Preliminary design of the MAORY Calibration and Test Unit

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ABSTRACT

MAORY is the multi-conjugate adaptive optics (MCAO) relay of the ELT telescope, that will be firstly used by MICADO, a near-infrared high-angular resolution imager, to compensate aberrations and provide high-Strehl images within a (53"x53") Field of View (FoV). The complexity of MAORY requires calibration functionalities for both the AIV (Assembly-Integration-Verification) and the operational phase. The function of the Calibration and Test Unit (CTU) is keeping the high efficiency of the adaptive correction provided by MAORY during the operational phase, through proper calibration sources, acting as both Natural Guide Stars (NGS) and Laser Guide Stars (LGS) sources. A recent review of the MAORY optical design has involved a deep change in both the concept and the position of the CTU, with respect to the original concept: an overview of the old design, the status of the new design and the main challenges to face in the future are presented in this paper.

Keywords: Adaptive Optics, MCAO, MAORY, Calibration Unit.

1. INTRODUCTION

MAORY (Multi-conjugate Adaptive Optics RelaY) is a post-focal adaptive optics module for the Extremely Large Telescope (ELT), based on Multi-Conjugate Adaptive Optics (MCAO), designed to enable high-angular resolution observations in the near infrared by real-time compensation of the wavefront distortions due to atmospheric turbulence and other disturbances, so that very precise measurements of the positions, brightness, and motions of stars are possible [1].

It shall support MICADO (Multi-AO Imaging Camera for Deep Observations) by offering two correction modes: Multi-Conjugate AO (MCAO) and Single-Conjugate AO (SCAO).

The MCAO mode of MAORY achieves spatially uniform adaptive optics compensation over the science FoV with high sky coverage. Wavefront sensing is performed by up to eight artificial LGS and up to three NGS, respectively for the measurement of high and low-order wavefront perturbations. Wavefront compensation is performed by two adaptive Deformable Mirrors (DMs) in MAORY (M9 and M10 in Fig.1), which work together with the telescope's adaptive and tip-tilt mirrors respectively.

The SCAO mode achieves best performance on a limited FoV, when a sufficiently bright reference object is available nearby the scientific target: wavefront distortions are compensated by the telescope adaptive mirrors, while the MAORY adaptive mirrors are kept fixed at their reference shape.

From the opto-mechanical point of view, MAORY consists of an optical relay, which re-images the telescope focal plane for the science instruments. The relay is supported by an optical bench, which is mounted on the telescope Nasmyth platform in a gravity invariant configuration. In the current Modified Offner Configuration (MOC), the relay is composed by eight mirrors (two of which are DMs) and a dichroic beam-splitter, which separates the NGS- and science-light from the LGS-light (see Fig.1).

The eight LGSs are produced by sodium-line (589 nm) lasers launched from the edge of the telescope aperture, imaged on the sky at a distance up to 45 arcsec from the centre of the MICADO FoV. The LGS wavefront sensor consists of eight, 80x80 sub-apertures Shack-Hartmann sensors.

In addition to them, the light from up to three NGSs over a 180 arcsec FoV feeds three NGS wavefront sensor probes. Each probe consists of a Low-Order channel, including a 2×2 Shack-Hartmann sensor working in the range 1.5-1.8 μm at adaptive optics speed, and a Reference channel, including a 10×10 Shack-Hartmann sensor working in the range 0.6-1.0 μm at slow speed. MAORY is required to deliver a Strehl Ratio (SR) of 0.3 (goal 0.5) at 2.2 μm wavelength over a 1 arcmin FoV with 50% sky coverage.

The complexity of MAORY requires calibration functionalities for both the AIV (Assembly-Integration-Verification) and the Operation phase. The Calibration and Test Unit (CTU) will provide proper calibration sources in order to keep the high efficiency of the adaptive correction provided by MAORY. Conceptually, the CTU is composed by a series of modules:

- A Sources Masks Unit (SMU), equipped with both NGS sources and movable LGS sources;
- A Focusing Optical System module (FOS), whose function is to focus the sources with the correct f-number;
- A Light Sources Unit (LSU), which hosts the physical light sources;
- A Source Selector Unit (SSU), which allows to select the sources and to set their brightness.

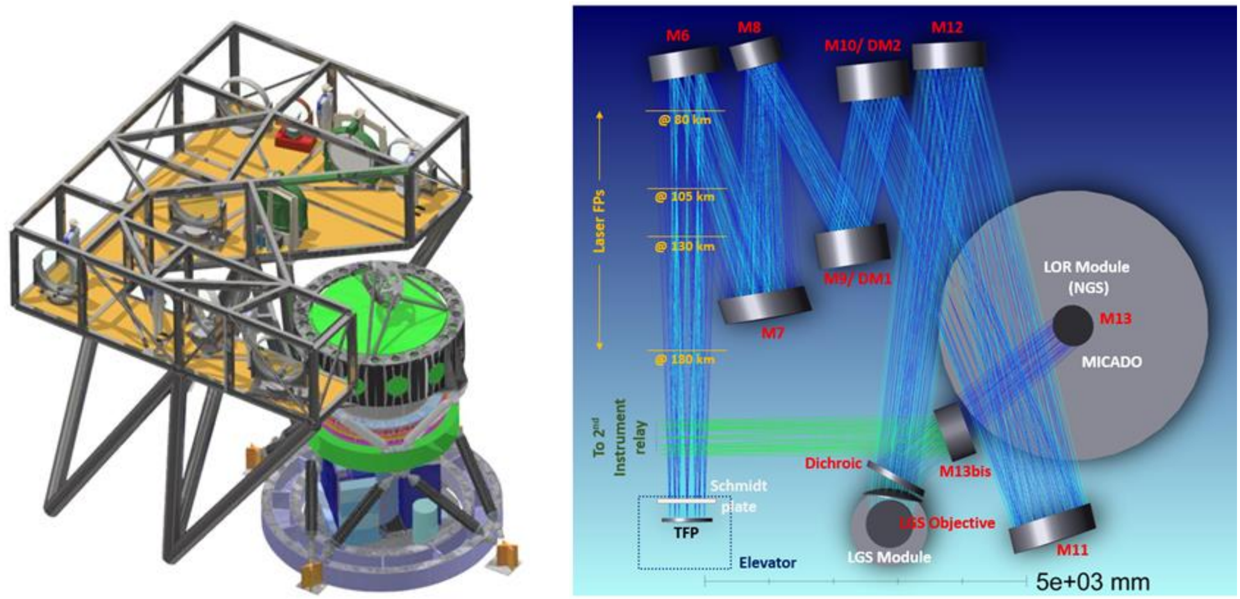

Figure 1. On the left: a sketch of MAORY post-focal relay optics (PFRO) bench and MICADO Tower, hosting also the LOR WFS module. On the right: the new MAORY PFRO design (MOC).

2. OVERVIEW OF CALIBRATION FUNCTIONS

An AO system requires a set of proper calibrations which concern for example:

- Interaction Matrix (IM) between actuators input and wavefront sensors output;
- Pupil tracking and misregistration, including pupil derotation;
- Tomography reconstructor model (specifically for MCAO);
- Non-common-path aberrations (NCPA), both static and non-static.

In addition, a set of periodical checks are needed, as for example:

- WFS cameras parameters (linearity, flatness…);
- Sub-systems and whole system health.

The CTU design must fulfill requirements specified in the Calibration Plan, which involve the use of a specific hardware. In MAORY, the CTU is fundamentally asked to provide:

- A grid of several NGS sources, diffraction-limited (DL) in H-band;
- Several LGS sources @589 nm, distributed on specific asterisms, conjugated on different LFPs.

Although one of the Calibration Plan's purposes is to minimize number and complexity of the calibration tasks, the requirements make the CTU design quite challenging, due to the very high SR of DL sources, the great accuracy of sources position, the pupil definition, the field curvature, the high and adjustable brightness of sources, and so on.

3. PFRO CHANGE: FROM THE OLD TO THE NEW CTU DESIGN

The original CTU design (Fig.2) was based on the PFRO Aspheric Mirrors Configuration (AMC).

In this optical configuration, the CTU was composed of a first module (CU#1), equipped with NGS sources and placed onto the Telescope Focal Plane (TFP), a second module (CU#2), equipped with LGS sources and movable between two Laser Focal Planes (LFPs), the sources being produced by optical fibre tips. Two additional sub-modules, the Light Sources Unit (LSU) and the Sources Selector Unit (SSU), for the physical production of the light and the fibres selection, both located inside the Electronics Cabinet. The blue dotted rectangle in Fig.3 shows the volumes occupied by the two sub-units.

The annular shape of the CU#2 mask allowed to image simultaneously both NGS on CU#1 mask (the most internal and external asterisms) and LGS sources. Mounted on a long-travel, high-accuracy linear stage, CU#2 source mask was able to cover the range between the LFPs conjugated with the altitudes of 180 km and 240 km, without vignetting the NGS footprints. Such a limited range for the LFPs was needed to avoid vignetting of the post-focal optical beam. Both masks were properly designed and all sources properly positioned on them and equipped with proper optical systems, in order to reproduce on FPs the correct curvature radii, chief-ray angles and *f*-numbers. CU#1 and CU#2 were mounted on two different elevators to include/exclude the sub-systems at will.

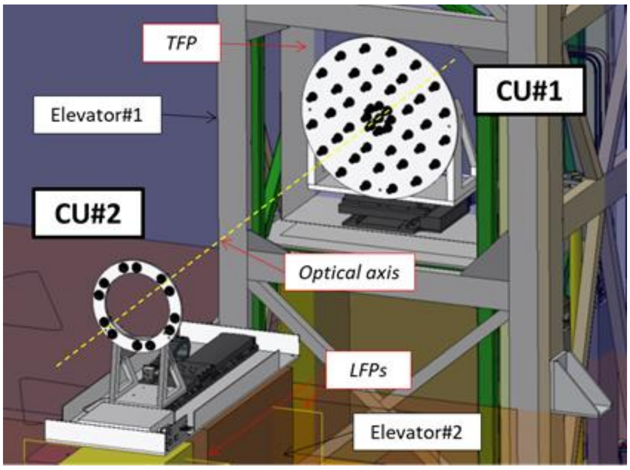

Figure 2. Mechanical design of the old CTU, composed by two modules located along the optical axis, in correspondence with the Telescope Focal Plane (CU#1) and the Laser Focal Planes (CU#2).

The change of baseline for the MAORY PFRO, from AMC to MOC, has led to a change of both position and concept of the CTU: in particular, the new PFRO includes a Schmidt plate near the Telescope Focal plane (see Fig.3), which is therefore no longer accessible for the CTU NGS sources.

Figure 3. Comparison between old and new MAORY PFRO design: the impact on CTU position and volume.

The new solution for the CTU forsakes the concept of the sources physically positioned on focal planes, in favor of a unique sources module, placed next to the Elevator#1 and the TFP, in the space left by the shift of M7 and M9 in the MOC (green dotted volume in Fig. 3), plus an optics module, placed in the same volume, between the sources and the telescope focal plane. This solution obviously requires to place a folding mirror (45°) inside the elevator, to inject the light into MAORY optical path.

4. CTU CURRENT DESIGN

4.1 CTU Architecture

A number of physical sources, fibre terminated white light sources for NGS, and 589 nm (Sodium) Solid State laser sources for LGS, are part of the Light Source Unit (LSU), located into the Electronics cabinet, placed about 6 meters below the MAORY bench. The Source Selector Unit (SSU) is also located into the Electronics Cabinet, near the LSU: it receives the input light from LSU, adjusts its flux and selects the proper output line, through linear stages. Six fibres connect the SSU to the SMU, where customized fibre splitters provide a proper splitting in order to have the correct number of fibres to feed each source on the two masks with the required flux range.
The CTU architecture is shown in Fig.4.

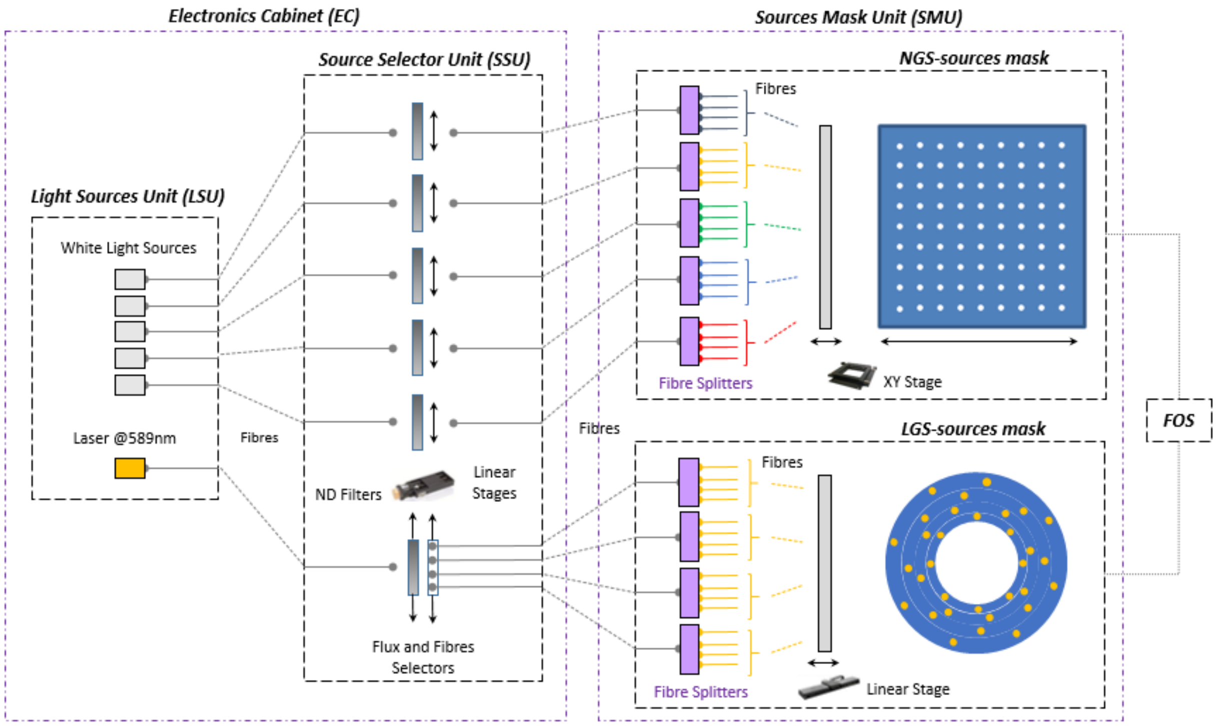

Figure 4. MAORY CTU Architecture. Light sources are generated into the LSU; the SSU selects output lines and sets light fluxes; fibres carry the light up to the SMU, where all the sources on the masks are fed via fibre splitters; the light coming out from the masks reaches the FOS, that focuses it on the proper focal plane with the proper *f*-number.

4.2 CTU sources module

The CTU shall provide:

- a grid of 9x9 NGS sources uniformly distributed within the NGS WFSs technical FoV (60”), sufficiently bright to cover the range 5-22 mag, DL in H-band,

- four asterisms, each including 8 LGS extended sources at 589 nm wavelength, on LFPs conjugated with the following altitudes: 160 km, 120 km, 104 km, 80 km

while meeting the mechanical constraints (e.g. fitting into the assigned volume).

Two possible solutions are under study (see Fig.5):

1) a unique source unit with both source masks aligned (LGS movable). The LGS mask must have an annular shape to avoid NGS sources vignetting, even if it cannot be completely avoided;
2) two separated sources subunits (NGS and LGS sources respectively). It is less demanding in terms of axial size and all the sources can be imaged together without vignetting. However, the insertion of a beam combiner in the CTU optical path is required, with all the typical drawbacks of such an optical device (e.g. alignment).

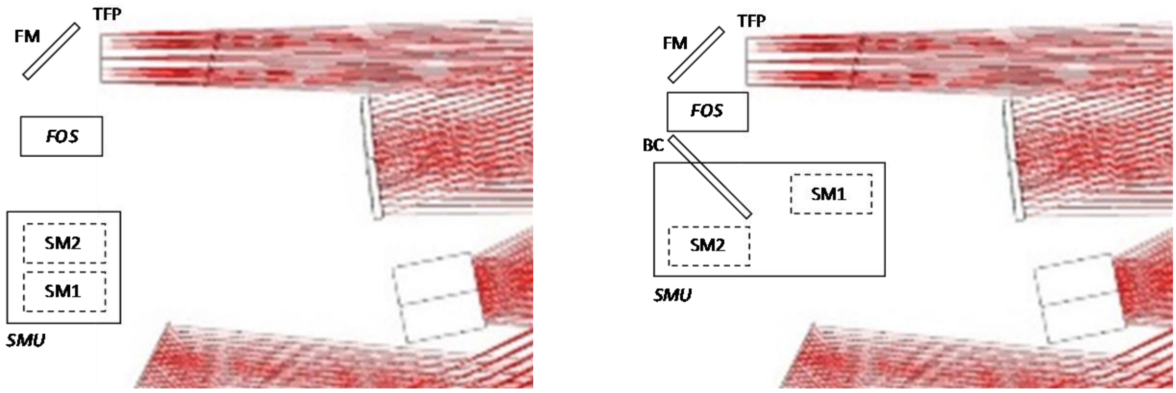

Figure 5. Comparison of the two possible configurations for the SMU: a unique source unit with both source masks aligned (on the left), two separated and not aligned sources units (on the right). Source mask 1 (SM1) is equipped with NGS light sources, Source mask 2 (SM2) with LGS light sources, BC is the beam combiner (necessary for the configuration on the right), FM is the 45° folding mirror (necessary for both configurations).

4.3 CTU optics module

An accurate optical system is required to ensure that the light sources from CTU have the same features of the light coming from the telescope. This is a list of the main optical constraints this system shall respect, besides the requirements listed in Section 4.2:

- Optical beams from CTU shall match ELT *f*-numbers (from 17.75 for objects @infinity to 20.98 for objects @80km);
- Light sources from CTU shall focus on focal planes matching ELT curvature radii (from -9884 mm for objects @infinity to -9170 mm for objects @80km);
- NGS light sources from CTU shall be DL on the TFP;
- LGS light sources from CTU shall be extended (3”) on the LFPs;
- The CTU optical system shall form an exit pupil located on the telescope entrance pupil.

The current solution is based on a single lens (LENS1), acting as pupil stop, plus a doublet (LENS2).

The whole system is shown in Fig.6. A zoom of the object space is shown in Fig.7. Spot diagrams for NGS sources are shown in Fig.8.

Figure 6. Zemax model of the Focusing Optical System (FOS).

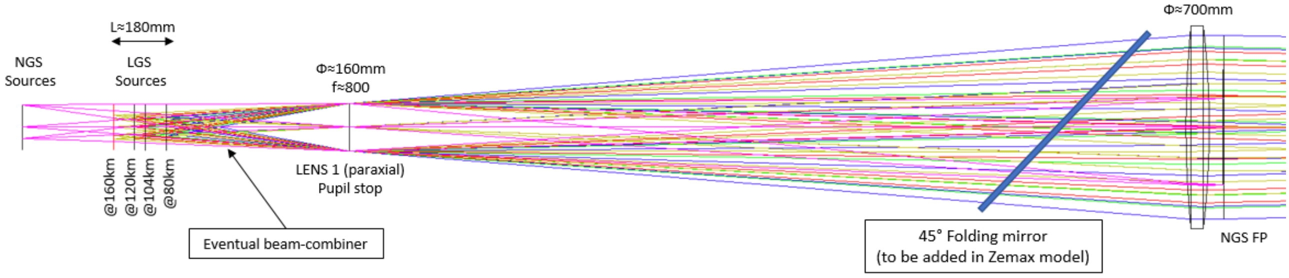

Figure 7. Zemax model of the Focusing Optical System (FOS): zoom of the object space.

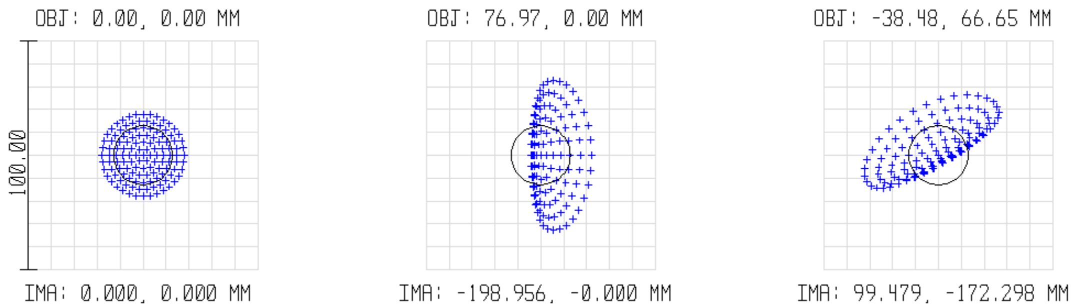

Figure 8. Zemax model of the Focusing Optical System (FOS): spot diagrams for NGS sources (λ=0.6um).

This initial model is still to be substantially improved (e.g. by turning LENS1 from paraxial to real, by adding the dichroic beam combiner, by adding the folding mirror) and optimized, first of all for chromatism over the wide spectral range expected. For this reasons an alternative, achromatic solution, based on mirrors only (e.g. in a configuration of "inverse Cassegrain") is also under study.

5. CTU ELECTRONICS CABINET

The Electronics Cabinet hosts all the Power, Electronics and Control devices, plus the Light Sources Unit (LSU) and the Source Selector Unit (SSU). In order to understand needed volumes and possible racks distribution, a CAD model of the Electronics cabinet has been developed; it is shown in Fig.9.

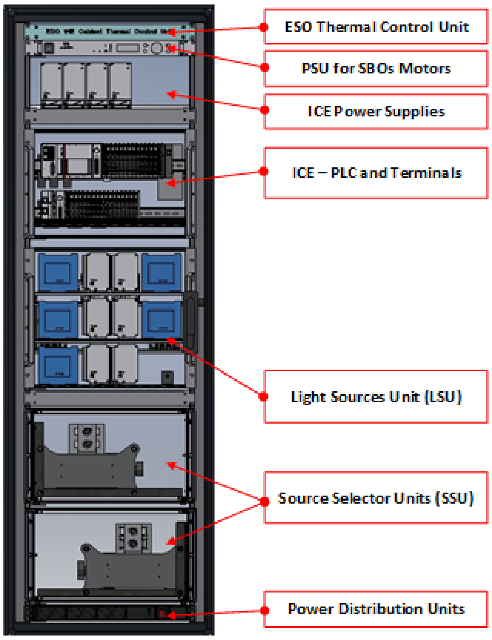

Figure 9. CAD design of CTU Electronics Cabinet.

6. NEXT STEPS

Prototyping and test activities for all the transmission chain (physical sources, fibre splitters, fibres) are planned within both the Preliminary and Critical Design phase. Another crucial activity will consist in designing the test apparatus for the future CTU AIV phase.

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[1] Ciliegi, P. et al., "MAORY for ELT: preliminary design overview", Proc. SPIE 10703 (2018).