Astronomy & Astrophysics manuscript no. master
August 16, 2016

SWEET-Cat update and MOOGme

A new minimization procedure for high quality spectra

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Received ...; accepted ...

ABSTRACT

Aims.
Methods.
Results.

Key words. data reduction: high resolution spectra – stars individual: Arcturus – stars individual: HD010853

1. Introduction

The study of extrasolar planetary systems is an established field of research. To date, nearly 3500 extrasolar planets have been discovered around almost 2500 solar-type stars[1]. Most of these have been found thanks to the incredible precision achieved in photometric transit and radial velocity methods. The increasing number of exoplanets allows us to do statistical studies of the newfound worlds by analyzing their internal structure, atmospheric composition, and planetary composition.

Precise and accurate planetary parameters (mass, radius, and mean density) are needed to distinguish between solid rocky, water rich, gaseous, or otherwise composed planets. A key aspect to this progress is the characterization of the planet host stars. For instance, precise and accurate stellar radii are critical if we want to measure precise and accurate values of the radius of a transiting planet (see e.g. Torres et al. 2012; Mortier et al. 2013). The determination of the stellar radius is in turn dependent on the quality of the derived stellar atmospheric parameters such as the effective temperature.

We continue the work of Santos et al. (2013) by deriving atmospheric parameters, namely the effective temperature ($T_{\rm eff}$), surface gravity ($\log g$), metallicity ([Fe/H], where iron often is used as a proxy for the total metallicity), and the micro turbulence ($\xi_{\rm micro}$) in a homogeneous way for a sample of planet host stars. This, in turn, allows us to study new correlations between planets and their hosts in a homogeneous way, or gain higher statistical certainty on the already discovered correlations.

The analysis of high quality spectra, i.e. spectra with high spectral resolution and an high signal to noise ratio (SNR), serves an important role in the derivation of stellar atmospheric parameters. Nevertheless, spectral analysis is a time consuming method. There has been an increase of the amount of optical high-resolution spectrographs available and, additionally, a number of near-IR spectrographs are either planned or are already available making the task of analyzing the increasing amount of spectra even more crucial.

In the era of large data sets, computation time has to be decreased as much as possible without compromising the quality of the results. In the light of this we have developed a tool to derive atmospheric parameters in a fast and robust way using standard spectroscopic methods. This works well for optical spectra which we demonstrate in Section 3.4 using the line list from Sousa et al. (2011). This tool also ships with a line list for near-IR spectra using the line list presented recently in Andreasen et al. (2016). The tool is provided to the community as an easy to use web tool to avoid any problems with installations. The tool is described in detail in Section 3.

2. Data

We obtain 43 spectra related to this work by using the UVES (Dekker et al. 2000), FEROS (Kaufer et al. 1999), and FIES (Frandsen & Lindberg 1999) spectrographs. Other how many? spectra were found in various archives. Additionally, we use spectra from HARPS (Mayor et al. 2003) and ESPaDOnS (Donati 2003). Some characteristics of the spectrographs are presented in Table 1 with the mean SNR for the spectra used. The SNR for each star can be seen in Table 4 along with the atmospheric parameters of the stars.

We obtain the spectra with the highest possible resolution for a given spectrograph, and in cases with multiple observations, we include all unless a spectrum is close to the saturation limit for a given spectrograph. For multiple spectra, we combine them after first correcting the radial velocity (RV) and using a sigma clipper to remove cosmic rays. The individual spectra are then combined to a single spectrum for a given star to increase

[1] For an updated table we refer to http://www.exoplanet.eu

the SNR. This single spectrum is used in the analysis below. For most of the spectra in the archive included here, several spectra were combined as described above, while for the observations dedicated to this work, the spectrum would be a single spectrum. This is mostly due to the difference in science cases behind the observations. E.g. the HARPS spectra were used for RV monitoring or follow up of the exoplanet(s).

Table 1. Spectrographs used for this paper with their spectral resolution, wavelength coverage, and typical (mean) SNR from the spectra used.

Spectrograph	Resolution	spectral coverage	Mean SNR
UVES	110 000	420 – 1100 nm	212
FEROS	48 000	350 – 920 nm	208
HARPS	115 000	378 – 691 nm	642
FIES	67 000	370 – 730 nm	763
ESPaDOnS	81 000	370 – 1050 nm	775

3. MOOGme

MOOGme (acronym for MOOG made easy) is a web tool[2] for analyzing spectra. MOOGme is written in Python and works as a wrapper around MOOG (Sneden 1973, version 2014), and ARES (Sousa et al. 2015) for an all-in-one tool. MOOG is a radiative transfer code under the assumption of local thermodynamic equilibrium (LTE). ARES is a tool to automatically measure equivalent widths (EW) from a spectrum given a line list. MOOGme has three different modes: i) Measure EWs using ARES, ii) derive stellar parameters from a set of measured Fe I and Fe II line EWs, and iii) abundances derivation for 15 elements, all described below. The model atmospheres are formatted in a grid of Kurucz Atlas 9 plane-parallel, 1D static model atmospheres Kurucz (1993). MOOGme can also manage the new grid of Atlas models calculated by Mészáros et al. (2012) for the APOGEE survey and the MARCS models (Gustafsson et al. 2008). The interpolation from the grid is calculated from a geometric mean for effective temperature, surface gravity and metallicity.

3.1. EW measurements

The EWs are strongly correlated with the atmospheric parameters. Measurements of the EW can be done manually using a tool like IRAF, but often when dealing with a large sample of stars this is not a suitable way to deal with the task. Therefore tools like ARES exist which can measure the EWs of spectral lines automatically. To use this mode of MOOGme, it just needs a spectrum (format should be 1D fits for ARES to read it) and a line list. For the latter, MOOGme is shipped with some line lists ready to use, in the format suitable for MOOGme. The output will be a line list in the format required for MOOG. The output can be used for either the EW method or the abundance method, both described below.

The line lists shipped with MOOGme are presented in Table **??**. These line lists are all calibrated for the Sun, i.e. the oscillator strengths for each absorption line are changed so the line with the measured EW from a solar spectrum return solar abundance for the given element.

[2] `super-cool-address-with-MOOGme`

Table 2. The line lists provided with MOOGme. The first two line lists are for parameter determination while the last line list is used to derive abundances for 15 different elements.

Line list	Fe I/Fe II	Elements	Usage
Sousa et al. (2008)	263/36	1	Parameters
Tsantaki et al. (2013)	120/17	1	Parameters
Andreasen et al. (2016)		1	Parameters
Neves et al. (2009)	-/-	15	Abundances

3.2. EW method

The standard determination of spectroscopic parameters for solar-type stars starts by measuring the EW of selected and well-defined absorption lines. Then we translate these measurements into individual line abundances, assuming a given atmospheric model. We obtain the correct stellar parameters by imposing excitation and ionization balance for the iron species.

- The effective temperature has a strong influence on the correlation of iron abundance with the excitation potential (excitation balance). We obtain the T_{eff} when Fe I abundance shows no dependence on the excitation potential, i.e., the slope of abundance versus excitation potential is zero.
- Surface gravity is derived from the ionization balance of Fe I and Fe II abundances. Therefore, the abundance of neutral iron should be equal to the abundance of ionized and consistent with the one of the input model atmosphere.
- Microturbulence is connected with the saturation of the stronger iron lines. However, the abundances for weak and strong lines of a certain species (in our case iron) should be the same independent of the value of ξ_{micro}. Iron abundances should show no dependence on the reduced equivalent width, i.e. the slope of abundance vs the reduced EW is zero.

With measured EWs of Fe I and Fe II lines we calculate abundances using a stellar atmosphere model for a given set of atmospheric parameters (T_{eff}, $\log g$, [Fe/H], and ξ_{micro}). By removing correlations between the measured abundances (through the measured EWs) and the excitation potential (EP) and reduced EW ($\log(EW/\lambda)$) we can constrain T_{eff} and ξ_{micro}. By obtaining ionization balance between Fe I and Fe II (that is the average abundance of all Fe I lines are equal to the average abundance of all Fe II lines) we constrain $\log g$. Lastly, we change the input [Fe/H] to match that of the average output [Fe/H]. Hence we have four criteria to minimize simultaneously:

1. The slope between abundance and excitation potential ($a_{\mathrm{EP}} \leq 0.001$).
2. The slope between abundance and reduced EW ($a_{\mathrm{RW}} \leq 0.003$). We use 0.003 rather than 0.001 since this slope varies more rapidly with small changes in atmospheric parameters.
3. The difference between the average abundances of Fe I and Fe II ($\Delta\mathrm{Fe} \leq 0.01$).
4. Input and output metallicity should be equal.

These criteria we denote as indicators for the physical parameters which we are trying to minimize for. We denote this method for obtaining stellar parameters for the EW method.

There exists many minimization routines available in Python. Most commonly known are the ones from the SciPy ecosystem[3]. There are some pros and cons with using proprietary minimization routines. Pros are that it is already written,

[3] `http://scipy.org`

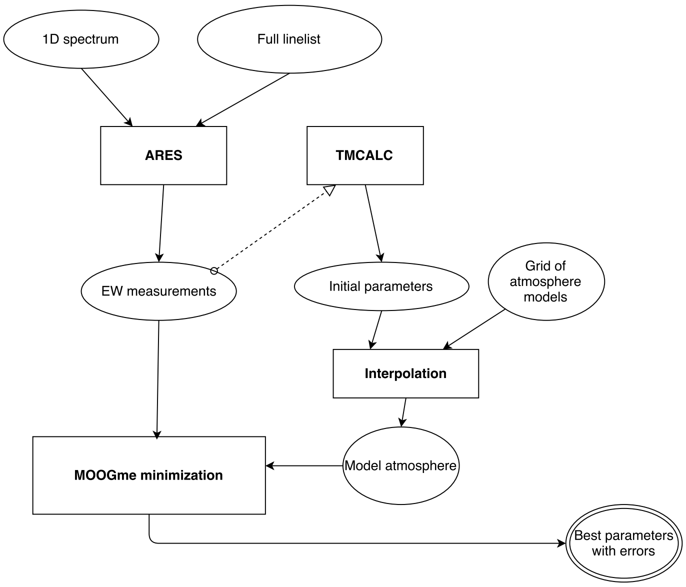

Fig. 1. A general overview over MOOGme from spectrum to parameters.

and usually there is good documentation for libraries such as SciPy. Cons in this situation is, that most minimization routines do not work well with vector functions returning another vector:

$$f(\{T_{\mathrm{eff}}, \log g, [Fe/H], \xi_{\mathrm{micro}}\}) = \{a_{\mathrm{EP}}, a_{\mathrm{RW}}, \Delta\mathrm{Fe}\ , \mathrm{Fe\,I}\}. \tag{1}$$

A work around is to combine the criteria into one single criteria by e.g. adding them quadratically and minimize that expression instead. Thus we have a vector function returning a scalar:

$$f(\{T_{\mathrm{eff}}, \log g, [Fe/H], \xi_{\mathrm{micro}}\}) = \sqrt{a_{\mathrm{EP}}^2 + a_{\mathrm{RW}}^2 + \Delta\mathrm{Fe}^{\ 2}}. \tag{2}$$

The minimization routines are also not physical in the sense that they are not optimized for the problem. These two cons were incitement for writing a minimization routine optimized for the problem at hand. Here is how it works.

1. Run MOOG once with a user defined initial parameters (default is solar) and calculate a_{EP}, a_{RW}, and ΔFe .
2. Change the atmospheric parameters (T_{eff}, $\log g$, [Fe/H], ξ_{micro}) according to the size of the indicator. A parameter is only changed if it is not fixed.
   – a_{EP}: Indicator for T_{eff}. If this value is positive, then increase T_{eff}.
   – a_{RW}: Same as above but for ξ_{micro}.
   – ΔFe : Positive ΔFe means $\log g$ should be decreased and vice versa.
   – For [Fe/H] it is changed to the output [Fe/H] in each iteration.
3. If the new parameters have already been used in a previous iteration, then change them slightly. This is done by drawing a random number from a Gaussian distribution with a mean at the current value and a sigma equal to the absolute value of the indicator.
4. Calculate a new atmospheric model by interpolating a grid so we have the requested parameters and run MOOG once again.
5. For each iteration save the parameters used and the quadratic sum of the indicators. If we do not reach convergence, then return the best found parameters.

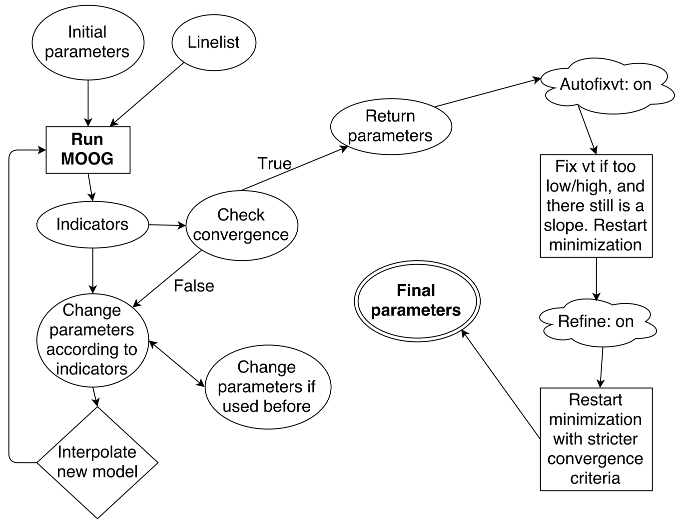

Fig. 2. A schematic overview over the minimization for MOOGme with the EW method.

This whole process is schematically shown in Figure 1 and the minimization routine itself in Figure 2. The stepping follows these simple equations:

$$T_{\mathrm{eff}} \mathrel{+}= 2000\,\mathrm{K}a_{\mathrm{EP}} \tag{3}$$

$$\xi_{\mathrm{micro}} \mathrel{+}= 1.5\,\mathrm{km/s}a_{\mathrm{RW}} \tag{4}$$

$$\log g \mathrel{-}= \Delta\mathrm{Fe}\,. \tag{5}$$

The metallicity is corrected at each step so the input metallicity matches that of the output metallicity of the previous iteration. The functional form for changing the parameters were found by changing one parameter, e.g. T_{eff}, while keeping the other parameters fixed at their convergence values. A linear fit was applied to $T_{\mathrm{eff}} - T_{\mathrm{eff},0}$ vs. a_{EP} in order to get the slope. Since we ignore all interdependencies between the parameters in doing so, we lower the slopes above a little and arrive to these very simple equations.

The error estimates is based on the same method presented in Gonzalez & Laws (2000), which is also described in details in Santos et al. (2003); Andreasen et al. (2016).

By using the indicators like this, we can relative fast reach convergence. Typical calculation time for an FGK dwarf with a high quality spectrum is around 2 min.

3.2.1. Options

It is possible to run the EW method with a set of different options which will be described here.

– *fixteff*: Fix T_{eff} and derive the other parameters. Same is available for $\log g$ (*fixlogg*), [Fe/H] (*fixfeh*), and ξ_{micro} (*fixvt*). One or more parameters can be fixed. When one or more parameters are fixed, the corresponding indicator will be ignored for each iteration, thus the parameter itself will not be changed.
– *outlier*: Remove outliers after the first run with the minimization routine and restarting the minimization from the previous best parameters. The options are to remove all outliers above 3σ once or iteratively, or remove one outlier above 3σ once or iteratively.
– *autofixvt*: If the minimization routine does not converge and ξ_{micro} is close to 0 or 10 with a significant a_{RW} (numerically bigger than 0.05), then fix ξ_{micro}. This option was added since

we saw this behaviour in some cases. The solution was typically to restart the minimization manually with $\xi_{\rm micro}$ fixed.
- *refine*: After the minimization is done, run it again from the best found parameters but with more strict criteria. If this option is set, it will always be the last step (after removal of outliers). The convergence criteria can be changed by the user, but we recommend using the defaults provided above.
- *tmcalc*: Use TMCalc (Sousa et al. 2012) to fast estimate the $T_{\rm eff}$ and [Fe/H] using the raw output from ARES. We then assume solar surface gravity (4.44 dex) and estimate $\xi_{\rm micro}$ based on an empirical relation (see below).

If $\xi_{\rm micro}$ is fixed it is changed at each iteration according to an empirical relation. For dwarfs it follows the one presented in Tsantaki et al. (2013) and for giants it follows the one presented in Adibekyan et al. (2015).

We use the line list presented in Sousa et al. (2008). However, this line list does not work well for cool stars. This was fixed in Tsantaki et al. (2013) by removing some lines from Sousa et al. (2008). For stars cooler than 5200 K we automatically rederive the atmospheric parameters after removing lines so the line list resemble that of Tsantaki et al. (2013).

All restarts of the minimization routine is done with initial condition at the last found best parameters.

3.3. Abundance method

With the line list from Neves et al. (2009) with 15 different elements it is possible to measure abundances for these elements by combining the ARES mode to measure the EWs and the EW method mode to obtain the atmospheric parameters. The abundances are saved to a table.

3.4. Testing MOOGme

To test the EW method implemented in MOOGme we derive parameters from the 582 sample by Sousa et al. (2011). We use ARES2 to measure the EWs. ARES can give an estimate on the signal to noise ratio (SNR) by analyzing the continuum in given intervals. For solar type stars the following intervals are working well: 5764-5766 Å, 6047-6053 Å, and 6068-6076 Å. From the estimated SNR, ARES can give an estimate on the very important *rejt* parameters (see Sousa et al. 2015, for more information). After measuring the EWs with ARES, we use the MOOGme minimization described in Section 3.2 to determine the stellar atmospheric parameters. The results are presented in Figure 3 which shows $T_{\rm eff}$, $\log g$, [Fe/H], and $\xi_{\rm micro}$ for MOOGme against those of Sousa et al. (2011).

The sample contains stars with $T_{\rm eff}$ too cold for the line list used. As described in Section 3.2 we should then convert the line list by Sousa et al. (2008) to the line list presented in Tsantaki et al. (2013). However, since this line list was not available when Sousa et al. (2011) derived parameters, we do not make this change in order to make a better test for MOOGme.

The mean of the difference between parameters from Sousa et al. (2011) and those by MOOGme are presented in Table 3.

We see small offsets that can be due to different versions of MOOG, measured line lists, interpolation of atmosphere grid, and minimization routine. Most likely the difference will be due to different used *rejt* parameters in ARES, which can alter the EWs and hence the parameters. We therefore randomly selected 20 stars with different $T_{\rm eff}$ and used the line lists directly from Sousa et al. (2011) to derive parameters. The results are presented in the last column of Table 3. We note that the $\log gf$ values from the original line lists by Sousa et al. (2011), which used the MOOG 2002 version, were not changed for the 2014 version of MOOG. This might lead to some errors as well. However, the offsets are very small and compatible with the errors on parameters normally obtained from high quality spectra.

Table 3. The difference in derived parameters by Sousa et al. (2011) and MOOGme. Second column is the mean difference with EWs measured by ARES in MOOGme, while the third column is the mean difference using 20 randomly stars with the exact same line list.

Parameter	Mean difference	Same line list
$T_{\rm eff}$	16 ± 36 K	21 ± 11 K
$\log g$	-0.04 ± 0.07	-0.007 ± 0.009
[Fe/H]	0.03 ± 0.02	0.004 ± 0.009
$\xi_{\rm micro}$	-0.04 ± 0.14 km/s	0.04 ± 0.02 km/s

3.5. Web interface

NOTE: More will be written once we have a web page.

We provide a web interface for MOOGme. In the web interface it is possible to use some of the line list provided with MOOGme to measure EWs of a spectrum (has to be provided by the user). This can be used for all the available MOOGme methods described above.

The web interface can be found at the following link `super-cool-address-with-MOOGme`.

4. New spectroscopic parameters for 49 planet hosts

Here we present the sample of 50 stars. We were unable to derive parameters for HD77065. This is a spectroscopic binary according to Pourbaix et al. (2004), and the spectrum is contaminated with the companion star. This make EW measurement very difficult, hence we exclude it from the sample.

The remaining 49 stars are presented in Table 4.

We present a Hertzprung-Russel diagram (HRD) of our sample in Figure 4. Figure 4 is made with a tool for post processing the results saved to a table by MOOGme. We also use isochrones (Morton 2015) to give an estimate of the age. The mass estimation is based on the relation by Torres et al. (2010). The age estimation is dependent on the mass of the star and the metallicity, which can be seen Figure 5.

We present a histogram of $T_{\rm eff}$ and [Fe/H] in discovered with planets, 21% of these stars have been analyzed in the homogeneous way as described in this work. We note that the limiting factor at the moment for increasing the sample of stars analyzed in the homogeneous way is the magnitude of that planet hosts. There have been found many planet hosts with space mission as *Kepler* and *CoRoT* using the transiting method. Most of these stars are faint and thus making them time expensive for the spectroscopic analysis required her.

5. Conclusion

Acknowledgements. This work was supported by Fundação para a Ciência e a Tecnologia (FCT) through the research grants UID/FIS/04434/2013 and PTDC/FIS-AST/1526/2014. N.C.S., and S.G.S. acknowledge the support from FCT through Investigador FCT contracts of reference IF/00169/2012, and IF/00028/2014, respectively, and POPH/FSE (EC) by FEDER funding through the program “Programa Operacional de Factores de Competitividade - COMPETE”. E.D.M. and B.J.A. acknowledge the support from FCT in form of

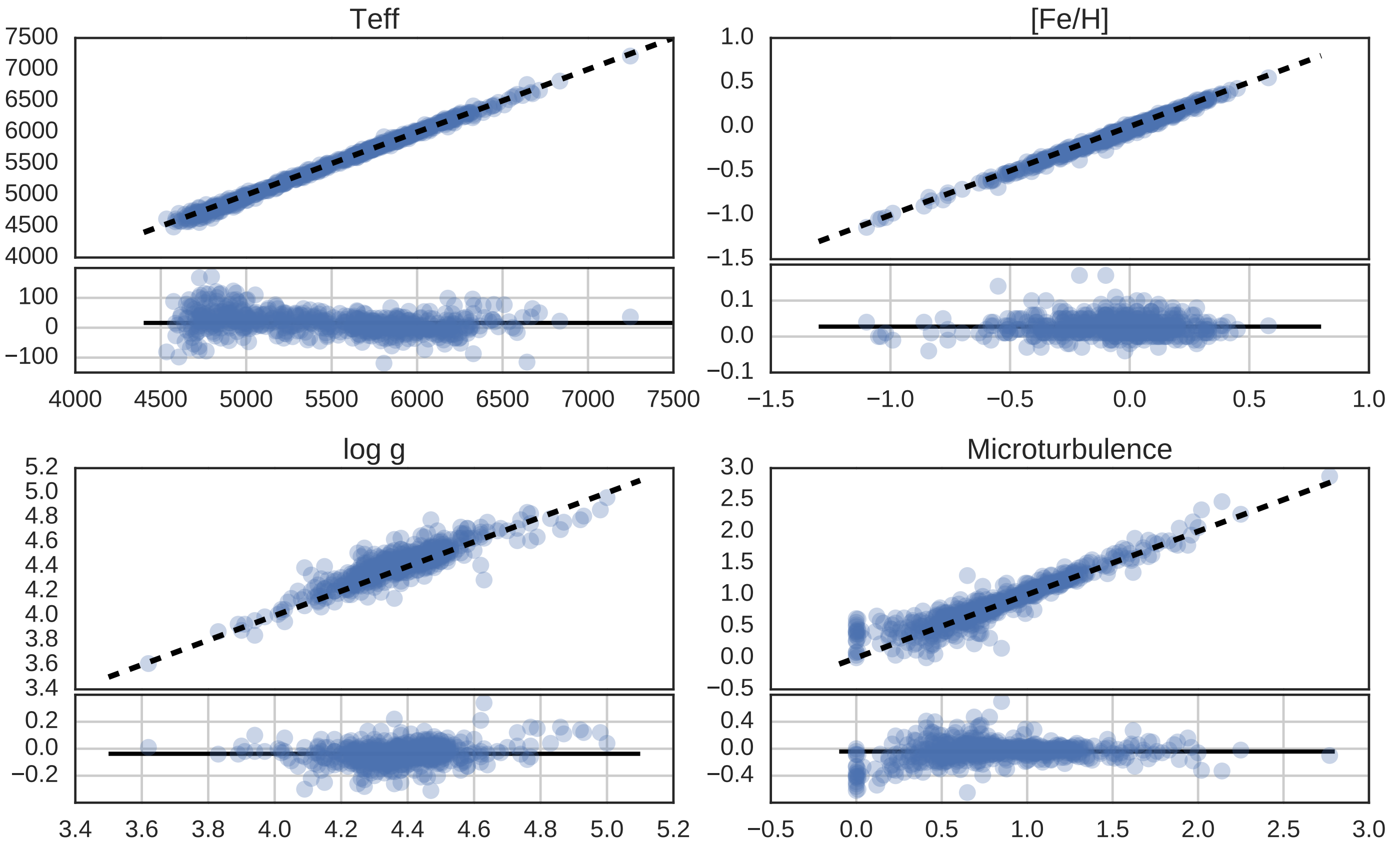

Fig. 3. Stellar atmospheric parameters derived by MOOGme compared to the sample by Sousa et al. (2011).

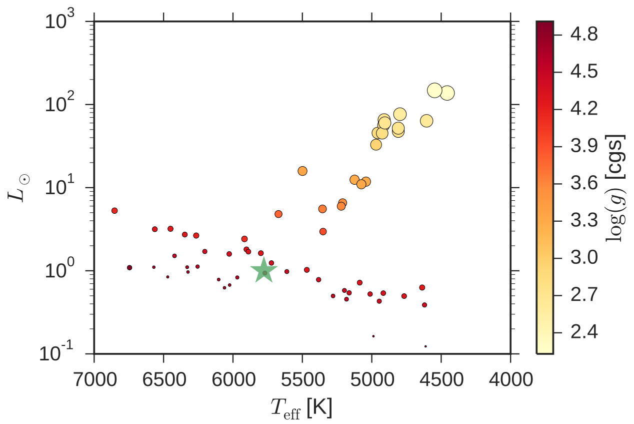

Fig. 4. Hertzprung-Russel diagram of our sample with the Sun as a yellow star. The size of the points represents the $\log g$, with bigger points being smaller $\log g$ (giants), and vice versa. The colour code show the same as the size. Red points are the dwarfs, while blue points are the giants.

the fellowship SFRH/BPD/76606/2011 and SFRH/BPD/87776/2012, respectively. This work also benefit from the collaboration of a cooperation project FCT/CAPES - 2014/2015 (FCT Proc 4.4.1.00 CAPES). AM received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement number 313014 (ETAEARTH). This research has made use of the SIMBAD database operated at CDS, Strasbourg (France).

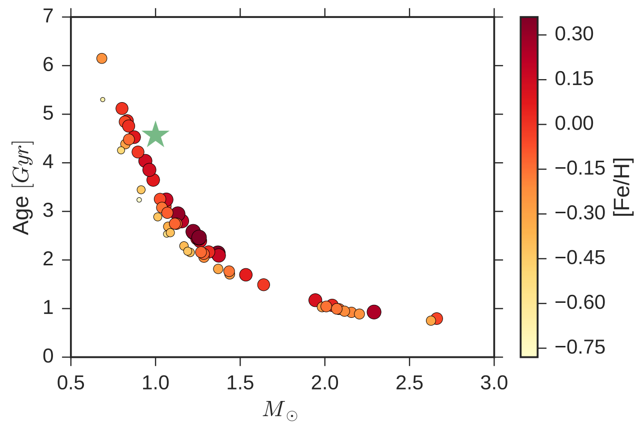

Fig. 5. Age versus mass for our sample, with colours representing the [Fe/H].

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Table 4. The derived parameters for the 49 stars in our sample. The SNR is measured by ARES.

Star	T_{eff} (K)	$\log g$ (dex)	[Fe/H] (dex)	ξ_{micro} (km/s)	ξ_{micro} fixed?	Instrument	SNR
WASP-37	6024 ± 58	4.70 ± 0.06	−0.15 ± 0.05	1.34 ± 0.09	no	FIES	250
WASP-44	5612 ± 80	4.47 ± 0.30	0.17 ± 0.06	1.32 ± 0.13	no	UVES	125
WASP-52	5197 ± 83	4.47 ± 0.30	0.15 ± 0.05	1.16 ± 0.14	no	UVES	125
WASP-58	6103 ± 64	4.68 ± 0.08	−0.10 ± 0.04	1.36 ± 0.11	no	FIES	293
WASP-60	6330 ± 64	4.66 ± 0.09	0.36 ± 0.04	1.61 ± 0.09	no	FIES	315
WASP-61	6265 ± 168	4.21 ± 0.21	−0.38 ± 0.11	1.44 ± 0.02	yes	UVES	163
WASP-72	6570 ± 85	4.71 ± 0.13	0.15 ± 0.06	2.30 ± 0.15	no	UVES	174
WASP-75	6203 ± 46	4.42 ± 0.22	0.24 ± 0.03	1.45 ± 0.06	no	UVES	189
WASP-76	6347 ± 52	4.29 ± 0.08	0.36 ± 0.04	1.73 ± 0.06	no	FEROS	165
WASP-82	6563 ± 55	4.29 ± 0.10	0.18 ± 0.04	1.93 ± 0.08	no	FEROS	239
WASP-88	6450 ± 61	4.24 ± 0.06	0.03 ± 0.04	1.79 ± 0.09	no	FEROS	174
WASP-95	5799 ± 31	4.29 ± 0.05	0.22 ± 0.03	1.18 ± 0.04	no	FEROS	247
WASP-97	5723 ± 52	4.37 ± 0.07	0.31 ± 0.04	1.03 ± 0.08	no	FEROS	219
WASP-99	6324 ± 89	4.70 ± 0.11	0.27 ± 0.06	1.83 ± 0.12	no	FEROS	249
WASP-100	6853 ± 209	4.15 ± 0.26	−0.30 ± 0.12	1.87 ± 0.02	yes	FEROS	166
HATS-1	5969 ± 46	4.61 ± 0.06	−0.04 ± 0.04	1.06 ± 0.08	no	UVES	155
HATS-5	5383 ± 91	4.40 ± 0.22	0.08 ± 0.06	0.91 ± 0.14	no	UVES	158
HAT-P-24	6470 ± 181	4.75 ± 0.26	−0.41 ± 0.10	1.40 ± 0.03	yes	UVES	158
HAT-P-39	6745 ± 236	4.91 ± 0.46	−0.21 ± 0.12	1.53 ± 0.04	yes	UVES	127
HAT-P-42	5903 ± 66	4.29 ± 0.10	0.34 ± 0.05	1.19 ± 0.08	no	UVES	130
HAT-P-46	6421 ± 121	4.53 ± 0.14	0.16 ± 0.09	1.67 ± 0.18	no	UVES	208
HR 228	5042 ± 42	3.30 ± 0.09	0.07 ± 0.03	1.14 ± 0.04	no	UVES	400
SAND364	4457 ± 104	2.26 ± 0.20	−0.04 ± 0.06	1.60 ± 0.11	no	UVES	220
GJ 785	5087 ± 48	4.30 ± 0.10	−0.01 ± 0.03	0.69 ± 0.10	no	HARPS	801
HD 102272	5037 ± 80	2.72 ± 0.25	−0.52 ± 0.08	0.67 ± 0.12	no	FIES	830
*HD 102272	4889 ± 30	2.72 ± 0.07	−0.30 ± 0.02	1.57 ± 0.04	no	FIES	953
HD 104985	4809 ± 48	2.73 ± 0.08	−0.26 ± 0.04	1.65 ± 0.05	no	FIES	1010
HD 114762	6061 ± 83	4.70 ± 0.08	−0.78 ± 0.05	0.02 ± 0.26	no	FIES	1628
*HD 114762	5884 ± 35	4.24 ± 0.04	−0.66 ± 0.02	1.21 ± 0.06	no	FIES	1533
HD 120084	4969 ± 40	2.94 ± 0.14	0.12 ± 0.03	1.41 ± 0.04	no	ESPaDOnS	852
HD 152581	5355 ± 82	3.65 ± 0.18	−0.39 ± 0.07	0.60 ± 0.15	no	UVES	692
HD 155358	5917 ± 51	4.12 ± 0.08	−0.55 ± 0.04	1.06 ± 0.08	no	FIES	888
HD 171028	5672 ± 29	3.80 ± 0.04	−0.42 ± 0.02	1.24 ± 0.04	no	FIES	1194
HD 192263	4946 ± 46	4.43 ± 0.14	−0.05 ± 0.02	0.66 ± 0.12	no	HARPS	415
HD 192699	5210 ± 27	3.56 ± 0.09	−0.12 ± 0.02	1.19 ± 0.03	no	FIES	781
HD 197037	6255 ± 44	4.58 ± 0.04	−0.12 ± 0.03	1.27 ± 0.06	no	FIES	1083
HD 2200964	5075 ± 28	3.32 ± 0.07	−0.16 ± 0.02	1.18 ± 0.03	no	FIES	1073
HD 220842	6027 ± 30	4.35 ± 0.05	−0.08 ± 0.03	1.19 ± 0.04	no	FIES	197
HD 219134	4767 ± 70	4.32 ± 0.17	−0.00 ± 0.04	0.59 ± 0.24	no	ESPaDOnS	725
HD 233604	4925 ± 44	2.79 ± 0.11	−0.15 ± 0.03	1.62 ± 0.05	no	FIES	320
*HD 233604	4926 ± 41	2.79 ± 0.10	−0.15 ± 0.03	1.62 ± 0.05	no	FIES	320
HD 283668	4988 ± 45	4.82 ± 0.10	−0.68 ± 0.03	0.34 ± 0.02	yes	FIES	709
HD 285507	4620 ± 126	4.42 ± 0.61	0.04 ± 0.06	0.74 ± 0.43	no	FIES	239
HD 37124	5468 ± 32	4.28 ± 0.04	−0.43 ± 0.03	0.67 ± 0.07	no	FIES	991
*HD 37124	5470 ± 32	4.28 ± 0.04	−0.43 ± 0.03	0.67 ± 0.07	no	FIES	991
HD 5583	4980 ± 35	2.76 ± 0.06	−0.36 ± 0.04	1.59 ± 0.04	no	FIES	936
HD 70573	5889 ± 186	4.32 ± 0.27	−0.42 ± 0.13	1.14 ± 0.01	yes	FIES	487
HD 81688	4906 ± 29	2.69 ± 0.06	−0.21 ± 0.02	1.60 ± 0.03	no	ESPaDOnS	1019
*HD 81688	4913 ± 29	2.64 ± 0.07	−0.21 ± 0.02	1.57 ± 0.03	no	FIES	1253
HD 82886	5124 ± 22	3.30 ± 0.05	−0.25 ± 0.02	1.15 ± 0.03	no	ESPaDOnS	1198
*HD 82886	5137 ± 36	3.35 ± 0.08	−0.23 ± 0.03	1.19 ± 0.04	no	FIES	1229
HD 87883	4917 ± 68	4.34 ± 0.19	0.02 ± 0.03	0.46 ± 0.21	no	ESPaDOnS	753
HD 96063	5220 ± 35	3.59 ± 0.08	−0.13 ± 0.03	1.20 ± 0.04	no	FIES	644
HD 97658	5182 ± 43	4.50 ± 0.12	−0.29 ± 0.03	0.77 ± 0.11	no	FIES	1001
HIP 11915	5770 ± 14	4.47 ± 0.03	−0.06 ± 0.01	0.95 ± 0.02	no	HARPS	709
HIP 116454	5012 ± 83	4.38 ± 0.16	−0.13 ± 0.04	0.78 ± 0.15	no	FIES	316
HIP 107773	4957 ± 49	2.83 ± 0.09	0.04 ± 0.04	1.49 ± 0.05	no	UVES	218
mu Leo	4605 ± 94	2.61 ± 0.26	0.25 ± 0.06	1.64 ± 0.11	no	ESPaDOnS	354
omi UMa	5499 ± 52	3.36 ± 0.07	−0.01 ± 0.05	1.98 ± 0.06	no	ESPaDOnS	527
11 Com	4911 ± 38	2.68 ± 0.08	−0.20 ± 0.03	1.56 ± 0.04	no	FIES	953
*11 Com	4907 ± 34	2.62 ± 0.09	−0.23 ± 0.03	1.56 ± 0.04	no	FIES	1191
omi CrB	4915 ± 33	2.74 ± 0.08	−0.14 ± 0.03	1.57 ± 0.04	no	FIES	932
42 Dra	4547 ± 55	2.23 ± 0.10	−0.31 ± 0.03	1.54 ± 0.05	no	FIES	569
14 And	4797 ± 44	2.58 ± 0.11	−0.23 ± 0.03	1.58 ± 0.04	no	FIES	731
Kepler-444	5163 ± 40	4.41 ± 0.11	−0.50 ± 0.03	0.78 ± 0.10	no	FIES	675
Qatar-2	4637 ± 316	4.23 ± 0.61	0.09 ± 0.17	0.63 ± 0.83	no	UVES	97
bd114672	4612 ± 86	4.83 ± 0.30	−0.23 ± 0.02	0.08 ± 0.08	yes	FIES	487
ksiaql	4809 ± 46	2.71 ± 0.11	−0.16 ± 0.03	1.55 ± 0.04	no	FIES	994
tyc	4886 ± 41	2.74 ± 0.08	−0.09 ± 0.03	1.56 ± 0.05	no	FIES	505