VLT

ERIS

Phase B

Sub-System Design & Performance Report - Calibration Unit

Doc. No.: VLT-TRE-ERI-14404-5001

Issue: 1.0

Date: 26.11.2015

Author(s):	M. Dolci	…26.11.2015…………………………………….....	
	Name	Date	Signature
	A. Riccardi	…26.11.2015…………………………………….....	
	Name	Date	Signature
	A. Valentini	…26.11.2015…………………………………….....	
	Name	Date	Signature
	P. Spanò	…26.11.2015…………………………………….....	
	Name	Date	Signature

ERIS Consortium

	G. Di Rico	…26.11.2015………………………………....	
	Name	Date	Signature
	D. Ferruzzi	…26.11.2015………………………………....	
	Name	Date	Signature
Proj. Manager:	E. Sturm	…………………………	
	Name	Date	Signature
Proj. Responsible	R. Davies	………………………………………………………..	
	Name	Date	Signature

CHANGE RECORD

ISSUE	DATE	SECTION / PARAGRAPH AFFECTED	REASON/INITIATION DOCUMENTS/REMARKS
1.0	26.11.15	All	First Version

TABLE OF CONTENTS

1 Scope

This document describes the design of the Calibration Unit (CU) for the ERIS instrument. It includes engineering (functional) analysis and technical (requirement) specifications. The corresponding optical, mechanical and electronic design are described and the results of sensitivity and performance analysis are reported. The document also includes a discussion on operation and maintenance-related aspects.

1.1 Applicable documents

The following applicable documents (AD) of the exact issue form part of the present document to the extent specified herein.

RD Nr	Doc. Nr	Doc .Title	Issue	Date
AD1	ESO-045162	ERIS Requirement Specification	2	19.06.2015
AD2	VLT-TRE-ESO-14400-5566	ERIS Phase A Operational Concept Definition	1.0	30.04.2012
AD3	VLT-PLA-MPE-14400-0010-001	ERIS NIX+SPIFFI Subsystem Calibration Plan	1.1	26.02.2014
AD4	VLT-PLA-ESO-14400-6095	Preliminary ERIS Calibration Plan	1	19.03.2014
AD5	VLT-TRE-ERI-14400-1004	ERIS System Design & Analysis	1.0	15.12.2015

Table 1: Applicable Documents

1.2 Reference documents

The following reference documents (RD) contain useful information relevant to the subject of the present document.

RD Nr	Doc. Nr	Doc .Title	Issue	Date
RD1	VLT-TRE-ERI-14400-1301	ERIS Sub-System Design & Performance Report - Electronics	1.0	15.12.2015
RD2	VLT-SPE-ERI-14401-1702	Instrument Software Functional Specification	1.0	15.12.2015
RD3	VLT-SPE-ERI-14401-1701	Instrument Software Requirements Specification	1.0	15.12.2015

Table 2: Reference Documents

1.3 Acronyms

4LGSF	4 Laser Guide Star Facility
AD	Applicable Document
AO	Adaptive Optics
AOF	Adaptive Optics Facility
ATC	United Kingdom Astronomy Technology Centre, Edinburgh
CCC	Closed-Cycle Cooler
CoG	Center of Gravity
CU	Calibration Unit
CUMB	CU Main Bench
CUFS	CU Fiber Switchyard
CUSM	CU Selector Mirror
CUUC	CU Use Cases
DSM	Deformable Secondary Mirror
ESO	European Organization for Astronomical Research in the Southern Hemisphere, Garching
ETH	Swiss Federal Institute of Technology (ETH Zürich), Institute for Astronomy
FoV	Field-of-View
FPL	Focal Plane for LGS
FPN	Focal Plane for NGS
HW	Hardware
INAF	Istituto Nazionale di Astrofisica (with OAA, OATe and OAPd), Italy
ICD	Interface Control Document
INS	Instrument Control Software
IS	Integration (or Integrating) Sphere
ISSM	IS Selector Mirror
LDLS	Laser-Driven Light Source
LGS	Laser Guide Star
MAIV	Manufacture, Assembly, Integration and Verification
MM	Multi-mode (fiber optics)
MPE	Max-Planck-Institut für extraterrestrische Physik (Garching)
NCP	Non-Common Path
NGS	Natural Guide Star
NIR	Near-Infrared
NIX	Near Infrared Camera System
OAA	Osservatorio Astrofisico di Arcetri
OAPd	Osservatorio Astronomico di Padova
OATe	Osservatorio Astronomico di Teramo
PAC	Preliminary Acceptance Chile
PAE	Preliminary Acceptance Europe
PHM	Pinhole Mask
PPL	Pupil Plane
PDR	Preliminary Design Review
PI	Principal Investigator
PM	Project Management
QTH	Quartz-Tungsten Halogen
RD	Reference Document

RTC	Real-Time Controller
SAM	Sparse-Aperture Masking
SH	Shack-Hartmann
SM	Single-Mode (fiber optics)
SoW	Statement of Work
SPIFFI	Spectrometer for Infrared FaintField Imaging
SW	Software
TBC	To Be Confirmed
TBD	To Be Defined
TFP	Telescope Focal Plane
UT	Unit Telescope
VLT	Very Large Telescope
WBS	Work Breakdown Structure
WFS	Wave Front Sensor
WO	Warm Optics

1.4 Tables and Figures

2 Introduction

ERIS, the Enhanced Resolution Imager and Spectrograph, is a 1 – 5 μm instrument for the Cassegrain focus of UT4/VLT, equipped with the Adaptive Optics Facility (AOF). ERIS uses and depends on the AOF infrastructure to perform the AO correction.

The ERIS concept maximizes the re-use of existing sub-systems and components. In particular, the AO correction is provided by the AOF Deformable Secondary Mirror (DSM), the artificial Laser Guide Star (LGS) is generated by the 4 Laser Guide Star Facility (4LGSF) at UT4, the wavefron sensor camera detectors are identical to those used for GALACSI and GRAAL (the two GLAO systems of the AOF) and the Real-Time Computer (RTC) is a modified version of SPARTA. In addition, one of the scientific instruments (ERIS-SPIFFI) is modified version of SPIFFI, the 1 – 2.5 μm integral field unit used on-board SINFONI.

ERIS consists of the following modules:

- the **Calibration Unit** which provides facilities to calibrate the scientific instruments and perform troubleshooting and periodic maintenance tests of the AO modules (e.g. calibrate Non-Common Path (NCP) aberrations and flexure pointing models);
- the **AO module**, which will use the AOF DSM and one AOF laser, providing NGS and LGS visible wavefront sensing with real-time computing capabilities. It is composed in turn by the following subassemblies:
  - a Natural Guide Star (NGS) Wavefront Sensor (WFS) that provides high-order AO correction or is used as low-order sensor for the LGS mode
  - a LGS WFS providing high-order AO correction

  The AO module will allow for single-conjugate adaptive optics (SCAO) operations.
- two **science instruments**:
  - **NIX (Near Infrared Camera System)** which provides diffraction-limited imaging, sparse-aperture masking (SAM) and pupil plane coronagraphy capabilities in the 1 – 5 μm (J to M') bands, either in "standard" observing mode or with "pupil tracking" and "cube" readout mode. NIX is a cryogenic instrument and is equipped with a 2048 × 2048 detector cooled at 40K by means of a Closed Cycle Cooler (CCC). The camera optics is able to provide a Field-of-View (FoV) of 27" × 27" in the J to Ks bands or 55" × 55" in the J to M' bands.
  - **ERIS-SPIFFI**, which is a refurbished version of SPIFFI, modified in order to be integrated into ERIS. Its observing modes are identical to those of SINFONI, with the goal of adding a high-resolution (R=8000) grating.

  Both NIX and ERIS-SPIFFI are fed by a dichroic beamsplitter which reflects the visible light to the AO module.

3 Calibration Unit Overview

The Calibration Unit (CU) is a subsystem of ERIS aimed to provide calibration capabilities for the ERIS instruments (NIX, SPIFFI and AO WFS). In particular, the ERIS-CU has to provide:

- photometric flat fields for NIX, in broad- (J, H, K) and narrow-bands;
- spectroscopic flat fields for SPIFFI over its full wavelength range (1 – 2.5 μm);
- wavelength calibration for SPIFFI, in the same range as above;
- point-like (DL and 0.5”) and extended (1.0 and 1.5”) sources for AO LGS and NGS WFS calibration (e.g. Non-Common Path Aberrations, Differential Flexures between science instruments and AO systems), at optical wavelengths (R-band);
- point-like (DL and 0.5”) and extended (1.0 and 1.5”) sources for NIX and SPIFFI technical checks (e.g. N-S test), at a working wavelength for these two instruments (K band, TBC).

Note that calibration capabilities for NIX higher wavelengths (L, M’ bands) are not foreseen for the CU. At these wavelengths, calibrations shall be made using on-sky sources.

The ERIS-CU is composed by two separate units. The first one, called **Calibration Unit Main Bench (CUMB)**, is optically and mechanically interfaced with the ERIS optical plate; the second one, called **Calibration Unit Fiber Switchyard (CUFS)**, is hosted inside one of the ERIS cabinets and interfaced with the CU only. It is therefore not directly interfaced with the ERIS instruments and the telescope.

The first unit (CUMB) is equipped with an objective transmitting from visible to 2.5 μm that operates with a magnification of 1 : 1.296 in order to project point sources of various sizes onto the Cassegrain focal plane and to deliver a projected virtual position of the pupil that coincides with the telescope secondary mirror.

A pattern of artificial point-like and extended sources (*pinhole mask*) is placed onto the back focal plane of the objective. It is provided with two precision stages aimed to provide extremely accurate (0.2 μm over a 25mm range) positioning of the sources over the focal plane (xy-plane). The plane can be placed at variable distances from the objective in order to reproduce either celestial sources and natural guide stars or laser guide stars (variable height between 80 km and 200 km). Focal plane selection, as well as fine focusing (z-direction), are ensured by a linear stage able to provide a positioning accuracy of 1 μm over a 102 mm range.

Flat field capabilities are obtained by inserting a plane mirror across the optical path, in order to project onto the telescope focal plane the light coming from an integrating sphere whose output port is placed at the position of the pupil. The insertion of the mirror is performed by rotating it by at least 90°, through a rotation stage able to provide a positioning accuracy better than 0.5 arcsec over a range of 270°.

A fixed pupil stop in the pinhole mask optical path (needed to ensure correct AO calibration operations) and a folding mirror (that allows to make the CU compact) are also part of the complete CU optical bench.

Point-like and extended sources on the pinhole mask are produced by rear-feeding of the mask with a mono-mode optical fiber (for the DL source) and a multi-mode optical fiber (for all other sources). The integrating sphere is fed by a multi-mode optical fiber (for flat fields capability) plus four pencil-style spectral calibration lamps (Ne, Xe, Ar, Kr), mounted inside a light pipe directly connected to the sphere. All the fibers come from the Fiber Switchyard and provide very low attenuation over the full wavelength range of operation.

The second unit (CUFS) hosts light sources for flat field capabilities and pinhole mask sources. A white-light, broad-spectrum lamp (Laser Driven Light Source, LDLS) provides an almost flat spectral output over the 0.4 – 2.4 μm wavelength range, delivering a power of 50 μW/nm at optical wavelengths and up to 10 μW/nm at 2.5 μm. In addition, a Quartz-Tungsten Halogen (QTH) lamp, able to provide up to 6 W/nm at optical wavelengths, is foreseen as backup for NIX narrow-band flat field and SPIFFI spectroscopic calibrations, where the photon rate from the LDLS only could be insufficient for the calibration procedures.

The lamps output is sent to a fiber selection mechanism placed inside the FS. This is composed by a fixed structure supporting the output fiber (from the lamps) plus an output collimator, and a movable structure supporting three input fibers (a mono-mode fiber and a multi-mode fiber to feed the pinhole mask, plus a multi-mode fiber to feed the integrating sphere), each fiber being provided with its own input collimator. It allows to alternatively feed one of the three fibers.

In order to adjust the light levels according to the different calibrations to be made (e.g. broad-band vs narrow-band flat field), a variable neutral density (ND) filter can be placed at different positions between the output and the input collimators.

The three input fibers are mounted onto a linear stage, able to provide a positioning accuracy of 1 μm over a 155 mm range. A second, identical stage is used for the variable ND filter positioning, meeting the same requirements on terms of travel range and positioning accuracy.

In order to fully comply with maintenance operations, the connections between the FS and the CU (power and signal cable, plus optical fibers) are segmented by means of intermediate connectors. To minimize light losses at every connection, the number of segments for the optical fibers shall be reduced as much as possible.

4 Engineering Analysis

4.1 Context and Stakeholders

In the overall ERIS architecture, the CU is a *subsystem* which in turn consists of *components*, possibly decomposed further into *sub-components* down to *LRUs* (sub-components themselves can be LRUs).

Its purpose is to serve all other ERIS subsystems, namely NIX, SPIFFI and the AO module, providing essentially light signals, either focussed and exactly positioned onto the telescope focal plane, or uniformly spread across it (flat fields), for calibration or technical check purposes. On the other side, the CU exchanges configuration (commands, instructions) and monitoring (lamps feedback, environment) data with the ERIS instrument software (INS).

In this context, the ERIS-CU stakeholders can be identified as follows:

- Other ERIS sub-systems (NIX, SPIFFI, AO Module) that are served for calibration purposes;
- ERIS instrument software (INS) that receives monitoring data and sends instructions and commands to the CU;

- external users (scientists, engineers, operators, analysts, etc.) allowed to access CU control for science instruments calibration and technical check (e.g. for maintenance purposes), as well as to CU monitoring data for inspection of its status (again for maintenance purposes).

4.2 CU Use Cases

The Calibration Plan for ERIS ([AD3]) defines a set of calibration and technical check procedures that involve the use of the Calibration Unit.

Therefore, a set of "Calibration Unit Use Cases" (CUUC) can be identified. It is important to note that this terminology is for CU internal purposed only: CUUC are not related to the ERIS UC defined in [RD2] and [RD3] or referred to in [AD2].

The list of CUUC is reported in Table 3 below. A detailed description is given in the NIX+SPIFFI Calibration Plan [AD3] and in the note on AO Module Calibration [AD4].

NIX-related	
ID	**Description**
ERIS.CU_NX_UC_03	NIX broad-band flat fielding
ERIS.CU_NX_UC_04	NIX narrow-band flat fielding
ERIS.CU_NX_UC_05	SAM/APP Mask alignment
ERIS.CU_NX_UC_06	NIX detector linearity
SPIFFI-related	
ID	**Description**
ERIS.CU_SP_UC_02	Wavelength calibration
ERIS.CU_SP_UC_04	SPIFFI flat fielding
ERIS.CU_SP_UC_05	SPIFFI detector linearity
ERIS.CU_SP_UC_06	SPIFFI detector distortion
ERIS.CU_SP_UC_07	SPIFFI slitlets N/S test
NGS WFS-related	
ID	**Description**
ERIS.CU_NG_UC_02	Size and geometry of the SH NGS spot array
ERIS.CU_NG_UC_03	Size of the NGS pupil
ERIS.CU_NG_UC_04	Location of the NGS pupil
ERIS.CU_NG_UC_05	Uniformity of the NGS pupil intensity distribution
ERIS.CU_NG_UC_06	NGS WFS CCD response in the bright-end regime
ERIS.CU_NG_UC_07	NGS WFS CCD response in the faint-end regime
ERIS.CU_NG_UC_08	NGS signal with diffraction-limited source
ERIS.CU_NG_UC_09	NGS signal with extended source

ERIS.CU_NG_UC_10	Calibration of the NGS slope signal vs tilt for each subaperture
ERIS.CU_NG_UC_11	NGS beam vignetting
ERIS.CU_NG_UC_12	NGS WFS non-common path aberrations
ERIS.CU_NG_UC_13	NGS Derotator and ADC pupil wobbling
ERIS.CU_NG_UC_14	NGS pupil stabilization mirror calibration
ERIS.CU_NG_UC_15	NGS WFS differential flexures
LGS WFS-related	
ID	**Description**
ERIS.CU_LG_UC_02	Size and geometry of the SH LGS spot array
ERIS.CU_LG_UC_03	Size of the LGS pupil
ERIS.CU_LG_UC_04	Location of the LGS pupil
ERIS.CU_LG_UC_05	Uniformity of the LGS pupil intensity distribution
ERIS.CU_LG_UC_06	LGS WFS CCD response in the bright-end regime
ERIS.CU_LG_UC_07	LGS acquisition camera hotspot
ERIS.CU_LG_UC_08	LGS signal with diffraction-limited source
ERIS.CU_LG_UC_09	LGS signal with extended source
ERIS.CU_LG_UC_10	Calibration of the LGS slope signal vs tilt for each subaperture
ERIS.CU_LG_UC_11	LGS beam vignetting
ERIS.CU_LG_UC_12	LGS WFS non-common path aberrations
ERIS.CU_LG_UC_13	LGS Derotator and ADC pupil wobbling
ERIS.CU_LG_UC_14	LGS pupil stabilization mirror calibration
ERIS.CU_LG_UC_15	LGS WFS differential flexures

Table 3: Calibration Unit Use Cases (for internal development purpose only).

4.3 CU Configurations

The CU is a complex system composed by several subunits. Each subunit can be characterized by a series of its own states, such as OFF, ON, STANDBY, READY, FAILURE, UNKNOWN, and can be undergoing specific actions like <init>, <move> and <wait for positioning completion> (for the positioning stages) or <power> and <wait for warm-up completion> (for the lamps).

Some assumptions must be made on the start-up sequence, in order to make as simple as possible the definition of a set of internal “global” states for the CU. With reference to Figure 1, we can assume the following typical start-up sequence:

1) all the controllers (positioning stages and lamps) are switched ON at startup and for each of them a transition from OFF to ON state occurs;
2) all the controllers for the positioning stages are then initialized, i.e. set to zero reference position, and for them a transition from ON to STANDBY state occurs.

These first two steps complete the “basic initialization” of the CU. After these steps, every action is somewhat related to the specific Use Case. Generally speaking:

3) each requested lamp is powered on, and for it a transition from ON to STANDBY state occurs. In STANDBY state the lamp is simply warming up to the final operating temperature/brightness;
4) each requested positioning stage is moved to the requested position, and for it a transition from STANDBY to READY state occurs when the final position is reached;
5) for each lamp, finally, upon completion of its warm-up, a transition from STANDBY to READY state occurs.

Basing on this scheme, the CU internal “global” states OFF, ON, INITIALIZING, STANDBY, SETTING, READY, FAULT, UNKNOWN can be defined. Since the CU is not to be used as a stand-alone subsystem, these states refer every time to the CUUC of interest. They are summarized in Figure 1.

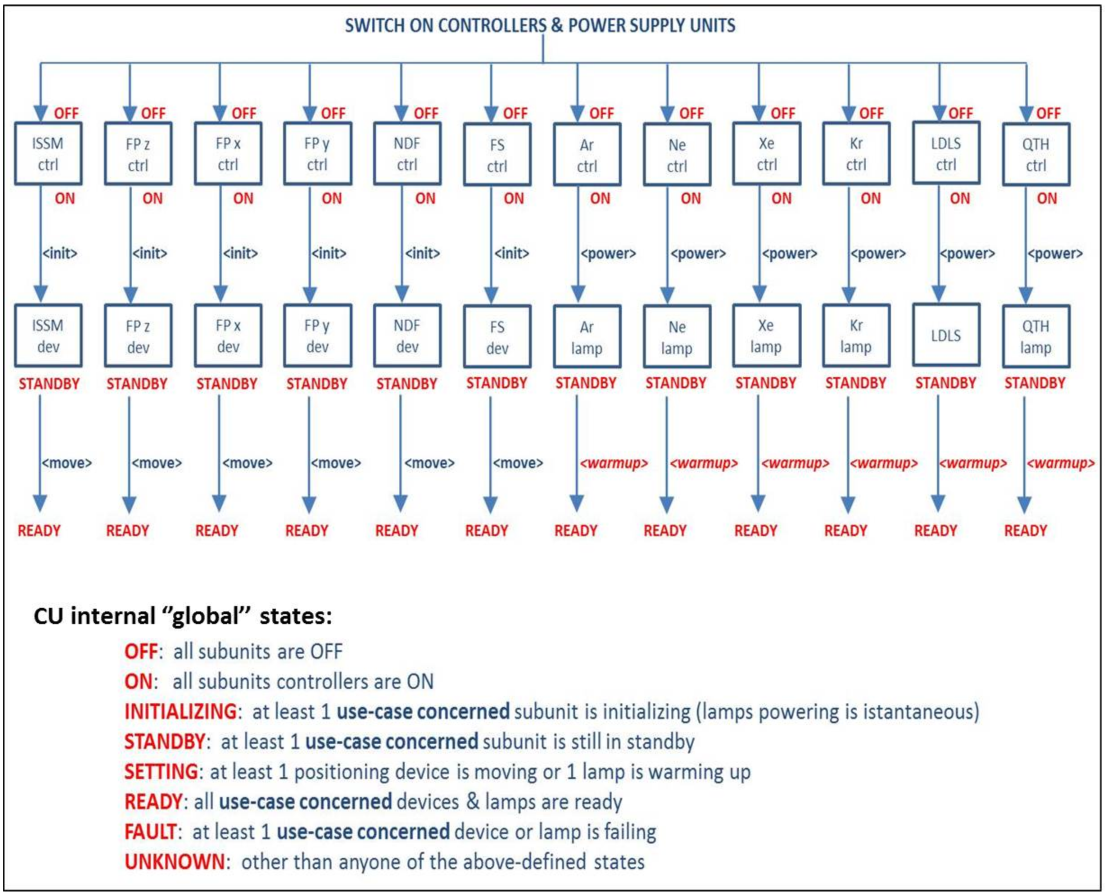


Figure 1: CU internal "global" states.

Each of the above-mentioned states can be internally assumed by the CU in a set of different “operating modes”. For compliance with the INS architecture, we will call these modes “Cu Configurations”.

By analyzing the CUUC, three main configurations have been identified:

A) PPL (Pupil Plane). In this configuration the telescope pupil is simulated (through the exit hole of a Integrating Sphere) and used to illuminate the exit pupil into the scientific instruments (for special calibration purposes) or the focal plane (mainly for flat field purposes);

B) FPN (Focal Plane, NGS). In this configuration a set of artificial sources, positioned at the telescope Cassegrain focal plane (i.e. at infinite distance), are used (for special calibrations of SPIFFI plus the calibration of the NGS WFS);

C) FPL (Focal Plane, LGS). In this configuration the same set of artificial sources is used, but positioned at the telescope focal plane corresponding to a finite distance (85 km, TBC). This configuration is used for the calibration of the LGS WFS.

Setting the CU for each of these three configurations requires a set of steps. Figure 2 shows a full operational life-cycle for the CU:

1) the system is initially in OFF state;
2) the start-up sequence puts it to the ON state (first blue arrow) and then in the STANDBY state (second blue arrow);
3) additional specific functions (e.g. moving the ISSM; moving the Focus Z stage and waiting for LDLS warm-up) allow it to reach one of the three operating modes (third blue arrow);
4) the system can move from each operating mode to each other (green arrows), or
5) it can move back to OFF state with a shut-down TBD procedure (red arrow).

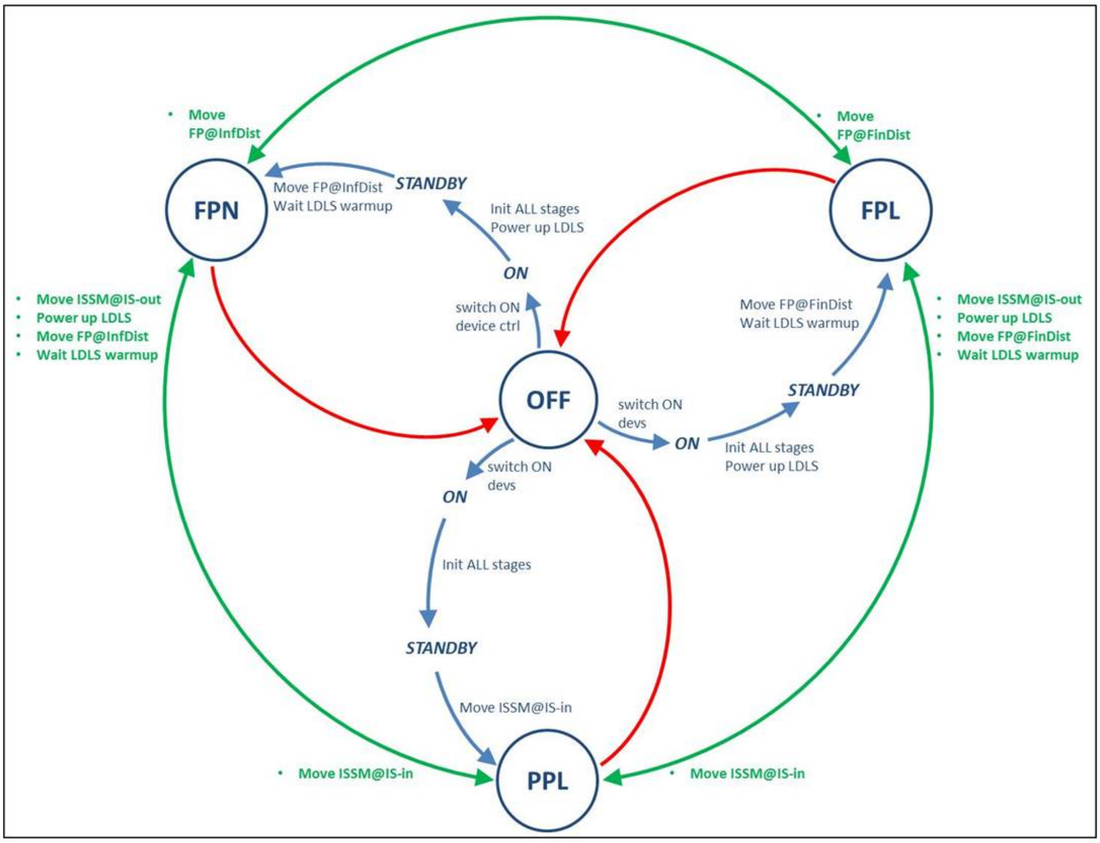


Figure 2: CU Configurations and operation lifecycle

4.4 Functional Decomposition

Starting from the CUUC and taking into account the definition of the CU Configurations made in the previous Section, a set of 10 basic functionalities has been finally identified for the CU. They are reported in Table 4.

ID	CU Config.	Functionality Description	Purpose(s)
CU-FUN-02	PPL	Providing a uniformly white-light illuminated pupil through a IS fed by a LDLS	NIX broad-band flat-field NIX detector characterization SPIFFI detector characterization
CU-FUN-03	PPL	Providing a uniformly white-light illuminated pupil through a IS fed by a QTH	NIX narrow-band flat field SPIFFI flat field
CU-FUN-04	PPL	Providing a uniformly illuminated pupil through a IS fed by a Ne spectral lamp	SPIFFI wavelength calibration
CU-FUN-05	PPL	Providing a uniformly illuminated pupil through a IS fed by a Ar spectral lamp	SPIFFI wavelength calibration
CU-FUN-06	PPL	Providing a uniformly illuminated pupil through a IS fed by a Xe spectral lamp	SPIFFI wavelength calibration
CU-FUN-07	PPL	Providing a uniformly illuminated pupil through a IS fed by a Kr spectral lamp	SPIFFI wavelength calibration
CU-FUN-08	FPN	Providing a array of 0.5" (integrated m(R)=17, G2 star), 1.0" (integrated m(R)=19, G2 star) and 1.5" (integrated m(R)=8, G2 star) artificial NGSs over a 2' FoV, plus a illuminated slit in TBD(x,y) positions over the Cassegrain focal plane	NGS WFS calibration NGS field selector calibration Differential flexures calibration Scientific detectors distortion SPIFFI slitlets N/S test
CU-FUN-09	FPN	Providing a DL@750nm, m(R)=8 (G2 star) NGS in TBD(x,y) positions over the Cassegrain focal plane	NGS WFS calibration
CU-FUN-13	FPL	Providing a array of 0.5" (integrated m(R)=17, G2 star, TBC), 1.0" (integrated m(R)=19, G2 star, TBC) and 1.5" (integrated m(R)=8, G2 star, TBC) artificial NGSs over a 2' FoV, plus a illuminated slit in TBD(x,y) positions over the Cassegrain focal plane	LGS WFS calibration Differential flexures
CU-FUN-14	FPL	Providing a DL@750nm (m(R)=8, G2 star, TBC) NGS in TBD(x,y) positions over the Cassegrain focal plane	LGS WFS calibration Differential flexures

Table 4: Basic CU functionalities.

On the basis of these functionalities, in turn, it is possible to derive the functions that must be fulfilled by the CU components. A total of 24 functions has been derived, as reported in Table 5. For each function, in particular, the location in the subunit (CUMB or CUFS) is reported.

ID	Device Position	Description
CU-Funct-01	CUFS	Switch ON-OFF white continuum source
CU-Funct-02/03/04	CUMB	Switch ON-OFF / Initialize / Move Integration Sphere Selector Mirror
CU-Funct-05/06/07/08	CUMB	Switch ON-OFF Ne / Ar / Xe / Kr spectral lamp
CU-Funct-09/10/11	CUFS	Switch ON-OFF / Initialize / Move Fiber Selector Stage
CU-Funct-12/13/14	CUFS	Switch ON-OFF / Initialize / Move Neutral Density Filter Stage
CU-Funct-15/16/17	CUMB	Switch ON-OFF / Initialize / Move focal plane X-positioning Stage
CU-Funct-18/19/20	CUMB	Switch ON-OFF / Initialize / Move focal plane Y-positioning Stage
CU-Funct-21/22/23	CUMB	Switch ON-OFF / Initialize / Move focal plane Z-positioning Stage
CU-Funct-24	CUMB	Switch ON-OFF supplementary lamp

Table 5: CU functions summary.

4.5 Requirements and Technical Specifications

Requirements and Technical Specifications can be finally derived starting from the upper-level documentation represented by the ERIS system-level requirements [AD1], the Operational Concept Definition [AD2], the Calibration Plan for the scientific instruments (NIX and SPIFFI) [AD3] and the Preliminary Calibration Plan for the AO module [AD4] (which however has been rebaselined to be part of the Maintenance Plan).

The following notes must be considered:

1. requirements on CU Electronics design are not provided, because CU electronics is not an independent system but is a part of the more general instrument software (INS);
2. no reliability requirement is provided for CU, because the upper-level requirement refers to observing time only. The CU is foreseen to be used in daytime;
3. no availability requirement is provided for CU, because the upper-level requirement refers to time used for scientific observations and relevant scientific calibrations only. The CU is foreseen to be used in daytime for non-scientific calibrations;
4. no requirement on preventive maintenance is provided for CU, because the upper level requirement refers to preventive maintenance for cryogenic instruments only;

5. no technical specifications on focal plane displacements as a consequence of gravity and/or thermal flexures are provided for CU, because the PHM sources can be re-positioned and re-focused according to needs.

The full list of requirements (REQ) and Technical Specifications (TSP) is reported below. For each requirement or specification the traceability to upper level requirements defined in [AD1], to other applicable documents and to specific sections of this document is reported. The proposed verification method is also indicated for each requirement or technical specification, adopting the following verification methods defined in [AD1] Sect. 6.1:

- design (review of)
- test
- analysis (analytical analysis, finite element analysis, thermal modeling, error budget, etc.)
- inspection
- similarity (with other systems with an existing proven component).

ERIS-CU-REQ-001: Identification
The CU will be a subsystem of the whole ERIS instrument (and not composed by single subassemblies of the various subsystems) and will be physically contained in the whole assembly.
Traceability: TS-ERIS-GEN-001, TS-ERIS-GEN-002
Verification method: Design

ERIS-CU-REQ-002: Modes
The CU shall always be used in combination with one or more ERIS instruments (NIX, SPIFFI, AO). It shall not be used in standalone mode, except for maintenance.
Traceability: TS-ERIS-GEN-016, TS-ERIS-OPS-007
Verification method: Design

ERIS-CU-REQ-003: Wavelength range
The CU shall provide calibration capabilities in the visible wavelength range (λ < 1 mm) for the AO module.
The CU shall provide calibration capabilities in wavelength range 1.1 - 2.45 μm for the NIX imager and the SPIFFI IFS. In particular, no calibration capability shall be provided for NIX operating wavelengths between 2.45 and 5.1 μm.
Traceability: TS-AO-GEN-029, TS-NIX-GEN-030, TS-SPIFFI-GEN-070, [AD3] Sect. 6.2.4, [AD2] Sect. 9.2.2
Verification method: Test

ERIS-CU-REQ-004: Compliance with global coordinates system
The CU opto-mechanical design shall be developed in accordance with the defined ERIS global coordinates system.
Traceability: TS-ERIS-INT-001
Verification method: Design

ERIS-CU-REQ-005: Compliance with telescope optical prescriptions, design and interfaces
The CU optical design shall be developed in accordance with the telescope optical prescriptions, design and interfaces.
Traceability: TS-ERIS-INT-015
Verification method: Design

ERIS-CU-REQ-006: Mechanical interfaces

The CU shall comply with the defined mechanical interfaces.
In particular:

a. *It shall be easy to mount and dismount, and shall allow easy dismounting of assemblies and sub-assemblies (mechanisms, lamps) without affecting the rest of the module.*
b. *All its internal surfaces and components shall be protected against corrosion, using best practice.*
c. *It shall be provided with all the required protection (for example covers) for instrument storage or maintenance and operational safety.*
d. *It shall be built and installed to be earthquake safe according to the defined rules.*
e. *It shall not expose the personnel to any sharp edges.*

Traceability: TS-ERIS-INT-030, TS-ERIS-RAM-023
Verification method: Design, Inspection

ERIS-CU-REQ-007: Compliance with mechanical standards
The design of the CU shall comply with the ESO mechanical standards. For standardization purposes, the use of different products, components and equipment as well as suppliers and manufacturers shall be minimized.
Traceability: TS-ERIS-STD-001
Verification method: Design, Inspection

ERIS-CU-REQ-008: Compliance with VLT motion control system
All moving mechanisms of CU shall be controlled by the VLT standard motion control system. All motors shall be equipped with a position sensor for feedback and monitoring. These sensors shall be compatible with the VLT motion control system.
Traceability: TS-ERIS-STD-002
Verification method: Design, Inspection, Test

ERIS-CU-REQ-009: Compliance with Service and Maintenance prescriptions
The CU Service and Maintenance shall follow the defined prescriptions.
Traceability: TS-ERIS-STD-030
Verification method: Inspection, Similarity

ERIS-CU-REQ-010: Compliance with La Silla Paranal Observatory policy
The CU design, as well as handling, operating and maintenance procedures at the La Silla Paranal Observatory shall comply with the defined policy.
Traceability: TS-ERIS-STD-040
Verification method: Inspection, Similarity

ERIS-CU-REQ-011: Usecases
For the CU at least the following two use cases shall be identified:

- *Calibrations: in combination with one or more ERIS instruments (NIX, SPIFFI, AO)*
- *Maintenance (even in standalone mode)*

Traceability: TS-ERIS-OPS-001, TS-ERIS-OPS-007
Verification method: Design

ERIS-CU-REQ-012: Internal states
Eventual internal states of the CU shall contribute at any time to build the generic operational states of ERIS.
Traceability: TS-ERIS-OPS-002
Verification method: Design

ERIS-CU-REQ-013: Operating modes
The defined mode for the CU shall be the following:

Calibration mode: in combination with one or more ERIS instruments (NIX, SPIFFI, AO).
Traceability: TS-ERIS-OPS-005, TS-ERIS-OPS-006
Verification method: Design

ERIS-CU-REQ-014: Configurations
There shall be no limitation in the ability of the operator to choose any CU configuration at any time. No configuration shall prevent or restrict the subsequent use of another configuration.
Traceability: TS-ERIS-OPS-015
Verification method: Design, Inspection

ERIS-CU-REQ-015: Protection against external illumination
The CU shall be designed and built in order to provide an illumination level insensitive to outside illumination, especially considering that most of calibrations will be performed in daytime.
Traceability: TS-ERIS-OPS-025, TS-ERIS-PER-140, TS-ERIS-PER-141
Verification method: Design, Test

ERIS-CU-REQ-016: Artificial sources magnitudes
The CU shall provide artificial sources with integrated magnitudes m_R (class G2) equal to 8, 12, 15 and 19, for AO calibration purposes.
Traceability: TS-ERIS-PER-007, TS-ERIS-PER-008
Verification method: Test

ERIS-CU-REQ-017: Artificial sources brightest magnitude
The CU shall provide at least one single point source with integrated magnitude m_R (class G2) = 1, for AO calibration purposes.
Traceability: TS-AO-PER-014
Verification method: Test

ERIS-CU-REQ-018: Artificial sources angular diameters
The CU shall provide extended sources with angular diameter of 0.5, 1.0 and 1.5 arcsec (goal 3.0 arcsec), for AO calibration purposes.
Traceability: TS-AO-PER-016, [AD4] Sect. 4.1.1
Verification method: Inspection, Test

ERIS-CU-REQ-019: NIX illumination
The CU shall deliver to NIX a photon flux not exceeding that from a G2 star of magnitude m_J=1 in SAM or coronagraphic mode, and not exceeding that from a G2 star of magnitude m_J=7 in all other modes.
Traceability: TS-NIX-PER-028
Verification method: Test

ERIS-CU-REQ-020: SPIFFI illumination
The CU shall deliver to SPIFFI a photon flux not exceeding that from a G2 star of magnitude m_J=7 (goal 5).
Traceability: TS-NIX-PER-070
Verification method: Test

ERIS-CU-REQ-021: Total calibration time
The CU shall be designed and built in such a way the total calibration time (including overheads) shall not exceed 3 hours per day, including health checks (goal 1.5 hours), assuming both scientific instruments have been used in maximum 10 different setups.
Traceability: TS-ERIS-PER-141

Verification method: Test, Analysis

ERIS-CU-REQ-022: Telescope position during calibration
The CU shall operate for calibration purposes with the telescope always at the zenith.
Traceability: TS-ERIS-PER-141
Verification method: Design

ERIS-CU-REQ-023: Monitoring GUIs
All parameters necessary to allow the instrument operator to evaluate the current CU status and performance in all instrumental setups shall be displayed on monitoring GUIs included in ERIS INS.
Traceability: TS-ERIS-INS-025
Verification method: Design, Inspection, Test

ERIS-CU-REQ-024: Environmental conditions
All CU requirements shall be met under the conditions specified in TS-ERIS-ENV-005.
Traceability: TS-ERIS-ENV-005
Verification method: Test

ERIS-CU-REQ-025: EMC requirements
The CU shall meet the defined electromagnetic compatibility requirements.
Traceability: TS-ERIS-ENV-005
Verification method: Design

ERIS-CU-REQ-026: Lifetime
The CU shall be designed for a minimum operational lifetime of 10 years.
Traceability: TS-ERIS-RAM-001
Verification method: Design

ERIS-CU-REQ-029: Line Replaceable Units (LRUs)
The design of the CU shall make use of the concept of ”Line Replaceable Units” (LRU's) in order to facilitate the maintenance or repair, and provide easy mounting/dismounting procedures.
Traceability: TS-ERIS-RAM-020
Verification method: Design, Inspection

ERIS-CU-REQ-030: Cables and connectors
Replacement of all CU cables and connectors shall be possible without dismounting any additional element. System identification (labelling) that provides the capability of tracing wiring, power sources, etc. and identification of components without use of drawings shall be maximized.
Traceability: TS-ERIS-RAM-021
Verification method: Design, Inspection

ERIS-CU-REQ-031: Identification numbers and labelling
The CU and its component LRUs, spare units, etc., shall be marked with unique identification numbers marked or equipped with sign plates, indicating as a minimum the name and address of the manufacturer, the part number and manufacturing year.
Traceability: TS-ERIS-RAM-022
Verification method: Design, Inspection

ERIS-CU-REQ-032: Corrective maintenance
Corrective maintenance of the CU, aimed at restoring its hardware integrity following anomalies or equipment problems encountered during operations, shall have to meet the following requirements:

a. Repairs of the CU shall normally be limited to the in-situ exchange of line replaceable units (LRUs, see TS-ERIS-RAM-0). Faulty LRUs will be sent away to be repaired.
b. It shall be possible to replace broken calibration lamps without removing the instrument or any sub-system from the telescope.
c. Any corrective maintenance action shall be performed with a maximum of 2 qualified maintenance technicians, using standard tools and/or special tools specific to instrument (delivered together with the spares).
Traceability: TS-ERIS-RAM-025
Verification method: Design, Inspection, Similarity

ERIS-CU-REQ-034: Predictive maintenance
Predictive maintenance of the CU shall have to meet the following requirements:
a. all 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.
b. each predictive maintenance action shall require at most 2 trained technicians.
Predictive maintenance will rely on software/tools that shall be delivered as part of the Instrument Software package.
Traceability: TS-ERIS-RAM-027
Verification method: Design, Inspection, Similarity

ERIS-CU-REQ-035: Maintenance Report
A Maintenance Report for the CU shall be delivered to be part of the Maintenance Plan for ERIS. It shall include all tools and procedures to support all maintenance tasks identified for the CU.
Traceability: TS-ERIS-RAM-030, TS-ERIS-RAM-035
Verification method: Inspection

ERIS-CU-REQ-036: Spares
The CU shall be delivered with a complete set of service and maintenance documentation (to be part of the ERIS manuals and documentation), as well as agreed spares for each LRU.
Traceability: TS-ERIS-RAM-040
Verification method: Inspection

ERIS-CU-REQ-037: Safety against earthquakes
The CU shall be designed so as to minimize the risk of damage in the event of an Earthquake as per TS-ERIS-SAF-015.
Traceability: TS-ERIS-SAF-105
Verification method: Design

ERIS-CU-TSP-001: Flat field illumination uniformity
The illumination spatial non-uniformity of flat fields provided by CU shall be less than 5% (goal: 2%).
Traceability: [AD2] Sect. 5.2.7.1, 5.3.6.1
Verification method: Test

ERIS-CU-TSP-003: ISSM positioning range
The Integration Sphere Selector Mirror (ISSM) positioning range shall be >100°.
Traceability: this document Sect. 5.2
Verification method: Design, Test

ERIS-CU-TSP-004: ISSM positioning accuracy
The ISSM shall allow to image the IS output port onto the telescope pupil with an accuracy < TBD1% of the IS output port diameter.
Traceability: this document Sect. 5.2

Verification method: Test

ERIS-CU-TSP-005: ISSM positioning repeatability
The ISSM shall have a positioning repeatability < TBD2% of the IS output port diameter.
Traceability: this document Sect. 5.2
Verification method: Test

ERIS-CU-TSP-006: PHM focusing range
The Z-range (focusing range) for the Pinhole Mask (PHM) shall be at least 72 mm (TBC), in order to image artificial sources from the infinity-conjugated plane (NGS) up to 80 km height-conjugated plane (LGS) onto the telescope focal plane.
Traceability: this document Sect. 5.1, 5.2
Verification method: Test, Analysis

ERIS-CU-TSP-007: PHM focusing accuracy
The Z-position (focus) of the PHM shall be reached with an accuracy >TBD3 μm.
Traceability: this document Sect. 5.1, 5.2
Verification method: Test

ERIS-CU-TSP-008: PHM focusing repeatability
The Z-position (focus) of the PHM shall be reached (bidirectional) repeatability >TBD4 μm.
Traceability: this document Sect. 5.2
Verification method: Test

ERIS-CU-TSP-009: PHM sources positioning range
The X- and Y- positioning (across the focal plane) range for the PHM shall be 25mm, corresponding to at least 60 arcsec side (85 arcsec diagonal) on the NGS plane, in order to cover the NIX FoV.
Traceability: this document Sect. 5.1 , [AD2] Sect. 4.1.2
Verification method: Test, Analysis

ERIS-CU-TSP-010: PHM diameter
The PHM diameter shall be > 32 mm (TBC), in such a way to offer calibration sources over the full NIX diagonal FoV.
Traceability: [AD2] Sect. 4.1.2
Verification method: Inspection

ERIS-CU-TSP-011: Pinholes diameter
The following pinhole diameters (TBC) shall be available onto the focal plane:
- *9.6 μm (corresponding to a DL@750nm on NGS plane)*
- *5.9 μm (corresponding to a DL@589nm on LGS plane)*
- *206 μm (corresponding to a 0.5 arcsec source on NGS plane)*
- *412 μm (corresponding to a 1.0 arcsec source on NGS plane)*
- *618 μm (corresponding to a 1.5 arcsec source on NGS plane)*

Traceability: this document Sect. 5.2, [AD4] Sect. 4.1.1
Verification method: Inspection, Test, Analysis

ERIS-CU-TSP-012: AO-NGS calibration sources positioning accuracy
Both X- and Y- positions for the AO calibration sources onto the NGS focal plane shall be reached with an accuracy < 3.9 μm (TBC), corresponding to λ/2D at 750 nm wavelength.
Traceability: this document Sect. 5.2, [AD4] Sect. 4.1.1
Verification method: Test

ERIS-CU-TSP-013: AO LGS calibration source positioning accuracy
Both X- and Y- positions for the AO calibration DL source onto the LGS focal plane shall be reached with an accuracy < 3.0 μm (TBC), corresponding to λ/2D at 589 nm wavelength.
Traceability: this document Sect. 5.2, [AD4] Sect. 4.1.1
Verification method: Test, Analysis

ERIS-CU-TSP-014: SPIFFI calibration sources positioning accuracy
Both X- and Y- positions for the SPIFFI calibration sources onto the NGS focal plane shall be reached with an accuracy < 0.5 μm (TBC), corresponding to 1/10th of a spatial pixel at the SPIFFI plate scale of 0.025 arcsec/pixel.
Traceability: [AD3] Sect. 6.2.4
Verification method: Test, Analysis

ERIS-CU-TSP-015: PHM sources positioning repeatability
Both X- and Y- positions for the PHM shall be reached with a (bidirectional) repeatability TBD5 micron.
Traceability: this document Sect. 5.2, [AD4] Sect. 4.1.1, [AD3] Sect. 6.2.4
Verification method: Test

ERIS-CU-TSP-016: PHM planarity during X-Y motion
The PHM plane shall exhibit a maximum Pitch of TBD6a arcsec and a maximum Yaw of TBD6b arcsec across the whole range of X- and Y-motion.
Traceability: this document Sect. 5.2
Verification method: Test

ERIS-CU-TSP-017: PHM planarity during Z motion
The PHM carriage shall exhibit a maximum Pitch of TBD7a arcsec and a maximum Yaw of TBD7b arcsec across the whole range of Z- (focusing) motion.
Traceability: this document Sect. 5.2
Verification method: Test

ERIS-CU-TSP-018: PHM illumination uniformity
For any couple of PHM sources having the same angular diameter, the integrated luminosity difference shall not exceed TBD8 % .
Traceability: [AD4]
Verification method: Test

ERIS-CU-TSP-019: PHM illumination stability
Time variability for the PHM sources luminosity shall not exceed TBD9 % over the duration of a typical calibration run.
Traceability: [AD4]
Verification method: Test

ERIS-CU-TSP-020: NDF OD range
The maximum Optical Depth (OD) for the Neutral Density Filter (NDF) will at least 4 (minimum OD is 0).
Traceability: this document Sect. 6.2
Verification method: Design, Analysis

ERIS-CU-TSP-021: NDF positioning range
The positioning range for the NDF shall be > TBD10 mm.
Traceability: this document Sect. 5.2, 6.2

Verification method: Design, Inspection

ERIS-CU-TSP-022: NDF operational accuracy
The NDF shall produce a luminosity attenuation with an accuracy < TBD11a . The positioning accuracy of the NDF shall accordingly be < TBD11b μm .
Traceability: this document Sect. 5.2, 6.2
Verification method: Test

ERIS-CU-TSP-023: NDF positioning repeatability
The NDF shall be positioned with a (bidirectional) repeatability < TBD12 μm.
Traceability: this document Sect. 5.2
Verification method: Test

ERIS-CU-TSP-024: Fiber Selector Positioning range
The positioning range for the Fiber Selector shall be > TBD13 mm, to allow any fiber be placed at its correct optical coupling location.
Traceability: this document Sect. 5.2
Verification method: Design, Inspection

ERIS-CU-TSP-025: Fiber Selector Positioning accuracy
The Fiber Selector shall be positioned with an accuracy < TBD14 μm.
Traceability: this document Sect. 5.2
Verification method: Test

ERIS-CU-TSP-026: Fiber Selector Positioning repeatability
The Fiber Selector shall be positioned with a (bidirectional) repeatability < TBD15 μm.
Traceability: this document Sect. 5.2
Verification method: Test

ERIS-CU-TSP-029: Pupil plane gravity displacement
Maximum displacement of the imaged pupil onto the telescope pupil plane due to CU gravitational flexures shall be TBD16 % of the pupil diameter.
Traceability: [AD4] Sect. 4.2.1, 4.2.2, 4.2.3
Verification method: Analysis, Test

ERIS-CU-TSP-030: Focal plane thermal displacement
Maximum displacement of the imaged pupil onto the telescope pupil plane for CU flexures induced by thermal gradients (TBD17) shall be TBD18 % of the pupil diameter per Celsius degree.
Traceability: [AD4] Sect. 4.2.1, 4.2.2, 4.2.3
Verification method: Analysis, Test

ERIS-CU-TSP-031: Optical quality gravity deterioration
The deterioration in CU optical quality, both onto the focal and the pupil plane, as due to CU gravitational flexures shall be less than TBD19 %.
Traceability: this document Sect. 5.1
Verification method: Analysis, Test

ERIS-CU-TSP-032: Optical quality thermal deterioration
The deterioration in CU optical quality, both onto the focal and the pupil plane, as due to CU flexures induced by thermal gradients (as per the TDB17) shall be less than TBD20 %.
Traceability: this document Sect. 5.1
Verification method: Analysis, Test

ERIS-CU-TSP-033: Temperature sensors
Temperature sensors shall be implemented at TBD21 locations inside the CU modules in order to assist monitoring of environmental conditions.
Traceability: this document Sect. 5.3, TS-ERIS-ENV-005
Verification method: Inspection

The list of TBDs included in the current list of requirements and technical specification is summarized in Table 6.

ID	Description	Note
TBD1	Positioning accuracy of the IS output port over the telescope pupil, expressed as percentage of the IS output port diameter.	The value depends on the Integration Sphere output port diameter. For a port wide enough, the positioning of the pupil inside shall have no substantial effect on the system performance. On the other hand, increasing the size of the IS output port reduces the illumination uniformity. A trade-off shall have to be found, taking into account the data coming from optical sensitivity and optical tolerance analysis.
TBD2	Positioning (bidirectional) repeatability of the IS output port over the telescope pupil, expressed as percentage of the IS output port diameter.	Same considerations as for TBD1 apply.
TBD3	PHM Z- (focus) position accuracy. Expressed in micron.	The value shall be defined according to the data coming from optical sensitivity and optical tolerance analysis.
TBD4	PHM Z- (focus) position (bidirectional) repeatability. Expressed in micron.	The same considerations as for TBD3 apply.
TBD5	PHM X- and Y- positions (bidirectional) repeatability. Expressed in micron.	
TBD6a	Maximum Pitch exhibited by the PHM plane over the X- and Y- motion range. Expressed in arcsec.	
TBD6b	Maximum Yaw exhibited by the PHM plane over the X- and Y- motion range. Expressed in arcsec.	
TBD7a	Maximum Pitch exhibited by the PHM carriage plane over the Z- motion range. Expressed in arcsec.	
TBD7b	Maximum Yaw exhibited by the PHM carriage plane over the Z- motion range. Expressed in arcsec.	
TBD8	Maximum integrated luminosity difference of PHM sources having the same diameter. Defined as $1 - L_{fainter} / L_{brighter}$. Expressed as a percentage.	
TBD9	Maximum time variability of PHM source luminosity, over the calibration run. Expressed as a percentage.	
TBD10	NDF positioning range. Expressed in mm.	The value shall depend on the physical length of the NDF.

TBD11a	NDF luminosity attenuation accuracy. Defined as delta_OD. No measurement units.	The value shall depend on the strict requirements about the photon fluxes to be provided for each calibration use case.
TBD11b	NDF positioning accuracy. Expressed in micron.	The value shall depend on the previous one and the physical characteristics of the selected NDF.
TBD12	NDF positioning (bidirectional) repeatability. Expressed in micron.	Same considerations as for TBD11b apply.
TBD13	Fiber Selector positioning range. Expressed in mm.	
TBD14	Fiber Selector positioning accuracy. Expressed in micron.	
TBD15	Fiber Selector positioning (bidirectional) repeatability. Expressed in micron.	
TBD16	Maximum displacement of the imaged pupil onto the telescope pupil plane due to CU gravitational flexures. Expressed as a percentage of the pupil diameter.	
TBD17	Thermal gradients across the CU. Expressed in Celsius degrees.	Reference positions across the CU shall have to be identified.
TBD18	Maximum displacement of the imaged pupil onto the telescope pupil plane for CU flexures induced by thermal gradients (defined as per TBD17). Expressed as a percentage of the pupil diameter per Celsius degree temperature difference.	
TBD19	Deterioration in CU optical quality, both onto the focal and the pupil plane, as due to CU gravitational flexures. Expressed as a percentage.	
TBD20	Deterioration in CU optical quality, both onto the focal and the pupil plane, as due to CU flexures induced by thermal gradients (as per the TDB17). Expressed as a percentage.	

Table 6: List of TBDs for CU requirements & technical specifications

5 CU Design

5.1 Optical design

The CU is based on a cemented triplet to: (a – focus mode) create point sources at the VLT focal plane at different altitudes, (b – pupil mode) illuminate the VLT focal plane with a uniform “flat field”. Figure 3 shows the optical layout of both modes.

In the pupil mode, a diaphragm just in front of an Integration Sphere simulates the VLT telescope pupil. The triplet places the image of this diaphragm at the same location of the telescope exit pupil, i.e. at 15.2 m before of the focal plane. The diaphragm diameter will define the proper focal ratio of the beams at the VLT focal plane.

In focus mode, point sources generated by a pinhole mask will be placed at the conjugate image plane of the VLT focus as seen by the triplet. These point sources can move axially to simulate sources at infinity, when simulating NGS sources, and at shorter distances, ranging from 80 to 200 km, for LGS sources. A motorized state will move those sources. More details on the selected point sources and the mechanisms are given in [AD4] and in Section 5.3.3 of this document.

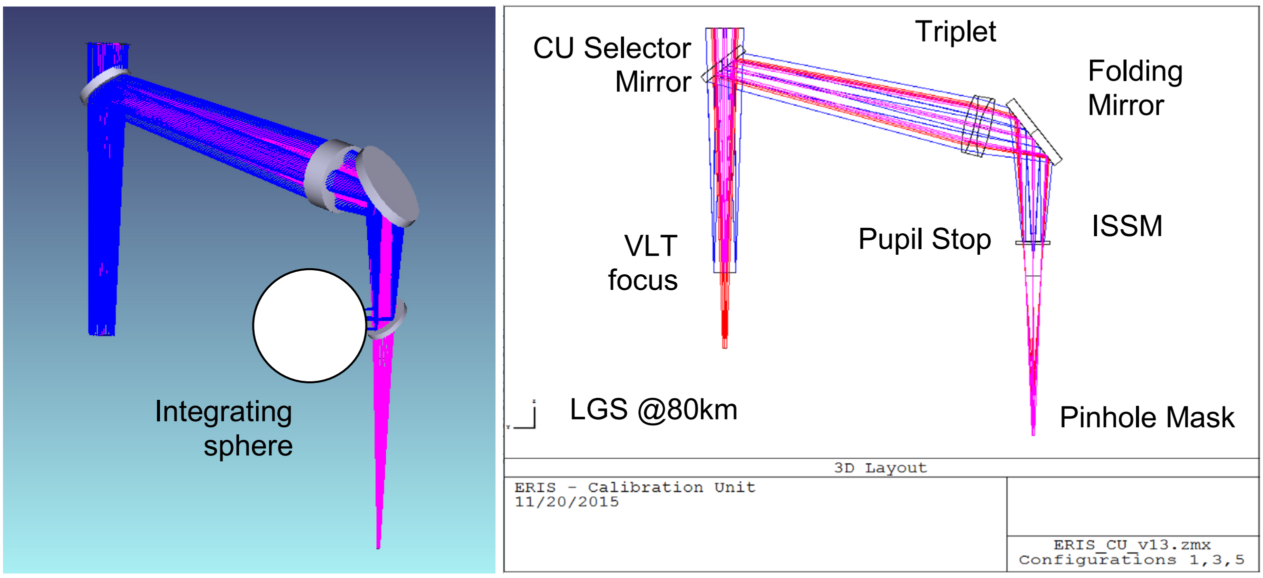


Figure 3: Optical layout of the calibration unit. Blue beams are for pupil mode, magenta for focus mode.

The triplet is based on common glasses and one asphere is place on one surface. Table 7 gives the prescription data of the triplet. The focal length of the triplet is 408 mm, and it works in a asymmetric relay system, where the pinhole mask is at a F/10.5 and the reimaged plane is at F/13.6, with a magnification factor of 1.29X. Stop diameter is 31.1 mm. In pupil mode, the full ERIS field of view is evenly illuminated. In focus mode, the corrected field of view is smaller, only ± 3.5 mm, or 7x7 arcsec^2.

Surface	Type	Radius of curvature	Thickness	Glass
first surface L1	spherical	-268.887	20.00	S-BAL3
second surface L1 first surface L2	spherical	320.773	10.00	S-NBM51
second surface L2 first surface L3	spherical	-159.196	23.00	S-FPL51
second surface L3	aspheric	404.260	4th -8.44e-9 6th 6.278e-14 8th -2.344e-18	

Table 7: Triplet prescription data.

5.1.1 CU image quality

Image quality in focus mode is very high, in order to simulate AO-corrected sources. Spot diagrams are given in the following images. Refocusing between different bands is allowed.

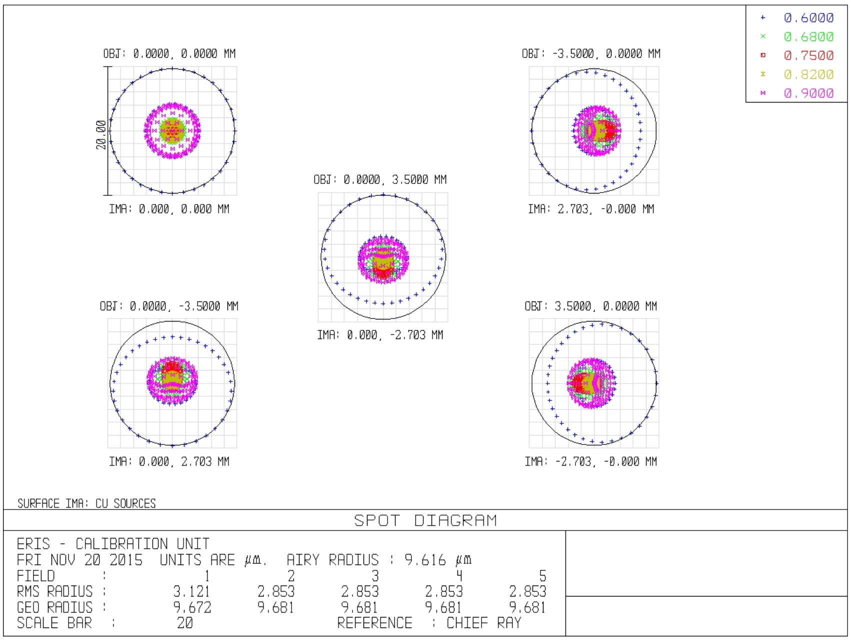


Figure 4: Spot diagram from 0.6 up to 0.9 microns.

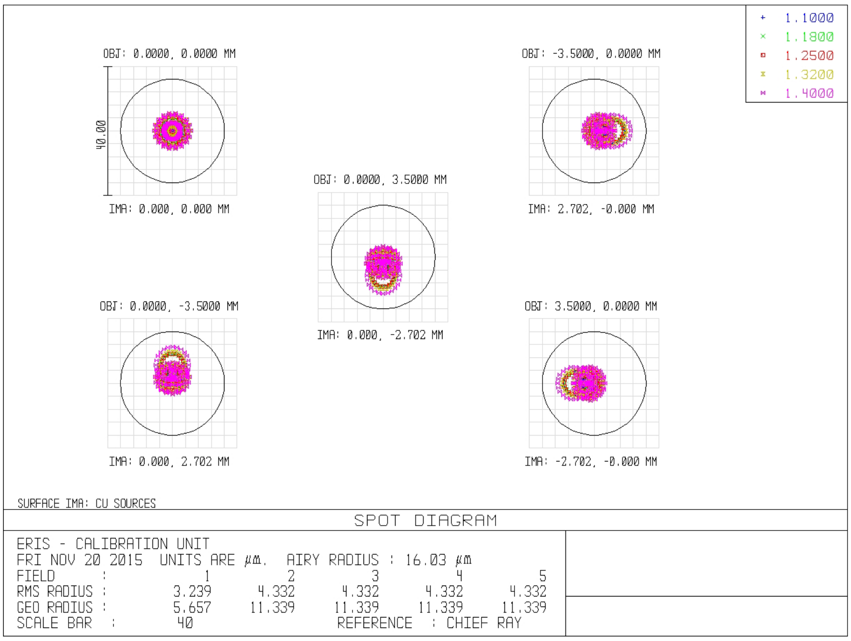


Figure 5. Spot diagram from 1.1 up to 1.4 microns.

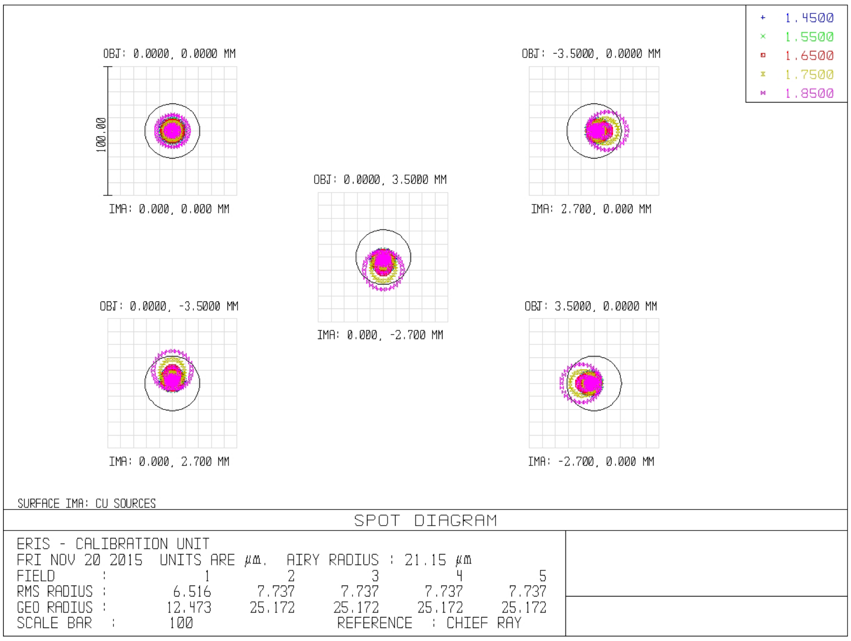


Figure 6. Spot diagram from 1.45 up to 1.85 microns.

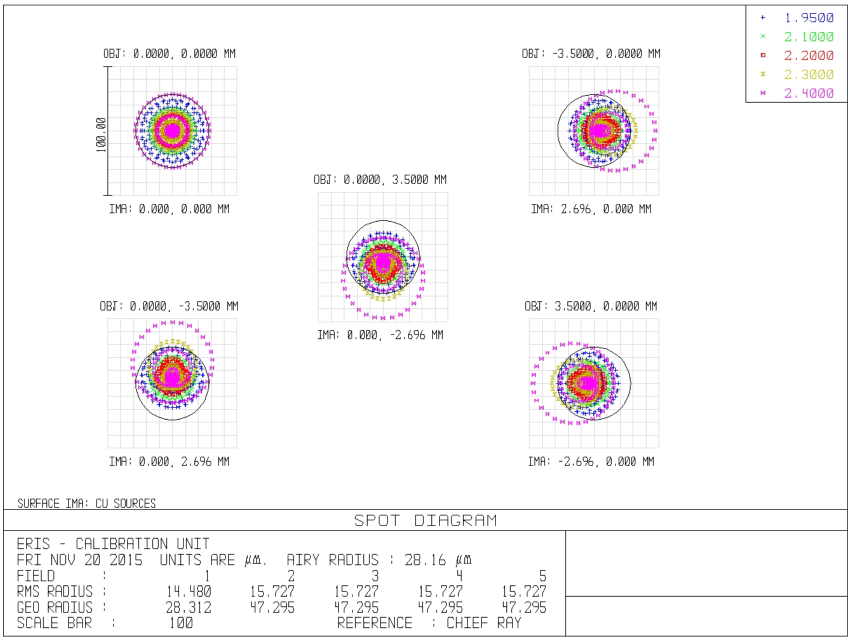


Figure 7. Spot diagram from 1.95 up to 2.4 microns.

5.1.2 Field illumination

Figure 8 gives the irradiance across the VLT focal plane illuminated by the calibration unit while in pupil mode. Within the ERIS field of view (NIX FOV 44 mm).

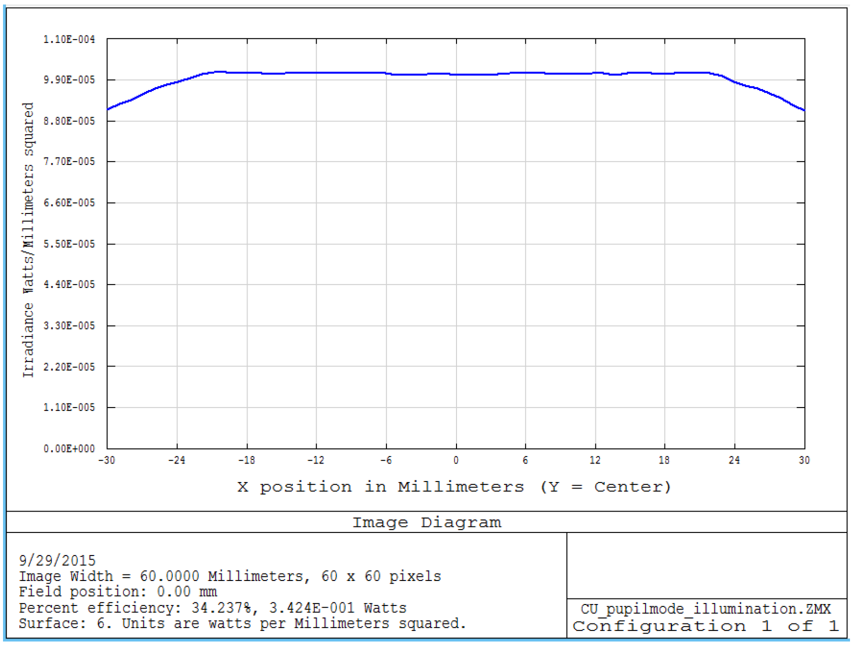


Figure 8. Illumination plot at the VLT focal plane.

5.1.3 CU Alignment Sensitivity Analysis

The sensitivity to misalignments of the CU optics have been computed and are reported in Table 8. Different effects have been computed, including image motion at the VLT focal plane, the image defocus, the pupil motion and the WFE.

Element	DOF	Sensitivity				
		Image X-dec	Image Y-dec	Image defocus	Pupil motion	Delta WFE
		(mm/mm) or (mm/mrad)	*(mm/mm) or (mm/mrad)*	*(mm/mm) or (mm/mrad)*	*(% pupil diam/mm) (% pupil diam/mrad)*	*(nm RSM/mm) or (nm RMS/mrad)*
		(zero where not specified)				
Pinhole Mask	X-dec	1.30				5
	Y-dec		1.30			5
	Z-dec			1.68		310
	X-rot					
	Y-rot					
	Z-rot					
Pupil stop	X-dec				3.2%	
	Y-dec				3.2%	
	Z-dec					
	X-rot					
	Y-rot					
	Z-rot					
Fold Mirror	X-dec					
	Y-dec					
	Z-dec		-2.03	-2.12	5.0%	423
	X-rot		1.58		1.8%	6
	Y-rot	-0.98			1.1%	5
	Z-rot					
Triplet Lens	X-dec	2.29			3.1%	6
	Y-dec		2.29		3.1%	6
	Z-dec			0.68		116
	X-rot		0.01			3
	Y-rot	-0.01				3
	Z-rot					
Selector Mirror	X-dec					
	Y-dec					
	Z-dec		1.25	1.57	0.1%	288
	X-rot		-0.84		2.6%	2
	Y-rot	0.66			2.1%	2
	Z-rot					

Table 8: CU alignment sensitivities.

5.2 Mechanical design

The mechanical design of the ERIS-CU has evolved according to the technical specifications, the optical prescriptions and the needs to integrate it in the overall ERIS mechanical design by taking into account the allowable space with respect to the other ERIS subsystems. The position of the Calibration Unit in the overall ERIS layout is shown in Figure 9.

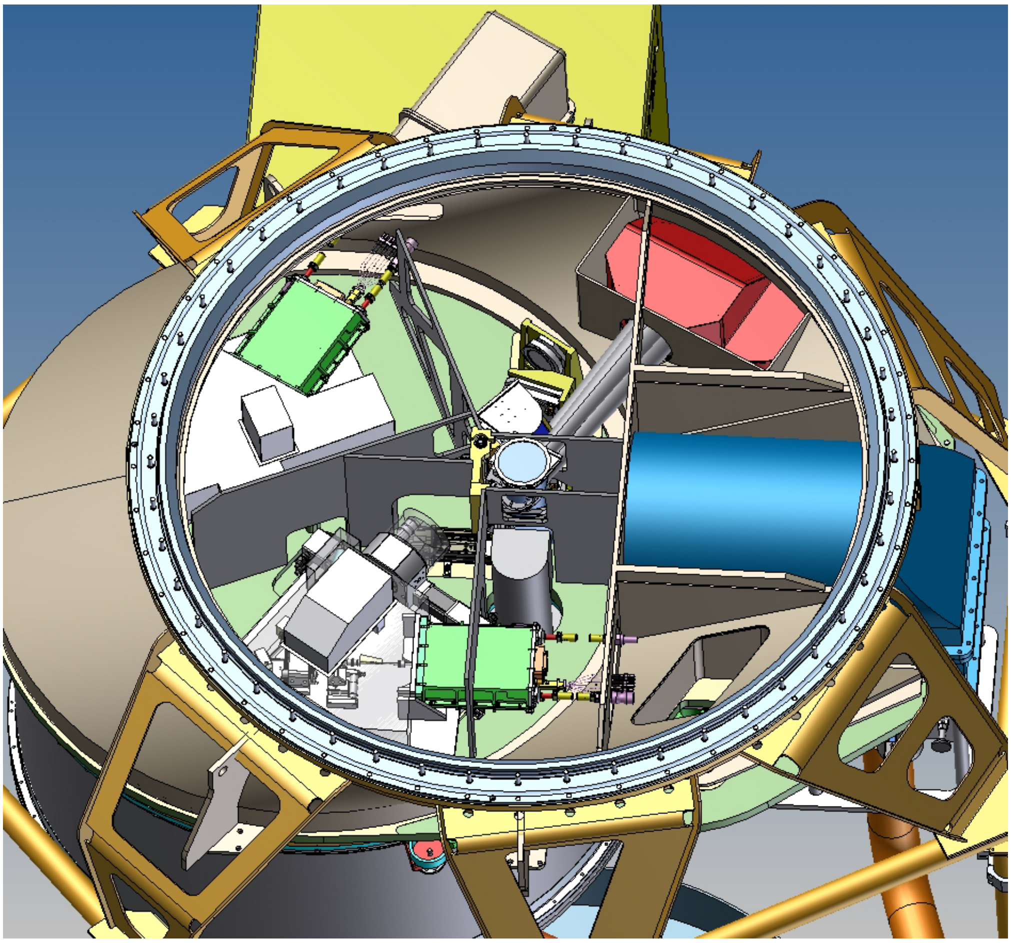


Figure 9: ERIS overall layout. The Calibration unit is the red box. The blue box is the NIX imager, while the SPIFFI camera is below the optical plate. Above it, the Warm Optics (WO) and the AO module.

From the mechanical point of view, the CU is composed by three physically separate units. The first one hosts the optical system aimed to feed the telescope focal plane and is called Calibration Unit Main Bench (CUMB). The second one hosts some of the light sources which fed the CUMB through optical fiber, and is called CU Fiber Switchyard (CUFS). Finally, the third one concerns the CU Selector Mirror (CUSM), devoted to redirect the output beam from the CU towards the focal plane and, at the same time, to stop the light from the telescope when the system is under calibration. For this system the mechanical design of just the manual adjustment device (for optical alignment purposes during the integration phase) has been designed as a part of the CU development work.

5.2.1 Local coordinate system definition

The mechanical design has been developed in compliance with the ERIS reference coordinate system, as defined in [AD5].

5.2.2 Main bench

Among the various options, the selected one considers the CUMB mounted across the ERIS optical plate, with the main axis parallel to the telescope axis and the entrance beam tilted by 103° with respect to it (13° with respect to the ERIS optical plate).

The external mechanical layout is shown in Figure 10, together with the mechanical interface to the ERIS optical plate.

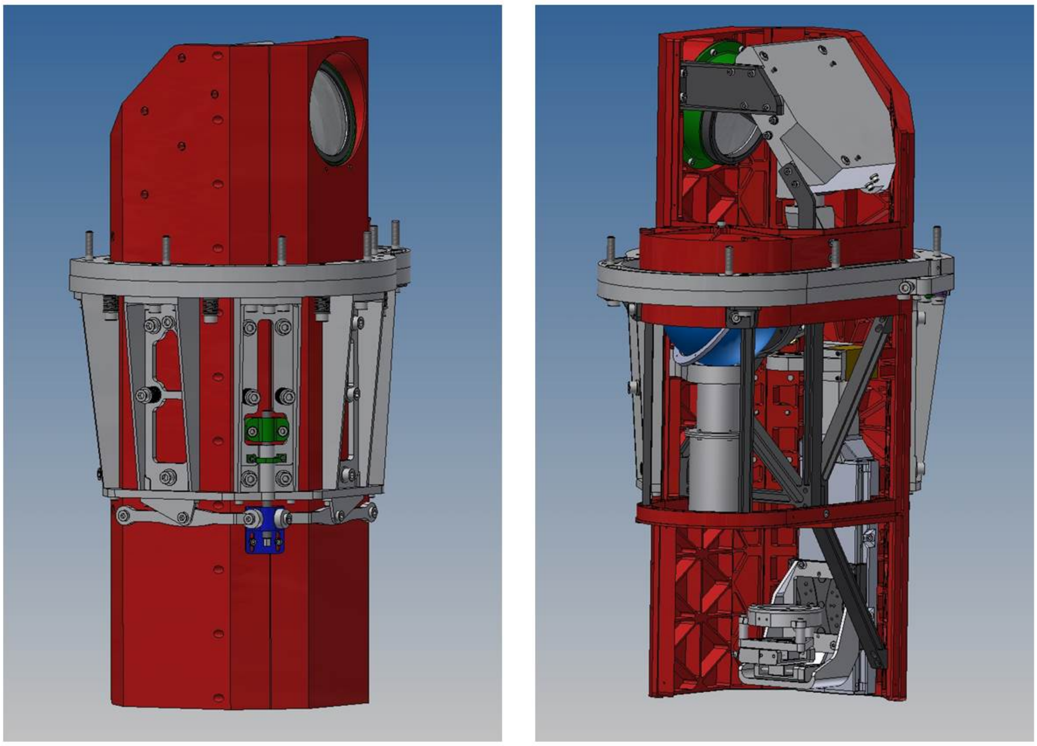


Figure 10: CUMB external layout (including mechanical interface to ERIS)

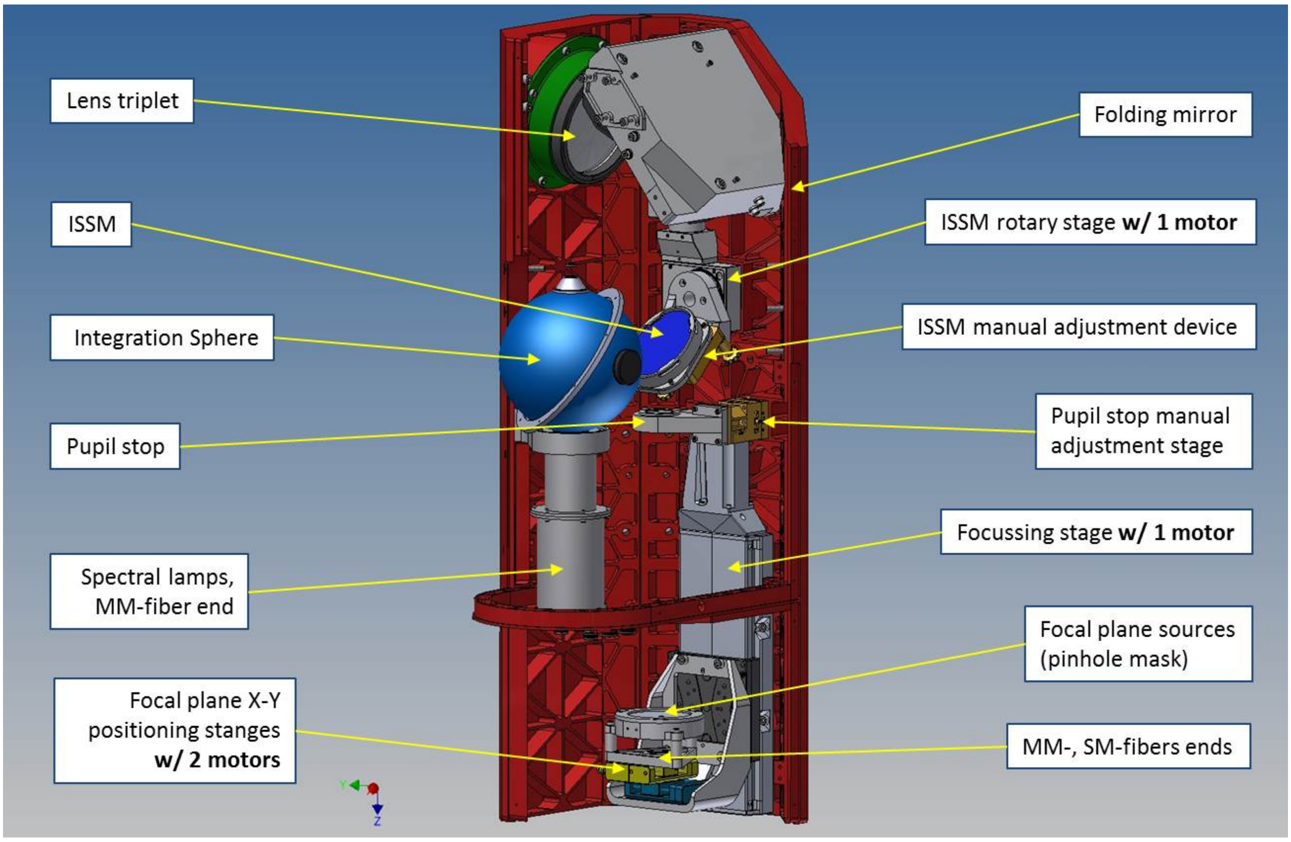


Figure 11: CUMB main components and devices

Figure 11 highlights the main components and devices inside the CUMB.

Sources are placed onto a pinhole mask (PHM) and at the entrance hole of a integrating sphere (IS, spectral calibration lamps). The beam from the PHM crosses a fixed pupil stop and is reflected by a folding plane mirror towards the exit triplet lens, which focusses the sources onto the telescope focal plane. The PHM can be moved in X and Y positions across the plane perpendicular to the optical axis, through the action of two motorized linear stages. A third movement along the Z-axis, performed through a devoted motorized linear stage, allows to place the PHM at different positions, in order to simulate point sources used for AO calibration purposes at infinite distance (NGS) or at finite distance (LGS at 80 km or 200 km height). The two extreme positions of the PHM are shown in Figure 12.

A second plane mirror, called Integration Sphere Selector Mirror (ISSM), can be placed across the above mentioned path, via a rotating motorized stage, in such a way to feed the folding mirror and the exit triplet with light coming from the output hole of a IS, in such a way to uniformly illuminate the telescope focal plane for flat field purposes.

The two positions of the ISSM are shown in Figure 13.

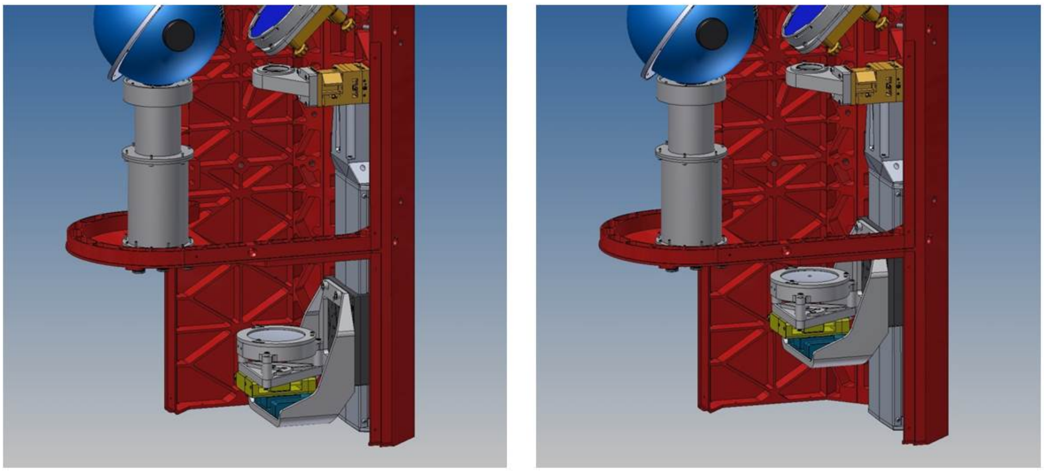


Figure 12: Pinhole mask (PHM) in NGS position (*left*) and NGS position (*right*).

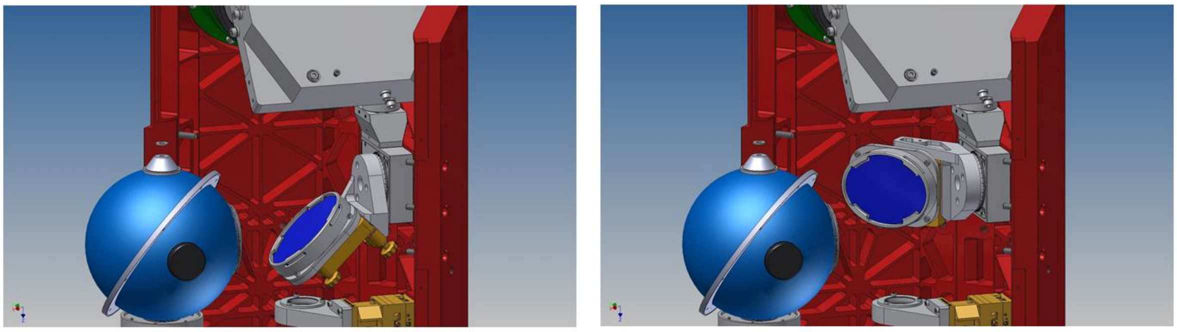


Figure 13: Positions of the ISSM. Integration Sphere feed on (*left*) and off (*right*).

The CUMB is provided with internal temperature sensors, aimed at monitoring the temperature of heating devices (lamps) or sensitive components. In particular, two temperature sensors are foreseen to be installed at the top and the bottom of the CUMB, in order to monitor thermal deformations of the overall mechanical structure.

A series of manual adjustment mechanisms have been included in the design, for internal alignment purposes. Tip/tilt adjustment is foreseen for the folding mirror, the pupil stop and the ISSM (whose manual mechanism is mounted onto the rotary stage). The triplet lens position can be eventually moved along the optical axis and the position of the integration sphere can be regulated, too.

The length of the CU is less than 90 cm. The most significant quotes of the CU layout are shown in Figure 14.

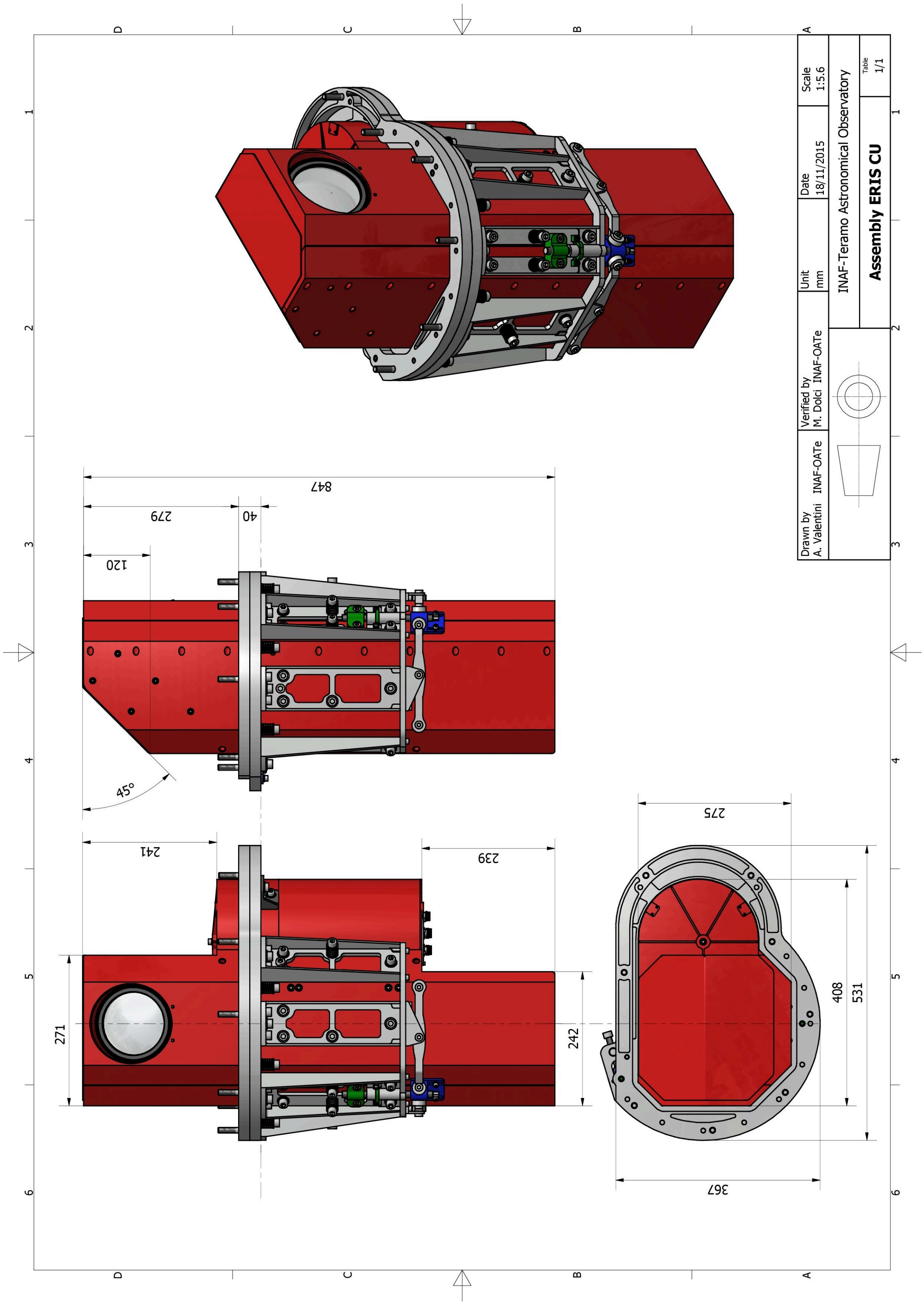


Figure 14: CU Main Bench most significant quotes

5.2.2.1 Total mass

The total mass of the Calibration Unit Main Bench is 54.5 kg. This does not include the cables for electrical and signal connections nor the optical fibers.

5.2.2.2 Center of gravity

The Center of Gravity (CoG) position varies according to the positions of the ISSM and the PHM supporting structure. The effect of the first change of position is essentially negligible, while for the two extreme positions of the PHM there is a substantial change in the Z-coordinate of the CoG. The values of the CoG XYZ coordinates, referred to the ERIS coordinate system, are reported in Table 9 for the two extreme positions of the PHM. Figure 15 shows the position of the CoG into the CU Main Bench.

	PHM in NGS position	PHM in LGS position
X (mm)	240.318	240.318
Y (mm)	-543.090	-543.090
Z (mm)	550.077	542.394

Table 9: Center of Gravity coordinates

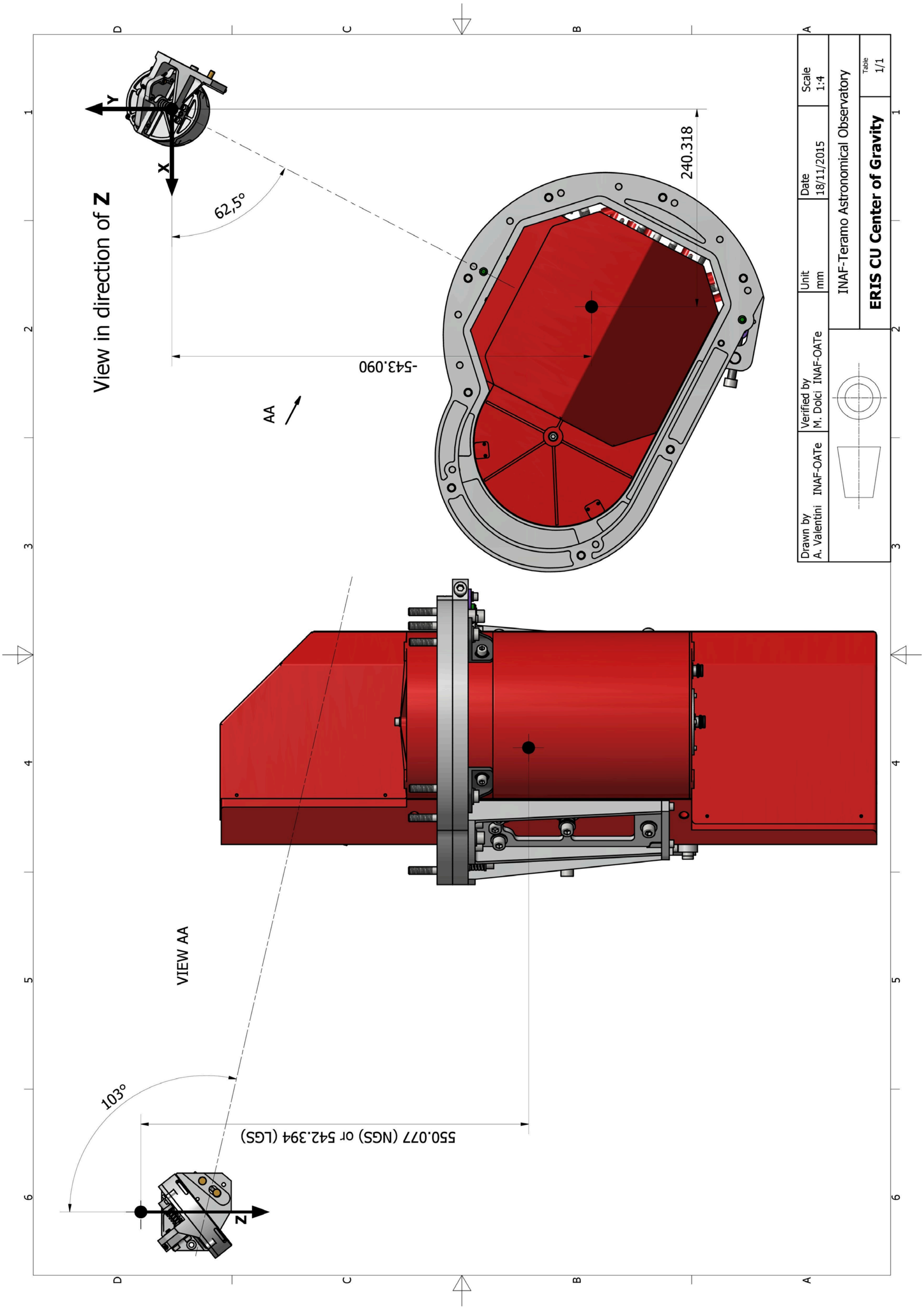


Figure 15: CUMB Center of Gravity (CoG) position

5.2.3 Fiber Switchyard

The CUFS hosts the light sources devoted to feed the PHM and the IS through optical fibers connecting it directly to the CUMB. The mechanical design has evolved to a final version where the components and devices in the CUFS are naturally located inside a standard 19 inch rack.

The layout is shown in Figure 16 and Figure 17, where the standard rack has been selected from the Schroff catalogue.

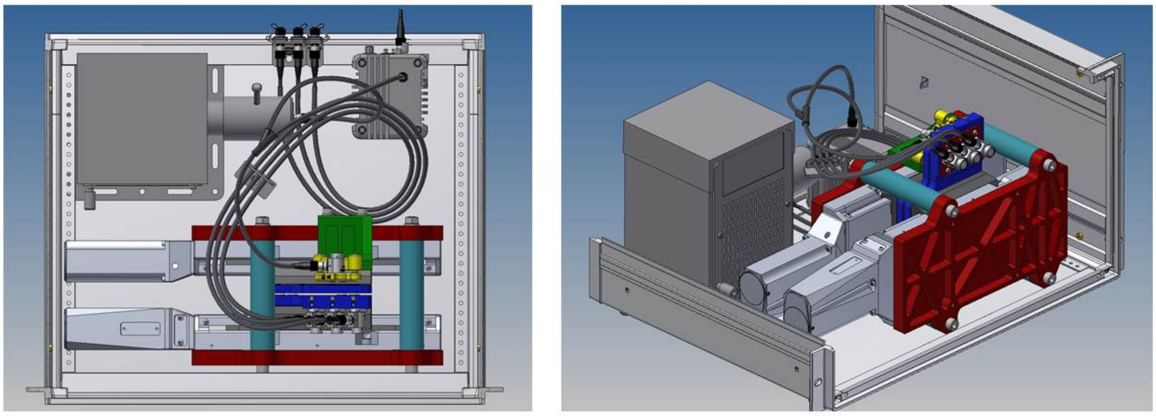


Figure 16: CUFS general layout. View from top (*left*) and back (*right*).

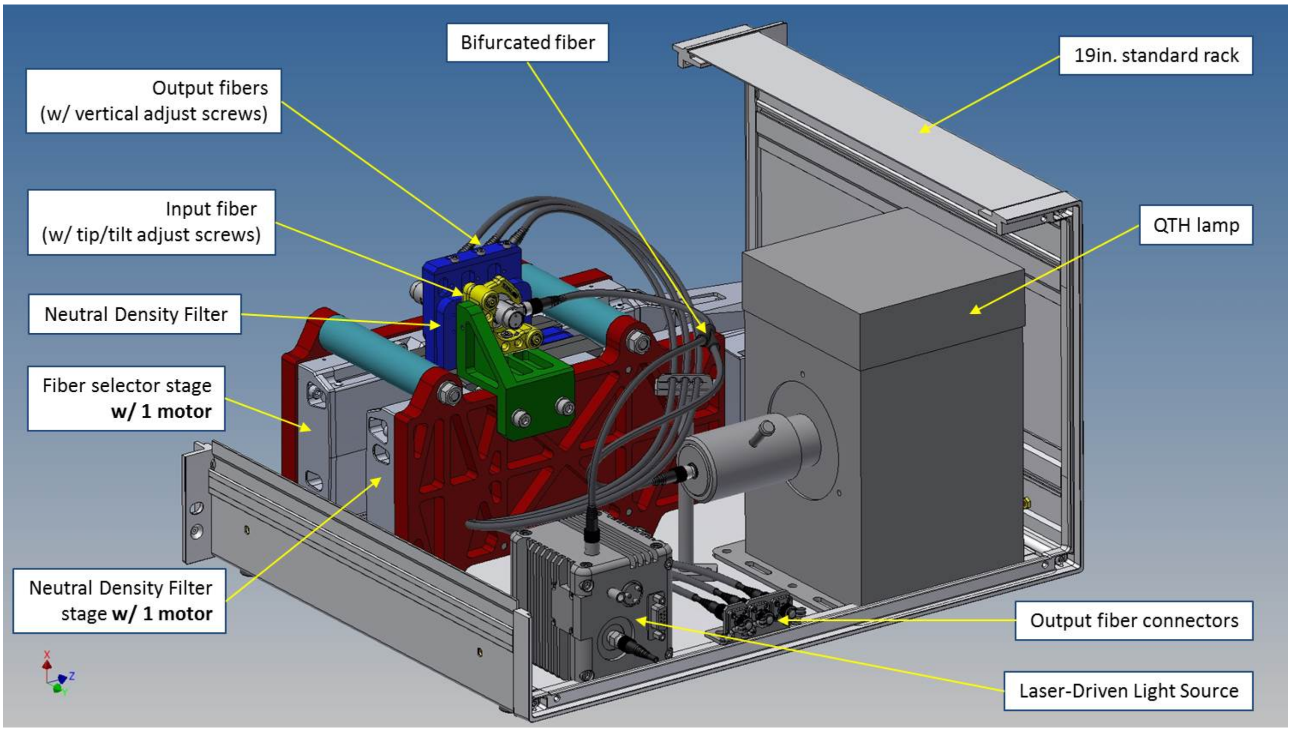


Figure 17: CUFS subsystem description.

Two light sources are hosted inside the CUFS: a white-light, wide spectrum Laser Driven Light Source (LDLS), and a Quartz-Tungsten Halogen (QTH) lamp. Both the lamps are provided with output optical fiber. The two fibers signals merge together into a bifurcated fiber, whose output end is used to illuminate alternatively three different optical fibers:

1) a multi-mode (MM) fiber feeding the IS;
2) a multi-mode (MM) fiber feeding the PHM, simulating extended sources;
3) a single-mode (SM) fiber feeding the PHM, simulating a diffraction-limited (DL) source.

The three fibers are alternatively selected by moving them across the output beam with a motorized linear stage. In order to adjust the photon flux to be sent to the sources, a Neutral-Density Filter (NDF) is placed between the output fiber and the input fibers. Its position, in turn, can be adjusted by moving it onto a second motorized linear stage.

The optical coupling of the fibers is performed by using fiber collimators. Since the light passing through the system covers a wide wavelength range (400 – 2450 nm), fibers having low attenuation at infrared wavelengths have been selected (InF_3 / $InZr_4$, hollow-core fibers). Moreover, for the same reason, reflective collimators, based on off-axis parabolic mirrors, have been selected.

Both the fixed fiber and the movable ones are provided with manual adjustment mechanisms for initial alignment purposes. In particular, the vertical position of the movable fibers and tip/tilt of the fixed one can be adjusted.

In order to fully comply with maintenance operations, the connections between the FS and the CU (power and signal cable, plus optical fibers) are segmented by means of intermediate connectors. To minimize light losses at every connection, the number of segments for the optical fibers shall be reduced as much as possible.

An independent feedback to check for the correct lamp operations is foreseen, composed by a photodiode-based flux sensor. Since all the lamps (LDLS, QTH and spectral lamps) send light to (or also to) the Integration Sphere, the flux sensor shall likely be mounted onto a output hole of it.

Finally, the CUFS (like the CUMB) is provided with internal temperature sensors, aimed at monitoring the temperature of heating devices (lamps) or sensitive components.

5.2.3.1 Total mass

The total mass of the Calibration Unit Fiber Switchyard is 20 kg. This does not include the cables for electrical and signal connections nor the optical fibers.

5.2.4 CU Selector Mirror

The CU Selector Mirror (CUSM) is aimed at redirecting the light beam coming from the CU toward the telescope focal plane (in such a way to be used by both the scientific instruments and the AO module).

The layout of the CUSM is shown in Figure 18. A manual adjustment device has been designed for the procedures of optical alignment between the Cu and the other ERIS subsystems during the integration phase. The device allows for tip/tilt adjustments and is based on differential screws to allow for high positioning accuracy.

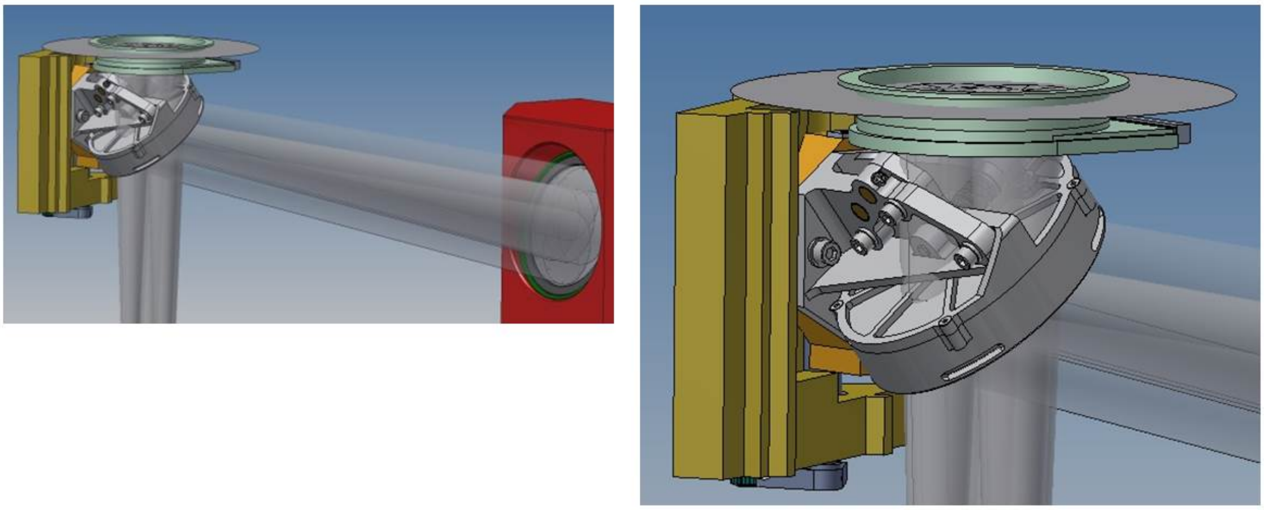


Figure 18: CU Selector Mirror (CUSM) overview (*left*) and detail zoom (*right*)

5.2.4.1 Total mass

The total mass of the CU Selector Mirror, as per the mechanical part designed by the CU Team, is 2.5 kg. This actually does not include mechanical interface with ERIS and the insertion motorized mechanism (designed by MPE).

5.3 Control Electronics design

The control electronics for the CU is based on Beckhoff PCU/PLC unit, communicating through the EtherCAT/Bus with the other system components.

The possibility to have a PCU/PLC unit for the WO+AO+CU subsystems is currently under discussion. In the current document the assumption is made of a single PCU/PLC unit for the whole ERIS-ICE.

5.3.1 Logical scheme

The CU electronics can be switched ON/OFF using Relays-Terminals (ES2602) by the main ICE. Each subsystem (TBD) is provided with an EtherCAT-Coupler for Data-Communication with the PLC, a number of specific analog and digital I/O, servo-controller, etc. An EtherCAT Extension is also needed to distribute the Communication to the next subsystem (TBD).

In Figure 19 the electronics architecture (block diagrams) of CU is shown. For each unit belonging to the subsystem (left part of the figure) the main components are shown, together with the corresponding I/O and control electronics communicating through the EtherCAT bus (right part of the figure).

The CUSM is not included in this section, since its development is part of the MPE work, with the only exception of the manual adjustment device mechanical design.

The detailed description of the devices and I/O and control electronics is given in [RD1].

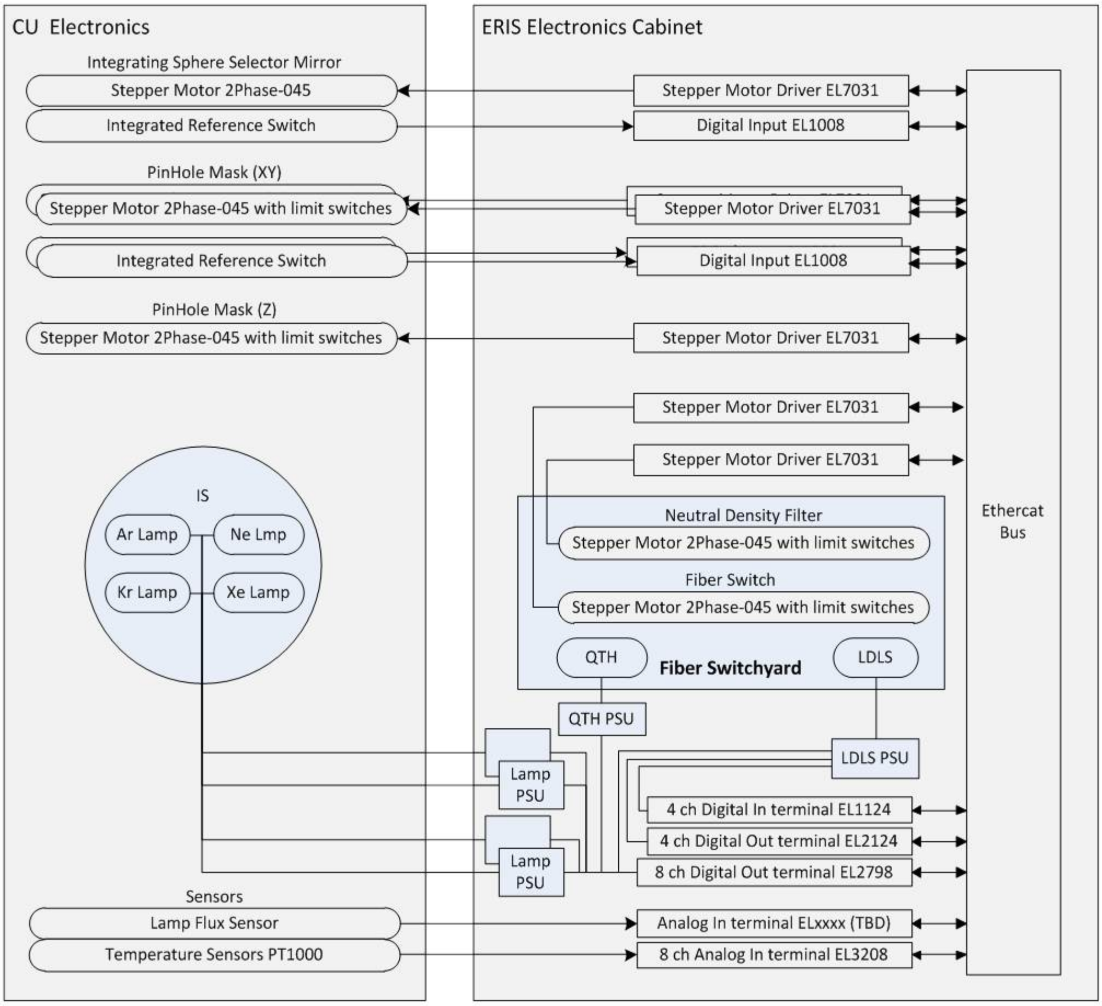


Figure 19: Logical scheme (block diagram) of the CU electronic connections

5.3.2 Preliminary wiring scheme

A preliminary wiring scheme for the CU system (i.e. including CUMB and CUFS) is reported in Figure 20.

The CUMB is provided with a connectors panel, which separates the internal connections from the external ones. Three electrical/signal connections are foreseen, having the following functions:

1) sending signals to the three PHM motorized linear stages and receiving signals from the corresponding limit switches;
2) sending signal to the ISSM motorized rotary stage and receiving signal from its limit switch, and providing electrical power to the four spectral calibration lamps (Ar, Kr, Ne, Xe);
3) receiving signals from the temperature sensors and the flux sensor.

Another three optical fiber connections are foreseen, as described in Sect. 5.2.3 (Fiber Switchyard).

The CUFS has connections toward the CUMB and other cabinets. It is connected to the CUMB through the three above-mentioned optical fibers, while two single/electrical connections with other cabinets have the following functions:

1) providing power (from the LDLS controller) to the LDLS head;
2) sending signals to the two motorized linear stages (Fiber Selector and Neutral Density Filter positioner) and receiving signals from the corresponding limit switches, receiving signals from the temperature sensors and providing power to the QTH lamp;

An external optical fiber connection is finally used to connect the LDLS controller (hosting the laser source) to the LDLS head (hosting the plasma bulb to be laser-excited).

The detailed description of the devices and I/O and control electronics is given in [RD1].

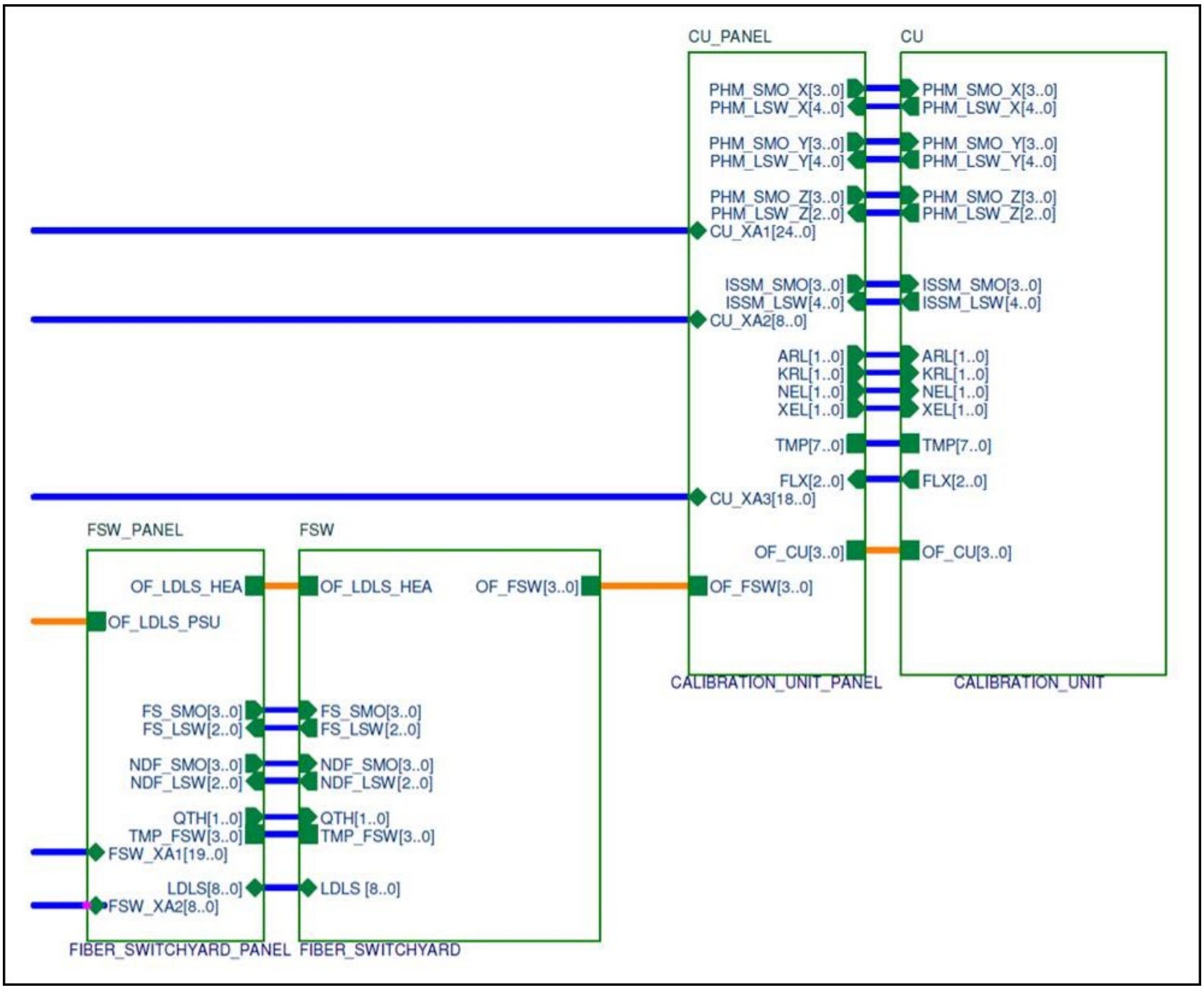


Figure 20: Wiring scheme for the Calibration Unit (Main Bench and Fiber Switchyard)

5.3.3 Preliminary list of selected components and devices

The list of main components for the CU is described in Table 10.

	Acronym	Units	Main Component Reference	Supplier
1	CU--ISSM	Integrating Sphere Selector Mirror (rotation stage)	M-060.2S	PI
2	CU-PHM	PinHole Mask (linear X,Y and Z stages)	M112.2S[1] LS-110 [2]	PI PI Micos
3	CU-ARL	Argon arc lamp	6030	Newport
4	CU-KRL	Kripton arc lamp	6030	Newport
5	CU-NEL	Neon arc lamp	6031	Newport
6	CU-XEL	Xenon arc lamp	6046	Newport
7	CU-QTH	Quartz-Tungsten Halogen lamp	6319	Newport
8	CU-LDLS	Laser Driven Light Source	EQ-99XFC	Energetiq
9	CU-NDF	Neutral Density Filter (linear stage)	LS-110	PI Micos
10	CUFS	Fiber Selector (linear stage)	LS-110	PI Micos
11	CU-TMP	Temperatures Sensors for CU module	PT1000	*TBD*
12	CU-RHU	Relative Humidity Sensors for CU Module	HMP110	Vaisala
Note: [1] X and Y axes; [2] Z axis				

Table 10: List of the CU subsystem units and their main components

5.4 Control Software design

The CU Control Software, initially thought as a separate package, is currently part of the unique ERIS Instrument Software (INS), described in [RD2] and [RD3], which includes in a single package the control software for the AO module and CU. For the aspects related to the software commands aimed to control the CU, therefore, reference must be made to the above mentioned documents.

6 CU Performance Analysis

6.1 Finite Element Modeling

6.1.1 Static analysis

A Finite-Element Analysis (FEA) has been carried out for both the CUSM and the CUMB, assuming boundary elements (i.e. the ERIS optical plate) as infinitely stiff and the telescope in its zenith position (operating position for CU). The results will have to be considered in conjunction with the results from the ERIS FEA by MPE team, carried out assuming each ERIS module, in turn, as infinitely stiff and represented by its CoG (where all the module mass is concentrated). The telescope pointing has been assumed towards the zenith, according to the requirements on calibration mode.

6.1.1.1 CUSM analysis

Results are shown in Figure 21, where X, Y and Z displacements are shown. Minimum and maximum displacements and deformations are summarized in Table 11.

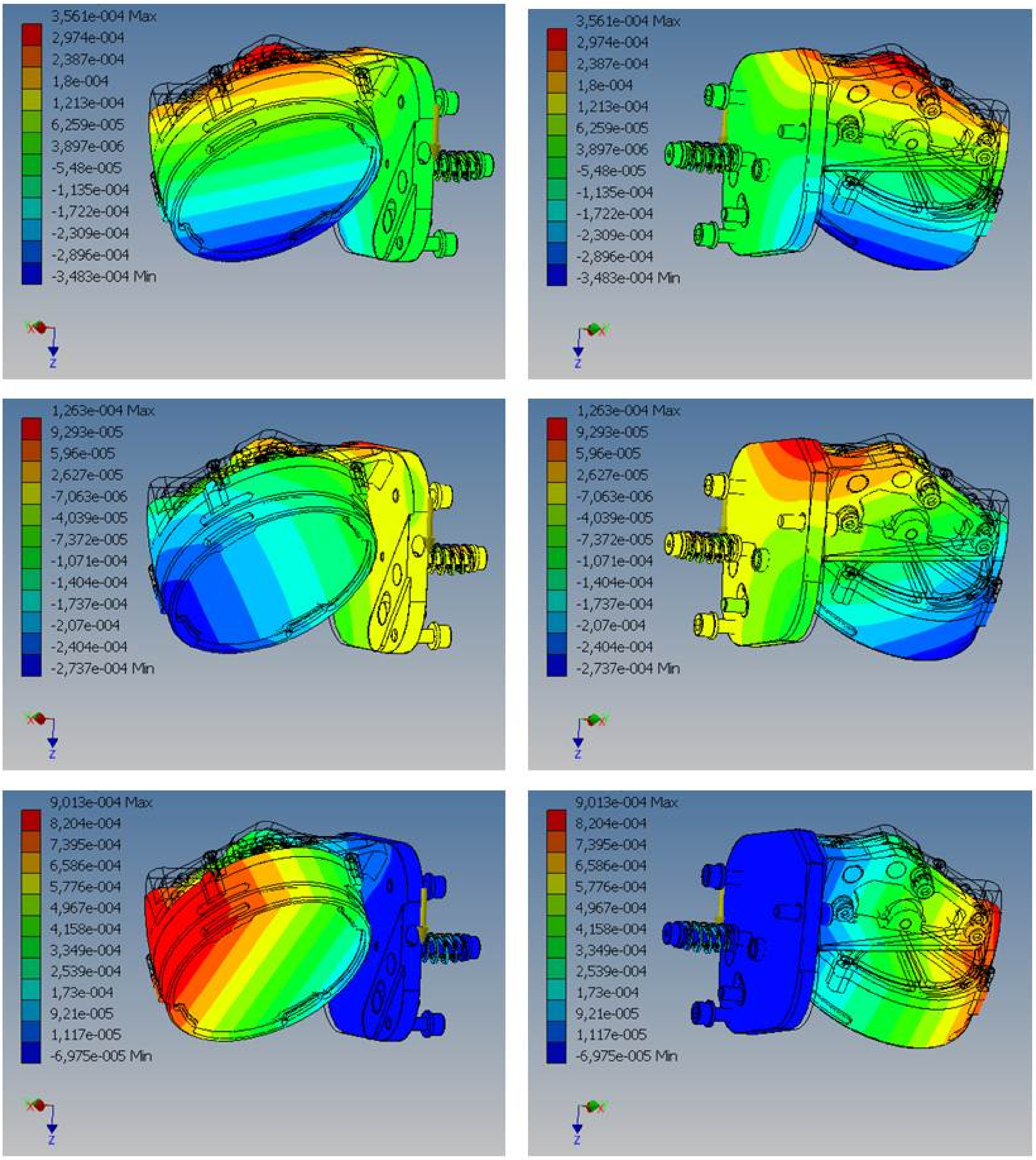


Figure 21: CUSM FEA displacements result. X, Y and Z displacements are shown from top to bottom, respectively. Units are in mm in the scales.

Name	Min value	Max value
X displacement	-0.348275 μm	0.356069 μm
Y displacement	-0.273707 μm	0.126259 μm
Z displacement	-0.0697511 μm	0.901332 μm
XX deformation ($\times10^{-6}$)	-5.98396	7.56039
XY deformation ($\times10^{-6}$)	-3.94425	4.53987
XZ deformation ($\times10^{-6}$)	-8.34569	4.78179
YY deformation ($\times10^{-6}$)	-4.51556	5.18361
YZ deformation ($\times10^{-6}$)	-6.21444	3.18167
ZZ deformation ($\times10^{-6}$)	-9.097	13.876

Table 11: CUSM FEA displacement and deformation results.

6.1.1.2 CUMB analysis

Results are shown in Figure 22, Figure 23 and Figure 24, where X, Y and Z displacements are shown, respectively. Minimum and maximum displacements and deformations are summarized in Table 12. No significant deformation is produced on both the triplet lens and the mirrors, so as to affect the optical performance of the system. It is important also to notice that the X- and Y- displacements of the PHM, and its Z-displacement, are not really a problem, since they are compensated by moving the PHM across the focal plane and refocusing it. The most important component, the pupil stop, is also the least displaced one: its X-, Y- and Z-displacements are always at sub-micrometric scale.

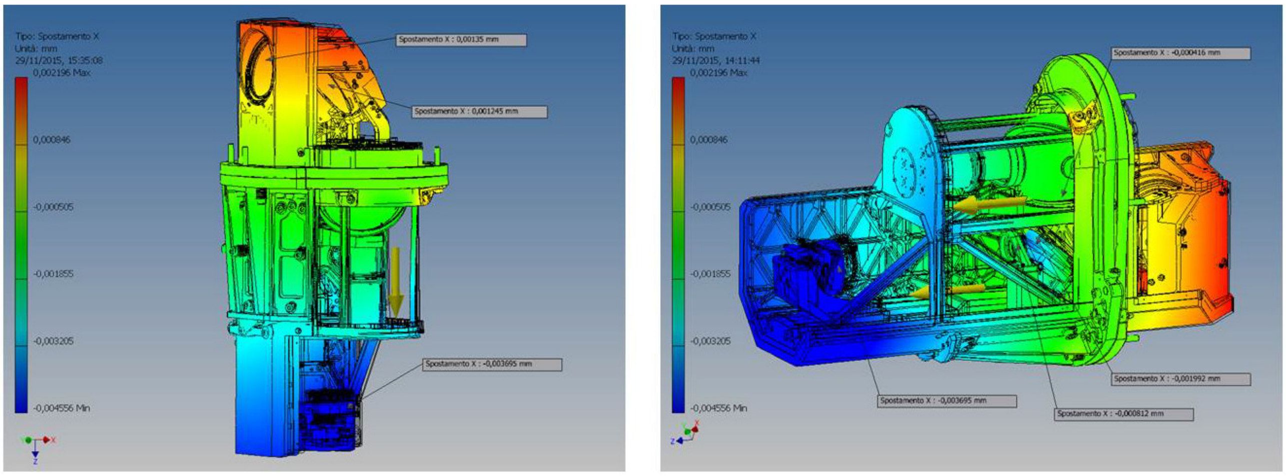


Figure 22: CUMB X-displacements.

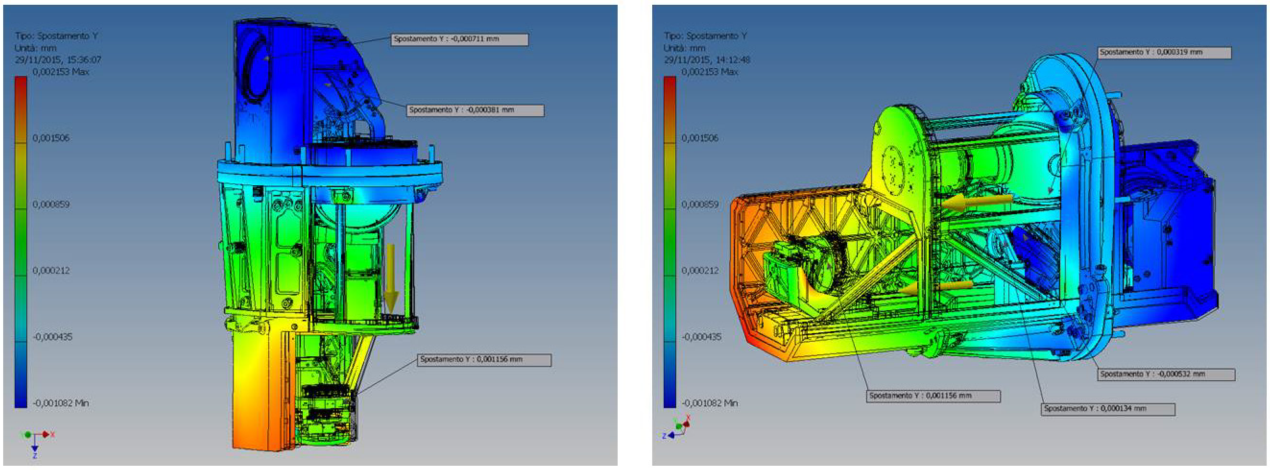


Figure 23: CUMB Y-displacements.

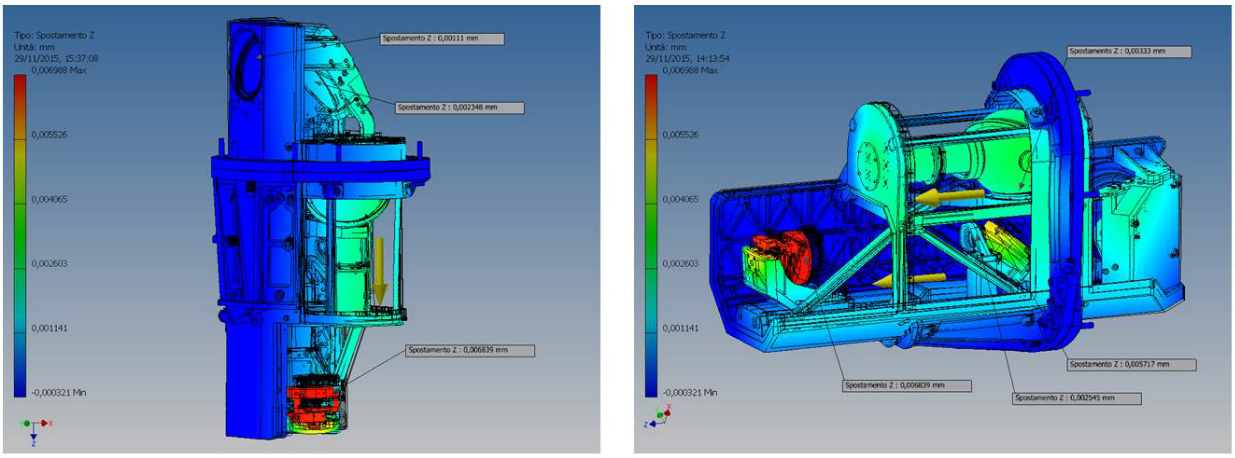


Figure 24: CUMB Z-displacements.

Name	Min value	Max value
X displacement	-8.1948 μm	9.13594 μm
Y displacement	-5.52556 μm	2.83751 μm
Z displacement	-0.320605 μm	6.98793 μm
XX deformation ($\times 10^{-6}$)	-27.7073	38.858
XY deformation ($\times 10^{-6}$)	-46.9082	37.2258
XZ deformation ($\times 10^{-6}$)	-15.4664	22.0218
YY deformation ($\times 10^{-6}$)	-44.498	43.988
YZ deformation ($\times 10^{-6}$)	-25.2807	25.8581
ZZ deformation ($\times 10^{-6}$)	-24.025	33.9979

Table 12: CUMB FEA displacement and deformation results.

6.1.2 Thermal analysis

This analysis is out of the scope for the current project phase.

6.1.3 Earthquake analysis

This analysis is out of the scope for the current project phase.

6.2 Expected photon rates

Photon fluxes expected at the telescope focal plane have been computed for the different CU configurations and are reported in this section. The scheme for the computation is shown in Figure 25. The two sources into the CUFS feed both the IS and the PHM into the CUMB, with the nearly same optical train. This is composed by low-attenuation optical fibers, optical fibers connectors (used for cable sectioning and connection to both the PHM and the IS) and fiber reflecting collimators (used in the fiber selection mechanism). Spectral calibration lamps are mounted into the light-pipe directly connected to the IS, so the optical train is essentially composed by this internally reflecting, gold-coated pipe. Finally, both PHM and IS feed the telescope focal plane (TFP) through an additional optical train composed by the lens triplet, the mirrors (ISSM and folding mirror) inside the CUMB and the CUSM.

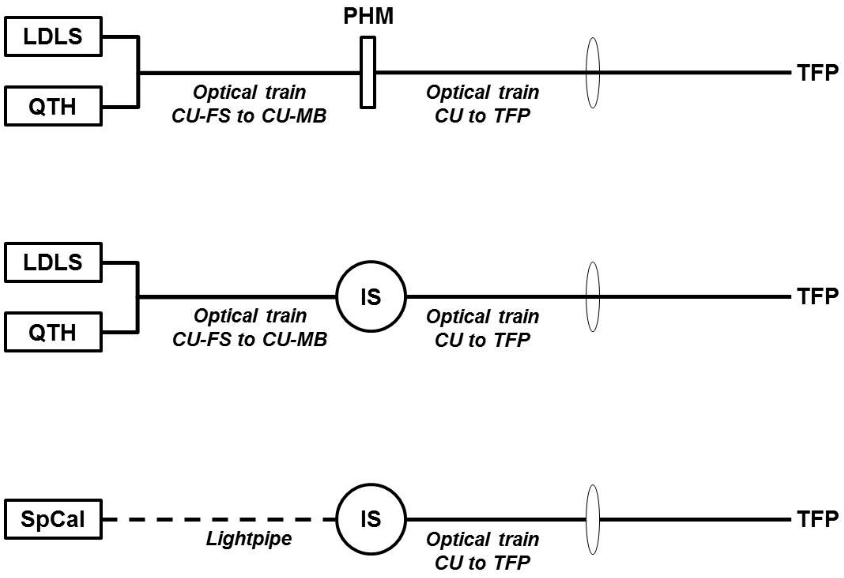


Figure 25: Light paths in the CU system

Calling T_1, T_2 and T_3 the overall efficiency of, respectively, the first optical train (CUFS to CUMB), the light-pipe and the second optical train (CU to TFP), the assumed values are those in Table 13.

Transm.	*Wavelength (nm)*									
	600	**800**	**1000**	**1200**	**1400**	**1600**	**1800**	**2000**	**2200**	**2400**
T_1	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
T_2	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
T_3	0.84	0.83	0.81	0.81	0.82	0.83	0.81	0.75	0.58	0.42

Table 13: Efficiency of optical trains in the CU system

The values for the T_1 were assumed conservatively taking into account the major losses due to the optical coupling at the fiber collimators and connectors. The attenuation by the fibers represents indeed a minor issue, as shown in Figure 26 for typical fluoride fibers manufactured by Thorlabs.

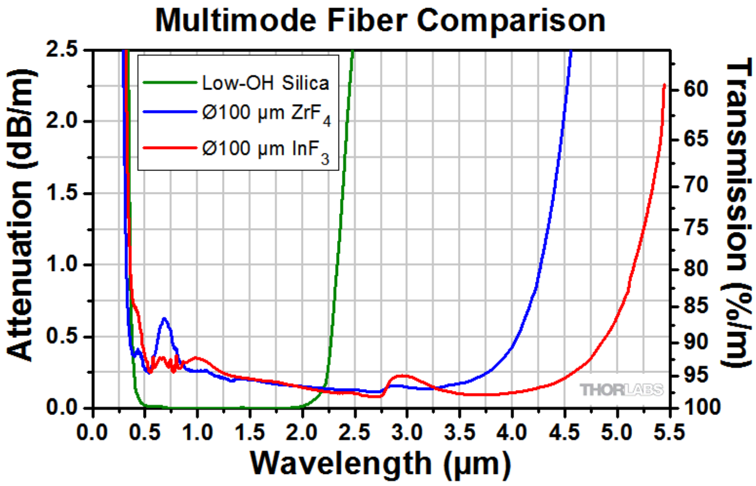


Figure 26: Attenuation of Thorlabs fluoride optical fibers

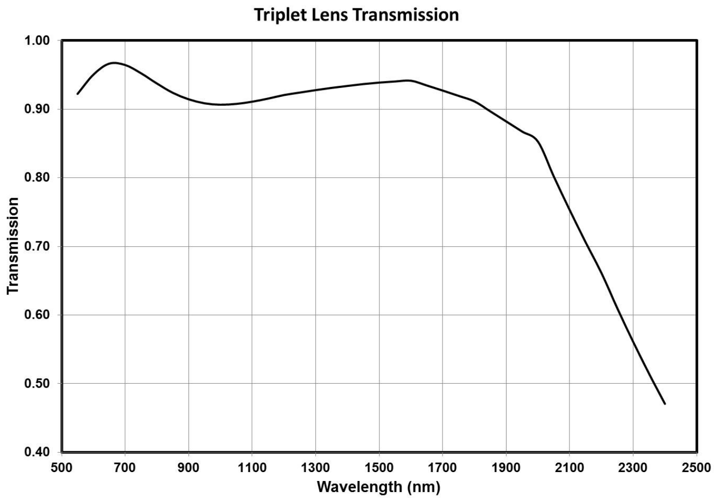


Figure 27: CU triplet lens transmission in the wavelength range of interest

The values for T_2 are essentially geometrical: no significant variation is expected in gold reflectivity over the wavelength range of interest (600 to 2450 nm).

Finally, the values for T_3 are determined by the optical transmission of the lens triplet, whose performance is slightly degrading toward long wavelengths, as reported in Figure 27. For each of the three mirrors a reflectivity of 96% has been assumed (aluminium), for a total reflection efficiency of 0.88 .

Another factor impacting on the photon rate is the efficiency of the IS. For the current model a 6 inch outer diameter IS, model 819C-SL-5.3 from Newport catalogue, has been adopted. This Integration Sphere has an inner diameter of 5.3 inch, is internally provided with a PTFE Spectralon coating and has three 1 inch ports plus one 2.5 inch port (port fraction 0.0734). Taking into account an output port reduction to a diameter only slightly larger than the pupil diameter (pupil area 762.09 mm^2), and the F/10.5 acceptance beam for the output flux (acceptance angle 0.00711 ster), the overall data for the IS efficiency are those in Table 14 (data are reported for a limited number of wavelengths, for readability reasons).

	Wavelength (nm)						
	600	**1000**	**1200**	**1600**	**1800**	**2200**	**2400**
Spectralon reflectance	0.97	0.97	0.97	0.96	0.95	0.90	0.90
Multiplier	9.583	9.583	9.583	8.689	7.933	5.419	5.419
Efficiency over pupil (ster^{-1})	0.0408	0.0416	0.0416	0.0377	0.0344	0.0235	0.0235
Efficiency over acceptance angle	0.000290	0.000296	0.000296	0.000268	0.000245	0.000167	0.000167

Table 14: Relevant data for the CU Integration Sphere (Newport 819C-SL-5.3)

The evaluation of the efficiency for the PHM takes into account two possible configurations. In the first one, the fiber end is directly connected to the mask and therefore it directly injects light into the optical path with 0.22 NA. In the second configuration the multi-mode fiber illuminates a light diffuser which, in turn, sends light into the output beam. In the second configuration an efficiency of 0.01 has been conservatively adopted for the diffuser. Moreover, the area ratio between the single pinhole and the whole diffuser, as well as the angular dilution of the output flux from each pinhole has be properly considered.

Finally, the photon flux emitted by each source has been taken into account. The LDLS manufactured by Energetiq has a spectrum which is rather flat from up to the end of the visible range and degrades slightly at near-infrared wavelengths (Figure 28). Although graphical data from the manufacturer catalogue are limited to 1800 nm, the degradation trend continues with the same slope at least up to 2400 nm (info by manufacturer). The output photon flux from the LDLS equipped with a 230 μm fiber is summarized in Table 15.

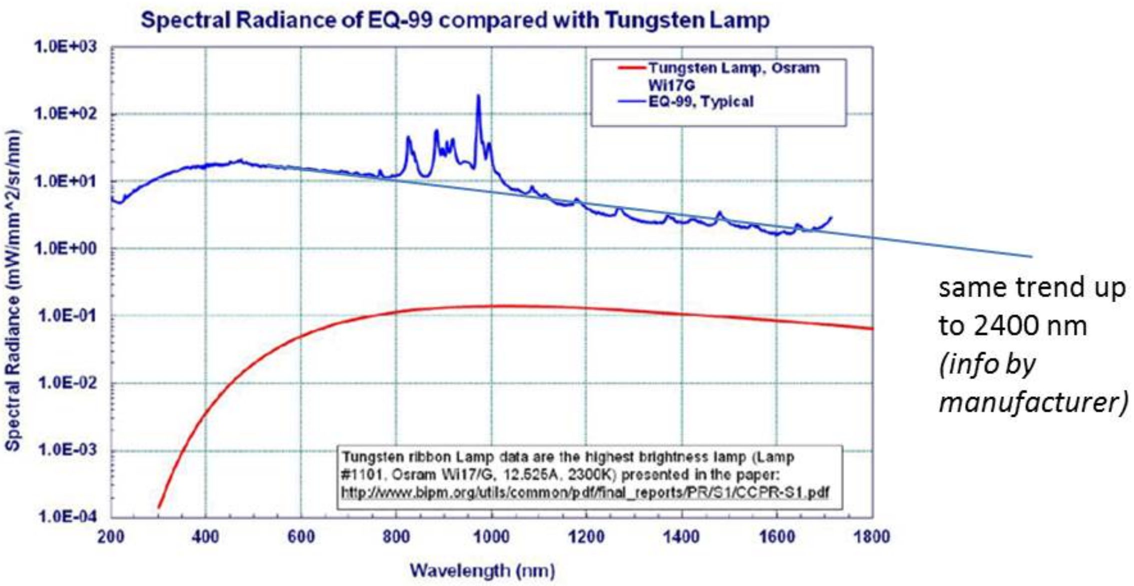


Figure 28: Spectral power (and trend up to 2400 nm) of Energetiq LDLS

	Wavelength (nm)									
	600	**800**	**1000**	**1200**	**1400**	**1600**	**1800**	**2000**	**2200**	**2400**
Spectral power (μW/nm)	50	40	60	20	11	9	6	4	2.5	2
Specific photon rate × 10^{13} (phot/s/nm)	15.1	16.1	30.2	12.1	7.75	7.25	5.44	4.03	2.77	2.42

Table 15: Output flux data for Energetiq LDLS

Output flux from the QTH lamp has been computed by adopting catalogue data for the Oriel-Newport QTH lamp model 6318 (10 W total power), whose emission curve is shown in Figure 29. A light collection efficiency by the output fiber equal to 0.3 has been conservatively adopted. The resulting data, relevant for near-infrared wavelengths only (the range where the QTH could be needed) have been compared to the output from the LDLS and the gain ratios at the three classical NIR bands are summarized in Table 16.

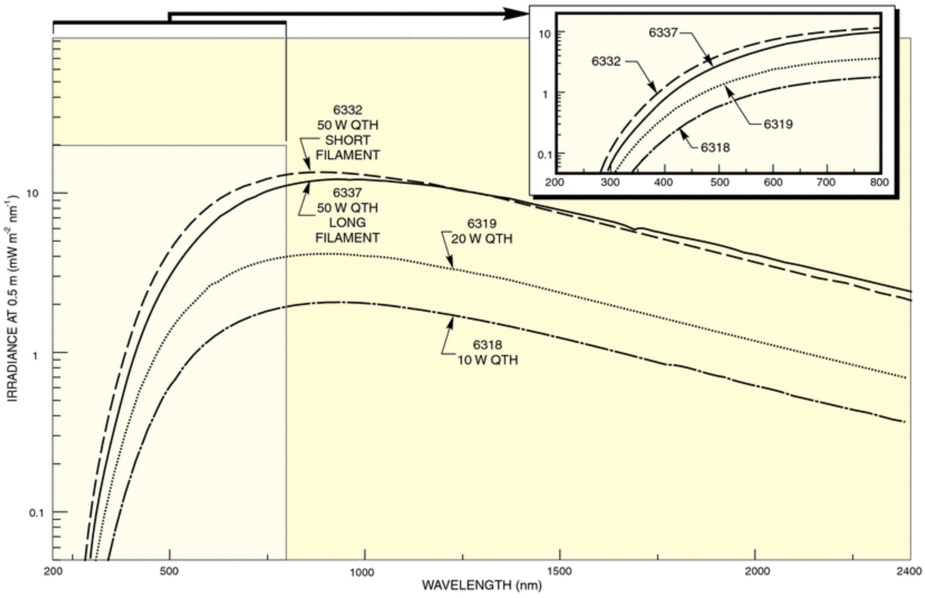


Figure 29: Typical output power curves of Oriel-Newport QTH lamps

	J-band (1250 nm)	*H-band (1650 nm)*	*K-band (2200 nm)*
QTH-to-LDLS gain	~100	~160	~210

Table 16: Oriel QTH model 6318 (10 W) output gain vs Energetiq LDLS

As a last input information, the typical brightness of spectral calibration lines has been considered. To perform the computation, the pencil-style Ar, Kr, Ne, Xe calibration lamps from Newport have been adopted (models 6030, 6031, 6032, 6033). Spectra of these lamps, available from Newport catalogue, are shown in Figure 30. Relative units of irradiance refer to the Hg(Ar) lamp line at 435 nm, whose irradiance is given. The computation has not been performed for each of the usable spectral lines: rather, the brightest line and some faint line have been considered for each lamp. Table 17 reports the values adopted to this purpose.

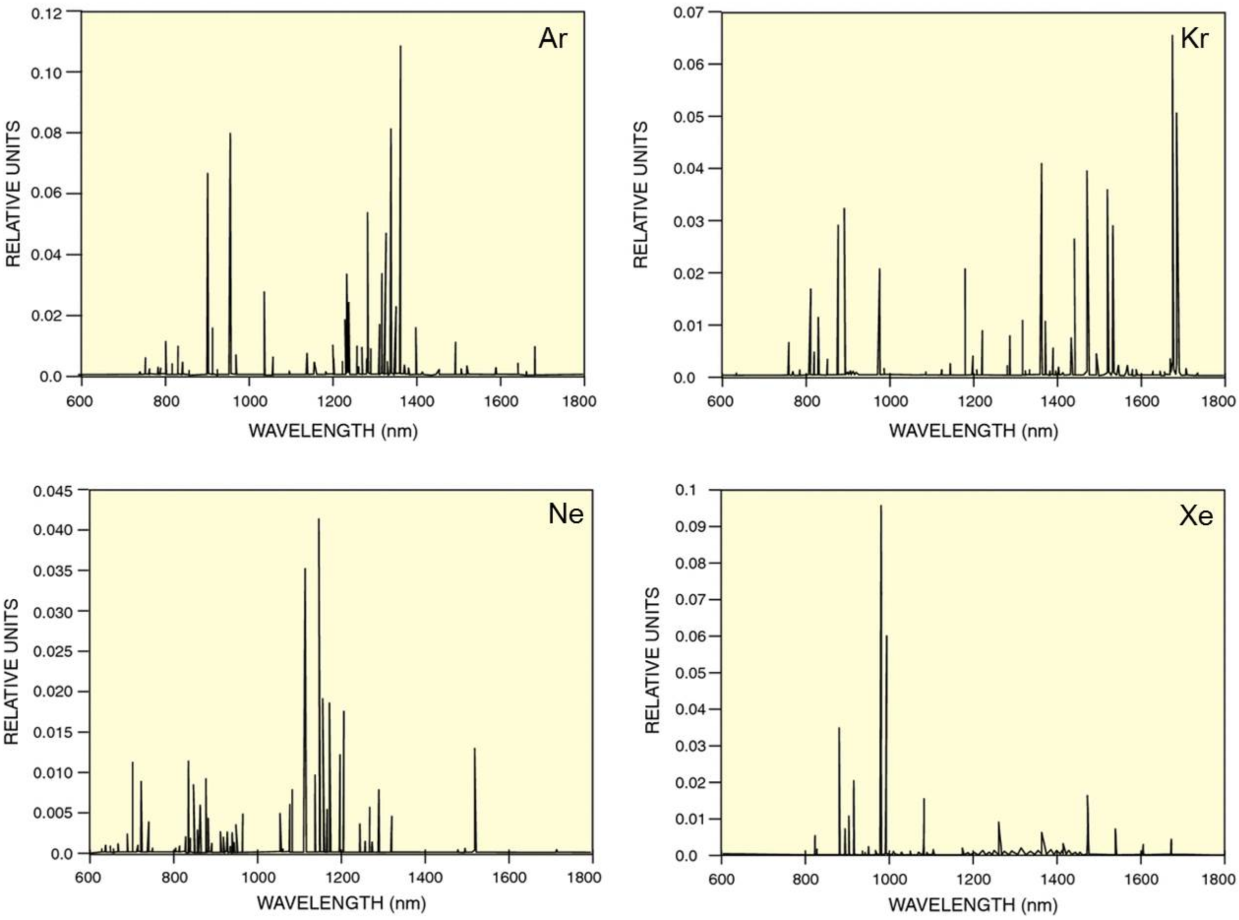


Figure 30: Oriel Newport calibration lamps typical spectra

Lamp/configuration	Emitted line flux ($\times 10^{12}$ phot/s)		
	J-band (1250 nm)	H-band (1650 nm)	K-band (2200 nm)
Ar / brightest	29.4	38.8	51.7
Ar / faint	21.4	28.2	37.6
Kr / brightest	17.6	23.3	31.0
Kr / faint	1.1	1.4	1.9
Ne / brightest	10.9	14.4	19.3
Ne / faint	3.5	4.6	6.1
Xe / brightest	25.9	34.2	45.6
Xe / faint	1.1	1.4	1.9

Table 17: Emitted line photon flux for Oriel/Newport pencil-style spectral calibration lamps

With the input data described so far, expected photon rates have been computed for point-like and extended sources onto the PHM, as well as for broad-band, narrow-band and spectroscopic flat fielding of NIX and SPIFFI and, finally, for wavelength calibration of SPIFFI. For completeness, the computation has been made taking into all the two plate scales foreseen for NIX and all the three ones for SPIFFI:

- NIX ps#1: 13 mas/pix
- NIX ps#2: 27 mas/pix
- SPIFFI ps#1: 250×125 mas/spax
- SPIFFI ps#2: 100×50 mas/spax
- SPIFFI ps#3: 25×12.5 mas/spax.

Finally, since the line width of the spectral calibration lines is much narrower than the spectral resolution bin (not smaller than 0.55 nm), it has been assumed that light coming from a line falls onto a single detector column.

The results for NIX and SPIFFI calibrations are reported in Table 18, Table 19 and Table 20.

	J-band (1250 nm cwl)		**H-band (1650 cwl)**		**K-band (2200 cwl)**	
	Broad (210 nm)	***Narrow (10 nm)***	***Broad (300 nm)***	***Narrow (15 nm)***	***Broad (390 nm)***	***Narrow (20 nm)***
NIX ps#1, LDLS only	3413	163	2710	136	589	30
NIX ps#1, QTH only	341293	16252	433612	21681	123743	6346
NIX ps#2, LDLS only	14722	701	11690	585	2542	130
NIX ps#2, QTH only	1472205	70105	1870431	93522	533780	27373

Table 18: NIX flat fielding expected photon rates (units: photons/s/pix)

	J-band (1250 nm cwl)	**H-band (1650 cwl)**	**K-band (2200 cwl)**
SPIFFI ps#1, LDLS only	1878	919	154
SPIFFI ps#1, QTH only	187824	146996	32269
SPIFFI ps#2, LDLS only	264	129	22
SPIFFI ps#2,	26413	20671	4538

QTH only			
SPIFFI ps#3, LDLS only	19	9	2
SPIFFI ps#3, QTH only	1878	1470	323

Table 19: SPIFFI spectroscopic flat fielding photon rates (units: photons/s/spax)

Spectral band	Line	SPIFFI ps#1	SPIFFI ps#2	SPIFFI ps#3
J	***Ar bright***	73036	10271	730
	Ar faint	53117	7470	531
	Kr bright	43822	6162	438
	Kr faint	2656	373	27
	Ne bright	27223	3828	272
	Ne faint	8632	1214	86
	Xe bright	64405	9057	644
	Xe faint	2656	373	27
H	***Ar bright***	89313	12560	893
	Ar faint	64955	9134	650
	Kr bright	53588	7536	536
	Kr faint	3248	457	32
	Ne bright	33289	4681	333
	Ne faint	10555	1484	106
	Xe bright	78758	11075	788
	Xe faint	3248	457	32
K	***Ar bright***	52147	7333	521
	Ar faint	37925	5333	379
	Kr bright	31288	4400	313
	Kr faint	1896	267	19
	Ne bright	19437	2733	194
	Ne faint	6163	867	62
	Xe bright	45984	6467	460
	Xe faint	1896	267	19

Table 20: SPIFFI spectral calibration lines photon rates (units: photons/s/spax)

Finally, results from the computation for the PHM point-like and extended sources, assuming a AO module entrance filter bandwidth of 20 nm and a reference wavelength of 750 nm, are reported in Table 21. For these data just the LDLS has been adopted, provided with its 230 μm optical fiber (QTH lamp is too bright).

Minimum magnitude (at reference wavelength) corresponds to the reported photon flux thru pupil. Maximum magnitude is related to the insertion of the Neutral Density Filter (in the CUFS) at its highest Optical Depth (OD=4).

Configuration	Data	Source type			
		DL	**0.5”**	**1.0”**	**1.5”**
Direct injection by fiber	**Photon rate thru pupil (phot/s)**	1.15×10^9	9.81×10^{11}	9.81×10^{11}	9.81×10^{11}
	Min mag	3.8	-3.5	-3.5	-3.5
	Max mag	13.8	6.5	6.5	6.5
Back illumination by diffuser (light box)	**Photon rate thru pupil (phot/s)**	*not applicable*	4.17E+05	1.67E+06	3.76E+06
	Min mag	*not applicable*	12.4	10.9	10.0
	Max mag	*not applicable*	22.4	20.9	20.0

Table 21: Expected photon rates for PHM sources. Illumination by LDLS with 230 μm fiber

Looking at the results of our computation, several criticalities actually exist for narrow-band flat fielding of NIX and spectroscopic flat fielding of SPIFFI, where the expected photon counts by using just the LDLS are rather low (sometimes very low). Critical choices on the design and the procedures could indeed be made. A 4 inch customized integration sphere, for example, would have a higher efficiency, even if tighter constraints on the flat field uniformity should represent a major drawback. Also, flat fields could generally performed not at any plate scale. All these choices, however, seem insufficient to raise the “critical” photon counts at acceptable levels (say above 5000).

On the other hand, the need for a flat-spectrum source is not clear yet. Once the requirement for a spectral uniformity will be definitively proven unnecessary, the LDLS could be removed from the design baseline and a QTH only (of proper output power, e.g. 20 W, like the Oriel-Newport QTH model 6319) could be adopted.

7 CU interfaces

7.1 Optical interface

The optical characteristics of the UT4 Cassegrain focus, as modified to adapt itself to a longer back focal length from the Cassegrain flange of 500 mm instead of 250 mm, is given as reference in Table 22.

Parameter	Value
VLT Entrance pupil diameter	8117.7 mm
VLT **modified** focal ratio	F/13.63
VLT focal length	110348 mm
Image scale	535 um/arcsec
Focal plane position	500 mm below Cassegrain flange
Optical axis	± xxx arcmin w.r.t. Cass flange
VLT exit pupil diameter	1116 mm (on M2)
VLT exit pupil distance	15170 mm in front of the focal plane
ERIS field of view	82 arcmin diameter (TBC)
ERIS guiding wavelength	xxx nm (TBD)

Table 22: Modified optical characteristics of the UT4 Cassegrain focus.

7.2 Mechanical interface

The mechanical interface between the CU and the ERIS optical plate is shown in Figure 31. It has been signed in order to allow easy mounting and dismounting operations, as well as adjustments of the CU position for optical alignment purposes, from the bottom side only.

The adjustment occurs through two movements involving the CU as a whole:

1) a rotation (current range: ±1°) around an axis perpendicular to the ERIS optical plate and passing close to the triplet lens (which lies therefore on the pivot point);

2) a translation (current range: ±1 cm) along the same axis.

Several sets of screws are used to allow for rotation and translation: tightening screws (that must be unscrewed to perform the adjustment), supporting screws (provided with springs, they prevent the CU to fall after unscrewing the previously-mentioned screws), position reference screws (that allow to easily recover the position in case of dismounting/re-mounting) and the adjustment screws (shown in the figure).

The interface is composed by two parts: a structure locked to the CUMB, and a ring that remains foxed to the ERIS optical plate. In case of dismounting the CU, two high-precision machined pivots on this ring allow to re-mount the it in nearly the same position, with great accuracy.

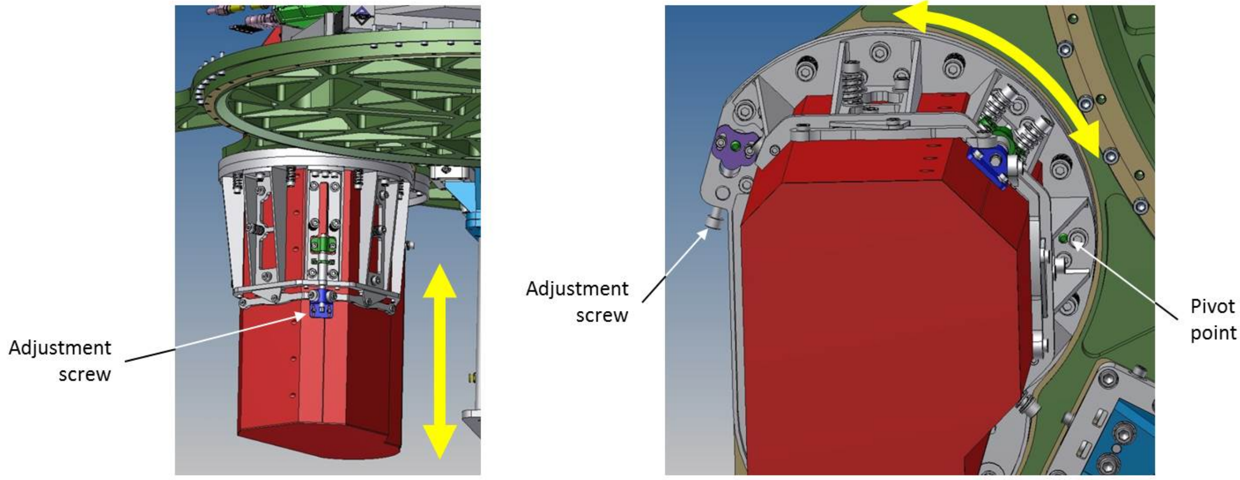


Figure 31: CUMB / ERIS optical plate mechanical interface

7.3 Electrical and electronic interface

Electrical and electronic interfaces are represented by the Beckhoff terminals used to control (and to supply power to) the CU components and devices. The connection to these terminals has been already shown in Section 5.3.2, while for the details reference must be made to [RD1].

7.4 Software interface

As already described in Section 5.4 (Software Design), the CU Control Software is part of the unique ERIS INS, described in [RD2] and [RD3], which includes the control software for the AO module and CU. Therefore, for the aspects related to the software interfaces between the CU control and other subsystems, reference must be made to the above mentioned documents.

8 CU Maintenance

8.1 Identification of LRUs

This part is out of the scope of the document at the current project phase.

8.2 Spares

This part is out of the scope of the document at the current project phase.

8.3 Maintenance operations

Although a detailed maintenance plan for the CU is out of the scope of this document at the current project stage, some starting considerations can be made here. Essentially the following two maintenance operations can be foreseen:

1) operations that require dismounting and re-mounting of the CU from the ERIS plate;
2) operations that could be performed even with the CU mounted at the ERIS plate.

For the first kind of operations, the CU/ERIS mechanical interface has been designed in order to allow an easy dismounting and re-mounting of the CU by acting from the bottom side only. To this purpose, the distribution of the ERIS cabinets has been designed by MPE in such a way to leave clearance to mount/dismount CU by direct insertion from the bottom (Figure 32). According to the current estimate, 2 operators are needed, plus a proper handling tool described in the following Section.

Operations that could be performed without removing the CU from ERIS are those related to the simple replacement of failed LRUs. Spectral calibration lamps are the most evident example of these components. To allow for this possibility (still TBC), the CU carters have been designed in order to be partially removed and to allow direct access to the components by operators (Figure 33). Spectral calibration lamps, in particular, shall be collectively hosted inside a cylindrical holder that can be completely extracted from the light-pipe, in such a way the spectral lamp replacement and remounting can be performed under maximum safety conditions (Figure 34).

Detailed sequences of maintenance operations will be described in a next version of this document.

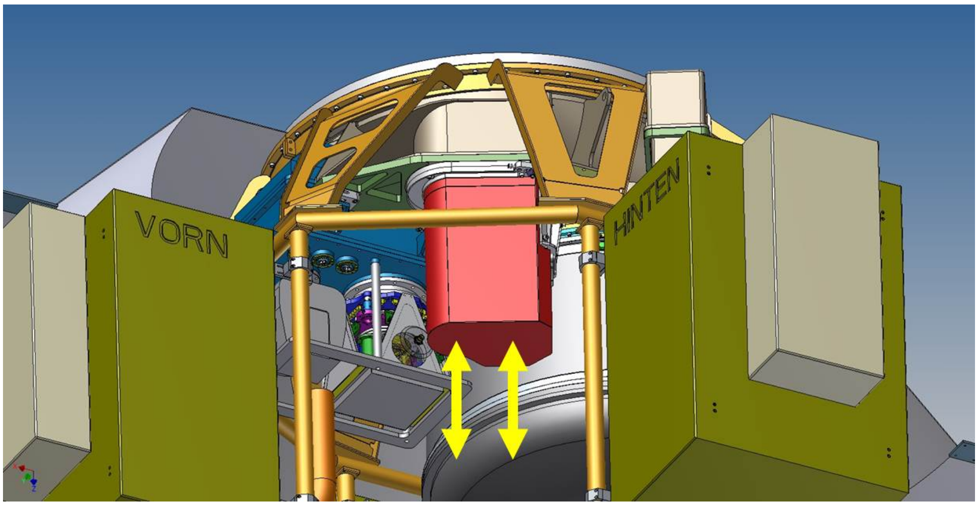


Figure 32: Allowed clearance for CU dismount/remount operations.

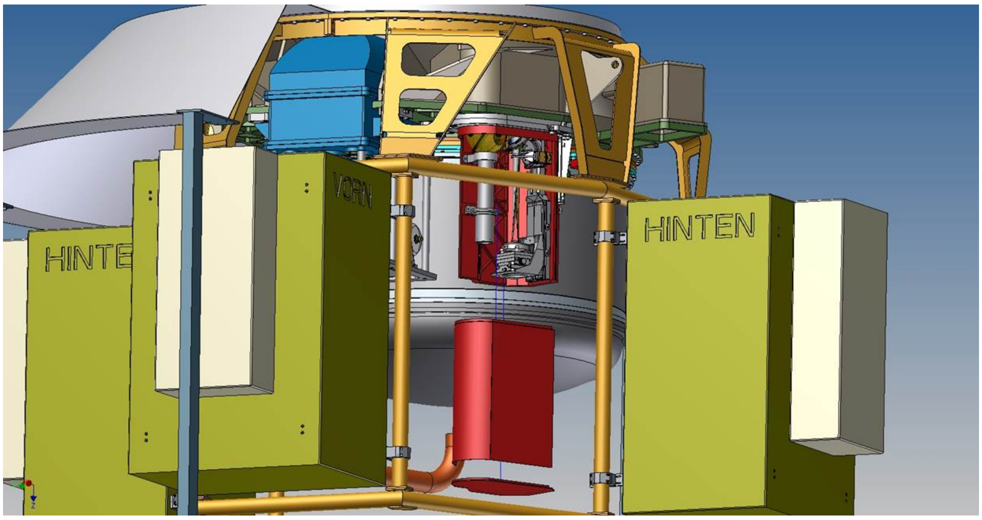


Figure 33: Carter partial removal to allow direct access to components.

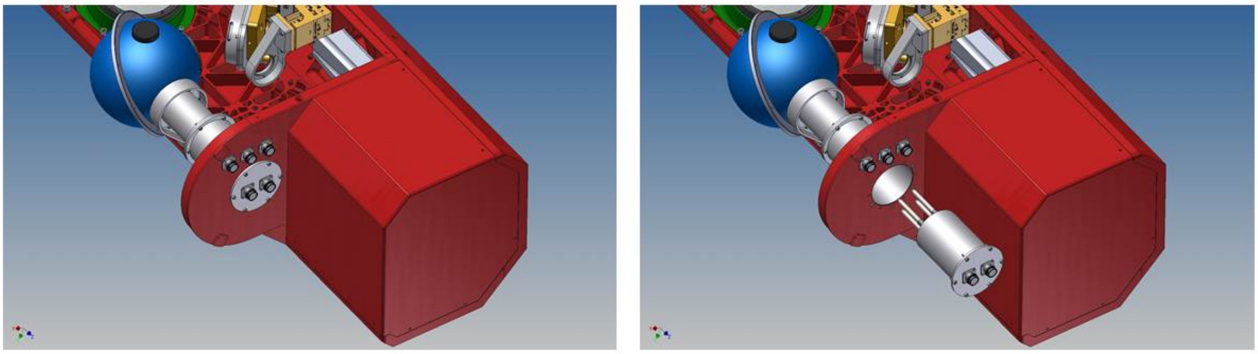


Figure 34: Extraction of spectral lamps holder for replacement purposes.

8.4 Handling tool

The design of the Handling Tool to be used for the mounting and dismounting operations of the ERIS Calibration Unit (CU) has been developed as a result of the analysis performed on the ERIS mechanical model taking into account the need of not interfering with ERIS instruments (NIX and SPIFFI) during operations, as well as the boundary conditions expected for the various phases of the ERIS MAIV Plan: integration in Arcetri, integration in MPE, installation at ESO (Paranal).

The basic concept of mounting/dismounting includes three fundamental steps:

1) moving vertically the CU, in order to completely extract it from the interface hole made on the ERIS optical plate;
2) moving the CU horizontally in outward direction, in order to extract it from the whole ERIS envelope;
3) taking the CU to a proper location in order to perform maintenance.

In order to accomplish these three steps, two possible options have been selected. The first option is based on two separate tools: a trolley-based lift (for steps 1 and 2) plus a crane for step 3. As an alternative option, a fork lifter could be used to perform all the three steps. The choice between the two options will depend on the possibility to use the same tool for the CU and the NIX camera, as well as the detailed boundary conditions at MPE.

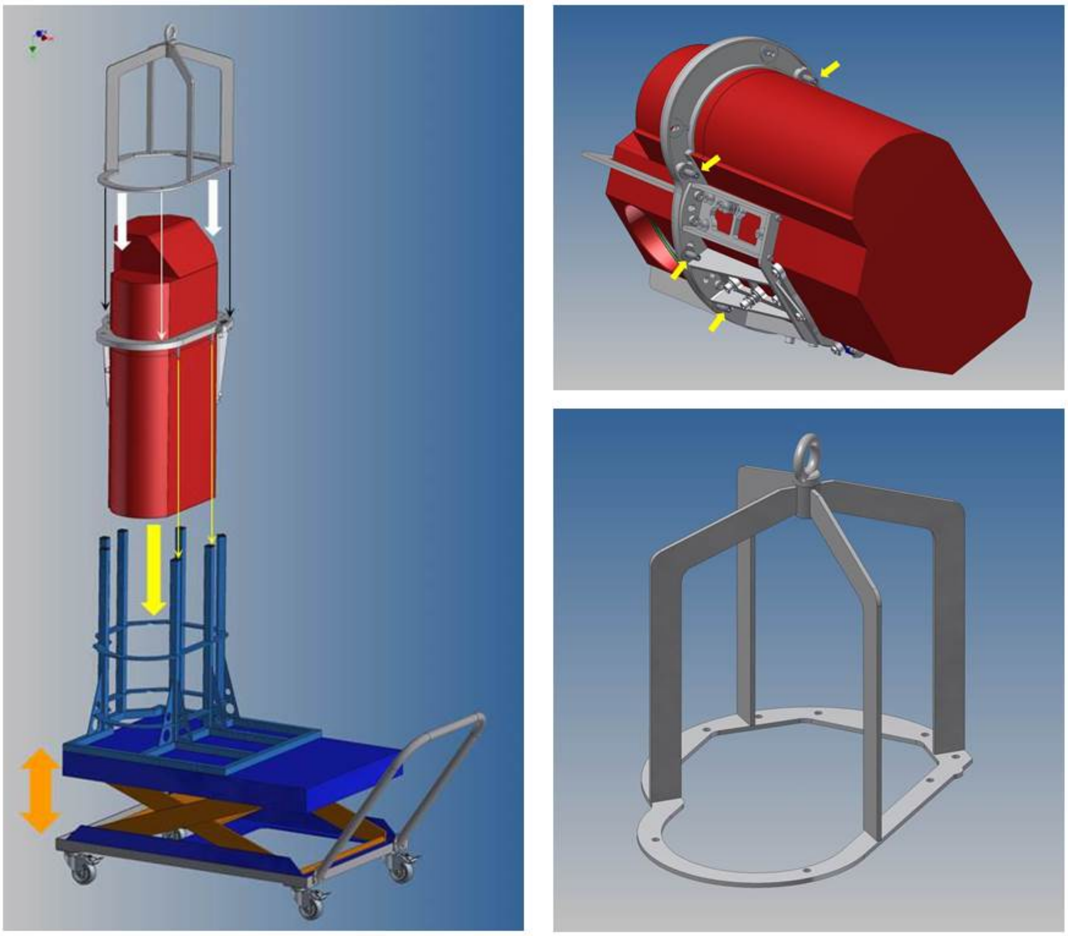


Figure 35: CU Handling Tool. Top right: locking points to the Cu mechanical interface . Bottom right: locking structure for the use of a crane.

Figure 35 shows the full concept for the first option. A scissor lift TCR 500, commercially available, is mounted onto a custom trolley whose vertical room does not exceed 25 cm. Above the lift a custom supporting structure is mounted which has to be locked at the CU mechanical interface through devoted pins (top right in the figure). Once the CU is extracted, a custom locking structure is mounted onto the mechanical interface ring in order to provide a lock point for a crane that must allow to lift this point up to 190 cm from the ground floor (bottom right in the figure).

The complete sequences expected for operations at the first integration in Arcetri and final integration at MPE is shown in Figure 36. In the first case the required height of the ERIS plate bottom surface is 150 mm from the floor, while at MPE a small ramp is necessary in order to place the trolley below the CU, due to the presence of the cabinets supporting structure (which is placed at the floor level, according to indications from MPE).

Sequences in the order 1 to 3 represent the dismounting procedure. The inverse sequences represent of course the mounting procedure.

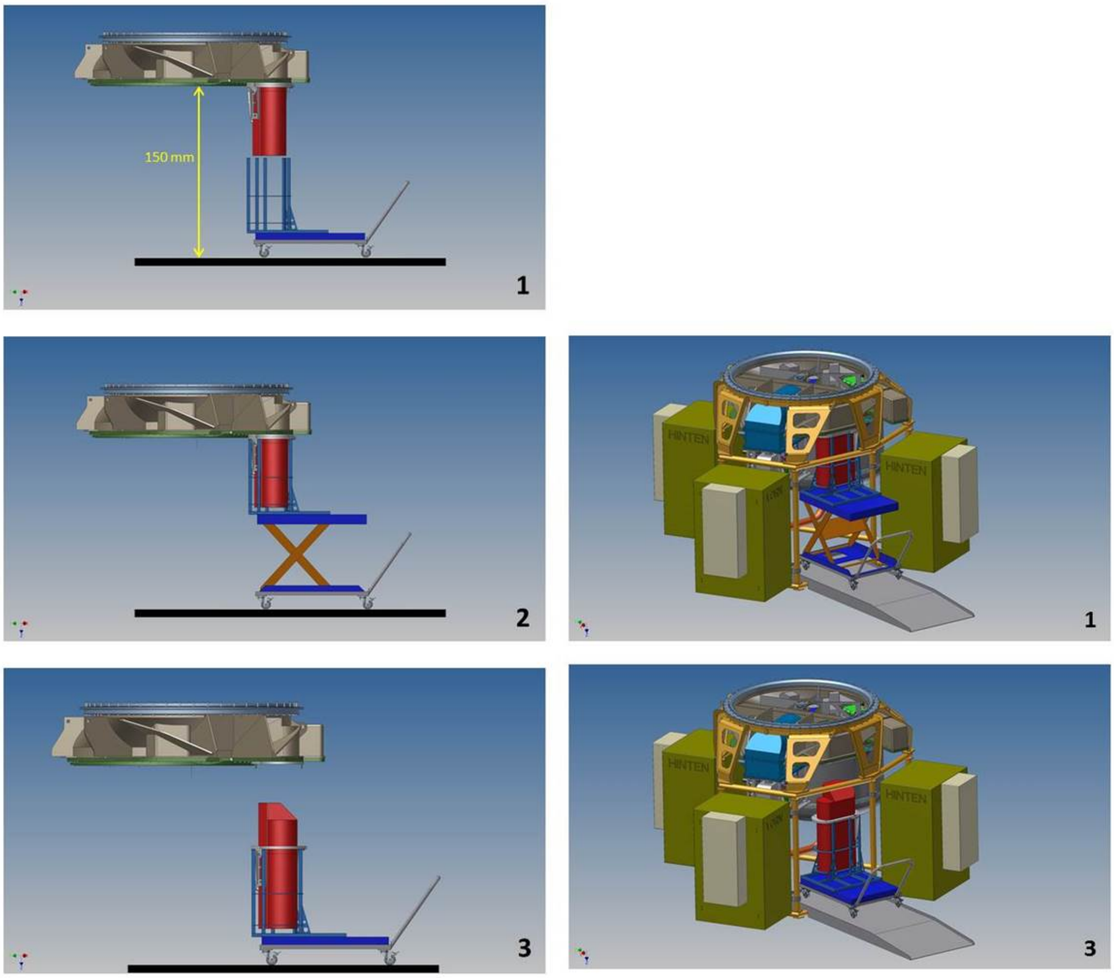


Figure 36: CU mounting/dismounting procedures at Arcetri (*left*) and MPE (*right*).

In order to make the operations even safer (mainly with respect to the possibility of mechanical collisions of the Handling Tool with NIX or SPIFFI), the possibility to “finely tuning” the horizontal position of the Tool has also been foreseen for operations at MPE, where both NIX and SPIFFI will be mounted in ERIS together with the CU. The concept for a simple manual mechanism is shown in Figure 37: adjustment screws, acted through manual knobs fixed to the ramp, allow to slightly change the position of the tool.

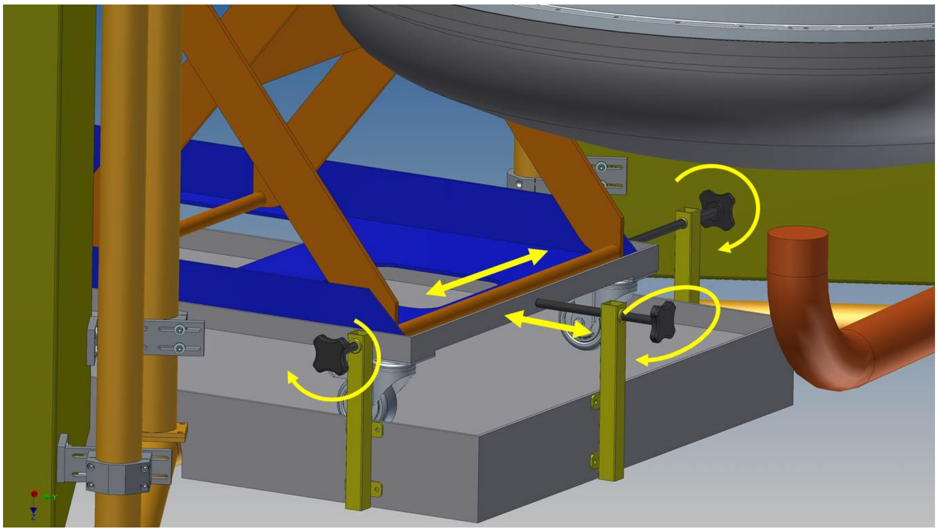


Figure 37: Concept for manual (fine) adjustment of the Handling Tool position

The second option is based on the same custom structures as the first one, but does not need the scissor lift and the trolley. The lower supporting structure is indeed provided with a special accessory, eventually custom-made, for the insertion of forks (Figure 38). In this case the vertical dismounting, horizontal extraction and transportation to a working station are performed with just one handling tool.

The final choice between the first and the second option shall be made only after evaluation of the NIX team needs and the eventual adoption of a unique, common Handling Tool for both NIX and the CU, and is currently out of the scope of this document.

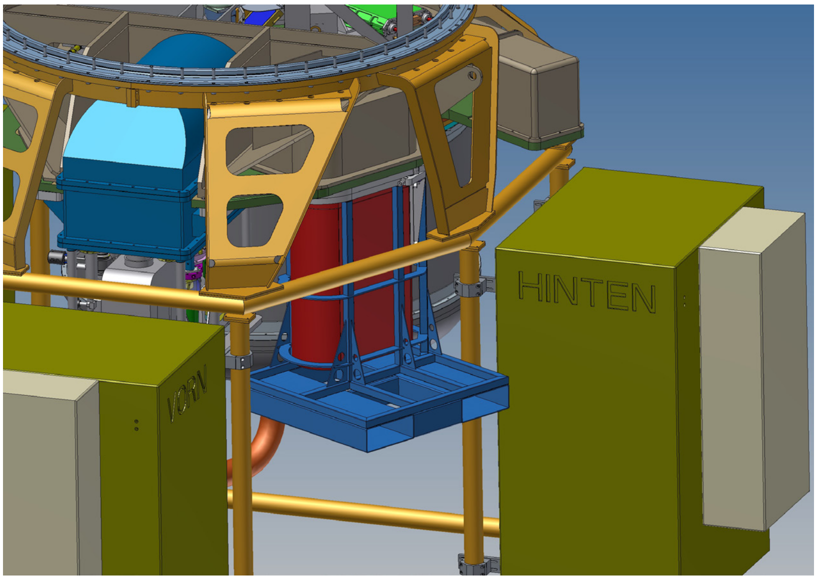


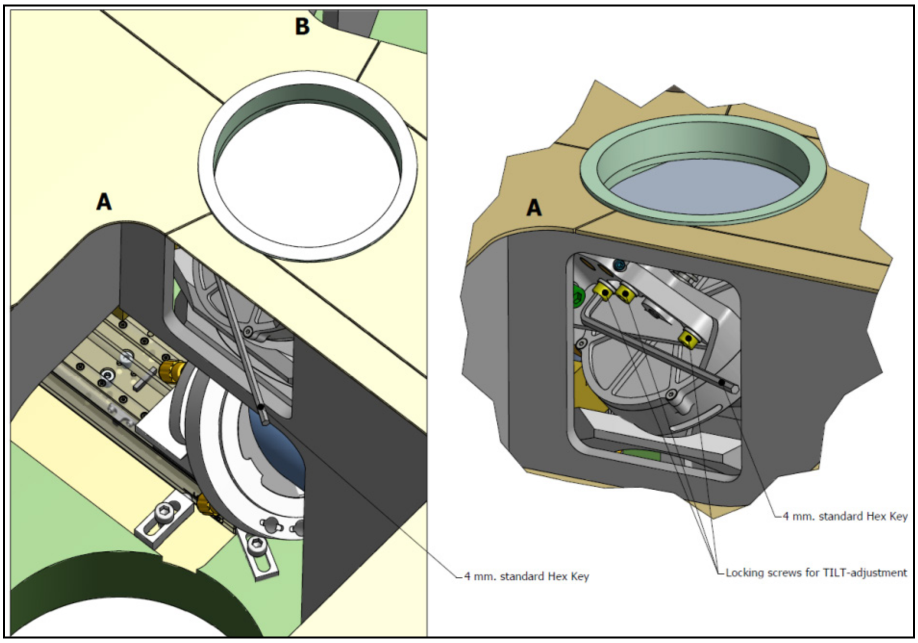
Figure 38: Handling Tool provided with a custom accessory for fork insertion

8.5 Operator's accessibility

The problem of accessing the manual screws aimed to adjust the tip and tilt of the CUSM has been addressed and analyzed together the MPE team. A basic fact to be considered is the access foreseen in the integration phase only, i.e. when the ERIS system is not mounted at the telescope.

According to the final choice, the CUSM can be accessed by an operator simply by temporarily removing the ERIS top cover. Figure 39 and Figure 40 show the operations to adjust tilt and tip, respectively, by acting on the CUSM proper screws. The figures refer to a situation slightly worse than currently allowed, concerning the existence of just two holes onto the ERIS top cover. The operations are clearly even more comfortable and easy in the real situation.

The wrenches are provisionally indicated as “standard hex key” (which implies the matching positions to the screw head are every 60°) but spline (30°) or double-square (45°) heads could also be adopted if necessary.



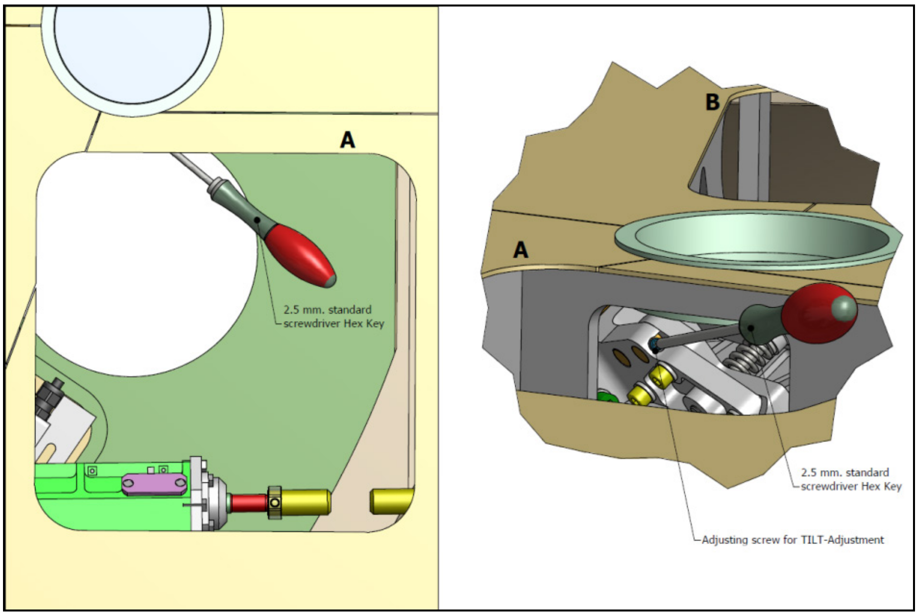


Figure 39: CUSM tilt adjustment (operation details)

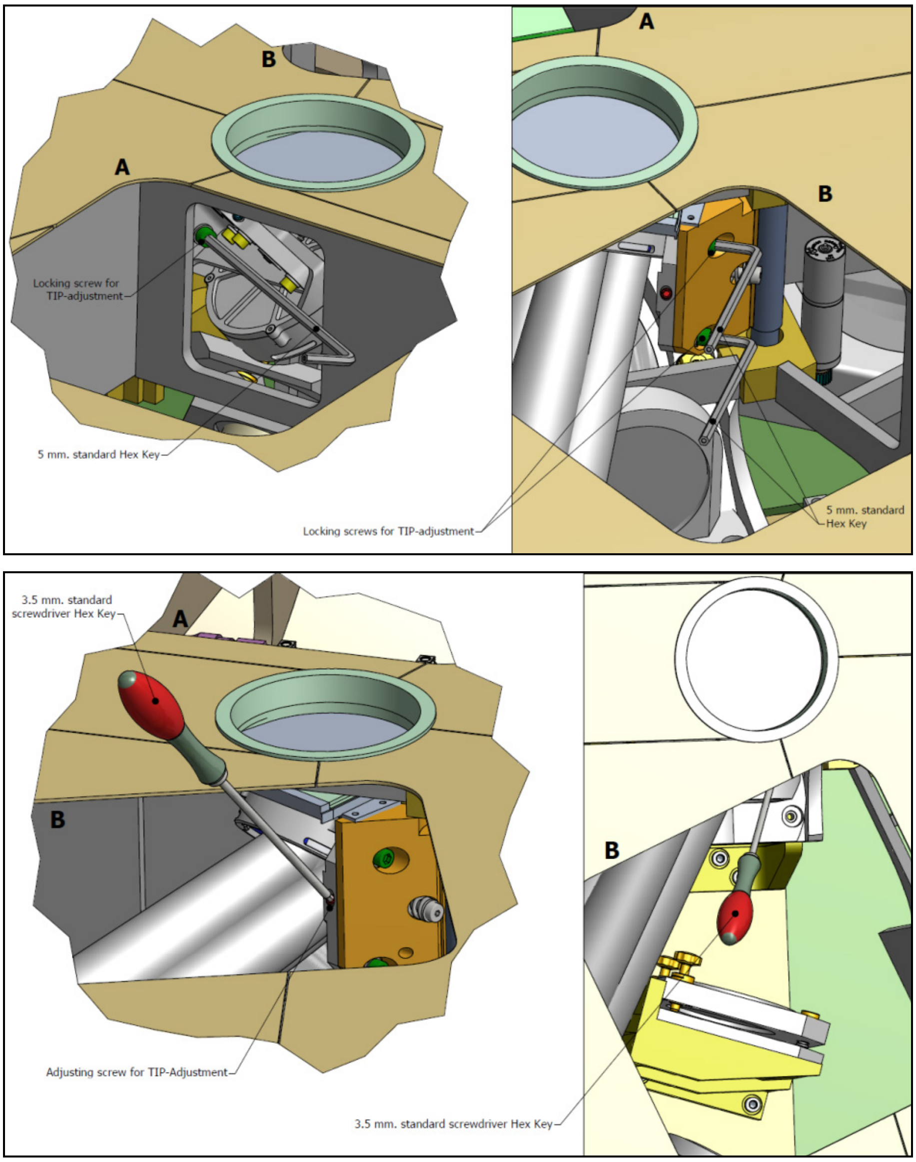


Figure 40: CUSM tip adjustment (operation details)

The operator comfort when performing CUSM adjustment has also been addressed. To this purpose, the access ways have been identified and the distances of operator to the areas of interest have been evaluated. Figure 41 (once again , referred to a worse situation) shows that operators can access comfortably from two sides currently free of devices (instruments, accessories or cabinets) and operate at a maximum distance of 72 cm from the respective holes. This is typically of the order of a human arm length.

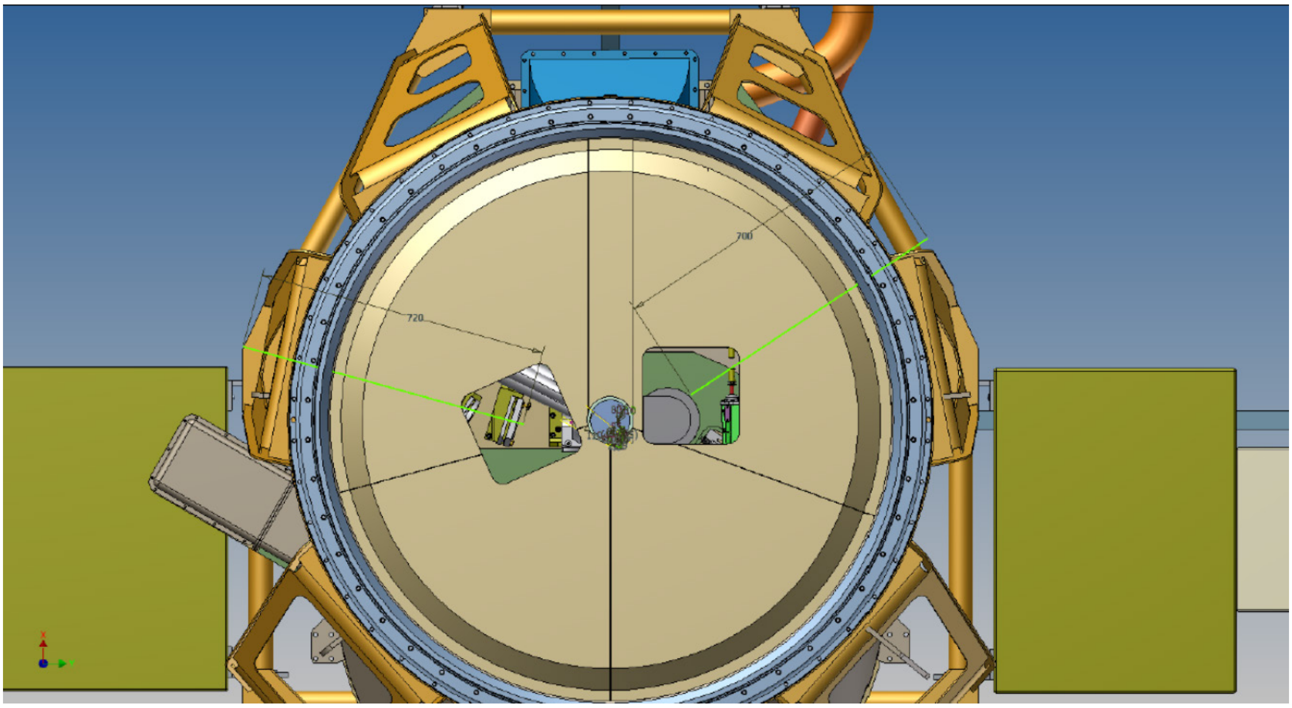


Figure 41: Operator access ways (green lines). The operator can operate at a maximum distance of 70 cm on the CU side, and at a max. distance of 72 cm on the opposite side.

In order to allow a full comfort and reduce risks of accidents, the ERIS supporting structure for the integration phase could be provided with a clamp (or similar) to allow the operator holding himself safely during the operation. The details of such a structure, however, are out of the scope of this document at the current project phase.

Appendix 1. Mechanical assembly drawings

This part is out of the scope of this document at the current project phase.

Appendix 2. Datasheets of selected components

This part is out of the scope of this document at the current project phase.

--- oOo ---