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PhD Project: The birth of exoplanets with ELT/MORFEO-MICADO

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Introduction: The discovery of exoplanets has revolutionized our understanding of planetary systems, revealing a stunning diversity of worlds and architectures. However, most known exoplanets have been detected through indirect methods, such as transits and radial velocities, which are not well-suited to studying planets during their earliest stages of formation. To uncover how planets form and evolve, we must observe them while they are still embedded in their natal disks. *Direct imaging offers a unique opportunity to study young, self-luminous protoplanets, providing insight into their temperatures, compositions, and formation mechanisms*. Current instruments can only detect planets at wide separations (>20 AU), leaving the inner regions—where most planets are expected to form—largely unexplored.

A new era with the Extremely Large Telescope: This gap will be addressed by the European Extremely Large Telescope (ELT), a next-generation observatory with a 39-meter primary mirror, designed to deliver unprecedented angular resolution and sensitivity. In particular, the combination of MORFEO (a multi-conjugate adaptive optics system) and MICADO (a near-infrared imager and spectrograph) will allow astronomers to directly detect forming planets within the inner 10 astronomical units of nearby young stars—regions that are critical for understanding both terrestrial and giant planet formation. This is shown in Figure 2 where the detection limits of MORFEO-MICADO are compared to that of other instruments.

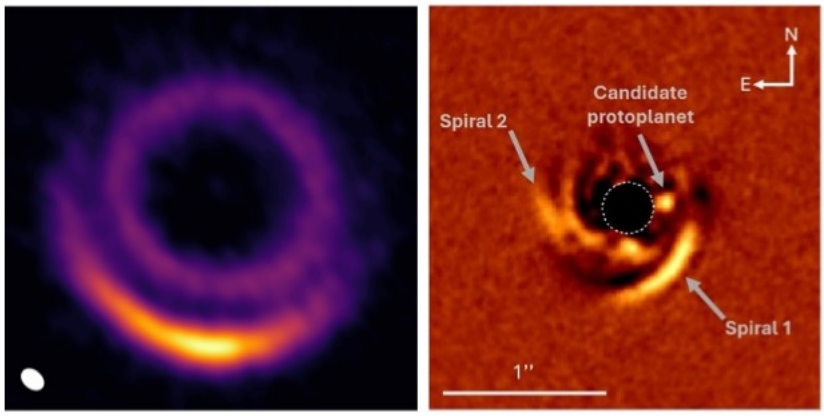

Figure 1: *(left) ALMA dust continuum observation of the disk around HD 135344 B. At mm wavelengths the disk is characterized by a ring with an inner cavity and by a vortex in the outer disk. (right) Recent VLT/ERIS HCI observations showing the presence of multiple spiral arms (previously known) and of a candidate protoplanet shown as green dot in the ALMA image).* ALMA data from Cazzoletti et al. 2017, ERIS data from Maio, **Fedele** et al. 2025)

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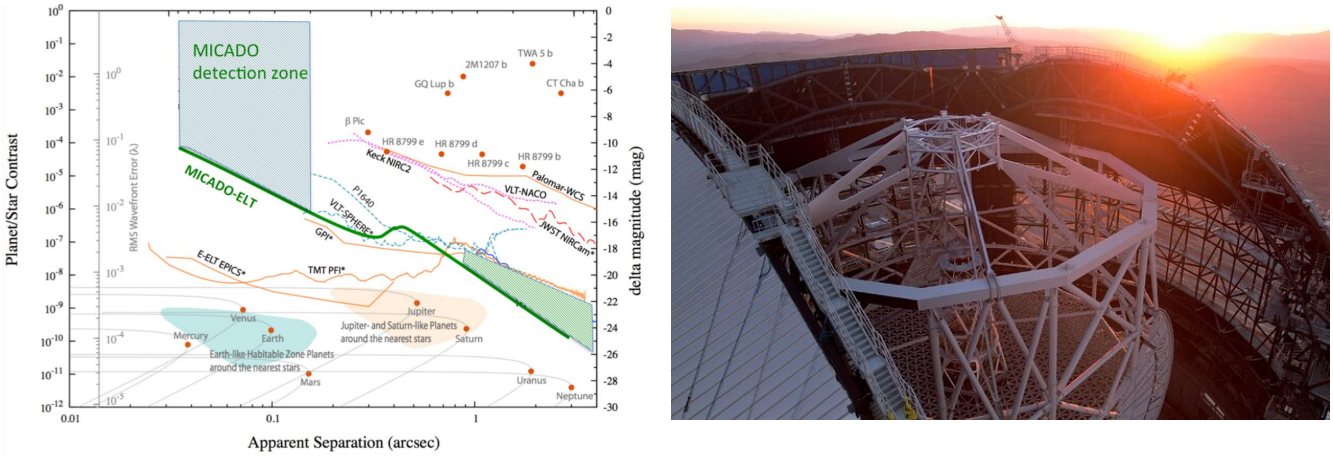

Figure 2: *(left) Contrast curve and detection limits of MORFEO-MICADO compared to other instruments (Baudoz et al. 2019).* ***MICADO will be the first instrument capable of directly detect planets with orbital radius < 10 AU*** *at the distance of the nearby star forming regions. (right) View of the Extremely Large Telescope taken in January 2025 (Credit: ESO/G. Vecchia)*

This PhD project focuses on preparatory studies for detecting and characterizing protoplanets with ELT/MORFEO-MICADO, enabling the candidate to contribute directly to one of the most transformative developments in modern astronomy.

Project Objectives: The PhD candidate will:

1. **Simulate Observations**: Create synthetic datasets of planet-forming systems to assess the detectability of protoplanets with ELT/MICADO under realistic observing conditions.
2. **Optimize High-Contrast Imaging**: Develop and test image processing techniques—such as PSF subtraction and machine learning algorithms—to enhance the detection of faint planetary signals close to bright stars.
3. **Prepare for Spectral Characterization**: Investigate strategies for extracting low-resolution spectra of detected planets to infer their physical and atmospheric properties.
4. **Define Targets and Observing Strategies**: Help compile a list of high-priority targets and design observing plans based on existing data from VLT/ERIS, JWST, and other facilities.

Training and Environment: The student will join an active research group specializing in high-contrast imaging and planet formation. The project offers hands-on experience in observational astrophysics, data analysis, and instrumentation. The candidate will benefit from collaborations within the ELT/MICADO-MORFEO community and have access to data from current instruments like VLT/ERIS and LBT/SHARK.

This PhD project offers a unique opportunity to play a leading role in the preparation for ELT science, helping to unlock the secrets of how planetary systems form. The candidate will develop critical skills in imaging, spectroscopy, and data science while contributing to one of the most exciting frontiers in modern astronomy.