The AMBRE project: creating a spectral library from the ESO archived spectra

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Abstract. The goal of AMBRE, a joint project between ESO and the Observatoire de la Côte d’Azur, is to provide a homogeneous determination of the stellar parameters (including mean metallicity and some chemical abundances) for the archived spectra of the FEROS, HARPS, UVES and FLAMES/GIRAFFE spectrographs. These parameters will be made available to the astronomical community via the ESO Archive. This will be a comprehensive spectral library with which the archived spectra can be newly explored and it will also provide a large set of homogeneously analysed reference stars with which to make comparison to other spectroscopic studies.

The stellar parameters determined in the now completed analysis of the FEROS archived spectra are presented here. The analyses of the HARPS and UVES archived spectra are underway. The FEROS stellar parameters make up the first layer of the ESO Archive spectral library which can be considered as a galactic chemical chart in its own right. We present the range of parameters that have been determined and the potential for scientific research with these parameters.

Keywords: Stars – fundamental parameters: Astronomical database – spectroscopic

1. Introduction

The recent advances in instrument and telescope technology have motivated many large scale spectroscopic surveys with which to make in-depth studies in the formation
and evolution of stellar systems, in particular the Milky Way galaxy. Current surveys include the Sloan Digital Sky Survey (SDSS) and SEGUE, the RAdial Velocity Experiment (RAVE) and the most recent Gaia-ESO Survey. Two key future projects specifically designed for studies of the Milky Way are the GALAH survey using HERMES on the Australian Astronomical Telescope (AAT), and the Gaia Mission which will obtain precision astrometry for a billion stars in the Milky Way, and chemical abundance information for a few millions of those targets. This wealth of information can be used to test and develop our theories on the formation and evolution of the Milky Way.

The vast quantity of data that are, and will be, collected have required the development of automated analysis pipelines that are able to consistently and reliably determine stellar parameters for such large datasets. Analysis pipelines have been specifically developed for many of the current and proposed surveys. These tools and processes can also be applied to pre-existing spectral datasets such as the spectra in telescope archives.

2. The AMBRE project

AMBRE, which stands for 'Archéologie avec Matisse: aBondances dans les aRchives de l’Eso' is a project to exploit the large spectral datasets that exist in the European Southern Observatory (ESO) archives. Under a contract between ESO and the Observatoire de la Côte d’Azur (OCA) the project team is tasked with determining the stellar parameters for the archived spectra of the ESO FEROS, UVES, HARPS and FLAMES/GIRAFFE spectrographs. The team members of AMBRE include C.C. Worley, P. de Laverny, A. Recio-Blanco, V. Hill, C. Ordenovic, F. Guitton, J.C. Gazzano and A. Bijaoui.

The combined archived dataset for these four spectrographs is greater than 350,000 spectra. This extensive dataset covers a large range of wavelengths and resolutions, including the wavelength domain and resolutions of the Gaia Radial Velocity Spectrometer (RVS). Hence there exists in the archive an untapped source of spectra with which to create a large homogeneously determined spectral library.

The key algorithm being used to determine the stellar parameters is MATISSE: MATrix Inversion for Spectral SynthEsis (Recio-Blanco, Bijaoui & de Laverny 2006; Bijaoui, Recio-Blanco & de Laverny 2008). This algorithm is based on a local multi-linear regression method which has been developed at OCA primarily for the analysis of the Gaia RVS spectra. The stellar parameters ($\theta$) such as effective temperature ($T_{\text{eff}}$), surface gravity (log $g$), global metallicity ([M/H]) and individual chemical abundances ([X/Fe]) are derived by the projection of an input observed spectrum on a vector function, $B_\theta$. The $B_\theta$ function is an optimal linear combination of theoretical spectra and are calculated from a synthetic spectra grid in the learning phase of MATISSE. These $B_\theta$ functions directly reflect the sensitivity of the selected spectral
Figure 1. AMBRE Automated Pipeline flowchart showing the key stages of the analysis, Spectral Processing (SP) A, B and C as well as the radial velocity determination.

region to the corresponding parameter, $\theta$. A $B_\theta$ function is calculated for each $\theta$ for each point in the spectral grid.

The grid of high resolution synthetic spectra upon which the AMBRE analysis is based is comprised of $\sim$16,000 spectra covering the whole optical domain and all stellar parameters with a maximum $T_{\text{eff}}$ of 8,000 K. The stellar parameters derived for the AMBRE project are $T_{\text{eff}}$, log $g$, [M/H] and $[\alpha/\text{Fe}]$, assuming the $\alpha$-elements to be: O, Ne, Mg, Si, S, Ar, Ca and Ti, although not all of these elements may necessarily be present in the selected wavelength regions. This high resolution synthetic grid will be presented in detail in de Laverny, Recio-Blanco, Worley, et al. (2012, in preparation).

A complex spectral reduction pipeline has been built around the MATISSE algorithm which treats the archived spectra and feeds them into MATISSE. The key stages of the pipeline are represented in a flowchart in Fig. 1. The Spectral Processing (SP) stages A, B and C carry out key routines for normalisation, cosmic ray cleaning and wavelength selection of the spectra. The determination of the radial velocities is performed using a programme supplied by C. Melo. Goodness of fit ($\chi^2$) and quality control tests have also been developed to provide further information on the nature of the spectral dataset. A full description of the pipeline is given in Worley, de Laverny, Recio-Blanco, Hill, Bijaoui & Ordenovic (2012a).

There are three key objectives for the AMBRE Project. The first is the production of advanced data products for ESO which will be made available with the cor-
responding spectra via the ESO archive. These products are expected to encourage
greater recycling of the archived spectra by the astronomical community. In essence
this transforms the ESO Archive into a spectral library of homogeneously determined
stellar parameters. The second is essential testing of MATISSE for the Gaia RVS
Analysis Pipeline. The archive includes large spectral samples at Gaia RVS wave-
lengths and resolutions providing a unique testing sample. Finally the creation of
a homogeneously determined galactic chemical chart from the archived spectra will
allow the pursuit of stellar populations in the Milky Way.

3. FEROS: validation of derived stellar parameters

The analysis of the FEROS archived spectra is now complete and a full description of
the stellar parameters is given in Worley et al. (2012a). FEROS is a high resolution
instrument (R $\sim$ 48,000) covering the entire optical domain. For the AMBRE analysis,
17 wavelength regions were selected amounting to 1500 Å in total. These regions
include the Magnesium triplet at $\sim$ 5160 Å and the H$_\beta$ line. A total of 21551 object
spectra were delivered to OCA by ESO for analysis covering the time period from
2005 to 2009.

It was crucial to validate the results from the pipeline by using key samples of
stellar spectra. First a test sample was constructed using high resolution atlases of the
Sun, Arcturus and Procyon (Wallace, Hinkle & Livingston 1998; Delbouille, Roland
& Neven 1973; Brault & Neckel 1999; Hinkle, Wallace, Valenti & Harmer 2000; Bag-
nulo, Jehin, Ledoux, Cabanac, Melo, Gilmozzi & The ESO Paranal Science Opera-
tions Team 2003). Second key spectral libraries were explored. In particular spectra
were obtained from the S$^4$N Spectral Library (Allende Prieto, Barklem, Lambert &
Cunha 2004) for the atlas sample as well as comparing the list of coordinates in S$^4$N
with the FEROS target list to generate a reference sample of 338 FEROS archived
spectra to compare with the stellar parameters reported in that library. A similar com-
parison was carried out for the PASTEL (Soubiran, Le Campion, Cayrel de Strobel &
Caillo 2010) extracting a sample of 618 FEROS spectra.

Two key studies that were also exploited were the Gaia RVS Standards (Crifo, Jas-
niewicz, Soubiran, Katz, Siebert, Veltz & Udry 2010) extracting 318 spectra for com-
parison of the radial velocity values, and the Bensby, Feltzing & Lundström (2003)
study of 66 disk stars for comparison of the [α/Fe] abundances in particular.

The comparison of the $T_{\text{eff}}$, log $g$, [M/H] and [α/Fe] values determined in the
pipeline for the reference sample with the literature values are shown in Fig. 2. There
is an excellent agreement as illustrated by the associated spread in the parameter dif-
fferences as follows: $\sigma(T_{\text{eff}}) = 150$ K, $\sigma(\log g) = 0.2$ dex, $\sigma([\text{M/H}]) = 0.1$ dex, and
$\sigma(\alpha/\text{Fe}) = 0.1$ dex. However, due to parameter limits in the available literature sam-
pies, the whole parameter space could not be tested.
Figure 2. Comparison of AMBRE stellar parameters for a reference sample of FEROS spectra with values reported in PASTEL, S4N and Bensby et al. (2003).

4. FEROS: stellar parameters for the archived spectra

The automated analysis pipeline identified spectral quality issues for \sim 10\% of the FEROS archived spectra and these were rejected from the analysis process. The full pipeline (SPC) then determined stellar parameters for \sim 89\% of the FEROS archived spectra. Further quality control criteria based on the errors associated with the radial velocity determination and full-width-at-half-maximum (FWHM) of the spectral features resulted in only 30.2\% of the total FEROS archived dataset finally being accepted for delivery to ESO.

Fig. 3a shows the HR diagram for all the spectra for which stellar parameters were determined in SPC. The red box indicates the boundaries of the accepted $T_{\text{eff}}$ and $\log g$ values. The main sequence and giant branch of stellar evolution are clearly seen. However there are many spectra with $T_{\text{eff}}$ at and beyond the boundary of 8000 K, the majority of which were ultimately rejected based on the quality criteria.

Fig. 3b shows the stellar parameters that remain after the quality control criteria are applied. The majority of the high temperature spectra are removed as well as the overdensity at $T_{\text{eff}} \sim 3000$ K and $\log g \sim 2.0$ dex. However the main sequence and giant branch are still distinct. The quality control criteria rejected spectra that had large measured FWHMs of the radial velocity cross-correlation function or of the
Figure 3. HR diagram of the FEROS spectra analysed in SPC: a) all the parameters determined in SPC, b) the remaining parameters after quality control criteria were applied. The red box in each are the boundaries of the accepted parameters.

Figure 4. a) HR diagram of the final set of FEROS archived spectra analysed in SPC. b) As for a) but [α/Fe] against [M/H].

spectral features themselves. Astrophysically such spectra could be interpreted to be hot stars and/or fast rotating stars neither of which are well represented by the current synthetic grid, which is optimised for FGKM slow rotating stars. Future extensions to the synthetic grid in temperature and rotational velocity may confirm this conclusion at a later time, but at this time these spectra were deemed to not be well-classified by the AMBRE analysis and were rejected from the final set of results.

Finally those spectra with parameters outside the boundaries of the grid were also rejected resulting in a total of 6508 spectra with stellar parameters, and 11963 spectra with radial velocities, being reported to ESO (Worley et al. 2012a). Fig. 4a shows the HR diagram of this final set of spectra. Fig. 4b shows the [α/Fe] against [M/H] for this final set.
The majority of the sample are on the main sequence with solar metallicities and α-element abundances. However the giant branch is also well represented and there are spectra with a range in chemical abundances values. Despite the high number of rejections the final sample presents itself to be an interesting dataset that has the potential to produce many lines of research. In particular the distribution of α-element abundances with metallicity show a trend of high [α/Fe] at low [M/H] decreasing to solar [α/Fe] at solar [M/H]. This replicates the relation often seen for thick disk stars (Bensby et al. 2003). Also the sample can be explored for objects in open clusters investigating chemical abundance gradients in the Milky Way disk. We have begun to explore both of these samples in the FEROS dataset (Worley, de Laverny, Recio-Blanco, Hill & Kordopatis 2012b).

5. Conclusions and future work

The first phase of the AMBRE project, the analysis of the FEROS archived spectra is now complete. Stellar parameters for 30.2% of the FEROS dataset and radial velocities for 56% of the FEROS dataset were accepted for delivery to ESO. The high number of rejection appears to be mainly due to the majority of the rejected spectra bearing the characteristics of hot and/or fast-rotating stars, which are not well-represented by the current synthetic grid.

Reference samples that were used to rigorously test the automated analysis pipeline have shown excellent agreement with literatures values for the radial velocities and the stellar parameters of $T_{\text{eff}}$, log $g$, [M/H] and [α/Fe].

With regards to the remaining three phases of the AMBRE Project, the analyses of the UVES and HARPS archived spectra are underway, while the analysis of the FLAMES/GIRAFFE archived spectra will soon commence with the project itself being completed by the end of 2012.

The analysis of the FEROS archived spectra represent the first set of homogeneously determined stellar parameters that will be added to the ESO Archive, in effect creating a spectral library of stellar parameters. Upon completion of the AMBRE Project the determined stellar parameters for all four sets of archived spectra will promote the use of the ESO archive as a spectral library for use in a multitude of scientific projects.

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