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MEGASTAR: A High-Resolution (R$\sim$ 20,000) Stellar Library Observed with MEGARA on the GTC: Second Release

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Abstract

MEGARA is a fiber-fed spectrograph on the 10.4m Gran Telescopio CANARIAS, offering integral field and multi-object spectroscopy with spectral resolutions of $R_{FWHM} \sim$ 6,000, 12,000, and 20,000. Our team is developing MEGASTAR, an empirical stellar spectral library based on observations from MEGARA. The goal of MEGASTAR is to provide stellar spectra and derived parameters essential for constructing stellar population synthesis models, facilitating the accurate interpretation of star clusters and galaxies observed with MEGARA. The stars are being observed with $R_{FWHM} \sim$ 20,000, in two spectral intervals: one centered on Hα (6420 − 6790 Å) and the other on Ca ii triplet (8370 − 8885 Å). In this contribution, we summarize the published papers of MEGASTAR, and present the second data release, DR2.0. MEGASTAR DR2.0 includes 2,838 spectra from 1,408 stars— 994 newly added stars along with the 414 stars from the first release. The spectra were obtained with an average continuum signal-to-noise ratio of approximately 215. We provide an overview of the new release sample, a summary of the observations, the data reduction procedure, and instructions for downloading the complete release or individual spectra from the MEGASTAR database.

1 Introduction

MEGARA (Multi Espectrógrafo en GTC de Alta Resolución para Astronomía) is a fiber-fed spectrograph on the Gran Telescopio CANARIAS (GTC) offering both bidimensional and multi-object spectroscopy (MOS) with three spectral resolutions. In bidimensional mode, an integral field unit (IFU) covers a field of view (FoV) of 2.5 arcsec × 11.3 arcsec, complemented by eight additional 7-fiber minibundles positioned on the outer part of the FoV for sky subtraction. In multi-object mode, 92 robotic positioners, each with a 7-fiber minibundle, cover a FoV of 3.5 arcmin × 3.5 arcmin. In both modes, the spatial sampling is 0.62 arcsec per fiber. MEGARA provides three levels of spectral resolution: low (LR), medium (MR), and high (HR), with resolutions of 6,000, 12,000, and 20,000, respectively. The low and medium resolutions cover the optical wavelength range of 3650 − 9750 Å using six and ten volume phase holographic gratings (VPHs), respectively. The two high-resolution configurations are centered on Hα (HR-R) and the Ca ii triplet, CaT, (HR-I), covering wavelength intervals of 6420 − 6790 Å and 8370 − 8885 Å, respectively. A detailed description of the instrument and its scientific validation can be found in [4].

MEGASTAR is a stellar spectral library tailored to MEGARA, created from IFU-mode observations with a resolution of $R_{FWHM} \sim 20{,}0000$. The objective of MEGASTAR is to provide a comprehensive spectral atlas for population synthesis models, essential for interpreting observations of star clusters and galaxies obtained with MEGARA. Accurate interpretation of galaxy spectra relies on population synthesis models that reconstruct star formation histories through combinations of Simple Stellar Populations (SSPs). Numerous researchers have developed SSP Spectral Energy Distributions (SEDs), and the outcomes depend on various inputs, including isochrones, stellar libraries, spectral coverage, and computational algorithms. Among these, the spectral resolution of the stellar libraries is crucial. In [6], we discuss the essential role of spectral libraries in SSP models and the advantages and limitations of empirical and theoretical libraries in these contexts. MEGASTAR was created to provide high-resolution spectra for the HR-pyPopStar evolutionary synthesis codecode[1], generating templates for interpreting MEGARA data at high resolutions HR-R and HR-I. The library offers robust coverage of stellar parameters, as discussed in [11].

We chose high-resolution configurations since, at the time of MEGARA's commissioning, no other theoretical or empirical library was compatible with MEGARA's high-resolution modes, HR-R and HR-I. Furthermore, we aim to derive stellar parameters such as effective temperature ($T_{\rm eff}$), surface gravity ($\log g$) and metallicity ([M/H]), for library stars using a consistent methodology.

In Paper I [6], we introduced the library, described the target selection criteria, and the initial observations during MEGARA commissioning. We also described the technique for estimating physical parameters ($T_{\rm eff}$, $\log g$ and [M/H]) for a sample of 97 stars, using a χ^2 fitting method to compare observed spectra with the theoretical models of [14]. Fig. 1 shows some examples of the rectified models at solar abundance ($Z{=}Z_\odot$) around Hα line. As expected for cool stars, $T_{\rm eff}$ variations have an important effect on the amplitude of the line

[1] The grid of HR-pyPopStar models can be found in `https://www.fractal-es.com/PopStar` and in `https://cdsarc.cds.unistra.fr/viz-bin/cat/J/MNRAS/506/4781`.

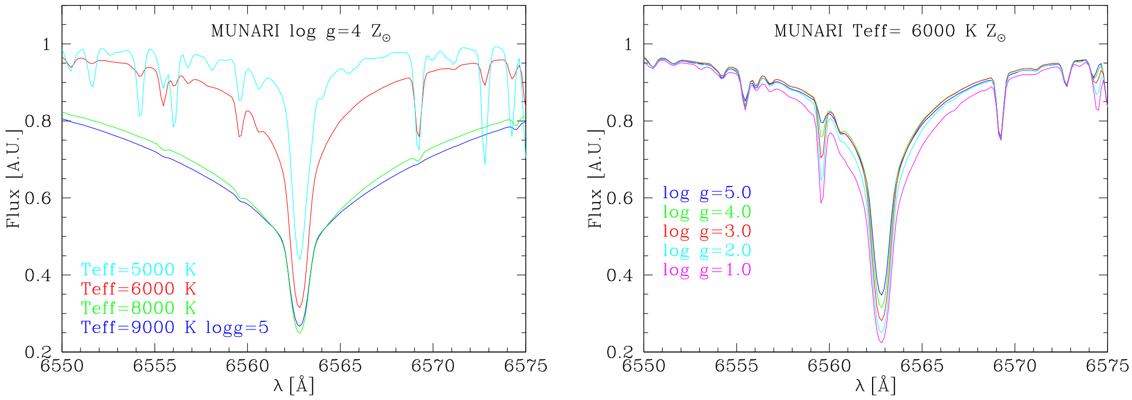


Figure 1: Some MUN05 solar metallicity rectified stellar models for cool stars. Left panel: comparison of spectra with different effective temperature and a constant surface gravity $\log g = 4$ (except for the case $\mathrm{T_{eff}} = 9{,}000\,\mathrm{K}$, where $\log g = 5$ is used because $\log g = 4$ model is not available). Right panel: comparison of spectra with different values of surface gravity, and a constant effective temperature of 6,000 K.

wings, while oscillations in $\log g$ mainly change the line depth. The results aligned well with the literature. We also proposed updated spectral indices suitable for MEGARA's resolution based on equivalent width measurements.

In Paper II [5], we presented the first data release (DR1.0) of the MEGASTAR library, including 414 stars and 838 spectra, with five stars observed twice. We provided an overview of the sample, observations, data reduction procedure, and access details for the MEGASTAR database. DR1.0 includes 419 spectra for each star in HR-R and HR-I, with literature-based spectral types and stellar parameters.

In Paper III [13], we used a sample of 351 MEGASTAR stars with spectral types later than B2 to estimate $\mathrm{T_{eff}}$, $\log g$ and [M/H] along with associated uncertainties. We detailed the parameter estimation process, which began with continuum determination for both observed and theoretical spectra, yielding "rectified" spectra. We then measured radial (topocentric) velocity, correcting observed spectra to the rest frame. Stellar parameters were obtained by comparing observed spectra to a theoretical grid, with results consistent with the literature. In Fig. 2 we show illustrative examples of the observed spectra and the best-fitting models derived in this work. We display the HR-R spectra at the left and the HR-I spectra at the right, for two different spectral types: K and late-B (from top to bottom panels). In each panel, the observed spectrum is represented by a red line, while the best-fitting model is drawn as a green line. When the color appears orange, it means that the fit is quite good since both lines are overlapped. We have selected five stars of each spectral type. The plots for the entire sample are given in Appendix B (Supplementary Material), of Paper III. We carried out measurements of 22 spectral indices. There are many strong spectral lines, as we had identified in Paper I. The list of some of these lines is shown in Appendix A of Paper III.

Data products, including rectified spectra, radial velocity values, best-fit models, stellar parameters with uncertainties, average parameters, and residuals, are accessible via the

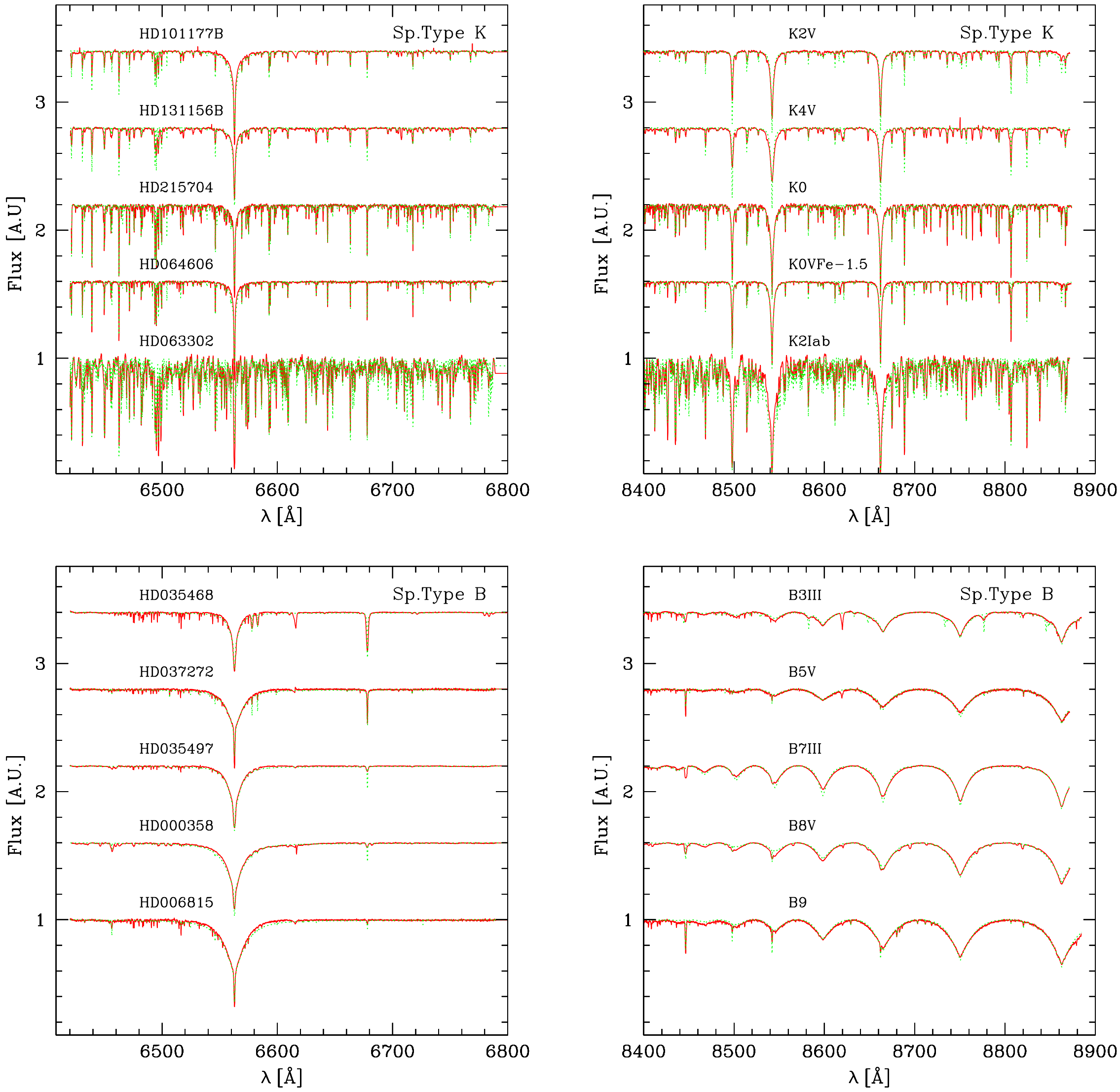


Figure 2: Some examples of our sample of stellar spectra (red colour) overplotted with their corresponding best-fitting model (green colour) for spectral types K (top) and (late) B (bottom), as labeled.

MEGASTAR database as part of DR1.1.

We dedicate the rest of this paper to present the MEGASTAR second data release, DR2.0, which consists of 2,838 spectra, including 838 from DR1.0 and 2,000 new spectra. Since DR1.0, we have observed 994 new stars, with six observed twice, resulting in 1,000 new HR-R and 1,000 new HR-I spectra. Section 2 describes the new sample, covering a range of spectral types and stellar parameters. Section 3 provides details of the filler-type observing program. Section 4 summarizes the data reduction, while Section 5 outlines new features of the MEGASTAR database and Section 6 describes the content of MEGASTAR DR2.0.

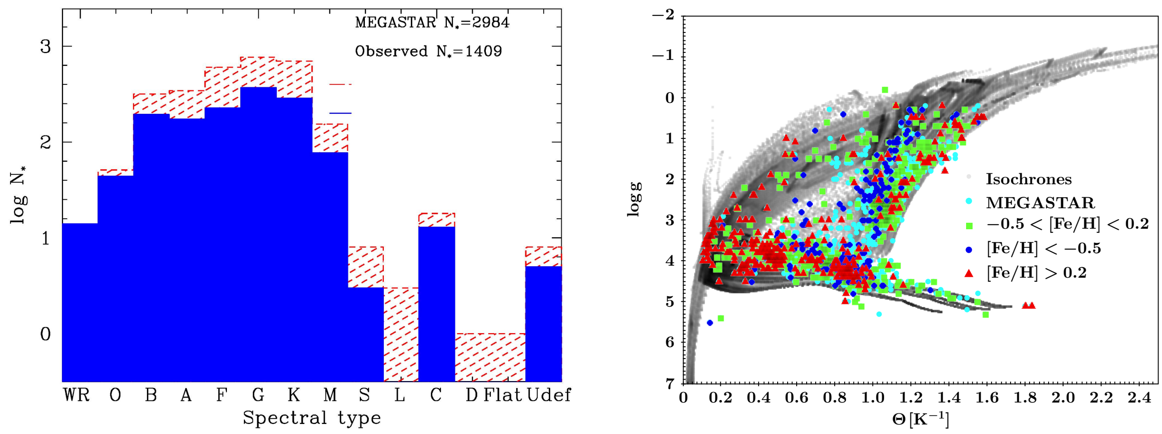


Figure 3: Left: Histogram with the logarithm of the number of stars in the library grouped by spectral type. MEGASTAR catalogue is shown in red while stars observed for DR2.0 are plotted in blue. Right: Surface gravity $\log g$ *vs.* Θ=5040/$T_{\rm eff}$ diagram. The values given by the Padova isochrones, which we would need for a synthesis code as PopStar, are shown in grey. The symbols represent the metallicity intervals indicated for the DR2.0 stars.

2 Sample

The MEGASTAR sample was created from stars in other catalogs that could be observed from the GTC, with resolutions comparable to those of MEGARA and broad coverage of stellar parameters (see Paper I for a full catalog description). Fig. 3-left shows a histogram of stellar types retrieved from the SIMBAD-CDS database[2] or from published papers. The solid blue bars represent the 1,408 stars in DR2.0, while the spectral types of the full MEGASTAR catalog are shown in red. The spectral types distribution in this release is as follows: G (370 stars), K (279), F (227), B (194), A (183), M (76), O (44), W (14), C (13), and S (3). Additionally, Fig. 3b presents the $\log g$ *vs.* Θ=5040/$T_{\rm eff}$ diagram. Stellar parameters for all MEGASTAR library stars from the literature are shown as cyan dots, while those for DR2.0 stars are plotted as blue circles, green squares, and red triangles, based on the metallicity intervals indicated. We also include Padova isochrones (in grey) [1, 7, 10,] used in the PopStar evolutionary synthesis models (see [12]), as these models will be applied to MEGASTAR spectra. This diagram helps identify gaps in the physical parameter space that require additional observations. The comparison of these figures with those in Paper II shows a significant improvement in coverage of stellar parameters. However, we have identified the need for further observations of metal-poor stars, cool giant and late-type stars. This shortfall is primarily due to the nature of the filler-type observing program discussed in Section 3.

[2] `http://simbad.u-strasbg.fr/`

Figure Fig. 4 shows histograms of T_{eff}, $\log g$ and [M/H] for DR2 stars, with N_* representing the number of data points in each histogram, as some stars lacked one or more parameters in the literature when the MEGASTAR catalog was created. Part of our project aims to derive stellar parameters homogeneously for all stars in the library.

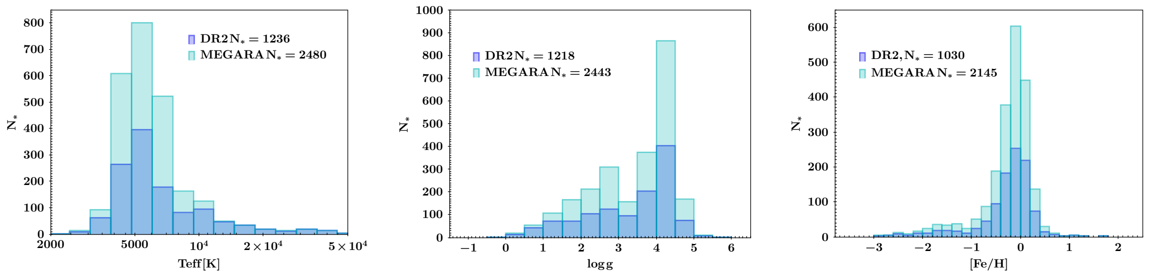


Figure 4: Histogram of T_{eff} (a); $\log g$ (b) and [Fe/H] (c) with values from the literature for DR2.0 (dark blue) and MEGASTAR complete catalog (light blue). The number of points is different in each graph as not all stars of the library have values of the stellar parameters from the literature.

For cool stars, we have derived stellar parameters for those with spectral types later than B2 in the DR1.0 sample (see Paper III). Hot, massive stars are being analyzed separately due to their unique properties and associated factors—such as stellar winds, mass-loss rates, and high rotational velocities—that influence their spectra and require specialized stellar atmosphere models.

For OB stars, stellar parameters are being derived using semi-automated tools for determining physical parameters, such as iacob-broad and iacob-gbat (see [20] and [19]). These tools rely on extensive grids of synthetic spectra generated with the non-LTE FASTWIND stellar atmosphere code, which incorporates sphericity and mass-loss effects ([18] and [17]) and has been extended to the I-band. This model grid spans a wide range of stellar and wind parameters typical of standard OB-type stars, from early O to early B types and from dwarf to supergiant luminosity classes. Since the spectra of WR stars are dominated by strong wind lines, they will be analyzed using the non-LTE CMFGEN stellar atmosphere code, specifically designed for massive stars with strong winds and high mass-loss rates (e.g., WR stars; see [9]). The results of the analysis of hot stars (spectral type earlier than B2) will be published in an upcoming paper (Berlanas et al., in preparation).

3 Observations

MEGASTAR is an ongoing project. Table 1 shows the observing time allocated to the project, which is conducted as a filler-type program. Of the 850 hours requested, 700 hours were granted, and 487 hours have been observed, allowing us to observe 1,408 stars. This results in an observing efficiency of nearly 70 percent, which is quite reasonable given the high number of concurrent instruments and the filler-type nature of MEGASTAR.

According to GTC guidelines, a filler-type program is observed under seeing conditions

Table 1: MEGASTAR open time obtained at GTC.

Semester	Requested h	Granted h	Observed h	N of stars observed
2018B	50	50	64	176
2019A	50	50	12	32
2019B	75	75	77	207
2020A	75	75	10	28
2020B	75	0	–	–
2021A	75	75	38	122
2021B	75	75	39	112
2022A	75	75	80	245
2022B	75	75	72	217
2023A	75	75	63	188
2023B	75	75	32	82
2024A	75	0	–	–
Total	850	700	487	1408

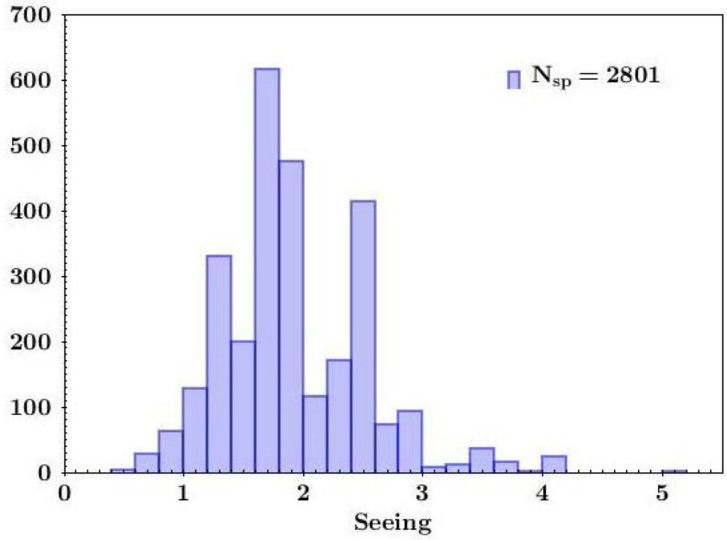


Figure 5: Seeing histogram for all the observations with seeing values reported.

larger than 1.5 arcsec, regardless of night type (especially bright) and under varying sky conditions (particularly spectroscopic), with seeing as the primary criterion. Figure 5 shows the histogram of seeing values from GTC log files for MEGASTAR observations, with a median seeing value of 1.9 arcsec. The minimum seeing value for starting a filler program is 1.2 arcsec. Despite the high-seeing conditions, we recover flux for all stars by summing individual spectra from 37 spaxels centered on the highest-flux fiber in the reconstructed IFU image. This approach ensures a constant spectral resolution, as the slit width is uniform for all stars, with the stop positioned at the microlens + fiber.

The observational strategy involves capturing both HR-R and HR-I setups within the same observing block (OB) to minimize overheads. Additionally, for each OB, the GTC provides a standard star for flux calibration and instrument response correction. The stars have a limiting V magnitude of 12.4, and the average exposure time per OB has been 1,100 seconds, calculated using the MEGARA Exposure Time Calculator.

For Phase 2 preparation, we use the MEGASTAR database, along with a visualization tool and other functionalities, to optimize target selection. We locate unobserved stars by filtering by R and I magnitude ranges, spectral type, or other stellar parameters. As mentioned, there is a shortage of metal-poor stars, cool giants and late-type stars, which require long exposure times. Consequently, despite being prioritized and scheduled in Phase 2, they were not selected by GTC observers. To address this gap, we recently applied for standard GTC open time to observe specific stellar types, aiming to fill these gaps in the stellar parameter space.

4 Data reduction

The data reduction procedure is detailed in Papers I and II. In brief, we used the publicly available MEGARA Data Reduction Pipeline (DRP)[3] developed by [3], [15] and [16]. The DRP recipes *MegaraBiasImage*, *MegaraTraceMap*, *MegaraModelMap*, *MegaraArcCalibration*, *MegaraFiberFlatImage* and *MegaraLcbStdStar* were applied sequentially to obtain all calibration images. Halogen and ThNe lamp exposures were used for flat field tracing and wavelength calibration, respectively.

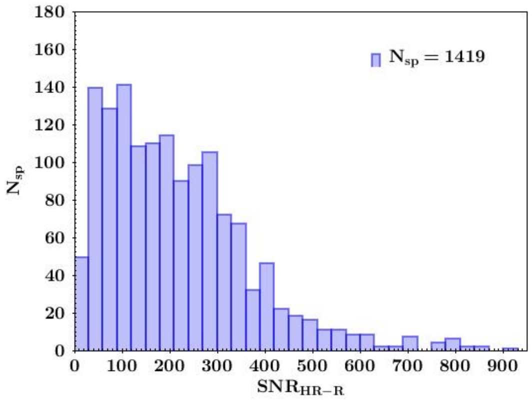
Each recipe generates a product file that must be copied to a designated directory, organized according to a predefined calibration file structure, and a quality control file, allowing for complete tracking of the process. The individual routines require an input *.yaml* file that specifies the images to be processed and the parameters required for each recipe.

There is a general configuration file, *control.yaml*, which contains all the necessary information for data reduction, such as the polynomial degree and the number of spectral lines required for wavelength calibration, among other parameters. The final output is a row-stacked-spectra file containing flux-calibrated (Jy) spectra for each individual fiber, corrected for atmospheric extinction and instrument response.

To obtain 1-D spectra, we use the reconstructed IFU image, generated via the Quick Look Application tool [8]. We then integrate three concentric rings centered on the fiber with the highest flux, consisting of 37 spaxels that cover approximately 4.8 arcsec, with each spaxel equivalent to 0.62 arcsec on the sky.

Figure 6 shows the distribution of the measured continuum S/N ratio, averaged over the complete spectrum following [21], for the HR-R (left) and HR-I (right) setups. The average S/N ratio is approximately 215 for both, as observations for the two setups are conducted

[3] `https://github.com/guaix-ucm/megaradrp`



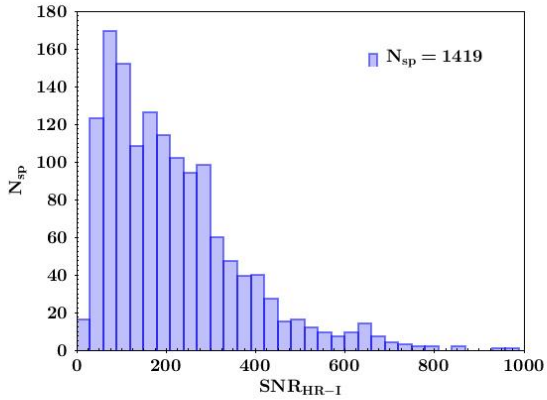


Figure 6: Distribution of the SNR obtained from the observed spectra in the HR-R (left) and HR-I (right) spectral configurations.

sequentially. The spread in the distributions reflects the nature of the GTC filler-type program, where observations are performed when other programs cannot proceed, primarily due to poor observing conditions. Filler observations may be conducted to complete the night or during twilight, occasionally in favorable conditions.

Each observation uses a predefined exposure time set in the GTC Phase 2 tool, unlike standard programs where observing conditions are guaranteed and exposure times are adjusted accordingly. In MEGASTAR observations, the integration time must be set in advance, irrespective of observing conditions, impacting the S/N. Nevertheless, our library program helps optimize GTC observing time, as this filler-type time would likely go unused otherwise.

Following the procedure described in Paper III, applied to a subsample of late-type stars in DR1, we are rectifying the spectra by fitting the continuum in HR-R and HR-I. We employ the method by [2], which generates splines for an arbitrary data set. This method initially applies an ordinary least squares fit, then assigns asymmetric weights to data points below and above the initial fit. Through an iterative process, the result converges towards either the lower or upper boundary of the data set, enabling an automated determination of the continuum for a given spectrum. This approach does not require identifying regions free of absorption lines, as data points in absorption regions have automatically assigned lower weights. Since the fitted data generally lie below the upper boundary, this method reliably finds the continuum even for spectra with high signal-to-noise ratios, where faint absorption features could otherwise bias the fit. To further reduce any bias from random noise, a median filter is applied to each spectrum prior to fitting. Each fitted spectrum is then visually inspected to ensure accuracy.

5 MEGASTAR DATABASE

As described in MEGASTAR previous papers, we developed a database in MySQL and a web-based tool to handle the stellar data and the observed spectra that are available to the

Table 2: Columns description of the release_summary_2.0 file.

Column	Description
Name	Star name (*)
RA	RA (2000.0) (hh:mm:ss.s) (*)
DEC	DEC (2000.0) (dd:dd:ss.s) (*)
Sp Type	Spectral Type (*)
U	Jonhson-Cousins U mag. (*)
B	Jonhson-Cousins B mag. (*)
V	Jonhson-Cousins V mag. (*)
R	Jonhson-Cousins R mag.(*)
I	Jonhson-Cousins I mag. (*)
J	Jonhson-Cousins J mag. (*)
Other name	Alternative name of the star
VPH	Grating used for observation
Teff	Teff (K) from literature
Log g	Log g from literature
[Fe/H]	[Fe/H] from literature
Reference	Original catalogue
<Teff>	Teff (K) averaged of the valid models
<Teff> error	Error in <Teff>
<Log g>	Log g averaged of the valid models
<Log g> error	Error in <Log g>
<[M/H]>	[M/H] averaged of the valid models
<[M/H]> error	Error in <[M/H]>
V_{rad}	Radial velocity
V_{rad} error	Error in radial velocity
Other Comments	Comments related to the star
ASCII/FITS file	ASCII/FITS spectrum file
Obs. Period	GTC Observing semester
No. Exp	Number of exposures
Exp. Time	Individual exposure time (s)
Seeing	Seeing values (arcsec) (**)
Gaia(ID) R3	Gaia DR3 Identifier
Obs-GTC	GTC-OB identifier
Paper III products	yes/no to identify if the star belongs to DR1.1
Rectified spectra	yes/no to identify if the rectified spectrum is available

(*) Source: SIMBAD 4 Release 1.7
(**) As reported in GTC log file

community as part of DR1.0 and DR1.1[4]. A detailed description of the database can be found in Paper II. To update the database we parsed the spectral types and the magnitudes (U,B,V,R,I,J) with the SIMBAD 4 Release 1.7. Additionally, we search for Gaia sources by comparing the coordinates between MEGASTAR and Gaia DR3 databases. We explore a circle centered in the SIMBAD coordinates and with a radius of 2.4 arcsec, that corresponds to MEGASTAR filler aperture. Gaia DR3 ID coincidence is assigned whenever the average between the RA and DEC coordinates differences is less or equal than 0.1 arscsec. Gaia DR3 identifiers have been found for 1,386 out of 1,408 DR2.0 stars.

Several upgrades have been developed to ease the database information searching. In addition to the original menus, *Source*, *Observations*, *Library Completion*, *Downloads*, *Utilities*, *Useful links*, *Projects description* and *Papers*, described in Paper II, there is now a new one called *Products* from which the user can search stars by intervals of stellar parameters and spectral indexes measured by MEGASTAR team. Once selected, the products, like an individual rectified spectrum, the measurements of the stellar indices or the physical stellar parameter can be downloaded as tables from this menu.

As part of this second release, the stellar data and the observed spectra will be available to the community once the DR2.0 paper is approved. Therefore, the user will be able to download the information of each star, the observations details, the individual reduced spectrum or the complete data release DR2.0.

6 MEGASTAR DR2.0

The information of DR2.0 is presented as a table named release2_summary_2.0. The column headers are shown in Table 2. DR2.0 will be available for downloading in MEGASTAR webpage under the menu *Downloads* as a zip file with the corresponding readme.txt.

Acknowledgments

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[4]`https://www.fractal-es.com/megaragtc-stellarlibrary/`; username: *public*; password: *Q50ybAZm*

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References

[1] Bertelli, G.,Bressan, A., Chiosi, C., Fagotto, F., Nasi, E., 1994, A&A Suppl. Ser. 106

[2] Cardiel, N., 2009, MNRAS, 396, 680

[3] Cardiel, N., Pascual, S., 2018, doi:10.5281/zenodo.2270518

[4] Carrasco, E. et al., 2018, Proceedings of the SPIE, Volume 10702, id. 1070216

[5] Carrasco, E., et al., 2021, MNRAS, 501, 3568

[6] García-Vargas, M. L., et al., 2020, MNRAS, 493, 871

[7] Girardi, L., Bressan, A., Bertelli, G., Chiosi, C., 2000, A&A, Suppl. Ser., 141

[8] Gómez-Alvarez, P. et al., 2018, Proceedings of the SPIE, Volume 10707 id. 107071L,

[9] Hillier, D. J., Davidson, K., Ishibashi, K., Gull, T. 2001, ApJ, 553, 2, 837-860

[10] Marigo, P., Girardi, L., Bressan, A., Groenewegen, M. A. T., Silva, L., Granato, G. L. 2008, A&A, 482, 3

[11] Millán-Irigoyen, I., Mollá, M., Cerviño, M., Ascasibar, Y., García-Vargas, M. L., Coelho, P. R. T., 2021, MNRAS, 506, 4781.

[12] Mollá, M., García-Vargas, M. L., Bressan, A., 2009, MNRAS, 398, 451

[13] Mollá, M. et al., 2023, MNRAS, 519, 5472

[14] Munari, U., Sordo, R., Castelli, F., Zwitter, T., 2005, A&A, 442, 1127

[15] Pascual, S., Cardiel, N., Picazo-Sánchez, P., Castillo-Morales, A., Gil de Paz, A., 2018, guaix-ucm/megaradrp: v0.8, doi:10.5281/zenodo.2206856

[16] Pascual, S., Cardiel, N., Gil de Paz, A., et al 2019,in Highlights on Spanish Astrophysics X, Proceedings of the XIII Scientific Meeting of the Spanish Astronomical Society held on July 16-20, 2018, in Salamanca, Spain, ISBN 978-84-09-09331-1. B. Montesinos, A. Asensio Ramos, F. Buitrago, R., Schödel, E. Villaver, S. Pérez-Hoyos, I. Ordóñez-Etxeberria (eds.) p. 227-227

[17] Puls, J. et al., 2005, A&A, 435, 2, 669-698

[18] Santolaya-Rey, A. E., Puls, J., Herrero, A., 1997, A&A 323, 488–512

[19] Simón-Díaz, S. et al., 2011, Journal of Physics: Conference Series, 328, Issue 1, id. 012021

[20] Simón-Díaz, S., Herrero, A., 2014, A&A 562, id.A135, 22 pp.

[21] Stoehr, F. et al., 2008, Astronomical Data Analysis Software and Systems XVII, P5.4, ASP Conference Series, J. Lewis, R. Argyle, P. Bunclarck, D. Evans, and E. Gonzales-Solares, eds.