Thesis subject

Name of the laboratory: Laboratoire d'Astrophysique de Marseille

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Subject's title: MassivE sTArs at Low metalLICities (METALLIC)

Subject description:
Massive stars (above 8 solar masses) have played a crucial role in the Universe throughout cosmological time. Massive stars eventually form a degenerate core and collapse down into a compact object, either a neutron star or a black hole. Most of them, either single or binaries, end their lives in luminous explosions as core-collapse supernovae; a fraction of these events produce long Gamma-Ray Bursts that enable us to probe the distant Universe. Binary neutron star mergers, the offsprings of some binary massive star systems, can also produce short Gamma-Ray Bursts, such as the one associated with some gravitational waves events detected by LIGO. The first generations of massive stars may also have played a pivotal role in the reionization of the early Universe, and in the assembly of the first galaxies. Understanding the lifecycle of massive stars thus lies at the core of a wide variety of topics in Astrophysics.

Despite many theoretical and observational studies, no global consensus has been achieved yet, on the details of the evolution and properties of massive stars. Of greater concern is that the same processes that govern the evolution of massive stars are even more uncertain at low metallicity. Understanding stellar evolution at low metallicity is indeed crucial for understanding early galaxy evolution since the Universe began with zero metals. Therefore, any description of massive stars aiming to be comprehensive must assess the role of chemical composition on their properties, evolution and fate, in order to understand the conditions of earlier cosmic epochs, and to ultimately to the time of re-ionization.

For years, we lacked a homogeneous observational sample to derive the mass loss and angular momentum loss rates of low metallicity massive stars throughout the main sequence, and infer their core and surface properties such as rotation and abundances. All these critical ingredients have profound effects on the impact of massive stars in the universe, including for example the astrophysical interpretation of gravitational wave outcome.

Time is now ripe to make decisive progress in our understanding of the role of massive stars as cosmic engines, with the advent of *ULLYSES*, the Hubble Space Telescope (HST) UV Legacy Library of Young Stars as Essential Standards (https://ullyses.stsci.edu). Up to 1000 orbits have been allocated, making of *ULLYSES* the largest program ever executed on HST. Half of *ULLYSES* will focus on massive stars in metal-poor environments, namely the Magellanic Clouds (MCs) and other galaxies of the Local Group with typically 10% of solar metallicity.

This thesis will build on *ULLYSES* (supplemented with spectroscopic data being presently obtained with X-shooter on the VLT) to obtain new constraints on key physical processes that govern massive star evolution. We will rely on powerful **cutting-edge modelling tools** to interpret quantitatively these observations, improve the characterization of the stellar and wind properties, and implement results in stellar evolution models. Synthetic spectra computed with the state-of-the-art model atmosphere code CMFGEN will allow us to draw accurate inferences on the structure, the evolution, and the associated radiation of massive stars, by connecting the output from evolution model calculations to observations.

The objectives of the thesis are to address the following questions:

- How different are low-metallicity stars from their higher-metallicity analogs in terms of physical properties and processes. The empirical data will be explored by machine learning techniques to extract information on physical effects and chemical enrichments, which are not obvious by "eye" from an object-to-object analysis.
- Does mixing of chemical elements due to stellar rotation depend on metallicity? This is one of the main predictions of evolutionary models including the effects of rotation, but this has not been verified observationnally so far. The *ULLYSES* sample will be a gold mine to address this for the MCs, while other samples already exist for the Galaxy.
- What is the metallicity dependence of stellar winds? Partial results have been obtained for the most luminous stars in the MCs but the low-luminosity range (more populated due to the stellar initial mass function shape) remains mostly unexplored. The large sample of stars observed by *ULLYSES* will help us pin down this question.

We are seeking for a candidate interested in one or more of the following fields: spectroscopic analysis, stellar evolution, numerical simulations. This thesis work will be performed in close collaborations with colleagues at Universities of Montpellier, Pittsburgh, Rio de Janeiro, that the student will be encouraged to visit. The thesis is an essential prerequisite to properly tackle the next milestone in the road to more primitive stellar populations and galaxies in both the high redshift and local Universe, or to address the tantalizing question of the gravitational wave source progenitors.

Selected bibliography related to the thesis:
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