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X-Shooting Ullyses

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Abstract. Massive stars have strong stellar winds that direct their evolution through the upper HR diagram, determine the black hole mass function, and set the amount of feedback such as the ionising flux as a function of metallicity Z. I discuss tests with the HST Director's spectroscopic UV project ULLYSES. Optimal scientific exploitation of this legacy dataset requires supplementary optical and infrared spectra obtained with X-Shooter on the VLT. I discuss the complementary aspects of these two large programmes in terms of wind physics and stellar feedback.

Keywords. Ullyses, massive stars, winds, low metallicity

1. Introduction

ULLYSES entails an ultraviolet spectroscopic Legacy Atlas of 250 OB stars in low Z galaxies.† Due to their proximity, the Large and Small Magellanic Clouds (LMC, SMC) are the best low-Z laboratories for massive-star studies, with respectively 50% and 20% $Z_{\odot}$. They are ideal to study spatially resolved, rich populations of low-Z massive stars to make a leap towards understanding the Early Universe. As a pilot study, several stars at sub-SMC metallicities (in Sextans A and NGC 3109; $\sim$10% $Z_{\odot}$) are also included. The prime aim is to uniformly sample all spectral sub-types O2−B9 and to observe all luminosity classes with spectral types O2−B1.5, for both LMC and SMC samples.

Although massive stars emit the bulk of their light at UV wavelengths, the optical region remains a cornerstone of spectroscopic studies. The UV regime is powerful to determine iron (Fe) abundances and to obtain information on wind parameters, such as the terminal velocity v_{∞} (see Hawcroft et al. in prep.). The optical regime is crucial to determine the basic stellar parameters, such as effective temperature $T_{\rm eff}$, gravity $\log g$, and He abundance. Key information on wind clumping and mass-loss rates only become reliable when optical observations are added to the UV data. Thus, the XShootU‡ project obtained complementary optical to NIR spectra of the ULYSSES targets with the medium-resolution (R$= 5,000 - 10,000$) spectrograph X-shooter at ESO's VLT.

2. XShootU Science

The XShootU project addresses a large variety of scientific questions concerning massive stars at low Z. During the project we derive sets of stellar & wind parameters, such as temperatures, luminosities, gravities, abundances, and mass-loss rates, using non-LTE wind codes such as CMFGEN, FASTWIND, and POWR. This will then enable us to establish how mass-loss rates decrease with Z, and test various predictions (e.g. Vink et al. 2001; Björklund et al. 2021; Vink & Sander 2021). Moreover, feedback parameters involving

† https://ullyses.stsci.edu
‡ https://massivestars.org/xshootu/

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wind momenta, wind kinetic energy, and ionising fluxes are key ingredients for building the next generation of spectral population synthesis models that may be applied to extra-galactic surveys such as CLASSY, and future projects.

In order to make progress not only the spectroscopic datasets need to be uniform – as provided by ULLYSES and XShootU – but so does the spectral analysis approach. To give one example: in order to determine $\dot{M} - Z$ one does not only require accurate mass-loss rate determinations, but one also needs reliable stellar parameters, such as effective temperatures, to compare $\dot{M}$ from one star with one set of stellar properties in one particular galaxy to the mass-loss rate from another star in another galaxy. The uniform data and spectral synthesis approach is at the heart of the XShootU project.

3. Strategy

The first objective of XShootU is to create a homogeneous Legacy Atlas of similar quality and scope as that in the UV. ULLYSES obtained moderately high-resolution spectra of OB stars with selected wavelength settings in the far- and near-UV during *HST* cycles $27 - 29$. A subset of the ULLYSES targets have previously been spectroscopically analysed. Considering their locations in the HRD, the SMC targets have masses in the range $10 - 60\ M_{\odot}$, whereas the LMC targets have masses in the range $15 - 150\ M_{\odot}$.

Medium-spectral-resolution spectroscopy was carried out with the X-shooter instrument. This slit-fed spectrograph provides simultaneous coverage of the wavelength region between $300 - 2500$ nm, divided into three arms; UVB ($300 \lesssim \lambda \lesssim 500$ nm), VIS ($500 \lesssim \lambda \lesssim 1000$ nm), and NIR ($1000 \lesssim \lambda \lesssim 2500$ nm). X-shooter's wide wavelength coverage made it the instrument of choice for the purpose of building an optical-NIR legacy dataset. The X-shooter slit widths were chosen to obtain a minimal spectral resolution of $R = 5000 - 10\,000$, required for estimating the stellar parameters. In addition to the wide wavelength coverage, a high signal-to-noise ratio (S/N) and a sufficient spectral resolution are essential to determine the fundamental stellar parameters and the abundances for various temperature regimes populated by O-type, B-type, and WR stars. In Vink et al. (in prep.) we show how the determination of $T_{\rm eff}$ and $\log g$ of a synthetic spectrum, to which various degrees of noise are added, becomes prohibitive for any quantitative interpretation if the S/N is < 100. To ensure maximal scientific return of XShootU, we thus aimed at a S/N of > 100 in the continuum for the UVB and VIS arms.

XShootU obtains a complementary dataset over the optical to NIR wavelength range for all ULLYSES targets that have not previously been observed with X-shooter. A key aspect of combing the ULLYSES and XShootU data sets is that it allows stellar and wind parameters to be derived from a combined optical and UV approach. There are no conclusive diagnostics in the UV to derive effective temperatures and gravities, but the UV wind profiles of O IV, O V, and N IV do impose a minimum effective temperature. More importantly, they are sensitive to mass loss and clumping properties. The optical provides many of the stellar parameters, as well as mass-loss and clumping information, which are crucial for constructing reliable stellar evolution and population synthesis models.

We have organised the Project into 14 Working Groups varying from stellar atmospheres & winds to spectral libraries & population synthesis. Anyone is welcome to join the project via the XShootU website.

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