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Optical design of the Post Focal Relay of MAORY

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ABSTRACT

The Multi Conjugate Adaptive Optics RelaY (MAORY) for the European Extremely Large Telescope is planned to be located on the straight-through port of the telescope Nasmyth platform and shall re-image the telescope focal plane to a wide field camera (MICADO) and a possible future second instrument. By means of natural and artificial (laser) reference sources for wavefront sensing, and of deformable mirrors for wavefront correction, MAORY shall be able to compensate the wavefront disturbances affecting the scientific observations, achieving high Strehl ratio and high sky coverage. A trade-off study among different design options has been carried out addressing optical performance at the exit ports (wave front error, field distortion, throughput), structure stability, interface constraints (mass, size, location and accessibility of the two client instruments), and the overall adaptive optics performance. We discuss the baseline configuration of the opto-mechanical design.

Keywords: optical design, Adaptive Optics, Laser Guide Stars, European Extremely Large Telescope

1. INTRODUCTION

The Multi Conjugate Adaptive Optics RelaY (MAORY) [1] is foreseen to be installed at the straight through focus over the Nasmyth platform of the future European Extremely Large Telescope (E-ELT) [2]. MAORY has to re-image the telescope focal plane with diffraction limited quality and low geometric distortion, over a field of view (FoV) of 180" diameter, for a wavelength range between 0.8 m and 2.4 m. Good and uniform Strehl ratio, accomplished with high sky coverage, is required for the wide field correction while high Strehl for the Single Conjugate Adaptive Optics (SCAO) shall be delivered. Two exit ports will be fed. The first one is for MICADO [3] that is supposed to be placed on a gravity invariant port at 1800m below the optical axis. An unvignetted FoV of 53’’x 53’’ with diffraction limited optical quality (< 54nm RMS of wavefront error at the wavelength of 1 μm) and very low field distortion (< 0.1% RMS) must be delivered. The full 180’’ FoV can be transmitted, by means of a deployable folding mirror after the last powered mirror, to the second exit port to feed an instrument to be defined yet. The optical interface at the exit ports, as the focal ratio, the exit pupil position and focal plane curvature have been agreed with MICADO team.

To achieve the above performances, the Phase A study [4] resulted in a series of requirements concerning Adaptive Optics (AO) system within MAORY. The Post Focal Relay (PFR) optical design shall create along the optical path two clear planes where to put two deformable mirrors (DMs) for the wavefront correction, to be carried out together with the telescope adaptive and field stabilization mirrors (namely M4 and M5); the post focal DM optical conjugates are planned to be at 4km and 12.7km altitude. The requirements regarding the optical quality, distortion and optical interfaces, together with the will of reducing the number of reflecting surfaces and consequently the thermal background, optics

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wavefront error (WFE), overall size, weight and possibly cost, drove the design to have DMs with optical power. The assumed DMs diameter is about 800mm, corresponding correspond to a minimum of 28 actuators along the diameter and 2m of projected pitch at the conjugated atmospheric layers, in case of voice-coil motor DMs [5].

The PFR is also required to split the 589 nm wavelength light of the Laser Guide Stars (LGS), used for high order wavefront sensing, from longer wavelength light used for science observation and for low order wavefront sensing by the use of Natural Guide Stars (NGS). The dichroic lets the light of 6 LGSs, arranged on a circle of about 120” diameter, pass through and reflects science beam and NGS light. Behind the dichroic an objective creates the LGS image plane for the WFSs channel.

MAORY phase B started in February 2016 and the design shown in this paper is the baseline that is being consolidated and further optimized at the time of writing. The consolidation of the adaptive optics system requirements and the results of the End-to-End (E2E) simulations regarding the system performance [6] are expected to not upset the design shown here.

2. OPTICAL DESIGN

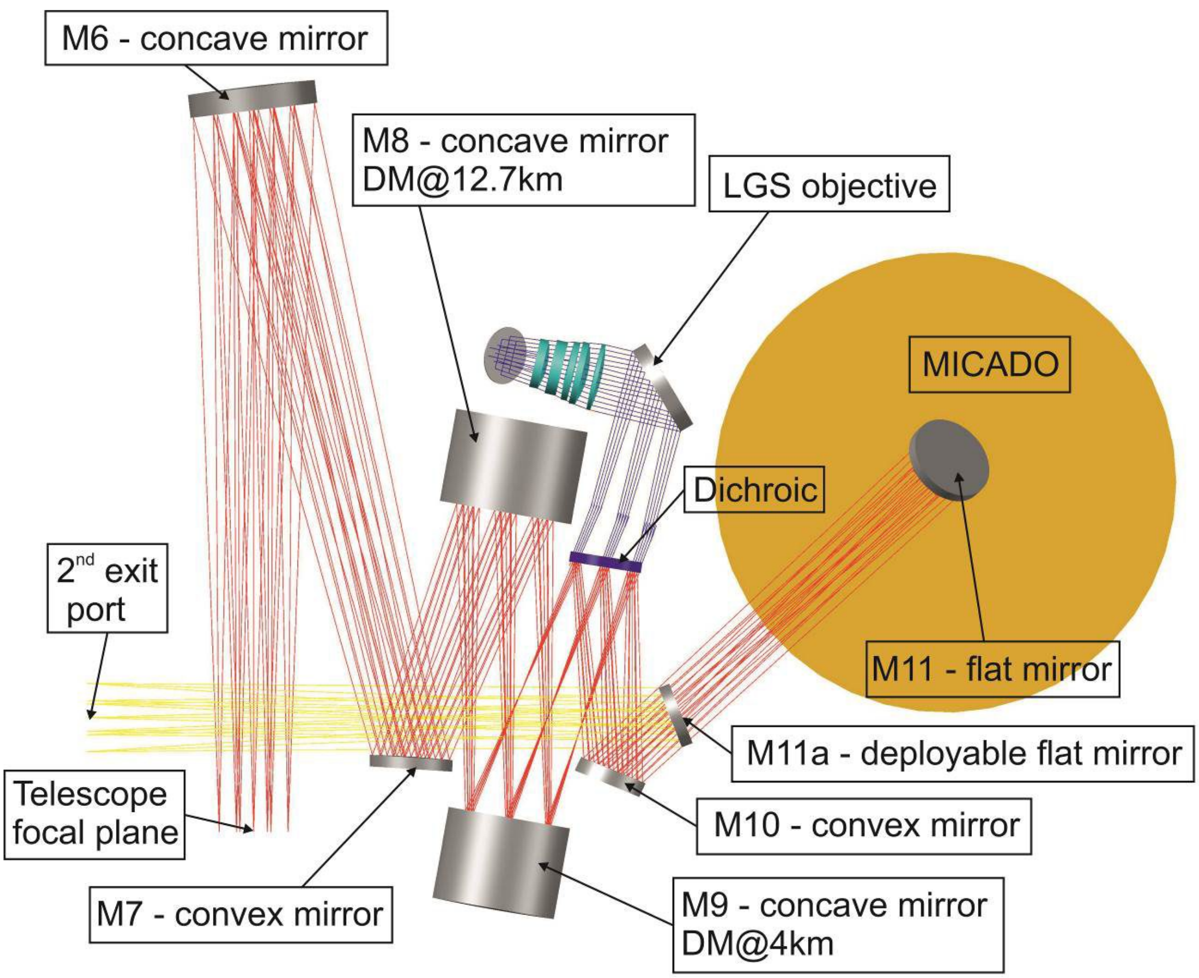

Figure 1. MAORY optical layout. Red rays: science path from telescope focal plane to MICADO. Yellow rays: science path to second instrument port. The M11 flat mirror to create the second port is deployable. It is clear from the optical layout that the MAORY and MICADO calibration units, which will be placed at the MAORY entrance focal plane, shall be designed in such a way to avoid vignetting the second instrument port.

The light path through the main optics of the PFR is shown in Figure 1. After telescope focal plane, the mirrors M6 and M7, both having optical power, create a pupil image where the LGS/NGS dichroic beam-splitter is positioned. Before the dichroic the two DMs, (M8 and M9), are placed at the layer conjugation ranges of 12.7km and 4km respectively. After the dichroic one mirror with optical power (M10) reproduces the exit focal plane. The M11 flat mirror folds light downward to create a gravity invariant port for MICADO and another flat mirror (M11a) can be inserted to create the second exit port.

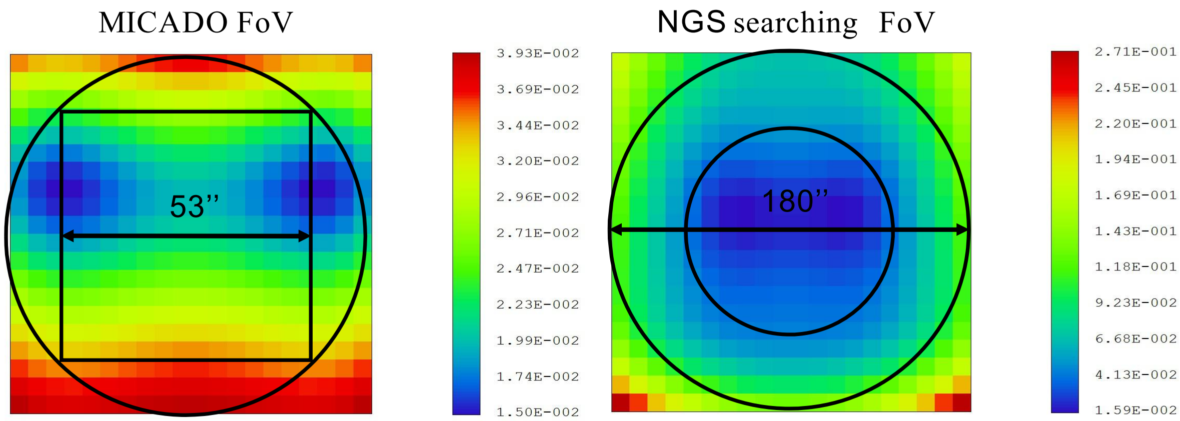

Figure 2. Wavefront error (in µm) at the exit ports of MAORY. Left: WFE of the MICADO field of view; right: WFE of the natural guide stars searching field of view.

Table 1: PFR optics main parameters.

Surface	**Diameter (mm)**	**Curvature**	**shape**
M6	1100	Concave	Off-axis hyperboloid
M7	700	Convex	Off-axis hyperboloid
M8 (DM1)	850	Concave	On-axis hyperboloid
M9 (DM2)	750	Concave	On-axis hyperboloid
Dichroic	600	Flat	
M10	600	Convex	Off-axis hyperboloid
M11	800	Flat	

In the current design the DMs are concave and they have the same curvature radius and conic constant. The beam splitter dichroic is placed after the DMs in order to let the LGS WFSs operate in close loop regime. The last powered mirror (M10) after the dichroic must be concave in order to maintain the focal aperture at the exit port very similar to the telescope one (≈F17.71) and deliver a curvature radius equal or longer than the value (9900mm) at the telescope focal plane (≈9900mm). These parameters values has been required by the client instrument. As a consequence of having a convex M10 the exit pupil distance is no longer than distance between the pupil image and the focal plane (≈8m respect to the ≈37m at the telescope focal plane).

The astrometric observations are one of the main scientific requirements of MICADO [7]. Relative field distortion residual shall be < 50 µas (goal <10 µas) in a 20'' FoV (goal 53'' x 53'' FoV) after 3rd order transformation, comprehending all error sources. The different off-axis optics of the PFR do not permit to deliver a null distortion pattern as possible for example by means of a couple of identical Offner relays ([8]) since it would require more optics than the current design choice, and would produce a very short curvature radius at the exit port, which is not acceptable by the

client instrument. An intense work in the design optimization phase as well as calibration strategy is being carried on to fulfil the requirement.
The main properties and interfaces of the MAORY optical relay described in this paper are summarized in Table 2

Table 2: Optical design properties.

Parameter	**Value**
Number of optical elements	6 mirror (of which 2 DMs) 1 dichroic beam-splitter
F/#	17.7
Exit pupil distance	8100 mm (before focus)
Field curvature	Less than telescope
Technical FoV	3 arcmin diameter
Exit focal plane position	1800 mm below entrance optical axis
Exit focal plane position with respect to MICADO	200 mm inside cryostat
RMS wavefront error over MICADO FoV	Average 32 nm Best 19 nm Worst 41 nm
Geometric distortion in MICADO FoV	< 8 μm *
* Definition of geometric distortion requirement: T = Maximum integration time for narrow band astrometric observations ≈ 60 s A = Maximum derotator angular velocity ≈ 5.3 x 15 arcsec/s T x A ≈ 1.35° During this rotation the FWHM of the long-exposure PSF due to the MAORY optics should not increase by more than 1/10 of its nominal value. For wavelength λ = 1.25 μm, the amount of distortion shall be < 8 μm at the MAORY exit focal plane on the MICADO FoV (assuming F/17.7 focal ratio).	

2.1 LGS Objective

The LGS objective (Figure 1) has the goal of delivering an image plane to the LGFS WFS for an LGS distance from 80km to 180 km. Moreover it has also to focus "infinite distant" LGS, when calibration sources at MAORY entrance focal plane are placed. Given the output focal ratio of 5, the LGS WFS image plane must be shifted of ≈ 500mm. The design is still in a preliminary phase and the direction of the gravity invariant WFS, if upward or downward, is still to be decided.

3. MECHANICAL DESIGN

The mechanical design of the MAORY support structure is based on a hexapod solution. Other approaches have been analyzed, but with lower performance. This approach gives to better results in terms of stability and vibrations. Two possible mechanical designs are currently under investigation, the MICADO stand-alone configuration and the MICADO fall-back configuration (where MICADO is attached to the MAORY bench). In the stand-alone configuration (Figure 4), the MAORY NGS WFS Module has to be mounted onto the MICADO cryostat, in order to measure the same tip-tilt disturbances experienced by MICADO itself. Two important remarks have to be taken into account concerning the stand-alone configuration:

- a requirement has to be set on the maximum misalignment/oscillations due to the mechanical de-coupling of the two instruments (MAORY and MICADO) which have to be measured and compensated by the MAORY adaptive optics system; the misalignment/oscillations has to be within the capture range of adaptive optics in terms of amplitude and frequencies;

- a fully functional "dummy" support structure with derotator, emulating the final MICADO support structure, is needed to support the NGS WFS Module during MAORY AIV.

The fall-back configuration with coupled instruments (phase A baseline) might improve the relative stability of the two instruments. The tight requirements applicable to MAORY and MICADO, related in particular to astrometry, are probably not achievable by mechanical precision only: active and adaptive compensations of dynamic alignment errors are needed anyway. However, the fall-back configuration scheme might be helpful to reduce these alignment errors in terms of amplitude and temporal bandwidth.

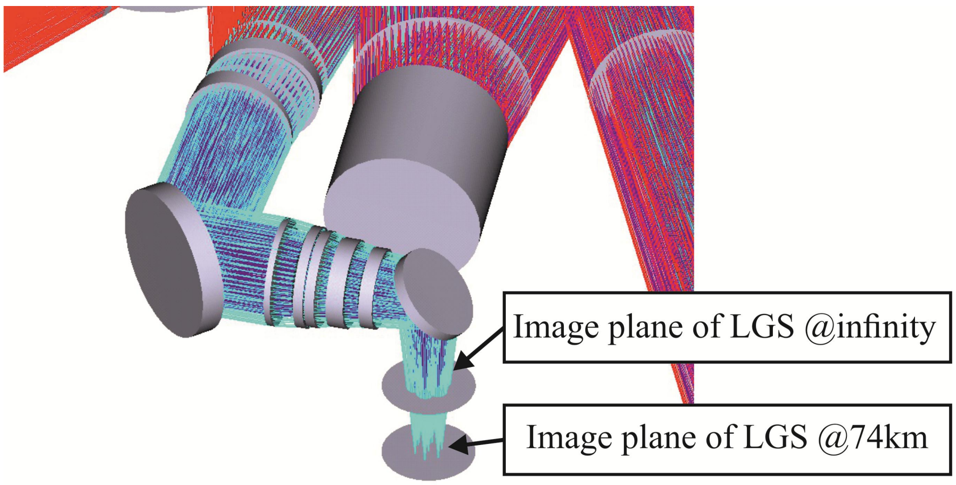

Figure 3: LGS Objective optical design

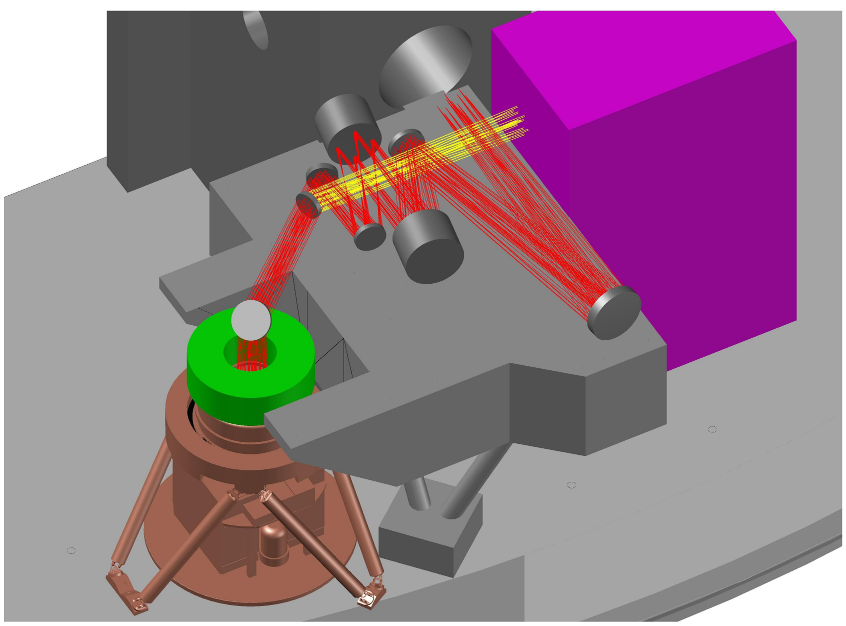

Figure 4. Preliminary mechanical design of the MAORY bench based on a hexapod solution. MICADO is on stand-alone configuration and support the NGS/SCAO wavefront sensors (green donut). In order to improve the relative stability of the two instruments, a fall back solution in which MICADO is supported by the MAORY bench is currently under investigation.

Conclusions

The current baseline opto-mechanical design of MAORY PFR has been presented. The optical design fulfills the requirements in terms of optical quality and distortion for astrometric observations. The mechanical design respect the frequency stability required to MAORY. Anyway the overall stability between MAORY and MICADO, both in the stand-alone and in the fall-back configurations are still under investigation.

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