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F. Martins, S. Boissier, V. Buat, L. Cambrésy and P. Petit (eds)

THE FIRST HOMOGENEOUS SET OF STELLAR PARAMETERS OF THE REFERENCE O-TYPE STARS: PRELIMINARY RESULTS

A. Hervé[1 2]

Abstract. Massive stars play a key role in various fields of astrophysics. In the 70s, the two dimensional spectral classification of O stars was developed by Walborn. Standard stars have been selected to be the reference object of each stellar type / luminosity class. These standard stars are still used today for the classification of the any newly discovered O stars. However, the stellar properties of these reference objects have never been determined in a homogeneous way. Consequently, there is no reference set of stellar parameters for these classification O stars. We propose to determine the stellar properties of all reference O stars using use state-of-the-art atmosphere models We will provide the community with a homogeneous catalog of high signal to noise, high resolution spectra as well as the stellar parameters for each reference stars. We present preliminary results for the standard O-type dwarfs.

Keywords: Stars: atmospheres Stars: fundamental parameters Stars: abundances

1 Introduction

Massive stars are the cornerstones of modern astrophysics. The heaviest elements of the universe are synthesized in their core and during the supernova explosion. This matter is subsequently released in the interstellar medium through their powerful stellar wind and on galactic scales at their death as supernovae. The mechanical energy associated to these flows triggers molecular cloud collapse and can lead to the birth of new stars. The strong UV radiation of massive stars is responsible for HII regions. And finally, these stars are the likely progenitors of long-soft GRBs. The classification of O-type stars started at the end of the 70's. Using low resolution, limited signal-to-noise spectra, Walborn (Walborn 1971, 1972) identified key lines varying across the population of O stars. Using these morphological modifications, he built a two dimensional classification of O stars, defining spectral types between O4 and O9.7 and luminosity classes from dwarfs (V) to bright supergiants (Ia). This classification is still relevant today. The relative strength of the HeI and HeII lines is used to define the spectral type. The strength and shape of specifics lines (ex: HeII 4686 Å) are used to determine the luminosity class of the early stellar types while the ratio of HeI and Si IV lines are used for late type stars. In order to establish a universal classification, Walborn selected one reference star for each type and luminosity class. These stars are still used today as reference stars. Since the studies of Walborn, numerous surveys have provided spectra of hundreds of O stars - VLT-FLAMES survey (Evans et al. 2005), TARENTULA survey (Evans et al. 2010), GOSS survey (Sota et al. 2011). Consequently, the classification of the newly discovered O stars is based on the comparison of the spectra of these objects to the standard O-type stars. Despite their crucial role, the stellar properties of the entire sample of standard O stars have never been studied homogeneously. Occasionally some of them have been analysed as part of specific studies. So currently, the astrophysics community does not have access to a high resolution, high signal to noise spectra database of reference O-type stars. More important, we do not have access to accurate stellar parameters of the standard stars.

In section 2, we present our data. In the section 3, we present the methodology for the spectroscopic analysis and in the section 4, we show the first results for the dwarfs.

[1] Astronomical Institute ASCR, Fricova 298, 251 65 Ondrejov, Czech Republic
[2] LUPM, Université de Montpellier, CNRS, Place Eugène Bataillon, F-34095 Montpellier, France

2 Observations

For the determination of the properties of the massive stars, we need high-resolution and high-signal-to-noise ratio (SNR) spectra for all the standard O-type stars. We have obtained spectra with the échelle spectrograph $SOPHIE$ on the 193cm telescope at the Observatoire de Haute Provence for the stars observable from the north hemisphere. We thus observed the north hemisphere reference O-type stars during 7 nights in August 2014 and 1 night in December 2014. To complete our sample with the south hemisphere stars, we have extracted from the $FEROS$ archive the spectra publicly available. The quality of some data is not good enough for our project. We have thus obtained new observation time with FEROS at the 2.2m telescope at la Silla. The future observations are planned in October 2015 and March 2016.

When available, we also use IUE archive data.

3 Spectroscopic analysis

We use the code CMFGEN (Hillier & Miller 1998) to determine the fundamental properties of the sample stars. CMFGEN computes non-LTE and spherical models of massive stars atmospheres and the code takes into account line-blanketing and the presence of stellar wind. The hydrodynamical structure (density, velocity) is given as an input. The expansion of the wind is described by the so-called β law. In order to decrease the computation time and the size of the problem, a super level approached is used. In our model and in order to take into account the effect of line-blanketing, we have included the following elements in our calculations: H, He, C, N, O, Ne, Si, S, Ar, Ca, Fe and Ni. Once the atmospheric structure is obtained, a formal solution of the radiative transfer equation, including the proper line profiles, is performed. A depth variable microturbulent velocity starting from 10 $km.s^{-1}$ at the photosphere and reaching 10% of the terminal velocity at the top of the atmosphere is assumed.

To compare the synthetic spectra to the observation we convolve the synthetic spectra by the rotational velocity of the star and by a macroturbulent velocity.

To constrain the stellar and wind parameters, we follow the methodology established for the analysis of the O-type stars of the MIMES survey and presented in Martins et al. (2015)

First, we need to determine the projected rotational velocity of the stars. We use the Fourier transformation method (Gray 1976; Simón-Díaz & Herrero 2007). We apply this method to the non blend O iii λ5592 line. Then we convolve our synthetic spectra by the result of the first zero in the Fourier transformation. The uncertainty on $Vsini$ is $\sim$10 $km.s^{-1}$

To mimic the effect of the macroturbulent velocity, we fit the O iii 5592 line with different synthetic spectra convolved by a Gaussian profile (in addition to the convolution by rotational broadening). Using a χ^2 method, we determine the best value of the macroturbulent velocity. Then, we convolve the whole synthetic spectrum by the rotational velocity and the macroturbulent velocity.

To determine the effective temperature, we use the presence of two consecutive ionization level of helium in the optical band. In practice, we use the He i λ4471 He ii λ4542, as main indicator. We can also use He i λ4026, He i λ4388, He i λ4713, He i λ4922, and the He ii λ4200, He ii λ5412 as secondary indicators.

Concerning the surface gravity we use the the wings of Balmer lines (except Hα which is very sensitive to the presence of a stellar wind) as main diagnostic of log g. As $SOPHIE$ and $FEROS$ are échelle spectrographes, the normalisation of the spectra is difficult and can lead to difference in the determination of the surface gravity. To determine the position of continuum in spectra, we use a synthetic spectrum to determine region in échelle spectra where no lines are present.

For the determination of the mass loss rate and the clumping parameters, we fit the intensity of the Balmer lines.

We will also determine the abundances of the the CNO elements from the fit of the different lines present in the optical band. The list of CNO lines and methodology to determine the abundances and their uncertainty is presented in Martins et al. (2015)

Concerning the luminosity of the O-type stars, we use the calibration of Martins et al. (2005).

For the majority of the stars, IUE spectra are available. We thus use the blue-ward extension of the absorption part of the Civ $\lambda\lambda$ 1548, 1551 PCygni profiles to determine the terminal velocity of the wind (Prinja et al. 1990). The typical uncertainty is $\sim$ 100 km.s^{-1}. If UV spectra is not available we use theoretical values of Muijres et al. (2012).

Table 1. Our preliminary results concerning the effective temperature, surface gravity, rotational velocity and macro-turbulent velocity for a sub-sample of the reference O-dwarfs.

ST	star	$\log \frac{L}{L_\odot}$ (1)	T_{eff} kK	*logg*	V*sini* $km.s^{-1}$	vmac $km.s^{-1}$
4	HD46223[2]	5.68	41.5	3.83	59	51
5	HD46150[2]	5.51	40.0	3.92	66	52
5.5	HD93204	5.41	$38.3^{+0.2}_{-0.5}$	$3.61^{+0.08}_{-0.05}$	120	35
6	HD42088	5.30	$37.9^{+2.5}_{-2.2}$	$3.86^{+0.25}_{-0.25}$	40	44
6.5	HD12993	5.20	$37.0^{+3.0}_{-3.0}$	$3.84^{+0.40}_{-0.30}$	79	39
7	HDE242926	5.10	$36.2^{+5.0}_{-4.0}$	$3.82^{+0.50}_{-0.40}$	100	41
7.5	HD152590	5.00	$35.4^{+2.5}_{-1.5}$	$3.90^{+0.25}_{-0.15}$	50	20
8.	HD191978	4.90	$34.5^{+1.0}_{-1.5}$	$3.89^{+0.13}_{-0.23}$	60	58
8.5	HD14633	4.82	$33.9^{+1.8}_{-2.0}$	$3.98^{+0.20}_{-0.20}$	117	55
9	10LAC	4.72	$34.7^{+0.8}_{-0.7}$	$4.08^{+0.07}_{-0.08}$	15	15
9.5	AE Aur[1]	4.62	$33.3^{+2.0}_{-2.}$	$4.01^{+0.2}_{-0.2}$	15	30

(1) Luminosities are from Martins et al. (2005).
(2) We are currently calculating models to determine the uncertainties.

4 First results

In a first step we have computed a grid of synthetic spectra with the radiative code CMFGEN. This grid have been computed using the theoretical values of stellar and wind parameters for each spectral type / luminosity class presented in Muijres et al. (2012). In order to determine the effective temperature and surface gravity with accuracy as well as their uncertainties, we have computed and added more models in our grid. Fitting simultaneously the HeI, HeII lines and the wings of the Balmer lines, we determined the surface gravity and effective temperature of a sample of O-dwarfs stars (see Table 1). From our results, we can see, as expected, the temperature is increasing from the late type to the early type. The variation of temperature is included between few hundred of Kelvin to less than two thousands kelvin from one stellar type to another. We note the exception of 10 Lac. We also obtained large error bars for the parameters of HDE242926. This is due to the low SNR (SNR $\sim$ 100) of the spectrum for this star in comparison to the other objects (SNR $\sim$ 400). Concerning the surface gravity, we determined values in agreement with the status of dwarf for all these stars. The only exception is HD93204. The surface gravity of this star is closer to the traditional value of a giant. In Figure 1, we present our best fit model of HD191978 one of the standard O8V. The simultaneous fit of the wing of the balmer lines and the HeI and HeII lines present in the spectrum allow us to determine the surface gravity and the effective temperature. Then we have found a mass loss rate of 5.6×10^{-10} $M_\odot.yr^{-1}$ by the fit of the intensity of the Balmer lines. In Figure 2, we show the analysis of the carbon and nitrogen abundances of HD191978. Using all the carbon (nitrogen) lines available in the visible band, we proceeded to a the χ^2 analysis of the carbon (nitrogen) abundances. The minimisation of the χ^2 allows us to determine the carbon (nitrogen) surface abundance of the star. We found solar abundances for carbon and nitrogen. So our results do not show any chemical enrichment, as expected for a dwarf.

5 Conclusions

With our *SOPHIE* spectra, our *FEROS* observations and *FEROS* public archives, we are building a high-resolution high-signal-to-noise ratio spectra catalog of all the standard O-type stars. Using the state-of-the-art radiative transfer code, we are currently analysing the the spectra of this sample. We will thus determine with accuracy the stellar and wind parameters (Teff, logg, $\dot{M}$, clumping properties and chemical composition) for each stars. Using these reference stars, we will thus constrain the variation of the properties of the O-type stars from one spectral type / luminosity class to another.

Once our analysis finished, we will provide the community with a homogeneous catalog of high-signal-to-noise ratio, high-resolution spectra as well as the stellar parameters for each reference stars.

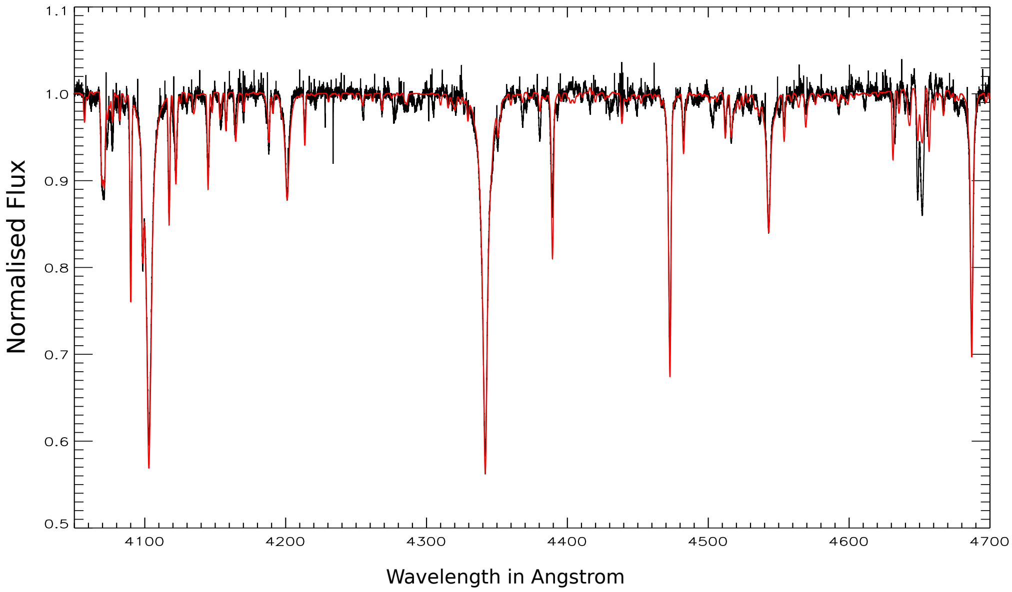

Fig. 1. Our best fit model (in red) compared to the *SOPHIE* spectrum of HD191978 (in black).

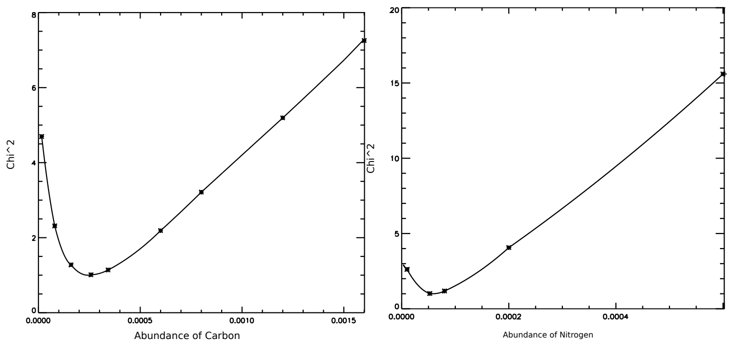

Fig. 2. Left: The bold solid curve shows the χ^2 of the analysis combining the carbon lines present in the optical band of HD191978. The black points correspond to the abundance of the different models used to determine the carbon abundance. Right: The same than on the left but for the nitrogen.

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