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THE MATISSE ANALYSIS OF LARGE SPECTRAL DATASETS FROM THE ESO ARCHIVE

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Abstract. The automated stellar classification algorithm, MATISSE, has been developed at the Observatoire de la Côte d'Azur (OCA) in order to determine stellar temperatures, gravities and chemical abundances for large datasets of stellar spectra. The Gaia Data Processing and Analysis Consortium (DPAC) has selected MATISSE as one of the key programmes to be used in the analysis of the Gaia Radial Velocity Spectrometer (RVS) spectra. MATISSE is currently being used to analyse large datasets of spectra from the ESO archive with the primary goal of producing advanced data products to be made available in the ESO database via the Virtual Observatory. This is also an invaluable opportunity to identify and address issues that can be encountered with the analysis large samples of real spectra prior to the launch of Gaia in 2012. The analysis of the archived spectra of the FEROS spectrograph is currently underway and preliminary results are presented.

Keywords: stars:fundamental parameters, astronomical databases, methods: data analysis

1 Introduction

Galactic archæology is the study of large datasets of stellar spectra in the search for underlying structures and populations within the Galaxy. Identification of such structures and populations allows astronomers to test theories of galactic formation and evolution. The main tool that is created by the assimilation of this information is a kinematic and chemical chart of the Galaxy. This chart is contructed using the key stellar parameters of radial velocity, proper motion, distance, effective temperature, surface gravity, metallicity and chemical abundances.

The current and future generations of telescopes and instruments have, and will, create large spectral datasets over a wide range of resolutions, wavelengths and signal-to-noise (SNR). This wealth of data can be used to derive kinematic and chemical signatures for the observed stars, providing unprecedented detail of the surrounding Galaxy. The analysis of such large datasets cannot be carried out 'by hand' and so it is essential that automated stellar classification algorithms are developed in order to provide a consistent and efficient analysis of these data.

The Gaia satellite is at the forefront of astronomical technology and, once launched, it will observe approximately a billion stars in the Galaxy. For this sample Gaia will measure stellar distances to new precisions at milliarcsecond accuracies. Of the three instruments that Gaia will carry, the Radial Velocity Spectrometer (RVS) will observe spectra at two different resolutions (R$\sim$11500 and R$\sim$7000) over the wavelength domain from 847 nm to 874 nm. This wavelength region includes several key spectral features which will be used to determine the stellar parameters for at least 25 million stars.

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Table 1. Details of the ESO spectrographs and publicly available archived spectra that are part of the AMBRE project.

Spectrograph	Resolution	Wavelength Range (nm)	No. Spectra
FEROS	48,000	350 – 920	$\sim$ 23,000
HARPS	115,000	378 – 691	$\sim$ 40,000
UVES	40,000 – 110,000	300 – 1100	$\sim$ 35,000
Flames/GIRAFFE	5,600 – 46,000	370 – 900	$\sim$ 100,000

2 The AMBRE project: tests of MATISSE

The stellar classification algorithm, MATISSE, is being developed at the Observatoire de la Côte d'Azur (OCA) (Recio-Blanco et al. 2006). It has been selected by the Gaia Data Processing Consortium (DPAC) as one of three stellar classification codes that will be used to analyse the RVS spectra for classification of the Gaia stellar sample. The AMBRE project team at OCA oversees the development of MATISSE and the work being carried out by AMBRE is formally connected to the Gaia DPAC under the Generalized Stellar Parametrizer-spectroscopy (GSP-spec) Top Level Work Package which is overseen by Coordination Unit 8 (CU8).

The AMBRE Project is the analysis of the archived spectra of four European Southern Observatory (ESO) spectrographs under a contract between ESO and OCA. The characteristics of the four spectrographs in question are listed in Table 1. The stellar parameters of effective temperature (T_{eff}), surface gravity (log g), metallicity ([M/H]), and α element abundances ([α/Fe]) will be derived for each of the archived stellar spectra. These will be delivered to ESO for inclusion in the ESO database and then made available to the astronomical community via the Virtual Observatory in order to encourage greater use of the archived spectra.

This analysis of the archived spectra of four separate instruments is a unique opportunity to test the performance of MATISSE on large datasets of real spectra. The datasets also include the Gaia RVS wavelength domain and resolutions and this will enable rigorous testing of MATISSE on general and Gaia-like spectra. This is necessary in order to optimise the performance of MATISSE in the Gaia analysis pipeline that is being compiled at the Centre National d'Etudes Spatiales (CNES). As such the AMBRE project has been formally designated as a sub-work package under GSP-spec.

3 MATISSE & FEROS

MATISSE (MATrix Inversion for Spectral SynthEsis) is an automated stellar classification algorithm based on a local multi-linear regression method. It derives stellar parameters ($\theta = T_{eff}$, log g, [M/H], individual chemical abundances) by the projection of an input observed spectrum on a vector $B_\theta(\lambda)$. The $B_\theta(\lambda)$ vector is an optimal linear combination of theoretical spectra calculated from a synthetic spectra grid. Key features in the observed spectrum due to a particular θ are reflected in the corresponding $B_\theta(\lambda)$ vector indicating the particular regions which are sensitive to θ (Recio-Blanco et al. 2006; Bijaoui et al. 2008).

A grid of high resolution synthetic spectra has been calculated using the MARCS stellar atmosphere models (Gustafsson et al. 2008) for $T_{eff} < 8000$ K. The grid spans the entire optical domain across the following stellar parameter range: 3,000 K $< T_{eff} <$ 8,000 K; $0.5 <$ log g < 5.0; $-5 <$ [M/H] $< +1$.

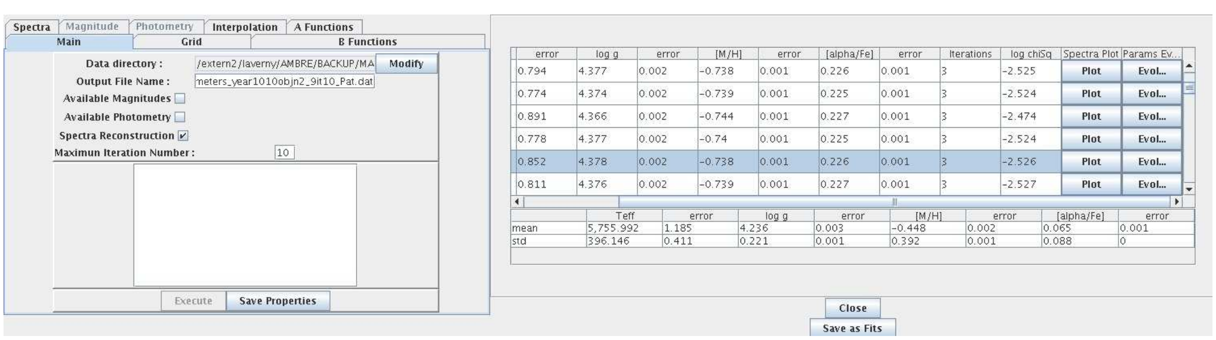

Fig. 1. Matisse java application showing input interface and results display.

MATISSE has been developed for integration into the CNES pipeline and also as a standalone java appli-

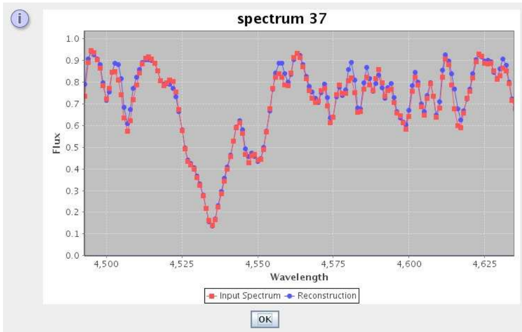

Fig. 2. Example of the comparison between the observed spectrum and the synthetic spectrum reconstructed at the stellar parameters of the corresponding MATISSE solution.

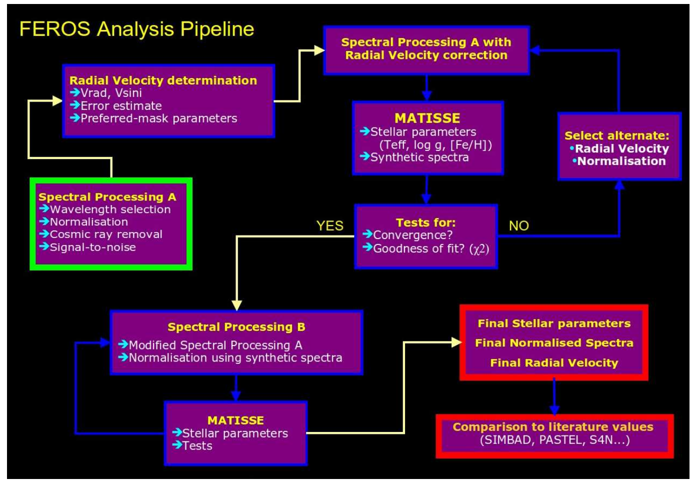

Fig. 3. Flowchart showing the different stages of analysis that the observed spectra undergoes in the FEROS analysis pipeline.

cation for use in a wide variety of projects. The archived spectra of the FEROS spectrograph (see Table 1) are currently being analysed using the java application. A picture of the java interface is shown in Figure 1. To the left is the user input where the observed spectra, signal-to-noise and photometric files can be specfied. To the right is the results display showing the parameters derived for the spectra as well as functions that enable the visual comparison of the observed spectrum with synthetic spectrum generated at the derived stellar parameters. An example of this is shown in Figure 2.

The java application can also be integrated into a local analysis pipeline, and such a pipeline has been developed for the FEROS spectra. Figure 3 shows a flowchart of the key stages of analysis in the FEROS pipeline. After initial normalisation and cleaning of the observed spectra the radial velocities are determined using a cross-correlation programme which compares the observed spectrum to masks created from synthetic spectra (private communication, C. Melo). A second stage of normalisation then occurs which includes the radial velocity correction to shift the spectra to laboratory wavelengths. The next stage is inital MATISSE analysis and the resulting stellar parameters are tested for convergence and for goodness of fit using a χ^2 test between the observed spectrum and the reconstructed synthetic spectrum. Potential issues regarding normalisation and radial velocity corrections are identified and remedied at this stage.

An iterative procedure is then executed which again cleans and normalises the observed spectrum but now normalisation is made relative to the reconstructed spectrum of the previous MATISSE analysis. This newly normalised spectrum is entered into MATISSE to derive new stellar parameters. This analysis cycle between normalisation and stellar parameter derivation is repeated ten times in order to converge on the final stellar parameters. Ultimately the procedure produces the final stellar parameters, the final normalised observed spectrum and the final reconstructed synthetic spectrum. This final observed normalised spectrum is entered into the radial velocity programme to confirm the radial velocity and determine the final radial velocity errors.

A crucial stage which is currently underway is the identification of previously analysed stars within the FEROS dataset. Key databases such as the S^4N library (Allende Prieto et al. 2004) have been used to identify reference samples within the FEROS dataset in order to compare the results of MATISSE with previous studies. Figure 4a compares the radial velocities calculated in the AMBRE-FEROS pipeline with the reported S^4N values. There is good agreement between the two sets of values.

Stellar parameters were determined for the S^4N sample using the AMBRE-FEROS pipeline and the comparison of the derived effective temperatures (T_{eff}) of AMBRE-FEROS with the S^4N values is shown in Figure 4b. There is good agreement between the two sets of T_{eff} values. Further investigation of other reference samples is also being pursued for a comprehensive comparison between MATISSE and other extended studies.

4 Conclusion

As part of the AMBRE Project we have developed a comprehensive analysis pipeline for the FEROS dataset that feeds the cleaned and normalised stellar spectra into MATISSE for derivation of the stellar parameters.

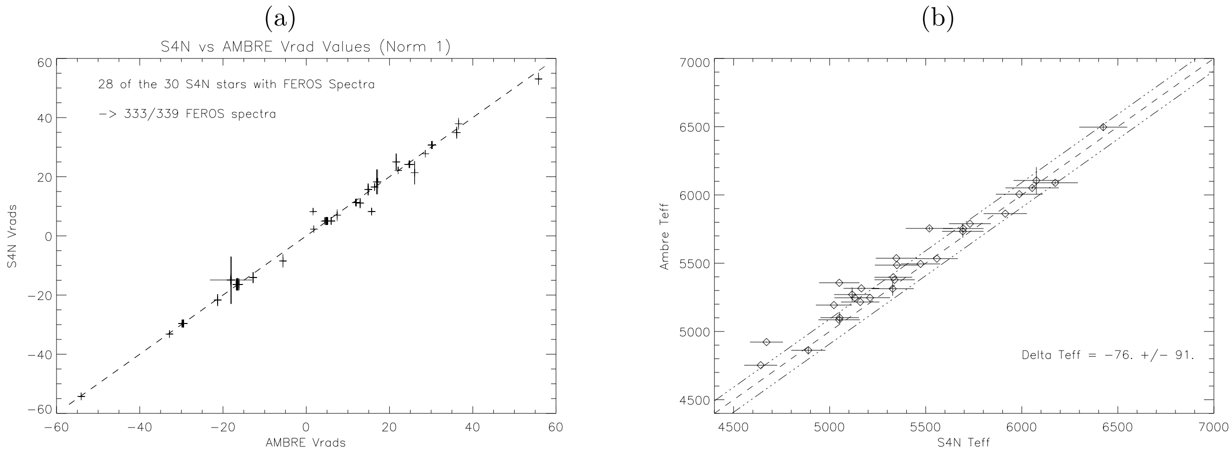

Fig. 4. a) Comparison of the radial velocity values reported in S^4N with those determined in the AMBRE-FEROS pipeline for the S^4N stars found in the FEROS dataset. Errorbars for each set are also shown. b) As for a) but for the effective temperature (T_{eff}).

This pipeline can be tailored to the specifications of the other three instruments that are also to be analysed in this project.

The preliminary results from the AMBRE-FEROS analysis show the great potential of MATISSE as a stellar classification tool for stand-alone projects and also for large-scale endeavours such as Gaia RVS spectra. The analysis of the ESO archive provides a unique opportunity to rigorously test MATISSE on RVS wavelengths and resolutions using large datasets of real stellar spectra in order to optimise its performance in the CNES pipeline.

The primary outcome of the AMBRE Project is to deliver to ESO the advanced data products (the stellar parameters) of the archived spectra for each of the four spectrographs, FEROS, UVES, HARPS and Flames/GIRAFFE. Considered as a whole this will be a homogeneous determination of stellar parameters for the archived spectra which will add an extra layer of key information to the ESO database. These parameters will in turn be made available to the astronomical community via the Virtual Observatory. The stellar parameters of these archived spectra will also create a galactic chemical chart which can be used to study stellar structures within the Milky Way in the pursuit of galactic archæology.

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