Astronomy & Astrophysics manuscript no. StellarParameters
December 1, 2019

Determination of stellar parameters

Ana C. Barboza

Departamento de Física e Astronomia - Faculdade de Ciências da Universidade do Porto R̈ua do Campo Alegre 1021, 4150-179 Porto
e-mail: up201506020@fc.up.pt

November 2019

ABSTRACT

Context. Spectroscopic data analysis is fundamental for the study of astronomical systems, since it is the main tool for the determination of parameters that allow us to describe them.
Aims. We aimed to develop a concise and efficient method for the determination of atmospheric stellar parameters such as effective temperature, surface gravity, metallicity and chemical abundances. This method is used for the study of two stellar spectra.
Methods. We estimate the parameters by using the equivalent width method though synthetic spectral fitting. This method is used for the study of two stars.
Results. An algorithm that performs automatic stellar spectral analysis is provided.

Key words. stellar parameters – spectroscopy

1. Introduction

One of the goals of astronomy is the classification of star systems. A core element for this is the study of stellar spectra, from which we gather sufficient information that allow us to obtain parameters that describe these systems.
On this day and age, we have a tremendous and increasing amount of spetroscopic data available, each spectra needing to be carefully analyzed. It would be wise to develop a method that allows us to automatically perfom this analysis.

Here we will be using a dabatase of synthetic spectra, directly comparing them with observed data, together with the equivalent width technique.

The first step is to estimate the excitation temperature, in order to reduce the amount of spectra we compare. The curve of growth for FeI lines is used to estimate this temperature, T_{est}. Then, in a range of$[T_{est} - 400, T_{est} + 400]K$, we compare the star's W_λ values to the corresponding ones of synthetic spectra, finding this way the best fit to the observed data.
After finding the closest synthetic spectrum, we re-sample it performing an interpolation, and apply resolution degradation through the introduction of an instrumental profile, so as to directly and graphically evaluate the quality of our results.

2. Method

2.1. Preliminary estimation of temperature

2.1.1. Equivalent width determination

For a first estimation of the temperature, we will need to calculate the equivalent width of the spectral lines we wish to study. The equivalent width is given by (**?**):

$$W_\lambda = \int \frac{F_c - F_\lambda}{F_c} d\lambda = \frac{\sqrt{2\pi} A\sigma}{B} \quad (1)$$

Where $F_c = Ae^{-(\lambda-\lambda_c)^2/(2\sigma^2)} + B$.

So we can obtain Wλ by fitting a gaussian curve to each line and obtaining the parameters A, B and σ.

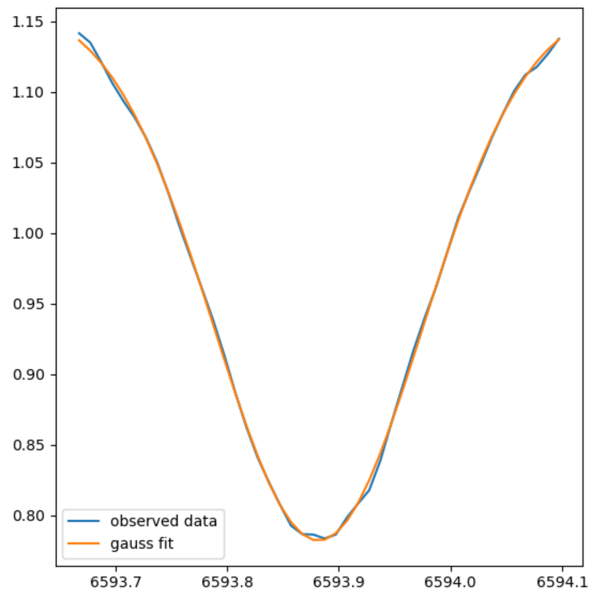

Fig. 1. Example of a gaussian fit of a line found in the spectrum of the first star studied

[1].

[1] An alternative method to check where the lines start and end would be through the first and second derivatives, however, for these particular cases it was found, through plotting the fits that use the δ method described above, that they were generally good enough

2.1.2. Growth curves

We then use Wλ to trace the growth curve, plotting $log(W_\lambda/\lambda)$ as a function of $log(gf\lambda)$. The temperature is given by the distance between multiplets, as follows in **?**:

$$T = \frac{|5040(\chi_1 - \chi_2)|}{\Delta} \tag{2}$$

Where χ_1, χ_2 are the average excitation energies for each multiplet, and Δ the distance between them.

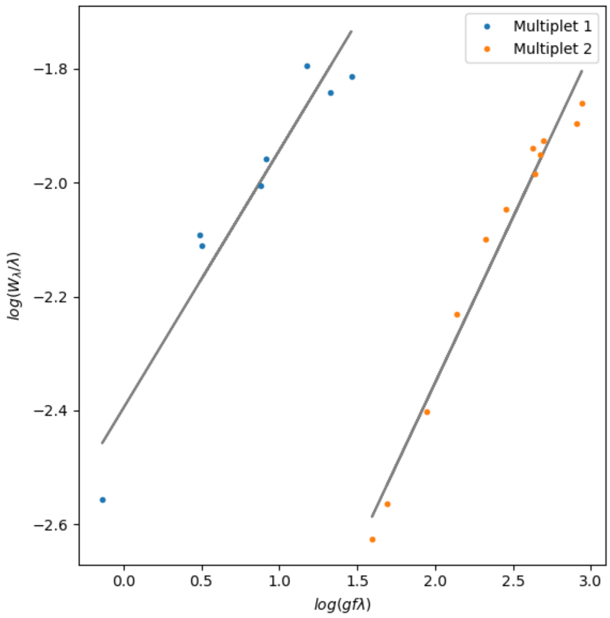

Fig. 2. Example of two solar multiplets, for $\chi_{1,2}$=([2.1,2.3],[4.2,4.3]). Linear fits are also represented

We chose to estimate Δ with the help of linear fittings (curve fittings, yet again!), obtaining the slope and y intercept for each multiplet. Firstly, we see where they have the same Y (ie, $log(W_\lambda/\lambda)$), calculate Δ for its minimum and maximum, then take an average of that value.

It is important to choose multiplets that have different enough excitation energy values, and for which we have the most number of lines.

In order to validate our algorithm, we use it to estimate the temperature of the sun, resulting in $T_{est.Sun} = 5635K$ and corresponding to an error of 2%.

The purpose of this preliminary estimation is only to limit the range of our study, so a 2% error is completely acceptable.

2.2. Determining the closest synthetic stectrum

The next and maybe the most important step in this work is the actual data comparison.

In short, we directly compare W_λ values for the observed and synthetic spectra. This is not an easy task, as it is later discussed in this report.

2.2.1. Finding the best fit

In theory, this is very straightforward: for each λ, values of $W_{\lambda,obs}$ and $W_{\lambda,synth}$ are calculated and compared.
Synthetic spectra found on **?** are used for this study, in a range of $T \in [T_{est} \pm 400]K$.
These synthetic spectra are generated for different values of $T, log(g)$, metallicity and chemical abundance. This means that, through this comparison, we'll determine all these parameters. The algorithm returns the file whose $W_{\lambda,synth}$ are the closest to $W_{\lambda,obs}$ by plotting $W_{\lambda,synth}$ as a function of $W_{\lambda,obs}$ and finding the linear fit whose slope is closest to one. [2]

2.2.2. Visual comparison and analysis

The next step is to process the determined synthetic spectrum.
We start by applying the experimental profile, ie, degrading the spectral resolution. This is done by convolving the fluxes with a Gaussian of parameters determined by (**?**):

$$\sigma = \frac{\Delta\lambda}{\sqrt{2ln(2)}} \tag{3}$$

Where $\Delta\lambda =< \lambda > /R$, R being the intrument's resolution. In this case, an $R \approx 50000$ is used (**?**).

Then, re-sampling is done, by using a linear interpolation, which evaluates the synthetic spectrum on the observed spectrum's λ values.

The last step for the processing is estimating the rotational velocity $vsinI$ by computing a fourier transform on spectral lines and analyzing its minima. We can estimate this velocity through the following equation (**?**):

$$vsinI = \frac{\Delta\lambda_M}{\lambda_0} c \tag{4}$$

c being the speed of light and λ_M obtained by comparison with values for the sun.

After estimating the rotational velocity, if this value is found to be significant, we'll need to to another convolution, applying this way a rotational profile. The final simulated spectrum is obtained convolving with a function given by:

$$G_\epsilon(\lambda - \lambda_0) = \frac{2(1-\epsilon)\left(1 - \left(\frac{\lambda-\lambda_0}{\Delta\lambda_M}\right)^2\right)^{1/2} + \frac{\pi\epsilon}{2}\left(1 - \left(\frac{\lambda-\lambda_D}{\Delta\lambda_M}\right)^2\right)}{\pi\Delta\lambda_M(1-\epsilon/3)} \tag{5}$$

3. Implementation and results

It is necessary to chose which lines are going to be used. Here, we worked with the lines found in **?**. This reference also provides us with other data we'll need on this work, for example $loggf$, excitation energy and also W_λ values for the su, the latter which we used in section 2.1 to test our algorithm.

Table 1. Excerpt of data taken from **?**

λ(Å)	EP (eV)	loggf ()	El	EW$_{sun}$(mÅ)
4523.40	3.65	-1.871	FeI	44.2
4537.67	3.27	-2.870	FeI	17.4
4551.65	3.94	-1.928	FeI	29.1
4556.93	3.25	-2.644	FeI	26.3
4566.52	3.30	-2.156	FeI	46.2

[2] This comparison could have been done through the least squares method. We choose this approach instead for reasons that will be later discussed.

3.1. Observations

1. While the calculations of W_λ, through the Gaussian fitting and δ method described above, for the observed spectra works smoothly, for the synthetic spectrum it results in errors. This is because, for example, these synthetic spectra not always have lines on the λs we're evaluating, due to their partial overlapping or to high rotational velocity. For the first star studied, however, it was seen that this isn't much of a problem, since the amount of error is of a small percentage, and because our final result is seen to match quite well. [3]

2. Given the Gaussian fit method implemented has adaptative intial conditions, it is safe to say that those that result in errors or that don't have a small enough s value aren't gaussian in behaviour. We can then simply ignore them and only compare equivalent widths of the remaining lines.

3. It was seen that multiplet selection greatly influences the results. For example, choosing $\chi_{1,2} = ([2.1, 2.3], [4.6, 4.7])$ leads us to a $T_{est,Sun} = 5447K$. Some multiplet lines have very different slopes, leading us to a worse distance estimation.
4. Since we ignore some of the lines, the number of equivalent widths we compare for different synthetic spectra aren't always the same. This means that directly employing the least difference method isn't ideal . Evaluating the slope of $W_{\lambda,synth}$ as a function of $W_{\lambda,obs}$ is independent of the number of lines evaluated, therefore being a better option.

3.2. Results

3.2.1. Star 1

For the first star studied, the multiplets χ_{1m2} = $([2.1, 2.3], [4.6, 4.7])$, were used to obtain the preliminary temperature:

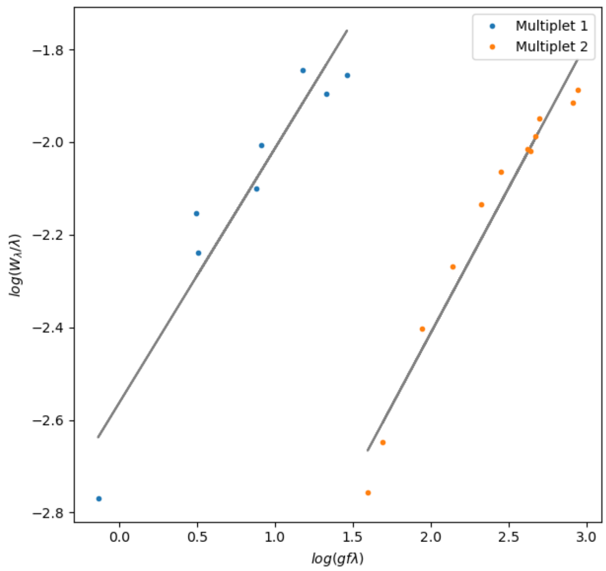

Fig. 3. Temperature estimate for the first star

[3] For a more general study it is indeed better to employ a method that uses step variation.

Which allowed us to estimate a temperature of $T = 5954K$, with no errors whatsoever.

Plugging in this temperature in our algorithm that limits the browse our databas e, we got the following results:

Table 2. Determined parameters for the first star

T	6000 K
logg	5.00
Fe/H	-0.25
α	0.10

Example of two solar multiplets, for $\chi_{1,2}$=([2.1,2.3],[4.2,4.3]). Linear fits are also represented

We see, through visual comparison, that not all lines match perfectly, but this seems to be a good first initial estimation. We didn't take into account the rotational velocity yet, so this could be one reason for the lines not matching perfectly.

3.2.2. Star 2

For the second star, using the same multiplets as for the first star, a rough temperature estimate of $T = 5300K$ was determined.
However, the code is still not ready for the full implementation and thus obtaining the best fit for a synthetic spectrum, since this spectrum isn't previously normalized and is of a somewhat worse quality in regards to noise.

4. Improvements and remaining work to be done

This is a first draft for this work, for it is clearly incomplete. Although this method seems to work decently for the first star, it still doesn't implement rotational velocity and a rotational profile.
In addition to this,

1. The second star poses a big challenge for this version of the algorithm, so it must be reviewed.
2. The continuum estimation and normalization needs to be further studied, since it is a crucial part of this study and wasn't taken much into account;
3. The implementation of an adaptative step on the gaussian fit, for a more general code, needs be further studied.

5. Conclusions

A code was developed to determine stellar parameters, and for the first star, it performed quite well, leading us to a result that seems to be successful in direct visual comparison. It was seen that the method needs to be improved, allowing us to take into consideration rotational velocity, and allowing us to study the second star.

References

Tsantaki et al., 2013, A&A, 555, A150
Monteiro et al., 2019, Astrofísica Estelar, FCUP CAUP
Monteiro et al., 2019, Astronomia Computacional, FCUP
Laverny et al., 2012, A&A, 544, A126