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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 shall re-image the telescope focal plane for the client instruments installed on two exit ports. 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. The optical interfaces to the client instruments must replicate the telescope one while the volume allocation on the Nasmyth platform is under definition at the moment of this writing. We show the latest version of the optical design that matches the current requests and its optical performance. The laser guide stars channel, separated from the science path by means of a dichroic beam-splitter, is also presented.

Key words. Telescopes – Instrumentation: adaptive optics

1. Introduction

The Multi Conjugate Adaptive Optics Relay (MAORY) (Diolaiti. E. et al. 2014) is foreseen to be installed at the straight through focus over the Nasmyth platform of the future European Extremely Large Telescope (EELT) (Ramsay, S. K. et al. 2014). MAORY has to re-image the telescope focal plane with diffraction limited quality and low geometric distortion, over a field of view (FoV) of 160" diameter, for a wavelength range between 0.8 μm and 2.4 μm. 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 (Davies, R. et al. 2010), that is supposed to be placed on a gravity invariant port at 1800m below the optical axis, with a volume footprint of 4200mm $\times$ 4200mm. An unvignetted FoV of $53'' \times 53''$ with diffraction limited optical quality (< 54nm RMS of wavefront error at the wavelength of $1\mu m$) and very low field distortion (< 0.1% RMS) must be delivered. The full 2.6' FoV is transmitted 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, is required to reproduce the telescope one.

To achieve the above performances, the Phase A study 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

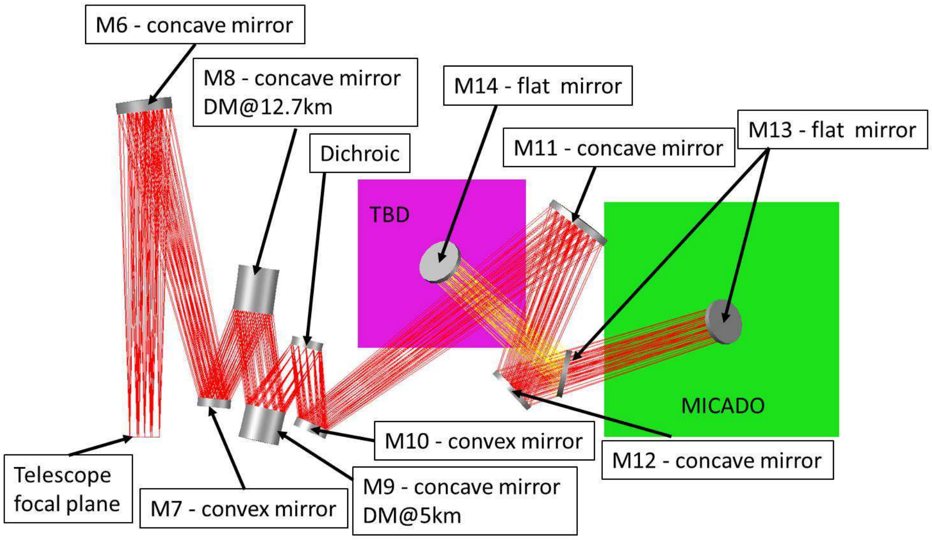

Figure 1. Post Focal Relay optical path.

Table 1. Main optical parameter of the Post Focal Relay. All values are in mm.

#	Shape	Curvature radius	Conic	Diameter	Off-axis distance
M6	Conc	12000	ellipse	1000	≈ 0
M7	Conv	6500	sphere	600	≈ 0
M8/DM	Conc	13000	ellipse	700	0
M9/DM	Conc	13000	ellipse	700	0
Dichroic	Flat	∞		600	0
M10	Conv	10000	sphere	700	0
M11	Conc	11000	ellipse	1200	≈ 0
M12	Conv	5000	hyperb	700	600
M13	Flat	∞		900*x*650	0

correction, to be carried out together with the telescope adaptive and field stabilization mirrors (called M4 and M5); the post focal DM optical conjugates are planned to be at 5km and 12.7km altitude. 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). At the present time, before MAORY Phase B that is expected to start in Fall 2015, a consolidation of the baseline design is being carried on. From the optical design point of view, part of the current work is focused on mitigating the risks associated to two crucial components: 1) the DMs, 2) the dichroic beam splitter. Voice-coil motor DMs are now assumed as baseline choice in the MAORY design, given their proven reliability and performance. The assumed DMs size is about 700mm and the pitch is 29mm, as on the VLT adaptive secondary (Gallieni, D. et al. 2013). This design choices correspond to

24 actuators along the diameter and ≈ 2m of projected pitch at the conjugated atmospheric layers. The dichroic, which is used to split the LGS/NGS/Science light, is designed to be smaller than in previous design versions. 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. In addition to the above mentioned risk mitigation, other design constraints and goals are focused to reduce the number of reflecting surfaces and consequently the thermal background, optics wavefront error (WFE), overall size, weight and possibly cost.

The design shown in this paper is in progress. Further consolidation will be needed following the refinement of the telescope interfaces, the consolidation of the adaptive optics system requirements and the results of the End-to-End (E2E) simulations regarding the system performance (Arcidiacono, C. et al. 2014). Little changes are expected to not upset the design shown here.

2. Main path optics

The light path through the main optics of the PFR is shown in Figure 1. After the 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 5km respectively. After the dichroic three mirrors with optical power (M10, M11 and M12) reproduce the exit focal plane preserving the optical interfaces of the telescope focal plane. The flat mirror M14 folds light downward to create a gravity invariant port for MICADO. The second gravity invariant exit port is created by means of a deployable fold mirror (M14), together with a flat mirror M15. The main parameters of the PFR are listed in Table 1.

The optical design of the main optics has been developed taking into account the constraints listed in the following:

- PFR maximum dimensions < 12m x 6m → to fit in the integration hall and Nasmith platform;
- same shape and dimension for the post focal DMs, DMs on axis → to reduce cost and allow commonalities for construction, test and integration:
- mirrors conic constant < 0 → easier to test;
- LGS light separation on a pupil plane → to allow flexibility on LGS and launching angle, less aberrations on transmitted beams;
- dichroic size as small as possible → reduced cost and better performance
- clearance for mirrors mounting;
- reduced number of reflecting surfaces → more throughput, less thermal backgorund, less overall WFE.

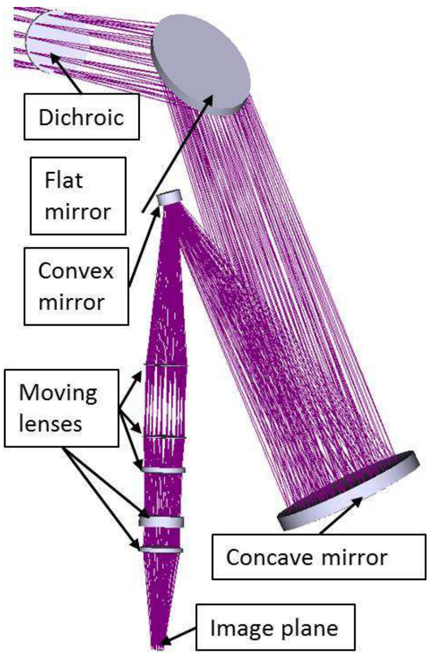

Figure 2. LGS objective. Image plane is kept fixed by the moving lenses that compensate for the source distance variation with the Zenith angle of observation.

2.1. Alternative design

An alternative design of the PFR has been developed with the aim to facilitate the procurement of the two most critical components, the DMs and the dichroic. In this design the DMs are identical and flat, instead of curved. In this way the brick concept for the actuators mounting and dismounting can be certainly borrowed from M4 (Vernet, E. et al. 2014), aside from a presumable reduction of the cost. After the second DM a concave mirror creates an intermediate focal plane and another concave mirror produces a pupil image where to put the dichroic, whose size can be pushed down to about 350mm instead of 600mm. Two more mirrors (one convex and one concave) deliver the exit focal plane with the appropriate optical quality and optical interfaces and finally a flat mirror folds the light down to MICADO. The drawbacks of this option are the increased size of the PFR and the presence of one more reflecting surface. For lack of space the alternative design is not shown. A similar layout, with a bigger DM size, can be found in (Lombini, M. et al. 2014).

2.2. LGS objective

The LGS objective must deliver a focal plane where to place the different probes, one for each LGS, for wavefront sensing. The current design (Figure 2) has the functionality of compensating for the moving image plane with the varying distance of the LGS in the sky, i.e. with the varying Zenith angle, by means of some movable lenses. The exit beam is telecentric and permits to fix the focal ratio. The image quality suffers from some low order aberrations but very slow varying with Zenith angle and foregone to be treated as slope offset in the wavefront measurement. The objective is capable to focus infinite distant sources, in order to use artificial sources at MAORY entrance focal plane for test and calibration. A simpler version of the objective does not fix the LGS image plane position, leaving to the LGS wavefront sensor the task of compensating the moving image plane, for instance by overall motion of the wavefront sensor itself. This option is also under investigation.

3. Conclusions

A feasible design of MAORY PFR has been presented in this paper. To finalize the design the following actvities will be carried on:

- investigation on components feasibility and cost (dichroic, curved DMs);
- consolidation of opto-mechanical interfaces with telescope and MICADO;
- detailed tolerance analysis;
- preliminary mechanical design volume, bench, legs and possible feedback on optical design;
- Confirmation (mainly) from AO simulations of:
- Layer conjugation altitude;
- Image quality @ DM planes; Image quality @ LGS WFS image plane, DM rotation, LGS launching angle.

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