Proposition de stage M1/M2 Instrumentation / Ingénieur

From simulation to laboratory: Developing a digital optical model and building a mini coronagraph for exoplanet imaging

Nom du proposant :

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Lieu du stage :

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Date du stage :

Début possible à partir de mars 2026, durée de 2-4 mois

Contact et renseignements complémentaires :

Merci d'inclure les deux correspondants dans l'ensemble des correspondances.

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Context:

One of the central goals of modern astrophysics is to understand how extrasolar planets form and evolve. Over the past three decades, numerous discoveries have revealed the remarkable diversity of these distant worlds, supported by increasingly advanced detection and characterization methods. Among them, **direct imaging** allows astronomers to capture photons from exoplanets themselves, enabling spectroscopic studies of their atmospheres and compositions.

Detecting such faint planets next to stars that are millions to billions of times brighter defines the challenge of **high-contrast imaging**. The contrast expresses the brightness ratio between the planet and its host star, and improving it requires extremely precise control of the optical wavefront. Even tiny **aberrations**, small distortions in phase or amplitude, can create speckles in the image that hide the planet's signal. To reach the contrasts needed to observe Earth-like planets, astronomers use **coronagraphs** to suppress starlight, **deformable mirrors** to correct optical errors, and advanced **image-processing algorithms** to extract the planetary signal. These techniques are implemented on observatories such as the VLT and ELT, and on future space missions like the Nancy Grace Roman Space Telescope (launch planned for 2026) and NASA's Habitable Worlds Observatory (HWO).

To develop and test these technologies under controlled conditions, we operate the **SPEED** testbed at Laboratoire Lagrange in Nice (https://www.oca.eu/en/lag-speed-home). SPEED is

designed to explore the limits of high-contrast imaging with **segmented telescopes** like the ELT and HWO, where maintaining optical stability is especially challenging. The bench combines a 163-segment telescope simulator, co-phasing optics, and a multi-deformable-mirror system integrated with deep coronagraphic imaging. It serves as a platform to design and test **optical control loops**, automated systems that measure and correct aberrations in real time. The goal is to advance the methods needed to reach the respective wavefront stability levels for future ground- and space-based observatories.

Internship topic:

This internship offers a unique opportunity to combine **numerical simulation** and **hands-on experimental optics** for high-contrast imaging. The student will build a **miniaturized coronagraph demonstrator** in the laboratory. Following an existing open-source design (https://www.babycatdemo.org) the student will assemble, align, and characterize a tabletop system that illustrates how coronagraphy suppresses starlight to reveal faint companions. This will provide practical experience with optical components, alignment procedures and image acquisition for high-contrast imaging instruments.

Following the assembly, the student will **develop a numerical optical model** of this demonstrator using the **HCIPy** Python library (https://hcipy.org). Building on a modern software stack (Python, HCIPy, Git, GitHub), the student will implement each optical element, simulate its performance, and validate the model against laboratory data for the assembled coronagraph demonstrator described above, forming a complete end-to-end "digital twin" of the bench.

This work connects directly to ongoing developments on the SPEED high-contrast imaging testbed in Nice, which targets future exoplanet instruments such as those on the ELT and HWO. Once completed, the demonstrator is expected to be used for **education and outreach**, for example in master's programs at Université Côte d'Azur (MAUCA, MASS), as well as public events such as the Fête de la Science, Nuit des Coupoles Ouvertes, Nuit des Étoiles.

Prerequisites:

The following notions would be useful:
- Wave optics, diffraction, Fourier optics
- Signal processing
- Python coding, object-oriented programming

Bibliography and resources:

- Demo coronagraph website: https://www.babycatdemo.org
- HCIPy library website: https://hcipy.org
- SPEED testbed website: https://www.oca.eu/en/lag-speed-home
- SPEED testbed bibliography: https://ui.adsabs.harvard.edu/public-libraries/-G0ZrNzvSqa8sByrzvrp2w
- Extremely Large Telescope website: https://elt.eso.org/
- Habitable Worlds Observatory website: https://science.nasa.gov/astrophysics/programs/habitable-worlds-observatory/