

# SWEET-Cat update and FASMA

## A new minimization procedure for stellar parameters using high quality spectra\*

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### ABSTRACT

**Context.** Thanks to the importance that the star-planet relation has to our understanding of the planet formation process, the precise determination of stellar parameters for the ever increasing number of discovered extra-solar planets is of great relevance. Furthermore, precise stellar parameters are needed to fully characterise the planet properties. It is thus important to continue the efforts to determine, in the most uniform way possible, the parameters for stars with planets as new discoveries are announced.

**Aims.** In this paper we present new precise atmospheric parameters for a sample of 50 stars with planets. The results are presented in the catalogue: SWEET-Cat.

**Methods.** Stellar atmospheric parameters and masses for the 50 stars were derived assuming local thermodynamic equilibrium (LTE) and using high-resolution and high signal-to-noise spectra. The methodology used is based on the measurement of equivalent widths for a list of iron lines and making use of iron ionization and excitation equilibrium principles. For the catalogue, and whenever possible, we used parameters derived in previous works published by our team, using well-defined methodologies for the derivation of stellar atmospheric parameters.

**Results.** The stellar parameters for the 50 stars are presented and compared with previously determined literature values. For the catalogue, we compile values for the effective temperature, surface gravity, metallicity, and stellar mass for almost all the planet host stars listed in the Extrasolar Planets Encyclopaedia. This data will be updated on a continuous basis. The compiled catalogue is available online. The data can be used for statistical studies of the star-planet correlation, as well as for the derivation of consistent properties for known planets.

**Key words.** planetary systems – stars: solar-type – catalogs

## 1. Introduction

The study of extrasolar planetary systems is an established field of research. To date, more than 3500 extrasolar planets have been discovered around more than 2500 solar-type stars<sup>1</sup>. Most of these have been found thanks to the incredible precision achieved in photometric transit and radial velocity methods. Not only do we have intriguing new types of planetary systems that challenge current theories but also the increasing number of exoplanets allow us to do statistical studies of the newfound worlds by analyzing their atmospheric composition, internal structure, 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 characterisation 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 ( $T_{\text{eff}}$ ), surface gravity ( $\log g$ ), metallicity ( $[\text{Fe}/\text{H}]$ , where iron often is used as a proxy for the total metallicity), and the micro turbulence ( $\xi_{\text{micro}}$ ) 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 a high signal to noise ratio (SNR), plays 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 num-

\* Based on observations collected at the La Silla Observatory, ESO (Chile), with FEROS/2.2m (run 2014B/020), with UVES/VLT at the Cerro Paranal Observatory (runs ID 092.C-0695, 093.C-0219, 094.C-0367, 095.C-0324, and 096.C-0092), and with FIES/NOT at Roque de los Muchachos (Spain) (runs ID 14AF14 and 53-202).

<sup>1</sup> For an updated table we refer to <http://www.exoplanet.eu>

ber 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, FASMA, to derive atmospheric parameters in a fast and robust way using standard spectroscopic methods. We made this tool available as a web interface at <http://www.astro.up.pt/resources/fasma/>. This works well for optical spectra which we demonstrate in Section 2.4 using the line list from Sousa et al. (2008) and Tsantaki et al. (2013). 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 2. In Section 3.2 we present the new parameters for SWEET-Cat.

## 2. FASMA

FASMA (acronym for Fast Analysis of Spectra Made Automatically) is a web tool<sup>2</sup> for analyzing spectra. FASMA is written in Python and works as a wrapper around ARES2 (Sousa et al. 2015) (hereafter just ARES) and MOOG (Sneden 1973, version 2014), for an all-in-one tool. ARES is a tool to automatically measure equivalent widths (EW) from a spectrum given a line list. MOOG is a radiative transfer code under the assumption of local thermodynamic equilibrium (LTE).

FASMA has three different drivers: i) Measure EWs using ARES, ii) derive stellar parameters from a set of measured Fe I and Fe II line EWs, and iii) abundance 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). FASMA 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.

### 2.1. EW measurements

The EWs are strongly correlated with the atmospheric parameters. Measurements of the EW can be done manually using a tool like *splot* in IRAF, but often when dealing with a large sample of stars this is not a suitable way to deal with the task. Therefore, several tools like ARES exist which can measure the EWs of spectral lines automatically. To use this mode of FASMA a line list<sup>3</sup> and a spectrum (the format should be 1D fits for ARES to read it) are needed. FASMA is shipped with some line lists ready to use. The output will be a line list with the newly measured EWs in the format required for MOOG. The output can be used for either stellar parameter derivation or the abundance method, both described below.

The line lists shipped with FASMA are presented in Table 1. 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.

**Table 1.** The line lists provided with FASMA. The first three 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)	249/5	1	Parameters
Neves et al. (2009)	-/-	15	Abundances

### 2.2. Stellar parameter derivation

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  $T_{\text{eff}}$  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  $\xi_{\text{micro}}$ . Iron abundances should show no dependence on the reduced EW, i.e. the slope of abundance vs. the reduced EW is zero.

Lastly, we change the input  $[\text{Fe}/\text{H}]$  to match that of the average output  $[\text{Fe}/\text{H}]$ . Hence we have four criteria to minimize simultaneously:

1. The slope between abundance and excitation potential ( $a_{\text{EP}}$ ) has to be lower than 0.001.
2. The slope between abundance and reduced EW ( $a_{\text{RW}}$ ) has to be lower than 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 ( $\Delta\text{Fe}$ ) should be less than 0.01.
4. Input and output metallicity should be equal.

These criteria are denoted as indicators for the physical parameters we are trying to minimize.

There exist many minimization routines available in Python. The ones from the SciPy ecosystem<sup>4</sup> are the most commonly known. There are some advantages and disadvantages using proprietary minimization routines. Advantages are that it is already written, and usually there is good documentation for libraries such as SciPy. Disadvantages in this situation is, that most minimization routines do not work well with vector functions returning another vector:

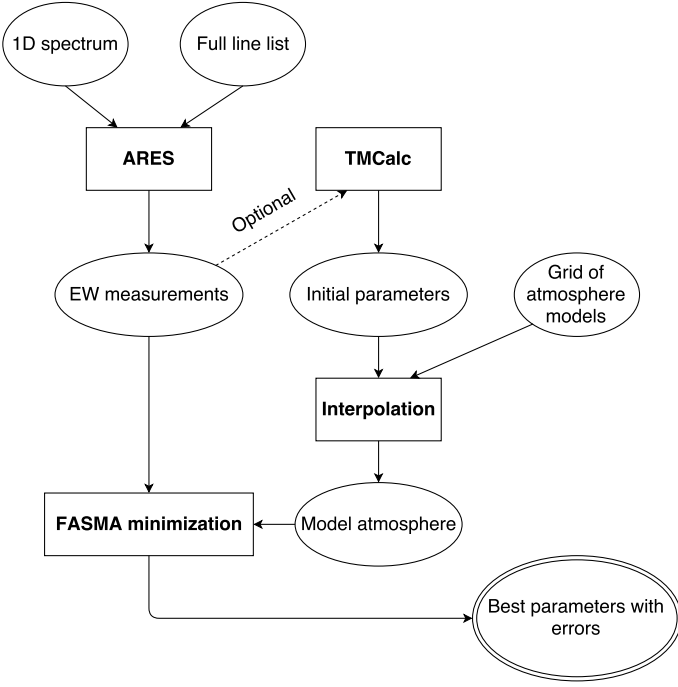
$$f(\{T_{\text{eff}}, \log g, [\text{Fe}/\text{H}], \xi_{\text{micro}}\}) = \{a_{\text{EP}}, a_{\text{RW}}, \Delta\text{Fe}, \text{Fe I}\}. \quad (1)$$

A work around this is to combine the criteria into one single criterion by e.g. adding them quadratically and minimize that

<sup>4</sup> <http://scipy.org>

<sup>2</sup> <http://www.astro.up.pt/resources/fasma/>

<sup>3</sup> ARES does in principle just need a list of wavelengths in order to run, but is often used with a line list with characteristics of the atomic absorption line.



**Fig. 1.** A general overview over FASMA from spectrum to parameters.

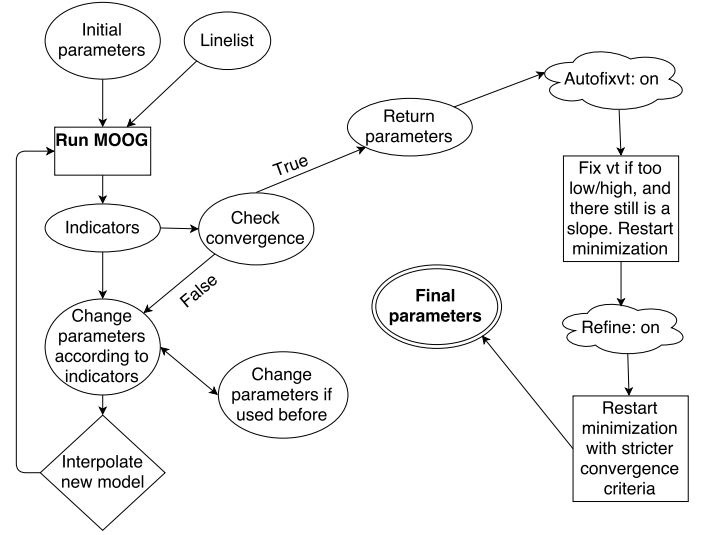
expression instead. Thus we have a vector function returning a scalar:

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

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

1. Run MOOG once with user defined initial parameters (default is solar) and calculate  $a_{\text{EP}}$ ,  $a_{\text{RW}}$ , and  $\Delta\text{Fe}$ .
2. Change the atmospheric parameters ( $T_{\text{eff}}$ ,  $\log g$ ,  $[\text{Fe}/\text{H}]$ ,  $\xi_{\text{micro}}$ ) according to the size of the indicator. A parameter is only changed if it is not fixed.
  - $a_{\text{EP}}$ : Indicator for  $T_{\text{eff}}$ . If this value is positive, then increase  $T_{\text{eff}}$ .
  - $a_{\text{RW}}$ : Same as above but for  $\xi_{\text{micro}}$ .
  - $\Delta\text{Fe}$ : Positive  $\Delta\text{Fe}$  means  $\log g$  should be decreased and vice versa.
  - $[\text{Fe}/\text{H}]$  is changed to the output  $[\text{Fe}/\text{H}]$  in each iteration.
3. If the new set of 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 of models 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.

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



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

these simple equations:

$$T_{\text{eff}} += 2000 \text{ K} \cdot a_{\text{EP}} \quad (3)$$

$$\xi_{\text{micro}} += 1.5 \text{ km/s} \cdot a_{\text{RW}} \quad (4)$$

$$\log g -= \Delta\text{Fe} \quad (5)$$

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.  $T_{\text{eff}}$ , while keeping the other parameters fixed at their convergence values. A linear fit was applied to  $T_{\text{eff}} - T_{\text{eff},0}$  vs.  $a_{\text{EP}}$  in order to get the slope. Since we ignore all interdependencies between the parameters, we lower the slopes found a little and arrived to the very simple equations above.

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

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

### 2.2.1. Options

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

- *fixteff*: Fix  $T_{\text{eff}}$  and derive the other parameters. Same is available for  $\log g$  (*fixlogg*),  $[\text{Fe}/\text{H}]$  (*fixfeh*), and  $\xi_{\text{micro}}$  (*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 a spectral line(s) after the the minimization is done, if the abundance of this spectral line is more than  $3\sigma$  away from the average abundance of all the lines. After the removal of outlier(s) the minimization routine restarts. The options are to remove all outliers above  $3\sigma$  once or iteratively, or remove one outlier above  $3\sigma$  once or iteratively.
- *autofixvt*: If the minimization routine does not converge and  $\xi_{\text{micro}}$  is close to 0 or 10 with a significant  $a_{\text{RW}}$  (numerically bigger than 0.05), then fix  $\xi_{\text{micro}}$ . This option was added since

we saw this behaviour in some cases. The solution was typically to restart the minimization manually with  $\xi_{\text{micro}}$  fixed. If  $\xi_{\text{micro}}$  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. (2015b).

- *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.
- *tmcaltc*: Use TMCaltc (Sousa et al. 2012) to fast estimate the  $T_{\text{eff}}$  and  $[\text{Fe}/\text{H}]$  using the raw output from ARES. We then assume solar surface gravity (4.44 dex) and estimate  $\xi_{\text{micro}}$  based on an empirical relation (see above).

For the optical 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). The line list for the NIR is also available (Andreasen et al. 2016).

All restarts of the minimization routine are done at the last found best parameters as initial conditions.

### 2.3. Abundance method

FASMA calculates element abundances for 12 different elements (Na, Mg, Al, Si, Ca, Ti, Cr, Ni, Co, Sc, Mn, and V) from spectral lines determined in Neves et al. (2009) and Adibekyan et al. (2012). It also includes three ionized elements: Cr II, Sc II, and Ti II. The atomic data were calibrated with the Sun as reference and solar abundances from Anders & Grevesse (1989). The EWs are measured automatically with the ARES driver of FASMA. The element abundance of each line is derived using the atmospheric parameters of the stars obtained from the previous step. The final element abundance is calculated from the weighted mean of the abundances produced by all lines detected for a given element as described in Adibekyan et al. (2015a).

### 2.4. Testing FASMA

To test the derivation of stellar parameters implemented in FASMA we derive parameters from the 582 sample by Sousa et al. (2011). We use ARES to measure the EWs. ARES can give an estimate on the SNR by analyzing the continuum in certain 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 FASMA minimization routine described in Section 2.2 to determine the stellar atmospheric parameters. The results are presented in Figure 3 which shows  $T_{\text{eff}}$ ,  $\log g$ ,  $[\text{Fe}/\text{H}]$ , and  $\xi_{\text{micro}}$  for FASMA against those of Sousa et al. (2011).

The sample contains stars with  $T_{\text{eff}}$  too cold for the line list used. As described in Section 2.2 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 fair comparison for FASMA.

The mean of the difference between parameters from Sousa et al. (2011) and those by FASMA are presented in Table 2.

**Table 2.** The difference in derived parameters by Sousa et al. (2011) and FASMA. Second column is the mean difference with EWs measured by ARES in FASMA, while the third column is the mean difference using 20 randomly stars with the exact same EWs from Sousa et al. (2011).

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

The comparison is very consistent as expected and the small offsets are within the errors except for metallicity. This 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 systematically and hence the metallicity. We therefore randomly selected 20 stars with different  $T_{\text{eff}}$  and used the EWs directly from Sousa et al. (2011) to derive parameters. The results are presented in the last column of Table 2. 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.

### 2.5. Web interface

We provide a web interface for FASMA. In the web interface it is possible to use some of the line list provided with FASMA to measure EWs of a spectrum. The spectrum is expected to be in a 1D format with the wavelength information stored in the header keys, CRVAL1 for the minimum wavelength, CDEL1 for the stepping in wavelengths, and NAXIS1 for the number of points. This can be used for all the available FASMA methods described above. ARES does the normalization, but best results are found when the spectrum is properly reduced (removal of cosmic rays, normalized, etc.).

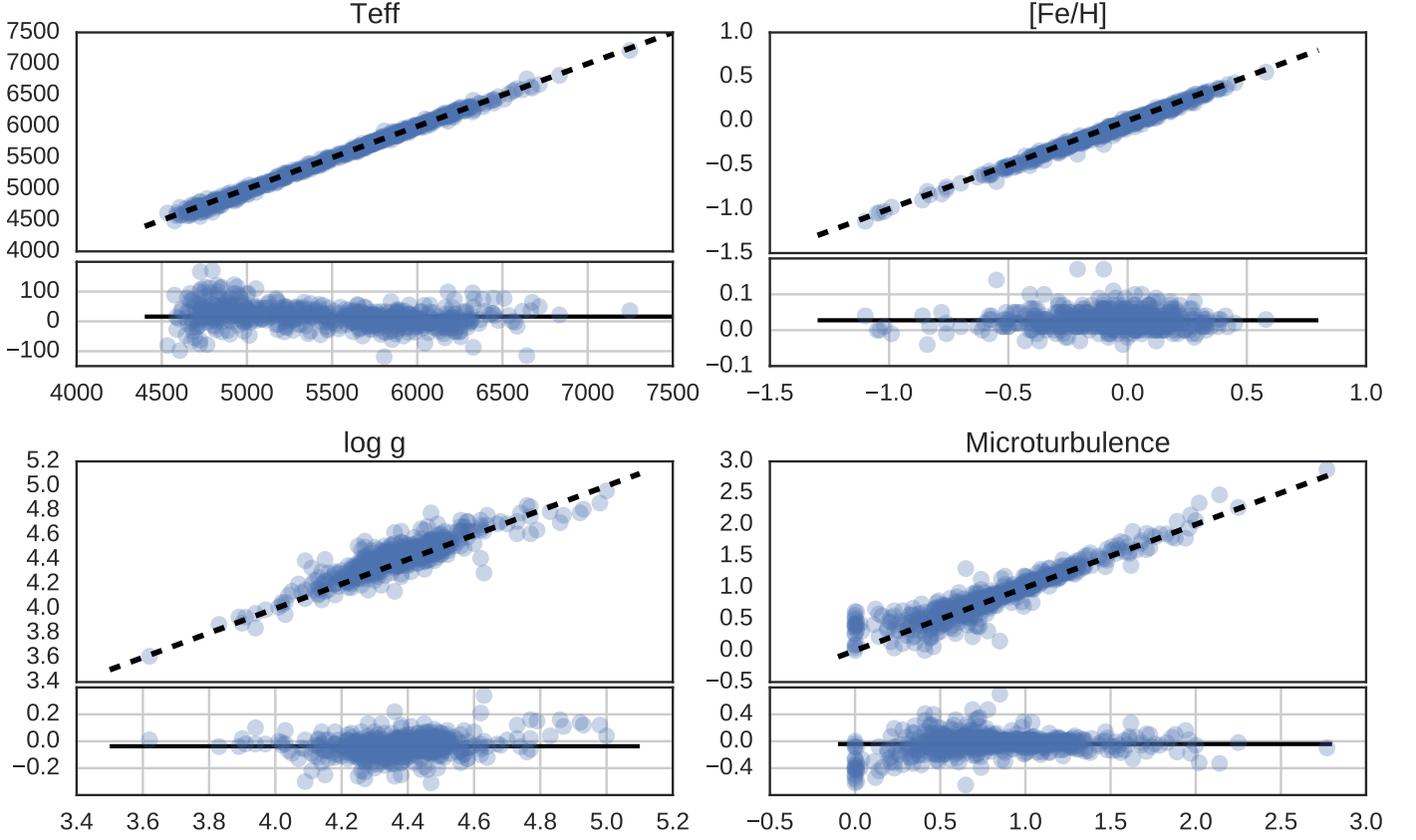
The web interface can be found at the following link <http://www.astro.up.pt/resources/fasma/>, where more information are available on each of the driver.

## 3. SWEET-Cat update

### 3.1. Data

In this paper we derived parameters for a sample of 50 stars, 43 were observed by our team using the UVES/VLT (Dekker et al. 2000), FEROS/2.2m telescope in La Silla (Kaufer et al. 1999), and FIES/NOT (Frandsen & Lindberg 1999) spectrographs. The rest (23) spectra were found in various archives. We use spectra from HARPS/3.6m telescope in La Silla (Mayor et al. 2003) and ESPaDOnS/CFHT (Donati 2003). Some characteristics of the spectrographs are presented in Table 3 with the mean SNR for the spectra used. The SNR for each star can be seen in Table A.1 along with the atmospheric parameters of the stars. The SNR is measured automatically by ARES, but we note that ARES smooth the spectra before measuring the SNR, hence it is listed higher than the actual SNR.

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



**Fig. 3.** Stellar atmospheric parameters derived by FASMA compared to the sample by Sousa et al. (2011). The x-axis in all plots show the results from FASMA while the y-axis is the parameters derived by Sousa et al. (2011).

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 the SNR. This single spectrum is used in the analysis described 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, or in cases of faint stars, it would be observed a few times to reach the desired SNR. 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), while the UVES spectra were used for characterisation of stellar parameters.

**Table 3.** Spectrographs used for this paper with their spectral resolution, wavelength coverage, and mean SNR from the spectra used.

Spectrograph	Resolution	Spectral range	Mean SNR
HARPS	115 000	378 – 691 nm	642
UVES	110 000	480 – 1100 nm	212
ESPaDOnS	81 000	370 – 1050 nm	775
FIES	67 000	370 – 730 nm	763
FEROS	48 000	350 – 920 nm	208

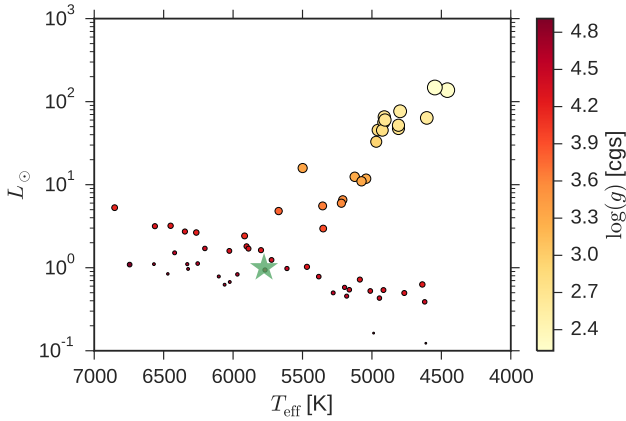
### 3.2. Analysis

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

Moreover we were not able to successfully derive parameters with this method for Aldebaran, a well known red giant star. Even though spectra of good quality are available for a bright star like Aldebaran, this spectral type is intrinsically difficult to analyse due to the molecular absorption that arises in the optical region at low  $T_{\text{eff}}$ . The fact that we are not able to derive parameters for Aldebaran is not a big concern, since it is well studied with other techniques, and we can trust the parameters already listed in SWEET-Cat.

Finally, we also removed 19 stars from our sample since the parameters for these stars did not converge during the minimization procedure. The  $T_{\text{eff}}$  for these stars is either too hot or too cold for the EW method to work.

The remaining 50 stars are presented in Table A.1. Note that we apply a correction to the spectroscopic  $\log g$  based on asteroseismology as found by Mortier et al. (2014). We only use this correction for FGK dwarf stars, i.e. between  $4800 \text{ K} \leq T_{\text{eff}} \leq 6500 \text{ K}$  and  $\log g \geq 4.2$ . For stars with a  $\log g$  lower than this limit we do not apply the corrections, and if the  $\log g$  change



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

to below this limit after the correction, we go back to use the spectroscopic  $\log g$  again.

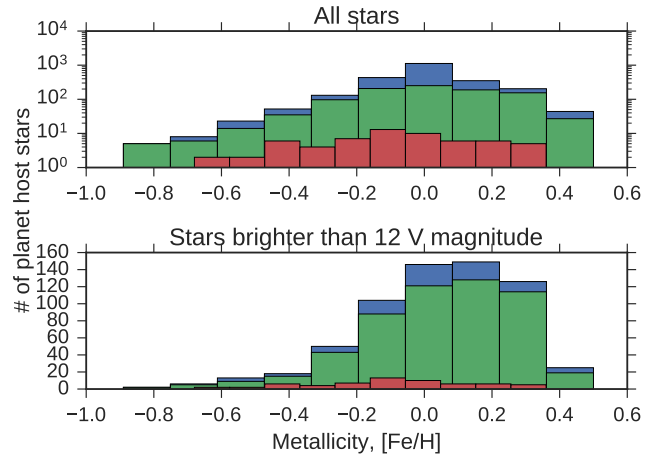
We present a Hertzsprung-Russell diagram (HRD) of our sample in Figure 4, which is made with a tool for post processing the results saved to a table by FASMA.

The new atmospheric parameters are presented in Figure 5 against the literature values we listed previously in SWEET-Cat. The old parameters are listed in Table A.3. Among 2461 stars discovered to be planet hosts, 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 the planet hosts. There have been found many planet hosts with space missions as *Kepler* and *CoRoT* using the transiting method. Most of these stars are faint and thus making them observationally expensive for the spectroscopic analysis required here. For stars brighter than magnitude 12 the completeness, i.e. the stars analyzed in a homogeneous way compared to the ones we did not analyze yet, is up to 77% now while it is at 85% for exoplanet hosts brighter than magnitude 10.

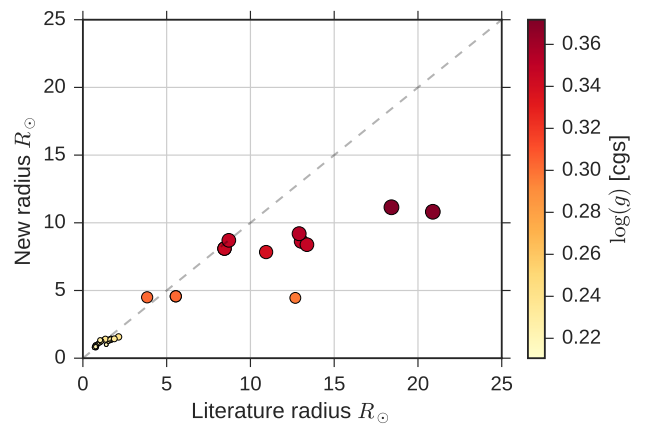
The metallicity distribution for all the planet host stars is important to understand e.g. planet formation. We present a distribution in Figure 6. The sample is divided in two, for all planet hosts in SWEET-Cat, and for stars brighter than 12 V magnitude. Stars dimmer are mainly observed with the *Kepler* space mission. These dim stars are very time consuming, and hence expensive to observe.

### 3.3. Discussion

We compute radius and mass of all stars (even the ones whose parameters may not be reliable, in order to be complete) using the empirical formula presented in Torres et al. (2010). Some of the stars have radius derived from different methods and generally show a good correlation with radius derived from Torres et al. (2010) if the literature parameters of  $T_{\text{eff}}$ ,  $\log g$ , and  $[\text{Fe}/\text{H}]$  are used. However, if we compare with the new radius derived using the parameters presented here the results can differ up to 65%. We show in Figure 7 how the radius calculated from Torres et al. (2010) differ between the literature atmospheric parameters and the new homogeneous atmospheric parameters pre-



**Fig. 6.** The metallicity distribution. In the *upper* plot we see all stars (logarithmic scale) in SWEET-Cat, divided in three. Blue (the largest distribution) are all stars available in SWEET-Cat, green (the middle distribution) are the stars with homogeneity flag 1, i.e. analyzed using the method described in this paper, red (the smallest distribution) are all new stars added from this paper. The *lower* plot shows a 12 V magnitude cut to exclude stars which are currently unavailable spectroscopically.

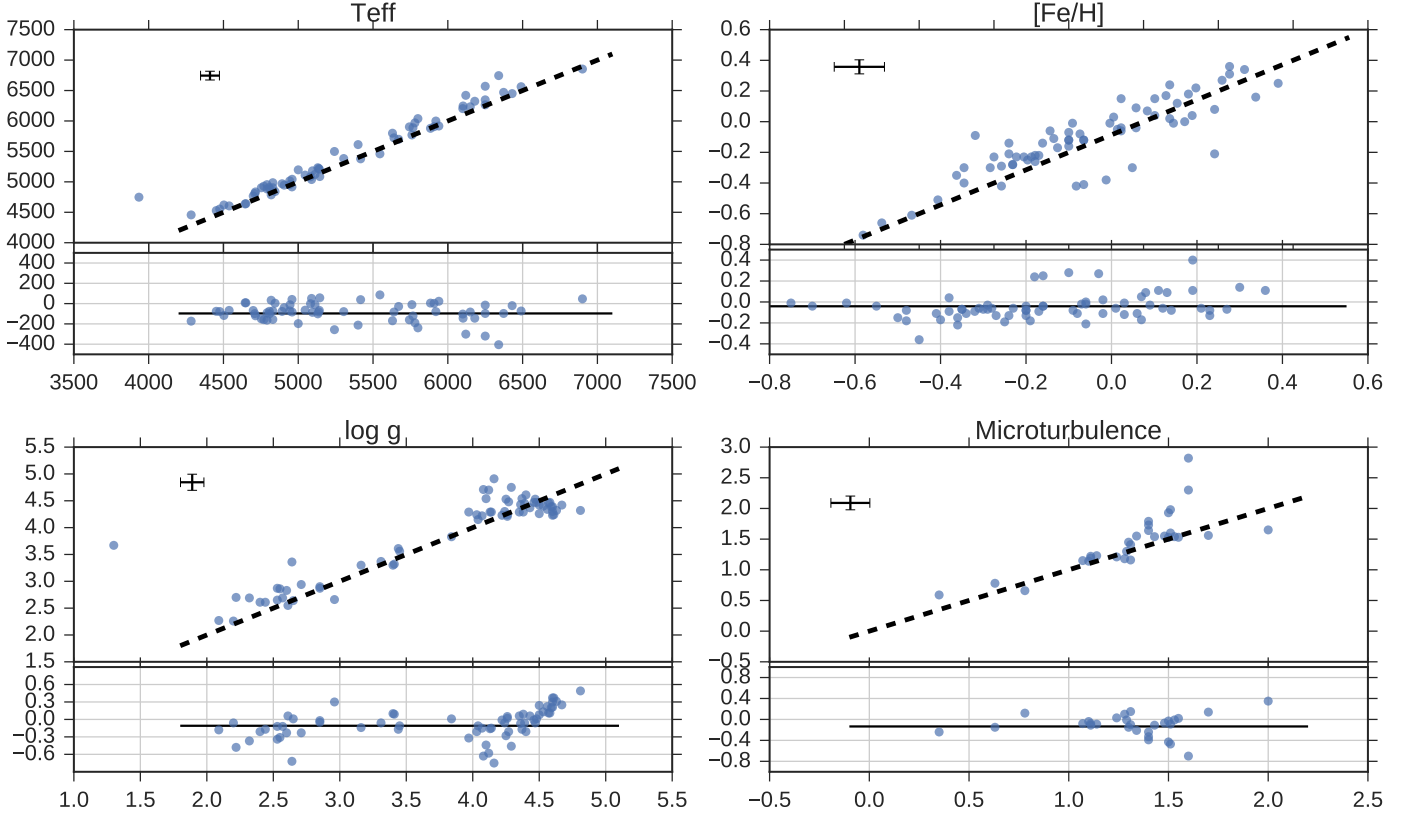


**Fig. 7.** The stellar radius on both axes calculated based on Torres et al. (2010). For the x-axis we show the stellar radius based on the atmospheric parameters from the literature, while the y-axis is from the new homogeneous parameters presented here. The colour and size present the surface gravity. This clearly shows that the disagreement is biggest for more evolved stars.

sented here. We note that stellar radii are provided by many of the authors from different discovery papers, but we chose to compare the atmospheric parameters via the derivation of the stellar radius as described above, rather than compare the stellar radii from different methods.

Below we discuss the systems (seven stars, eight exoplanets) where the radius or mass of the stars changes more than 25% and how this influences the planetary parameters. The changes in radius for a star are primarily due to changes in  $\log g$ , which can be used as an indicator of the evolutionary stage of a star.

We rederive the planetary radius, mass and semi-major axis when possible following the three simple relations:



**Fig. 5.** Atmospheric parameters of the updated planet host stars. The x-axis are the previous values in SWEET-Cat (see Table A.3), while the y-axis is the new updated values. In the upper left corner of each of the four plots we show the typical error on the parameters.

$$M_{\text{pl,new}} = \left( \frac{M_{*,\text{lit}}}{M_{*,\text{new}}} \right)^{-2/3} M_{\text{pl,lit}} \quad (6)$$

$$R_{\text{pl,new}} = \left( \frac{R_{*,\text{lit}}}{R_{*,\text{new}}} \right) R_{\text{pl,lit}} \quad (7)$$

$$a_{\text{pl,new}} = \left( \frac{M_{*,\text{lit}}}{M_{*,\text{new}}} \right)^{1/3} a_{\text{pl,lit}}, \quad (8)$$

where subscript "lit" denotes the value from the literature which we compare with, subscript "new" is finally the new computed values, subscript "pl" is short for planet, and last subscript "\*" is short for star.  $M$ ,  $R$ , and  $a$  are mass, radius, and semi-major axis, respectively. Note that for the literature values, we use the values reported directly from the literature, and not the derived radius and mass from Torres et al. (2010). To identify outliers, we compare radii and masses derived from Torres et al. (2010) since this is a measure of how the atmospheric parameters have changed.

### 3.3.1. HAT-P-46

HAT-P-46 has two discovered exoplanets according to Hartman et al. (2014a). The outer planet HAT-P-46 c is not transiting hence we do not have any radius for this planet. The results we present in this paper for this star comes from UVES/VLT data with a SNR at 208. Hartman et al. (2014a) derives the following spectroscopic parameters:  $T_{\text{eff}} = 6120 \pm 100$  K,  $\log g =$

$4.25 \pm 0.11$ , and  $[\text{Fe}/\text{H}] = 0.30 \pm 0.10$ . We note that for this star the asteroseismic correction we apply as mentioned in Section 3.2 results in a corrected  $\log g$  below 4.2 dex, so we end up using the spectroscopic  $\log g$  for this star.

If we derive the mass and radius of HAT-P-46 b with our new parameters, we obtain the following:  $R_{\text{pl}} = 0.93R_J$ , while Hartman et al. (2014a) derived  $R_{\text{pl}} = 1.28R_J$ . We see no change in mass (Hartman et al. (2014a) found  $M_{\text{pl}} = 0.49M_J$ ), however there is a decrease in the radius, and we end up with a more dense planet,  $\rho_{\text{pl}} = 0.76 \text{ g/cm}^3$  from  $\rho_{\text{pl}} = 0.28 \pm 0.10 \text{ g/cm}^3$ .

As the secondary companion does not transit we only have a limit on the minimum mass for this planet. Here we get:  $M \sin i_{\text{pl}} = 1.97M_J$ , Hartman et al. (2014a) presented  $M \sin i_{\text{pl}} = 2.00M_J$ , so a very small change as expected.

### 3.3.2. HD 120084

The exoplanet orbiting this star with a period of 2082 days and a quite eccentric orbit at 0.66 was discovered by Sato et al. (2013a). Atmospheric parameters were derived by Takeda et al. (2008) using a similar method as described in this paper. The spectra they analyzed however, was not of as high quality as used here. Using the HIDES spectrograph at the 188cm reflector at NAOJ Takeda et al. (2008) reported an average SNR for their sample of 100-300 at a resolving power of 67 000. We used data from ESPaDOnS with a resolving power of 81 000, and with a SNR for this star of 850. With our new parameter we obtain a slightly lower stellar mass for the star at  $1.93M_{\odot}$  compared to



$2.39M_{\odot}$  obtained by Takeda et al. (2008), hence the minimum planetary mass is also decreased slightly from  $m_{\text{pl}} \sin i = 4.5M_J$  to  $m_{\text{pl}} \sin i = 3.9M_J$ . We see a decrease in the stellar radius by 28% from  $9.12R_{\odot}$  to  $7.81R_{\odot}$ . Since there are no observations of the planet transiting, the planetary radius has not been computed.

### 3.3.3. HD 233604

HD 233604 b was discovered by Nowak et al. (2013) while the atmospheric parameters of the star were derived by Zieliński et al. (2012) with the same method as described in this paper using the HRS spectrograph at HET with a resolving power of 60 000 with a typical SNR at 200-250. We obtained the spectrum for this star using the FIES spectrograph with a slightly higher resolution at 67 000, and similar but also slightly higher SNR at 320 for this star.

This planet is in a very close orbit with a semi-major axis of  $\sim 15R_*$  ( $R_*$  is the stellar radius) using the parameters from Nowak et al. (2013). With the updated parameters presented in this paper we see a slight increase in the stellar mass from  $1.5M_{\odot}$  to  $1.9M_{\odot}$  and a decrease in stellar radius from  $10.5R_{\odot}$  to  $8.6R_{\odot}$ . This gives an increase of the semi major axis to  $\sim 21R_*$ . Note that the correct stellar radii are used to describe the semi-major axis in both cases.

The increase in stellar mass leads to an increase in the minimum planetary mass, from  $m_{\text{pl}} \sin i = 6.58M_J$  to  $m_{\text{pl}} \sin i = 7.79M_J$ .

Nowak et al. (2013) found a high Li abundance at  $A(\text{Li})_{\text{LTE}} = 1.400 \pm 0.042$  for this star speculating if this star might have engulfed a planet. A more likely explanation is that this star has not yet reached the first dredge-up process (Nowak et al. 2013). We found a much lower value,  $A(\text{Li})_{\text{LTE}} = 0.92$  and hence we find the star to not be Li rich. The Li abundance we find is in excellent agreement with Adamów et al. (2014). Even applying a NLTE correction as done in Adamów et al. (2014) ( $A(\text{Li})_{\text{NLTE}} = 1.08$ ) this star is not Li rich.

### 3.3.4. HD 5583

This exoplanet was discovered by Niedzielski et al. (2016) with an orbital period of 139 days around a K giant. This exoplanet was discovered with the radial velocity technique, and we do not have a planetary radius. The stellar parameters were derived in a similar manner as presented here (see Niedzielski et al. 2016, and references therein) where our biggest disagreement is in the surface gravity. We derive a 0.34 dex higher  $\log g$  giving us a smaller stellar radius (37% smaller). The derived mass is 15% higher which in turn increases the minimum planetary mass from  $m_{\text{pl}} \sin i = 5.78M_J$  to  $m_{\text{pl}} \sin i = 8.63M_J$ . Even with the increase in mass, it is still within the planetary regime for most inclinations as noted by Niedzielski et al. (2016).

### 3.3.5. HD 81688

This exoplanet was discovered by Sato et al. (2008) with the RV method. The host star is a metal-poor K giant. The atmospheric parameters presented in Sato et al. (2008) are obtained from the same method as presented in this paper, and we have quite good agreement. Once again the big disagreement is in the surface gravity where ours is 0.48 dex higher. Even though the stellar parameters, and hence the planetary, do change, the radius and mass we derive are not far from what is presented in the paper by Sato et al. (2008). This is a case where the star was marked

as an outlier due to the comparison between the radius and mass derived from Torres et al. (2010).

The new stellar mass is the same as before,  $2.1M_{\odot}$ . The stellar radius change from  $13.0R_{\odot}$  to  $10.8R_{\odot}$ . Since a transit of this star has not been observed and the stellar mass remains the same, we do not see any change in the planetary parameters.

We note that this system is in an interesting configuration with a very close orbit around an evolved star. This system, among others, have been subject to work on planet engulfment (see e.g. Kunitomo et al. 2011).

### 3.3.6. HIP 107773

The planetary companion was presented in Jones et al. (2015) as an exoplanet around an intermediate mass evolved star. The stellar parameters were obtained from the analysis by Jones et al. (2011) using the same method as presented here, however with a different line list which might lead to some disagreements. For this star we derive a higher  $\log g$  at 2.83 dex compared to 2.60 dex, thus we derive a slightly smaller star with  $11.6R_{\odot}$  to  $9.2R_{\odot}$  and  $2.4M_{\odot}$  to  $2.1M_{\odot}$  for radius and mass of the star, respectively. The other atmospheric parameters are very similar to those derived by Jones et al. (2011). This leads to a reduced minimum mass of the planetary companion from  $m \sin i = 1.98M_J$  to  $m \sin i = 1.78M_J$ . The planetary radius has not been measured.

### 3.3.7. WASP-97

The exoplanet orbiting WASP-97 was discovered by Hellier et al. (2014). The host star parameters were derived in a similar method as described in this paper after co-adding several spectra from the CORALIE spectrograph. They reach a SNR of 100 with a spectral resolution of 50 000. The parameters presented here comes from the UVES spectrograph with a SNR of more than 200.

The parameters do not change much for this planet. The planetary mass is changed from  $m_{\text{pl}} \sin i = 1.32M_J$  to  $m_{\text{pl}} \sin i = 1.37M_J$  and the radius from  $1.13R_J$  to  $1.42R_J$ . This does affect the density quite a lot, changing from  $1.13 \text{ g/cm}^3$  to  $0.59 \text{ g/cm}^3$ . This exoplanet is then in the same category as Saturn with a density lower than water, however with a size slightly larger than Jupiter.

### 3.3.8. $\omega$ Serpentis (ome Ser)

The exoplanet orbiting this star with a period of 277 days and an eccentric orbit at 0.11 was also presented by Sato et al. (2013a). The atmospheric parameters were derived in the same way as for HD 120084. We used data from FIES with a resolving power of 67 000, and with a SNR for this star of 1168. With our new parameters we obtain a slightly higher stellar mass for the star at  $2.19M_{\odot}$  compared to  $2.17M_{\odot}$  obtained by Takeda et al. (2008). This change is not significant enough to change the minimum planetary mass at  $m_{\text{pl}} \sin i = 1.7M_J$ . The stellar radius decrease with more than one solar radius, from  $12.3R_{\odot}$  to  $11.1R_{\odot}$ . However, since there are no observations of exoplanet transiting, we can not see the change in the planetary radius.

### 3.3.9. $\alpha$ Ursa Major (omi UMa)

omi UMa b was discovered by Sato et al. (2012) using the RV method. The stellar parameters are from Takeda et al. (2008) as discussed above. The spectrum used for this star is from ES-



PaDONs with a SNR of more than 500 compared to the 100-300 SNR reached for the large sample presented in Takeda et al. (2008). The luminosity and mass for omi UMa were obtained from theoretical evolutionary tracks (see Sato et al. 2012, and references therein). The radius was then estimated using the Stefan-Boltzmann relationship and the measured luminosity and  $T_{\text{eff}}$ .

The parameters presented here mainly differ in the surface gravity where ours is 0.72 dex higher at  $\log g = 3.36$ . These leads to a big change in stellar mass and radius from  $3.1M_{\odot}$  to  $1.6M_{\odot}$  and  $14.1R_{\odot}$  to  $4.5R_{\odot}$ , respectively. omi UMa b was reported to be the first planet candidate around a star more massive than  $3M_{\odot}$  by Sato et al. (2012). With these updated results, the minimum mass of the planet is now  $m \sin i = 2.7M_J$  whereas it was  $m \sin i = 4.1M_J$  (Sato et al. 2012). The exoplanet is not reported to transit as seen from Earth, so we do not have a radius for this exoplanet, which would have changes a lot with these new results.

## 4. Conclusion

With this update we bring the completeness of SWEET-Cat for stars brighter than magnitude 10 (V band) up to 85% (77% for stars brighter than 12). The parameters are available for the public in an easy accessible form at <https://www.astro.up.pt/resources/sweet-cat/> which is continuously updated. The importance of the homogeneous analysis which we keep striving for is shown in Figure 7 where we see quite different derived stellar radii when the atmospheric parameters comes from different methods. As have been discussed in Section 3.3 this has a direct impact on the planetary parameters. It is of great importance to know the planetary parameters very well, both for individual systems but also for an ensemble. With accurate and precise planetary parameters we will be able to distinguish the different possible composition, let it be gas giant, water worlds, or rocky planets.

Finally we also provide an online tool to derive the stellar atmospheric parameters using FASMA. We recommend to only use this tool for spectra and stars where this method is working, i.e. high resolution spectra with a high SNR. The stars can be FGK dwarfs and FGK subgiants/giants. We are working on applying this method in the NIR in order to include the cool solar type stars.

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## **Appendix A: Updated parameters of 50 planet hosts**

**Table A.1.** The derived parameters for the 50 stars in our sample. The SNR is measured by ARES.

Star	$T_{\text{eff}}$ (K)	$\log g$ (dex)	[Fe/H] (dex)	$\xi_{\text{micro}}$ (km/s)	$\xi_{\text{micro}}$ fixed?	Instrument	SNR
BD -11 4672	4553 $\pm$ 75	4.87 $\pm$ 0.51	-0.30 $\pm$ 0.02	0.14 $\pm$ 0.07	yes	FIES	487
BD +49 828	5015 $\pm$ 36	2.87 $\pm$ 0.09 <sup>a</sup>	-0.01 $\pm$ 0.03	1.48 $\pm$ 0.04	no	FIES	567
GJ 785	5087 $\pm$ 48	4.42 $\pm$ 0.10	-0.01 $\pm$ 0.03	0.69 $\pm$ 0.10	no	HARPS	801
HATS-1	5969 $\pm$ 46	4.39 $\pm$ 0.06	-0.04 $\pm$ 0.04	1.06 $\pm$ 0.08	no	UVES	155
HATS-5	5383 $\pm$ 91	4.41 $\pm$ 0.22	0.08 $\pm$ 0.06	0.91 $\pm$ 0.14	no	UVES	158
HAT-P-12	4642 $\pm$ 106	4.53 $\pm$ 0.27	-0.26 $\pm$ 0.06	0.28 $\pm$ 0.63	no	FIES	185
HAT-P-24	6470 $\pm$ 181	4.33 $\pm$ 0.27	-0.41 $\pm$ 0.10	1.40 $\pm$ 0.03	yes	UVES	158
HAT-P-39	6745 $\pm$ 236	4.39 $\pm$ 0.47	-0.21 $\pm$ 0.12	1.53 $\pm$ 0.04	yes	UVES	127
HAT-P-42	5903 $\pm$ 66	4.29 $\pm$ 0.10 <sup>a</sup>	0.34 $\pm$ 0.05	1.19 $\pm$ 0.08	no	UVES	130
HAT-P-46	6421 $\pm$ 121	4.53 $\pm$ 0.14 <sup>a</sup>	0.16 $\pm$ 0.09	1.67 $\pm$ 0.18	no	UVES	208
HD 120084	4969 $\pm$ 40	2.94 $\pm$ 0.14 <sup>a</sup>	0.12 $\pm$ 0.03	1.41 $\pm$ 0.04	no	ESPaDOnS	852
HD 192263	4946 $\pm$ 46	4.61 $\pm$ 0.14	-0.05 $\pm$ 0.02	0.66 $\pm$ 0.12	no	HARPS	415
HD 219134	4767 $\pm$ 70	4.57 $\pm$ 0.17	0.00 $\pm$ 0.04	0.59 $\pm$ 0.24	no	ESPaDOnS	725
HD 220842	5999 $\pm$ 39	4.30 $\pm$ 0.06 <sup>a</sup>	-0.08 $\pm$ 0.03	1.21 $\pm$ 0.05	no	FIES	459
HD 233604	4954 $\pm$ 46	2.86 $\pm$ 0.11 <sup>a</sup>	-0.14 $\pm$ 0.04	1.61 $\pm$ 0.05	no	FIES	314
HD 283668	4841 $\pm$ 73	4.51 $\pm$ 0.18	-0.74 $\pm$ 0.04	0.16 $\pm$ 0.61	no	FIES	592
HD 285507	4620 $\pm$ 126	4.72 $\pm$ 0.61	0.04 $\pm$ 0.06	0.74 $\pm$ 0.43	no	UVES	239
HD 5583	4986 $\pm$ 35	2.87 $\pm$ 0.09 <sup>a</sup>	-0.35 $\pm$ 0.03	1.62 $\pm$ 0.04	no	FIES	933
HD 81688	4903 $\pm$ 21	2.70 $\pm$ 0.05 <sup>a</sup>	-0.21 $\pm$ 0.02	1.54 $\pm$ 0.02	no	<sup>b</sup>	1350, 860
HD 82886	5123 $\pm$ 18	3.30 $\pm$ 0.04 <sup>a</sup>	-0.25 $\pm$ 0.01	1.16 $\pm$ 0.02	no	<sup>c</sup>	1198, 1294
HD 87883	4917 $\pm$ 68	4.53 $\pm$ 0.19	0.02 $\pm$ 0.03	0.46 $\pm$ 0.21	no	ESPaDOnS	753
HIP 107773	4957 $\pm$ 49	2.83 $\pm$ 0.09 <sup>a</sup>	0.04 $\pm$ 0.04	1.49 $\pm$ 0.05	no	UVES	218
HIP 11915	5770 $\pm$ 14	4.33 $\pm$ 0.03	-0.06 $\pm$ 0.01	0.95 $\pm$ 0.02	no	HARPS	709
HIP 116454	5038 $\pm$ 82	4.53 $\pm$ 0.18	-0.12 $\pm$ 0.04	0.74 $\pm$ 0.15	no	FIES	309
HR 228	5042 $\pm$ 42	3.30 $\pm$ 0.09 <sup>a</sup>	0.07 $\pm$ 0.03	1.14 $\pm$ 0.04	no	UVES	400
KELT-6	6246 $\pm$ 88	4.22 $\pm$ 0.09 <sup>a</sup>	-0.22 $\pm$ 0.06	1.66 $\pm$ 0.13	no	FIES	374
Kepler-37	5378 $\pm$ 53	4.47 $\pm$ 0.12	-0.23 $\pm$ 0.04	0.58 $\pm$ 0.13	no	FIES	205
Kepler-444	5111 $\pm$ 43	4.50 $\pm$ 0.13	-0.51 $\pm$ 0.03	0.37 $\pm$ 0.15	no	FIES	675
mu Leo	4605 $\pm$ 94	2.61 $\pm$ 0.26 <sup>a</sup>	0.25 $\pm$ 0.06	1.64 $\pm$ 0.11	no	ESPaDOnS	354
ome Ser	4928 $\pm$ 35	2.69 $\pm$ 0.06 <sup>a</sup>	-0.11 $\pm$ 0.03	1.55 $\pm$ 0.04	no	FIES	1168
omi UMa	5499 $\pm$ 52	3.36 $\pm$ 0.07 <sup>a</sup>	-0.01 $\pm$ 0.05	1.98 $\pm$ 0.06	no	ESPaDOnS	527
Qatar-2	4637 $\pm$ 316	4.53 $\pm$ 0.62	0.09 $\pm$ 0.17	0.63 $\pm$ 0.83	no	UVES	97
SAND364	4457 $\pm$ 104	2.26 $\pm$ 0.20 <sup>a</sup>	-0.04 $\pm$ 0.06	1.60 $\pm$ 0.11	no	UVES	220
TYC+1422-614-1	4908 $\pm$ 41	2.90 $\pm$ 0.12 <sup>a</sup>	-0.07 $\pm$ 0.03	1.57 $\pm$ 0.05	no	FIES	506
WASP-37	5917 $\pm$ 72	4.25 $\pm$ 0.15	-0.23 $\pm$ 0.05	0.59 $\pm$ 0.13	no	FIES	232
WASP-44	5612 $\pm$ 80	4.39 $\pm$ 0.30	0.17 $\pm$ 0.06	1.32 $\pm$ 0.13	no	UVES	125
WASP-52	5197 $\pm$ 83	4.55 $\pm$ 0.30	0.15 $\pm$ 0.05	1.16 $\pm$ 0.14	no	UVES	125
WASP-58	6039 $\pm$ 55	4.23 $\pm$ 0.10	-0.09 $\pm$ 0.04	1.12 $\pm$ 0.08	no	FIES	310
WASP-61	6265 $\pm$ 168	4.21 $\pm$ 0.21 <sup>a</sup>	-0.38 $\pm$ 0.11	1.44 $\pm$ 0.02	yes	UVES	163
WASP-72	6570 $\pm$ 85	4.25 $\pm$ 0.13	0.15 $\pm$ 0.06	2.30 $\pm$ 0.15	no	UVES	174
WASP-73	6203 $\pm$ 32	4.16 $\pm$ 0.06 <sup>a</sup>	0.20 $\pm$ 0.02	1.66 $\pm$ 0.04	np	<sup>d</sup>	193,231
WASP-75	6203 $\pm$ 46	4.42 $\pm$ 0.22 <sup>a</sup>	0.24 $\pm$ 0.03	1.45 $\pm$ 0.06	no	UVES	189
WASP-76	6347 $\pm$ 52	4.29 $\pm$ 0.08 <sup>a</sup>	0.36 $\pm$ 0.04	1.73 $\pm$ 0.06	no	UVES	165
WASP-82	6563 $\pm$ 55	4.29 $\pm$ 0.10 <sup>a</sup>	0.18 $\pm$ 0.04	1.93 $\pm$ 0.08	no	UVES	239
WASP-88	6450 $\pm$ 61	4.24 $\pm$ 0.06 <sup>a</sup>	0.03 $\pm$ 0.04	1.79 $\pm$ 0.09	no	UVES	174
WASP-95	5799 $\pm$ 31	4.29 $\pm$ 0.05 <sup>a</sup>	0.22 $\pm$ 0.03	1.18 $\pm$ 0.04	no	UVES	247
WASP-97	5723 $\pm$ 52	4.24 $\pm$ 0.07	0.31 $\pm$ 0.04	1.03 $\pm$ 0.08	no	UVES	219
WASP-99	6324 $\pm$ 89	4.34 $\pm$ 0.12	0.27 $\pm$ 0.06	1.83 $\pm$ 0.12	no	UVES	249

**Notes.** <sup>(a)</sup> Spectroscopic  $\log g$ .<sup>(b)</sup> Weighted average of ESPaDOnS and FIES results. The parameters are (FIES in parantheses):  $T_{\text{eff}} = 4870(4934) \pm 30(29)$ ,  $\log g = 2.50(2.73) \pm 0.14(0.05)$ ,  $[\text{Fe}/\text{H}] = -0.26(-0.19) \pm 0.03(0.02)$ , and  $\xi_{\text{micro}} = 1.50(1.59) \pm 0.03(0.03)$ .<sup>(c)</sup> Weighted average of ESPaDOnS and FIES results. The parameters are (FIES in parantheses):  $T_{\text{eff}} = 5124(5121) \pm 22(29)$ ,  $\log g = 3.30(3.31) \pm 0.05(0.07)$ ,  $[\text{Fe}/\text{H}] = -0.25(-0.24) \pm 0.02(0.02)$ , and  $\xi_{\text{micro}} = 1.15(1.17) \pm 0.03(0.04)$ .<sup>(d)</sup> Weighted average of UVES and FEROS results. The parameters are (FEROS in parantheses):  $T_{\text{eff}} = 6313(6162) \pm 61(37)$ ,  $\log g = 4.26(4.14) \pm 0.15(0.06)$ ,  $[\text{Fe}/\text{H}] = 0.22(0.19) \pm 0.04(0.03)$ , and  $\xi_{\text{micro}} = 1.85(1.61) \pm 0.08(0.04)$ .

**Table A.3.** The previous parameters from SWEET-Cat.

Star	$T_{\text{eff}}$ (K)	$\log g$ (dex)	[Fe/H] (dex)	$\xi_{\text{micro}}$ (km/s)	Reference
BD-114672	$4475 \pm 100$	$4.10 \pm 0.36$	$-0.48 \pm 0.05$	$0.67 \pm 0.16$	Moutou et al. (2015)
BD +49 828	$4943 \pm 30$	$2.85 \pm 0.09$	$-0.19 \pm 0.06$	...	Niedzielski et al. (2015b)
GJ 785	$5144 \pm 50$	$4.60 \pm 0.06$	$0.08 \pm 0.03$	...	Howard et al. (2011)
HATS-1	$5780 \pm 100$	$4.40 \pm 0.08$	$-0.06 \pm 0.12$	...	Penev et al. (2013)
HATS-5	$5304 \pm 50$	$4.53 \pm 0.02$	$0.19 \pm 0.08$	...	Zhou et al. (2014)
HAT-P-12	$4650 \pm 60$	$4.61 \pm 0.02$	$-0.29 \pm 0.05$	...	Lee et al. (2014)
HAT-P-24	$6373 \pm 80$	$4.29 \pm 0.04$	$-0.16 \pm 0.08$	...	Kipping et al. (2010)
HAT-P-39	$6340 \pm 100$	$4.16 \pm 0.03$	$0.19 \pm 0.10$	...	Hartman et al. (2012)
HAT-P-46	$6120 \pm 100$	$4.25 \pm 0.11$	$0.30 \pm 0.10$	$0.85 \pm \dots$	Hartman et al. (2014b)
HAT-P-42	$5743 \pm 50$	$4.14 \pm 0.07$	$0.27 \pm 0.08$	...	Boisse et al. (2013)
HD 120084	$4892 \pm 22$	$2.71 \pm 0.08$	$0.09 \pm 0.05$	$1.31 \pm 0.10$	Sato et al. (2013a)
HD 192263	$4906 \pm 57$	$4.36 \pm 0.17$	$-0.07 \pm 0.02$	$0.78 \pm 0.12$	Tsantaki et al. (2013)
HD 219134	$4699 \pm 16$	$4.63 \pm 0.10$	$0.11 \pm 0.04$	$0.35 \pm 0.19$	Motalebi et al. (2015)
HD 220074	$3935 \pm 110$	$1.30 \pm 0.50$	$-0.25 \pm 0.25$	$1.60 \pm 0.30$	Lee et al. (2013)
HD 220842	$5920 \pm 20$	$4.24 \pm 0.02$	$-0.17 \pm 0.02$	...	Hébrard et al. (2016)
HD 233604	$4791 \pm 45$	$2.55 \pm 0.18$	$-0.36 \pm 0.04$	...	Nowak et al. (2013)
HD 283668	$4845 \pm 66$	$4.35 \pm 0.12$	$-0.75 \pm 0.12$	$0.02 \pm 0.30$	Wilson et al. (2016)
HD 285507	$4503 \pm 73$	$4.67 \pm 0.06$	$0.13 \pm 0.01$	...	Quinn et al. (2014)
HD 5583	$4830 \pm 45$	$2.53 \pm 0.14$	$-0.50 \pm 0.18$	...	Niedzielski et al. (2016)
HD 81688	$4753 \pm 15$	$2.22 \pm 0.05$	$-0.36 \pm 0.02$	$1.43 \pm 0.05$	Sato et al. (2008)
HD 82886	$5112 \pm 44$	$3.40 \pm 0.06$	$-0.31 \pm 0.03$	...	Johnson et al. (2011)
HD 87883	$4958 \pm 44$	$4.56 \pm 0.06$	$0.07 \pm 0.03$	...	Valenti & Fischer (2005)
HIP 107773	$4945 \pm 100$	$2.60 \pm 0.20$	$0.03 \pm 0.10$	...	Jones et al. (2015)
HIP 11915	$5760 \pm 4$	$4.46 \pm 0.01$	$-0.06 \pm 0.00$	...	Bedell et al. (2015)
HIP 116454	$5089 \pm 50$	$4.59 \pm 0.03$	$-0.16 \pm 0.08$	...	Vanderburg et al. (2015)
HR 228	$4959 \pm 25$	$3.16 \pm 0.08$	$0.01 \pm 0.04$	$1.12 \pm 0.07$	Sato et al. (2013b)
KELT-6	$6102 \pm 43$	$4.07 \pm 0.06$	$-0.28 \pm 0.04$	...	Collins et al. (2014)
Kepler-37	$5417 \pm 70$	$4.57 \pm 0.01$	$-0.32 \pm 0.07$	...	Barclay et al. (2013)
Kepler-444	$5046 \pm 74$	$4.60 \pm 0.06$	$-0.55 \pm 0.07$	...	Campante et al. (2015)
mu Leo	$4538 \pm 27$	$2.40 \pm 0.10$	$0.36 \pm 0.05$	$1.40 \pm 0.10$	Lee et al. (2014)
ome Ser	$4770 \pm 10$	$2.32 \pm 0.04$	$-0.24 \pm 0.02$	$1.34 \pm 0.04$	Sato et al. (2013a)
omi UMa	$5242 \pm 10$	$2.64 \pm 0.03$	$-0.09 \pm 0.02$	$1.51 \pm 0.07$	Sato et al. (2012)
Qatar-2	$4645 \pm 50$	$4.60 \pm 0.02$	$-0.02 \pm 0.08$	...	Bryan et al. (2012)
SAND364	$4284 \pm 9$	$2.20 \pm 0.06$	$-0.02 \pm 0.04$	...	Brucalassi et al. (2014)
TYC+1422-614-1	$4806 \pm 45$	$2.85 \pm 0.18$	$-0.20 \pm 0.08$	...	Niedzielski et al. (2015a)
WASP-37	$5940 \pm 55$	$4.39 \pm 0.02$	$-0.40 \pm 0.12$	...	Simpson et al. (2011)
WASP-44	$5400 \pm 150$	$4.48 \pm 0.07$	$0.06 \pm 0.10$	...	Anderson et al. (2012)
WASP-52	$5000 \pm 100$	$4.58 \pm 0.01$	$0.03 \pm 0.12$	...	Hébrard et al. (2013)
WASP-58	$5800 \pm 150$	$4.27 \pm 0.09$	$-0.45 \pm 0.09$	...	Hébrard et al. (2013)
WASP-61	$6250 \pm 150$	$4.26 \pm 0.01$	$-0.10 \pm 0.12$	...	Hellier et al. (2012)
WASP-72	$6250 \pm 100$	$4.08 \pm 0.13$	$-0.06 \pm 0.09$	$1.60 \pm 0.10$	Gillon et al. (2013)
WASP-73	$6030 \pm 120$	$3.92 \pm 0.08$	$0.14 \pm 0.14$	$1.10 \pm 0.20$	Delrez et al. (2014)
WASP-75	$6100 \pm 100$	$4.50 \pm 0.10$	$0.07 \pm 0.09$	$1.30 \pm 0.10$	Gómez Maqueo Chew et al. (2013)
WASP-76	$6250 \pm 100$	$4.13 \pm 0.02$	$0.23 \pm 0.10$	$1.40 \pm 0.10$	West et al. (2016)
WASP-82	$6490 \pm 100$	$3.97 \pm 0.02$	$0.12 \pm 0.11$	$1.50 \pm 0.10$	West et al. (2016)
WASP-88	$6430 \pm 130$	$4.03 \pm 0.09$	$-0.08 \pm 0.12$	$1.40 \pm 0.10$	Delrez et al. (2014)
WASP-95	$5630 \pm 130$	$4.38 \pm 0.03$	$0.14 \pm 0.16$	...	Hellier et al. (2014)
WASP-97	$5640 \pm 100$	$4.43 \pm 0.03$	$0.23 \pm 0.11$	...	Hellier et al. (2014)
WASP-99	$6180 \pm 100$	$4.12 \pm 0.03$	$0.21 \pm 0.15$	...	Hellier et al. (2014)
WASP-100	$6900 \pm 120$	$4.04 \pm 0.11$	$-0.03 \pm 0.10$	...	Hellier et al. (2014)