Optimization of Fourier-based wavefront sensors for high performance Adaptive Optics systems.

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Europe is currently preparing the largest telescope of the world: the ELT [European Extremely Large Telescope] [1]. Planned by 2024, this huge telescope of 39 m diameter will allow to answer fundamental questions of contemporary astrophysics by imaging exoplanets or studying large scales of the universe. However, images of astrophysical objects done by ground based telescopes suffer from the distortion caused by the atmospheric turbulence which reduces the capacity of instruments to distinguish objects too close to each other. Adaptive Optics [AO] [2] is a technique which allows to restore this loss of angular resolution by correcting the effects of atmospheric turbulence. In operation, on several astronomical observatories for almost 25 years, it is now applied to other domains where imaging suffers from inhomogeneous media as cellular microscopy, ophthalmology, functional imaging, etc. This technology is based on a deformable mirror which corrects in real time the incoming wave front by using information coming from a sensor which measures the turbulent phase called «Wave Front Sensor » [WFS]. WFS is the heart of any AO system. Ultimately it drives the final performance of the AO and thus of the associated astrophysical instrumentation. Often combined with artificial laser guide stars [LGS] (produced by the telescope itself thanks to the excitation of atmospheric Sodium Layer at 90 km with a powerful laser) for compensating the lack of sufficiently bright sources in the sky to perform the wave front sensing, AO has now become the most critical part of any ground-based giant telescope. It is particularly essential for

- the direct detection and characterisation of extrasolar planets where extreme performance is required
- the study of the very faint scientific targets (earliest galaxies of the Universe for instance) in dark regions (close to the galactic poles) where LGS and tomographic based AO systems are required for accessing to the whole sky

Thus, improving the AO systems (and in particular their sensing capabilities) will have a direct impact on the astrophysical science enabled with ELT. Until very recently, the vast majority of AO systems had used the Shack-Hartmann WFS. After more than 25 years of operation in a large variety of instruments for a large variety of applications, SHWFS is well known and mastered [3] but suffer from intrinsic limitations: its poor sensitivity and the need of very large detector (in the case of extended objects) when the telescope size increase.

New concepts based on Fourier filtering (Fourier Filtered WFS [FFWFS]), have however just been put in operation in several professional observatories and their results seem to outperform the Shack-Hartmann. We mention in particular the Pyramid WFS [4] which provides images with an astonishing quality at the Large Binocular and Subaru Telescopes or the Zernike WFS which allows to considerably improve the performance of the exoplanets imager at the Very Large Telescope [5]. Very recently, LAM and ONERA have propose an unified and rigorous analytical description of this new particular class of WFS [6][7][8]. It has allowed to identify the three clear stages (beam shaping, spatial Fourier filtering, pupil plane detection and its associated signal processing) required for an efficient wave front measurement and how each stage impacts the WFS performance. Using this powerful analytical scheme, it now becomes possible to play with the main characteristics of the WFS (opto-mechanical features and signal processing) and directly see the impact on the AO performance. Indeed, despite their very promising and recent success, FFWFS lack of maturity and some steps have yet to be addressed to reach a fully operational level and to address the news challenges of the next generations of AO systems for giant telescopes. Hence, the project objectives are threefold and summarized hereafter

First, the candidate will take benefit of this major breakthrough in the WFS approach in order to develop a design-oriented tool based on the analytical description of any kind of FFWFS. Using rigorous inverse problem approaches, we will be able to define the main characteristics of FFWFS intrinsic parameters which will ensure the best possible set of performance (from the AO point of view) under several technical constraints. Combining this tool with end-to-end simulation, he/she will (i) perform a comprehensive analysis of FFWFS ultimate performance and fundamental limitations and (ii) develop robust sensors allowing to deal with various exogenous conditions inherent to their use in operational conditions within complex environments.

Second, he/she will perform the experimental validation of the proposed FFWFS concepts. A prototype of each FFWFS will be realized and tested on a dedicated experimental test bench. This bench, located in LAM premises, will be based on existing facilities [9,10]. It will be modified in order to accommodate all the specificities related to the FFWFS environment. The bench will also include state-of-the-art WFS (Shack Hartmann and Classical Pyramid Sensor) in order to be able to perform comprehensive comparisons with these well-known devices and to qualitatively demonstrate the interest of our new sensors.

Finally, some very preliminary on-sky tests could be foreseen using state-of-the-art AO instrumentation accessible for LAM and ONERA teams at the Observatoire de la Cote d'Azur and William Herschell Telescope.

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