How much can we trust high-resolution spectroscopic stellar atmospheric parameters?

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Abstract

The determination of atmospheric parameters depends on the use of radiative transfer codes (among other elements such as model atmospheres) to compute synthetic spectra and/or derive abundances from equivalent widths. However, it is common to mix results from different surveys/studies where different setups were used to derive the parameters. These inhomogeneities can lead us to inaccurate conclusions. In this work, we studied one aspect of the problem: When deriving atmospheric parameters from high-resolution stellar spectra, what differences originate from the use of different radiative transfer codes?

1 Introduction

In the last years we have experienced a significant increase in the number of high-resolution stellar spectra available to the scientific community. This has been possible thanks to different surveys such as APOGEE (Eisenstein et al., 2011) or the Gaia-ESO Public Spectroscopic Survey (GES; Gilmore et al., 2012; Randich et al., 2013). The analysis of all these data can be carried out by different approaches like the synthetic spectral fitting technique or the classical equivalent width method. But such a huge quantity of data requires to automatize the analysis, and different authors have developed codes and pipelines to derive stellar atmospheric parameters (Recio-Blanco et al., 2006; Koleva et al., 2009; Tabernero et al., 2012; Magrini et al., 2013; Mucciarelli et al., 2013; Schönrich & Bergemann, 2014; Ness et al., 2015; Czekala et al., 2015; Masseron et al., 2016; Casey, 2016; Brahm et al., 2016).

The result of all this recent development in the field of stellar spectroscopy is an increase in the number of available atmospheric parameters and chemical abundances, provided by independent studies and surveys using different setups (e.g., radiative transfer codes, stellar model atmospheres, continuum normalization). However, when combining all these results into a single data set in order to increase the statistical value, a challenge arises: The inhomogeneities of the original studies might end up affecting our scientific conclusions. Thus, it is important to evaluate the impact of these differences.

Previous studies, such as Hinkel et al. (2016), already evaluated the global impact of different spectroscopic methods with different setups. In this study, we decided to tackle the problem by focusing on one single element. We fixed all the components of the spectroscopic analysis except one: the radiative transfer code. With this approach, we can better isolate the impact on the atmospheric parameter determination and compare the results between the synthetic spectral fitting technique and the equivalent width method. To address this complex experiment, we used iSpec\(^1\) (Blanco-Cuaresma et al., 2014a) and its flexibility to build a spectroscopic pipeline with different radiative transfer codes.

2 Method

iSpec is an open source spectroscopic framework that can be used to treat observed 1-D spectra (e.g., perform continuum normalization, measure and correct radial velocities) and it can also derive atmospheric parameters and abundances using the synthetic spectral fitting technique or the equivalent width method. However, until very recently, iSpec offered only one single radiative transfer code: SPEC-TRUM (Gray & Corbally, 1994).

In the stellar community there are plenty of other radiative transfer codes. Hence, we decided to integrate into iSpec some of the most popular ones:

- WIDTH9/SYNTHE (Kurucz, 1993; Sbordone et al., 2004)
- SME (Valenti & Piskunov, 1996)
- Turbospectrum (Alvarez & Plez, 1998; Plez, 2012)

\(^1\)http://www.blancocuaresma.com/s/
To test all these codes, we used a set of very well known stars with reference parameters derived independently of spectroscopy: the Gaia FGK Benchmark Stars (Jofré et al., 2014, 2015; Heiter et al., 2015; Hawkins et al., 2016). The spectra used in the experiment was obtained from its public high-resolution spectral library\(^2\) (Blanco-Cuaresma et al., 2014b).

The synthetic spectral fitting technique implemented in iSpec does not use the full spectrum, but only the spectral features that the users choose (e.g., spectral regions that carry more information). The same happens for the equivalent width method due to the nature of the technique. To prepare the line selection, we used a solar spectrum from the library and we applied the following procedure for each radiative transfer code:

1. Fix the atmospheric parameters to the solar reference values reported in Heiter et al. (2015).
2. Normalize the spectrum, correct the radial velocity and convolve to a resolution of 47 000 (using exactly the same algorithms and setup that will be used for the experiment).
3. Automatically cross-match all the observed absorption lines with atomic data obtained from VALD (Kupka et al., 2011).
4. Derive chemical abundances for each of the identified lines using model atmospheres from MARCS\(^3\) (Gustafsson et al., 2008) and solar abundances from Grevesse et al. (2007).
5. Select lines for which the determined chemical abundances is within ±0.05 dex (given that it is a solar spectrum, we expect all [El/H] abundances to be close to 0.00 dex).

Finally, we derive atmospheric parameters for all the Gaia FGK Benchmark Stars using only the absorption lines that were selected for all the radiative transfer codes in the solar spectrum (i.e., lines that all the codes are capable of correctly reproducing the solar spectrum).

3 Results

The results for the effective temperature when using the synthetic spectral fitting technique are shown in Fig. 1. Each star has more than one result because several spectra were analyzed. The median difference and dispersion is shown in the upper right part of each subplot. The agreement between SPECTRUM and SYNTHETE is remarkable, while Turbospectrum and SME is good although it deviates a little bit for colder and metal-poor stars. On the contrary, MOOG is the code that disagree the most with SPECTRUM or any of the other codes included in the study.

If we check only the effective temperatures derived using the equivalent width method (Fig. 2), we see that the level of disagreement (i.e., dispersion) between both methods is higher than the typical level for synthesis.

Finally, when we compare the effective temperature derived using the spectral synthesis technique (with SPECTRUM) and the equivalent width method (with WIDTH9) as shown in Fig. 3, the disagreement is even more important. Note that in the figure, the scale in the Y-axis was increased (compared to previous figures) to fit all the results.

For all these comparisons, the same global behaviour is found for surface gravities and metallicities. Codes that agree on effective temperature tend to agree on the rest of parameters and vice-versa.

4 Conclusions

We showed how different radiative transfer codes impact the determination of atmospheric parameters, and we quantified this impact for a wide range of stars. The level of agreement varies between different codes and it is noteworthy that the disagreement is higher when different methods are used (i.e. synthesis and equivalent width).

More importantly, this experiment was designed to keep all the variables fixed except the radiative transfer code and the method. The selection of lines was careful done to chose only the ones that reproduce better the Sun for all the codes. The condition were very favorable for a good convergence toward similar values. Nevertheless, the disagreement can-

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\(^2\)http://www.blancocuaresma.com/s/
\(^3\)http://marcs.astro.uu.se/
not be completely ignored. This should discourage us from blindly mixing results coming from different sources where complete different setups and ingredients (and not only the radiative transfer codes) were used to derive their atmospheric parameters. Additionally, the discrepancies in atmospheric parameters are going to propagate to the determination of chemical abundances. Thus, if we want accurate scientific conclusions when using abundances to study stellar aggregates and the Galaxy, it is necessary to make sure they were obtained homogeneously or, at least, perform an exhaustive assessment of the consequences of combining results obtain with different setups.

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Figure 2: Differences in effective temperature (K) between two codes when using equivalent widths (upper left text). Median difference and dispersion in the upper right text. Color code as in Fig. 1.

Figure 3: Differences in effective temperature (K) between codes using synthesis and equivalent width (upper left text). Median difference and dispersion in the upper right text. Color code as in Fig. 1.