Non-Common Path Aberrations correction for the GTC Adaptive Optics system: calibration and compensation of static aberrations.

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ABSTRACT

The Adaptive Optics system of the GTC features a single deformable mirror (DM) with 373 actuators, conjugated to the telescope pupil, and a Shack-Hartmann wavefront sensor with 312 subapertures, using an OCAM2 camera. The expected performance of the GTCAO system when working on average atmospheric conditions and bright natural guide stars is to provide the science instrument with a 65% Strehl Ratio beam in K-band.
To achieve the ultimate performance of the system we have to correct the Non-Common Path Aberrations (NCPA) that are unseen by the Wavefront Sensor. We have implemented a Phase Diversity (PD) technique in our system, introducing known aberrations with the DM and measuring the aberrated images in the science camera. Using the DM has the advantage that the science instrument does not need to be translated to obtain the defocused images, but the drawback is that errors in modelling the DM or the science camera translate into errors in the NCPA algorithm.
We discuss in this contribution the problems we have faced to model and calibrate the system adequately, the practical implementation of the PD technique in the laboratory and the results of the tests in the optical bench.

Keywords: adaptive optics, NCPA correction

1. INTRODUCTION

The GTCAO system is designed to provide single-conjugate adaptive optics for its scientific instrument, FRIDA. It will use one NGS in first light. The preliminary design was described by Bello et al [1], and its main parameters are shown in Table 1. The project is now in the Laboratory Test Phase. In the meantime, we are working in an upgrade to install a TOPTICA Na laser [2] in GTC to generate a LGS. The present WFS would be used as Tip-Tilt (TT) NGS and a LGS WFS will be placed on the GTCAO bench (Figure 1).

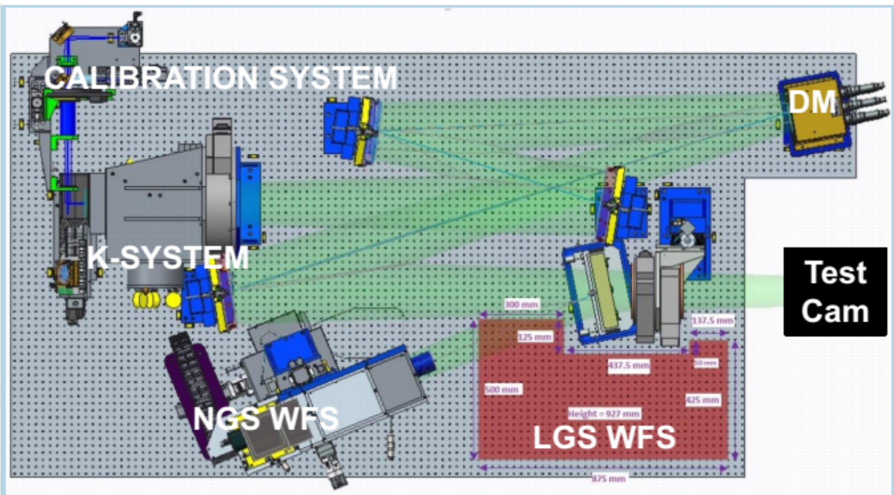

Figure 1: GTCAO bench

GTCAO SYSTEM PARAMETERS	
Diameter	10.4 m
Obscuration	1.4 m
Subapertures/diam	20
WFS Pix/subap	10
Pixel scale	0.35 arcsec/pix
WFS Field stop	3.5"
Frequency	2 KHz
Exposure time	0.5 ms
t_{delay}(exp+comm)	1 ms
WFS ron	0.1 e/pix/frame
Bandwidth	470-900 nm
Wavelength	2.2 μm

Table 1: GTCAO system parameters

2. NCPA CALIBRATION WITH PHASE DIVERSITY

The Phase Diversity (PD) technique [3] consists in obtaining images which are in-focus and out-of-focus by a known amount, and apply an algorithm to determine the Zernike coefficients which best match the data. Main error sources are of three types: imperfect system knowledge, image acquisition and pre-processing and limitations of the algorithm. In the GTCAO system the defocus will be introduced using the DM. To do that a very reliable characterization of the DM is necessary. The PD algorithm results strongly depend on having a good model of the theoretical PSF and a good characterization of the DM in the case it is used for the defocusing. To relax this requirement we plan to use the NGS WFS. Working in close loop, the NGS WFS is displaced and automatically a defocus is sensed and corrected by the DM. In that way we do not depend on the DM model for applying a reliable defocus.
We have written a PROPER-based [4] code in MATLAB to search for the optimum Zernike coefficients of the diversity input images. The code computes the Optical Transfer Function (OTF) of every image, compares it with the OTF of the corresponding reconstructed image and minimizes the rms error globally. We tested it with synthetic images with good results, as can be seen in Figure 2 and Figure 3.

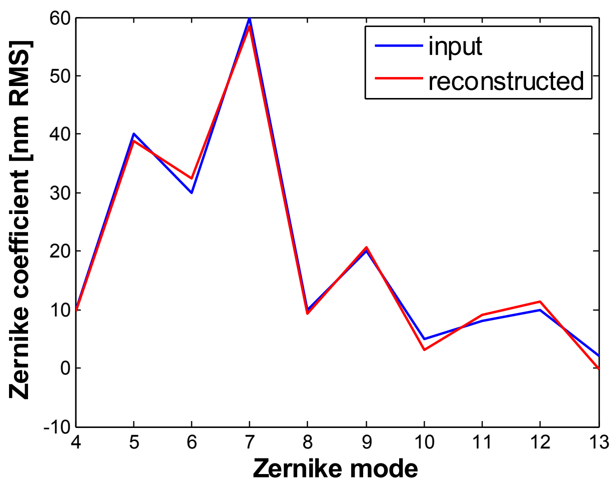

Figure 2: Zernike coefficients of the aberrations applied to the synthetic images vs. retrieved Zernike coefficients after applying the PD algorithm.

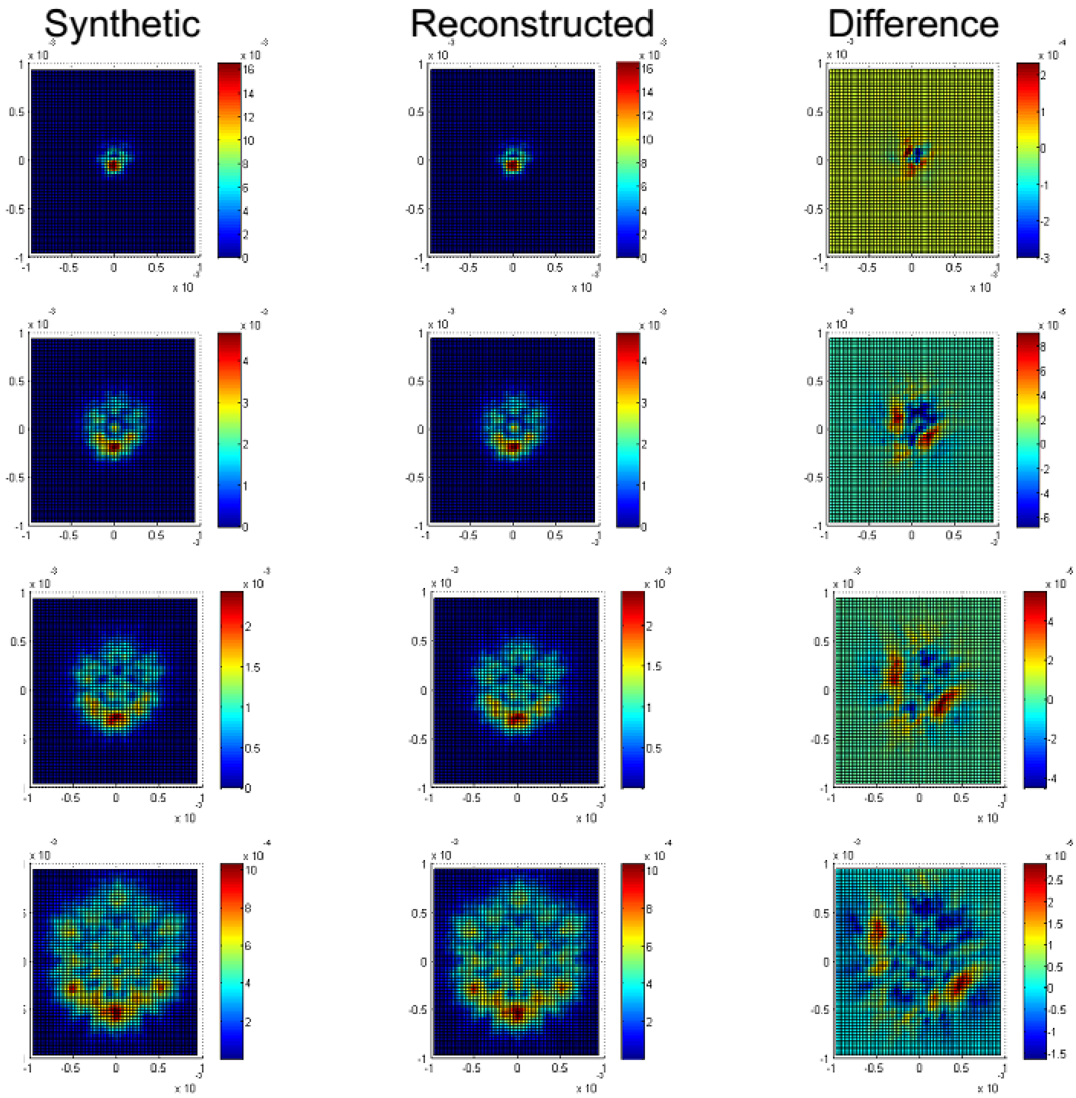

Figure 3: results of the NCPA calculation algorithm with synthetic images. The column on the left shows the synthetic images, the column in the center the images reconstructed by the algorithm with the calculated NCPAs, and the column at the right shows the differences among them.

3. NCPA COMPENSATION: LAB RESULTS

Our plan was to acquire the diversity images in the TC in close loop, moving the NGS WFS to command the defocus in the DM. Due to a problem we encountered measuring the scale among the displacement of the WFS and the defocus applied to the DM we didn't succeed with that approach. We therefore decided to model the DM and command a pure defocus directly, in open loop. In Figure 4 we have plotted the real images acquired in the bench for each defocus, giving the Z4 coefficient in nm rms. We compare them with the images reconstructed with the PD algorithm. We were successful with this strategy and the close loop Strehl changed from 0.88 to 0.98 @ 1.6 micron as can be seen in Figure 6. The retrieved Zernike coefficients are shown in Figure 5 and result in 49.8 nm wavefront rms.

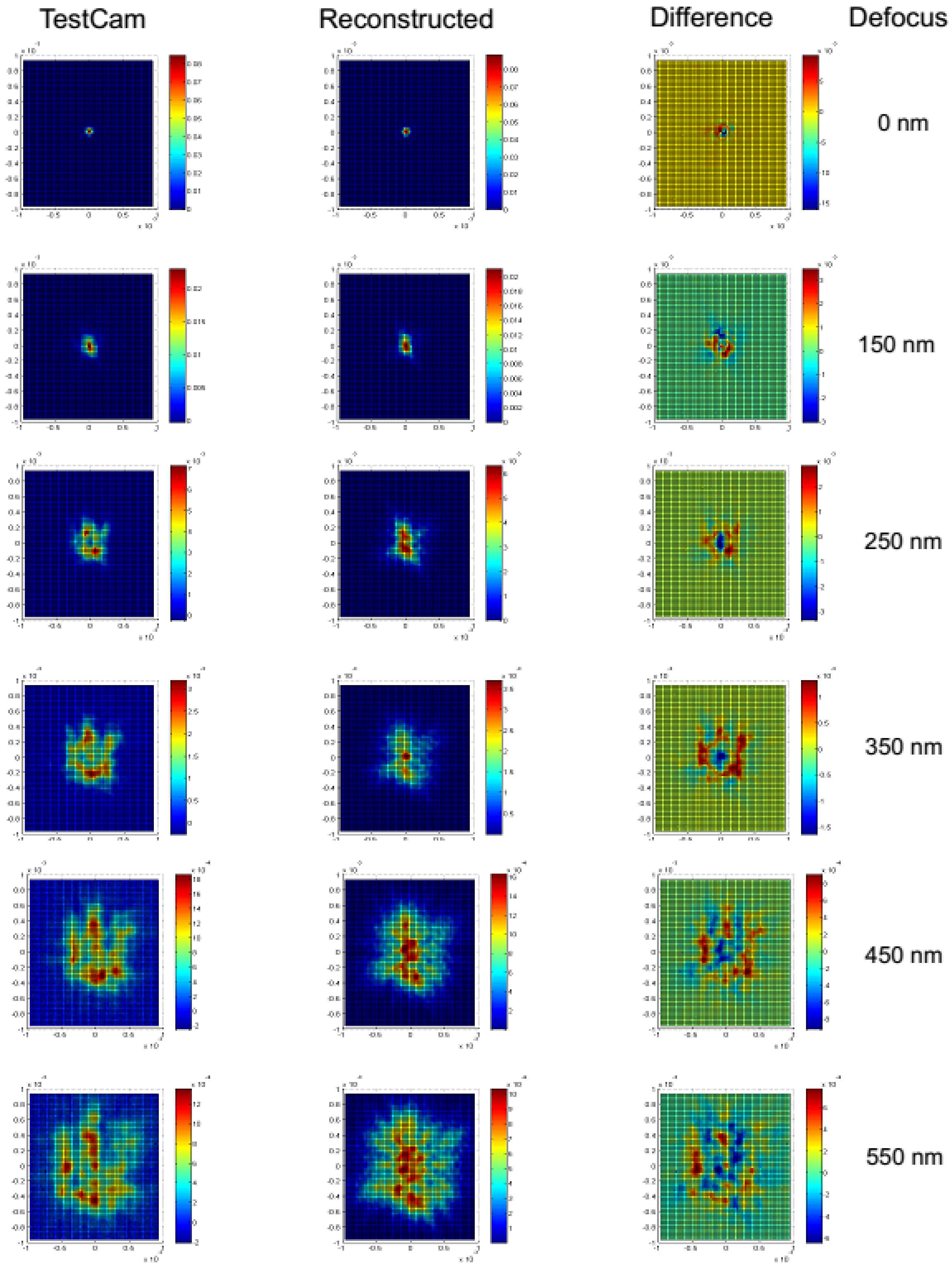

Figure 4: results of the NCPA calculation algorithm with images from the GTCAO bench. The column on the left shows the real images, the column in the center the images reconstructed by the algorithm with the calculated NCPAs, and the column at the right shows the differences among them. At the right is the Z4 defocus expressed in nm rms.

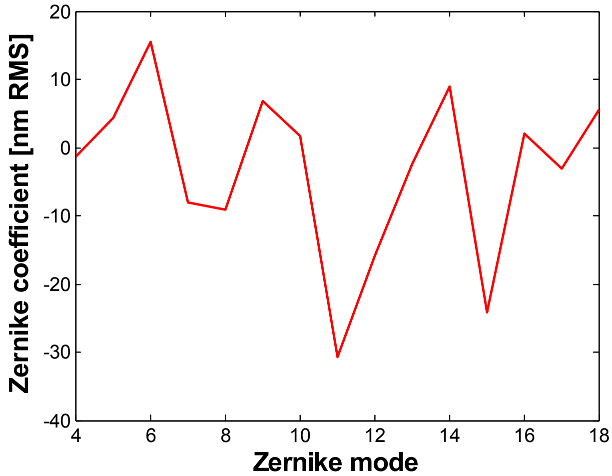

Figure 5: Zernike coefficients of the NCPAs measured with the PSD algorithm in the GTCAO bench.

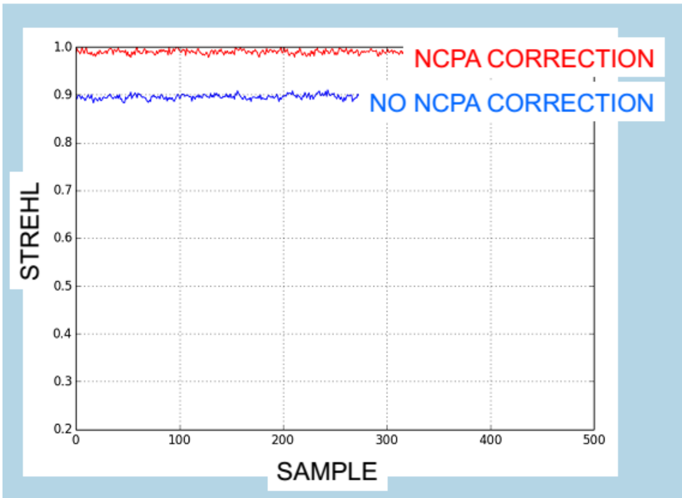

Figure 6: comparison of the Strehl of the GTCAO system in closed loop with and without NCPAs correction.

4. DISCUSSION

We had a successful result acquiring the diversity images in open loop, but this strategy is not optimal since it depends strongly not only in the model of the DM (which may change with time, temperature, etc…) but also in the environmental conditions. NCPAs must be calibrated and corrected periodically and environmental conditions in the telescope (e.g. vibrations) may be different than in the Assembly, Integration and Verification lab where we are testing the system. Therefore, the ideal approach is to acquire the science instrument images in close loop, moving the NGS WFS. In the future we plan to investigate the problems we encountered with the close loop strategy in order to be able to implement it in the instrument.

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REFERENCES

1. D. Bello, L. Boucher, M. Rosado, J. Castro López, P. Feautrier, "Characterization of the main components of the GTCAO system: 373 actuators DM and Ocam2 camera" Proc. Third AO4ELT Conference 1, (2013).
2. M. Enderlein et al., "Series production of next-generation guide-star lasers at TOPTICA and MPBC" Proc. SPIE. 9148, (2014).
3. Blanc, A. et al., "Calibration of NAOS and CONICA static aberrations", Astron. Astrophys., 299, pp373-383 (2003).
4. John E. Krist, "PROPER: an optical propagation library for IDL", Proc. SPIE 6675, Optical Modeling and Performance Predictions III, 66750P (23 October 2007).