LiLiMaRlin, a Library of Libraries of Massive-Star High-Resolution Spectra with applications to OWN, MONOS, and CollDIBs

Jesús Maíz Apellániz¹, Emilio Trigueros Páez¹,², Irene Jiménez Martínez¹,³, Rodolfo H. Barbá⁴, Sergio Simón-Díaz⁵, Anne Pellerin⁶, Ignacio Negueruela², and João Rodrigo Souza Leão⁷

¹ Centro de Astrobiología, CSIC-INTA, Spain
² Universidad de Alicante, Spain
³ Universidad Complutense de Madrid, Spain
⁴ Universidad de La Serena, Chile
⁵ Instituto de Astrofísica de Canarias and Universidad de La Laguna, Spain
⁶ State University of New York at Geneseo, U.S.A.
⁷ Universidade Federal do Rio Grande do Norte, Brazil

Abstract

LiLiMaRlin is a library of libraries of massive-star high-resolution optical spectra built by collecting data from [a] our spectroscopic surveys (OWN, IACOB, NoMaDS, and CAFÉ-BEANS) and programs and [b] searches in public archives. The current version has 18,077 spectra of 1665 stars obtained with seven different telescopes (HET 9.2 m, NOT 2.56 m, CAHA 2.2 m, MPG/ESO 2.2 m, OHP 1.93 m, Mercator 1.2 m, and Stella 1.2 m). All the spectra have been filtered to eliminate misidentifications and bad-quality ones, uniformly reprocessed, and placed on a common format. We present applications of this library of libraries to the analysis of spectroscopic binaries (OWN and MONOS, see poster by E. Trigueros Páez at this meeting) and the study of the interstellar medium (CollDIBs). We discuss our plans for the future.

1 Introduction

The last two decades have seen an explosion of stellar high-resolution optical spectroscopic data due to the increase in the number of telescopes, some technological improvements, the use of reduction pipelines, and the availability of archives. However, significant hurdles remain for the use of the data: telescopes process the data differently and to different degrees,
they usually do not filter between good- and bad-quality data, and object identification is unclear or has errors in some cases. It is clear that a standardization process is needed. Here we present LiLiMaRlin, a Library of Libraries of Massive-Star High-Resolution Spectra which is an ongoing project to achieve that goal for the case of massive stars.

2 Building LiLiMaRlin

Table 1: Telescopes and data sources used to build LiLiMaRlin.

| Telescope       | Spectrograph(s) | Observatory   | Spectral resolution(s) | Declination range | Source(s)          |
|-----------------|-----------------|---------------|------------------------|-------------------|--------------------|
| HET 9.2 m       | HRS             | McDonald      | 30 000                 | ≥ −11°            | NoMaDS            |
| NOT 2.56 m      | FIES            | La Palma      | 25+46+67 000           | ≥ −47°            | IACOB+others      |
| CAHA 2.2 m      | CAFÉ            | Calar Alto    | 65 000                 | ≥ −25°            | CAFÉ-BEANS        |
| MPG-ESO 2.2 m   | FEROS           | La Silla      | 48 000                 | ≤ +25°            | OWN+archive       |
| OHP 1.93 m      | ELODIE+SOPHIE   | Haute-Provence| 40+42+75 000           | ≥ −24°            | archive           |
| Mercator 1.2 m  | HERMES          | La Palma      | 85 000                 | ≥ −36°            | IACOB+others      |
| Stella 1.2 m    | SES             | Teide         | 55 000                 | ≥ −24°            | others            |

We build our stellar sample starting from the Galactic O-Star Catalog (GOSC, \url{http://gosc.cab.inta-csic.es}, \cite{6, 8, 12, 19}), which currently has 8588 objects, most of them early-type stars. The Galactic O-Star Spectroscopic Survey (GOSSS, \cite{7, 11, 20, 21}) is obtaining intermediate-resolution spectroscopy of GOSC targets to classify them, of which 2941 have already been observed and processed.

We are building LiLiMaRlin by collecting high-resolution optical spectra obtained with the seven telescopes listed in Table 1. The data can be divided into two blocks: (a) Four surveys led by us with the original purpose of studying different aspects of massive stars: OWN \cite{1}, IACOB \cite{18}, NoMaDS \cite{8}, and CAFÉ-BEANS \cite{16}. (b) Spectra found by searching the public archives and from additional programs led by us for five telescopes: NOT 2.56 m, MPG/ESO 2.2 m, OHP 1.93 m, Mercator 1.2 m, and Stella 1.2 m.

The data collection is just the first step of the process required to maximize the usefulness of LiLiMaRlin. After having the data, we check spectrum by spectrum to guarantee the proper source identification, as some archives have data with wrong/unknown IDs or coordinate uncertainties of ∼2′, which are especially problematic in stellar clusters. A related issue is that of source confusion: which components of a multiple system are included in the aperture? That requires analyzing target by target with the help of the information in GOSC, the Washington Double Star catalog (WDS, \cite{15}), high-spatial resolution images obtained with the lucky imaging instruments AstraLux Norte and Sur \cite{3}, and lucky spectroscopy data \cite{14}. We also eliminate noisy, lamp-contaminated, or poor order-stitching data.

After the spectra are selected we do our own post-processing. First, we look for errors in the headers by checking the coordinates and time, the wavelength calibration, and the heliocentric correction. The spectra are then rectified and corrected for telluric lines (see \cite{2}). Finally, we convert each spectrum into a binary FITS file with a uniform format and
generate an entry for the observation in a MySQL archive that has an interface (based on the one for GOSC: \url{https://gosc.cab.inta-csic.es/gosc-v3-query}) that allows us to search the data.

As of the time of this writing, Table 2 lists the data currently in LiLiMaRlin: a total of 18,077 epochs of 1,665 stars.

Table 2: Spectra and stars in LiLiMaRlin (October 2017).

| Telescope       | Spectra | Total stars | O stars | B-A0 stars | Other stars |
|-----------------|---------|-------------|---------|------------|-------------|
|                 |         |             |         | + ASG      | (WR, late, |
|                 |         |             |         | + sdOB     | extragal., |
|                 |         |             |         |            | unclas.)    |
| HET 9.2 m       | 678     | 117         | 74      | 27         | 16          |
| NOT 2.56 m      | 2,590   | 639         | 275     | 203        | 161         |
| CAHA 2.2 m      | 834     | 162         | 133     | 29         | 0           |
| MPG-ESO 2.2 m   | 5,987   | 675         | 290     | 302        | 83          |
| OHP 1.93 m      | 3,952   | 240         | 113     | 127        | 0           |
| Mercator 1.2 m  | 3,760   | 667         | 166     | 264        | 237         |
| Stella 1.2 m    | 276     | 67          | 56      | 11         | 0           |
| **Total**       | 18,077  | 1,665       | 549     | 691        | 425         |

3 Applications

We discuss here the two applications we have used LiLiMaRlin for: the calculation of orbits of spectroscopic binaries and the analysis of the signature of the intervening ISM in the spectra of hot massive stars.

3.1 OWN and MONOS: spectroscopic binaries

The most obvious use of LiLiMaRlin is the calculation of spectroscopic binary (SB) orbits of massive stars, as multiple epochs are needed with both good sampling and a large time span (the first epoch in our library dates back to 1994). To study those orbits we have divided the sky into a northern and a southern regions, placing the dividing line at $\delta = -20^\circ$ to leave similar numbers of OB stars in each region (there are more OB stars in the southern hemisphere due to the position of the Galactic Center, a fact that becomes more pronounced at higher extinctions).

The southern region is the subject of OWN [1], which is based on their own programs with FEROS and with other spectrographs in Chile and Argentina. There we use LiLiMarlin by supplying additional non-OWN FEROS spectra as well as data obtained with northern telescopes (we have used the NOT at La Palma to obtain spectra of targets with declinations down to $-47^\circ$).

The northern region is the subject of the PhD thesis of Emilio Trigueros Páez (see pre-
LiLiMaRlin and applications to OWN, MONOS, and CollDIBs

Figure 1: Phased radial velocity curves for $\Delta v$ (left) and $v_1 + v_2$ (right) for the O3.5 If* + O3.5 If* SB2 system LS III +46 11 obtained with LiLiMaRlin and GOSSS data [9]. The color code identifies the telescope.

presentation at this meeting) and the Multiplicity Of Northern O-type Spectroscopic systems (MONOS) project. We have started to compare the LiLiMaRlin spectra with the predictions of the published orbits in the north and after that we will derive new orbits. The prototypes of the MONOS analysis were those of LS III +46 11 [9] and Fig. 1 and $\sigma$ Ori AaAb [17].

The analysis of the spectroscopic orbits is complemented in both the north and the south with information about visual multiples [3, 21, 13].

3.2 CollDIBs: the intervening ISM

As a second application, we are using LiLiMaRlin to build Collection of DIBs (CollDIBs), the largest database of Diffuse Interstellar Bands (DIBs) ever built. The aim of the project is to study several tens of DIBs for over 1000 stars over a wide range of extinction values. Some preliminary results are given in [10] and [4]. The results will be combined with GOSSS spectral types and Gaia distances to map the 3-D distribution of DIBs in the solar neighborhood and the correlations with extinction [5]. DIBs are correlated among them but not perfectly: two types of sightlines ($\sigma$ and $\zeta$) are characteristic of UV-exposed and UV-shielded ISMs, respectively (Fig. 2).
4 Future work

We will expand LiLiMaRlin by adding spectra from our projects and from the archives we have already explored. We also plan to explore additional archives such as those of HARPS@ESO 3.6 m, UVES@VLT, ESPaDOnS@CFHT, and NARVAL@Bernard Lyot. However, our primary goal is to exploit the LiLiMaRlin data with OWN, MONOS, and CollDIBs.

Acknowledgments

J.M.A. and E.T.P. acknowledge support from the Spanish Government Ministerio de Ciencia, Innovación y Universidades through grant AYA2016-75931-C2-2-P. E.T.P., S.S.-D., and I.N. acknowledge support from the Spanish Government Ministerio de Ciencia, Innovación y Universidades through grant AYA2015-68012-C2-1/2-P. R.H.B. acknowledges support from the ESAC Faculty Council Visitor Program.

References

[1] Barbá, R. H. et al. 2010, RMxAC 38, 30
[2] Gardini, A. et al. 2013, HSA VII, 947
[3] Maíz Apellániz, J. 2010, A&A 518, A1
[4] Maíz Apellániz, J. 2015, MmSAI 86, 553
LiLiMaRlin and applications to OWN, MONOS, and CollDIBs

[5] Maíz Apellániz, J. & Barbá, R. H. 2018, A&A 613, A9
[6] Maíz Apellániz, J. et al. 2004, ApJS 151, 103
[7] Maíz Apellániz, J. et al. 2011, HSA VI, 467
[8] Maíz Apellániz, J. et al. 2012, ASPC 465, 484
[9] Maíz Apellániz, J. et al. 2015a, A&A 579, A108
[10] Maíz Apellániz, J. et al. 2015b, A&A 583, A132
[11] Maíz Apellániz, J. et al. 2016, ApJS 224, 4
[12] Maíz Apellániz, J. et al. 2017a, HSA IX, 509
[13] Maíz Apellániz, J. et al. 2017b, MNRAS 464, 3561
[14] Maíz Apellániz, J. et al. 2018, A&A 615, A161
[15] Mason, B. D. et al. 2001, AJ 122, 3466
[16] Negueruela, I. et al. 2015, HSA VIII, 524
[17] Simón-Díaz, S. et al. 2015a, ApJ 799, 169
[18] Simón-Díaz, S. et al. 2015b, HSA VIII, 576
[19] Sota, A. et al. 2008, RMxAC 33, 56
[20] Sota, A. et al. 2011, ApJS 193, 24
[21] Sota, A. et al. 2014, ApJS 211, 10