.12.1.1

Maory shall be designed such that the level of vibration induced by the said Maory at the interface with the Nasmyth platform complies with the following specification:

The RMS forces generated by the vibrational sources of each Maory per one-third octave frequency bands shall be smaller than the values defined in the following table for the given frequency intervals.

OLE_AB_4159824256c050ad_23_2100009ec4_28000002f8_Baseline_4159824256c050ad-00009ec4-1000009-attr18_0.ole
OLE_AB_4159824256c050ad_23_2100009ec4_28000002f8_Baseline_4159824256c050ad-00009ec4-1000009-attr18_0.png OLE Object

Test Description

We mount Accelerometers at Nsmyth equivalent interface and we measure in all operative use cases.

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes:

8.5.39 TEST_2.10: R-INS-755 Daytime temperature difference

Requirement description:

R-000-2.5.12.2.1

During day time, the temperature difference between the Maory (or any associated equipment) outer surface and the ambient air shall not be larger than: ±2.5 ºC

Test Description

Measure with FLIRcamera

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes

8.5.40 TEST_2.11: R-INS-757 Nighttime temperature difference

Requirement description:

R-000-2.5.12.2.3

During night time, the temperature difference between the Maory (or any associated equipment) outer surface and the ambient air in still wind conditions (a wind speed inside the dome of 2 m/sec and a convection coefficient of 2W/m2/K) shall not be larger than: ±1.5 ºC

Test Description

Measure with FLIRcamera

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: *Design? This cannot be tested in the BIH* *no wind speed*

8.5.41 TEST_2.12: R-INS-797 Surface emissivity

Requirement description:

R-000-2.5.12.3.1

Maory shall not have any sources inside the telescope chamber that emit light (in the wavelength range from 0.3 to 3 micrometer) when not in operational state (see #738). In operational state this is allowed as long as no other E-ELT system functionality is affected (to be discussed by ESO and consortium on a case by case basis).

In addition, no infrared remote controllers shall be used in operational state.

Test Description

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes:

8.5.42 TEST_2.13: R-INS-722 identification of failures

Requirement description:

R-000-2.6.3.2.2

In case of system failure, this software (test and maintenance SW) shall allow identification of the subsystem level at which the failure happened.

Test Description

Bernardo will test this software

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: *[]*

8.5.43 TEST_2.14: R-INS-1191 Personel limitation for maintenance

Requirement description:

Inspection and analysis

Any corrective maintenance action shall be performed with a maximum of 2 qualified engineers or technicians, using standard tools and/or special tools specific to Maory .

Test Description

It will be tested in the BIH for every sub-system that will be subject to maintenance

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: *Two persons plus the crane operator?*

8.5.44 TEST_2.15: R-INS-503 actions limitations

Requirement description:

R-000-2.6.4.2.1

For Maory all preventive and predictive maintenance actions shall be carried out during non-observational hours that are in a daytime maintenance period window of 8 (eight) hours each day.

Test Description

It will be tested in the BIH for every sub-system that will be subject to maintenance

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: *[]*

8.5.45 TEST_2.16: R-INS-504 splitability over more days

Requirement description:

R-000-2.6.4.2.2

If preventive/predictive maintenance action duration lasts more than 8 staff-hours, it shall be possible to split the task over more maintenance shifts in order to not interfere with the nighttime operations.

Test Description

It will be tested in the BIH for every sub-system that will be subject to maintenance

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: *[]*

8.5.46 TEST_2.17: R-INS-461 Relaiability libraries adoption

Requirement description:

R-000-2.10.4.1

Where data from reliability libraries (e.g. Bellcore/Telcordia, NPRD-95, MIL-HDBK-217, etc.) for electrical, electro and electro-mechanical components are not available and where a failure of a specific component will be safety-critical (i.e. risk score (s) is high or medium, see SAF-GEN-MAN-3444), an accelerated reliability testing technique, like the Highly Accelerated Life Tests (HALT), shall be applied to ensure that the quantitative reliability requirements of the Technical Specification and RAM and Safety Analyses are achieved.

The list of components for which an accelerated reliability testing technique is foreseen shall be provided for approval to ESO.

The accelerated reliability testing technique to be adopted shall be agreed, too.

Test Description

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: *at the mooment is non applicable so no test foreseen*

8.5.47 TEST_2.18: R-INS-1116 End of warranty phase MTBF update

Requirement description:

R-000-2.10.4.2

At the end of the Warranty Phase of the Maory (prior to Final Acceptance) and during the HALT Campaign (if any), the reliability requirement(s) shall be demonstrated by accounting for all unreliability induced failures.

The observed MTBF shall meet the specified MTBF with 90% confidence level (computed Upper MTBF value shall be greater than the required MTBF). The chi-squared test shall be adopted, unless otherwise agreed.

The Upper MTBF value shall be computed using the following formula:

OLE_AB_4159824256c050ad_23_2100009ec4_280000045c_Baseline_4159824256c050ad-00009ec4-1000009-attr18_0.ole OLE_AB_4159824256c050ad_23_2100009ec4_280000045c_Baseline_4159824256c050ad-00009ec4-1000009-attr18_0.png OLE Object

where:

T = Total Time - Total Down Time

OLE_AB_4159824256c050ad_23_2100009ec4_280000045c_Baseline_4159824256c050ad-00009ec4-1000009-attr18_1.ole OLE_AB_4159824256c050ad_23_2100009ec4_280000045c_Baseline_4159824256c050ad-00009ec4-1000009-attr18_1.png OLE Object = a-th percentile of the Chi-squared distribution with b degrees of freedom a = percentile of the Chi-squared distribution = 1-(alfa/2) = 0.95

1-alfa = 0.90 (90% confidence level)

b = degrees of freedom of the Chi-squared distribution = 2*r

r = Number of unreliability induced failures during the period considered.

Test Description

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: *Analysis and Inspection?*

8.5.48 TEST_2.19: R-INS-463 Maintainability testing

Requirement description:

R-000-2.10.5.1

As part of the overall verification of the Maory , and its Auxiliary Equipment, the Consortium shall demonstrate by testing the maintainability of the product. The maintainability demonstration shall verify and validate the following, as a minimum:

Troubleshooting techniques as detailed in the Maintenance Manual;

Maintenance tools and equipment;

MTTR values and maximum allocated time (where applicable), both for corrective and preventive /predictive maintenance actions;

Corrective, Preventive and Predictive maintenance procedures and instructions;

Software routines used for maintenance, if applicable.

Test Description

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: *[]*

8.5.49 TEST_2.20: R-INS-1054 End of warranty phase MTTR update

Requirement description:

R-000-2.10.5.2

At the end of the Warranty Phase of the Product (prior to Final Acceptance) and during the HALT Campaign (if any), the maintainability requirement related to the MTTR value(s) shall be demonstrated by accounting for all unreliability induced failures.

The observed MTTR shall meet the specified MTTR with 90% confidence level (computed Upper MTTR value shall be greater than the required MTTR). The chi-squared test shall be adopted, unless otherwise agreed.

The Upper MTTR value shall be computed using the following formula:

OLE_AB_4159824256c050ad_23_2100009ec4_280000041e_Baseline_4159824256c050ad-00009ec4-1000009-attr18_0.ole OLE_AB_4159824256c050ad_23_2100009ec4_280000041e_Baseline_4159824256c050ad-00009ec4-1000009-attr18_0.png OLE Object

where:

T = Total Down Time

OLE_AB_4159824256c050ad_23_2100009ec4_280000041e_Baseline_4159824256c050ad-00009ec4-1000009-attr18_1.ole OLE_AB_4159824256c050ad_23_2100009ec4_280000041e_Baseline_4159824256c050ad-00009ec4-1000009-attr18_1.png OLE Object = a-th percentile of the Chi-squared distribution with b degrees of freedom

a = percentile of the Chi-squared distribution = 1-(alfa/2) = 0.95

1-alfa = 0.90 (90% confidence level)

b = degrees of freedom of the Chi-squared distribution = 2*r

r = Number of repairs/replacements due of unreliability induced failures during the period considered

Test Description

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: *[]*

8.5.50 TEST_2.21: R-INS-841Surface temperature verification

Requirement description:

R-000-2.10.6.1

The requirements on surface temperature shall be verified by:

1. thermal analysis during the design phase

2. test in representative conditions during acceptance testing using

a. infrared camera to provide overview and estimates of temperatures

b. local temperature measurement with appropriate accuracy for critical cases

Test Description

Every component/sub-system with thermal emission will be tested in the BIH in specified conditions and with the specified metodology

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: *[]*

8.5.51 TEST_2.22: R-INS-885 Analysis and testing needs

Requirement description:

R-000-2.10.7.1

The vibration requirement 2.5.12.1 shall be verified by a combination of analysis and testing. Maory team shall identify and characterize all possible vibration sources, and by analysis estimate the interface forces in amplitude and frequency defined in 2.5.12.1.

Test Description

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes:

8.5.52 TEST_2.23: R-INS-1223 Tests constraints

Requirement description:

R-000-2.10.7.2

The characterization of vibration sources by test shall consider the following:

Under operational conditions, e.g. mechanical boundary condition, coolers, pumps electronic racks in nominal operation.

· Measurements with duration of at least 30 seconds with sampling of at least 300Hz shall be performed.

· Each measurement set (same condition) shall be repeated at least ten times and an average over 30 sec shall be constructed.

· A spectral analysis of the measured data (averaged data) shall be performed, e.g. PSD (Power Spectral Density) shall be estimated.

Test Description

All the identified sources of vibrations shall be tested as specified in the req.

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: *Same as above*

8.5.53 TEST_2.24: R-INS-1231 EMC test

Requirement description:

Verification of EMC- and Safety-related requirements shall be according to Sec. 4 of ESO-262825.

Test Description

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes:

TEST_3 ,test_ESO-253082

AD5 Common ICD between the E-ELT Nasmyth Instruments and the Rest of the E-ELT System
ESO-253082 Version 4.1

8.5.54 TEST_3.1: I-INS/ELT-327 Power Factor

Requirement description:

R-000-3.8.1.3

The power factor (lambda) of each Nasmyth instrument shall be greater than or equal to 0.85.

Test Description

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes:

8.5.55 TEST_3.2: I-INS/ELT-354 compatibility with volume and power

Requirement description:

R-000-3.11.5

The instrument control system shall comply with the electrical power and space allocated to the instrument in the computer room. Electrical power and space will be allocated on an instrument-specific basis.

Test Description

Responsible:

HTs/SEq needed:

Success Criteria:

Duration:

Prerequisities:

Notes: *by design*

8.5.56 AO System test

Test the AO system functionalities, the technical calibration templates and AO instrument performance using the Test Unit

Responsible: SGO, NDE, LBU, MBO, JFA

HTs/SEq needed: CU/Test tower

Success Criteria: Verification of the system performance against the requirements

Duration: TBD

Prerequisites: 8.4 AI process

Description

<u>The AO related system test covered in RD15.</u>

Notes: We assume that the overall test phase will last 180 days.

9. PACKAGING AND TRANSPORT

This section will be detailed for the FDR, Prior to the packaging and shipping activities, the instrument shall be fully dismounted.

9.1.1 Dismounting of the whole MAORY & shipping

Dismounting of all the optomechanics, MSS and MES, packaging and shipping preparation

Responsible: JFA

HTs/SEq needed: BIH Bridge crane, Dedicated HTs, Scissor lifts, Cherry picker, forklift

Success Criteria: MAORY fully disassembled, packed and shipped

Duration: 52 days

Prerequisites: 8.5 System Test Phase

Notes: a full description of the dismounting activities will be given for the FDR

9.2 Packaging

This section will be prepared for the FDR. General rules to be followed are anyhow mentioned in the following.

All the transport boxes shall be compliant with the requirements that apply to transport from Europe to Chile, and should be compatible both with air and naval expedition. The equipment inside the transportation boxes shall be protected with barrier bags. All the boxes shall be equipped with tilt and shock sensors, positioned both in the inner and in the outer part of the boxes. The orientation of the boxes during the transportation shall be clearly indicated with arrows. The opening side for inspection shall also be clearly indicated. Finally, the boxes shall be re-usable.

9.3 Transport

This section will be prepared for the FDR. General rules to be followed are anyhow mentioned in the following.

The shipping strategy is to transport the instrument completely disassembled, using as much as possible the same containers/box used for the sub-system shipping to Bologna.

The sub-system transport containers shall be compatible with shipping over sea (meaning the box material shall be compatible with this kind of shipping and all the relevant equipment shall be protected inside the box by a “transport barrier bag” water proof).

Every box will be equipped with shock and tilt sensors, and the MAORY instrument will be insured (possibly with an “all risk” insurance). A responsible of the insurance company will be required to follow both the *boxes closure operations* in Bologna and the *boxes opening operations* in Chile.