Developing new technology for nanometric accuracy wavefront measurements with applications to high precision optical components metrology and exoplanet direct detection

Institute: Centre de Recherche Astrophysique de Lyon – UMR 5574 (https://cral.univ-lyon1.fr/)

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Context: The development of innovative optical systems for the next generation of telescopes and instruments poses new instrumental questions essential to address to achieve objectives such as imaging of exoplanets, gravitational wave detection, and understanding the nature of dark matter and dark energy ,... In particular, these new objectives all require improvements in high precision wavefront measurement, which are currently setting the main limitations. This thesis subject will aim at developing a key new wavefront sensing technology with the capability to improve optical metrology, which is at the heart of several scientific objectives and in particular studying exoplanets in direct imaging. These types of astronomical observations involve the use of dedicated instruments and extreme adaptive optics (XAO) system to achieve the required very high contrast by minimizing the blinding effect from the host star. Recent work by our team has made it possible to develop a new wavefront measurement method for astrophysical goal. Our team has started already to develop a proof-of-concept for the new compact integrated wavefront sensor iMZ prototype which has been tested in the laboratory and at the telescope (using the 4 meter diameter William Hershel telescope) aiming toward the development of a new concept for exoplanet studies application. This wavefront sensing provides simultaneous measurements of the amplitude and phase of an incoming optical beam allowing very high accuracy. Traditional wavefront sensors such as Shack-Hartmann wavefront sensor (SHWFS) for astronomy and metrology phase shifting wavefront sensor all suffer from a fundamental tradeoff between spatial resolution and phase estimation and consequently can only achieve limited resolution or are extremely costly.

Project description: The PhD project will develop this novel Mach-Zehnder wavefront interferometer based technique to replace these wavefront sensors in both contexts. Preliminary results obtained by our team already validate that iMZ design principle to measure optical aberrations at high-resolution with high precision (10 nm) that are not seen by the commonly used Shack-Hartman type sensors. The solid version of the iMz we have developed provide unique measurement stability. In Addition, the physics behind the iMz is comparable to the phase shifting interferometers (ZYGO in use at LMA) used for fine metrology with the advantage of providing its own reference wavefront (self-referenced). Comparing to the phase shifting metrology sensors the iMz should provide as accurate as sub-nanometric precision performances when used in similar conditions (using several measurements taken at different wavelengths and orientation). As a consequence the iMz offers a very good alternative for extreme accuracy wavefront sensing at very small spatial scale while not relying on very expensive optical components used to generate a reference wavefront for metrology. The outcome for metrology at LMA will be a new possibility to test larger components at various wavelenths, which will be beneficial for the next generation instruments (Euclid, LSST, Advanced LIGO and Virgo). We propose to further develop the iMz concept for both extreme accuracy metrology at IP2I and extreme adaptive optics for exoplanet studies at CRAL. While the thesis research will focus on these two aspects, iMz has the capability to improved optical communication and remote sensing systems in the future and the proposed subject will also pave the way towards these applications. This project is novel and ambitious, and it is scientifically and technologically feasible through our unique interdisciplinary collaboration.

The ultimate goal of the thesis is to develop wavefront sensing technology scalable to very large optical system metrology at ultra-fine precision (< 1 nanometer rms) and very small spatial scale, which will dramatically improve the performances of futur optical systems (and thus for exoplanets direct detection), or will dramatically reduce the cost, and extend the wavelength range of their metrology (for astronomical or gravitational wave applications). The methodology will concerns numerical modeling and experimental validations of a new wavefront sensor, based on the Mach-Zehnder self-referenced interferometer, which has the potential to achieve sub-nanometric precision. After a work of synthesis of the existing, the work will focus on the ultimate limitations of such an analyzer, and will propose developments to repel them using new techniques and algorithms already developed at both laboratories (in metrology and XAO). It is foreseen to extend iMz performances by developing new multi-wavelength and multi-orientations measurements and analysis. These developments will be evaluated on optical components at LMA and compared with classical metrology measurements. In parallel, the thesis work will also consist in developing, and putting in use different wavefront sensing methods to ensure optimal detectability of exoplanets with XAO by using the existing experimental bench at CRAL, in order to offer original solutions for high imaging contrast and exo-biomarkers detections in the context of future giant telescopes.

Keywords: Optical metrology, Adaptive optics, High contrast instrumentation, Exoplanets
Skills: Instrumentation, Numerical simulations, Experimentation, Data analysis

Starting PhD date: 1st October 2020

PhD thesis funding is granted from Labex LIO "young researchers PhD" program. The Lyon Institute of Origins (LIO) is a long-term project gathering four laboratories of the University of Lyon, in a « Laboratory of Excellence (LabEx) » created in 2011 to investigate the topics of the origins, from the origin of matter to the origins of cosmic structures and life. It funds technical facilities, positions for young researchers, training and valorization.

Salary and social benefits will be proposed in accordance to French laws and regulations. In addition, an annual 3000 € package is also provided for equipment and travels.

The candidates will be selected in partnership with the Doctoral School « Physics and Astrophysics » . Submit you application with your academic achievements in the last three years, a letter of motivation, and a letter of recommendation to Maud Langlois (maud.langlois@univ-lyon1.fr) with a copy to Mrs Souad Lafehal (souad.lafehal@univ-lyon1.fr) before June the 2nd, 2020. Candidates on the short list will be interviewed on June the 9th or 10th, via videoconference.

Hosting Institutes:

The Centre de recherche astrophysique de Lyon (CRAL) is a public laboratory for fundamental research in astrophysics and for the development of instruments intended for large astronomical observatories. CRAL is supported by the National Center for Scientific Research, the University Claude Bernard Lyon 1 and the École normale supérieure de Lyon. CRAL is the leader of the European consortium of the Multi Unit Spectroscopic Explorer (MUSE) instrument, an integral field spectrograph for the Very Large Telescope of the European Southern Observatory. CRAL is also part of a large number of collaborative scientific research projects supported by national or foreign organizations (SPHERE, HARMONI, GRAVITY,…). In this context, it hosts several partnerships such as ERC, ANR projects and the Labex LIO.

The Laboratoire des Matériaux Avancés (LMA - http://lma.in2p3.fr/) is a public laboratory specializing in the deposition of thin layers, as well as in optical characterizations and metrology. The laboratory is involved in the LIGO-Virgo collaboration, and is closely associated to the first detection of gravitational waves GW1509141. The main mirrors of the LIGO-Virgo interferometers were produced by the LMA. The laboratory is a member of Labex LIO and is one of the seven research units that make up the André Marie Ampère research federation.