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**Adaptive Optics for Extremely Large Telescopes 4 -
Conference Proceedings**

Title

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Journal

Adaptive Optics for Extremely Large Telescopes 4 - Conference Proceedings, 1(1)

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Publication Date

2015

DOI

10.20353/K3T4CP1131551

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Deformable Mirrors developments at ESO

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ABSTRACT

Already several deformable mirrors are in use at Paranal and more will come in the next years. With the next generation and telescope and associated instruments, adaptive optics become an integrated part of the telescope and provide as such the first layer of image correction. The M4 E-ELT has been specified to provide a good image quality under average seeing but it is also clear that going to larger field of view or when looking for higher performance additional deformable mirrors need to be implemented in the instruments. We present here how the needs in term of performance have evolved in the last decade. After a description of the performance for the future ELT M4, a review of the parameter space will be outlined and the development plan presented.

Keywords: Deformable Mirrors, Adaptive Optics, Wavefront corrector.

1. INTRODUCTION

Extremely large telescopes are now starting their manufacturing phase. All the first generation instruments foreseen for the E-ELT have already their deformable mirror technology available. The instruments which foresee an adaptive optics system with one deformable mirror will make use of the M4 Adaptive Optics unit which is in the E-ELT. The multi-conjugate adaptive optics system will have one or two additional deformable mirrors for which at least two different technologies can be used.

Instead, the deformable mirror needs for the second generation of instruments are not available yet. Using the E-ELT instruments phase A studies, and reviewing the deformable mirrors available and their associated parametric space, we have concluded that the new kind of wavefront correctors need to be developed.

After a presentation of the E-ELT instrument roadmap, we describe the tasks, characteristics and development status of the M4 deformable mirror. We continue with the description of the technical analysis performed, explaining the parameter space of the wavefront correctors. We deduce the requirements of the deformable mirrors for multi-object adaptive optics systems and high contrast adaptive optics systems, the two systems needed for the second generation of E-ELT instruments.

We conclude with the description of the development programme we have settled with its objective and the estimated timeline.

1.1 Roadmap for E-ELT instruments

Six instruments went through a Phase A study in the period 2006-2011. As part of the studies, the consortia estimated risks and availability of the technologies needed in order to understand if the instruments project could be part of the first generation of E-ELT instruments.

The final reviews showed that three of them could be part of the first light instruments: the ELT-Integral field Unit instrument, the ELT-camera and the ELT-Mid Infrared instrument. These three instruments will make use of the M4 Adaptive mirror. They will work in single conjugate adaptive optics mode. Figure 1 presents the roadmap obtained at the end of the phase A studies. Three instruments started in 2015 while a call for proposal was issued to for a high-resolution spectrograph and a multi-resolution spectrograph with the objective to select the proposal and associated consortia in 2016.

In 2016, another call for instrument will be issued while the extreme adaptive optics instrument will be launched as soon as all the required technologies are demonstrated.

Year	ELT-IFU	ELT-CAM	ELT-MIR	ELT-MOS	ELT-HIRES	ELT-6	ELT-PCS
2014	Decide science requirements, AO architecture.		VISIR start on-sky	Develop science requirements for MOS/HIRES			Start ETD
2015				Call for Proposals Start Phase A			
2016				Consortium Selection for construction		Call for proposals	
2017							
2018							TRL check
2019						Selection	Start when ready

Figure 1: E-ELT roadmap obtained after E-ELT instruments Phase A studies. Grey color indicates Pre-studies taking the form of phase A or delta-Phase A work and/or ESO-funded Enabling Technology development. Yellow color indicates the decision point. Green color indicates the development of technical specifications, statement of work, Agreement, Instrument start.

1.2 The M4 Adaptive mirror

The M4 Adaptive Mirror is using the voice coil technologies; technology already implemented on Adaptive Secondary mirrors for 8-10 classes telescopes. Due to its size, 2.4 meters diameter, the mirror will be segmented in six parts. More than 5000 actuators will be controlled at frequency up 1 kHz, 4866 actuator being in the clear aperture of the mirror. The preliminary design phase was completed in May 2015. The design is presented in Figure 2. The unit includes a hexapod to provide decentering, tip-tilt capabilities, and a de-rotator to direct the light to the Nasmyth foci localized at 180 degrees one from the other. The M4 mirror will be conjugated at 625 mm.



Figure 2: The M4 Adaptive Mirror Preliminary Design

1.3 The MAORY deformable mirrors: two technologies available

The ELT-Camera, MICADO will have also a multi-conjugate adaptive optics module called MAORY. The MAORY module will have one or two additional deformable mirrors conjugated at different altitudes. It will provide large field adaptive optics correction to the camera.

Two different types of deformable mirrors are available for MAORY depending on the selected optical design. MAORY team has baselined their delta-Phase A study on the use of voice coil technology with the advantage that the technology is already well proven at larger dimensions but with the inconvenient that its size puts strong constraint on the design itself and in particular on the relay optics which need to be large and therefore expensive.

Current design of adaptive mirror with voice coil technology foresees 700 mm diameter deformable mirror with an actuator pitch of 29mm for 600 actuator count.

The alternative solution is based on piezo-stack actuators. This technology was used in the past widely for 8 meters adaptive optics systems but it has never been proved for larger pupil diameters, which are needed for E-ELT instruments to avoid too fast optical beam inside the instrument inducing other problems. A 500mm diameter piezo-stack mirror would have 2168 actuators. Whatever the final solution selected, no additional development technology is needed.

2. TECHNOLOGIES FOR DEFORMABLE MIRRORS

2.1 Technologies diagram

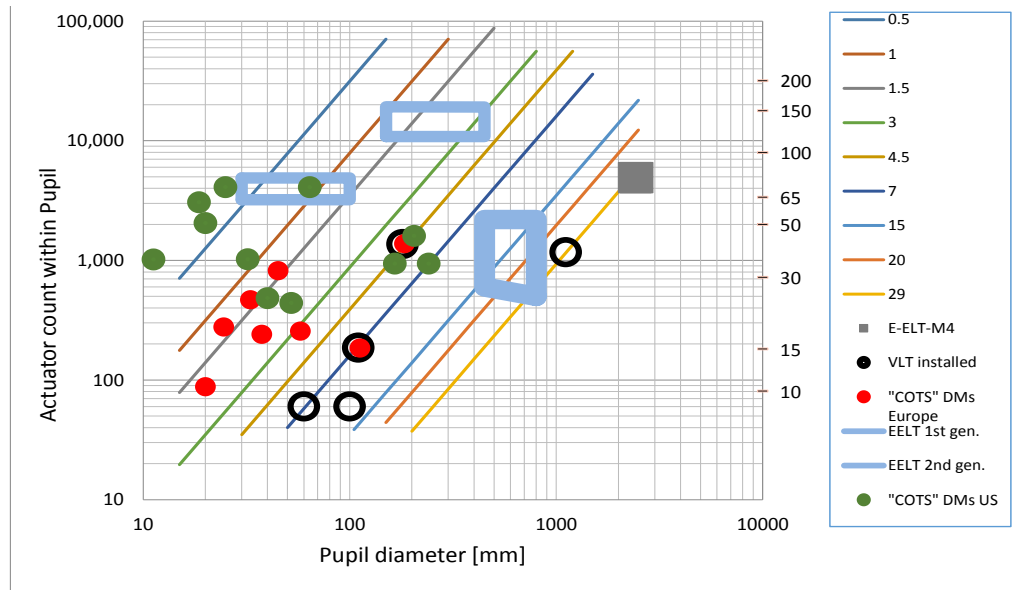


Figure 3. Log-log diagram representing the available actuators count per pupil diameter and the needs for E-ELT.

To have a better overview of the parameter space and of our needs, we developed a diagram (shown in Figure 3) representing the pupil dimension with respect to the actuator count in the filled pupil or across the pupil. The actuator pitch is indicated as well on the diagram by all the diagonal lines. Commercial of the shelf products have been reported with red dot for European Companies and Green dots for American ones. We indicated all the deformable mirrors already available at ESO using black dots.

Considering all the deformable mirror manufacturers, a large range of pupil diameter is available on the market. It is nevertheless clear that the number of actuators is limited to a few thousand maximum.

We have evidenced the parameter space for our needs in term of deformable mirrors on the diagram with some blue shape. The darker blue shape indicates the parameters obtained after the Phase A study of MAORY. As already discussed in previous section, one can identify that current technology is already fulfilling the requirements. The lighter blue rectangle is representing results from EAGLE Phase A multi-object instrument and EPICS Phase A extreme adaptive Optics instrument.

Considering only actuator count and pupil diameter, some COTs seem to be available in US for EAGLE needs but as we will see in the next section, the stroke available is too small for our needs. By plotting the same information on two others diagrams: stroke / pitch and stroke / actuator count, one can visualize what is the technology development requested for the various types of adaptive optics system. We discuss the two diagrams in the next sections.

2.2 Stroke/pitch needs

Figure 4 is representing the commercial of the shelf deformable mirrors from the five most important deformable mirror manufacturers: Xinetics and Boston Micro machines from US, ALPAO, CILAS and Adoptica from Europe. The needs in term of stroke and the range of acceptable pitches is shown both the compact deformable mirrors and extreme adaptive optics deformable mirrors. We can deduce that the market provide already deformable mirrors with adequate stroke for the required pitch for the two technologies. While for XAO, two manufacturers provide the required stroke for 0.9-3 mm pitches, only ALPAO provides the required stroke for compact DM pitches of 0.4-1.7mm.

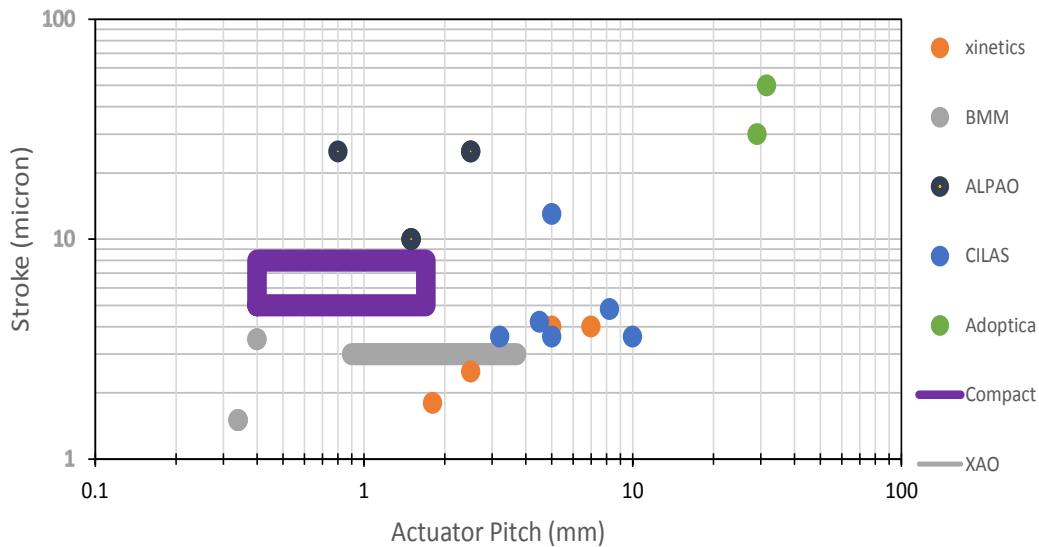


Figure 4: Log-log diagram showing the deformable mirrors stroke available for different pitches.

2.3 Stroke/ Actuator counts

Figure 5 is representing the stroke of the deformable mirrors available on the market as a function of actuator number.

The five most important deformable mirror manufacturers are indicated using different colors. Both for compact and extreme adaptive optics, the needs in term of combination Stroke/actuator count is far beyond what is currently done nowadays. We go deeper in the analysis of our needs in the next section.

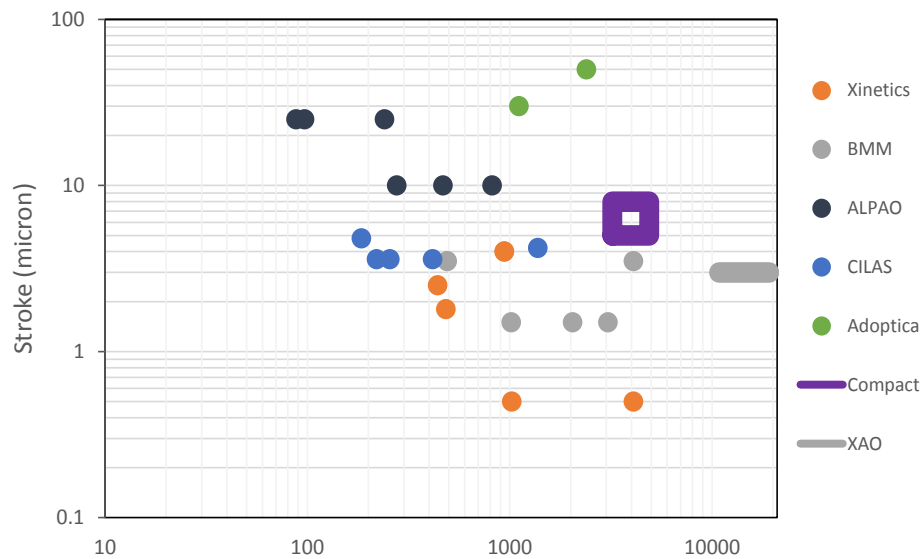


Figure 5: Log-log diagram showing the deformable mirrors stroke available on the market for different number of actuator counts.

3. NEEDS FOR THE SECOND GENERATION OF INSTRUMENTS

3.1 Multi-Object Adaptive Optics case

We developed a requirement document to specify the main parameters of a deformable mirror to be used in multi-object adaptive optics.

Multi-object adaptive optics require the use of several deformable mirrors which are placed in the field of view of the instrument on selected positions depending on the scientific target. The mirror need to be compact with a limited weight and volume. The diameter range accepted is between 30 and 100 mm with a goal at 45 mm.

Open loop control is required in multi-object adaptive optics; the deformable mirror need to have an excellent linearity better than 3% (goal 1 %) and a very good stability of 15 nm RMS over one hour with temperature variations. Stability can be achieved by applying offsets.

At least 2800 (goal 5000) actuators are needed within the clear aperture and a maximum stroke of 5 to 8 micron. The interactor stroke shall be larger than 1.3 micron. Small stroke of 250 nm shall be reached within less than 700 microseconds while full stroke shall be reached within 3microseconds. It shall have its first mechanical resonance at frequency higher than 500 Hz.

The need in the actuator count is 2 to 3 times higher than what is currently produced. This implies an increase of the deformable mirror dimension, inducing some development on the connection aspects for some technologies or on the face sheet dimension for others. Companies will need as well to demonstrate that their technology fulfill the stability requirement.

3.2 Extreme Adaptive Optics case

Instruments using extreme adaptive optics try to detect new companions, planets much fainter than the observed star. A high number of actuator is required to correct higher order mode. From phase A study of EPICS, between 11000 and 20000 actuators shall be within the clear aperture. The correction is expected to be uniform, long lifetime of the actuators

is mandatory. Planet finder instruments are using coronagraphy techniques imposing that the actuator pattern does not change over time. Depending on the technology/ coupling factors, dead actuators can be critical in particular if it stays blocked in a position when it is dead. Less than five actuators (with a goal at 0) can die over the complete lifetime of the deformable mirror.

The diameter of such mirror will be between 150mm and 450mm with a goal at 270mm. A maximum stroke of at least 3 micron is needed when actuating 3x3 actuators array with an interactor stroke larger than 1.2 micron for bad seeing conditions. A quasi-static actuator position resolution better than 0.1nm (goal of 0.06nm) for speckle nulling. This requirement is inducing some resolution and noise requirement on the drive electronics.

Settling time requirements are essential in extreme adaptive optics, the system need to be fast to reach ultimate performance. A full stroke settling time has been limited to 2ms while a small stroke of 50nm shall be reached within maximum 150 microseconds (goal 100 microseconds) including the latency from the drive electronics. Hysteresis induces a frequency independent phase lag, which can affect the loop stability. We limited the hysteresis requirement to 5% (goal 1 %) as it correspond already to almost 3 degree at 200Hz.

4. DEVELOPMENT OBJECTIVES AND TIMELINE

We have decided to launch two development studies to demonstrate the feasibility of deformable mirrors for multi-object adaptive optics and extreme adaptive optics on time for the instruments design phase. As we empathized in Section 1.1, the multi-object spectrograph instrument will start in 2016. It is also clear that technological gap to be filled for compact deformable mirror is smaller than for the extreme adaptive optics mirrors. We have planned for a 2 years development for compact deformable mirrors while a four-year development is required for extreme Adaptive Optics mirrors.

4.1 The compact deformable mirror case

After a detailed review of the technical technologies, a straw man design will be developed as well as a detailed design of the mirror prototype. The prototype will be manufactured, assembled and test in parallel to the preliminary design preparation of the final mirror. We requested all critical technologies to be demonstrated through breadboards before manufacturing the prototype to reduce at maximum any technical risk.

4.2 The extreme Adaptive Optics case

The technological gap between our needs and what is currently available is quite large for extreme adaptive optics. Whatever the technology considered, many aspects need to be demonstrated at breadboard level before considering the possibility to manufacture a prototype. We request, like for the compact deformable mirror development study, to have a detailed list of critical technologies and a breadboard development plan allowing to reduce or even cancel all of them. A conceptual design shall be developed in parallel. After two years, all critical technologies shall have been demonstrated. Two additional years may be granted to one of the development study to proceed with the preliminary design and manufacturing, assembly and test of a prototype.

5. CONCLUSIONS

ESO has decided to push forward the development of deformable mirror for two specific uses: for multi-object adaptive optics and extreme adaptive optics. Our objective is to make available to the E-ELT instrument consortia deformable mirrors fulfilling their needs for an optimal scientific performance. This development phase will not provide a commercial of the shelf component but a component for which the feasibility will demonstrated.