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PROPOSITION DE STAGE EN COURS D'ETUDES

Référence : **DOTA-2026-22**
(à rappeler dans toute correspondance)

Lieu : Laboratoire d'Astrophysique de Marseille & centre ONERA de Salon de Provence

Département/Dir./Serv. : PHY/DOTA/HRA

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DESCRIPTION DU STAGE

Thématique(s) : Optics, Physics, Adaptive Optics, Wave-Front Sensing

Type de stage : ☒ Fin d'études bac+5 ☒ Master 2 ☐ Bac+2 à bac+4 ☐ Autres

Intitulé: Exploring spatio-temporal correlation for sensing Tip-Tilt with Laser Guide Stars

Sujet :

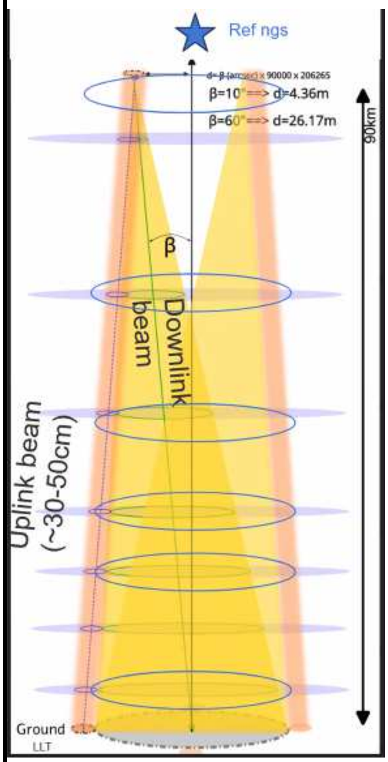
Adaptive optics (AO) is a technology that corrects distortions caused by atmospheric turbulence in real time, providing diffraction-limited images for ground-based telescopes. AO has revolutionized sky observation, enabling the imaging of astrophysical objects such as black holes, star clusters, nebulae,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

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.

Although AO is now a mature technology, it remains limited by the need for photons (and therefore luminous objects) to measure and correct atmospheric turbulence every millisecond. 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 lasers (typically tens of watts per laser) are launched from laser launch telescopes (LLTs) located near the main telescope. These lasers excite atoms or molecules in order to use the backscattered flux to measure turbulence defects.

Actual VLT [left, picture ESO] and future (ELT, artist view) with their respective laser guide stars. 4 for the VLT, 6 for ELT.



Already implemented in several observatories (ESO Paranal, Keck…), Laser Guide Star operations have brought about 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 cancel out 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 interest 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 measurement and thus **being able to retrieve tilt and tip information from the LGS itself.** This would allow access to the entire sky with a high angular resolution instrument and observation of any astrophysical source, no matter how faint.

Amongst the several solutions proposed over the past 30 years, none has yielded satisfactory 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.

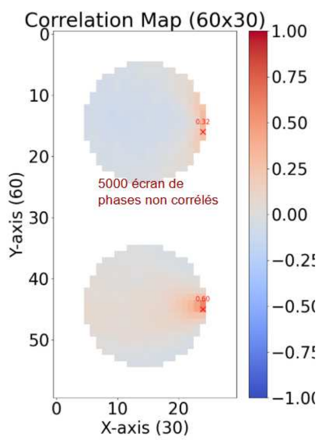
In this context, the primary objective of the internship will be to reexamine and study the uplink and downlink propagation characteristics of the LGS in order to identify the potential non-reciprocity between the two paths. These differences will be exploited by combining several beams with various spatial and spectral characteristics to recover the tip-tilt contribution in the line of sight: In particular, the following points will be carefully examined:

- The uplink and downlink beams pass through different parts of the atmosphere, with the ascending beam typically being a small telescope (30 cm) launched from the side of the telescope, and the descending beam being the size of the telescope (several meters). This diversity can be exploited through the use of AO wavefront sensor (WFS) telemetry and, in particular, through spatial diversity across the pupil.
- The LGS system typically consists of a combination of several beams (4 to 6) located at different points on the telescope. Each laser may have a specific wavelength and geometry (focalization distance, position w.r.t the telescope pupil …). Using these spatial and spectral diversities can help to overcome the contribution of uplink tilt and recover the contribution of the downlink part only.

New results obtained recently with numerical simulations are showing that a correlation exist between the sub-apertures located close to the launch telescope in the pupil and the uplink tilt. Exploiting these correlations might help to disentangle between the uplink and downlink Tilt and therefore to produce an estimate of atmospheric downlink tilt.

In practice the objectives of the internship are in priority :

- To use an end-to-end numerical model of an LGS AO system in a simple SCAO system, already developed by the team.
- To develop several simple cases with this model allowing to understand the problem
- To explore the impact of realistic components (noise on the detector).
- To implement a correlation algorithm able to plot spatial, spectral and temporal correlations between subapertures signal and uplink signal.
- *Example of correlation maps, between the uplink Tilt and downlink Tilt signals, from subaperture to subaperture. The LLT is located on the right of the pupil.*



The background of the supervising team in term 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 internship 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.

Est-il possible d'envisager un travail en binôme ? Oui

Méthodes à mettre en oeuvre :

☒ Recherche théorique	☒ Travail de synthèse
☒ Recherche appliquée	☐ Travail de documentation
☒ Recherche expérimentale	☐ Participation à une réalisation

Possibilité de prolongation en thèse : Oui (If fundings allows)

Durée du stage :	Minimum : 5 months	Maximum : 5 months (6 months on exemption only)

Période souhaitée : spring semester/summer 2026

PROFIL DU STAGIAIRE

Connaissances et niveau requis :	Ecoles ou établissements souhaités :
- Geometrical and Fourier Optics - Data Analysis, - Programming skills (Python preferred) - English language required	Engineering school of Optics, Master in Astronomy, Master in Instrumentation, Optics, Physics