AUTOMATED ANALYSIS OF STELLAR SPECTRA: APPLICATION TO THE GAUDI ARCHIVE.

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ABSTRACT

In this paper we describe a methodology to be used for the automated analysis of the spectroscopic contents of the GAUDI archive. We perform chi-square minimisation in the 5000-5200 Å spectral window to infer the atmospheric parameters and their random internal uncertainties. Effective temperatures are anchored using a zero-point correction into the scale defined by the method described in Ribas et al. (2003). Surface gravities and metallicities were put in the scale defined by nearby stars included in the S^{4}N archive. Comparison with the Elodie.3 stellar library has shown excellent agreement. Our final goal is to build a VO application, available from the Spanish Virtual Observatory (SVO, http://svo.laeff.inta.es), to derive physical parameters of large samples of stellar objects in an automated and uniform way.

Key words: stars: fundamental parameters; methods: data analysis; techniques: spectroscopy; Virtual Observatory.

1. INTRODUCTION

Advances in astronomical instrumentation as well as in computational capabilities are providing the means to make accurate, precise and fast comparisons between extensive libraries of synthetic spectra and large observational datasets covering wide wavelength ranges. In this framework, the classical methodology used for the determination of the fundamental stellar parameters (effective temperatures, luminosities, surface gravities, rotational velocities and chemical abundances), where a high degree of human intervention is present, has proved to be quite inappropriate. Automated methods, on the contrary, represent an optimal approach to guarantee efficiency and repeatability.

GAUDI (Ground-based Asteroseismology Uniform Database Interface, http://sdc.laeff.inta.es/gaudi/) is a Virtual Observatory compliant archive built for the COROT (COnvection, ROtation and planetary Transits) mission. Its purpose is to make the preparatory observations of the asteroseismology programme available in a simple and efficient way. It contains spectroscopic and photometric data together with inferred physical parameters for more than 1500 objects.

In order to take full advantage of the COROT data the seismic information needs to be complemented with precise and reliable information on the fundamental stellar physical parameters. However, due to the lack of efficiency of the "classical" methodology, detailed analyses have been performed only for a handful of GAUDI spectra.

In this paper, we present the results obtained for a subset of the GAUDI spectra using a minimum distance optimisation method and a grid of synthetic spectra.

2. THE DATA

We have selected the GAUDI spectra observed with ELODIE, a fibre-fed spectrograph in operation on the 193cm telescope of Observatoire de Haute-Provence. ELODIE has a resolving power R=42000 and covers a wavelength range from 3900 to 6800 Å. A total of 1345 GAUDI spectra of 776 objects were selected.

A grid of synthetic spectra has been built using Kurucz's model atmospheres (Kurucz 1993). The grid is composed of 1170 ($10\times13\times9$) synthetic spectra covering the intervals $4500 \leq T_{\rm eff} \leq 7500$; $1.0 \leq \log g \leq 5.0$ and $-4.0 \leq [M/H] \leq 0.5$ with steps of 250 K, 0.5 dex and 0.5 dex, respectively. This choice guarantees the avoidance of extreme conditions where Kurucz models may fail like too cool temperatures at which the contribution of molecules is not fully taken into account, departures from LTE or extremely low values of metallicities for which metal lines vanish. The α-elements O, Mg, Si, Ca, and Ti were enhanced at low metallicity, as in Eq. (2) of Allende Prieto et al (2006).

3. PREPROCESSING

Before the observed spectra can be compared to the synthetic grid, the following steps must be performed:

- Order Concatenation: A weighted average of the flux in the overlap regions of adjacent Echelle orders was calculated using the signal-to-noise information and resampling the blue order to the step of the red order.
- Radial velocity correction: Displacements in velocity were measured by cross-correlating the observed spectrum with a grid of synthetic spectra covering a spectral window around Hβ. The final radial velocity correction was defined as the weighted average of the displacements measured in the 10% of the pairs O-C (observed-computed) that best fit.
- Resampling: Both observed and synthetic spectra were degraded to a resolution power of R=7700. This value is low enough to make the effects of rotational and macroturbulent broadening negligible in late-type stars but, at the same time, high enough to be able to recover information on the line profiles.
- Selection of the spectral window: Although the spectral coverage of ELODIE goes from 3900 to 6800 Å, we have considered for efficiency purposes a much narrower region: 5000-5210 Å. This region is red enough to avoid the difficulties of dealing with metal opacities in the ultraviolet and, at the same time, blue enough to include a statistically significant number of metal lines (Fe, Ca and Mg lines with different intensities and with different responses to the variation of the physical parameters) for a reliable determination of the metal abundance even in metal-poor stars. A bluer, alternative region centred on Hβ was checked but it was finally discarded due to the strong influence of the uncertainties associated to the normalisation of the continuum of the line on the calculated physical parameters.

4. THE FITTING PROCEDURE

The principle to follow in the estimation of the stellar physical parameters is very simple: find the synthetic spectrum that best fits the observed one. However, at least four different methodologies can be found in the literature to tackle this issue: minimum distance methods, principal component analysis, neural networks and Gaussian probabilistic models (see Bailer-Jones 2002 for a detailed review of the most widely used techniques for automated classification of stellar spectra).

In our case we have chosen to perform χ^2 minimisation, a type of minimum distance method (MDM) where the normal Euclidean distance metric is assumed. MDMs have the advantage of their easy implementation and interpretation. They do not require training, always a time-consuming task. On the other hand, the major disadvantage associated to these methods – the lack of efficiency for large, multi-parametric surveys– is not a problem in our case as the number of parameters to estimate (3), the number of synthetic spectra (1170) and the number of points per spectra (1030) is small.

Finding the synthetic spectra that best fits an observed one is equivalent to solving the optimisation problem of finding the minimum distance between the observed spectrum and the synthetic grid. There exists a large variety of algorithms to reduce the number of evaluations of the function to be optimised (the distance in our case). We have used the non-linear simplex method proposed by Nelder & Mead (1965), an efficient and fast method that does not require derivatives but only function evaluations.

In order to avoid restricting the derived physical parameters to the values provided by the discrete set of synthetic spectra, interpolation has been performed in the flux space. The generation of the interpolated synthetic models has been speeded up by the interpolation of the opacities in the plane (log ρ, log T) at any given metallicity (Koersterke, priv. comm.). The small steps of the grid and a third-order interpolation scheme (see, e.g., Auer 2003) guarantee accuracy, continuity and smoothness.

5. EVALUATION OF THE RESULTS

We have tested our procedures on two sets of high-resolution spectra and atmospheric parameters for nearby stars: the S^{4}N archive (Allende Prieto et al. 2004) and the Elodie.3 library (Prugniel & Soubiran 2004). Visual inspection of the fittings indicates that temperatures higher than 6800 K and lower than 5000 K have very large errors associated. The reasons for this are diverse. On one hand, there are physical parameters not considered in the fitting process (e.g. the rotational velocity) that have a clear impact on the degradation of the results for hot stars. On the other hand, the increase in intensity and number of metal lines as well as a degeneracy between temperature and metallicity degrades the quality of the fittings at low temperatures. To avoid the problematic edges, we have restricted our analysis to the interval $5000 < T_{\rm eff} < 6800$ K. Further investigation is foreseen to expand the temperature range.

The internal consistency of our determinations was evaluated by comparing the values obtained for objects with more than one spectrum (183). It has proved to be excellent as the median of the standard deviations are 24 K, 0.05 dex and 0.02 dex for $T_{\rm eff}$, logg and [Fe/H], respectively.

The effective temperatures obtained from the fittings were anchored to the scale defined by the method of Ribas et al. (2003) by performing zero-point corrections. The catalogue of effective temperatures of Ribas et al. is based on fitting 2MASS infrared photometry with accurately calibrated synthetic photometry, and includes 123 of the 776 objects observed with ELODIE. The effective temperatures derived from our χ^2 fittings for these stars are, on average, 2.6% warmer than those of Ribas et al., with an rms scatter of 3.63% (see Figure 1). The gravities for 55 stars included in S^{4}N, which rely on Hipparcos parallaxes, as well as their metallicities, are used to set the zero point for the values derived from our χ^2 fittings. Before applying these corrections, surface gravities and metallicities from our fittings are, on average, 0.2 dex ($\sigma = 0.12$ dex) higher and -0.23 dex ($\sigma = 0.05$ dex) lower, respectively, than those in the S^{4}N catalogue.

Figures 2,3 and Table 1, illustrate the agreement between the parameters inferred from our method and those in the S^{4}N and Elodie.3 catalogues, after applying the zero-point corrections described above. The dashed line indicates the line with slope of unity whereas the solid line represents the χ^2 fitting. The average of the differences between the surface gravities from our fittings and those in the S^{4}N archive are perfect by design, as we use this spectral library to set the zero points.

Table 1. Comparison between the parameters derived by our procedure for 55 stars in the S^{4}N archive and 282 stars in the Elodie.3 library with the reference values extracted from the corresponding associated catalogues. Note that the 55 stars from the S^{4}N archive are used to set the zero-points for our spectroscopic surface gravities and metallicities, and therefore the two scales agree perfectly.

Library	N	Parameter	Average	Stdev
			<FIT-REF>	(FIT-REF)
S^{4}N	55	T$_{\rm eff}$	2.12 %	1.52 %
		$logg$	0.00	0.13
		$[M/H]$	0.00	0.05
Elodie.3	282	T$_{\rm eff}$	0.25 %	2.74 %
		$logg$	0.017	0.27
		$[M/H]$	-0.02	0.10

6. FUTURE PLANS

6.1. New parameters

Stellar spectra show much more diversity than what is represented by the three major parameters analysed here (effective temperature, surface gravity, overall metallicity). An interesting extension of this work will undoubtedly be the estimation of abundance ratios (e.g. the α-elements to iron ratio) in addition to metallicities. This will require disentangling the effects that the chemical abundance and the gravity play on the strong Mg and Ca lines used in our analysis.

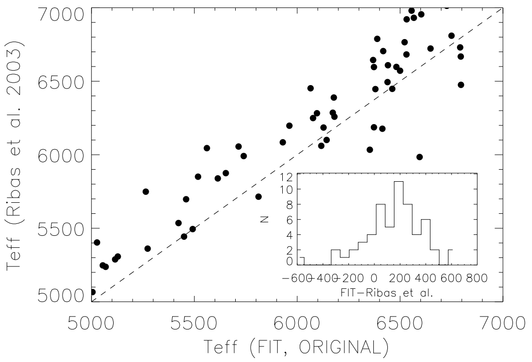

Figure 1. Comparison between the effective temperatures derived by our procedure and those of Ribas et al. (2003).

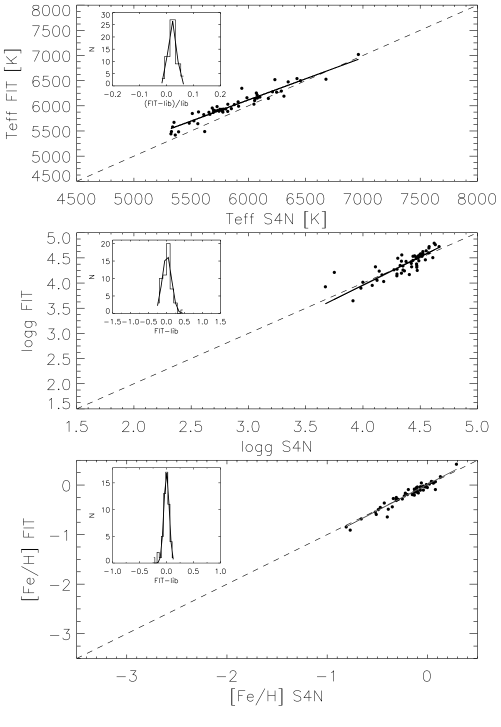

Figure 2. Comparison between the zero-point corrected parameters derived by our procedure and those in the S^{4}N catalogue.

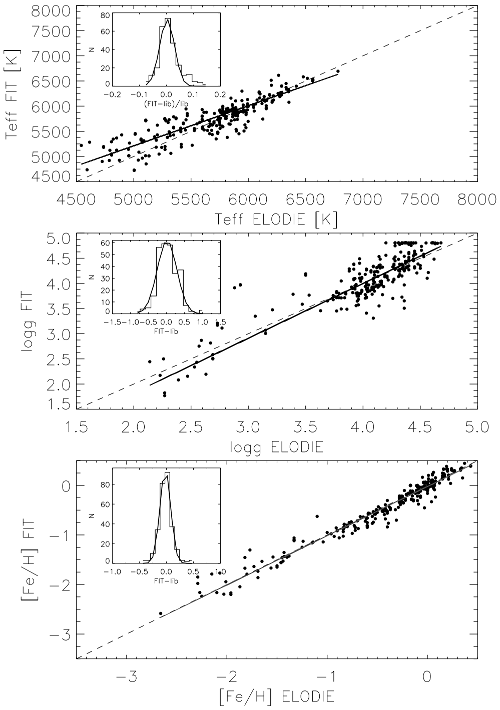

Figure 3. Comparison between the zero-point corrected parameters derived by our procedure and those in the Elocie.3 catalogue.

6.2. Development of a VO service

In the framework of the Spanish Virtual Observatory (SVO) we plan to implement the method described in this paper in a VO service. In particular, the service will provide the following facilities:

- Pre-processing module: It will contain routines for order concatenation, radial velocity correction, rebinning and normalisation.
- Access to synthetic spectra from the SVO Theoretical Data Server using the TSAP[1] protocol.
- Identification of spectral lines using the Simple Line Access Protocol (SLAP) and the associated Data Model.[2]
- Refinement of the atomic data of the spectral lines of interest using VO services that may be available in the future (e.g. VALD-VO).

6.3. Application to new datasets

- GAUDI archive: In addition to the spectra observed with ELODIE, the GAUDI archive contains spectra from other instruments/telescopes: FEROS at the 1.52 and 2.2m telescopes at ESO (681 spectra), SARG at the 3.6m Telescopio Nazionale Galileo (78 spectra), CORALIE at the 1.2m ESO telescope (23 spectra) and at the Serra La Nave 0.91m telescope (53 spectra). Our aim is to apply the method described in this paper to these datasets to build a uniform set of physical parameters for the spectroscopic contents of the GAUDI archive.
- Other COROT datasets: Follow-up observations of the targets of the COROT Exoplanet fields showing transit events are necessary to affirm their planetary nature filtering out no-planetary transiting objects and to obtain planet and parent stars properties in more detail. These observations will play a major role, significantly increasing the scientific return of the mission.

  Given the expected large number of candidates (around 5000 dwarfs with R<15 are surveyed in each COROT long run), an automated analysis procedure like the one here described will represent the only way to perform an efficient and uniform study.

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