Simulation of circulation and fingering convection in the atmosphere of irradiated exoplanets

Contract:
3 years at Maison de la Simulation, CEA Paris-Saclay, France. The funding is secured by the ERC project ATMO.

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Context & Role:
This thesis aims to study the atmospheres of irradiated exoplanets in order to correctly interpret the data that will be obtained as part of the JWST (James Webb Space Telescope) space mission.

The successful candidate will develop and run High Performance Computing (HPC) simulations of the circulation induced by irradiation in the atmosphere of exoplanets and look at its impact on fingering convection within the ERC Project ATMO\(^1\). The target application is to characterize the temperature in the deep atmosphere of irradiated exoplanets to explain the radius inflation of these objects (Tremblin et al. 2017) by using newly developed Earth global circulation model (e.g. fluid dynamics simulation with the code Dynamico). He/she will also characterize the impact of the circulation on fingering convection triggered by chemical transitions (e.g. CO/CH\(_4\)) in the atmosphere of irradiated exoplanets (Tremblin et al. 2016). The goal here is to produce and use high-end simulation tools designed for the next generation of largest supercomputers (GPUs, Xeon Phis, etc) for the study of the impact of shear flows on fingering convection in these irradiated objects. These results will then be used for the interpretation of JWST data, to get access to a robust estimation of the chemical composition of irradiated exoplanet atmospheres.

He/she will be part of the ATMO team at Maison de la Simulation (numerical simulation lab of CEA) and will also work in collaboration with astrophysicists at the Department of Astrophysics at CEA and collaborators in the international scientific community. He/she will have the opportunity to work on production level HPC codes running on the most powerful supercomputers.

\(^1\) http://www.wilder.diskstation.me/erc-atmo/ or http://www.erc-atmo.eu
**Left:** Dynamico icosahedral grid (Dubos & Tort 2014). **Middle:** fingering convection simulation (Brown et al. 2013). **Right:** JWST artist view (NASA)

**Required skills:**

- Master or equivalent in Astrophysics or HPC
- Operational knowledge of techniques and programming language (Fortran90, C or C++) for application development
- Skills to work in a team

**Included Benefits:**

Additional funding for conferences, collaborations, personal equipment and publications is available. The positions include comprehensive benefits packages such as transportation and lunch subsidies, medical insurance, maternity leave and retirement benefits. + unlimited coffee!

**Application:**

To apply, please send a CV and a motivation letter to pascal.tremblin[at]cea.fr and arrange to have 2 letters of reference forwarded to the same email address.

**The ATMO Project:**

Which molecules are present in the atmosphere of exoplanets? What are their mass, radius and age? Do they have clouds, convection (atmospheric turbulence), fingering convection, or a circulation induced by irradiation? These questions are fundamental in exoplanetology to better understand planet formation and exoplanet habitability with JWST.

« James Webb Space Telescope will tell us more about the atmospheres of extrasolar planets, and perhaps even find the building blocks of life elsewhere in the universe. »

This project aims at characterizing the impact of fingering convection in the atmosphere of stars, brown dwarfs, and exoplanets and its interaction with the circulation in the case of irradiated planets. By developing innovative numerical models, we will characterize the effect of the fingering instability induced by chemical transitions (e.g. CO/CH₄) and the impact of the circulation induced by irradiation on this instability. We will then
predict and interpret the mass, radius, and chemical composition of exoplanets that will be observed with future missions such as the James Webb Space Telescope (JWST).

**What is fingering convection?**

Fingering convection is a known phenomenon happening in Earth Oceans, that has been introduced in oceanography by Stern (1960) and in stellar astrophysics in the 70's by Ulrich (1972). Recently it has been proposed to occur in the atmosphere of brown darfs and exoplanets (Tremblin et al. 2015 and Tremblin et al. 2016).

In the atmosphere of brown dwarfs and exoplanets, the instability can be triggered by chemical transitions (see Tremblin et al. 2016):

- $\text{CH}_4+\text{H}_2\text{O} \leftrightarrow \text{CO}+3\text{H}_2$
- $2\text{NH}_3 \leftrightarrow \text{N}_2+3\text{H}_2$

The methane+water mixture or the ammonia mixture will form in the upper layers of the stably-stratified atmosphere, at cold temperatures. The mean molecular weight of these mixtures is, however, higher than the one of the carbon monoxide+di-hydrogen or di-nitrogen+di-hydrogen mixtures in the deep atmosphere (less molecules on the left hand side on the chemical reactions than on the right hand side), hence triggering the fingering instability.