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XSL, the X-Shooter Spectral Library: Overview and status

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Abstract. We present an overview of and status report on XSL, the X-Shooter Spectral Library. XSL is an ESO Large Programme that is using the X-Shooter three-beam spectrograph to collect moderate-resolution (R = 7000–11000), high signal-to-noise spectra of more than 700 stars across the Hertzsprung-Russell diagram with a large range of compositions. XSL is designed primarily as an input library for stellar population synthesis models but has already been used for a wider range of topics, a few of which are discussed here. The first data release of XSL, representing near-ultraviolet and optical spectra of the first ∼ 250 stars, will be available in early 2014, with later data releases to include the near-infrared spectra and the complete library.

Keywords : stars: atmospheres — galaxies: stellar content — catalogs

1. Introduction

In the previous International Workshop on Stellar Spectral Libraries, the first author of this paper reviewed empirical (i.e., observed, not modeled) stellar spectral libraries (SSLs: Trager 2012). Libraries of empirical stellar spectra can be used for a number of different purposes: they provide a testing ground for theories of stellar atmospheres and evolution; they allow us to measure stellar compositions and the (radial) motions of stars; and they are the basis of stellar population models. On the last point, Trager

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suggested that we require the following properties of our SSLs for use in stellar population modeling:

Good calibrations Excellent flux and wavelength calibration and high-precision stellar atmospheric parameters are keys to making good stellar population models.

Lots of stars An ideal SSL for stellar population models must cover *all* phases of stellar evolution at *all* masses at *all* metallicities and *all* (conceivable) abundance ratios.

Moderate-to-high spectral resolution We want to measure the properties of the *smallest* galaxies (and even star clusters) in as much detail as possible. This requires high spectral resolution to resolve the internal stellar motions of those stellar systems.

Broad wavelength coverage No *single* stellar evolutionary phase contributes at all wavelengths, and multiple evolutionary phases contribute to different wavelengths.

Simultaneous observations at all wavelengths Stellar variability – particularly in cool stars – is a killer for stellar population models, especially when the number of stars in the input SSL is small.

Trager pointed out that no single present-day empirical SSL met all of these requirements at that time (end 2011). This prompted us (in 2009) to begin XSL, the X-Shooter Spectral Library. In the following we describe the design of XSL, its current status, projects connected with XSL, and its future.

2. XSL: design and sample

X-Shooter (Vernet et al. 2011, and references therein) is the three-arm, highly-efficient spectrograph for ESO's VLT. X-Shooter covers 320–2500 nm in a single exposure at resolutions up to $R \sim 18000$ (for a very narrow slit). Its high efficiency coupled with the large collecting area of the VLT means that quite faint stars previously unobtainable at moderate resolution and high signal-to-noise – such as those in the Galactic bulge or the Magellanic clouds – can be easily reached.

We have exploited these characteristics to design a moderate-resolution ($R \sim$ 7000–11000, varying somewhat with wavelength), high signal-to-noise spectral survey of stars across the Hertzsprung-Russell diagram (Fig. 1). To achieve a wide range of stellar metallicities and compositions, we have targeted (giant) stars in the Galactic bulge (primarily but not restricted to Baade's Window) and the Magellanic Clouds (Fig. 2). These allow us to probe moderately-metal-rich populations with different (chemical) evolutionary histories than the Milky Way's disk.

We selected stars from a variety of sources, including previous stellar-population

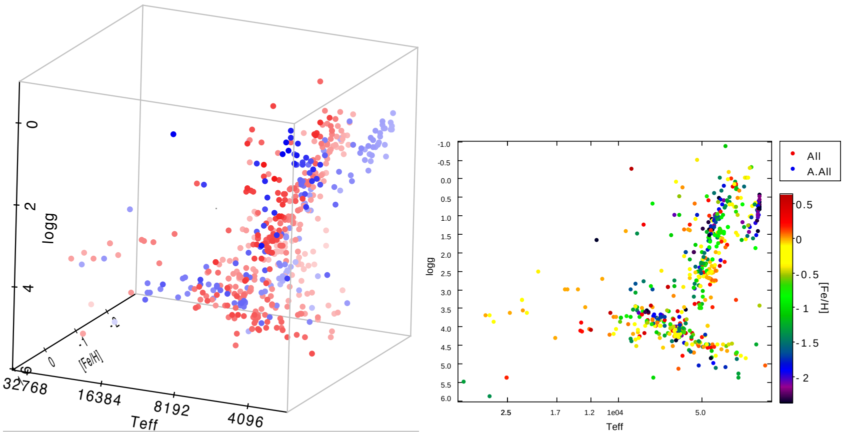

Figure 1. The distribution of atmospheric parameters of stars in the XSL Pilot Program (Chen et al. 2013, blue) and the XSL Large Programme (red) observed to date (mid-October 2013) with known (or estimated) parameters. Left: a three-dimensional view of the parameter space. Right: the Hertzsprung-Russell diagram, coded by metallicity.

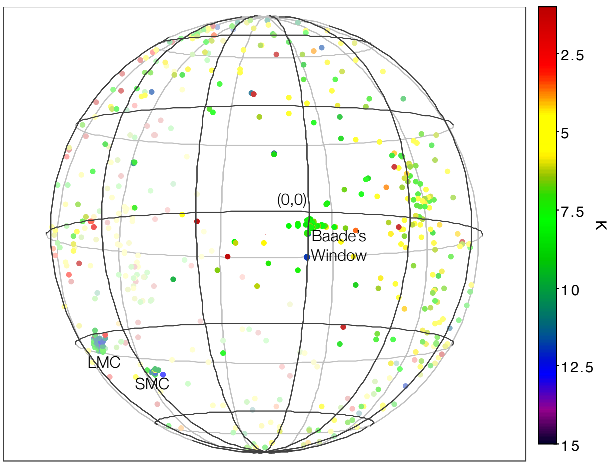

Figure 2. The distribution in Galactic coordinates (J2000.0) of the XSL sample observed to date (mid-October 2013), coded by K-band magnitude (taken from SIMBAD). Baade's Window in the Galactic bulge and the Large and Small Magellanic Clouds (LMC and SMC) are labeled for orientation.

libraries (MILES, Sánchez-Blázquez et al. 2006; IRTF-SpeX, Rayner, Cushing & Vacca 2009; Lick/IDS, Worthey et al. 1994; NGSL, Gregg et al. (2006); ELODIE, Prugniel et al. (2007); Lançon & Wood 2000; Ivanov et al. 2004), catalogs of stellar atmosphere parameters (Soubiran et al. 2010, also known as PASTEL), samples of Galactic and Magellanic Cloud red supergiants (RSGs: Levesque et al. 2005, 2007), red giants (Blanco, McCarthy & Blanco 1984; Zoccali et al. 2008; Ryde et al. 2009) and Mira variables (Groenewegen & Blommaert 2005) in the Galactic bulge, and field giants (Pompéia et al. 2008), long-period variables and carbon stars in the Magellanic Clouds (Hughes & Wood 1990; Cioni et al. 2003). In total, roughly 715 stars were targeted in the six periods (ESO Periods 84 and 85 – the Pilot Program – and 89–92 – the Large Programme) of the XSL observing campaign.

We note that several hundred A and B stars (mostly dwarfs) have also been taken as telluric standard stars. As these stars were taken through the same setup as the main XSL sample (and with reasonable signal-to-noise), we will include them in the final data releases of the library as full-fledged (but not *a priori* selected) sample members.

3. Observations and current status

As described elsewhere (Chen et al. 2013, Chen et al., this volume; Gonneau et al., this volume), we take multiple, relatively short exposures of these typically bright stars with narrow slits to preserve the moderate resolution, nodding the telescope between exposures to improve sky subtraction in the NIR. We also take single wide-slit (5″), short exposures to determine the overall shape of the spectra.

To date (mid-October 2013), about 615 stars in the main sample have been observed (not including the telluric standards), plus a handful of re-observations of long-period and other variable stars. The completion rate of the observational campaign has been excellent (> 90% in each period). Given the brightness of the stars, we request poor conditions – poor seeing, thin or thick clouds – and therefore this program is often used as a backup when X-Shooter cannot observe faint targets due to bad weather.

Currently, the UVB- and VIS-arm (320–1020 nm) spectra for the first two periods – 235 stars – have been reduced and are about to be released as the first data release (DR1: Chen et al. 2013, Chen et al., this volume). The largest problem has been the removal of telluric (Earth's atmospheric) absorption lines and the flux calibration around dichroic split between these two arms at $\sim$ 570 nm. DR1 will be accessible through a dedicated web site as well as being released through CDS. The NIR spectra (1000–2500 nm) are being reduced for all periods simultaneously, but the telluric absorption line removal and flux calibration need to be performed simultaneously, which is still under development (see Gonneau et al., this volume, for more information).

4. XSL projects

XSL spectra will be useful for a variety of topics, ranging from studies of individual stars (e.g. Davies et al. 2013, Gonneau et al., this volume) to stellar population models (Chen 2013) to spectral templates for galaxy velocity (dispersion) determination (Spiniello et al. 2012). Chen (2013) has made the first XSL stellar population models with the Pilot Program spectra (Chen et al. 2013), showing a rich set of spectral features over a wide spectral range at $R = 7000$. Davies et al. (2013) has used XSL spectra of RSGs to test a metallicity-determination method, which led to a redetermination of RSG temperatures in the Magellanic Clouds, showing that these complex, young, cool stars are likely warmer than previously believed. Gonneau et al. (this volume) are using XSL spectra to test (currently static) models of carbon stars in the visible to near-infrared; they will soon extend this to hydrodynamic models of carbon stars and RSGs.

5. XSL: Summary and future look

Data collection for XSL is nearly complete. The final spectra will likely be taken by mid-2014, at which point ~ 715 sample stars and > 200 telluric calibration stars will have been observed simultaneously over a very wide wavelength range. The spectra will have excellent wavelength and very good flux calibration. The data reduction is ongoing, with DR1 available in early 2014, and DR2 (incorporating the NIR spectra of the Pilot Program) following not long thereafter.

XSL will provide a benchmark library for stellar population studies in the near-ultraviolet, optical, and near-infrared in the era of JWST and the ELTs; stellar atmosphere studies, especially for cool (super)giants; telluric corrections; and many other topics. XSL is however, incomplete, in a few critical areas, and these will be the topic of coming work by our team and others. In particular, XSL contains only a handful of M dwarf stars, critical for modern studies of the low-mass initial mass function in integrated stellar populations (see, e.g., Conroy & van Dokkum 2012). The X-Shooter archive contains a reasonable number of M (and cooler) dwarfs, which our team will analyze after the XSL data reduction is complete. Furthermore, XSL is missing hot, very massive (young) stars, hotter than about B0 or O9. The lack of these stars compromises our ability to make stellar population models of very young populations. This lack will be addressed in the coming years, partly through our own efforts and partly through the efforts of others who specialize in observing such stars (e.g., Hartoog et al. 2012).

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