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NIR spectroscopy of the Sun and HD20010

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ABSTRACT

Aims.
Methods.
Results.
Conclusions.

Key words. data reduction: high resolution spectra – data reduction: low resolution spectra – stars individual: HD20010 – stars individual: Sun

1. Introduction

Effective surface temperature ($T_{\rm eff}$), surface gravity ($\log g$), and metallicity ([Fe/H], where iron is used as a proxy) are fundamental atmospheric parameters necessary to characterise a star, as well to determine other inderict fundamental parameters, such as mass, radius, and age from stellar evolutionary models (Girardi et al. 2000).

Precise and accurate stellar parameters are also essential in exoplanet searches. Planetary radius, and mass are found from lightcurve analysis and radial velocity analysis, respectively. These parameters are related to the stellar parameters.

2. The method

Generally speaking there are two methods for determining parameters from a spectrum. One is the spectral synthesis method, where a synthetic spectrum is created and by minimization procedure a best fit is found bewteen the synthetic spectrum and the real spectrum. The stellar parameters are give from the input to the synthetic spectrum.

The other method is the equivalent width (EW) method, which we use in this work. With this method the EW are measured for all lines in a line list. The EW is given as

$$EW = \int_0^\infty \left(1 - \frac{F_\lambda}{F_0}\right) d\lambda, \quad (1)$$

where F_0 is the continuum level and F_λ is is the flux as a function of wavelength. In other words, the EW width is the area from a spectral line up to the normalized continuum level.

With the EW the abundance for individual lines can be found with a code like MOOG[1]. By changing atmospheric parameters as input for MOOG, similar abundances will be achieved for similar elements when the right atmospheric parameters are chosen. Here we use neutral iron and single ionized iron: FeI and FeII, respectively.

A disadvantage for this method, and a general problem with spectroscopy, is the determination of the continuum flux level. Misplacement of the continuum leads to wrong measurements of the EW. Many spectroscopic features make it difficult to determine the continuum. This is especially true for cool stars in the optical where molecular depression and line blending is an issue. By moving the analysis to the NIR, we reduce the molecular depression, and cooler stars line M-dwarfs emit more in this spectral region, why the continuum is at least easier to determine.

We look at the spectral region covered by the J, H, and K bands, which cover a spectral region larger than 15 000 Å.

2.1. Compiling the line list

All iron lines with atomic line data were downloaded from the VALD database[2]. In total 78537 lines were present in the spectral region (both FeI: 50198 and FeII: 28339). Many of these lines to faint to see in a spectrum. To select the lines for the line list a spectrum of the Sun is used downloaded from the BASS2000 web page[3]. The spectrum were downloaded in the highest possible resolution. Since the resolution is not constant the entire spectrum were interpolated to a regular grid with constant wavelength step. The wavelength step in the analysis is 0.01 Å.

After the spectrum is on a regular wavelength grid we measured the EW for all the lines using the ARES software[4](Sousa et al. 2007). This software can measure EW automatically and thus saved us a lot of time. For a given line ARES output the wavelength of the line, the number of lines fitted for the end re-

[1] The MOOG code can be downloaded free at http://www.as.utexas.edu/~chris/moog.html

[2] The VALD database can be found here: http://vald.astro.univie.ac.at/~vald3/php/vald.php

[3] The web page can be found here: bass2000.obspm.fr/solar_spect.php

[4] The ARES software can be found here: http://www.astro.up.pt/~sousasag/ares/

sult, the depth of the line, the FWHM of the line, the EW of the line, and last Gaussians coefficients for the line.

We wort the line list based on the EW and the number of lines fitted for the end result.

- If the number of fitted lines for a given line is higher than 10, this line is rejected because it is believed to be severely blended.
- If the EW is lower than 5 mÅ for a given line, the strength is too low and may be difficult to see in spectra with low S/N or a spectrum with many spectral features.
- If the EW is higher than 200 mÅ for a give line, the strength is too high and non-LTE effects is present in the core of the line, and therefore rejected.
- If the fitted central wavelength is more than 0.05 Å away from the wavelength provided by VALD, the line will also be rejected to avoid false identification.

2.2. Manually removal of lines

At this step we reduced the number of lines to 6060 and 2735 for FeI and FeII respectively. A manual inspection of the lines is necessary at this point in order to sort bad lines. We only removed lines where we were certain they did not belong to either FeI or FeII from our list. The rest were kept as they would appear as outliers later on in the analysis.

For the remaining iron lines, all lines from all elements in a small window where downloaded. Again iron lines were removed from the list, if another element fitted the absorption line better. Some iron lines were marked for further investigation while the rest was kept in the line list.

2.2.1. Synthesis of selected lines

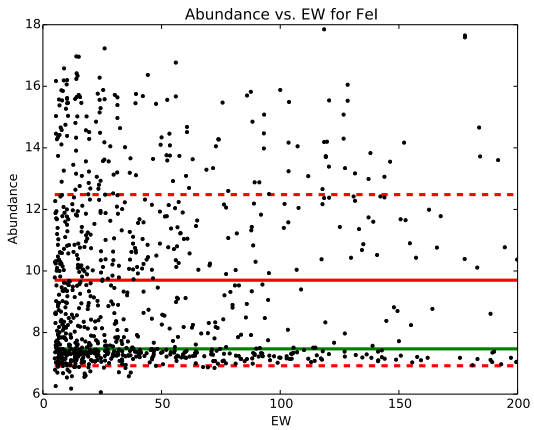

Fig. 1. Here is shown an abundance against EW. All the points a re individual FeI lines. The green line is the Solar abundance, 7.47. The red lines are the mean abundance with the standard deviation. It is clear that we need to recalibrate the line list, so we in the end will measure the same abundance.

2.2.2. Recalibrating the $\log gf$ values

The oscillator strength are know to be notorious difficult to measure or calculate. Even though we have values for $\log gf$ values it is common to recalibrate them for a star we know well (Önehag et al. 2012). For this purpose I use the Sun. The recalibration is done line by line and follows these small steps:

1. Use MOOG to calculate the abundance for a single line with the given data as described in Section **??**.
2. Calculate the difference between the abundance from MOOG with the known abundance for the star, in this case I use 7.47 for the Sun as Gonzalez and Laws (2000).
3. If the difference is not zero, then the $\log gf$ value is changed.

This procedure is done iteratively until we reach convergence.

For finding the zero point, which this problem with recalibrating the $\log gf$ boils down to, I use the bisector method. This method repeatedly bisects an interval and then selects a subinterval in which the root must lie for further processing. The iteration follows this simple steps, where a, b, and c are $\log gf$ values, and the function f is the difference between the abundance from MOOG and the fixed value (in the case of Sun, I use 7.47):

1. The interval is from a to b (by default I set this values to -10 and 10).
2. Calculate the midpoint of the interval $c = (a + b)/2$.[5]
3. If $a - c$ is sufficiently small, i.e. the interval is small, or $f(c)$ is sufficiently small, then return c and stop the iteration.
4. Else the sign of $f(c)$ should be examined. If f have different signs at a and c, then the upper bound (b) should be replaced with the midpoint c. Else the lower bound (a) should be replaced with the midpoint.

In Figure 2 is shown a run with recalibration for a single line. We see how the difference in abundance is converging towards zero, when changing the $\log gf$ value.

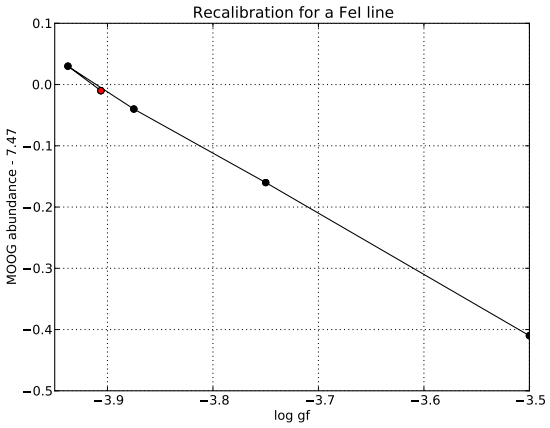

Fig. 2. Here is shown graphically how recalibration of the $\log gf$ works. By changing the $\log gf$ value the difference in abundance, that is the abundance derived from MOOG and the reference abundance, is converging towards zero.

2.3. MOOG

MOOG is best described with a few lines from the website, `www.as.utexas.edu/~chris/moog.html`:

> MOOG is a code that performs a variety of LTE line analysis and spectrum synthesis tasks. The typical use of MOOG is to assist in the determination of the chemical composition of a star.

[5] If $c = 0$ then a small amount (relative to the interval size) is added to c, since the abundance at $\log gf$ gives strange values.

MOOG can perform different task, where I use *abfind*. This task "force-fits abundances of species to yield computed equivalent widths that agree with observed ones previously measured with other software packages."[6]

3. Summary

It is a lengthy process to compile a final good line list for spectral analysis, and with a high possibility to make errors along the way. E.g. the data that was first used from the `vso.nso.edu` was not corrected in radial velocity was used. This was only discovered by an accident after many of the above steps were already taken. Therefore all the steps needed to be done again, after switching to the BASS2000 dataset.

Now the solar spectrum are ready for analysis. All the neutral and first ionized iron lines in a wide wavelength coverage in the NIR have been downloaded from the VALD database. With the lines follows the excitation potential and the oscillator strength. The latter has to be recalibrated for all the lines before an analysis can take place.

Far from all the lines from the VALD database are useful for a spectral analysis in the NIR domain. Therefore many of the lines have been removed following the selection criteria in Section **??**.

3.0.1. The future work

At the moment of writing the next step is to remove "false-positive" lines, which are lines there are found in the VALD database and seems to hit a spectral line, but in reality the spectral line belongs to another element. This step has to be done before recalibrating the $\log gf$ values makes sense. Even though yet another somewhat lengthy process awaits ahead, the recalibration software is ready, as it was already shown in Figure 2.

The recalibration will be done with respect to the Sun, the star we know best. The goal is to characterise M-dwarfs, but since the Sun (G2V by definition, Gray (2005)) is not far away in spectral class, it should be save to use the Sun as a starting point. However, for benchmarking the line list a sample of FGK-dwarfs will be analysed. These stars will have well known stellar parameters in order to test the line list. After the benchmarking some small corrections might be made to the line list, in order to have consistent results.

This will be the final step before the determination of stellar parameters using iron lines in the NIR combined with the equivalent method on M-dwarfs, and the characterisation of this cool planet hosts.

[6] From `http://www.as.utexas.edu/~chris/moog.html`

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