Second stage Adaptive Optics with double Zernike mask for future Extreme Adaptive Optics systems on Extremely Large Telescope : theory, simulation and experimental validations

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Abstract

The next generation of Extremely Large Telescopes (ELT) will provide high angular resolution and broad sky coverage allowing astronomers to study very faint object such as exoplanets. To do this, an Extreme Adaptive Optics (XAO) systems is required. The Single-Conjugated Adaptive Optics systems of the ELT will be equiped of a Pyramid wave-front sensor, allowing to highly mitigate the atmospheric turbulence. However, a second correction stage is needed to further reduce the AO residuals down to a level compatible with high-contrast performance and to correct the aberrations induced by the telescope itself such as Low-Wind Effect or differential piston. This two-stage correction will provide high angular resolution and allow the coronagraph to increase the contrast and image planets closer to their host stars.

To reach this requirement, the second stage has to provide a very fast correction, leading the

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wave-front sensor (WFS) of the second stage to be as sensitive as possible. For this reason we are considering a Zernike wave-front sensor (ZWFS) as the ideal WFS for this task. Yet high sensitivity in the case of the ZWFS comes at the cost of a small dynamic range. To counterbalance this small dynamic, we combine two Zernike masks in order to double the linearity range of the classical ZWFS. This dual ZWFS with its higher dynamic range and still high sensitivity will increase the efficiency of the AO correction.
First, we present a full theoretical description of this double Zernike mask with its characteristics. We will focus on its ability to both measure phase residuals and phase discontinuities such differential piston in the ELT case. We will then present an End-to-End simulation of this two-stage AO system and its performances. To that end we will run a full two-stage correction with a first stage dedicated to the turbulence correction with a modulated Pyramid and the dual ZWFS as the second stage WFS. Finally, we will present the first experimental results of this two-stage AO system obtained on the LOOPS bench. The optical set-up of the cascade AO system for the PAPYRUS bench will also be presented.

Keywords: Second stage AO, High angular resolution, High contrast, Fourier Filtering Wavefront sensor