Massive Stars Near and Far
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Observations of Very Low-Metallicity Massive Stars

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Abstract. Very metal-poor massive stars hold the key to interpret high-redshift star-forming galaxies and the early reionization epoch, but also contemporary events such as gravitational waves. To study these objects in resolved environments, we need to resort to dwarf irregular galaxies far from the potential wells of M31 and the Milky Way, and therefore distant. While the archives, recently boosted by the ULLYSES and XSHOOTU programs, store a healthy dataset of massive stars in the Milky Way and the Magellanic Clouds, the number of observed targets with poorer metal content than the SMC ($1/5\ Z_{\odot}$) is dramatically small. This paper reviews the state of observations of very metal-poor massive stars, assessing what can be realistically learned about their physics and evolution with current instrumentation, and arguing whether or not near-future facilities can remedy the gaps in the knowledge that remain.

Keywords. Low metallicity, Massive stars, Spectroscopic observations, Spectroscopic analyses

1. Introduction

Considering the monotonic (even if anisotropic) growth of metallicity (Z) of the Universe after the Big Bang, metal-poor massive stars are fundamental to model and interpret past cosmic epochs. Studies of high-redshift star forming galaxies, the use of γ-ray bursts (GRBs) and superluminous supernovae (SLSNe) as distance and star-formation rate diagnostics, the formation of the first stars, and the true identity of the sources that powered the reionization of the Universe, are some prominent open fronts that hold very metal-poor massive stars at their core. The interest in these objects was further rekindled by gravitational wave experiments reporting $\sim 30\,M_{\odot}$ double black holes, suggesting that the amount of mass lost during evolution is small, hence that low-metallicity may favor the formation of progenitors.

Up to now, massive stars in the Small Magellanic Cloud (SMC, $1/5\,Z_{\odot}$) make the current reference for the metal-poor Universe. Extensive samples and batteries of observations exist that enable studying the physics of these objects to high detail. However, we need to push further to lower metallicity values akin to the average metal content of the Universe at redshifts earlier than z=1 (e.g. Madau & Dickinson 2014) in order to tackle the problems described before.

The physical properties of sub-SMC metallicity massive stars during their evolution are still unknown. The weaker radiation-driven winds that can be powered by the decreased amount of iron, compared to solar analogs, induces strong changes in evolution. The smaller angular momentum loss favors fast rotating stars which may enter chemically homogeneous evolution (CHE). Pure CHE is a whole new channel of evolution that has never been observed to date, but which may have a dramatic impact on the feedback of metal-poor massive star populations (Szécsi et al. 2015). This is just an example of how important it is to characterize the evolutionary pathways of metal-poor massive stars. However, until we have well-populated (complete if possible) samples in very metal-poor galaxies we will not know how massive stars evolve, nor will we be able to link them as progenitors of GRBs, SNe and SLSNe. The role of binary evolution in these environments is also uncharted territory at the moment.

The past two decades have witnessed valiant efforts to improve our knowledge on these objects, by studying massive stars in resolved very metal-poor galaxies of the Local Group and vicinity with 8 and 10 m telescopes. They commenced with the exploratory works on WLM, IC 1613 and NGC 3109 framed in the Araucaria project (Bresolin et al. 2006, 2007; Evans et al. 2007). These galaxies were selected because of their low oxygen nebular abundances ($N(O/H) \sim 1/7\, N(O/H)_\odot$, hereafter denoted as $1/7\, O_\odot$), later-on confirmed by the analysis of early-B supergiants. Yet, independent studies of the optical spectrum of late-B/early-A supergiants (Hosek et al. 2014) and the ultraviolet spectrum of O-type stars (Garcia et al. 2014; Bouret et al. 2015), showed that the abundance of Fe-group elements was actually $1/5\, Fe_\odot$ and similar to the SMC's. Since radiation-driven winds are largely responsible for the expected changes in the evolution of very metal-poor massive stars, and mass loss is driven by Fe-group elements, these results implied that WLM, IC 1613 and NGC 3109 are not fit to study the very metal-poor regime.

Thus began the exploration of other galaxies at the very outskirts of the Local Group and beyond. The list includes systems with promising low nebular abundances of $1/10\, O_\odot$ (Sextans A), $1/20\, O_\odot$ (Leo A, SagDIG) and $1/30\, O_\odot$ (Leo P). Low iron abundances have already been confirmed for young stars in Sextans A and Leo P (Kaufer et al. 2004; Garcia et al. 2017; Telford et al. 2021). However, the galaxies are distant (Leo A – 0.8 Mpc, SagDIG – 1.1 Mpc, Sextans A – 1.3 Mpc, Leo P – 1.7 Mpc) or suffer from severe foreground extinction (SagDIG) and observations are challenging. In the following pages we will list the parameters needed to characterize the evolution of sub-SMC metallicity massive stars, we will advise an observational strategy to constrain them, and we will finally discuss what results can be expected according to the capabilities of current and near-future facilities.

2. Strategy

In order to characterize the evolution of massive stars at any metallicity, the following stellar parameters must be constrained for a large sample that covers different states of evolution: effective temperature $T_{\rm eff}$, gravity $\log g$, luminosity $L_{\rm bol}$ (from these, stellar radii R_* and present-day masses M_* follow), and mass loss rate ($\dot{M}$). Rotational velocities (for which we measure the projection into the line of sight $v\sin i$) and surface abundances (He, C, N, O) of blue massive stars are needed to understand the mixing mechanisms. Understanding the role of binary evolution requires following-up a healthy sample of systems to obtain statistics for the period and mass fraction distributions, and identifying and studying post-binary interaction products (BIPs).

Since no massive stars were previously known in the sub-SMC metallicity galaxies, and bearing in mind that photometry does not suffice to assign spectral types (on the blue side O and B subtypes cannot be distinguished, and red supergiants may be confused with foreground red-clump stars), a four step approach is recommended:

1 Census: Optical-range spectroscopy of photometry-selected candidates can confirm massive stars and assign spectral sub-types. It may also provide the first list of binary candidate systems. Spectroscopic resolving power of $R=\lambda/\Delta\lambda \sim 700$–1000 and signal-to-noise ratio S/N$\sim$ 50 suffice, although higher S/N would provide suitable data for step 2. The census must aim for completeness and contain of the order of 100–1000 stars.

2 Photospheric parameters: $T_{\rm eff}$ and $\log g$ can be constrained from R=1000, S/N$\sim$100 optical spectra (although see Sect. 3.1). Measuring projected rotational velocities and element abundances of blue-type massive stars, however, require a higher resolving power of R=5000. Ideally, photospheric parameters would be derived for all the stars in the census, although a sample of hundreds of stars should suffice.

3 Mass loss rates of all the stars studied in step 2 are needed in order to fulfill their evolutionary status, yet this is the most elusive parameter of all. The dust-driven $\dot{M}$ of red supergiants can be derived from their mid-infrared excess or by characterizing their circumstellar material (Mauron & Josselin 2011; Beasor et al. 2020). The winds of Wolf-Rayet (WR) stars and Luminous Blue Variables (LBV), should one such specimen be found, can be characterized from the data taken in step 2. As for OB-stars, however, only the ultraviolet range (UV) contains suitable $\dot{M}$ diagnostics because the Balmer series is not sensitive to the weak radiation-driven winds expected at sub-SMC metallicity. Considering the long required observing time induced by non-negligible extinction towards some of the candidates, and HST's oversubscription factor and remaining operation time, a sample of ten-some UV spectra of OB-stars can be realistically expected.

4 Multi-epoch observations: Finally, high spectral resolution follow-up of the candidate binaries detected in steps 1 and 2 is needed to produce the distribution of orbital periods and mass fractions of the systems. A dedicated monitoring program to detect additional systems would be necessary, but likely unfeasible considering the long observing times needed to reach massive stars at ~1 Mpc with sufficient S/N. Specific techniques to pin down and characterize BIPs (e.g. stripped stars, Götberg et al. 2018) will also provide invaluable information on the role of binary evolution at this metallicity.

2.1. *Available instrumentation*

From this section on we will focus on the observations of OB-type stars. At a distance of ~1 Mpc (25 distance modulus) the faintest O dwarfs will have V~21. Obtaining S/N≥50 optical spectra of such faint V-magnitudes requires very long observing times and therefore multi-object spectroscopy (MOS) is the optimal choice. The lowest end of the initial mass function, the B dwarfs, will basically be out of reach.

Near-infrared (NIR) spectroscopy could theoretically enable the steps described in the previous section, however, stars are fainter in this spectral range ($(V-J)_0 \sim$ -0.65, $(V-K)_0 \sim$ -0.85, Martins & Plez 2006) and observations are further challenged by the strong background emission of the Earth's atmosphere. The short exposure times imposed by the sky coherence time in the K-band make observations of O-type stars at ~1 Mpc unfeasible in this spectral range and challenging even for the Extremely Large Telescope (ELT). This may be a problem for observing very metal-poor massive stars with first-light ELT instrumentation, optimized for near- and mid-infrared wavelengths.

Figure 1 summarizes suitable instruments as a function of the number of objects they can observe simultaneously (multiplexing) and their resolving power. All 8 and 10m class telescopes have workhorse R~500–2000 spectrographs operating in the optical range with long-slit and mask-based MOS modes. These can be used to build the census of massive stars within a galaxy and the spectra could also be used to determine $T_{\rm eff}$ and log g. Yet, the multiplexing is limited and the required observing campaigns would be of the order of ~ 70 hours long (see e.g. Lorenzo et al. 2022a).

Large field, high spatial resolution integral field spectrographs (IFS) are much more efficient to register the population of massive stars within a galaxy. Since observations are not targeted, IFS have the added capability of unveiling reddened stars and other objects that cannot be easily identified from their photometric colors (e.g. WRs and LBVs). With $1' \times 1'$ field of view and $0.2'' \times 0.2''$ spatial sampling, MUSE at the Very Large Telescope (VLT) has an enormous discovery potential even though its $\lambda > 4650$Å

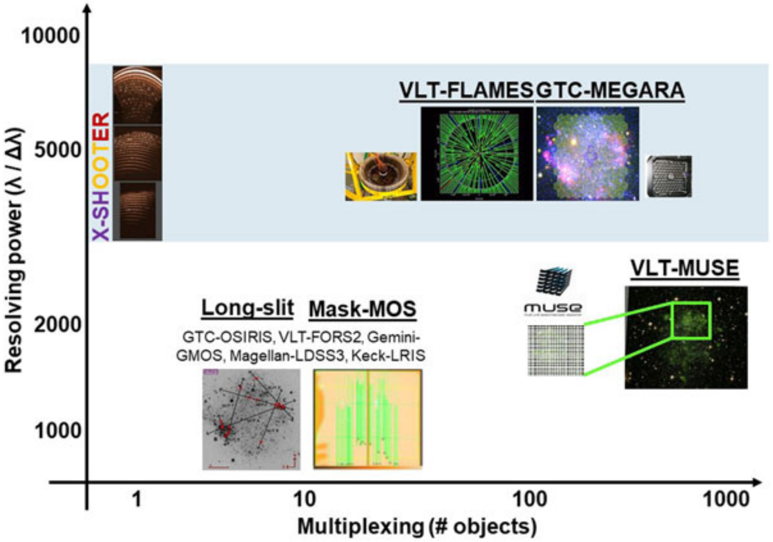

Figure 1. Summary of spectroscopic instrumentation suitable to study massive stars in Local Group galaxies. Instruments have been sorted according to spectral resolving power and multiplexing. Additional important parameters such as wavelength coverage, field of view, fiber aperture and fiber patrol area have not been considered.

wavelengh coverage is not optimal to study blue massive stars. Its successor, BlueMUSE (Richard et al. 2019), will unite MUSE's unique IFS capabilities with blue wavelength coverage, and will mean a breakthrough for the studies of massive stars in the Local Group. By targeting entire populations at once, both MUSE and BlueMUSE are also very well suited to spot spectroscopic binary systems.

Measuring element abundances and projected rotational velocities means a qualitative step up in spectral resolution to R$\geq$5000 and requires more sophisticated instrumentation. VLT-XSHOOTER has outstanding sensitivity and registers the spectra of objects from the optical range all the way to the NIR, with the required resolution. However, it only enables observations of one or two objects at once, hence observing a sample of $\sim$100 V$\sim$21 stars would be prohibitive in observing time. VLT-FLAMES and its 132 MEDUSA fibers meet the multiplexing requirement although its radial fiber positioning mechanism is not optimal for small galaxies, and the GIRAFFE spectrograph is rather insensitive in the blue spectral range. Furthermore, the fibers have 1.2$''$ apertures on the sky, which hinders a good sky subtraction and will not resolve moderately close sources.

MEGARA mounted at the Gran Telescopio Canarias (GTC) makes for an interesting alternative (Gil de Paz et al. 2022). Similarly to FLAMES, it covers the whole 3600-5200Å range with R$\sim$5000 with two settings. However, its design is optimal to obtain spectroscopy of resolved objects within small fields. The instrument has 100 robot positioners for fibers, evenly distributed at the focal plane. Each of them can patrol an hexagon, and together they achieve coverage of the $3.5' \times 3.5'$ field of view. This fiber distribution is less prone to fiber obstruction as opposed to circle-based positioners such as FLAMES, and therefore it is better suited to study populations of massive stars that tend to be spatially concentrated. The instrument has the added advantage that each robot positioner handles a bundle of 7 fibers of 0.67$''$ diameter each that keep information on the sky emission around each target. MEGARA will be crucial for advanced studies of very metal-poor massive stars once the robot positioners are commissioned and the multi-object mode is online.

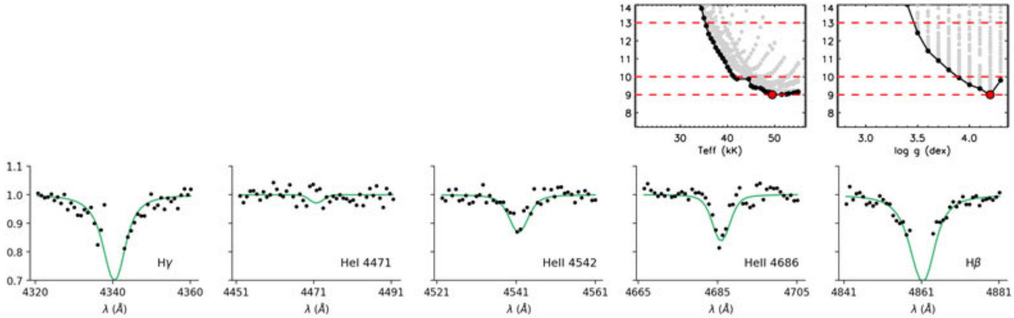

Figure 2. Preliminary fit to star LSS3.OB13206 (O5 Vz, V$\sim$20.4) from Lorenzo et al. in prep. The spectrum (S/N=110) was analyzed with IACOB-GBAT. The top panels show well-defined, though broad, χ^2 distributions for $T_{\rm eff}$ and log g. The bottom panels show the best-fitting model for strategic Balmer, HeI and HeII lines.

3. Current status and a critical view of recent results

Even though previous work existed on massive stars in Local Group galaxies beyond the Magellanic Clouds, the work on very metal-poor dwarf irregulars has begun only recently. In this section we review progress according to the strategy outlined in Sect. 2, and discuss the precision of the derived parameters and the potential of different datasets.

3.1. *Census and first stellar parameters $T_{\rm eff}$, log g, $v$sin i*

Great advances have been made on registering massive stars in metal-poor galaxies from low-resolution spectroscopy. Ten years ago, only 6 stars had been observed in Sextans A (Kaufer et al. 2004), 10 in Leo A (Brown et al. 2007), SagDIG had not been explored and Leo P had not yet been discovered. Nowadays, the presence of massive stars has been confirmed in SagDIG (Garcia 2018) and Leo P (Evans et al. 2019), and Leo A is subject to close scrutiny (Gull 2022). Moreover, an extensive census of 150 OB-type stars in Sextans A is about to be published (Lorenzo et al. 2022a) and 7 RSGs have been reported in this galaxy (Britavskiy et al. 2019).

The low-resolution discovery spectra also enable the first spectroscopic analyses to constrain stellar parameters. Figure 2 shows the best fitting model obtained with the χ^2 algorithm IACOB-GBAT that runs on FASTWIND models (Simón-Díaz et al. 2011; Puls et al. 2005) for the R$\sim$1000, S/N=110 spectra of an O-type star in Sextans A. While the algorithm returns a good fit and well-defined χ^2 distributions for $T_{\rm eff}$ and log g with clear minima, the distributions are wide and the error bars will be large. Poorer results are anticipated for most of the stars in the discovery census, observed with lower S/N, and for which log g will be largely undetermined (see also Camacho et al. 2016). In other words, R$\sim$1000 spectra may not yield precise effective temperatures and gravities even if the S/N is high, and in the worse case scenario it may not constrain log g at all. Projected rotational velocities (therefore, macroturbulence) will neither be constrained unless $v$sin i is extremely high (see Fig. 3). At least R$\geq$2000 and outstanding S/N spectra are needed to measure $v$sin i.

VLT-MUSE has the potential to enhance the census of very metal-poor massive stars by one order of magnitude. It delivered the first list of OB-type stars in Leo P (Evans et al. 2019), and it also shows great promise out to 2 Mpc in the galaxy NGC 300 (McLeod et al. 2020). Recent MUSE observations in Sextans A (PI F. Tramper) will finally mine the population of OB-type stars in the large HII shells at the East of Sextans A.

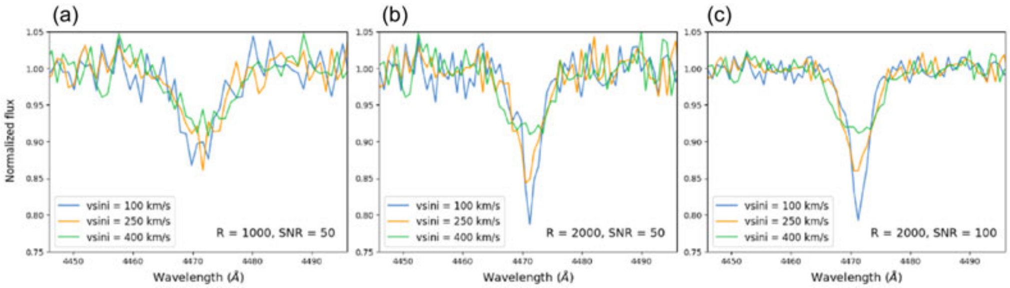

Figure 3. The HeI4471 line from a FASTWIND model has been broadened according to different $v\sin i$ values and simulating configurations with different spectral resolutions. Since metallic lines are very weak in the optical spectra of O-stars, $v\sin i$ will be determined from HeI lines. The rotational profiles cannot be distinguished at the S/N=50, R∼1000 typical spectra of discovery observations (panel a). An increase in resolution only (b) still cannot differentiate 100 and 250 km/s profiles, nor resolve the wings of the 400km/s model. Only at S/N= 100 and R = 2000 the rotational profiles can be discerned (c). *Courtesy: M. Lorenzo.*

MUSE's R=2000 spectral resolution is apt for quantitative spectroscopic analysis. However, the 4650-9300Å covered spectral range, modulated by the spectral energy distribution of O- and early-B type stars that make the observed fluxes to quickly drop at $\lambda >$7000Å, offers only a limited number of diagnostic lines to study these objects (e.g. Martins & Palacios 2021). Effective temperatures and gravities of O-type stars can be determined from $H\beta$ and the He ionization equilibrium, yet S/N is again critical. McLeod et al. (2020) derived $T_{\rm eff}$ and $\log g$ of NGC 300 stars but with ± 3000 K and ±0.3 dex error bars respectively. In a MUSE study of stars in the Large Magellanic Cloud observed with better quality (S/N> 50), Castro et al. (2021) obtained more precise effective temperatures with typical errors of ± 1000 K, but gravity just as poorly constrained. Moreover, when comparing results for overlapping stars with the VLT-FLAMES Tarantula Survey (VFTS), Castro et al.'s MUSE $\log g$ estimates are systematically lower than those from the VFTS by ∼0.3 dex. Whether this offset is caused by MUSE's lower spectral resolution or by $\log g$ being determined mostly from $H\beta$, which is also sensitive to winds, remains to be further tested.

3.2. *Abundances and R∼5000 optical studies*

To assess whether constraining the surface abundances of very metal-poor massive stars is feasible, we resort to previous similar studies in IC 1613 (∼750 Kpc), NGC 3109 (∼1 Mpc) and NGC 55 (∼2 Mpc). Element abundances of He, C, N, O, Si and Mg can be derived from the R∼1000, 4000–5000Å spectra of early-B supergiants with a precision of ±0.2 dex as long as S/N≥100 (Bresolin et al. 2007; Castro et al. 2012). Likewise, the analysis of high quality spectra of late-B and early-A supergiants in the 4000–5500Å range can yield a global value for the abundances of Fe-group elements Fe, Cr and Ti (Hosek et al. 2014). In this case S/N≥100 warrants ±0.1 dex precision, while poorer S/N results in ±0.25 dex error bars or larger.

Deriving CNO surface abundances of O-type stars is even more challenging. Grin et al. (2017) provide some illustrative examples observed with VLT-FLAMES. The lines are weak and extremely high S/N, together with R≥5000, are required to ensure their detection and proper analysis (see also e.g. Martins et al. 2015; Carneiro et al. 2019). Alternatively, CNO abundances could be derived from photospheric ultraviolet lines (e.g. Bouret et al. 2013) although high R≥10000 resolution spectroscopy that allows disentangling the interstellar from the stellar component is again necessary.

What are the prospects for R≥5000 optical spectroscopy of very metal-poor massive stars? The highly sensitive VLT-XSHOOTER spectrograph would seem an ideal choice with its ample spectral coverage providing simultaneous observations of all the classical spectral diagnostics in the 4000-5500Å spectral range plus $H\alpha$. Tramper et al. (2011, 2014) obtained XSHOOTER observations of 10 O-type stars in IC 1613, WLM and NGC 3109 with R$\sim$6000 in the UVB channel and S/N$\sim$50-90 per resolution element. Their analysis obtained $T_{\rm eff}$ and log g with typical error bars of ±2000 K and ±0.2 dex or larger for log g, while the spectral quality prevented constraining CNO abundances. A bolder approach is needed, aiming for S/N well in excess of 100.

Considering that Tramper et al. devoted 3–4 hours for each NGC 3109 target, and the number of targets to be ideally observed in order to provide useful constraints to stellar evolution, a higher multiplexing spectrograph with similar spectral resolution is needed. The apparently obvious choice, FLAMES, lacks the required sensitivity in the UVB range. Moreover, the fiber positioning mechanism is not optimal to study resolved stars in very metal-poor galaxies, which have diameters smaller than $7'$, as argued in Sect. 2.1. Because of its even distribution of fibers in the focal plane and its comparatively higher sensitivity in the 4000-5000Å spectral range, MEGARA is the optimal choice to obtain R$\sim$5000 spectroscopy of very metal-poor massive stars and to determine surface abundances.

3.3. *The winds of very metal-poor OB-type stars from UV spectroscopy*

Diagnostic lines for the radiation-driven winds of blue-type stars exist across the electromagnetic spectrum, from X-ray to radio wavelengths (Kudritzki & Puls 2000). However, because very metal-poor massive stars are located at $\sim$1 Mpc, most of these stars are only accessible to space UV and optical facilities at the moment. Spectroscopy in the optical range would enable characterizing the strong winds of LBVs and WRs should one of these objects be found (Herrero et al. 2010; Tramper et al. 2013), although this is highly unlikely because radiation-driven mass loss decreases with metallicity (Mokiem et al. 2007; Björklund et al. 2021). For this same reason the classical diagnostic lines for the winds of OB-type stars in the optical range, the higher Balmer lines and HeII4686, will likely be insensitive to the expected low $\dot{M}$ values. This renders the strong resonance lines at 900–1900Å as the only means to characterize the winds of very metal-poor OB-type stars. The first UV observations of massive stars in Sextans A demonstrated that the spectra do show wind features (e.g. Fig. 4).

Ultraviolet spectroscopy comes with additional advantages. For moderate to weak winds, the terminal wind speed v_∞ can only be measured from the P Cygni profiles and blue troughs exhibited by the sensitive UV lines (Kudritzki & Puls 2000). On the other hand, the UV spectra of OB-type stars host a wealthier variety of metallic lines than the optical range. For instance, it is possible to measure CNO abundances of O-stars (Sect. 3.2) but, even more interestingly, Fe-group abundances can be constrained from multiple lines that deplete the continuum (Fig. 4). UV spectroscopy has been fundamental to demonstrate that the Leo P and Sextans A galaxies are not only more oxygen-poor but also more iron-poor than the SMC (Telford et al. 2021; Garcia et al. 2017).

Despite providing important information, UV spectroscopy exists only for a small number of very metal-poor OB-stars: 3 stars in Leo A, 9 stars in Sextans A and 1 star in Leo P. These numbers will improve slightly thanks to the *Hubble UV Legacy Library of Young Stars as Essential Standards* Director's discretionary program (ULLYSES†) which has among its goals to provide a library of very metal-poor massive stars. Unfortunately, the target list was severely limited by the number of objects that was known when the program was designed and only 3 additional stars in Sextans A will be included.

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† `https://ullyses.stsci.edu/`

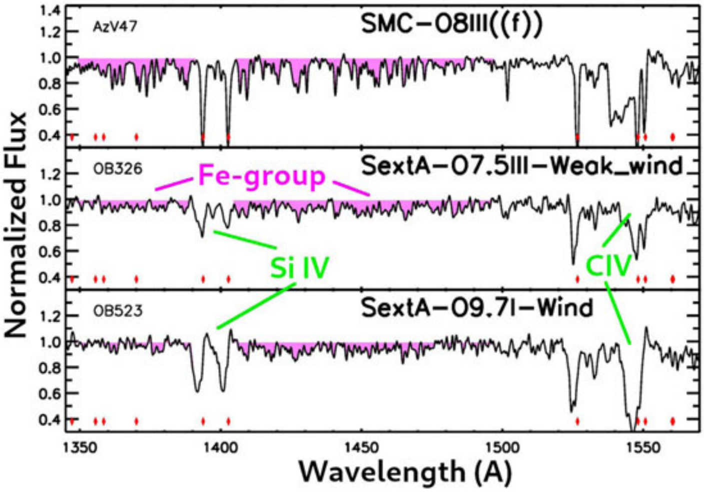

Figure 4. HST-COS observations of two O-type stars of Sextans A, compared to the HST-STIS spectrum of an SMC star of similar spectral type convolved to the equivalent spectral resolution. Diamond marks signal interstellar lines. The pink-shaded areas mark the location of multiple lines of iron-goup elements, roughly corresponding to FeVI and FeV. The stronger absorptions in the spectrum of the analog SMC star in these regions indicate that the Sextans A stars are more iron-poor. Both Sextans A stars exhibit SiIV and CIV wind profiles that will enable $\dot{M}$ and v_∞ determinations. The latter can be fully constrained in OB523, with a stronger wind and a well-developed CIV P Cygni profile.

Nonetheless, ULLYSES has provided another very important product: HST-WFC3 UV photometry of Sextans A that will enable more realistic exposure time estimates for COS spectroscopy, and an easier follow-up of interesting targets.

3.4. *Binary systems*

The number of binary systems in sub-SMC metallicity galaxies is scarce. Until now only one eclipsing binary has been studied (Bonanos 2013) and Lorenzo et al. (2022b) just delivered the first list of spectroscopic binary candidates. The number of known systems will likely increase thanks to the new MUSE observations of Sextans A, although the massive, multi-epoch, R∼5000 follow-up needed to produce period and mass fraction distributions is at the limit of current instrumentation (see Sect. 2.1).

The existing photometric databases may be more amenable to find post-binary interaction products. Lorenzo et al. (2022b) found a handful of O-type stars in Sextans A with bluer colors than the ZAMS that have been postulated as candidate stripped stars. Schootemeijer et al. (2022) identified a parallel feature to the main sequence in the $V - I \; vs \; V$ color-magnitude diagrams of very metal-poor galaxies, which is mostly populated by Be stars at absolute magnitudes fainter than $M_V > -5$ (see also Gull 2022). All these cases require confirmation by spectroscopic analysis at least for a subset of the candidates, but the possibility of identifying BIPs from photometry only greatly reduces the cost in observing time.

4. Summary and concluding remarks

Great advances are being made in the field of very-metal poor massive stars. Several groups are working in parallel to answer, in the long run, important questions such as *What is the evolutionary sequence of these objects?, Can we relate it to the relative frequency of GRBs, SNe and SLSNe?, What is the incidence of chemically-homogeneous* *evolution?, Does the metallicity-dependence of radiation driven winds hold at extremely low-Z?, What is the role of binary evolution and the contribution of BIPs to the integrated ionizing flux of massive star populations?, Do metal-poor environments really favor the formation of double black holes?*

Lacking a previous list of massive stars adequate for these studies, work began at unveiling the stars, which is already very demanding in observing time at 8–10 m telescopes. Some of these spectra will yield $T_{\rm eff}$ and log g, abundances for some B-supergiants, and $v\sin i$ for the fast rotators, but the bulk of the quantitative results will require S/N$\geq$100, R$\sim$5000 spectroscopy feasible with a very reduced number of spectrographs worldwide. UV spectroscopy exists for about a dozen objects but, because of extinction and the uncertain remaining lifetime of HST, the realistic expectation is that the sample will only be doubled at best. This is insufficient to constrain stellar winds at any given metallicity regime.

The advent of the ELT will supply the sensitivity needed to obtain spectra of very-metal poor massive stars with the required quality. However, its instrumentation is not optimally designed for the science of large samples of very metal-poor massive stars. The work carried out *today* by the research groups will be fundamental to craft the most optimal list of targets for follow-up with ELT-HARMONI or MOSAIC. As for sensitivity-enhanced UV observations, we can only enthusiastically support the construction of the next large IR/optical/UV observatory in space†.

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Discussion

No time was left for questions.