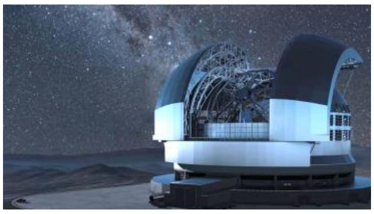
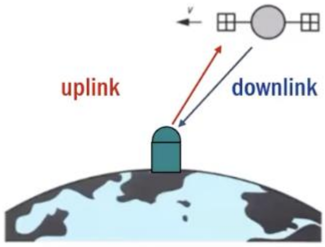
Fast Adaptive Optics for Space observations: Predictive control and machine learning.





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Research project:

The proposed research project concerns the technological developments necessary for high angular resolution observation from the ground, and in particular Adaptive Optics (AO). AO has been used in astronomy for ~30 years to correct the effects of atmospheric turbulence and to recover the diffraction limit of large ground-based telescopes. AO is at the heart of major astronomical discoveries, and to name just one, the 2020 Nobel Prize in Physics relies heavily on this technology.

To correct the effects of turbulence the AO implements a mirror deformed by actuators controlled in real time (typically on the order of milliseconds). The commands sent to the motors are determined from measurements made by a wave surface analyzer (WSA) observing a reference star. There are therefore 3 key technological components at the heart of the AO: a wave surface analyzer (WSA), a real-time computer (RTC) and a deformable mirror (DM). The development of the last two components is the core business of ALPAO; the innovation in wavefront analysis and the implementation of integrated and operational AO systems for high angular resolution observation from the ground is one of the expertise of the LAM.

Today, the fields of application of Adaptive Optics are expanding beyond astronomy, and in particular towards optical communications (Free Space Optics - FSO), which is a rapidly expanding field. For FSO, optical communication between satellites and optical ground stations allows high-speed data transfer between space and Earth. In the case of Low Earth Orbit (LEO) satellites, a higher data rate would allow direct links to Earth and offer an alternative to geostationary satellite relay architectures, which may not be available for small constellations. But these applications bring new challenges for the AO, including:

- Communication with targets in low earth orbit (LEO): the deflection of satellites in these orbits generates a high "apparent wind".
- Deployment of ground stations (OGS) in sites with non-ideal observation conditions (eg high winds).
- The ambition to reduce the size of ground stations, which expose them to higher wind and mechanical vibration conditions.
- Unlike traditional astronomical applications, LEO-ground links must operate at low elevation angles (preferably between 20° and 10°) in order to extend the link duration. At these angles, the propagation distance through the atmosphere is very long (> 50 km), resulting in a longer propagation path and thus traversing a larger volume of turbulence. Daytime operation also faces stronger turbulence due to temperature gradients caused by solar radiation.

For FSO applications, the main performance limitation comes from the temporal error, and the classical approach is to increase the system rate in order to increase its bandwidth.

This need to increase the rate and the performance of the correction provided by AO is also found in astronomy, for the direct imaging of exoplanets. One of the main scientific motivations for the construction of future Extremely Large Telescopes is the detection and possible characterization of Earth-like planets orbiting nearby stars. The detection of CO_2, water or even complex molecules in the atmosphere of a rocky exoplanet would undoubtedly be one of the greatest revolutions in our vision of the Universe, and one of the major scientific results of the next decade.

However, the fast atmospheric residuals, poorly compensated by the AO correction operated at a limited speed, currently limit the exoplanet detection capabilities. To reach this ambitious scientific objective, it is necessary to accelerate the AO systems and to improve the performances compared to the state of the art. For the applications of atmospheric turbulence correction, in particular those resulting from the optical communication (FSO) but also astronomy, the company ALPAO needs today to make evolve the control laws of its product ALPAO RTC. The objective of this thesis is to study, characterize and validate:

- Improving system performance at lower speeds through the use of predictive laws, identification of system vibrations, and the implementation of optimized control laws
- Taking into account the dynamics of the corrector in the control law in order to open the door to RTC rates higher than its bandwidth
- The exploration of innovative solutions based on machine learning (Artificial Intelligence) to improve the understanding of non-linear models and predictive control.

Solutions at the level of the RTC, but also at the level of the embedded electronics of the deformable mirror could be considered. The thesis will cover theoretical aspects, numerical simulations and experiments in order to validate one or several operational solutions.

This work will rely on the expertise of the ALPAO and LAM teams, and on previous work done on the subject in common. The student will benefit from the access to the simulation means, to the experimental benches and to the field - in particular to the Haute Provence Observatory - provided by ALPAO and the LAM during the thesis.

Presentation of the Private Partner:

ALPAO designs, manufactures and markets a complete range of adaptive optics products for research and industry since 2008. ALPAO provides deformable mirrors, wavefront sensors and software. ALPAO products are suitable for various applications such as astronomy, ophthalmology, microscopy, wireless optical communication and laser technologies. ALPAO has launched many products since its creation, such as deformable mirrors (DM), its own wavefront sensor for closed-loop operations, the DM97-08 dedicated to ophthalmology, a large DM (DMX) and a modal deformable mirror. It also delivered Europe's largest deformable mirror at the end of 2018 that includes 3,228 actuators. ALPAO is an international company with customers on 4 continents in over 20 countries. More than 90% of its sales are made in exports with products manufactured in France. Resulting from the work carried out at CNRS and UGA, ALPAO has a strong link with the scientific community, and is involved in many instrument projects for astrophysics (VLT, EELT, CHARA...)

More information : www.alpao.com

Presentation of the academic partner:

LAM (Laboratoire d'Astrophysique de Marseille), a joint research unit of CNRS (INSU), Aix-Marseille University and CNES, is one of the largest laboratories (about 190 people) of the Observatoire de Marseille (Institut Pytheas). The LAM combines fundamental research in astrophysics, and more particularly planetary sciences, detection and characterization of extrasolar planets, formation and evolution of galaxies, cosmology, with advanced technological research in instrumentation. LAM researchers lead international programs combining observation, analysis, modeling and theory. LAM's technical skills in instrumentation development are based on in-situ expertise in optical and mechanical design, technological facilities unique in Europe and an astrophysical data center (CESAM).

More information: www.lam.fr

LAM and ALPAO are today respectively the leading laboratories and SME in the development of Adaptive Optics. The developments carried out within the framework of this joint project will allow the transfer of knowledge and skills, and a reinforced synergy between these major actors. The expected outcomes will be both scientific (new algorithms), but also technological and industrial, and will be used to propose new devices.

Profile sought:

Students of engineering school, master in automatic, optics, astronomy, photonics.

How to apply:

Please send your CV, a letter of motivation and the name of 2 reference contacts.

This PhD is fully funded