PROPOSITION DE SUJET DE THESE

Intitulé : High performance adaptive optics with laser guide stars wavefront sensing

Référence : **PHY-DOTA-2026-24**
(à rappeler dans toute correspondance)

Début de la thèse : Octobre 2026 à Janvier 2027 selon le type de financement	**Date limite de candidature :** 01/06/2026

Keywords:
Adaptive Optics, High Angular Resolution, Wavefront Sensing, Astronomy, Space Situational Awareness

Profile and skills sought:
Master's degree in research in the fields of Fourier optics, instrumentation, and optical systems. An interest in physical and digital modeling

Sujet :

Presentation of the doctoral project, context, and objective:

Adaptive optics (AO) is a technology that corrects distortions caused by atmospheric turbulence in real time, providing diffraction-limited images for ground-based telescopes. AO has revolutionized sky observation, enabling the imaging of astrophysical objects such as black holes, star clusters, nebulae, asteroids, circumstellar disks, exoplanets with unprecedented accuracy.

In particular, the direct imaging and characterization of exoplanets around their host star is a relatively recent instrumental challenge. Being able to detect the few photons coming from the planet hidden in the large flux coming from the star has only become possible with large telescopes equipped with adaptive optics systems at high performance. =. Imaging a furtive spy satellite nearby a geostationary satellite is very similar to the detection of an exoplanet orbiting its nearby star. The photometric signature, angular separation, apparent contrast, are very similar. Both these applications are calling for very high performance adaptive optics.

Today, all major astronomical telescopes are equipped with AO-assisted instruments, and the next generation of giant telescopes (30 to 40 meters) will become fully adaptive by integrate AO into their own optical design.

The ingredients for high performance adaptive optics (also called XAO) are well known: a fast, low-latency & high-density correction of wavefront are the key parameters. The capacity to use the central star, or geostationary satellite, as a guide star remains however limited by the need for photons (and therefore luminous objects) to measure and correct atmospheric turbulence every millisecond if not faster. The limited sky coverage (the part of the sky observable with an AO system) restricts the use of AO-assisted instruments to relatively bright targets (magnitude < 14) and a reduced field of view (a few tens of arc seconds).

One potential solution is to use artificial light sources such as laser guide stars (LGS). Powerful laser launch telescopes (LLTs, typically tens of watts per laser) are located near the main telescope. These lasers excite atoms or molecules in order to use the backscattered flux to measure turbulence defects.

Actual VLT [picture ESO] with its4 laser guide stars

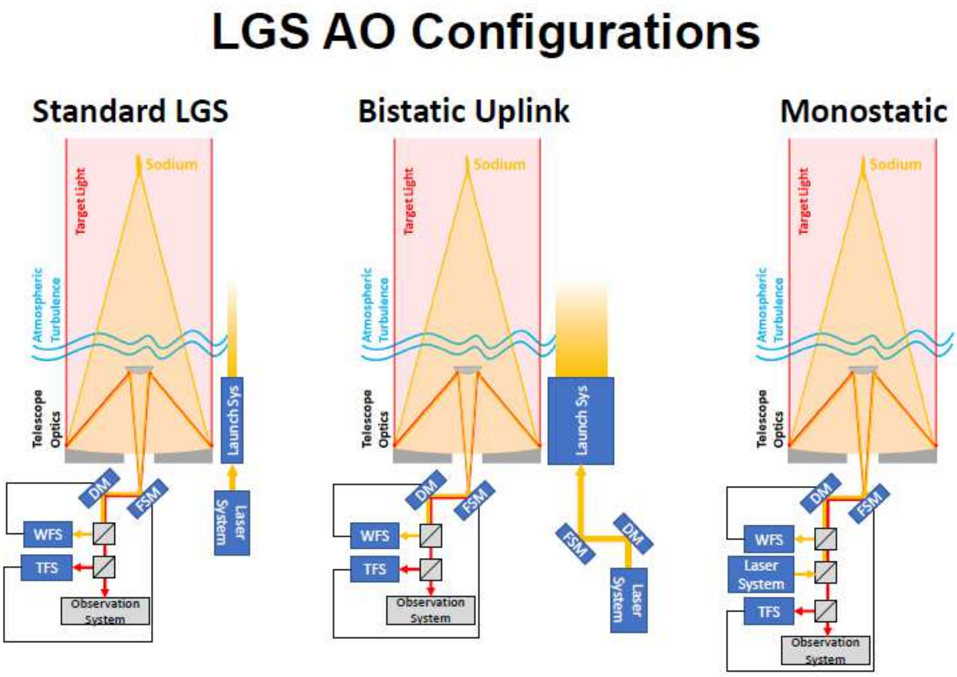
Already implemented in several observatories (ESO Paranal, Keck, etc.), Laser Guide Star operations have led to a real improvement in AO-assisted instruments on large telescopes. However, the fundamental limitation of LGS stems from its inability to measure the specific Tip-Tilt aberration. The apparent displacement of the LGS during the uplink and downlink propagation mixed each other, making it extremely difficult to extract the relevant value from the signal measured by the telescope and therefore to correct the Tip-Tilt contribution on a interesting object. As a result, LGS-assisted operations still require additional tip-tilt measurements from a star sufficiently bright and close to the object of interest. This requirement, although less restrictive than a conventional AO system, remains very demanding, and the ability to find a faint object (typically magnitude 18) is a limiting factor for the sky coverage of LGS-driven AO systems.

A paradigm shift for the LGS AO involves eliminating these additional measures and thus being able to retrieve tilt information from the LGS itself. This would allow access to the entire sky with a high angular resolution instrument and observation of any astrophysical or artificial (satellite) source, however faint.Among the several solutions proposed over the past 30 years, none has yielded satisfactory and operational results. New laser technologies (which are becoming increasingly powerful), new detection methods, new wavefront sensor concepts, and processes based on artificial intelligence could change the game and provide an innovative solution in the field of high angular resolution sky observation.

The PhD will be based mainly on theoretical and numerical simulations coupled with access to experimental on-sky data coming from LGS assisted telescopes (VLT, Gemini) to explore the following objectives :

- Measurement of TT from an LGS, explore solutions like up/do correlation, side versus central launch
- Coupling optical and accelerometry signals for improving the final tip-tilt signal estimation and correction especially using data-fusion, AI assisted, solutions
- Study the effect of the spot elongation for measurement of high orders, explore fourier filtering options aided by IA non-linear approaches
- Explore high performance XAO with different LGS configurations, from a single to several, including LGS chromatic diversity

Depending on the development and results obtained for these objectives, the PhD can take benefit of existing LGS systems on which we can have access to validate results on-sky (SINFONI instrument on VLT).



LGS AO configuration from AFRL [Richey et al].

This work will combine a bibliography study, theoretical analysis, simulation developments, data analysis and proposals for new measurement strategies. The background of the supervising team in terms of Adaptive Optics, Wavefront sensing, Laser guide stars and operational systems is of course, the foundation of the internship. The tools developed in the team (Python AO simulator OOPAO, Fourier simulator TipTop) will be a great help as well).

The big milestones of this PhD will be the following:

- Demonstrate that the spatial correlations of Tip-Tilt observed by the WFS are a good indicator of uplink Tip-Tilt. The candidate will carry out this work using an analytical approach together with numerical modeling using existing tools (Python OOPAO library). The candidate will explore the various concepts providing an estimation of the uplink tilt. Combination and optimization of concepts will be proposed to reach a uplink measurement compatible with a global downlink Tip-Tilt estimation and correction. .Use these spatial correlations to perform a pre-compensation of the uplink tilt from the laser launch. The candidate will do this can be done also with analytic approach as well as numerical modeling. We will consider different scenario of a perfect pre-compensation, then a realistic one including partial correction & vibrations.
- In parallel with these two main milestones, the work in the PhD will perform a survey of technological capacities of new laser launch telescopes. They embed now a high-level control of stability, with accelerometers and vibration control, which can be used as additional inputs for our problem on top of uplink atmospheric tilt estimation.

- Lastly, we have the capacity in the frame of this PhD to consider on-sky validation of the methods developed on large size facility. In particular, a collaboration with ESO on the Very Large Telescopes is possible as well as with other facilities on smaller telescopes.

The PhD will take place at the Laboratoire d'Astrophysique de Marseille (LAM) within the integrated LAM-ONERA team. This team brings together specialists in adaptive optics, lasers, and instrumentation, and aims to develop new instrumental concepts for the next generations of ground-based and space-based observatories. Students will have access to all of ONERA's and LAM's resources in terms of simulation tools and experimental facilities.

Collaborations envisagées :

LAM (V. Chambouleyron, B. Neichel)
Space ODT (P. Jouve)
ONERA (T. Fusco, A. Bonnefois)
ESO (Felipe Pedreros, Pascale Hibbon)

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