université de BORDEAUX

ED SPI 209
Ecole Doctorale
des Sciences Physiques et de l'Ingénieur

Appel Contrat doctoral UBx /
Ecole Doctorale SPI

Spécialité de thèse : **Astrophysique**

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TITRE DU SUJET DE THÈSE : **A study of the winds of evolved cold stars: understanding the properties and the chemistry of the wind forming region and the more extended CSE through high angular resolution observations and modeling.**

COLLABORATIONS SCIENTIFIQUES : consortium PEPPER (Laboratoire Lagrange, LESIA, LUPM, IRAP-France), consortium ATOMIUM (KU Leuven-Belgium, Harvard-Smithsonian Center for Astrophysics-USA, University of Manchester-UK, I. Universität zu Köln-Germany, IRAM), IPAG

RELATIONS INDUSTRIELLES :

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DESCRIPTIF DU SUJET DE THÈSE :

Evolved cool stars are major cosmic engines, providing strong mechanical, chemical, and radiative feedback to their host environments. Through strong stellar winds, still poorly understood, **they enrich their environment with chemical elements, which are the building blocks of planets and life**. A complete understanding of their evolution in the near and distant Universe can only be achieved with detailed knowledge of wind physics over the life cycle of these stars as well as in relation to their circumstellar environment. **A complete picture of all the physical processes that simultaneously trigger and shape the strong winds of evolved cold stars is still missing**.

The physical ingredients should play a predominant role in initiating and maintaining the high mass-loss. In the first place the evolution of these objects is impacted by stellar convection. The second ingredient is the magnetic field. Lastly, evolved cool stars are surrounded by a gaseous and dusty circumstellar envelope (CSE) sustained by their mass-loss which spreads heavy elements into the interstellar medium. The observational characterization of the mass-loss process is carried out by studying the properties of the escaping CSE material. This includes the study of its geometry and kinematics chemical composition and its dependence on stellar characteristics such as mass, luminosity, magnetic field.

This thesis is part of the ANR project *PEPPER* ***(https://lagrange.oca.eu/fr/welcome-to-anr-pepper)*** **aiming to build a coherent and comprehensive description of the mass-loss mechanism.** The main *questions* we endeavour to tackle in this project are: How are the winds launched and which physical processes determine their properties? How do the mass-loss rate and other wind properties depend on fundamental stellar parameters? What is the origin of the detected magnetic field on the stellar surface? What chemical processes dominate in the winds? Where does the interaction between dynamics and chemical phenomena lie? The core of our approach is the **synergy between theory and observation** in order **to obtain a global, coherent vision of the evolved cool stars, from the bottom of the atmosphere up to the circumstellar environment.** The whole picture of all the physical processes generating and ruling the winds can only be obtained by investigating the interplay between the sub-photospheric region (convection and pulsation), the atmosphere (strong radiative shocks), the wind forming region (dust condensation and radiative acceleration), and the circumstellar envelope.

Specifically, the Ph D student will focus of the following questions:

- What chemical processes dominate in the winds?

The proposed work will **focus on the dust in the wind forming region and in the more extended CSE.** We will use **high-angular resolution observations with** SPHERE **and** MATISSE **and observations** made quasi-simultaneously **with** ALMA **(all already in hand)** to identify/map the regions of dust formation in order to determine the major dust ingredients and constrain their sizes and radial distribution. Some additional observations will also be performed with NOEMA. This will provide us with a detailed knowledge of the wind physics and will constrain the free parameters and uncertainties in the wind models in Asymptotic Giant Branch stars and Red SuperGiants.

The PhD student will work on deeper data analysis and interpretation of the **ATOMIUM Large Program data** (https://fys.kuleuven.be/ster/research-projects/aerosol/atomium/atomium). For the interpretation, he will actively participate in the modeling using the MCFOST code. **MCFOST calculations coupled with 3D simulations** by our collaborators in Nice aim at providing a full comprehensive synthetic view for the interpretation of ALMA data.

- Where does the interaction between dynamics and chemical phenomena lay?

Based on the spectroscopic **observations of the ATOMIUM Large Program** and future submitted proposals with ALMA and NOEMA, the PhD will study the properties of the escaping material of the CSE (geometry, kinematics, molecular content) and investigate how CSE chemistry varies depending on winds and mass-loss rates. The outflows of evolved stars are the best laboratories to determine the phase transition from simple molecules to larger gas-phase clusters eventually leading to the formation of dust grains. **We hence aim during this thesis at understanding the dust and chemistry composition in the wind.** The interpretation of the observed line emissions will be done using radiative transfer codes. MCFOST including a non-LTE line transfer module will be used, but a detailed 3D model including the wind morphology will also be developed with LIME.

Spectro-polarimetric proposals will be submitted to IRAM-30m and ALMA to specifically trace the presence of a magnetic field in the CSE and constrain its role in the mass loss driving mechanism in close collaboration with the LUPM and IRAP.

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The *Laboratory of Astrophysics of Bordeaux* (LAB, https://astrophy.u-bordeaux.fr) is a joint research unit of CNRS and University of Bordeaux, part of the *Observatoire Aquitaine des Sciences de l'Univers*. The LAB plays an important role at the instrumental level in past, current, and future technological projects (e.g. ALMA, SKA, HERSCHEL, Mars2020, JUICE, SPICA).

Fabrice Herpin is the coordinator of the Star formation and evolution group at the LAB. He is a specialist of radio and IR observations, single-dish and interferometry, high resolution spectroscopy in general and expert of the molecular circumstellar envelopes and radiative transfer in radio astronomy and far-IR astronomy (ALMA, IRAM, SOFIA, Herschel). He has a long experience in line modelling. He is also an expert in radio polarimetry.

A large proportion of the observations necessary for the accomplishment of this thesis are already in hand. In addition, to use MCFOST and LIME the PhD student **will benefit from the experience** of the members of the PEPPER and ATOMIUM consortia, which he will become a member.

During the thesis, the student will acquire a broad physical, chemical, and computing knowledge and develop strong collaborations within our consortia and beyond hence opening easy **opportunities for a future post-doc position.**