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# T-REX Operating Unit 3

E. Diolaiti[1], R. Abicca[1], G. Agapito[2], J. Antichi[2], C. Arcidiacono[1], A. Baruffolo[3], M. Bellazzini[1], M. Bergomi[3], G. Bregoli[1], R.C. Butler[4], E. Cascone[5], S. Cavazzani[3], P. Ciliegi[1], F. Cortecchia[1], G. Cosentino[6], V. De Caprio[5], A. De Rosa[4], G. Di Rico[2], M. Dima[3], S. Esposito[2], R. Falomo[3], D. Fantinel[3], J. Farinato[3], L. Fini[2], I. Foppiani[1], C. Giordano[2], E. Giro[3], L. Greggio[3], M. Gullieuszik[3], F. Lascaux[2], M. Lombini[1], D. Magrin[3], G. Malaguti[4], L. Marafatto[3], E. Masciadri[2], G. Morgante[4], S. Ortolani[7], S. Paiano[3], F. Patru[2], M. Patti[1,6], I. Porceddu[8], E. Portaluri[3], R. Ragazzoni[3], A. Riccardi[2], S. Ricciardi[4], M. Riva[9], B. Salasnich[3], L. Schreiber[1], P. Spanò[2], A. Turchi[2], M. Uslenghi[10], V. Viotto[3], S. Zaggia[3], F.M. Zerbi[11], and V. Zitelli[1]

[1] INAF-OABO, Via Ranzani 1, I-40127 Bologna, Italy
[2] INAF-Arcetri, L.go E. Fermi 5, I-50125 Firenze, Italy
[3] INAF-OAPD, Vicolo Osservatorio 5, I-35122 Padova, Italy
[4] INAF-IASFBO, Via Gobetti 101, I-40129 Bologna, Italy
[5] INAF-NA, Salita Moiariello 16, I-80131 Napoli, Italy
[6] Univ. di Bologna, Dip. di Fisica e Astronomia, V.le Berti Pichat 6/2 I-40127 Bologna, Italy
[7] Univ. di Padova, Dip. di Fisica e Astronomia, Via Marzolo 8, I-35131 Padova, Italy
[8] INAF-OA Cagliari, Via della Scienza 5, I-09047 Selargius (CA), Italy
[9] INAF-Brera, Via E. Bianchi 46, I-23807 Merate (LC), Italy
[10] INAF-IASF Milano, Via Bassini 15, I-20133 Milano, Italy
[11] INAF, Viale del Parco Mellini 84, I-00136 Roma, Italy

**Abstract.** OU3 is one of the six Operating Units of the Progetto Premiale T-REX. It is focused on the development of adaptive optics instrumentation for the European Extremely Large Telescope. The main activities of OU3 are the MAORY adaptive optics module, the MICADO infrared camera, the characterisation and forecast of atmospheric parameters for the E-ELT site and general developments for future adaptive optics systems.

**Key words.** Technology: adaptive optics – Telescopes: E-ELT

## 1. Introduction

The MAORY adaptive optics module and the MICADO infrared camera form part of the first light instrument suite for the European Extremely Large Telescope (E-ELT) (Tamai 2014, 2015). These two instruments have been approved for construction (Ramsay et al.

2014) and the phase B of the respective projects is expected to start soon at the moment of this writing. INAF is the lead institute of the MAORY instrument project and is involved in the MICADO instrument project. MAORY and MICADO were the core activity of the Operating Unit 3 (OU3) of T-REX in its first year. In the second year of T-REX the scope of work of OU3 was extended to include two more activities: forecast of atmospheric parameters and development of new technologies for wide-field adaptive optics.

This introductory paper contains an overview of the activities which have been supported by OU3. The interested reader will find more details in the specific contributions presented in this Conference.

## 2. MAORY

MAORY (Diolaiti et al. 2014) is a post-focal adaptive optics module for the E-ELT. It offers two adaptive optics modes to support the MICADO near-infrared camera (Davies et al. 2010): Multi-Conjugate Adaptive Optics (MCAO) and Single-Conjugate Adaptive Optics (SCAO). In the MCAO mode, MAORY uses the adaptive mirror M4 and tip-tilt mirror M5 in the telescope and up to two post-focal adaptive mirrors in the module itself to achieve high performance with excellent uniformity of the point spread function across the field of view; wavefront sensing is performed by a suite of up to six Laser Guide Stars (LGS) and three Natural Guide Stars (NGS), ensuring high sky coverage. In the SCAO mode, MAORY uses only the telescope's M4 and M5 and a single NGS SCAO wavefront sensor to achieve excellent performance on a narrow field of view around the NGS itself. In both modes wavefront sensing is performed in closed-loop fashion with optical feedback from the sensors to the deformable mirrors.

Support from T-REX has been essential for defining a number of programmatic and technical aspects of the MAORY instrument project in preparation for phase B. These activities and achievements are summarised below.

The MAORY consortium has been consolidated and is now in its final configuration. It consists of three partner organisations: INAF (Italy), INSU-IPAG (France) and ESO. INAF is the lead institute, bearing responsibility for the system development, for its delivery to ESO and for several sub-systems, including the instrument platform and, among the adaptive optics sub-systems, the optical relay with adaptive mirrors, the NGS and SCAO wavefront sensor, the real-time computer. IPAG is responsible for the development and delivery of the LGS wavefront sensor sub-system. ESO is responsible for the supply of components and tools, i.e. wavefront sensor cameras, common specifications and toolkit for the real-time computer development, software simulator of the telescope control system.

The technological choice for the adaptive mirrors in MAORY has been changed since phase A. The current design is based on voice-coil motor actuator adaptive mirrors (Biasi et al. 2010). This technology has been chosen for its high technology readiness level and recognised performance. Considering that the same technology has been adopted by ESO for the telescope M4, commonalities are possible and will be exploited as much as possible. An industrial study on the MAORY adaptive mirrors, fully funded by T-REX, will be launched in parallel to the MAORY project phase B.

The optical design of MAORY has been changed (Lombini et al. 2014) in order to take into account the new choice of adaptive mirrors and new telescope interfaces. The instrument is located on the telescope straight-through focus on the Nasmyth platform. The optical relay inside MAORY forms a 1-to-1 image of the telescope focal plane. The exit port for MICADO is gravity invariant. A second gravity invariant port is also provided for an instrument to be defined yet. The optical relay design contains two identical voice coil adaptive mirrors; the trade-off between flat and curved shape is still in progress. The current status of the optical design has been presented in this Conference by Lombini et al. (2015).

The NGS wavefront sensor is an essential complement to the LGS wavefront sensor in the MCAO mode. The NGS wavefront sensor requires three natural stars, even very faint, to be found over a technical field of view of 160 arcsec. In order to implement the above mentioned SCAO mode of MAORY, a fourth specialised wavefront sensor has been added in the design volume allocated to the NGS wavefront sensor, in the framework of a joint development between the MICADO and MAORY consortia. Recent work on the MAORY NGS and SCAO wavefront sensor has been shown in this Conference by Esposito et al. (2015).

An end-to-end simulation code is under development (Arcidiacono et al. 2014; Schreiber et al. 2015): it is an essential tool for the adaptive optics system modelling and design. The code has modular structure and relies on the use of Graphic Processing Units to speed up the time demanding parts of the simulations. Specific functions are available for detailed modelling of the sodium layer where the LGSs are generated (Schreiber et al. 2014a). The code allows the user to choose between two simulation modes: accurate mode, for detailed modelling, and fast mode, which is useful for exploring the parameter space or for statistical calculations such as sky coverage evaluation. To provide experimental support to numerical simulations, a reduced-scale laboratory prototype of the MAORY wavefront sensing system has been developed (Patti et al. 2015), offering the possibility to emulate realistic LGS images under different working conditions.

A complex and big instrument as MAORY requires special facilities for its integration. The selected assembly hall is an existing laboratory at IASF-Bologna, one of the INAF institutes involved in the project. The hall has suitable size and is under remodelling to be adapted to the needs of the MAORY project. The design of the civil works has been completed and the necessary authorisations by public offices have been obtained. The contract for the civil works is expected to be awarded in the next few months and the works themselves are expected to be completed well in advance before the start of the instrument integration. Tools and equipment have also been purchased to support the instrument integration. A second laboratory is under remodelling at INAF Osservatorio Astrofisico di Arcetri for the integration of the NGS and SCAO wavefront sensor sub-system.

## 3. MICADO

The participation of INAF in the MICADO instrument project is mainly related to the definition of the instrument science cases. The main science cases investigated by the INAF team are related to the study of the stellar population of nearby and high redshift galaxies with ELTs. The study has been carried out by simulation of E-ELT observations, taking into account the expected performance of the E-ELT - MAORY - MICADO system, and by analysis of the simulated images by standard photometric analysis methods to assess the feasibility of the science cases. The interested reader may find detailed descriptions of the science cases which have been analysed and of the results in Greggio et al. (2012), Gullieuszik et al. (2014), Schreiber et al. (2014b) and in the contribution by Gullieuszik et al. (2015) in this Volume.

## 4. Atmospheric parameters

Evaluation and forecast of atmospheric conditions are essential elements for planning scientific observations. Two different concepts have been studied in OU3. The first concept is based on the use of a meso-scale atmospheric model for the forecast of optical turbulence and atmospheric parameters. The final goal of this study is the implementation of an automatic forecast system to be installed at the E-ELT site. Results can be found in Lascaux et al. (2014) and Masciadri et al. (2015). The second concept relies on the use of multi-wavelength satellite observations of the Earth for the forecast of the could cover and of the photometric quality of the sky. Results are presented in Cavazzani et al. (2014). A further extension of this method is under study for the forecast of the turbulence strength accordingly to a step-wise scale such as strong-regular-quiet.

## 5. Technology developments for adaptive optics

The development of new technologies for adaptive optics within OU3 has been mainly focused on Global Multi-Conjugate Adaptive

Optics (GMCAO). In the GMCAO approach, wavefront sensing is performed by natural stars. In order to achieve high sky coverage, the stars have to be searched on a wide field of view at the telescope focal plane, which corresponds to the entrance focal plane of a post-focal module such as MAORY: relaying the same focal plane at the exit port of the post-focal module would be extremely difficult for optical design reasons. The shape of the post-focal adaptive mirrors, which are not seen by the wavefront sensor, is monitored by fast metrology. Description of the GMCAO approach and preliminary results of the simulations can be found in Viotto et al. (2014) and Ragazzoni (2015).

## 6. Conclusions

Support by T-REX to the E-ELT activities at INAF has been essential. In the framework of OU3, T-REX has funded general expenses, 13 grants for young researchers and 1 PhD grant and, in the specific case of the MAORY project, T-REX has allowed INAF to set up the facilities for the instrument integration and to support the instrument design.

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