Massive Stars Across Redshifts in the Era of JWST and Large Surveys
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X-Shooting ULLYSES

Frank Tramper

Centro de Astrobiología (CAB), CSIC-INTA, Carretera de Ajalvir km 4, E-28850 Torrejón de Ardoz, Madrid, Spain
email: ftramper@cab.inta-csic.es

Abstract. XShootU is an open world-wide collaboration aiming to provide high-quality optical to near-infrared spectra for all massive stars in ULLYES. Here, an overview is given of the available and upcoming data releases, as well as the scientific output so far.

Keywords. Stars: massive, Stars: fundamental parameters, Stars: winds, outflows, Stars: evolution

1. Introduction

With approximately 1000 orbits, the *Hubble Space Telescope* (HST) Director's Discretionary Time (DDT) program ULLYSES† is the largest DDT program ever performed. About 50% of the orbits were allocated to observe massive OB-type stars in the Magellanic Clouds and low-metallicity galaxies. The aim of ULLYSES is to provide a legacy UV spectral atlas spanning all spectral subtypes and luminosity classes (see Figure 1). The program was executed between 2020 and 2023, and complemented with archival data with similar instrumental setup and data quality (Table 1).

The UV spectral range provides excellent diagnostics to determine, for instance, stellar wind parameters and iron abundance. However, the optical regime remains critical for the determination of key stellar parameters such as effective temperature, surface gravity, and rotation rate. Information on wind clumping and mass-loss rate only become reliable when combining the UV diagnostics with those from the optical. Furthermore, with the advent of the *James Webb Space Telescope* and the upcoming extremely large telescopes such as the *ELT*, the focus shifts to longer wavelengths, and knowledge of the near-IR is desirable.

For these reasons, XShootU‡ (Vink *et al.* 2023) was initiated by the IAU Commision G2 for massive stars. XShootU is an open, world-wide collaboration that aims to:

- Provide high-quality, optical to near-IR spectra for all massive stars in ULLYSES;
- Collaborate on the analysis of the combined datasets to address key science questions concerning massive stars at low metallicity.

Examples of the scienctific aims are: provide stellar and wind parameters from the combined datasets, benchmark atmoshpere models and fitting methods, test and improve evolution models at low metallicity, investigate the mass-loss behavior at cooler temperatures (e.g., bi-stability jump), population synthesis, and stellar libraries.

To reach these goals, the data need to meet several requirements: a large wavelength coverage, ideally spanning the full optical to near-IR wavelength range; a medium resolving power of $R = \lambda/\Delta\lambda > 5\,000$ (needed to disentangle the several broadening mechanisms); a signal-to-noise ratio $S/N > 100$ (needed for quantitative analysis); and

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

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Table 1. Distribution of ULLYSES stars.

	LMC	SMC	Low-Z
Core Sample	129	105	6 → Sextans A & NGC 3109
Archival	53	28	34 → Sextans A, IC 1613, WLM, Leo A, Leo P, Magellanic Bridge
Total	**182**	**133**	**40**

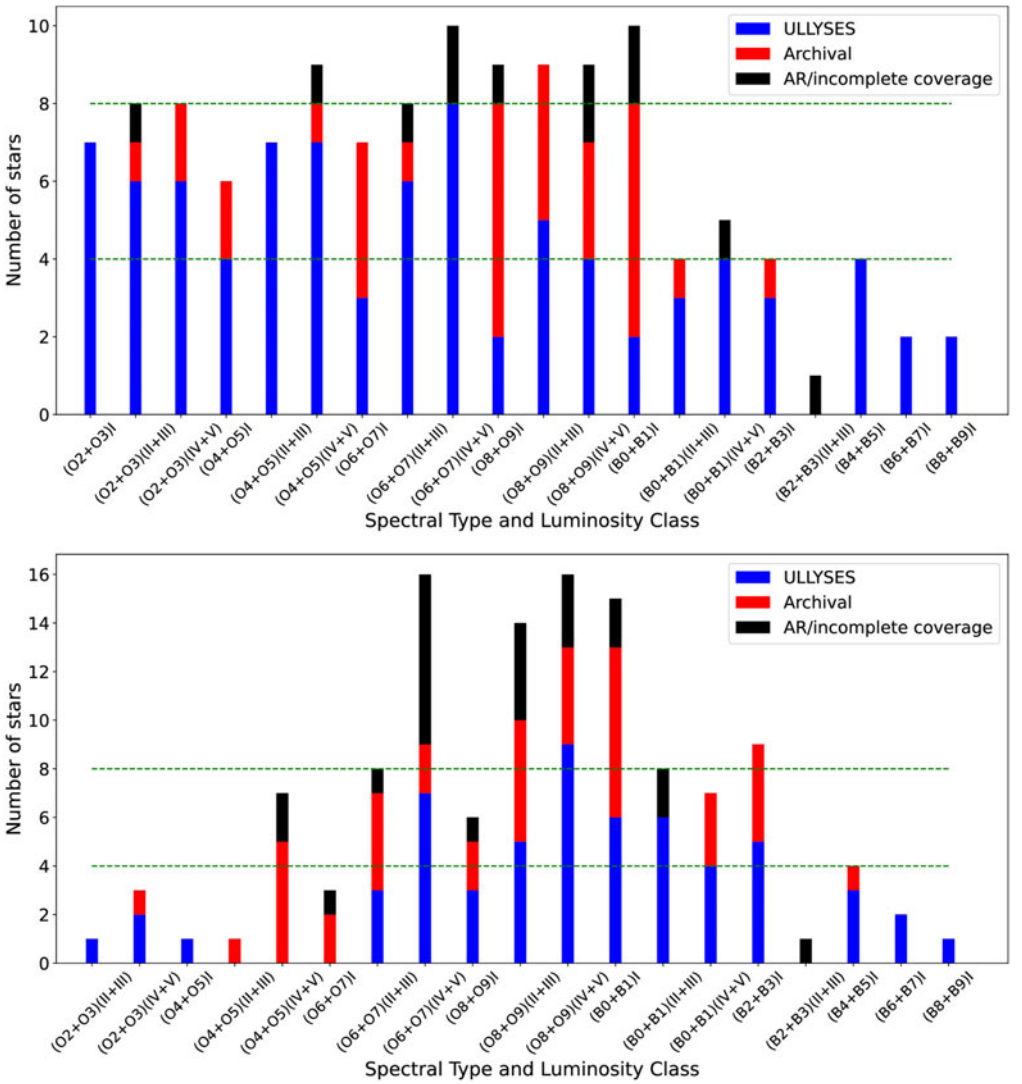


Figure 1. Top: Distribution of the targets in the ULLYSES sample in the LMC (top) and SMC (bottom). Figure from Roman-Duval *et al.* (2025).

a good absolute flux calibration (essential for use in population synthesis and stellar libraries).

To meet these requirements, X-Shooter (Vernet *et al.* 2011) on ESO's *Very Large Telescope* was selected as the instrument of choice. X-Shooter provides a wavelength coverage from 300nm to 2.5μm at medium to high resolving power, has a high throughput

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Table 2. Overview of XShootU observing programs.

Program	ID	Hours	Stars	Dates[1]	Status[1]
XShootU LP	106.211Z	126	232+3[2]	Oct 2020 - Jan 2022	UVB & VIS data products for the Magellanic Clouds released
XShootU+	112.25D1	33	39	Oct 2023 - Mar 2024	Observations completed
XShootU++	116.28LN	9	10	Sep 2025 - (Mar 2026)	Observations ongoing
XShootU+++	117.29KZ	22	11	(Apr 2026 - Mar 2027)	Submitted

Notes: [1] Status as of Sep 2025. Estimated future dates in parenthesis.[2] Three stars were observed that were removed from the ULLYSES sample.

making it efficient, and has a good relative flux calibration. The latter, however, is affected by slit losses, telluric absorption, and variable sky transparency.

The next Section describes the data obtained by the XShootU collaboration, and presents the available and upcoming data releases. Section 3 gives an overview of the current status of the science goals, followed by a summary in Section 4.

2. Data overview

This section describes the X-Shooter data that has been obtained by the XShootU consortium, as well as the public data releases available and planned. The core ULLYSES sample has been observed by a Large Program, followed by three normal programs targeting the extended sample. Table 2 gives an overview of the observing programs. None of the programs have a proprietary time, so that the standard data products are available to the public as soon as they appear on the ESO archive.

All observations were done in stare mode, using slit widths of 0.8" ($R = 6\,700$), 0.7" ($R = 11\,400$), and 0.6" ($R = 8\,000$) in the UVB, VIS, and NIR arms, respectively. Below, a description of the available and upcoming data releases is given.

2.1. *DR1: UVB and VIS data products of the core ULLYSES sample*

The first public data release (DR1) contains advanced UVB and VIS data products for the core sample of ULLYSES stars, excluding those for which archival X-Shooter data is available. The data have been reduced using the standard X-Shooter pipeline, with an improved flatfielding strategy and new flux models.

To obtain an absolute flux-calibrated spectrum, the following steps are taken:

- Slit-loss correction (SLC), taking into account the wavelength and airmass dependence of the seeing;
- Telluric absorption correction (TAC), using Molecfit (Smette *et al.* 2015; Kausch *et al.* 2015) – Only performed for the VIS data;
- Absolute flux calibration by scaling the UVB data to the B-band magnitude and lining up the VIS to the UVB.

Figure 2 shows an example spectrum for each of these steps. Finally, a version of the absolute flux calibrated spectrum normalized to the continuum is provided.

DR1 is publicly available on the ESO archive† and Zenodo‡. The data reduction and data products are described in detail in XShootU Paper II (Sana *et al.* 2024).

2.2. *DR2: NIR data products of the core ULLYSES sample (in prep.)*

As all XShootU observations were done in stare mode and have relatively long exposure times, the sky subtraction and TAC in the NIR is more challenging. Furthermore,

† https://archive.eso.org/scienceportal/home?data_collection=XShootU
‡ https://zenodo.org/records/12743023

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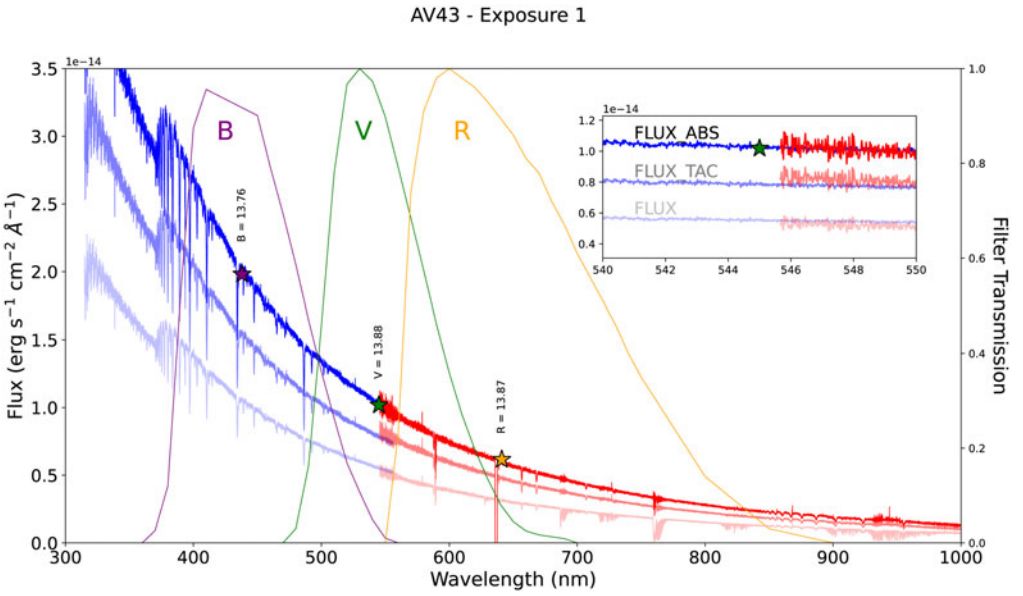


Figure 2. Example of the spectrum of AV-43 after the pipeline reduction (bottom), slit-loss and telluric absorption correction (middle), and absolute flux calibration (top). Figure from Sana *et al.* (2024).

Table 3. Overview of XShootU publications.

Number	Reference	Title
		A&A series
I	Vink *et al.* (2023)	Project description
II	Sana *et al.* (2024)	DR1: Advanced optical data products for the Magellanic Clouds
III	Hawcroft *et al.* (2024)	Terminal wind speeds of ULLYSES massive stars
IV	Sander *et al.* (2024)	Spectral analysis methods and exemplary results for O stars
V	Martins *et al.* (2024)	Effect of metallicity on surface abundances of O stars
VI	Backs *et al.* (2024)	Atmosphere and mass-loss properties of O-type giants in the Small Magellanic Cloud
VII	Bernini-Peron *et al.* (2024)	Stellar and wind properties of B supergiants in the Small Magellanic Cloud
VIII	Ramachandran *et al.* (2024)	Stellar and wind parameters of newly revealed stripped stars in Be binaries
IX	Verhamme *et al.* (2024)	Empirical constraints on mass-loss rates and clumping parameters for OB supergiants in the Large Magellanic Cloud
X	Gómez-González *et al.* (2025)	Physical parameters and feedback of massive stars in the LMC N11 B star-forming region
XI	Bestenlehner *et al.* (2025)	Pipeline-determined physical properties of Magellanic Cloud OB stars
XII	Brands *et al.* (2025)	Clumped winds of O-type (super)giants in the Large Magellanic Cloud
XIII	Alkousa *et al.* (2025)	Testing the bi-stability jump in the Large Magellanic Cloud
		Publications outside main series
	Vink *et al.* (2024)	X-Shooting ULLYSES: Massive Stars at Low Metallicity
	Furey *et al.* (2025)	The wind properties of O-type stars at sub-SMC metallicity

the current X-Shooter pipeline produces an incorrect wavelength scale in the NIR, causing further issues with the TAC. Hence, the NIR data will be made available in a separate data release.

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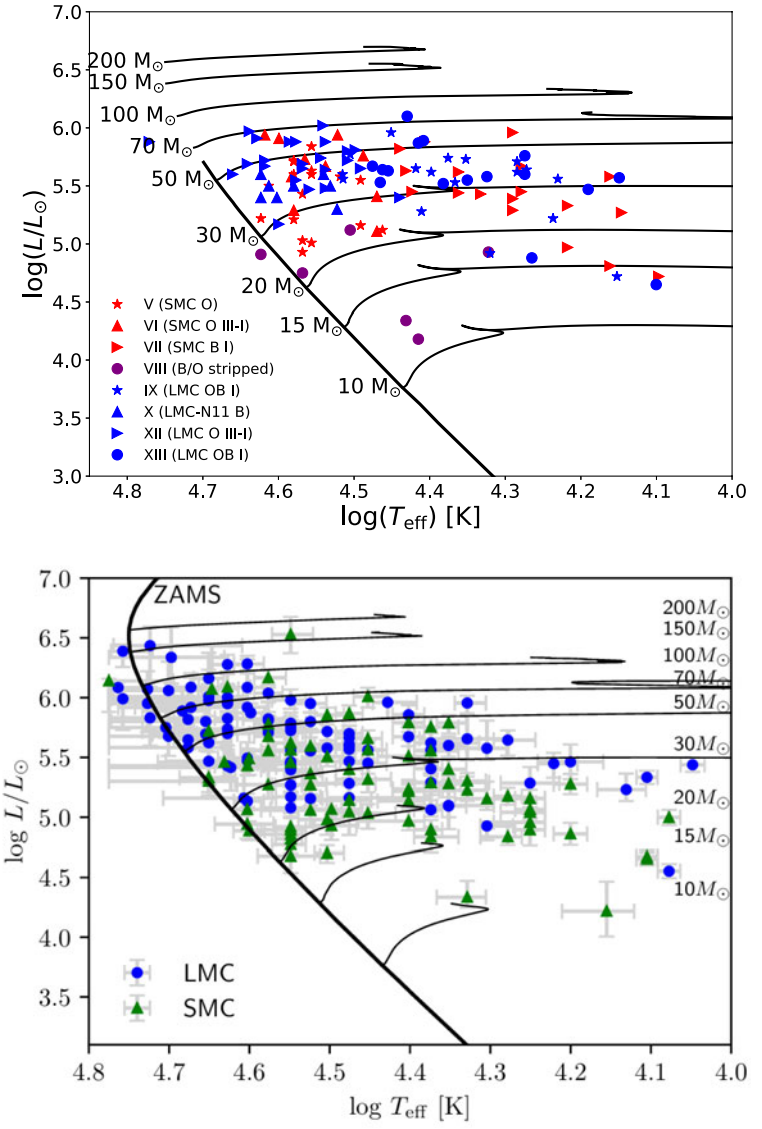


Figure 3. Top: HRD with results of detailed analyses (Martins *et al.* 2024; Backs *et al.* 2024; Bernini-Peron *et al.* 2024; Verhamme *et al.* 2024; Gómez-González *et al.* 2025; Brands *et al.* 2025; Alkousa *et al.* 2025). Bottom: HRD with results of pipeline analysis (Bestenlehner *et al.* 2025).

The NIR data reduction involves an improved sky subtraction strategy, using small sky windows close to the stellar trace. An (currently not public) improved version of the pipeline will be used to correct the wavelength calibration based on the location of telluric lines in telluric standard star observations. Finally, the telluric absorption correction will be performed by splitting up the NIR data in several (~ 10) wavelength regions for which the telluric model is fitted independantly.

DR2 will contain advanced NIR data products for the core ULLYSES sample, and is scheduled for public release by the end of 2025 / early 2026.

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2.3. *DR3: Data products of extended ULLYSES sample and low-Z galaxies (planned)*

The last data release will contain advanced UVB/VIS/NIR data products for the extended ULLYSES sample for the Magellanic Clouds, including the data obtained by the XShootU programs as well as archival data. Furthermore, UVB and VIS data products for all low-metallicity targets will be included. This data release is planned for mid to late 2026.

3. Science overview

Significant progress has been made in the analysis of the shared ULLYSES and XShootU datasets. Table 3 gives an overview of all XShootU papers to date. Various papers are dedicated to the quantitative spectroscopic analysis of sub-samples of stars, an overview of which is given in the Hertzsprung-Russel diagram (HRD) presented in Figure 3. These studies make use of several codes (`fastwind`, Puls *et al.* (2005); `CMFGEN`, Hillier & Miller (1998); `PoWR`, (e.g., Gräfener *et al.* 2002)), as well as methods (by eye; genetic algorithm, Brands *et al.* (2022); grid-based (e.g., Simón-Díaz *et al.* 2011)). A benchmarking study comparing these codes and methods was published in Paper IV (Sander *et al.* 2024). Paper XI (Bestenlehner *et al.* 2025) provides optical-only analysis of the full sample of 'regular'† OB stars using a pipeline method.

4. Summary

XShootU provides high-quality X-Shooter spectra for all stars in ULLYSES. Advanced UVB and VIS data products for the core ULLYSES sample have been publicly released, and two more public data releases are scheduled. The scientific exploitation of the combined datasets is well underway, with 13 papers published and many more in preparation.

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† Excluding Wolf-Rayet stars, OBe stars, binaries, etc.

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