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The MAORY first-light adaptive optics module for E-ELT

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ABSTRACT

The MAORY adaptive optics module is part of the first light instrumentation suite for the E-ELT. The MAORY project phase B is going to start soon. This paper contains a system-level overview of the current instrument design.

Keywords: Extremely Large Telescopes, E-ELT, multi-conjugate adaptive optics, MAORY

1. INTRODUCTION

MAORY[1] is a post-focal adaptive optics module that forms part of the first light instrument suite for the E-ELT[2][3][4]. It offers two adaptive optics modes: multi-conjugate adaptive optics (MCAO) and single-conjugate adaptive optics (SCAO). The MCAO mode ensures high-quality adaptive optics compensation with excellent uniformity of the point spread function over a relatively large scientific field of view; the MCAO technique, coupled with Laser Guide Stars (LGS), offers excellent coverage of the observable sky. Primary science cases in MCAO mode are astrometry and deep photometry with very high relative accuracy. The SCAO mode may deliver even higher performance than the MCAO mode on a smaller field of view, when a bright natural star is available nearby the scientific target of interest.

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MAORY is not a scientific instrument in itself, as it does not produce scientific data on its own. The primary client instrument of MAORY is MICADO[5], the near-infrared high-angular resolution camera for the E-ELT. The unique spatial resolution of the E-ELT-MAORY-MICADO system is one of its key features.

The MAORY instrument will be designed and built by a Consortium including INAF (Italy), acting as lead institute, and INSU IPAG (France). ESO, in addition to its role of project customer, is also actively involved in the project.

The MAORY instrument project is advancing towards phase B. Consolidation of the baseline instrument design is underway, following the refinement of the top-level requirements and interfaces. A system level overview of the project is presented in this contribution.

2. INSTRUMENT REQUIREMENTS

MAORY has to be installed on the E-ELT Nasmyth platform on the telescope straight-through focus.

MAORY has to provide two adaptive optics modes to support science observations with MICADO:

- MCAO mode, in which at least two deformable mirrors are conjugated to different altitudes in the atmosphere; one of these deformable mirrors is the telescope adaptive quaternary mirror M4;
- SCAO mode, in which wavefront compensation is performed using M4 only.

The MCAO mode of MAORY is based on the use of 6 LGS wavefront sensors. Natural guide star wavefront sensors (3 in the baseline design) are also required to complement LGS measurements.

The SCAO mode relies on a single NGS wavefront sensor. This mode is developed in the framework of a joint collaboration between the MAORY and the MICADO instrument consortia.

MAORY contains an optical relay to re-image the telescope focal plane at the client instrument port. The exit port for MICADO has to be gravity-invariant.

MAORY has to provide a second port for an instrument to be defined.

In MCAO mode, MAORY will have to provide a Strehl Ratio SR ≥ 0.3 at $\lambda = 2.2$ μm under median atmospheric conditions. This requirement is intended as average value over the MICADO field of view (~1 arcmin) for observations close to zenith. The requirement has to be achieved over at least 50% of the sky observable by the telescope. The performance goal, which could be achievable with two deformable mirrors in MAORY, is SR = 0.5 at $\lambda = 2.2$ μm. Performance values will be consolidated in the project phase B.

Regarding relative astrometric accuracy, which is one of the science drivers of the MCAO mode, MAORY will have to permit observations such that the relative position on the sky of an unresolved, unconfused source of optimal brightness with respect to an optimal set of reference sources is reproducible to within 50 μas (goal 10 μas) over a central field of 20 arcsec diameter – and across the entire MICADO field as a goal – over timescales in the range of 1 hour to 5 years.

Concerning relative photometric accuracy, MAORY will have to permit observations with MICADO such that the relative flux of an unresolved, unconfused source of optimal brightness with respect to an optimal set of reference sources is reproducible to within 0.02 mag (goal: 0.01 mag) across the MICADO field of view over timescales in the range of 1 hour to 5 years.

MAORY shall permit observations of non-sidereal objects also in MCAO mode.

3. INSTRUMENT DESIGN OVERVIEW

3.1 E-ELT wavefront control interface

E-ELT is an adaptive telescope. The telescope control equipment maintains the telescope alignment at a level such that the optical quality is within the capture range of post-focal instruments. Quasi-static aberrations in the telescope are compensated by the active optics system. Adaptive optics compensation of fast wavefront aberrations due to atmospheric turbulence, windshake effects etc. relies on resources distributed in MAORY (LGS and NGS wavefront sensors, post-focal deformable mirrors, real-time computer) and in the telescope (LGS launchers, adaptive quaternary mirror M4, tip-tilt mirror M5, other actuators such as the telescope main structure). The interfaces of this complex control system are under definition and will be consolidated in the MAORY project phase B.

3.2 MCAO mode

The instrument sub-systems in the baseline design and their inter-relations in MCAO mode are shown in the block diagram in Figure 1.

The light from the E-ELT enters MAORY through the main path optics (common path). Upon wavefront compensation by the post-focal deformable mirror(s) (which complement the telescope's M4/M5), the light is split by a dichroic beam-splitter, which is still part of the main path optics.

The light of wavelength shorter than about 600 nm is propagated from the dichroic beam-splitter to the LGS path optics and then to the LGS wavefront sensor sub-system (this sub-system is in use only in the MCAO mode, although a possible use for optical metrology of the post-focal deformable mirrors in the SCAO mode, if necessary at all, is under discussion).

The light of wavelength longer than about 600 nm is propagated from the dichroic beam-splitter through the last segment of the main path optics (science path) to the exit port. At the exit port the MAORY exit focal plane is made available to MICADO. The light of the required NGSs is picked off by the low-order & reference (LOR) wavefront sensor units in the NGS wavefront sensor module[6], to measure fast low-order aberration modes which cannot be measured reliably by the LGS (such as tip-tilt, focus, astigmatism) and for de-trending slow low/medium-order wavefront aberrations modes which could be affected by instrumental effects of the LGS wavefront sensor due to the sodium layer properties[7].

The wavefront measurements performed by the LGS and low-order & reference wavefront sensors in the MCAO mode are processed by the MAORY real time computer, which drives in closed loop the MAORY post-focal deformable mirrors and the actuators in the telescope, including the adaptive quaternary mirror M4 and the tip-tilt mirror M5.

All instrument operations are controlled by the MAORY instrumentation software, which also provides interfaces to the telescope central control system and to the MICADO (or other) client instrument instrumentation software.

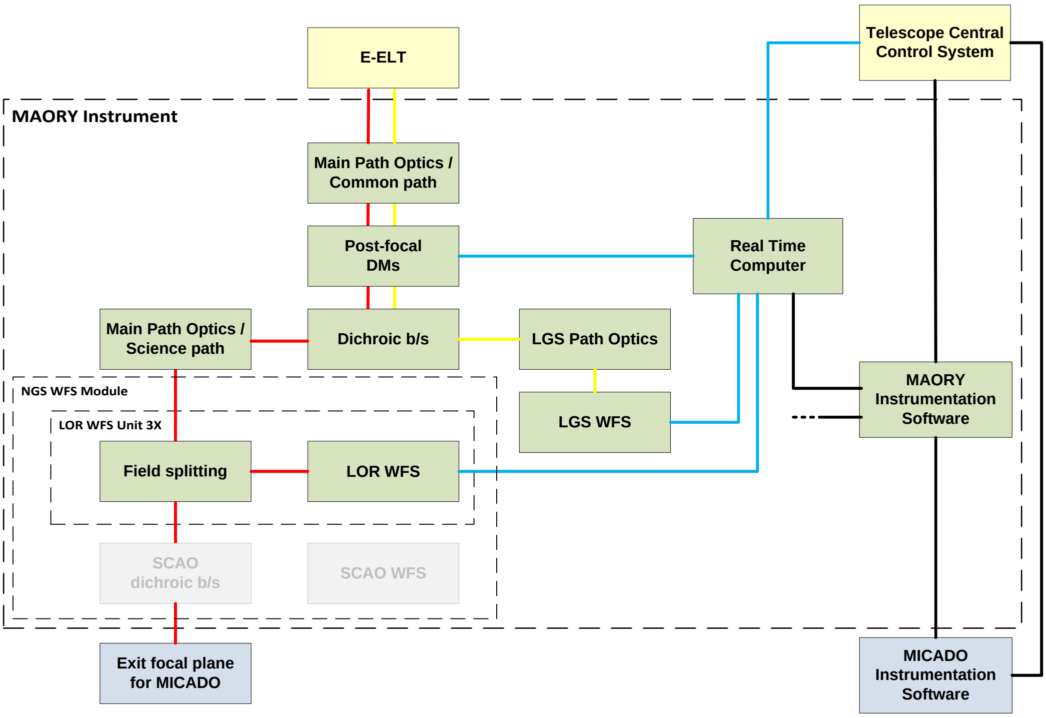

Figure 1. MCAO functional block diagram. Red lines: light path. Yellow lines: LGS light path. Blue lines: real-time signals. Black lines: non real-time signals. Light grey blocks are not used in MCAO mode.

3.3 SCAO mode

The SCAO mode[6][8] is described in the block diagram in Figure 2.

LGS are not used in SCAO mode. The light path is essentially the same as in the MCAO mode, with the exception of the exit port. Here the light of a NGS nearby the scientific target of interest is selected in wavelength by a dichroic beam-splitter close to the exit focal plane. This dichroic beam-splitter is deployable: it is inserted in the optical beam only in SCAO mode and it transmits the science wavelength to MICADO. Signals from the SCAO wavefront sensor in the NGS wavefront sensor module are sent to the MAORY real time computer, which drives the actuators in the telescope.

In SCAO mode the MAORY post-focal deformable mirrors are kept at their reference shape. Possible control schemes to perform this function, if needed, are under investigation.

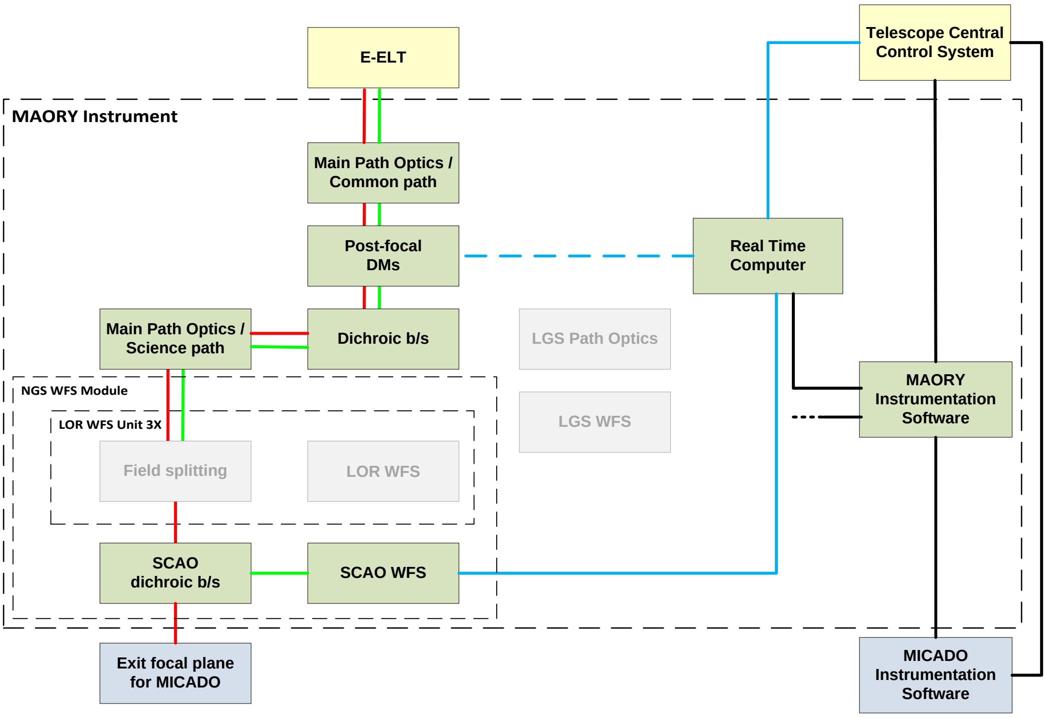

Figure 2. SCAO functional block diagram. Red and green lines: light path. Blue lines: real-time signals. Black lines: non real-time signals. Light grey blocks are not used in SCAO mode. The dashed blue line corresponds to the possible post-focal deformable mirrors control in the SCAO mode.

3.4 Optical design

The MAORY layout has been significantly changed since phase A. The instrument design volume is now on the telescope straight-through focus, which is a convenient location in term of space and available field of view.

A possible opto-mechanical layout of MAORY on the Nasmyth platform is shown in Figure 3.

The telescope focal plane is relayed by the MAORY all-reflective optical relay to the exit port for MICADO. The LGS light is separated from the science path light by the dichroic beam-splitter, which is placed downstream the deformable mirrors. The dichroic beam-splitter transmits the LGS light, which is focused by the LGS path optics objective at the entrance of the LGS wavefront sensor (Figure 4). The NGS wavefront sensor module, including the LOR wavefront sensor for the MCAO mode and the SCAO wavefront sensor for the SCAO mode, is located at the exit port. The volume for the second instrument is on the right in Figure 3.

The optical design of the MAORY post-focal relay[9] shown in Figure 3 contains 7 mirrors (including the deformable mirrors) and the dichroic-beam-splitter. It is a 1:1 relay, i.e. the exit port optical interface is the same as the telescope optical interface in terms of focal ratio, exit pupil distance, field curvature.

A detailed optical and mechanical trade-off study is in progress at the moment of writing. The study aims at consolidating the MAORY baseline design taking into account optical performance requirements, mechanical structure stiffness, interfaces to MICADO and to the Nasmyth platform. Different designs are being developed, with different number of mirrors in the MAORY post-focal relay. In order to maximise the optical performance and minimise the thermal background due to optics emissivity, designs with reduced number of mirrors are under investigation; in these cases it might not be possible to achieve the 1:1 relay condition.

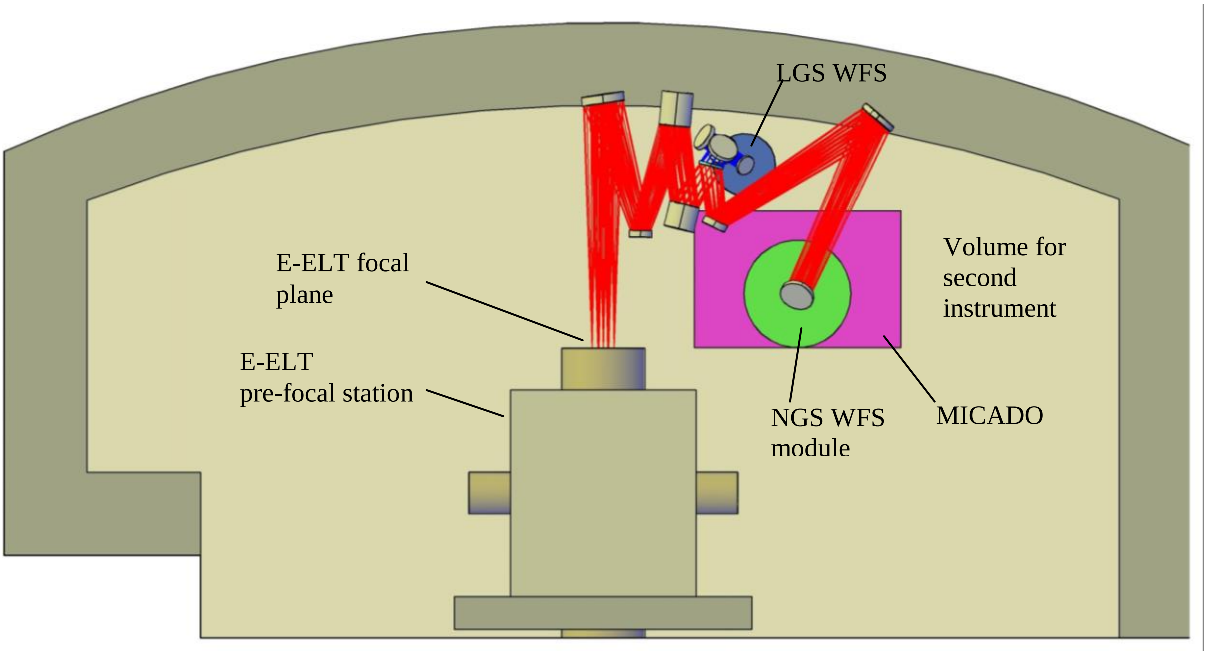

Figure 3. Preliminary MAORY layout on the E-ELT Nasmyth platform. The telescope is outside the picture (below). The telescope focal plane is relayed by the MAORY optical relay to MICADO on the exit port. Scale: the NGS WFS module is 2600mm in diameter.

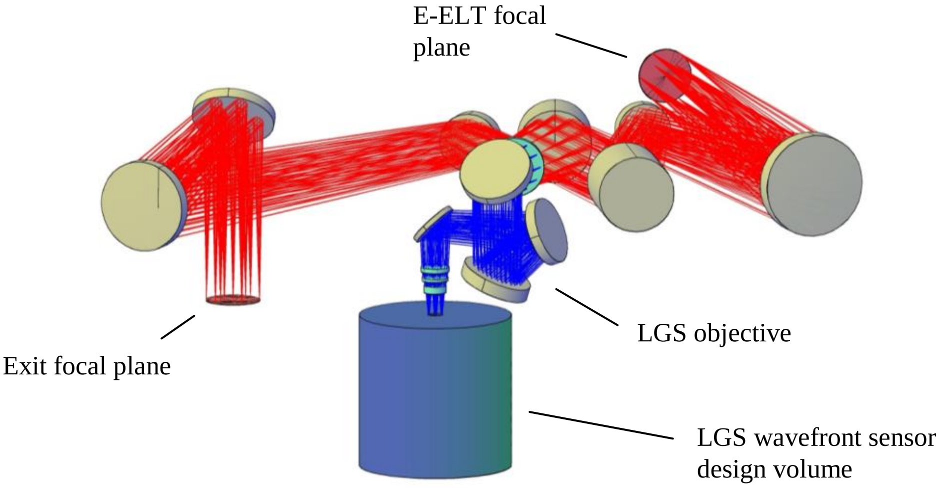

Figure 4. Preliminary optical design of MAORY showing the LGS objective. The telescope focal plane (upper right) is relayed to the exit port focal plane (lower left). The LGS light (blue rays) is transmitted by the dichroic beam-splitter and focused by the LGS objective, consisting of mirrors and lenses. The LGS wavefront sensor is in gravity invariant configuration.

4. CONCLUSIONS

The current status of the MAORY instrument design has been presented in this paper.

Significant changes of requirements and instrument design have been made since the MAORY project phase A[1].

The instrument location on the Nasmyth platform has been changed from a folded focus to the straight-through focus of the telescope, which is more convenient in terms of space and field of view.

The phase A design was based on piezo-electric deformable mirrors[10]: voice-coil motor actuator deformable mirrors[11] have also been recently considered, showing that the adoption of this technology is fully feasible in MAORY.

A SCAO mode has been included in the MAORY baseline, to be developed in collaboration with the MICADO instrument consortium.

Consolidation of interfaces and requirements will be one the major topics of the project early phase B, which will start soon.

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