Massive Stars Near and Far
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One step closer to the First Stars: +150 OB stars in the metal-poor galaxy Sextans A

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Abstract. Local Group (LG) very metal-poor massive stars are the best proxy for the First Stars of the Universe, fundamental to model the early evolution of the first galaxies, and key to unravelling new evolutionary pathways restricted to low metallicities, such as chemically homogeneous evolution. Yet, due to the great leap in distance required to reach metal-poor galaxies of the LG and vicinity, no comprehensive spectroscopic studies have been carried out at sub-SMC metallicities so far.

We focus on the massive star population of the 1/10 $Z_\odot$ galaxy Sextans A. After five observing campaigns at the 10.4-m Gran Telescopio Canarias (GTC), we have assembled a spectroscopic catalogue of more than 150 OB stars. This catalogue will be fundamental to test stellar evolution at very low metallicity, to detect the first binary systems at 1/10 $Z_\odot$ and to unveil the most recent star formation history of this galaxy.

Keywords. Stars: early-type, stars: Population III, galaxies: stellar content, galaxies: individual (Sextans A), catalogs

1. Introduction

The study of massive stars in very low-metallicity environments is key to understanding the physics of analogue massive stars at the early epochs of the Universe. Yet, very little is known about their properties and evolution. A large sample of resolved massive stars with very low metal content is required to address the growing number of open questions in the field. These questions include the specific evolutionary pathways of massive stars at metallicities lower than the Small Magellanic Cloud (Groh et al. 2019; Szécsi et al. 2022), the incidence of chemically homogeneous evolution (CHE, (CHE, Szécsi et al. 2015), and the role of radiation driven winds and binary interactions in shaping the evolution of very metal-poor massive stars (Shenar et al. 2020).

Given its relative proximity, the Small Magellanic Cloud (SMC) constitutes the current standard of metal-poor regimes. However, its 1/5 $Z_\odot$ metallicity is too high to describe the Universe at redshift above $z = 1$. To extend the metallicity prescriptions of the physical properties of massive stars to the low-metallicity end, several groups have targeted massive stars in Local Group galaxies with lower metal content (1/10 - 1/20 $Z_\odot$). However, due to their long distances, the list of known massive stars with sub-SMC metallicities was scarce up to now.

In this work, we present the first major effort to mine the population of massive stars in the galaxy Sextans A. Located 1.34 Mpc away and presenting low foreground extinction ($E(B-V)_{fg} = 0.044$, Tammann et al. 2011), this dwarf irregular galaxy stands

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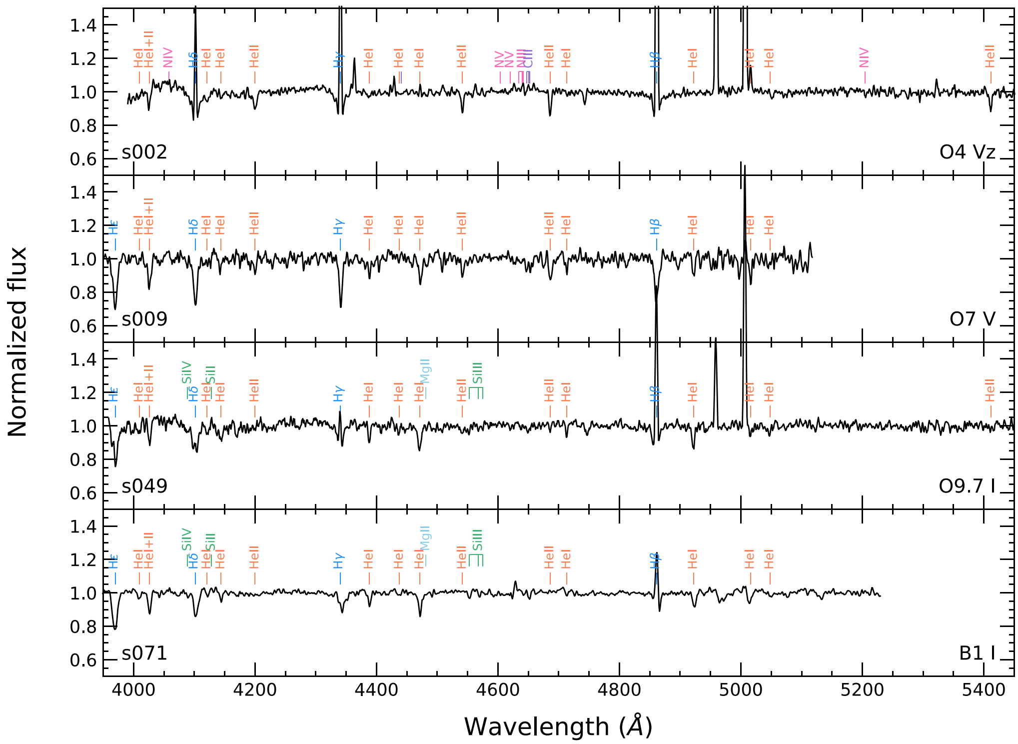

Figure 1. GTC-OSIRIS spectra of four OB stars in our catalogue. The data have been corrected by heliocentric and radial velocity, and smoothed for clarity based on the S/N of the spectrum.

out among other LG galaxies for its low metallicity values. Nebular oxygen abundance measurements range between 12+ log(O/H)= 7.49 – 7.71 (1/15 - 1/10 $O_{\odot}$, Skillman et al. 1989; Pilyugin 2001; Kniazev et al. 2005; Berg et al. 2012) and the iron abundance determined from blue stars is $\langle[(\text{Fe II, Cr II})/\text{H}]\rangle$ = -0.99 ± 0.06 (1/10 $Fe_{\odot}$, Kaufer et al. 2004; Garcia et al. 2017), the lowest value confirmed by UV spectroscopy in the LG. The resulting sample will yield first-order information on the evolution of massive stars with sub-SMC metallicity and provide an extensive collection of spectra to characterise their physical properties at these very low-Z regimes.

2. The first extensive catalogue of OB stars in Sextans A

The catalogue was built through five observing campaigns, three runs based on long-slit spectroscopy (one of them already published in Camacho et al. (2016)) plus two multi-object runs. All of them were carried out with the Optical System for Imaging and low-Intermediate-Resolution Integrated Spectroscopy (OSIRIS) installed at the 10.4-m Gran Telescopio Canarias (GTC). The observations were designed to cover all the UV-bright sources of Sextans A and the massive stars located in the large bubbles of ionised gas of the galaxy. We obtained spectroscopy of 174 sources in total, with an average resolution of $R = \lambda/\Delta\lambda \sim 1000$ in the optical blue range, from 4000 to 5500 Å. Figure 1 shows four examples of the resulting spectra, covering different spectral types.

Of these 174 sources, 5 are foreground stars, 4 are red giants/supergiants members of Sextans A, 6 are A- and F-type stars, and 159 are OB-type stars. The OB sample includes 71 O stars, with types down to O3.5, and 38 BA supergiants. The latter collection will allow us to derive the abundances of α- and iron-elements and better constrain

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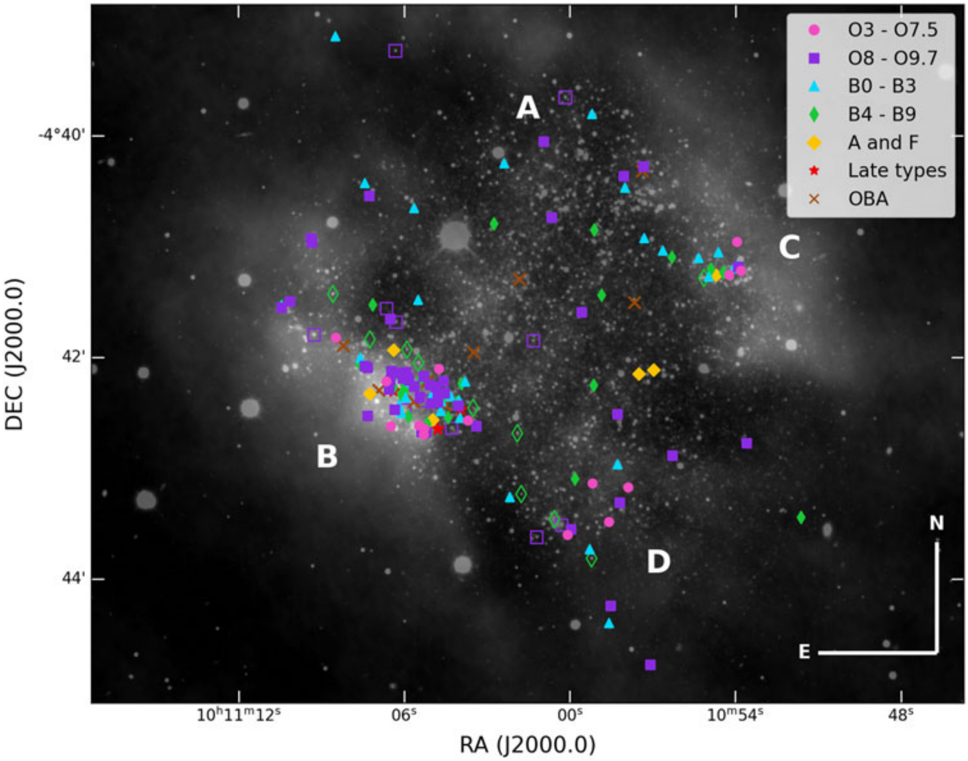

Figure 2. Sextans A. *LITTLE THINGS* neutral hydrogen map (Hunter et al. 2012) overlaid on a V–band image of Sextans A (Massey et al. 2007). Regions–A, –B, –C and –D with ongoing star formation are marked in the figure. We show the catalogue sources, excluding foreground stars, with spectral types coded as indicated in the legend. Stars with an undefined spectral subtype are drawn with empty markers.

the chemical composition of the galaxy. In addition, a total of 33 sources show some signatures of binarity in their spectra. These are the first binary candidates ever reported in Sextans A. However, their confirmation will need follow-up observations.

This makes this sample the largest spectroscopic catalogue of massive stars at metalicities lower than the Small Magellanic Cloud (SMC) to date and constitutes an increase of one magnitude with respect to previous lists in Sextans A. The catalogue will be published in Lorenzo et al., submitted.

3. The recent star forming history of Sextans A

In Fig. 2, we show the location of the sample stars in Sextans A and use the 159 OB sources to trace the star formation in the galaxy.

Most of the OB stars are located in regions–B and –C, overlapping with the high-column density of neutral gas and producing the large structures and bubbles of ionised hydrogen of the galaxy.

Region–B presents more dispersion in spectral types and hosts a large fraction of the earliest stars. The distribution of its massive population appears to be layered by spectral type and correlated with the column-density of the neutral gas. The early O-type stars overlap with the high gas density areas, and later types are located at the inner rim of the H I cloud. This apparent stratified pattern might suggest a temporal sequence of star formation in this region, starting from the inner edge of the cloud and moving outwards.

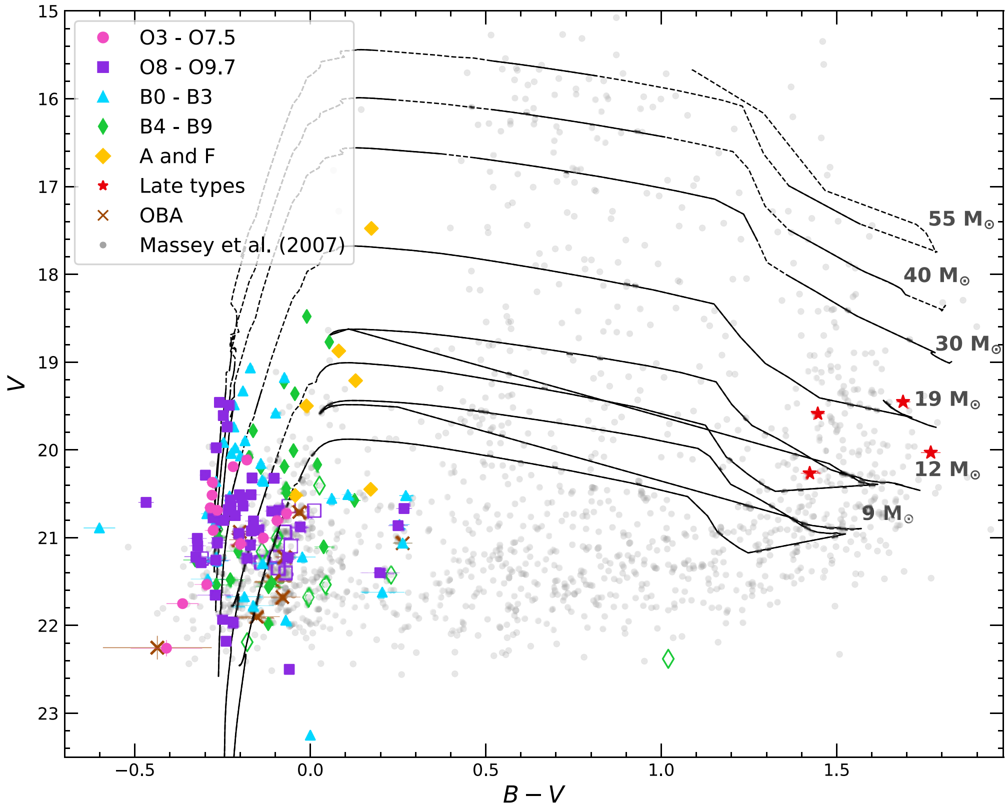

Figure 3. Colour magnitude diagram of Sextans A, showing Massey et al. (2007)'s catalogue in grey and our sample sources, excluding foreground stars, in different colours and symbols according to their spectral type, as listed in the legend. Those without a defined spectral subtype are drawn as empty symbols. $Z = 0.10\ Z_{\odot}$, $v \sin i = 100$ km s^{-1} evolutionary tracks by Szécsi et al. (2022) are also provided. The tracks have been shifted by E$(B-V)_{\rm fg}$= 0.044 (Skillman et al. 1989) to account for foreground extinction towards Sextans A and by the distance modulus of the galaxy ($\mu_0 = 25.63$, Tammann et al. 2011).

In addition, we also detect massive stars in unexpected areas where the column density of neutral gas is low. This was already pointed out by Garcia et al. (2019) in the South of Sextans A, but we detect some additional stars in the gas-void centre and other outer areas of the galaxy. Some reasons that could explain this odd star-forming locus are that these massive stars could be products of mergers of two or more lower-mass sources. On the other hand, star formation could occur in compact, CO-dark gas clouds undetected by H I maps.

4. A glimpse into the evolution of 1/10 $Z_{\odot}$ massive stars

Figure 2 shows Sextans A's colour magnitude diagram (CMD) built with Massey et al. (2007)'s catalogue and highlighting our sample stars with different colours and symbols.

The OB stars are spread across the blue plume. The observed dispersion can be explained mostly by the internal interstellar extinction in Sextans A. This stresses the need of untargeted spectroscopy to locate the massive star population in dwarf irregular galaxies with non-negligible redenning.

In addition, 18 OB-type stars present bluer colours than the evolutionary tracks. This number may increase after applying a detailed reddening correction towards individual

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sources, which we plan as future work. We proposed two scenarios to explain these blue outliers: chemically homogeneous evolution and systems hosting a stripped star. We have evaluated the different features that these two objects would exhibit under the constraints of the quality of our data and produced a list of candidates (see Lorenzo et al., submitted). However, follow-up observations with higher resolution and signal-to-noise ratio will be needed to confirm either scenario.

5. Conclusions and future work

Using the 10.4-m Gran Telescopio Canarias, we have assembled an extensive spectroscopic survey of more than 150 massive stars in Sextans A, a Local Group galaxy with 1/10 $Z_{\odot}$ metallicity. This is the largest census of massive stars at metallicities lower than the Small Magellanic Cloud and represents a fundamental first step to unveiling the properties, evolutionary pathways and fates of very metal-poor massive stars. We also provide the first list of candidates undergoing chemically homogeneous evolution or systems hosting a stripped star at 1/10 $Z_{\odot}$. In addition, we identify 33 sources with signs of multiplicity in their spectra.

We have already started the quantitative spectroscopic analysis of the sample O stars with higher spectral signal-to-noise ratio. These analyses will yield their stellar parameters which will help to constrain their evolution. We also plan to measure the current chemical composition of Sextans A and study the [α/Fe] abundance ratio with our collection of BA supergiants. Finally, we have submitted a proposal for follow-up spectroscopy of the blue outliers with the instrument FORS2 of the Very Large Telescope. The observations request spectra with higher resolution and signal-to-noise that will enable discerning between the two proposed scenarios, CHE and systems hosting a stripped star. Finding even one single case of these objects will have critical implications for the stellar evolution theories, the interpretation of high-redshift galaxies and the progenitors of gravitational wave events.

6. Acknowledgements

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Discussion

Renzo: Could the isolated stars be runaways? What are the distances between the isolated stars and the confirmed star-forming regions? In Renzo et al. (2019), we measured that ejected stars present higher velocities at lower metallicities.

Lorenzo: I do not have the numbers right now, but I can check them later and we can discuss that posibility.

McQuinn: Do you know the column-density of the neutral gas where the isolated OB stars are located?

Lorenzo: Our analysis has been only qualitative using the map of *LITTLE THINGS* survey. We plan to do a quantitative one in the future. However, I think that Garcia et al. (2019) listed a column-density of the order of 1 $M_{\odot}pc^{-2}$ in the southern region of Sextans A.

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