Exploring the Nearest Ultracool Dwarfs for Potentially Habitable Exoplanets Well-Suited for Detailed Atmospheric Characterization

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The SPECULOOS Project

Our view of our Solar System and its place in the universe has expanded enormously over the past three decades, driven by the discovery of thousands of exoplanets since the seminal detection of 51 Pegasi b in 1995. We now know that most stars in our galaxy host their own systems of planets, and that the majority of these planetary architectures differ radically from our own. Their study has transformed our understanding of planetary formation and evolution, while also highlighting the inherently stochastic nature of these processes.

For a subset of exoplanets that transit nearby stars, detailed characterization is already possible. We can now measure their orbital parameters, determine their mass and radius with high precision (yielding bulk densities that constrain their internal composition), and probe the chemical and physical properties of their atmospheres.

Over the last decade, several atoms and molecules have been detected in the atmospheres of both giant and smaller planets, inaugurating a new field of astronomy: *comparative exoplanetology*, the systematic study of planets orbiting stars other than the Sun. The James Webb Space Telescope (JWST), launched in 2021, has propelled this discipline into a new era. Its unprecedented sensitivity has already revealed atmospheric signatures—water vapor, carbon dioxide, methane, sulphur dioxide, among others—in a wide variety of transiting exoplanets. Notably, JWST has begun probing the atmospheres of rocky and sub-Neptune-sized planets such as GJ 486b, LHS 475b, and K2-18b, placing the first constraints on their atmospheric composition and thermal properties. Most recently, JWST delivered the first thermal phase-curve maps of Earth-sized exoplanets, TRAPPIST-1b and TRAPPIST-1c (Gillon, Ducrot et al., 2025). These results provide direct constraints on their energy budgets, heat redistribution, and atmospheric properties, marking a decisive step toward the detailed study of temperate terrestrial worlds. Together, these pioneering observations are opening the way to a systematic exploration of rocky exoplanets, including those residing in the habitable zone of their star.

The SPECULOOS project (Search for habitable Planets EClipsing ULtracOOl Stars; Gillon 2018) has grown out of these developments. This dedicated exoplanet transit survey focuses on the nearest ultracool dwarf stars—very low-mass stars (<10% the mass of the Sun) with sizes comparable to Jupiter, located at the bottom of the main sequence. These tiny stars had long been overlooked by exoplanet searches, and their planetary population remained largely unexplored. The discovery of the remarkable TRAPPIST-1 system with the SPECULOOS prototype (Gillon et al. 2016, 2017) demonstrated that compact systems of temperate, Earth-sized planets are common around ultracool dwarfs. Over the past years, SPECULOOS has expanded this exploration, identifying or confirming new terrestrial worlds transiting nearby very low-mass stars. Many of these planets, like the TRAPPIST-1 worlds, are now among the most promising targets for atmospheric characterization with JWST and other next-generation observatories, offering a realistic path toward the detection of chemical traces of life beyond our Solar System.

The Balzan Project: Goals and Status

The goal of this Balzan Prize project is to maximize the potential and scientific return of SPECULOOS. At the start of the project, SPECULOOS relied on a single facility, the SPECULOOS Southern Observatory (SSO), consisting of four 1-m robotic telescopes installed at Paranal Observatory in Chile between 2016 and 2018, and in operation since January 2019. The aim was then to extend the project to the Northern sky, in order to achieve a complete exploration of all nearby ultracool dwarf stars. This extension began in 2019 with the installation of a first 1-m Northern SPECULOOS telescope at Teide Observatory in Tenerife, Canary Islands. This Balzan Prize project contributed to this expansion by funding part of the installation costs of the new telescope (groundwork and cabling).

The project's contribution to SPECULOOS also included the funding of scientific missions, conference participations, team meeting, and in the organisation of the international scientific conference TRAPPIST-1 held at Liege from 11 to 14 June 2019.

Finally, this Balzan Prize project supported the salaries of several young scientists who played a crucial role in making SPECULOOS a success:

- **Dr. Daniel Sebastian (postdoctoral fellow)** was hired from September 2018 to June 2020 to take charge of the technical and operational management of SSO and to work on the scientific exploitation of its data.
- **Lionel Garcia (PhD student)** received support for the first six months of his PhD thesis (April–September 2019), partially dedicated to developing innovative methods to analyse SPECULOOS data. He successfully defended his thesis in July 2023.
- **Elsa Ducrot (PhD student)** received support for the final stage of her PhD thesis (July 2020–September 2021). Initiated in October 2017, her work focused on managing and optimizing the observations of the SSO and SNO telescopes (target selection, automation, strategy), contributing to the scientific exploitation of their data (transit searches and analyses), and to the detailed characterization of discovered planets (radius, mass, orbit, atmosphere).

SPECULOOS: Scientific Results

The scientific results of SPECULOOS can be divided into two categories. The first concerns the core program of SPECULOOS (80% of the observing time), namely the search for transiting planets around a volume-limited (40 pc) sample of ~1600 ultracool dwarfs (very low-mass stars and late-type brown dwarfs) (Sebastian, Gillon et al. 2021). To date, this program has led to the discovery of two rocky planets: the potentially habitable super-Earth SPECULOOS-2c (Delrez et al. 2022), and the ultra-short-period rocky planet SPECULOOS-3c (Gillon et al. 2024).

The second category (20% of the observing time) corresponds to an "ancillary" program, focused on the confirmation of rocky planet candidates identified by NASA's TESS mission. This program has already resulted in the discovery of numerous planets, such as TOI-2267b and c (Zúñiga-Fernández et al. 2025).

Prospects and Conclusion

SPECULOOS is still in development, and its operations are expected to continue for at least 5–10 years. In the coming months, a new telescope, *Orion,* will be installed at Teide Observatory in Tenerife. Funded by the Walloon Region, this facility will be the first SPECULOOS telescope equipped with both an infrared camera and a CCD camera, enabling simultaneous observations in the two channels. This unique configuration will (1) enhance SPECULOOS's ability to detect the first rocky planets around brown dwarfs, (2) improve the discrimination between stellar and planetary signals, and (3) allow the verification of the achromaticity of transit signals identified by the TESS mission and, in the near future, by PLATO. Moreover, the other SPECULOOS telescopes will be upgraded to allow such dual-channel observations, through the installation of an infrared camera, an optical modification, and a dichroic beam splitter. The installation of a third SPECULOOS-North telescope at Tenerife is also envisioned.

In this context, the remaining project budget (€68k) has been allocated to operations and equipment, in order to flexibly cover part of the project's future needs. This approach is important, as the PI's other funding sources (Walloon Region, FNRS, ULiège) are tied to specific items and offer no flexibility. It is therefore not possible to specify exactly when this Balzan project will come to an end. Nevertheless, it is already clear *that* ***this project has made a major contribution to the success of SPECULOOS and to the study of the diversity of rocky exoplanets orbiting very low-mass stars and their potential habitability.***

References

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For a complete list of SPECULOOS publications, see the project website: http://www.speculoos.earth