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# **Adaptive Optics system of the Evanescent Wave Coronagraph** (EvWaCo) – optimised phase plate and DM characterisation

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#### ABSTRACT

The Evanescent Wave Coronagraph (EvWaCo [1]) is an achromatic coronagraph mask with adjustable size over the spectral domain [600 nm, 900 nm] that will be installed at the Thai National Observatory (TNO). We present in this work the development of a bench to characterise its Extreme Adaptive Optics system (XAO) comprising a DM192 ALPAO deformable mirror (DM) and a 15x15 Shack-Hartmann wavefront sensor (SH-WFS). In this bench, the turbulence is simulated using a rotating phase plate (PP) in a pupil plane. In general, such components are designed using a randomly generated phase screen. Such single realisation does not necessarily provide the wanted structure function (SF). We present a solution to design the printed pattern to ensure that the beam sees a strict and controlled Kolmogorov statistics with the correct 2D structure function. This is essential to control the experimental conditions in order to compare the bench results with the numerical simulations and prediction. This bench was further used to deeply characterise the full 27 mm pupil of the ALPAO DM using a 54×54 ALPAO SH-WFS. We measure the average shape of its influence functions as well as the influence function. We study the linearity of the actuator amplitude with the command as well as the linearity of the actuator amplitude with the command as well as the linearity of the actuator amplitude with the command as well as the linearity of the actuator to study the linearity of the actuator amplitude with the command as well as the linearity of the actuator amplitude with the command as well as the linearity of the actuator and a the linearity of the actuator amplitude with the command as well as the linearity of the actuator amplitude with the command as well as the linearity of the actuator amplitude with the command as well as the linearity of the actuator amplitude with the command as well as the linearity of the actuator amplitude with the command as well as the linearity of the actuator amplitude with the actuator amplitude wit of the influence function profile. We also study the actuator offsets as well as the membrane shape at 0-command. This knowledge is critical to get a forward model of the DM for the XAO control loop.

# **1. AO SYSTEM OF EVWACO**

![](_page_0_Picture_13.jpeg)

![](_page_0_Picture_14.jpeg)

# 2. AO CHARACTERISATION BENCH

![](_page_0_Picture_16.jpeg)

(a) EvWaCo WFS in Fried's geometry pupil based on the ALPAO DM192: 15×11 subapertures (green squares) and 16×12 actuators (black dots). Red ellipse: EvWaCo elliptical unobstructed pupil of 1.17×0.83 m<sup>2</sup>. Blue circle: 27.5 mm DM full aperture. (b) EvWaCo WFS hardware: Nüvü 128AO EMCCD and custom designed lenslet array from Smart MicroOptical Solution company [2] (green). Red: camera mount and lenslet adaptor and clamping system designed and manufactured at NARIT.

![](_page_0_Figure_18.jpeg)

AO loop algorithms development [3]. Colours: theoretical and designed sizes, sizes limited by the **EvWaCo pupil** or by the **DM aperture**. (b) PP to emulate the turbulence with two tracks corresponding to typical nights at the **TNO** (median and best quartile).

(a) Dedicated AO bench designed and built

at NARIT for component characterisation and

(c) PSF after flattening the DM with the  $54 \times 54$ ALPAO SH-WFS [without  $L'_5$ ]. Green circles: DM diffraction orders.

(d) Pupil image of the full DM aperture (green circle) [with  $L'_5$ ].

(e) Selecting the EvWaCo or the ALPAO SH-WFS with the flip mirror. Raw data of the EvWaCo WFS.

(f) EvWaCo WFS lenslet array imaged with scattered light (orange beam in (a)) [with  $L'_5$ ].

## **3. PHASE PLATE DESIGN AND CHARACTERISATION**

![](_page_0_Figure_25.jpeg)

(a)

(a) Layout of the PP. Blue curved arrow: the PP rotates in front of the beam (black circles).

(b) A single random realisation from a process that follows in average a 2D Kolmogorov statistics [4] does not produce the expected 2D SF. Dotted (full screen) and dashed (on the

annulus) curves: in the PP frame. Plain curves: in the beam frame, as schemed by the black circles in (a). x-axis: 0-12 mm. (c) We select among 1500 realisations the draw giving the best SF cut-profiles in the beam frame.

(d) Zoom on the proposed PP design in the beam frame. Coloured dashed lines: cut-profile orientations. (e) 54×54 ALPAO SH-WFS measurements on the PP manufactured by Lexitek [5]. Despite a manufacturing artefact, the

### 4. ALPAO DM192 CHARACTERISATION

(a) Robust influence function measurement of the DM (a1) Measured phase for  $5 \times 192$  binary random commands of an amplitude c.

(a2,3) After inverting the measurement model, we retrieve both the 192 influence functions (a2) and the **bench background** (a3).

(b) Spatial frequency decomposition of the background

- (b1) Low order Zernike fit. (b2) High order residuals.
- (b3) Out-of-focus beam features match (b2).

![](_page_0_Figure_36.jpeg)

![](_page_0_Figure_37.jpeg)

![](_page_0_Figure_38.jpeg)

0.02

![](_page_0_Figure_39.jpeg)

(b1) Zernike background 

![](_page_0_Figure_41.jpeg)

(b3) Beam in the bench

![](_page_0_Picture_43.jpeg)

produce a large scale aberration.

![](_page_0_Figure_47.jpeg)

(c) Fitting the influence functions with radially axisymmetric splines is more general than the standard

super-Gaussian profiles [6]. Example on the actuator 54. Spatial scale: actuator pitch.

(c1) Red (resp. black) curves: global (resp. local) profile fitted in the grey data of all the actuators (resp. the **blue** data of **the given actuator**). The coupling is around 34.5%.

(c2) Residuals of the global fit: the profile slightly differs from the average profile.

(c3) Residuals of the local fit: there is some cross-talk with the neighbouring actuators.

upper right corner: cluster of actuators with significantly lower maximal stroke of  $\sim 1.8 \,\mu m$ .

(d3) After removing the offsets, the linearity deviation is in the range of [-4%, 2%].

![](_page_0_Figure_55.jpeg)

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