Position Description

1. General Information

Name of the position	**High-Angular Resolution Astronomy**
Foreseen date of enrolment	1 October 2024
Position is funded by	• COFUND, Marie Skłodowska-Curie Actions (MSCA), Horizon Europe, European Union • Aix-Marseille Université (AMU) • Macquarie University (MQ)
Research Host	Aix Marseille Université
PhD awarding institutions	Aix-Marseille Université & Macquarie University
Locations	Primary: Marseille, France Secondary: Sydney, Australia
Supervisors	Benoit Neichel (AMU) and Jon Lawrence (MQ)
Group of discipline	Astronomy & Astrophysics, Instrumentation, Optics, Ground & space based Telescopes, Adaptive Optics, wave-front control

2. Research topics (only one of these projects will be funded)

Project 1: *Tomographic Adaptive Optics for ground-based giant telescopes: exploring the super resolution opportunity*
European astronomy is about to take on one of the greatest instrumental challenges ever imagined: the construction of the ELT (Extremely Large Telescope), a telescope 39 m in diameter, expected to go into operation by 2030. LAM and ONERA are developing together the adaptive optics that will equip the first light spectro-imager of the ELT, called HARMONI. HARMONI will have access to the whole sky with a very high spatial and spectral resolution and thus allow unique astrophysical advances concerning the understanding of the birth and the evolution of galaxies in the primordial universe. This double instrumental constraint (high resolution and access to the whole sky) led us to propose the concept of Laser Tomographic Adaptive Optics (LTAO). The HARMONI LTAO system will make use of Artificial Stars generated by high power lasers (> 20 W output power) with a tomographic reconstruction of the whole turbulence volume located above the telescope. While the concept of tomographic AO itself has been proposed for several decades now (Beckers-1988, Ellerbreok-1994, Fusco-2001), the practical and operational implementation on 8m diameter astronomical telescopes is quite recent (Rigaut-Neichel

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2018, Oberti-2018). Its application to a giant 39m diameter telescope poses new challenges related to the complexity of the telescope itself combined with the ever-increasing performance requirements imposed by the increasingly ambitious scientific objectives associated with these giants of modern astronomy.

The objective of the thesis is to propose alternative and innovative solutions to the key problems identified in the application of tomographic AO on giant telescopes. In particular, the student will study the contribution of the concept of super-resolved wavefront sensors recently proposed in AO (Fusco-2021, Oberti-2022) and its practical application in the framework of the LTAO. This understanding of the super-resolved wavefront measurement will pass through a theoretical analysis, numerical simulations and an experimental validation on a bench and on sky.

The proposed developments will naturally be used for HARMONI but can also be extended to future tomographic AO systems which will be operational in the next decade (MAVIS at VLT, KAPPA at Keck, GNAO at Gemini, MAORY and MOSAIC on the ELT).

Supervisors:
Benoit Neichel (AMU, LAM), Jon Lawrence (MQ), Thierry Fusco (ONERA) & Julien Charton (ALPAO)

Research Fields: Astronomy, Instrumentation, Ground-based telescopes, Adaptive optics, Wave-front sensing, Super resolution

Project 2: *Machine learning data processing for Adaptive Optics assisted astronomical observations*

High-resolution images from large ground-based telescopes have revolutionized visible and near-infrared astronomy over a wide range of astrophysical fields, including finding and characterizing exoplanets, black holes, brown dwarfs, and the earliest galaxies in the Universe. These discoveries relied on adaptive optics (AO) systems, which compensate in real-time for the blurring effects of the Earth's turbulent atmosphere (called "seeing"). AO systems give superior spatial resolution over space-based alternatives at a fraction of the cost and have been deployed on nearly all of the world's largest telescopes, as the European Very Large Telescope (VLT) and its 10m-class telescopes counterparts. The power of AO is now widely recognized and it will be built into the 1st-light instruments of ALL the next-generation giant telescopes -- the European ELT, the Giant Magellan Telescope and the Thirty Meter Telescope with diameters up to 40m. The exceptional advancement in AO technology and observational capability has, however, not been followed by a comparable advancement in the development of data analysis methods. Additionally, the increase of the telescope size introduces new effects that can be barely characterized by models of current level of complexity. This results in a difficult understanding of the AO performance, and in particular in the characterization of the AO Point Spread Function (PSF), which eventually limits the scientific analyses. Candidates will therefore develop innovative research into data-analysis algorithms aimed to extract the most precise measurements of photometric brightness, astrometric position, and morphology for planets, stars, and galaxies from adaptive-optics assisted observations on current and future ground-based telescopes. A particular focus will be on the use and development of machine learning methods applied to astronomy. Indeed, AO systems are producing a tremendous amount of data - called telemetry data - with all the wave-front sensors engaged, which could be used to improve our understanding and prediction of the AO performance. All this data is not currently used, and this Ph.D. will explore how Machine learning could be exploited for that. The innovative algorithms developed during this PhD will be tested and validated on a large set of data, already available from VLT, and on simulation of future ELT observations.

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Research Fields: Astronomy, instrumentation, Ground-based telescopes, Adaptive Optics, Data processing, Machine learning

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Project 3: *Space Adaptive Optics*
The direct imaging of Exo-Earth planets is crucial for understanding planet formation, and finding biomarkers on exoplanets atmosphere. The huge flux ratio between such a planet and its host star, around several billions, as well as the proximity between them, makes this task however extremely challenging. It is out of reach today, and requires the development of a very large and stable space observatory (the US-lead space telescope LUVEX) coupled to future high-contrast science instruments. This last part is based on coronagraphy and allows to physically suppress the star light, to the benefit of the planet light. In the case of LUVEX, where a contrast of 10^{10} is required, the aberration should be as small as a few picometers. It constrains the whole observatory in term of extreme stability, wave-front sensing and control, down to this level. In order to reach the extreme performance level, it is mandatory to close fast active loops, correcting for fast and small perturbation existing onboard a space platform. We call this change of paradigm the space adaptive optics. Adaptive optics have equipped ground-based astronomical telescopes for decades now. Based on the knowledge of AO on the ground, we want to deploy a similar approach to a space-based observatory, called space adaptive optics. The candidate will work on the modelisation of expected perturbations, modelisation of AO measurement & correction, and develop a multi-sensor and multi-correction approach. Based on the JWST experience, and access to telescope phasing data through a close collaboration with STScI, the candidate will develop a simplified AO model for space. Validation with bench experiments (HiCAT bench at STScI) and potentially in-orbit demonstration with the AZIMOV project is also foreseen.
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Research Fields: Astronomy, Instrumentation, Space-based telescopes

3. Employment Benefits and Conditions

Aix-Marseille Université offers a 36-months full-time work contract (with the option to extend up to a maximum of 42 months).

The remuneration, in line with the European Commission rules for Marie Skłodowska-Curie grant holders, will consist of a gross annual salary of 28,764 EUR. Of this amount, the estimated net salary to be perceived by the Researcher is 1,926 EUR per month (before the deduction of tax at source). However, the definite amount to be received by the Researcher is subject to national tax legislation.

Benefits include

- Becoming a Marie Skłodowska-Curie fellow and be invited to join the Marie Curie Alumni Association.
- Access to all the necessary facilities and laboratories at Aix-Marseille Université and Macquarie University.
- Tuition fees exemption at both PhD awarding institutions.
- Yearly travel allowance to cover flights and accommodation for participating in AUFRANDE events.
- 10,000 EUR allowance to cover flights and living expenses for 12 months in Australia.
- 25 days paid holiday leave.

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- Contractual doctoral students are subject to the same sick leave rights as other contractual employees of the State Civil Service, namely: the contractual agent in activity benefits, on presentation of a medical certificate, during twelve consecutive months if its use is continuous or during a period including three hundred days of effective services if its use is discontinuous, of sick leave within the following limits
    - After 4 months of service: 1 month on full pay and 1 month on half pay;
    - After 2 years of service: 2 months on full pay and 2 months on half pay;
    - After 3 years of service: 3 months on full pay and 3 months on half pay.
- Parental leave: if the employee has at least 1 year's seniority at the date of the child's birth, he/she is entitled to parental leave at his/her request (after maternity leave for the mother or paternity leave for the father). This leave ends at the latest when the child is 3 years old. The leave is granted for renewable periods of 2 to 6 months. He/She must apply for it at least 2 months before the start of the parental leave.

4. PhD enrolment

Successful candidates for this position will be enrolled by the following institutions and must comply with their specific entry requirements, in addition to AUFRANDE's conditions.

Applicants must hold a Master's or equivalent degree with a major research component at Distinction level (75% or greater).

Applicants must demonstrate an English language proficiency equivalent to an overall IELTS score above 6.5 and no band below 6.

More information on Aix-Marseille Université's requirements

Doctoral candidates holding a Master's degree outside the Bologna process or a degree equivalent to a Master's degree must submit an application for a Master's Degree for validation to the doctoral school secretariat prior to their enrolment.

Visit the website: https://college-doctoral.univ-amu.fr/en

More information on Macquarie University's requirements

Short-listed applicants will need to demonstrate their suitability for entry to the program by submitting an application to the PhD program and the Cotutelle scholarship via Macquarie University's online application system. The application must include:

- A detailed research proposal; and
- Evidence of the required level of English language proficiency.

Furthermore, applicants must qualify for a Cotutelle scholarship. Macquarie University assesses applicants for the scholarship based primarily on academic merit and research experience, emphasising previous thesis

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outcomes. Additional information such as peer-reviewed publications, conference and poster presentations and relevant work or professional experience may also be taken into account. Applicants are rated according to the principle and process outlined in the Higher Degree Research Scholarship Rating Sheet.

Successful applicants (if non-Australian citizen) will be required to:

- Meet Australian visa requirements; and
- Obtain Overseas Student Health Cover (OSHC) for the entire duration of their study in Australia.

Visit the website: https://policies.mq.edu.au/document/view.php?id=380

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