Preliminary design of a Calibration and Test Unit for MAORY

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INTRODUCTION

MAORY [1] is the multi-conjugate adaptive optics system of the **ELT**. It will be firstly used by MICADO, a near-infrared high-angular resolution imager, to compensate aberrations and provide high-Strehl images within a large (53''x53'') Field of View. The Calibration Unit [2] (CU), providing suitable light sources, will enable MAORY to run calibration templates, such as wavefront sensors (WFS), Non-Common-Path Aberrations and tomographic reconstructor calibrations, as well as verification and test procedures, in standalone mode, drastically reducing the amount of required night-time for such operations. The CU will be also used to ease the alignment of MAORY and to test and verify its performances after the assembly (AIV phase). The CU architecture, the optical and mechanical design and the main analyses performed are here presented.

ARCHITECTURE

Four typologies of light sources, different in position, size, amount and wavelength have to be provided, each one feeding a different WFS: **NGS-REF** (R-band), **NGS-LO** and **NGS-MIC** (H-band), **LGS** (589nm).
The CU is divided in 2 sub-systems: Electronics Cabinet (CUE) and Main Bench (CUMB).

The **CUE** (Fig.1) consists of a standard cabinet containing 7 sub-racks, needed to operate and control all the electronic devices. Among them, three electro-opto-mechanical modules host the physical light sources: QTH lamps for the REF, SLEDs for the LO and MIC, narrow-band laser diodes for LGSs. The light is injected into suitable optical fibers and the flux is adjusted by moving neutral density filters.

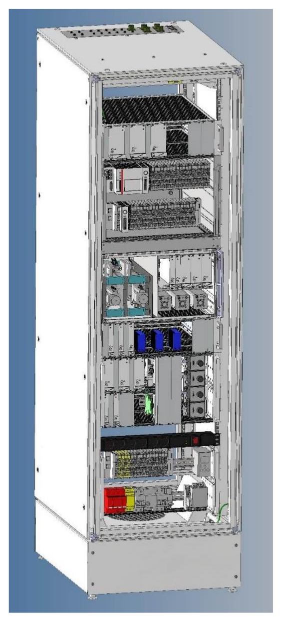


Fig. 1 – CUE.

The NGS and LGS **fibers** are stretched from the CUE up to the CUMB, positioned into the MAORY Main Structure (Fig.3), where they reach the Fiber Splitting Unit (FSU) and the LGS Mask (LGSM) respectively.
In the FSU a set of fiber splitters provide the final number of NGS fibers, plus some ready-to-use spares, to the NGS Mask (NGSM). Here, some REF and LO terminations are also coupled in custom dual-core fibers (Fig.2).

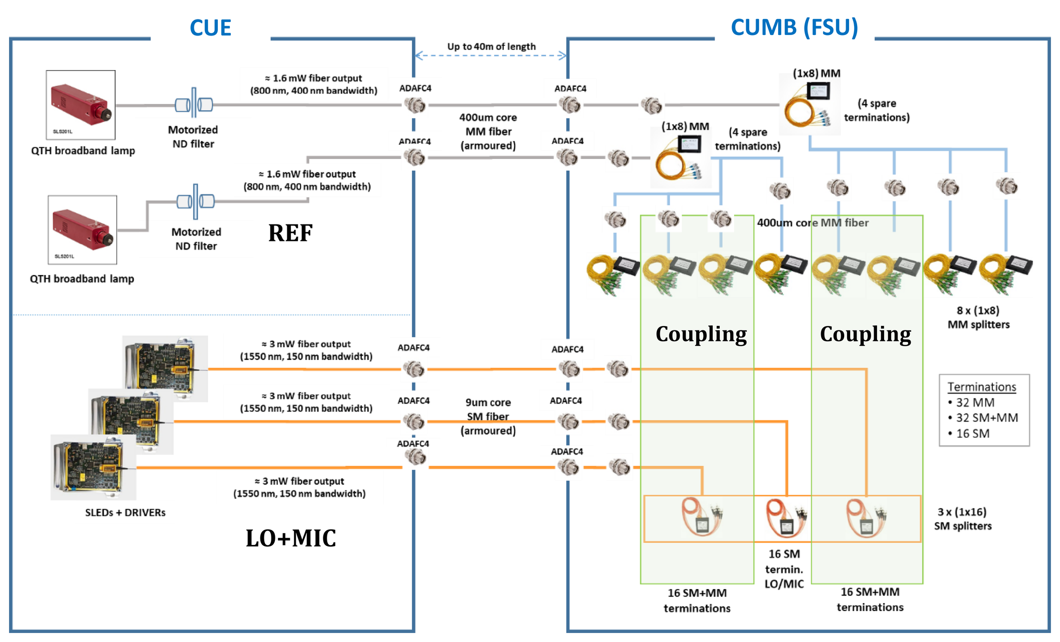


Fig. 2 – Scheme of the NGS transmission chain.

The LGS fibers reach directly the LGS mask (LGSM), where 3mm-pinholes are backlit through diffusers. The LGSM is moved by a linear stage, since two conjugation altitudes are required for the LGS sources (104km and 150km).
The light sources, coming out from NGSM and LGSM assemblies, after passing through the CU optical relay, are injected into the MAORY path through a Folding Mirror (CUFM) and focused on the MAORY/ELT focal plane.

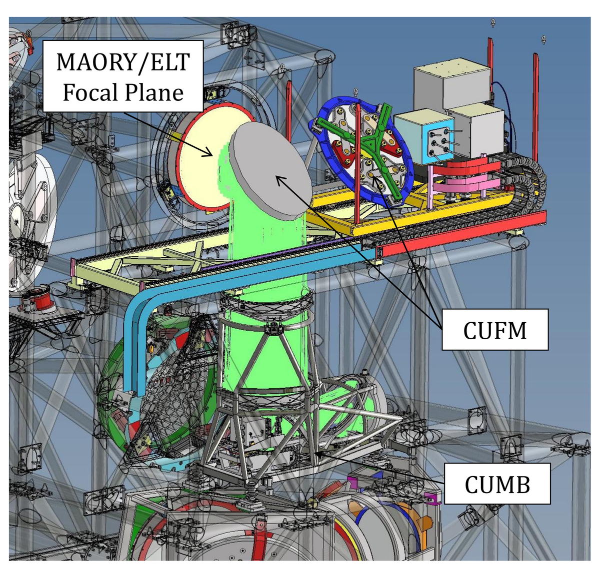


Fig. 3 – CUMB inside MAORY Main Structure.

OPTICAL DESIGN

The CU optical design (Fig.4) consists of a **catadioptric** system, chosen for its compactness and very good optical performances. The largest optics (W, SM ~600mm diam.) are semi-transmissive, as well as the flat Beam Splitters (BS1 and BS2). The pupil size and accessibility is driven by the necessity to install a commercial Deformable Mirror, so that it is possible to fully test and verify MAORY during the AIV. The baseline design foresees the presence of a bulky cubic beam splitter (CBS ~140mm side) to make the pupil accessible. A backup solution (Fig.6) has also been preliminarily developed, that does not require the CBS, but more complex lenses in the LGS path (aspherical biconics), to compensate for the astigmatism collected by the LGS beams through BS1.

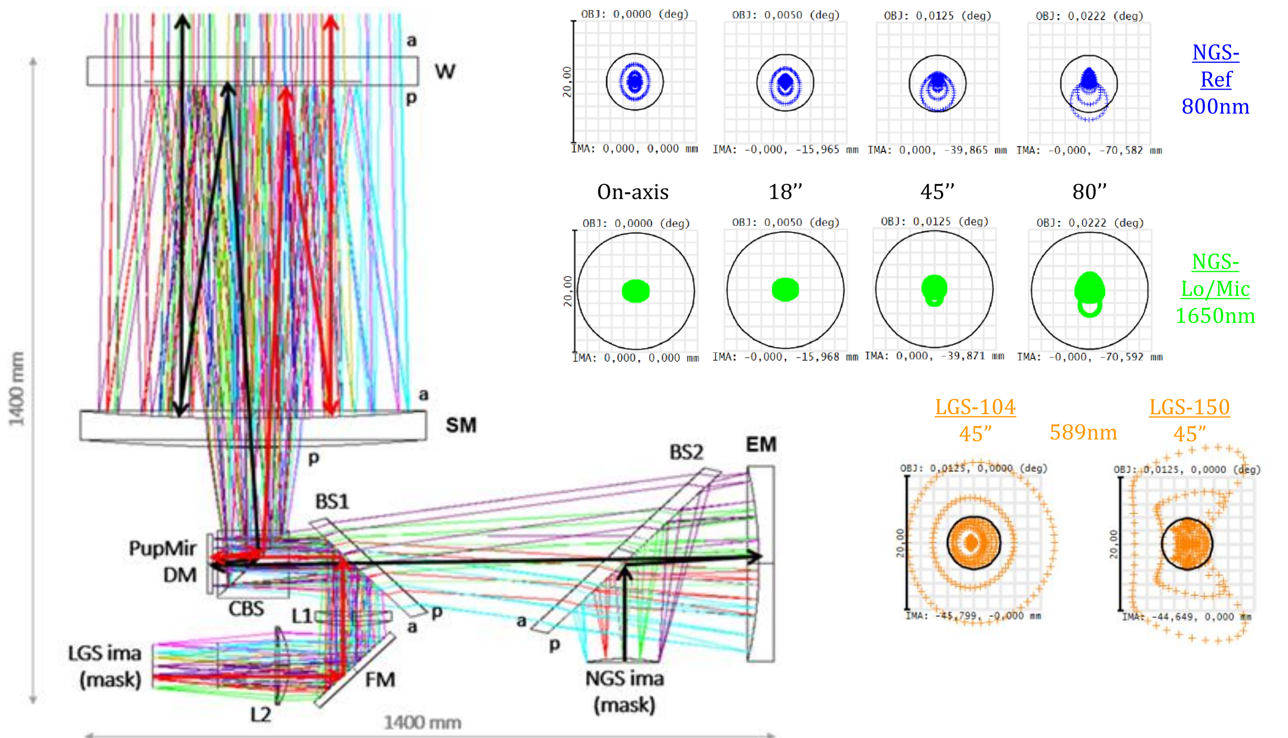


Fig. 4 – CU optical design and nominal spot diagrams. Pupil blur and distortion are ≤ 1% of pupil diameter.

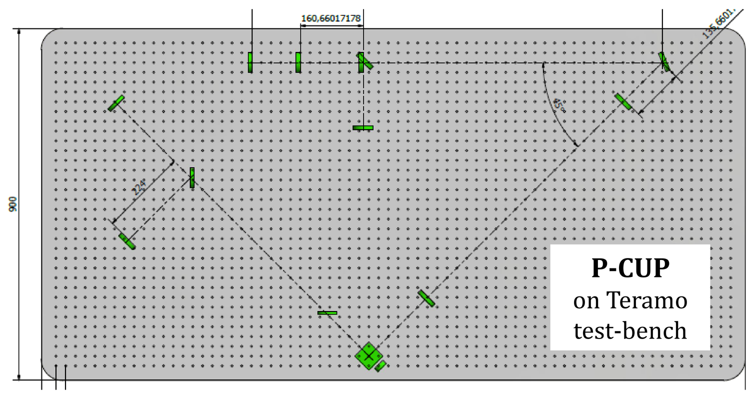


Fig. 5 – Prototype of paraxial-CU (P-CUP - 2-inch optics - NGS path only). Goal: gain familiarity with the alignment strategy.

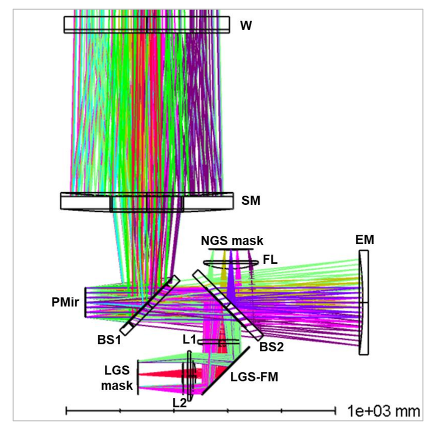


Fig. 6 – CU backup optical solution.

MECHANICAL DESIGN

The **CUMB** (Fig.7) is the main opto-mechanical module of the CU. The CUMB supporting structure, whose position is adjustable in all directions, is made of commercial steel welded tubular profiles, connected to the MAORY Main Structure through 3 Spherolinders© (ensuring the repeatability). The opto-mechanics have been organized in 4 blocks to ease the alignment process and maintenance and to provide all the needed DoFs: each block will be internally aligned before proceeding with the mutual alignment of the blocks, following a well-defined step-by-step procedure.

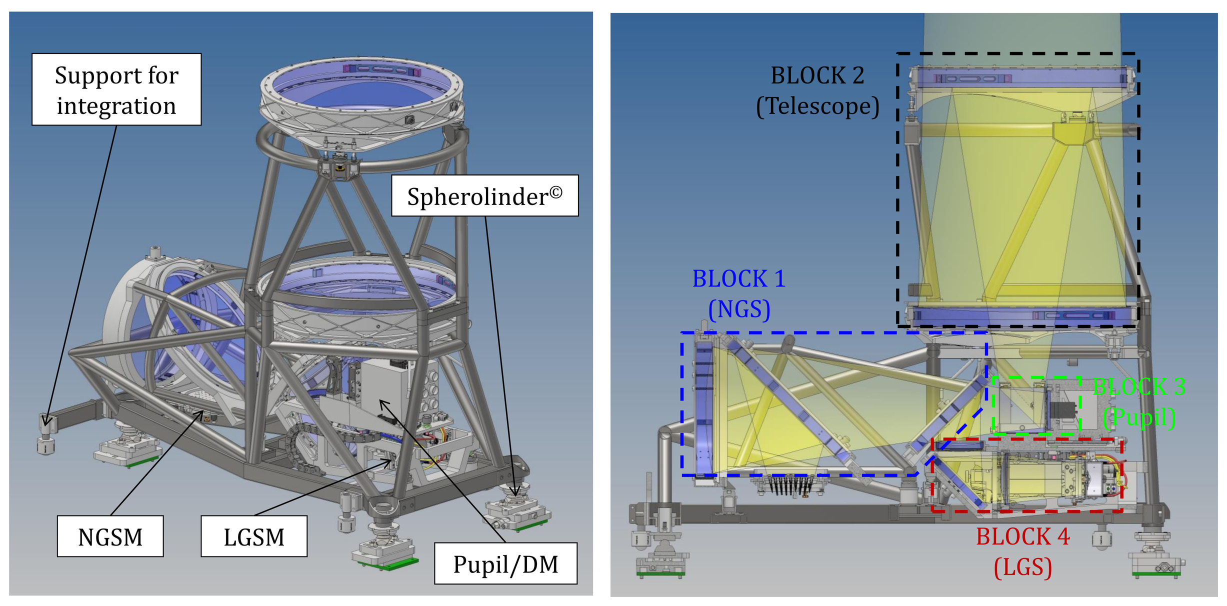


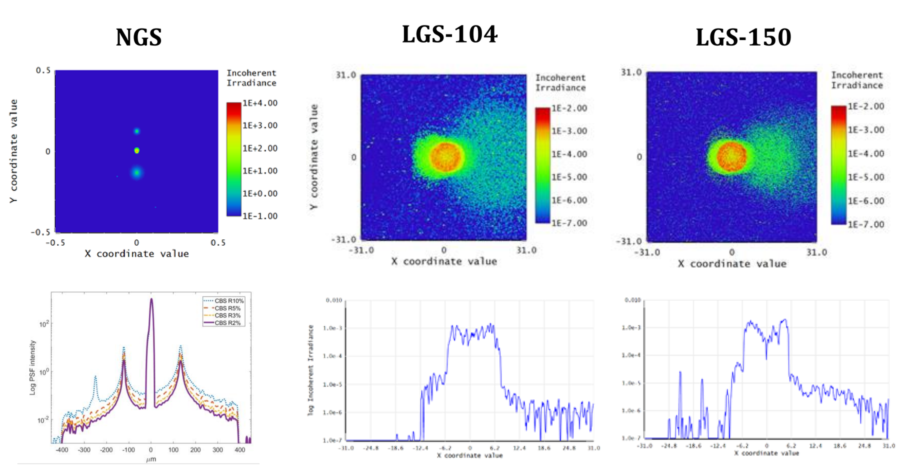
Fig. 7 – CUMB with its blocks (external cover, FSU, fibers and cables are not shown).

ANALYSES

Starting from the nominal optical design WFE and considering all the contributions coming from the various analyses (un-correlated), it has been possible to define the CU **WFE breakdown**, reported in the table beside. The contributions 1 and 2, retrieved from tolerance analyses, refer to a mean (statistic) condition.

#	Contribution		rms WFE (nm)		
			NGS-REF	LGS-104	LGS-150
0	Optical design		16	37	40
1	Alignment	Internal: single optics	13	11	12
		Internal: among blocks	15	14	15
		External: CU-MAORY	15	15	15
2	Optics manufact.	Geometry & Flatness	36	58	54
		Glass homogeneity	20	30	30
3	Opto-mech. induced aberration		10	15	15
4	Thermal stability		10	20	20
5	Contingency		10	10	10
	Total WFE		**54**	**83**	**82**
	CU WFE Budget		***60***	***100***	***100***

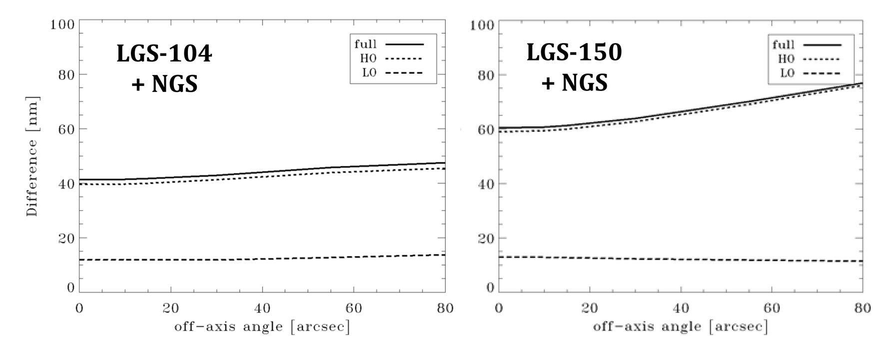
The **ghost analyses**, run with non-sequential models, show a PSF/ghosts ratio ~1%, proving that the ghosts are not harmful for the CU tasks and will not interfere with the alignment. (LGS sources are much larger than NGSs).



	NO scatter	Scatter A001
THROUGHPUT (%) @ CU focal plane		
NGS (on-axis)	0.193	0.152
NGS (off-axis)	0.175	0.140
LGS	0.614	0.486
WFSs calibration with CU sources – SNR @ WFS focal planes		
NGS-LO/MIC (1650nm)	76	67
NGS-REF (750nm)	23	26
LGS - 3mm pinhole (589nm)	8	7
CU AIV operations with CU test cameras – SNR @ CU focal plane		
NGS-LO/MIC (1600nm)	113	93
NGS-REF (800nm)	63	57
LGS - 3mm pinhole (589nm)	59	50

The **straylight analyses** showed a very low throughput (as expected) and this excluded the use of end-to-end interferometry for the alignment. Nevertheless, the derived signal-to-noise ratios (SNR) are fully compliant with the CU tasks: WFS calibrations, CU AIV, MAORY AIV.

The **propagation of a real set of CU aberrations** (mean statistic condition) into the MAORY AO loop (closed loop with no turbulence) has been preliminarily simulated.
The residual error (ELT-CU differential) seen by the REF-WFS, presents a rather flat trend across the FoV and is significantly lower than 100 nm.



CONCLUSION

The CU design is ready to start to the Final Design phase. A preliminary error budget breakdown has been derived from the analyses, confirming that the requirements of WFE are fulfilled. The level of detail of the mechanical design is advanced, although some opto-mechanics key features are going to be improved with the support of the manufacturers. FEAs have been carried out in parallel with the development of the mechanical design. The optics prescription have been defined and ROM pricings from manufacturers have been collected. The alignment strategy has been defined. The whole transmission chain has been analyzed to assess the final throughput.

References

[1] Ciliegi, P., et al. "MAORY: the adaptive optics module for the Extremely Large Telescope (ELT)", Proc. SPIE, 11448-33, 2020
[2] Di Antonio I., et al. "MAORY calibration unit design status", Proc. SPIE, 11448-30, 2020