SPADES: a Stellar Parameter 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 softwares 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 most of all elemental abundances. 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, A&A,338,151; Soubiran et al., 2003, A&A,398,141), ETOILE (Katz 2001, Journ. Of Astron. Data , 7 ,8) and Abbo (Bonifacio & Caffau, 2003, A&A,399,1183B) softwares. This poster presents the method behind our software. The performances are illustrated with GIRAFFE-like simulated spectra in high resolution (R = 25000), in high and low signal to noise ratios (down to SNR= 30). These spectra should be close to what could be targeted by the Gaia Chemo-Dynamical Survey (GCDS).

Need for automatic spectra analysis softwares

Surveys:

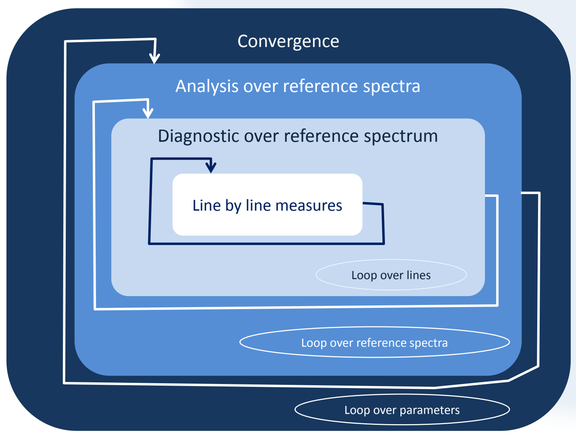
Gaia-ESO Survey : about 160'000 stars , Gaia: 5'000'000 stars for chemical abundances , RAVE: 452'398 so far and about 1'100'000 expected, etc…

Existing softwares:

TGMET (ETOILE), MATISSE, MyGIsFOS, Neural Network, SEGUE pipeline, Ulyss etc..

Parameters to be determined:

- Radial velocity (Vr)
- Effective temperature (Teff)
- Metallicity ([Fe/H])
- Micro-turbulence (χ)
- Gravity (logg)
- Elemental abundances ([M/H])



General idea

The general idea is a comparison between the observed (studied) spectrum and a grid of reference spectra with known parameters.

1. For each parameter to be determined, one or several methods of determination (diagnostics) are possible. One is chosen.
   The list of diagnostics for each parameter are:
   -Vr: "classic" cross-correlation method (will not be detailed)
   -Teff: excitation equilibrium or Balmer lines profile fitting.
   -logg : ionization equilibrium or strong lines profile fitting.
   -[Fe/H]: Fe lines profile fitting.
   -[X/H] : X lines profile fitting.
   -χ: empiric method and nulling the ΔW = f(reduced equivalent widths) function slope. ΔW being the residuals of the difference between the observed and synthetic line.
   The so far implemented and tested diagnostics are detailed in the next box.
   Note that one diagnostic gives one parameter, as opposed to existing methods where one diagnostic gives all parameters.
2. For one parameter and one diagnostic, a 1D (in the parameters space) reference spectra grid is defined, varying over the parameter to be determined only. For now, the reference grid is pre-calculated using ATLAS9 (Kurucz). When needed, the software calculates a new reference grid by interpolation based on the pre-calculated one.
3. For each reference spectrum, a line by line analysis is made (compared to global methods where the analysis is done over the whole spectrum). No equivalent widths are measured. Instead the measures are based on profile fitting like methods between observed and synthetic lines.
4. Iterations and convergence : at one iteration, each parameter is determined independently from the others. The rest of the parameters is fixed to their input values. At the next iteration, all parameters values are updated and the i iteration output values become the i+1 iteration input values and so on. The software stops when the differences between the parameters values at iteration i and iteration i+1 are smaller than pre-fixed values.

Diagnostics (implemented)

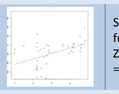
Measure on line	Diagnostic on reference spectrum	Analysis on reference grid

Teff

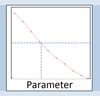
Excitation equilibrium:

$$\Delta W = \sum_{pixels} -(x_{obs} - \hat{x}_{ref})$$

ΔW as function of excitation potential => slope



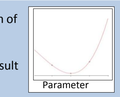
Slope as function of Teff. Zero of function = result Teff



Hα wings fit method :

$$S^2 = \sum_{pixels} \frac{(x_{obs} - \hat{x}_{ref})^2}{\sigma^2}$$

S^2 as function of Teff. Minimum of function = result Teff



Ionisation Equilibrium:

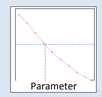
logg

$$\Delta W_{FeI} = \sum_{pixels} -(x_{obs} - \hat{x}_{ref})$$

$$\Delta W_{FeII} = \sum_{pixels} -(x_{obs} - \hat{x}_{ref})$$

$$\Delta = \overline{\Delta W_{FeI}} - \overline{\Delta W_{FeII}}$$

Δ as function of logg Zero of function = result logg



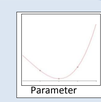
Profile adjustment over the X element lines :

[X/H]

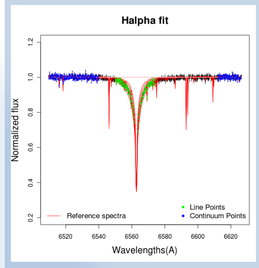
$$S^2 = \sum_{pixels} \frac{(x_{obs} - \hat{x}_{ref})^2}{\sigma^2}$$

$$S^2 = \sum_{lines} \sum_{pixels} \frac{(x_{obs} - \hat{x}_{ref})^2}{\sigma^2}$$

S^2 as function of [M/H] Minimum of function = result [M/H]



Line fit example: Hα



Determination of Teff based on H α line fit:

1. The analyzed spectrum is a synthetic noised spectrum. A 1D Teff reference grid is defined with Teff values around the input Teff value.
2. We work in a spectral domain around the central line wavelength (Hα wavelength in this case). The continuum pixels (blue points) and line pixels (green dots) are determined on the reference spectra.
3. The local continuum of the reference spectra is then fitted to the local continuum of the studied spectrum. We visualize the observed Hα spectral domain (black line) with the superposed synthetic spectral domain (red line).
4. The measure is done over the defined line pixels (green). In this case, it's a quadratic difference between the observed flux and the corresponding reference line flux.

Future work

-On the fly reference grid calculation: dynamic call of the SYNTHE software for calculating the reference grid directly from SPADES
-Fix a method for determining micro-turbulence
-Improve the determination of Teff by excitation equilibrium
-Determine the individual errors
-Test on known stars spectra (e.g sun)
-First scientific use: analyze medium to high resolution Thick Disk stars GIRAFFE spectra. Foreseen within 6 months.

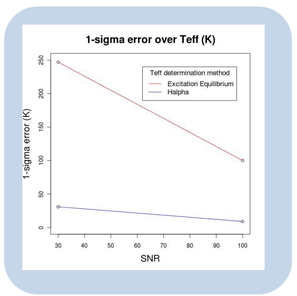
TESTS

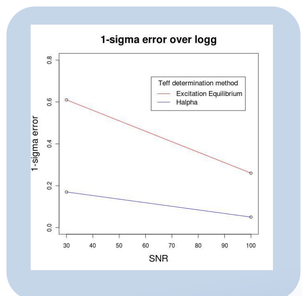
Teff= 5800 K ; logg = 4.40 ; [Fe/H] = -1.0 dex ; χ = 1km/s; [Ca/H] = 0.0 dex ; [Ni/H] = 0.0 dex; R=25000

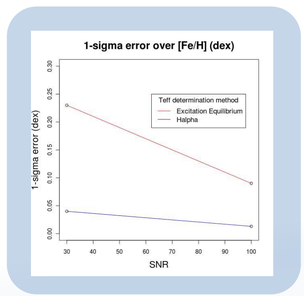
Reference Grid

SYNTHE synthetic spectra calculated from ATLAS models Atlas9

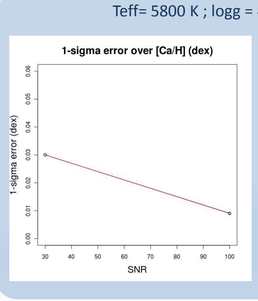
-Teff ϵ [5200,6400] K. Step = 200 K
-log g ϵ [3.40 , 6.40]. Step = 0.5
-[Fe/H] ϵ [-2.0 , 0.5] dex . Step = 0.5 dex
-[Ca/Fe] and [Ni/Fe] ϵ [-1.0,1.0] dex. Step = 0.5 (unidimensional for Teff = 5800 K, logg = 4.40, [Fe/H] = -1.0 dex)
-χ fixed = 1km/s

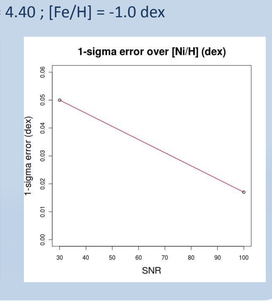






Teff= 5800 K ; logg = 4.40 ; [Fe/H] = -1.0 dex





Performances

-No significant systematic errors
-Using the Hα wings fit method for Teff determination, the precisions on each parameter are:

SNR = 30	SNR = 100
Teff : 31 K logg : 0.14 [Fe/H] : 0.04 dex [Ca/H] : 0.03 dex [Ni/H] : 0.05 dex	Teff : 9K logg : 0.05 [Fe/H] : 0.013 dex [Ca/H] : 0.009 dex [Ni/H] : 0.017 dex

-Using Hα also improves the determination of other parameters . This reflects a correlation between these parameters.
We note that, of course, the Hα 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 Teff determination method can not be used for giant stars for example.