# The First Active Segmented Mirror at ESO

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**The Active Phasing Experiment (APE) is part of the Extremely Large Telescope Design Study which is supported by the European Framework Programme 6. This experiment, which is conducted in collaboration with several partners is a demonstrator to test and qualify newly-developed phasing sensors for the alignment of segmented mirrors and test the phasing software within a telescope control system to be developed for a future European Extremely Large Telescope. The segmentation of a primary mirror is simulated by a scaled-down Active Segmented Mirror of 61 segments which has been developed in-house.**

## Background

In order to gain experience with the phasing of segmented mirrors, in particular to develop new optical phasing sensors and to test the interface with the rest of the wavefront control system, ESO decided to perform an optical-bench type experiment, named the Active Phasing Experiment (APE). This project is part of the Extremely Large Telescope Design Study (ELTDS) which is supported by the European Framework Programme 6. The project is performed in close collaboration with the Istituto Nazionale de Astrofisica di Arcetri, the Instituto de Astrofísica de Canarias (IAC) and the Laboratoire d'Astrophysique de Marseille (LAM), and the industrial firm Fogale. The core optical element of APE, simulating the segmented primary mirror in a large telescope, is a scaled-down Active Segmented Mirror (ASM) with 61 segments which can all be controlled in piston, tip and tilt. The pupil of the telescope is re-imaged onto the ASM. The optical beam is then re-adapted to behave like the VLT output beam and distributed to the four phasing sensors to be tested in the experiment.

The design and integration phases of APE, which started in 2005, have been completed and the test phase will start in June 2007 during which time APE will be installed at the focus of one of the VLT unit telescopes in 2008.

Initially the APE team wanted to contract the design and manufacture of the ASM to a private company. However, when no company could be found which could meet the rather stringent requirements, it was decided to develop the ASM in-house, involving ESO groups in Integration, Optics, Electronics, Software and the ELT Project Office.

## Design and integration

The current design of the primary mirror of the European Extremely Large Telescope consists of 984 hexagonal segments (Gilmozzi and Spyromilio 2007). Each segment has a diameter of around 1.5 m and the size of the gaps between the segments is approximately 4 mm. In order to achieve the performance required for high-resolution imaging with extreme Adaptive Optics (AO), the hexagonal mirrors have to be aligned with a precision better than 15 nm rms. It was clearly not feasible to produce a scaled-down version of the full primary mirror. However, from a statistical point of view, a mirror with approximately 50 segments is already representative of a mirror with many more segments in terms of the study of issues like alignment algorithms or the effect of misalignments on image quality. The main requirements for the ASM can be summarised as:
- 61 segments in four rings around the central segment
- Segment size 17 mm to minimise the size of the re-imaged pupil and the relay optics on the optical bench
- Three degrees of freedom for rigid body movements, that is piston, tip and tilt for each segment
- Precision of displacement better than 2 nm (similar to an ELT)
- Range of displacement more than 15 µm (similar to an E-ELT)
- Size of the gaps between segments between 80 and 150 µm (scaled-down from the gap size in the ELT primary)
- Surface form quality better than 15 nm RMS (similar to the required surface quality of a real segment with active shape control)
- Operational temperature between 0˚C and 25˚C
- Possibility to exchange a segment in case of failure.
- Optical fibres to be inserted in two of the hexagonal mirrors (central mirror and one of the perimeter mirrors) to align APE with high efficiency

A segment unit, shown in Figure 1, consists of a base, three actuators, three springs and a hexagonal mirror. The 61 modules were assembled on a base plate (Figure 2). Since the precision of positioning the surfaces of the hexagonal mirrors relative to the base plate is better than 15 µm, it is necessary to be able to actively align all the mirrors. Among the set of candidates for the commercially available actuators, only piezo actuators could fulfil the ASM requirements. Since this type of active segmented mirror is the first of its kind it was decided to start development in mid-2005 with a prototype of only seven segments.

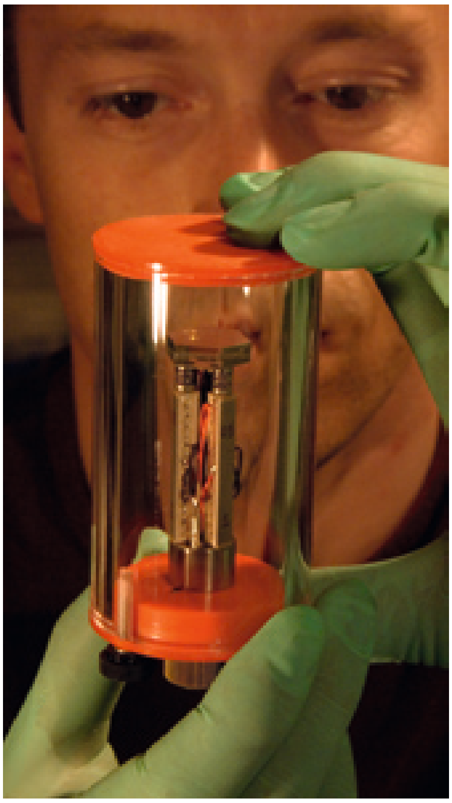

Photo: H. H. Heyer, ESO

Figure 1: Each segment is integrated separately. It is composed of one base, three piezo-actuators, three springs and a hexagonal mirror.

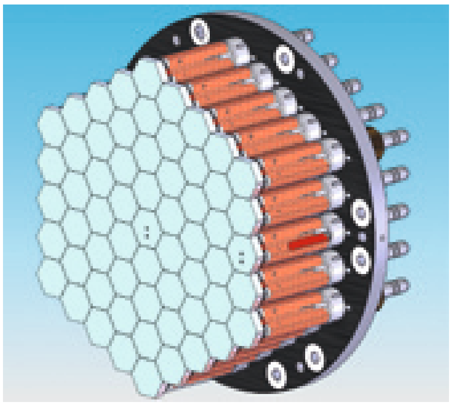

Figure 2: Mechanical design of the ASM made by Christoph Frank. The 61 segments are seen with the three actuators per segment, the module base, the support plate and the connectors behind the support plate. The fibres inserted in the central mirror and one of the mirrors on the right side of the ASM can also be seen.

Photo: H. H. Heyer, ESO

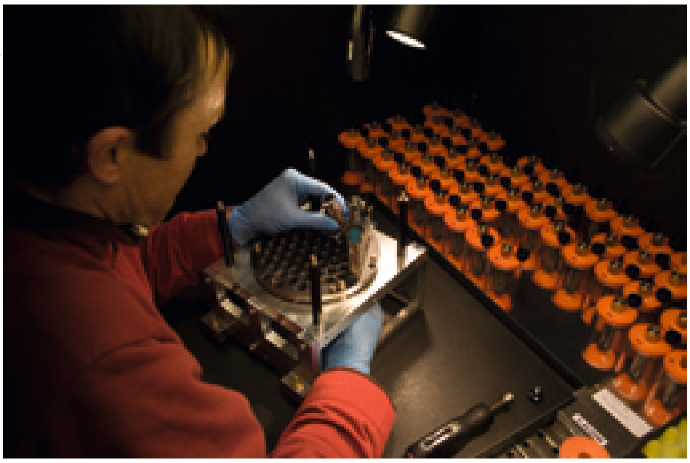

Figure 3: Integration of the ASM (having a plug and play concept) by Christophe Dupuy. Each segment is added one by one on a support polished plate which has a surface flatness better than 2 microns.

Photo: H. H. Heyer, ESO

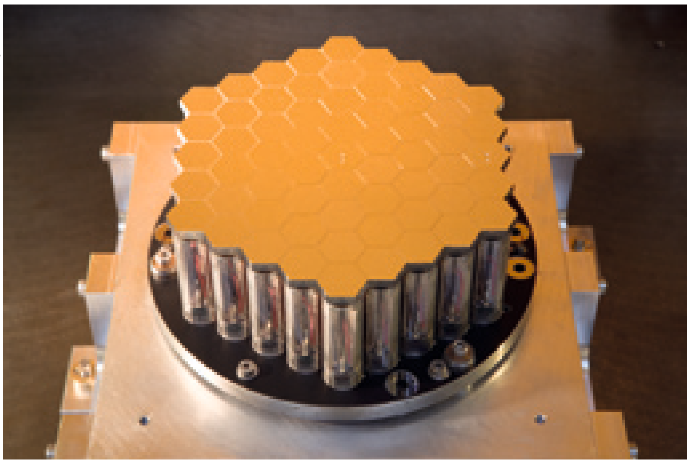

Figure 4: Photo of the fully assembled ASM.

The mechanical design has been made by Christoph Frank. The integration has been conducted by Christophe Dupuy for the opto-mechanical parts (see Figure 3), by Roland Brast for the drive electronics and by Robert Frahm for the software. The tests were performed by Constanza Araujo. Information obtained during the tests of the seven-segment prototype was used to improve the final design.

## Current tests

Several features have been tested on the fully integrated ASM (Figure 4), for example fatigue of the components, eigenfrequencies, speed and hysteresis of the positioning, drift of an actuated position, resolution and accuracy of the positioning, quality and cosmetics of the surfaces of the segments. The fully integrated ASM has fulfilled and, in some cases, even surpassed the specifications. Figure 5 shows an interferogram of the surface of the ASM while being tested. The tips and tilts of the segments have been selected such that the letters of the acronym ASM appear in the interferogram.

During the APE experiment, the ASM will be driven in closed loop based on signals obtained by an Internal Metrology system which consists of a two-wavelength interferometer developed by Fogale. The seven-segment prototype has been used to test the closed-loop system and achieved a performance better than 5 nm rms for the alignment errors at the intersegment borders.

The fully integrated ASM has now fulfilled and, in some areas, even surpassed the specifications. The success of this realisation now provides the possibility to fully test future phasing sensors of the E-ELT within the Active Phasing Experiment.

### References

Gilmozzi R. and Spyromilio J. 2007, The Messenger 127, 11

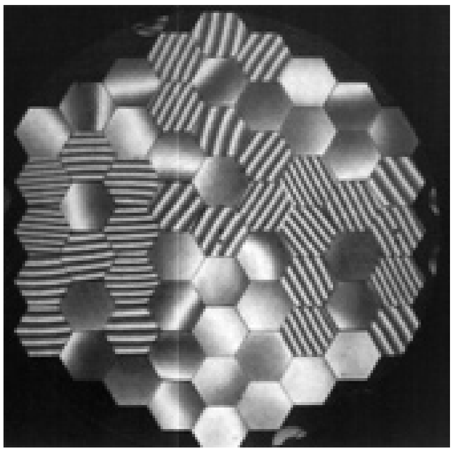

Figure 5: Interferogram of the surface of the ASM. Some segments have been tip-tilted to create fringes on some selected segments to write on it the acronym ASM.