Publ. Astron. Obs. Belgrade No. 92 (2013), 169 - 174 *Poster*

PARSES PIPELINE FOR DETERMINING THE STELLAR PARAMETERS

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Abstract. PARSES is a pipeline for determining physical parameters of a star from the stellar spectra – effective temperature, metallicity, surface gravity and rotational velocity. It utilizes the grid of templates based on synthetic spectra, and the search routine is based on the Minimum Distance Method. In order to calibrate the routine, we tested it with different wavelength ranges used for fitting the observed spectra. Results for stellar parameters are compared with the literature values from the ELODIE library. The last step was to choose final solution for full implementation on the data produced with the STELLA telescope. The modified version of the pipeline is going to be used in processing the data from the ELODIE spectral library and also tested on some Gaia ESO data.

1. INTRODUCTION

Robotic and semi-robotic telescopes are automatically followed by unsupervised data reduction pipelines and automated analysis. PARSES is a pipeline for automatic determination of the stellar parameters from stellar spectra. In this paper we are presenting work-in-progress on its future implementation on spectra obtained using the STELLA robotic observatory[1]. The STELLA robotic observatory hosts the STELLA Échelle spectrograph (SES), which has been successfully in operation since 2006. SES is producing high-resolution spectra covering the visual wavelength range covering from 3850 to 8700 $\mathring{A}$ at a resolution of 55 000. The spectra are consisting of 82 slightly overlapping orders.

The pipeline is planned for determination of four parameters – metallicity [Fe/H], projection of rotational velocity $V \sin i$, effective temperature $T_{\rm eff}$ and surface gravity $\log g$.

[1]`http://www.aip.de/stella`

2. METHODOLOGY

The classical method for quantification of physical parameters of a star from its spectra has been performed by measuring the equivalent width of lines and comparing it to a model-based computed spectra. Robotic dedicated spectroscopic surveys require faster methods which mainly use tables of synthetic spectra.

The grid of synthetic spectra we used was based on the newest MARCS model atmospheres (Gustafsson et al. 2008).
The parameter range for the grid was following:

- effective temperature T_{eff} : (3000 − 7000) K, step 250 K,
- surface gravity $\log g : (0 - 5.5)$, step 0.5,
- metallicity [Fe/H] : (−2.5 − 1.0) dex, step 0.25 dex,
- projected rotational velocity $V \sin i : (0 - 150)$ km/s, scale is logarithmic.

The synthetic spectra were built using the code Turbospectrum (Alvarez and Plez 1998, Plez 2012). The line-list used by Turbospectrum was the most up-to-date and comprehensive atomic line-list called VALD3 (Kupka et al. 2000). The stars observed with SES are cold (mainly K, G and F), and some of them are expected to have strong molecular lines, for example, some Titanium oxides lines. The tests were done using molecular lines but no significant differences were found. The synthetic spectra in our grid are built using only atomic lines. In order to get rectangular grid of models, the holes and edges are filled by calculating the model flux through interpolation and extrapolation respectively. The synthetic spectra are then convolved with the instrument profile of SES. We concluded that in the final grid of model fluxes microturbulence can be fixed to one or two values, based on the relatively small range of parameters (and spectral types) of the stars observed with SES. Of course, there is a possibility of adding (or subtracting) a parameter to the grid, one of them being the microturbulence. Broadening due to macroturbulence is also added (values from Gray 1992). Broadening due to rotation is not applied on spectra in three-dimensional case. Continuum normalization is done for both acquired and calculated spectra.

Wavelength ranges in which the observed spectra will be fitted with the synthetic one are specified in the input file used by the pipeline – database file.

Input empirical spectra obtained by SES have been reduced beforehand (also using a pipeline) in the usual manner. Radial velocity pipeline is also operational and it was used to apply a correction for radial velocities.

For the analysis of the observed spectra PARSES uses a method which belongs to the type of Minimum Distance Methods (also stands for Metric Distance Minimization). MDMs are based on the simple concept of maximizing the agreement between observed and the model fluxes (flux is some function of physical parameters here) by defining some sort of distance. Direct χ^2 minimisation, which is a type of MDM, has been performed for evaluation of the distance between an observed and computed spectra. To reduce the number of evaluations of the distance, a non-linear simplex optimization method (see Nelder and Mead 1965) was used. Significant improvements in precision are achieved by using interpolation. Interpolation is performed in the flux space, so the model flux becomes a continuous function of the parameters, and then optimization methods can be employed. The cubic Bézier model flux interpolation from a multi-dimensional grid was interpolation used here.

3. CALIBRATION

Testing of the different input files for the pipeline – database files – was the main part of the calibration procedure. Six different versions of the pipeline were run on a sample of 262 spectra of 29 stars observed with SES, and the comparison with the literature values given in the ELODIE library[2] was done. The database files are made of a grid of synthetic spectra and spectral ranges used for fitting.
The basic features of different database files are as follows:

1. The first version of the pipeline used only eighteen orders from the échelle spectra. The orders used are in the blue part of the spectra. The grid is four-dimensional in this case so it includes rotational velocity. Temperature is truncated at 5000 K. The spectra in the grid are based on the Kurucz models (Kurucz 1993).

2. The second version used the same orders as the first one, but the grid was three-dimensional (without a projected rotational velocity), and the model atmospheres were MARCS. The temperature range was $4000 - 7000$ K, and we fixed microturbulence ξ_t value to 2.

3. The ranges for the third one are the same as in the radial velocity pipeline for SES - 62 orders.

4. The fourth version has been done in the most elaborate manner. A star that was both well-documented in the literature and has also been observed with SES was chosen, and that was HD 212943. We built a small grid of the synthetic spectra based on the MARCS models, and just by using the search routine we have found the synthetic spectra that is closest to the observed high signal-to-noise spectra. Visual inspection of the observed and synthetic over-plotted spectra gave us a final assessment of the usable regions – 73 wavelength ranges in 62 orders were chosen. Regions with strong telluric lines, high noise and Hα-line were omitted. Two different values for the microturbulence were used, $\xi_t = 1$ for $\log g \geq 3.5$, $\xi_t = 2$ for $\log g < 3.5$.

5. This was a red subset of the orders used in the third version, 41 of them.

6. Same as the version three above, but with two different values for the microturbulence: $\xi_t = 1$ for $\log g \geq 3.5$ and $\xi_t = 2$ for $\log g < 3.5$.

In order to test and represent the quality of the results produced with PARSES we had to compare it to parameter values given in the literature or produced by some other pipeline. In the initial stage we planned to use the values inferred from the spectra in the ELODIE spectral library. The ELODIE spectral library has been chosen for comparison because of the similarities between the spectrographs used,

[2]http://http://atlas.obs-hp.fr/elodie/intro.html

Table 1: σ (estimated standard error of regression) and r (correlation coefficient) are given as statistical measures of the agreement between parameter values calculated by PARSES pipeline (x-axes) and literature parameter values from the ELODIE library (y-axes). These parameters are given for the six different databases (input files) that were used by the pipeline.

dbNo.	$\sigma_{\mathrm{T_{eff}}}$[K]	$r_{\mathrm{T_{eff}}}$	$\sigma_{\mathrm{[Fe/H]}}$[dex]	$r_{\mathrm{[Fe/H]}}$	$\sigma_{\log g}$	$r_{\log g}$
1	440.684	0.78323	0.422591	0.851709	0.86179	0.814176
2	142.880	0.97947	0.114268	0.989911	0.54270	0.930759
3	135.449	0.98157	0.106560	0.991232	0.51096	0.938877
4	206.719	0.95653	0.162290	0.979542	0.72844	0.871289
5	126.532	0.98394	0.116162	0.989572	0.53074	0.933882
6	135.658	0.98152	0.108929	0.990836	0.50882	0.939405

their resolution, the wavelength ranges and the selection of targets. Because of the lack of parameter values determined independently by a pipeline on the ELODIE spectra (subject of ongoing work), comparison with the literature values given by the ELODIE are presented here.

PARSES has been run on the sample of stars cross-matched with the ELODIE library. Where possible 10 SES spectra with highest S/N for each sample star were used, and preferably from different years of observation. Different periods of observation have been used because there were some modifications of the reduction procedures. PARSES has been run on every spectra and using all six different versions of the grid and spectral ranges – databases from No.1 to No.6.

The results from the pipeline were plotted against the ELODIE literature values for $\mathrm{T_{eff}}$, [Fe/H] and $\log g$. The data has been fitted with the regression line.

In order to evaluate the agreement between parameter values produced by PARSES and the literature, some statistical criteria were employed. The estimated standard error of regression and Pearson's correlation coefficient were calculated (see Table 1). Here standard error of regression is a square root of the sum of the squared residuals divided by the number of degrees of freedom.

We have built four-dimensional grids for the spectral ranges and other settings from the third and the fourth version. We ran the pipeline on the four-dimensional (4D) grids using the settings described earlier. The fourth parameter in the grid was a projection of the rotational velocity $V \sin i$, as it is usually given in the literature. The estimated standard error of fitted regression line σ and correlation coefficient r for a 4D case of databases No.3 and No.4 are given in Table 2. The plot representing agreement between parameters calculated on the four-dimensional version of the grid with database No.4 settings and values given in the literature can be seen in Figure 1. Errors are not shown in the plots here and their more accurate determination is a subject of an ongoing work.

The results are different for 3D and 4D case which is expected because of the degeneracies between the parameters, among other things. For example, we expected $V \sin i$ and the difference between the parameter value obtained with 3D and 4D pipeline to be correlated. No clear trend was found. The plot representing the differences for surface gravity plotted against $V \sin i$ can be seen in Figure 2.

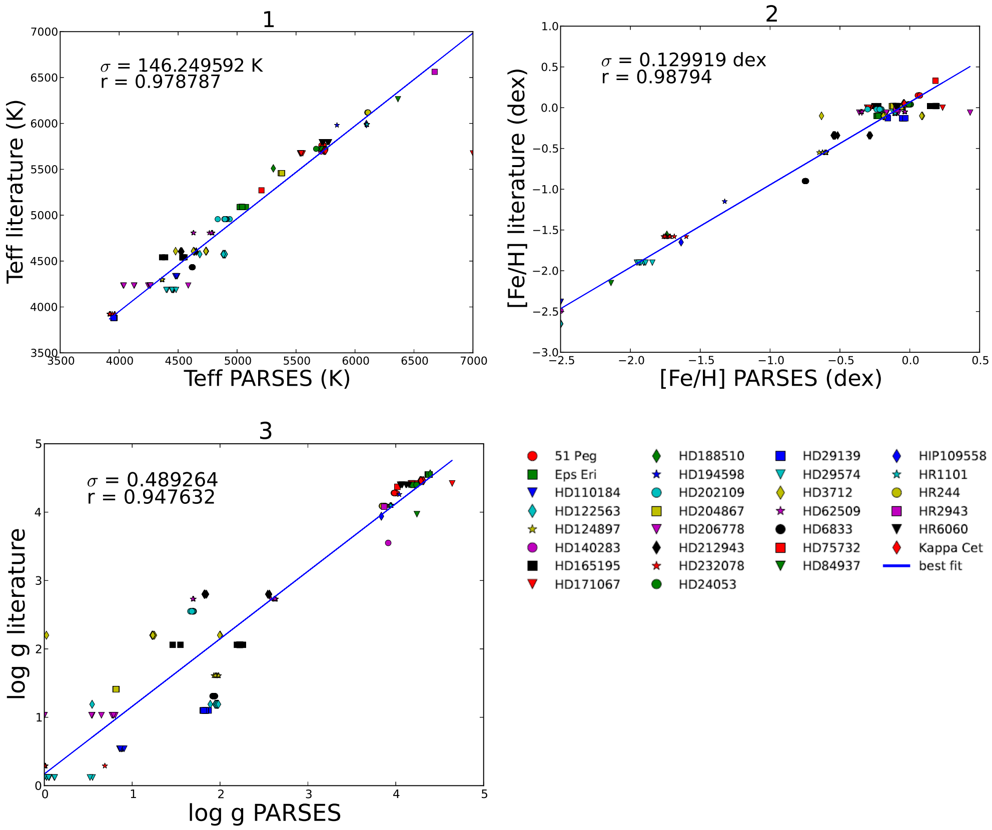

Figure 1: The results from No.4 4D database PARSES plotted against the ELODIE literature values for the same stars. Plots No.1, 2 and 3 show effective temperature, metallicity and surface gravity, respectively. The estimated standard error of regression σ and correlation coefficient r are given in the plot.

Table 2: The estimated standard error of the fitted regression line σ and correlation coefficient r for the data points that are representing parameter values given by PARSES pipeline (x-axes) and literature value given by the ELODIE library (y-axes). These parameters are given for the four-dimensional case of databases No.3 and No.4.

dbNo.	$\sigma_{\rm T_{eff}}$[K]	$r_{\rm T_{eff}}$	$\sigma_{\rm [Fe/H]}$[dex]	$r_{\rm [Fe/H]}$	$\sigma_{\log g}$	$r_{\log g}$
3	137.3436	0.981315	0.127274	0.988429	0.425163	0.960719
4	146.2496	0.978787	0.129919	0.987940	0.489264	0.947632

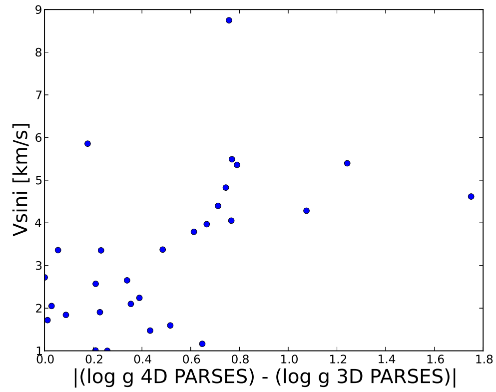

Figure 2: Projection of rotational velocity $V \sin i$ plotted against the difference in determining surface gravity by 3D and 4D pipeline.

The 4d database No.4 is most likely going to be used for final implementation. Testing and further calibration are in progress.

ACKNOWLEDGEMENTS. M.J. acknowledges the support of the Ministry of Education, Science and Technological Development of the Republic of Serbia through the project no. 176021 "Visible and invisible matter in the nearby galaxies: theory and observations". M.J. acknowledges the financial support provided by the European Commission through project BELISSIMA (BELgrade Initiative for Space Science, Instrumentation and Modelling in Astrophysics, call FP7-REGPOT-2010-5, contract no. 256772) used for the visit to the Leibniz-Institut für Astrophysik Potsdam (AIP). This work has made use of the VALD database, operated at Uppsala University, the Institute of Astronomy RAS in Moscow, and the University of Vienna.

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