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Coupling of WFS with a segmented DM

"Test of different concepts: SH, Pyramid, Zernike phase sensor"

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ABSTRACT

LAM is developing several R&D activities for E-ELT instrumentation, in particular, different WFS concepts are investigated (Pyramid, ZELDA, a Zernike phase mask sensor, Phase diversity or still NL Curvature) and an ESO-EELT M1 mirror segment (1.5 m) has been demonstrated. Segmented mirrors are not only the solution for the problem of ELTs monolithic size but also for other questions related to fabrication, optics replacement and transport. And, they are widely used today for other applications: fiber coupling, LGS beam shaping, etc. Their only problem is how to assure the cophasing of segments to take advantage of the full optimum size. In the present work, we study the sensitivity to different WFS (Sack-Hartmann, Pyramid and ZELDA) to pupil phase discontinuity using a PTT mirror from Iris AO. Various test such as segment phasing, stability, saturation, flat, or still the addressing mode are then performed and compared.

Keywords: E-ELT, Adaptive Optics, wavefront sensing, Pyramid WFS, Shack-Hartmann WFS, Zernike phase mask sensor, Segmented mirror, segments phasing.

1. INTRODUCTION

Segmented mirrors are widely used today in several domains [1,2,3,4,5]: fiber bundle coupling, laser beam shaping, microscopy, retina imaging and many other applications such as wavefront control of LGS beam, Fibered Imager for Single Telescope [1,2,3,4].

In astronomy, and more particularly in the era of the giant telescopes, segmented mirrors (SM) represent mainly mitigation to the problem of bigger mirror sizes (twin 10-meter Keck Telescopes: today state-of-the-art or still the next generation ones: GMT, TMT and E-ELT). Furthermore, they could offer other solutions relative to questions of fabrication, optics replacement or transport. However, the segmented mirrors also raise the problem of cophasing of segments, characterization and measurement of phase discontinuities due to the segmented pupils.

In the E-ELT frame work, The Laboratoire d'Astrophysique de Marseille (LAM) is developing several R&D activities for active and adaptive optics instrumentation. Indeed, our institute is deeply involved in the design of SCAO (Single Conjugated Adaptive Optics) and LTAO (Laser Tomography Adaptive Optics) systems for example, in the development of the OCAM2 camera, a state of the art detector (up to 2.2 kHz frame rate and RON close to zero) or still in the demonstration of an ESO-EELT M1 mirror segment (1.5 m). In adaptive optics in particular, different wavefront sensing concepts ($OCAM^2$-Pyramid, ZELDA: Zernike phase mask sensor, Phase diversity or still NL Curvature) are developed [5, 6, 7, 8].

The present work consists in coupling a segmented mirror with three different wavefront sensors: Shack-Hartmann, Pyramid and ZELDA. We aim to study their sensitivity to a segmented pupil and propose a suitable wavefront sensing approach for phase discontinuity measurements: segment phasing, stability, saturation, flat, or still different addressing modes are then performed.

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In the following, we will briefly introduce the Iris AO PTT111 mirror [9], used to simulate a segmented pupil, and describe specific software adaptations which we developed for our applications. Then, the experimental characterizations using our different wavefront sensors will be presented, analyzed and compared.

2. HEXAGONAL SEGMENTED MIRROR: PTT111

2.1 PTT111 presentation

The segmented mirror used for this work is a 37 hexagonal segments with three degrees of freedom (Piston-Tip-Tilt) and 111 actuators (PTT111 from Iris AO [9]). The technical specifications are summarized in Table 1.

Table 1. Iris AO PTT111 Mirror: technical specifications.

DM Type	111 actuator, 37 piston-tip-tilt segments
Stroke	5 or 8 µm
Tilt Angle	±4 or ±6.4 mrad
Optical Coating	Gold, protected-aluminum, protected-silver
Open-Loop Flat Surface Figure	< 20 nm rms
Inscribed Aperture	3.5 mm
Mechanical Response	< 200 µs
Maximum Operating Temperature	80°C
Drive Electronics	Low noise, 14-bit resolution with USB Interface
Interface Libraries	C/C++, Matlab

Figure 1 illustrates the different Deformable Mirror (DM) types and gives an overview of the MEMS technology used to achieve segmented mirrors with different degrees of freedom. In the figure 2 are shown the PTT111 with its electronic driver and a detailed view of its surface.

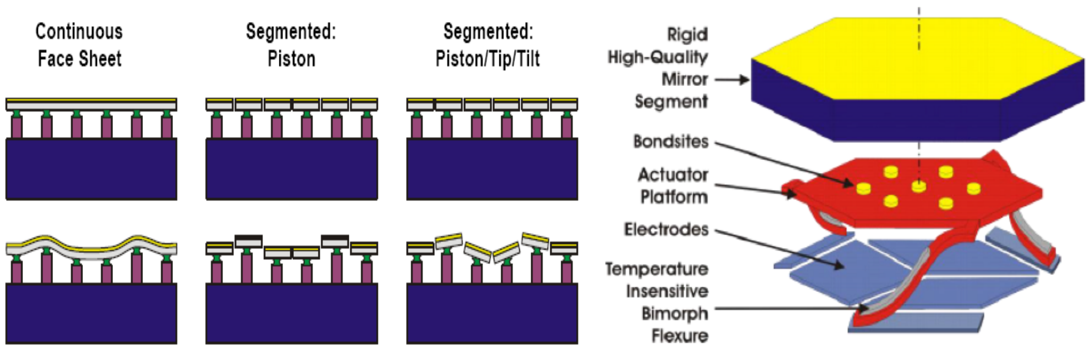

Figure 1. [Left]: Different DM types (Michael Helmbrecht). [Right]: MEMS Segmented DM technology principle.

Figure 2. [Left]: Presentation of the PTT111 and its driver [Right]: Surface view of the PTT111 DM (Iris AO).

2.2 LAM specific software developments

In order to fully perform our experiments and adapt the use of the segmented DM to our applications (ZELDA, Pyramid), we have developed a specific software module for its use. Figure 3 shows a Matlab user interface for the PTT111 control while in the Figure 4 is illustrated an example of different addressing modes.

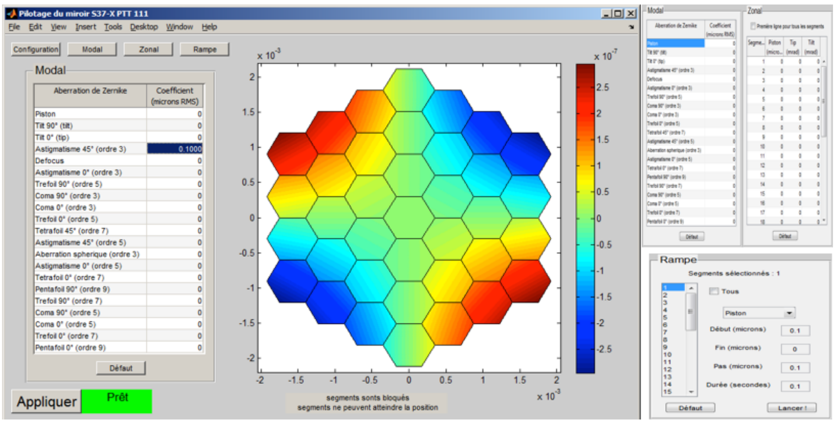

Figure 3. Matlab user interface developed at LAM (zonal &modal configurations, ramps ...)

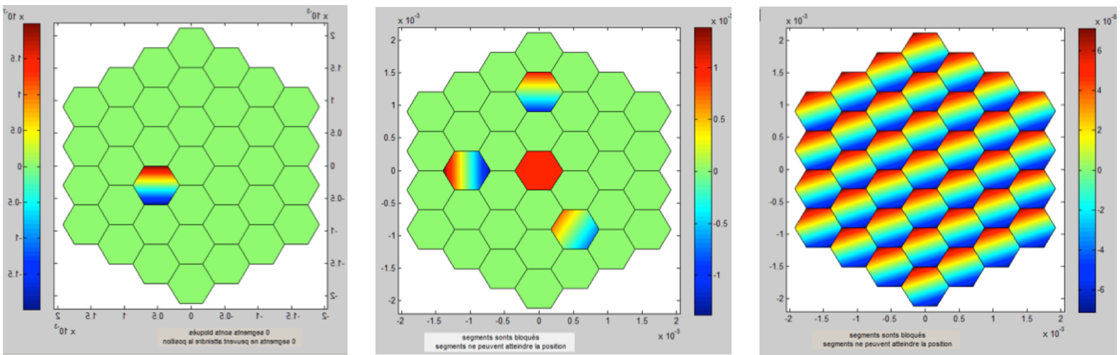

Figure 4. Example of individual and collective addressing modes.

3. EXPERIMENTATION

3.1 PTT111 coupling with a Shack-Hartmann WFS

We used an Imagine Optic's Shack-Hartmann wavefront sensor (HASO3 32 model: 32x32 sub-pupils).
The AO bench shown below (Figure 5) was used to perform and compare measurements obtained from both Shack-Hartmann and Pyramid wavefront sensors (respectively SH WFS and P-WFS). Only measurements with the SH are given in this section.

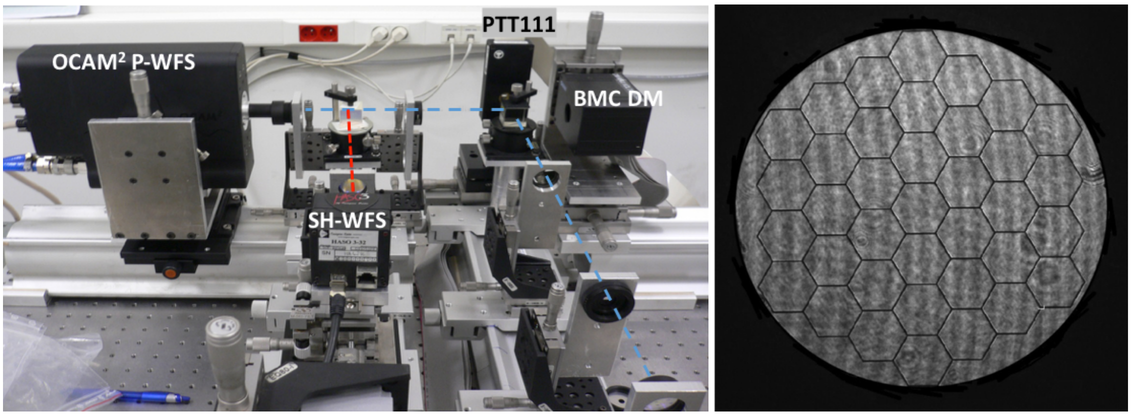

Figure 5. [Left]: LAM AO bench showing the PTT111 aligned with both sensors: P-WFS and SH-WFS (The Boston Micromachines DM is not used in this work). [Right]: Pupil view showing the active surface of the PTT111 segmented mirror.

Using the SH-WFS, we first verified the ability of the PTT111, as mentioned by Iris AO, to produce Zernike modes in Open Loop mode operation. Figure 6 is showing a quite good agreement between the Mirror shape Open-Loop produced by Iris AO and our measured Zernike modes.

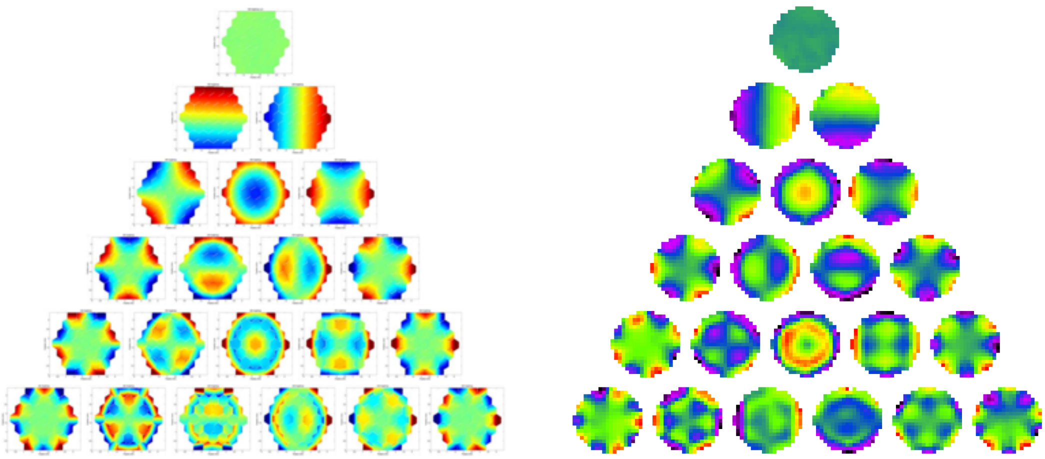

Figure 6. [Left]: Mirror Shape for Open-Loop (Iris AO). [Right]: Measured Zernike modes with a SH-WFS (0.02 μm RMS)

Then, we performed various other tests among which the stability over time or still the Input/output calibration: indeed, the PTT111 has shown a very good segments shape stability over a long time (few hours) and quite good ability to produce a desired shape (Figure 7).

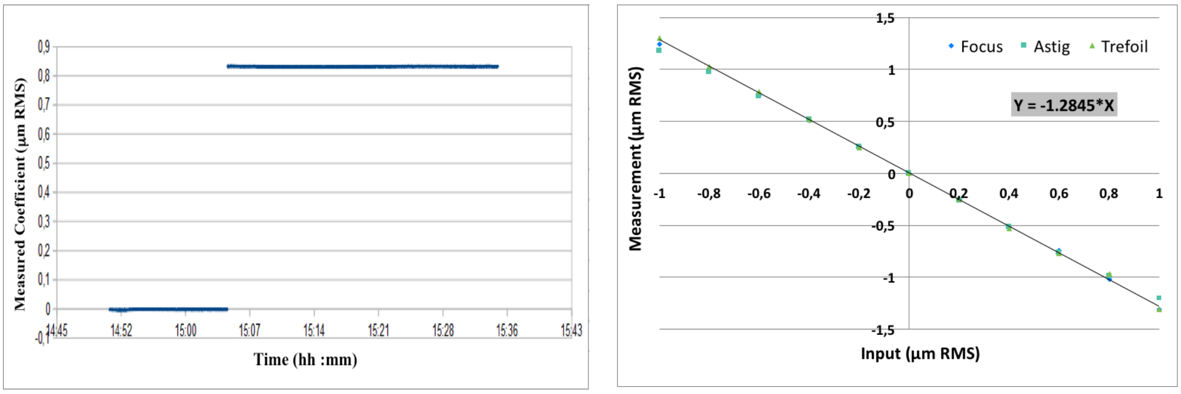

Figure 7. [Left]: Example of stability over time. [Right]: PTT111 Input / Output calibration showing a slope of -1.3

However, for high order spatial frequencies measurements, and contrary to the previous measures, the SH WFS was unable to perform properly. Indeed, when addressing the segments individually, the signal obtained from the SH was seen over the entire analyzed pupil (3 mm diameter) while the segment size is only about 700 µm diameter.

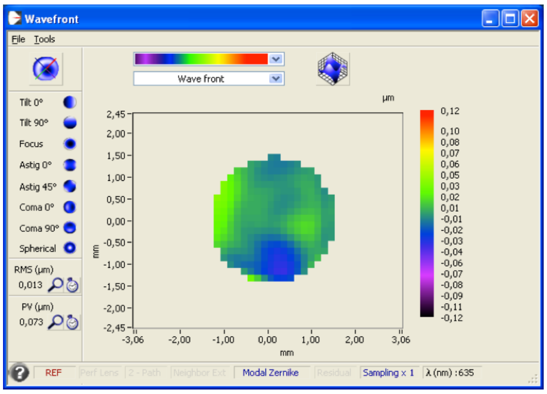

Figure 8. Single segment piston (segment size: 700 µm diameter; analyzed pupil size: 3 mm diameter)

3.2 PTT111 coupling with a Pyramid WFS

To perform these measurements, the LAM OCAM^2-Pyramid WFS was used on the same AO bench (shown in figure 5) and in a 40x40 regime without modulation (Table 2).

Table 2. LAM Pyramid WFS specifications.

Detector (state-of-the-art)	OCAM^2 (1500 FR and RON< 1e-); 240x240 pixels (24 µm)
Pyramid mode	Unmodulated
Pupil Size	40x40

As illustrated in the figure 9 for few examples of aberrations, the P-WFS is performing very well for the low spatial frequencies measurements. Contrary to the SH WFS, the Pyramid has especially shown a high sensitivity to high order frequencies: figure 10 is showing clearly the ability of the pyramid to measure high spatial frequencies when addressing the segments individually for example.

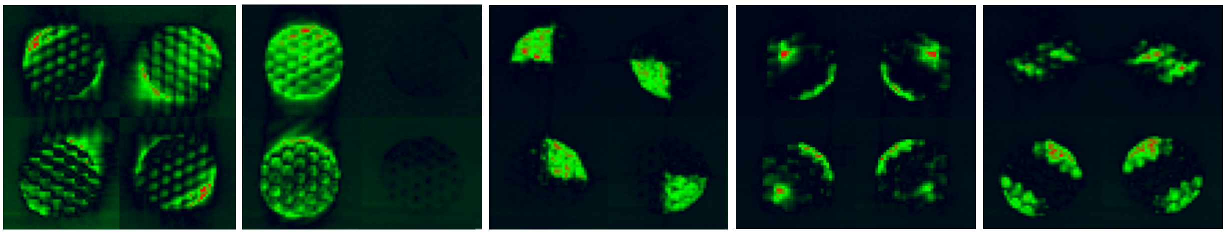

Figure 9. Example of measured aberrations with the Pyramid WFS (with image processing). From left to right: No aberration (flat mirror), Tilt, Astigmatism 45, Spherical and Coma Y.

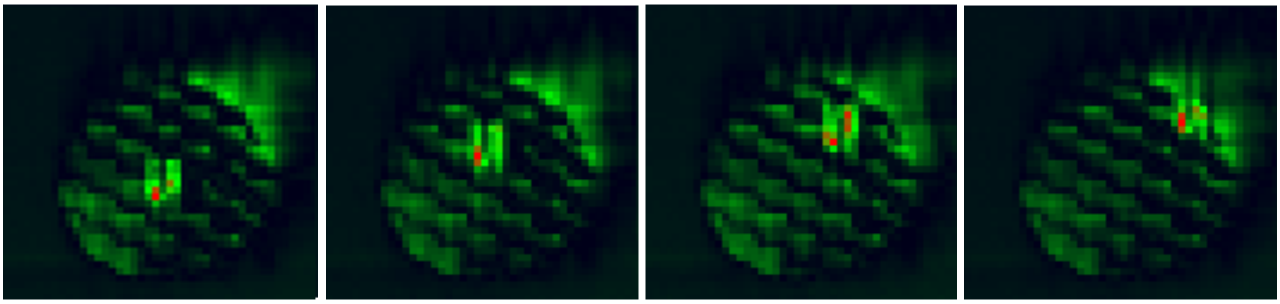

Figure 9. Example of single segment piston addressing (only same/one pupil is shown). From left to right: Segments 1, 2, 9 and 22.

3.3 PTT111 coupling with Zernike phase mask sensor (ZELDA)

The principle of the ZELDA, a Zernike phase mask (ZPM) sensor, developed by LAM is shown on figure 11 [left]. Based on a phase aberration to intensity variation conversion (phase mask diffraction) and a simple phase retrieval algorithm, it is mainly dedicated to small phase aberrations [8]. The coupling of the PTT111 with ZELDA is also shown on figure 11 [right].

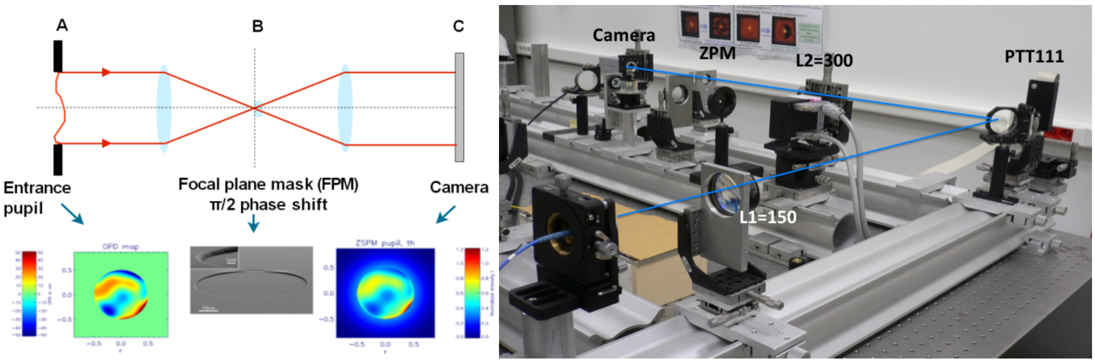

Figure 11. [Left]: Zernike phase mask principle. [Right]: ZELDA Bench with PTT111 DM.

For ZELDA also, we developed a specific Matlab user interface (Figure 12). In the Figure 13 are given examples of few aberrations measured with ZELDA. When using a single segment addressing The ZELDA sensor has been shown to be clearly sensitive to high order frequencies: Pison and Tilt are applied on the central segment and shown on figure 14.

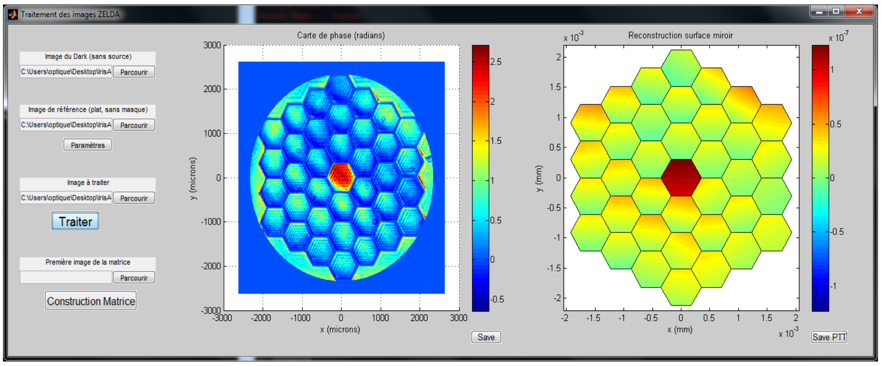

Figure 12. ZELDA user interface (developed at LAM) showing phase map and corresponding PTT111 mirror surface.

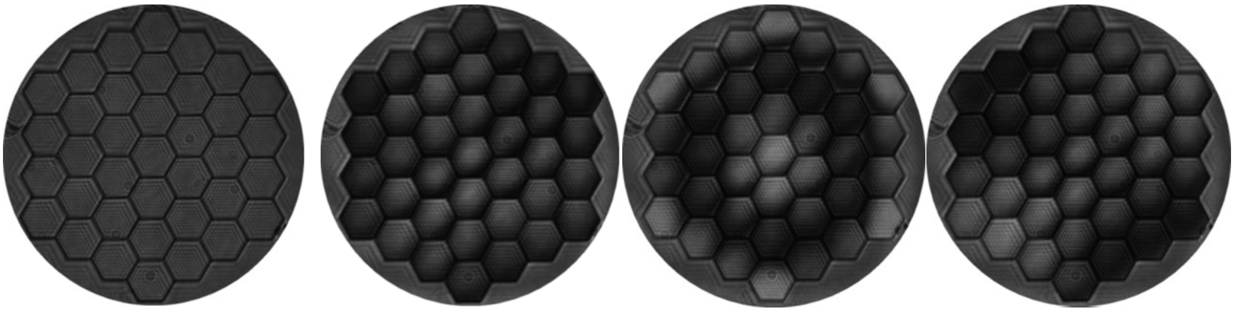

Figure 13. Examples of few aberrations measured with ZELDA. From left to right: Flat mirror without Zernike mask, flat mirror with Zernike mask, spherical and astigmatism 45 aberrations.

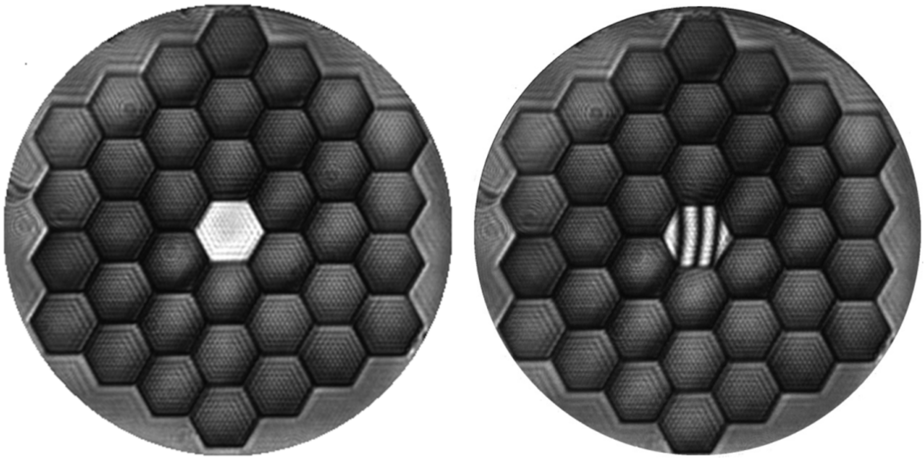

Figure 14. Single segment addressing: Piston (left) and Tilt (right) on central segment.

4. CONCLUSION AND PERSPECTIVE

In this we used an Iris AO PTT111 DM to simulate and study the effect of segmented pupil with different WFS concepts: Shack-Hartman (SH-WFS), Pyramid (P-WFS) and Zernike phase mask (ZELDA).

- SH-WFS: various tests with this sensor have shown the ability of the PTT111 to generate, with quite good agreement, the first 21 Zernike modes. A good stability (over a day) has been observed. However, for high order modes and high amplitudes, our characterization has shown a blocking of few segments, located around the edge. Except for low order modes, the SH is very limited for high order spatial frequencies (ex: single segment measure) and, consequently, not a suitable sensor for phase discontinuity errors measurements.

- P-WFS: our characterization, although qualitative, has nevertheless shown a higher sensitivity of this sensor and its capacity to measure both low/high order spatial frequencies. Further tests still remain to be performed.
- ZELDA Sensor: more sensitive to small phase errors and with very high spatial resolution, this sensor, already implemented on the VLT-SPHERE [8], is a good candidate for phase discontinuity measurements (low wind effect).

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