

Chasing exo-aurorae

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Abstract

Aurorae are well known optical phenomena in the Solar System planets. Aurorae have great diagnostic value, as their emissions reveal the planets' atmospheric compositions, the occurrence of magnetic fields and the solar wind conditions at the planet's orbit. Looking for aurorae on exoplanets and brown dwarfs is the next frontier. A first breakthrough in this direction has occurred recently, with the detection of a CH₄ emission attributed to auroral excitation on the brown dwarf W1935. This detection, and the prospects of observing other auroral features with existent and upcoming telescopes, is what motivates this project. In particular, we will build the first model dedicated to investigate CH₄ and H₃⁺ auroral emission on exoplanets and brown dwarfs. The model will be used to investigate the conditions at W1935, and to predict the detectability of aurorae on other sub-stellar objects.

Project description

Aurorae are well known optical phenomena in the Solar System. Besides their obvious beauty, aurorae have great diagnostic value and tell us much about the conditions on the planets and their environment. Indeed, auroral emissions from the ultraviolet to the infrared are used to reveal the planets' atmospheric composition, the occurrence of magnetic fields (local or large-scale), or to probe the solar wind conditions at the planet's orbit. Looking for aurorae on sub-stellar objects (exoplanets and brown dwarfs) is the next frontier, and what motivates this project. **JWST** has found the first evidence for optical aurorae in the emission at 3.326 μm of the cool brown dwarf W1935 [Faherty+2024], a line attributable to CH₄. The observations remain without a physically-motivated interpretation because the necessary models do not exist yet. As the search for aurorae with **JWST** goes on [Shkolnik+2006; Lenz+2016; Nasedkin+2025], it is apparent that we are witnessing an emerging field in the characterization of sub-stellar objects. Very soon, ESA's **ARIEL** in space or ESO's European-Extremely Large Telescope on the ground will search for evidence of aurorae in the spectra of other sub-stellar objects. Such observational efforts need to be supported by the corresponding theory, currently non-existent, but that we will develop in this project.

In this project, we will build the first model dedicated to investigate CH₄ and H₃⁺ auroral emission on sub-stellar objects. (The H₃⁺ ion's emission is well-known in the IR spectrum of the Solar System giants [Melin+2025], where it can be traced to particles precipitating into the atmospheres.) We will use the PI's chemical-collisional-radiative models [GM+2020, GM+2021]. These models predict that, for example, H₃⁺ is abundant in the atmospheres of some, moderately cold exoplanets. As part of the project, we will establish the in-detail collisional-radiative paths that determine the populations of the CH₄ and H₃⁺ rotational-vibrational states. We will leverage recent work on rate coefficients and cross sections [Le Bourlot+2023]. Once the model is developed, we will validate it against Solar System detections with **JWST** [Melin+2025] (that also remain to be physically interpreted) and use it for the interpretation of the W1935 data [Faherty+2024] and to predict their detectability with e.g. ESA/**ARIEL** and ESO's **E-ELT**. Further, we will quantify the electron precipitation rates required for strong auroral excitation. We will relate the findings to recent knowledge of exoplanet magnetospheres obtained at radio frequencies [Callingham+2021]. Our work will provide a sound, physics-based path towards the full exploitation of aurorae detections.

The project is timely, as it connects with ongoing observations, but it also connects with the possibilities open by future facilities. The physics behind the excitation of the CH₄ and H₃⁺ molecules is relevant to other plasma applications, and therefore our work will provide valuable insight into those applications as well.

The PI leads an **ARIEL** Working Group concerned with this theme, and is involved in another **ARIEL** Working Group dedicated to the characterization of brown dwarfs. The scientific case to be developed in this project will make a significant contribution to those Working Groups, and consolidate the CEA/DAP's position in the ARIEL Consortium.

A M2 stage proposal has been submitted to find a suitable M2 stagiaire for the 2025-2026 academic year who could continue on a PhD dissertation in September 2026. The project will provide the PhD student an opportunity to contribute to exoplanet science, itself a thrilling and rapidly evolving field. The project will take place at the CEA Paris-Saclay, which is contributing to a number of space missions and ground-based telescopes (in particular some ideally suited to look for auroral emission, such as **JWST**, **ARIEL** and **E-ELT/METIS**, and more into the future, the **Habitable Worlds Observatory HWO**). Our team is very active in a number of activities related to exoplanets and their host stars, which will provide the PhD student with a very valuable perspective of stellar and substellar astrophysics.

Candidate profile

The candidate must have a Masters in Astrophysics or a related field (e.g. Applied Mathematics or Engineering) and a strong interest in theoretical/numerical work and in the comparison of observations with model simulations. In particular, the candidate must:

- be proficient in scientific programming (one of fortran, C, C++).
- be proficient in numerical simulations of physical systems.
- have some knowledge of or the interest to learn about chemical kinetics.
- be willing to learn about exoplanet atmospheres.

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