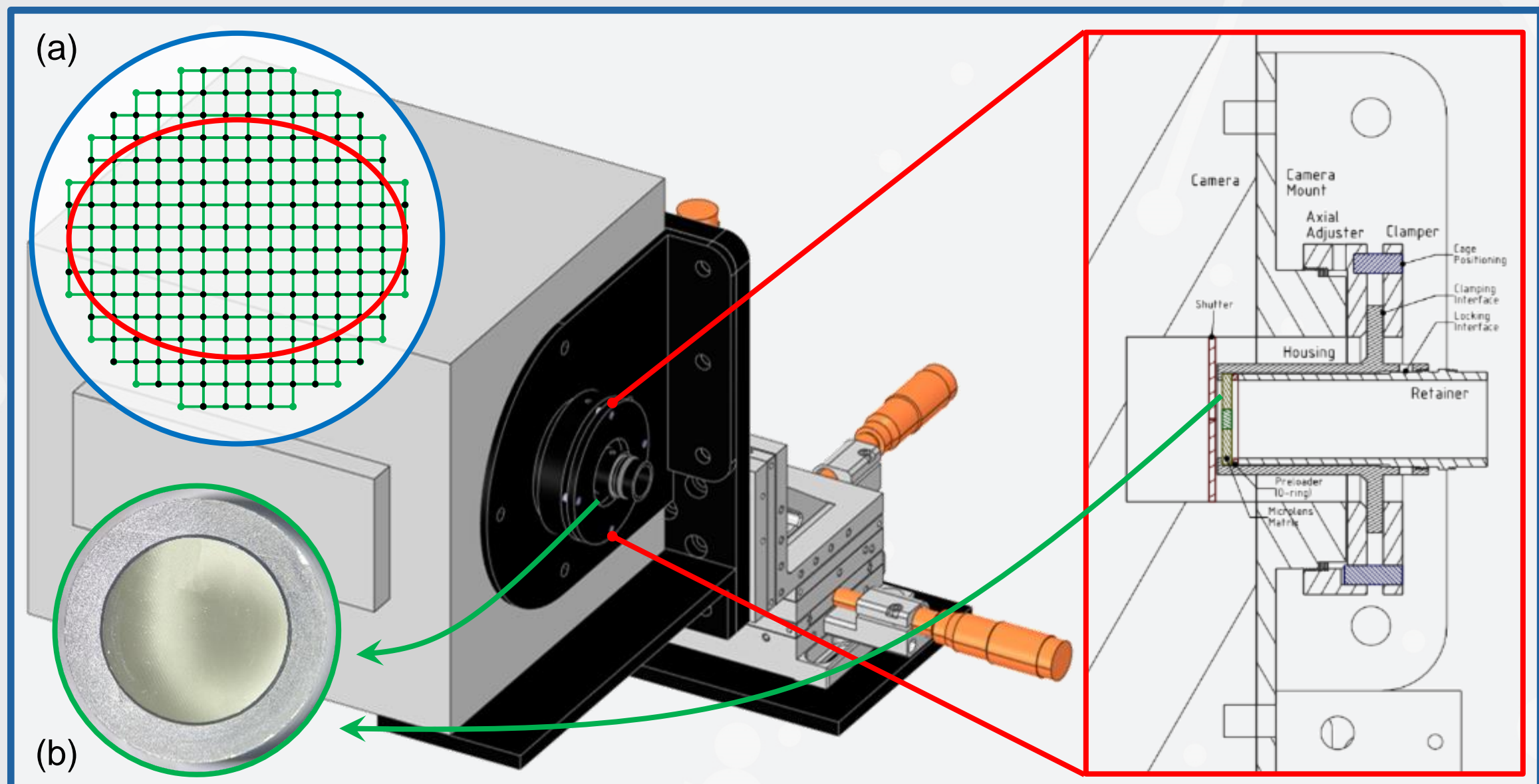


ABSTRACT

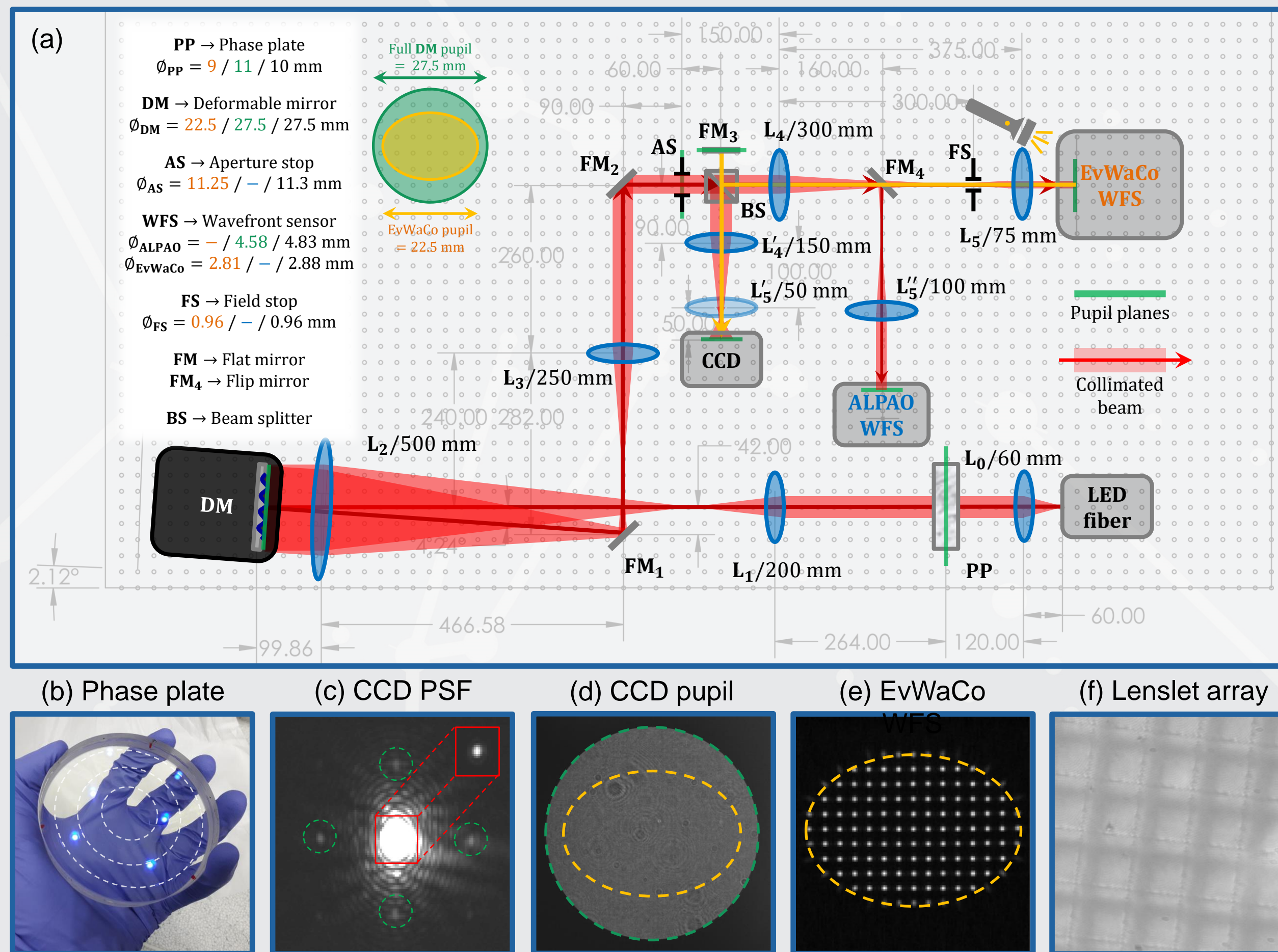
The **Evanescent Wave Coronagraph (EvWaCo)** [1] is an **achromatic coronagraph mask with adjustable size** over the spectral domain [600 nm, 900 nm] that will be installed at the Thai National Observatory (TNO). We present in this work the development of a bench to characterise its Extreme Adaptive 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 54x54 ALPAO SH-WFS. We measure the average shape of its influence functions as well as the influence function of each single actuator to study their dispersion. We study the **linearity of the actuator amplitude** with the command as well as the **linearity 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



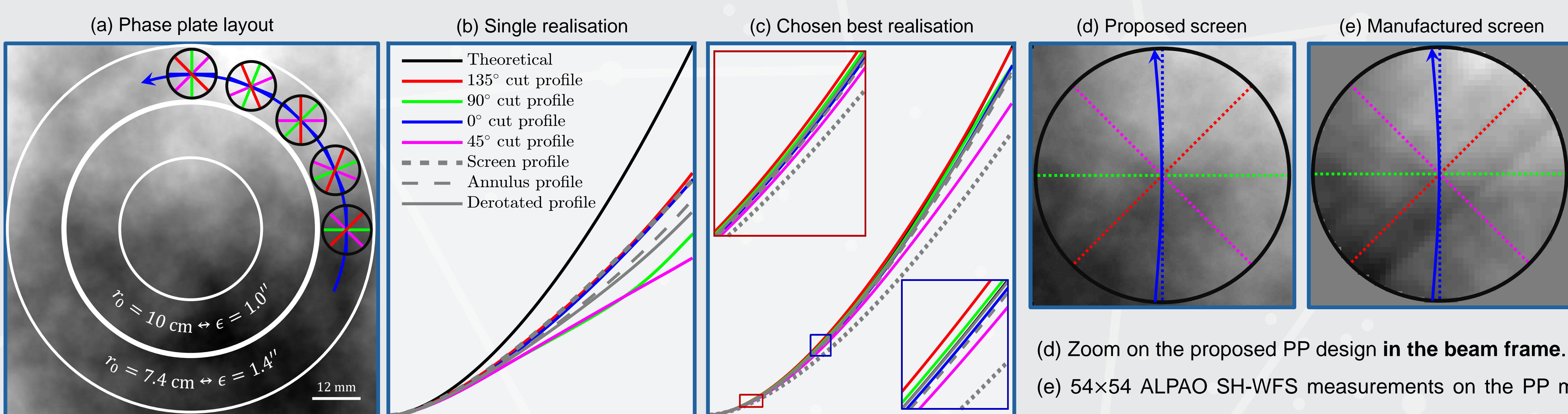
(a) EvWaCo WFS in Fried's geometry pupil based on the ALPAO DM192: 15x11 sub-apertures (green squares) and 16x12 actuators (black dots). Red ellipse: EvWaCo elliptical unobstructed pupil of 1.17x0.83 m². Blue circle: 27.5 mm DM full aperture.
(b) EvWaCo WFS hardware: Nüvü 128AO EMCCD and custom designed lenslet array from Smart MicroOptical Solution company [2] (green). Red: camera mount and lenslet adaptor and clamping system designed and manufactured at NARIT.

2. AO CHARACTERISATION BENCH



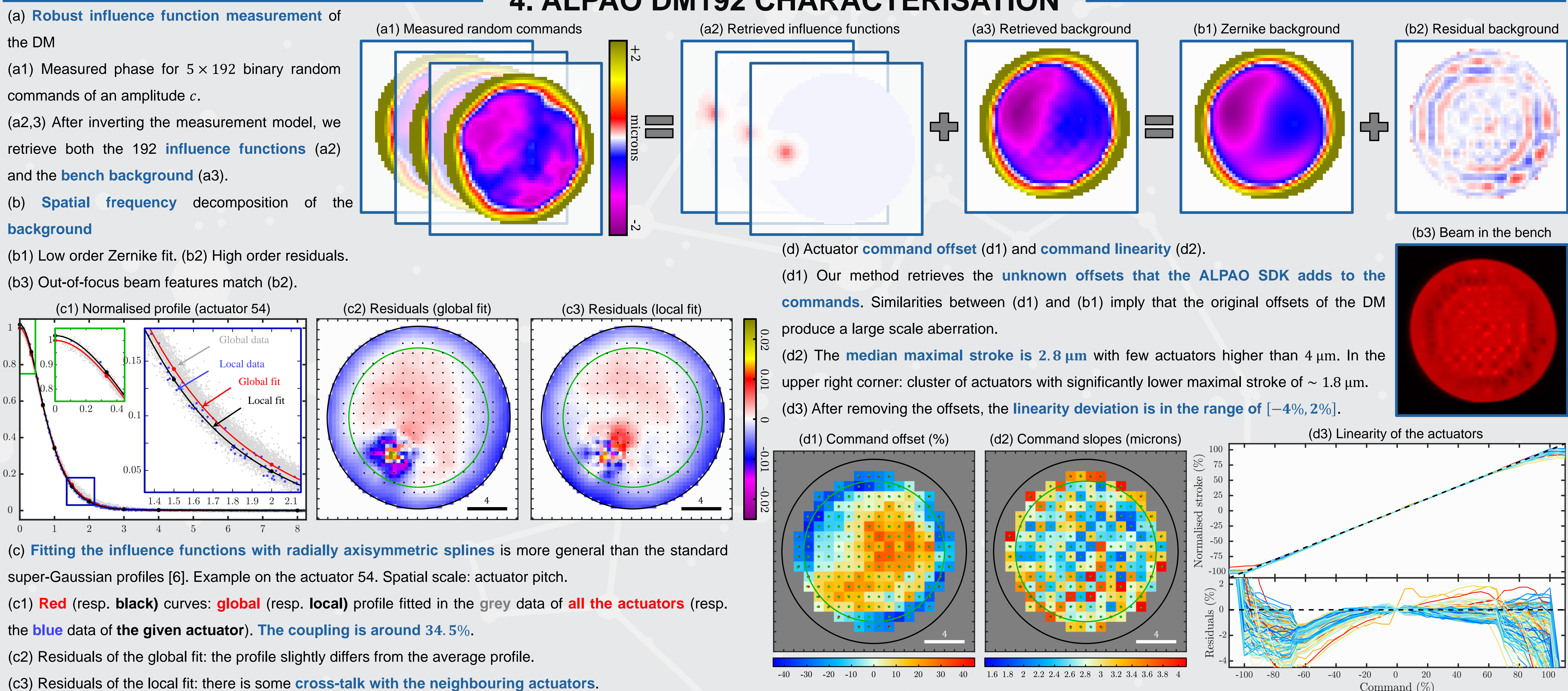
(a) Dedicated AO bench designed and built at NARIT for component characterisation and AO loop algorithms development [3]. Colours: theoretical and designed sizes, sizes limited by the EvWaCo pupil or by the DM aperture.
(b) PP to emulate the turbulence with two tracks corresponding to typical nights at the TNO (median and best quartile).
(c) PSF after flattening the DM with the 54x54 ALPAO SH-WFS [without L₅]. Green circles: DM diffraction orders.
(d) Pupil image of the full DM aperture (green circle) [with L₅].
(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 L₅].

3. PHASE PLATE DESIGN AND CHARACTERISATION



(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) 54x54 ALPAO SH-WFS measurements on the PP manufactured by Lexitek [5]. Despite a manufacturing artefact, the procured PP has a 2D Kolmogorov SF with controlled r₀.

4. ALPAO DM192 CHARACTERISATION



(a) Robust influence function measurement of the DM
(a1) Measured phase for 5 x 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).
(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.
(d) Actuator command offset (d1) and command linearity (d2).
(d1) Our method retrieves the unknown offsets that the ALPAO SDK adds to the commands. Similarities between (d1) and (b1) imply that the original offsets of the DM produce a large scale aberration.
(d2) The median maximal stroke is 2.8 μm with few actuators higher than 4 μm. In the upper right corner: cluster of actuators with significantly lower maximal stroke of ~ 1.8 μm.
(d3) After removing the offsets, the linearity deviation is in the range of [-4%, 2%].
(d1) Command offset (%)
(d2) Command slopes (microns)
(d3) Linearity of the actuators