

## SPADES: A STELLAR PARAMETERS DETERMINATION SOFTWARE

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**Abstract.** With the large amounts of spectroscopic data available today and the very large surveys to come (e.g. Gaia), the need for automatic data analysis software is unquestionable. We thus developed an automatic spectra analysis program for the determination of stellar parameters: radial velocity, effective temperature, surface gravity, micro-turbulence, metallicity and the elemental abundances of the elements present in the spectral range. Target stars for this software should include all types of stars. The analysis method relies on a line by line comparison of the spectrum of a target star to a library of synthetic spectra. The idea is built on the experience acquired in developing the TGMET (Katz et al. 1998, Soubiran et al. 2003), ETOILE (Katz 2001) and Abbo (Bonifacio & Caffau 2003) software. The method is presented and the performances are illustrated with GIRAFFE-like simulated spectra with high resolution ( $R = 25000$ ), with high and low signal to noise ratios (down to  $\text{SNR} = 30$ ). These spectra should be close to what could be targeted by the Gaia-ESO Survey (GCDS).

Keywords: stellar parameters, spectra analysis, Giraffe

### 1 Introduction

One of the major applications of spectroscopy is the determination of stellar parameters like the radial velocity ( $V_r$ ), effective temperature ( $T_{\text{eff}}$ ), surface gravity ( $\log g$ ), micro-turbulence ( $\xi$ ), metallicity ( $[\text{Fe}/\text{H}]$ ) and chemical abundances ( $[\text{X}/\text{H}]$ ). The present and future large spectroscopic surveys are going to significantly increase the number of spectroscopic data to be analysed. A few examples are the Gaia-ESO Survey with about 160000 stars to be observed, Gaia with about  $2 \times 10^6$  stars to be analysed for chemical abundances (Katz et al. 2004), RAVE with some 400000 stars observed so far (Boeche et al. (2011) and Siebert et al. (2011)) etc. The space mission Gaia will provide the largest survey ever, and that, in the decade to come. To analyse these quantities of data, automatic spectra analysis software is needed. Different families of software exist. A few examples are software like TGMET (Katz et al. (1998) and Soubiran et al. (2003), ETOILE (Katz 2001), MATISSE (Recio-Blanco et al. 2006), Abbo (Bonifacio & Caffau 2003) etc... The work presented is about the development of a new automatic stellar spectra analysis software. In its first version the software will be optimised for medium-resolution Giraffe spectra (VLT) and will thus be tested on Giraffe like spectra. The software is called SPADES (Stellar PArameters DEtermination Software) and is coded with Java.

### 2 SPADES

#### 2.1 General idea

The software is based on the comparison between observed spectra and a grid of synthetic spectra (with known parameters). Contrary to many existing software, in SPADES, the comparison between spectra is not made over all the spectrum but around pre-selected lines. Another particularity is that the determination of the stellar parameters does not use any equivalent width measures but is based on profile fitting methods. Another important characteristic of SPADES is that it determines elemental abundances. The general idea is as follows:

For each parameter to be determined, one or several methods of determination (diagnostics) are available. One is chosen by the user. The list of diagnostics for each parameter are:

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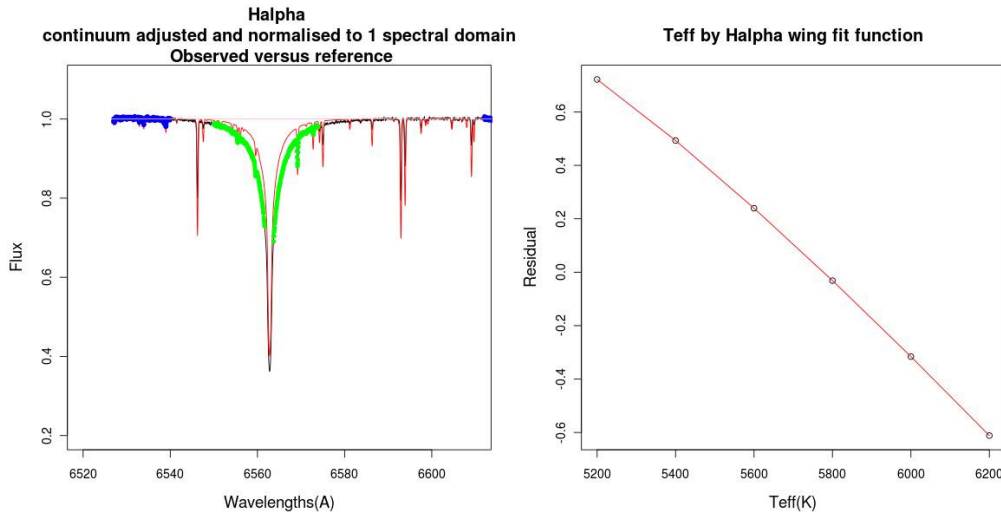
- $V_r$ : cross-correlation in direct space with a template
- $T_{\text{eff}}$ : excitation equilibrium or Balmer lines profile fitting.
- $\log g$ : ionization equilibrium or strong lines (e.g. MgIb green triplet) profile fitting.
- $[\text{Fe}/\text{H}]$ : Fe lines profile fitting.
- $[\text{X}/\text{H}]$ : X lines profile fitting.
- $\xi$ : empiric calibration or nulling the  $\Delta W = f(\text{reduced equivalent widths})$  function slope.  $\Delta W$  being the residuals of the difference between the observed and synthetic line.

The diagnostics so far implemented and tested are detailed in the next section. Each of the parameters,  $T_{\text{eff}}$ ,  $\log g$ ,  $[\text{Fe}/\text{H}]$  and  $\xi$  atmospheric parameters is determined one by one assuming all the others known. The process is iterated until convergence. The elemental chemical abundances are then determined.

## 2.2 Diagnostics

### 2.2.1 Effective temperature : $T_{\text{eff}}$

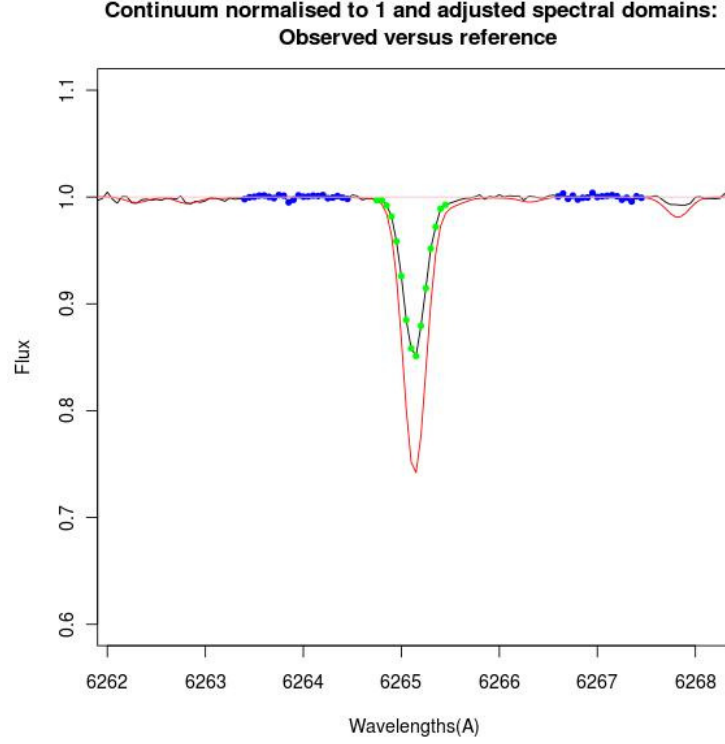
**H $\alpha$  wings fit method.** The first step is defining the reference grid to be used: a 1D (in the parameters space) reference spectra grid is defined. This grid varies over  $T_{\text{eff}}$  only, the other parameters being fixed to their input values. This grid is read or calculated by interpolation based on a pre-calculated reference spectra grid. The analysis is limited to the H $\alpha$  line, more generarely to a spectral range around this line. This range will be now called the ‘‘H $\alpha$  spectral domain’’. For each reference spectrum ( $T_{\text{eff}}$  value), the H $\alpha$  spectral domain continuum is fitted to the studied H $\alpha$  spectral domain continuum. An example of superposed continuum fitted H $\alpha$  spectral domains is presented in Fig. 1 (Left). The spectral domains differ by their  $T_{\text{eff}}$ .



**Fig. 1. Left:** The reference spectrum H $\alpha$  spectral domain in red is superposed to the studied spectrum H $\alpha$  spectral domain in black. The continuum pixels are in blue. The H $\alpha$  wings pixels are in green. **Right:** The residuals as function of the reference spectra  $T_{\text{eff}}$ . The result  $T_{\text{eff}}$  is the value that nulls this function.

The wavelengths ranges used for the continuum fit are pre-defined. The corresponding pixels are in blue. The green pixels represent the H $\alpha$  wings. The wavelength limits of the wings are also pre-defined. Over the H $\alpha$  wings pixels the residual is calculated as:  $s = \sum_{\text{pixels}} (x_{\text{obs}} - \tilde{x}_{\text{ref}})$ . That is done for all the spectra in the 1D reference spectra grid.  $s = f(T_{\text{eff}}(\text{ref}))$  is thus constructed. An example of this function is presented in Fig. 1 (Right). The result  $T_{\text{eff}}$  is the one that nulls this function.

**Excitation equilibrium.** In this method a list of pre-selected FeI lines is used. As in the previous method, a 1D (in the parameters space) reference spectra grid is defined with  $T_{\text{eff}}$  values varying around the input value while the other parameters are fixed to their input values. Around each central wavelength a spectral domain is cut in the reference and observed spectra. The line and continuum limits are determined automatically. For each reference spectrum, the spectral domains around the pre-selected lines are continuum fitted to the continuum of their corresponding spectral domain in the studied spectrum. An example of superposed, continuum fitted spectral domains is given in Fig. 2.



**Fig. 2.** In red the spectral domain of a FeI line in the reference spectrum superposed to the studied spectral domain of the same line, in black. The studied and the reference spectra are at different  $T_{\text{eff}}$ s which explains the difference between the line. The continuum pixels are in blue. The line pixels are in green.

For each reference spectral domain, and over the line pixels (green pixels) the residual is measured as such:  $\Delta W = \sum_{\text{pixels}} -(x_{\text{obs}} - \tilde{x}_{\text{ref}})$ .

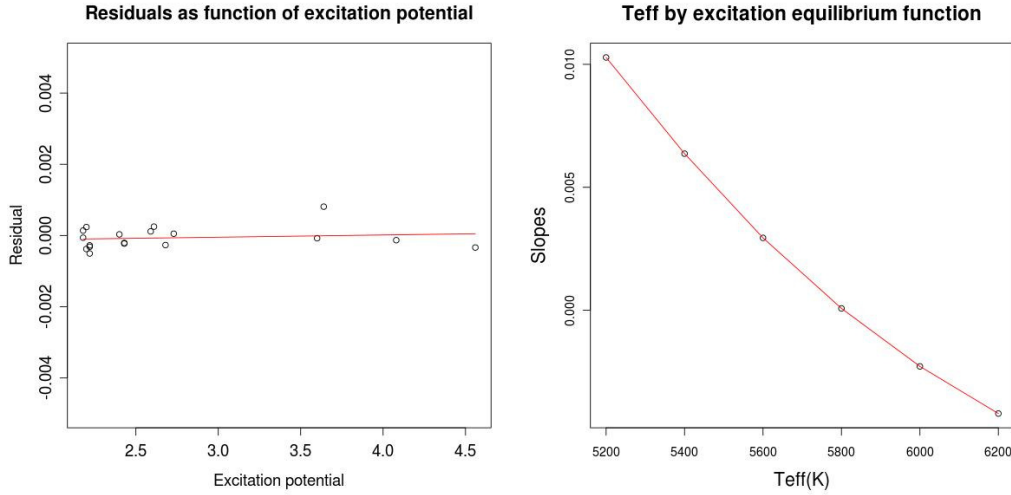
This measurement is done for all the used lines. Let  $\Delta W_n$  be the residual of the  $n$ th line. For each reference spectrum, the lines  $\Delta W_n$  are plotted as a function of the lines respective excitation potentials  $\xi_n$ . An example of this function is given in Fig. 3 (Left).

For each reference spectrum ( $T_{\text{eff}}$  value) the slope  $a$  of this function is measured ( $\Delta W_n = a * \xi_n + b$ ). Another function is then constructed: the  $a = f(T_{\text{eff}})$  function. An example of this function is presented in Fig. 3 (Right). The result  $T_{\text{eff}}$  is the one that nulls the  $a = f(T_{\text{eff}})$  function.

### 2.2.2 Gravity: $\log g$

**Ionisation equilibrium.** In this method the measurement made over the FeI and the FeII lines to be used are:  $\Delta W_{\text{FeI}} = \sum_{\text{pixels}} -(x_{\text{obs}} - \tilde{x}_{\text{ref}})$  and  $\Delta W_{\text{FeII}} = \sum_{\text{pixels}} -(x_{\text{obs}} - \tilde{x}_{\text{ref}})$ .

The diagnostic to be analysed is :  $\Delta = \Delta \bar{W}_{\text{FeI}} - \Delta \bar{W}_{\text{FeII}}$  where  $\Delta \bar{W}_{\text{FeI}}$  (respectively  $\Delta \bar{W}_{\text{FeII}}$ ) are the mean of the  $\Delta W_{\text{FeI},n}$ s (respectively the  $\Delta W_{\text{FeII},n}$ s) for all the FeI (respectively the FeII) lines. The result  $\log g$  nulls the  $\Delta$  as a function of the reference spectra  $\log g$  function.



**Fig. 3. Left:** Line residuals ( $\Delta W_n$ ) as function of excitation potentials  $\xi_n$  for the reference spectrum with  $T_{\text{eff}} = 5800$  K. **Right:** The slopes such as  $\Delta W_n = a * \xi_n + b$  as a function of the reference spectra  $T_{\text{eff}}$ . The result  $T_{\text{eff}}$  is the value that nulls this function.

### 2.2.3 Metallicity and elemental abundances: [X/H]

**Profile fit.** In this method the measurement over the  $n$  lines of the X element to be used is :  $s^2 = \sum_{pixels} (x_{obs} - \tilde{x}_{ref})^2 / \sigma^2$ . The diagnostic to be analysed over all the X element lines is:  $S^2 = \sum_{lines} \sum_{pixels} (x_{obs} - \tilde{x}_{ref})^2 / \sigma^2$ . The result [X/H] is the one that nulls the  $S^2$  as function of the reference spectra [X/H] function.

### 2.3 Tests and performances

SPADES was tested by Monte-Carlo over synthetic spectra with resolution  $R = 25000$ , effective temperature  $T_{\text{eff}} = 5800$  K, gravity  $\log g = 4.40$ , metallicity  $[Fe/H] = -1.0$ , with individual abundances of Ca and Ni:  $[Ca/H] = 0.0$  and  $[Ni/H] = 0.0$ . The tests were made for 2 signal to noise ratios (SNR): 30 and 100 (200 reference spectra for each SNR). The values of the dispersions at  $1 - \sigma$  of the residuals (difference between the estimated and the real value) for each parameter are as follows (Table 1).

**Table 1.** Monte-Carlo simulations.

	$SNR = 30$	$SNR = 100$
$T_{\text{eff}}$ (K)	31	9
$\log g$	0.14	0.05
[Fe/H] (dex)	0.04	0.0013
[Ca/H] (dex)	0.03	0.009
[Ni/H] (dex)	0.05	0.017

The mean results of these Monte-Carlo runs for each parameter show no bias. The dispersions are acceptable. Actually, for the  $T_{\text{eff}}$  determination using the  $H\alpha$  method, the dispersion is at SNR of 100 (respectively 30) about 10 times (respectively 3 times) smaller than the systematic error (estimated by Cayrel et al. 2011) linked to the physics behind the models used. We note that, of course, the  $H\alpha$  line is not always available for use: one reason is that it can simply not be in the spectral domain used, another is that this  $T_{\text{eff}}$  determination method cannot be used for all stars (cool stars for example). The excitation equilibrium method is then used.

## 3 Future work

The future work to be done on the software is :

- On the fly reference grid calculation: dynamic call of the SYNTHE software for calculating the reference grid directly from SPADES (completed at the time of writing the proceedings)
- Fix a method for determining micro-turbulence
- Determine the external errors (as opposed to the internal errors determined by Monte-Carlo). One of the methods will be the test on known stars (e.g. Sun)
- In its first version, the software will be fine-tuned to analyze medium to high resolution GIRAFFE spectra of Thick Disk stars .

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