ISOSCELES:

GRID OF STELLAR ATMOSPHERE AND HYDRODYNAMIC MODELS FOR MASSIVE STARS

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Abstract

Spectroscopy can decode the radiation from stars in an appropriate way and derive many properties of different stellar objects. In this work we seek to derive simultaneously stellar and wind parameters of massive stars. Our stellar properties encompass: effective temperature, surface gravity, micro-turbulence velocity, projected rotational velocity and chemical composition. For wind properties we consider: mass-loss rate, terminal velocity and line–force parameters (α, k and δ) obtained from the standard line-driven wind theory. To model the data we use the radiative transport code FASTWIND with the hydrodynamic solutions derived using our stationary code HYDWIND as input, instead of the β-law. Then, ISOSCELES, our grid of stellar atmosphere and hydrodynamic models of massive stars, is used to derive the physical properties of the observed spectra through spectral line fittings. This quantitative spectroscopic analysis provide an estimation about the line–force parameters, whose theoretical calculations are complex.

In addition, we expect to confirm that the hydrodynamic solutions obtained with a value of $\delta \gtrsim 0.25$, called δ-slow solutions, describe quite reliable the radiation line-driven winds of A and late B supergiant stars and, at the same time, explain disagreements between observational data and theoretical models for the Wind–Momentum Luminosity Relationship (WLR).

Grids of Models

ISOSCELES is the first grid of synthetic data for massive stars that involves both, the m-CAK hydrodynamics and the NLTE radiative transport. To produce the grid of synthetic line profiles, we first computed a grid of hydrodynamic wind solutions with our stationary code HYDWIND (Curé 2004). These hydrodynamic wind solutions, based on the CAK theory and its improvements (Castor et al. 1975, Friend & Abbott 1986, Curé 2004, Curé et al. 2011) are used as input in the NLTE radiative transport code FASTWIND (Puls et al. 2005). Each HYDWIND model is described by six parameters: $T_{\rm eff}$, log g, R_*, α, k, and δ. All these models consider, for the optical depth, the boundary condition $\tau = 2/3$, at the stellar surface. Figure 1 shows the location of the different synthetic models. The range for the other values considered for HYDWIND and FASTWIND grids are listed in Table 1.

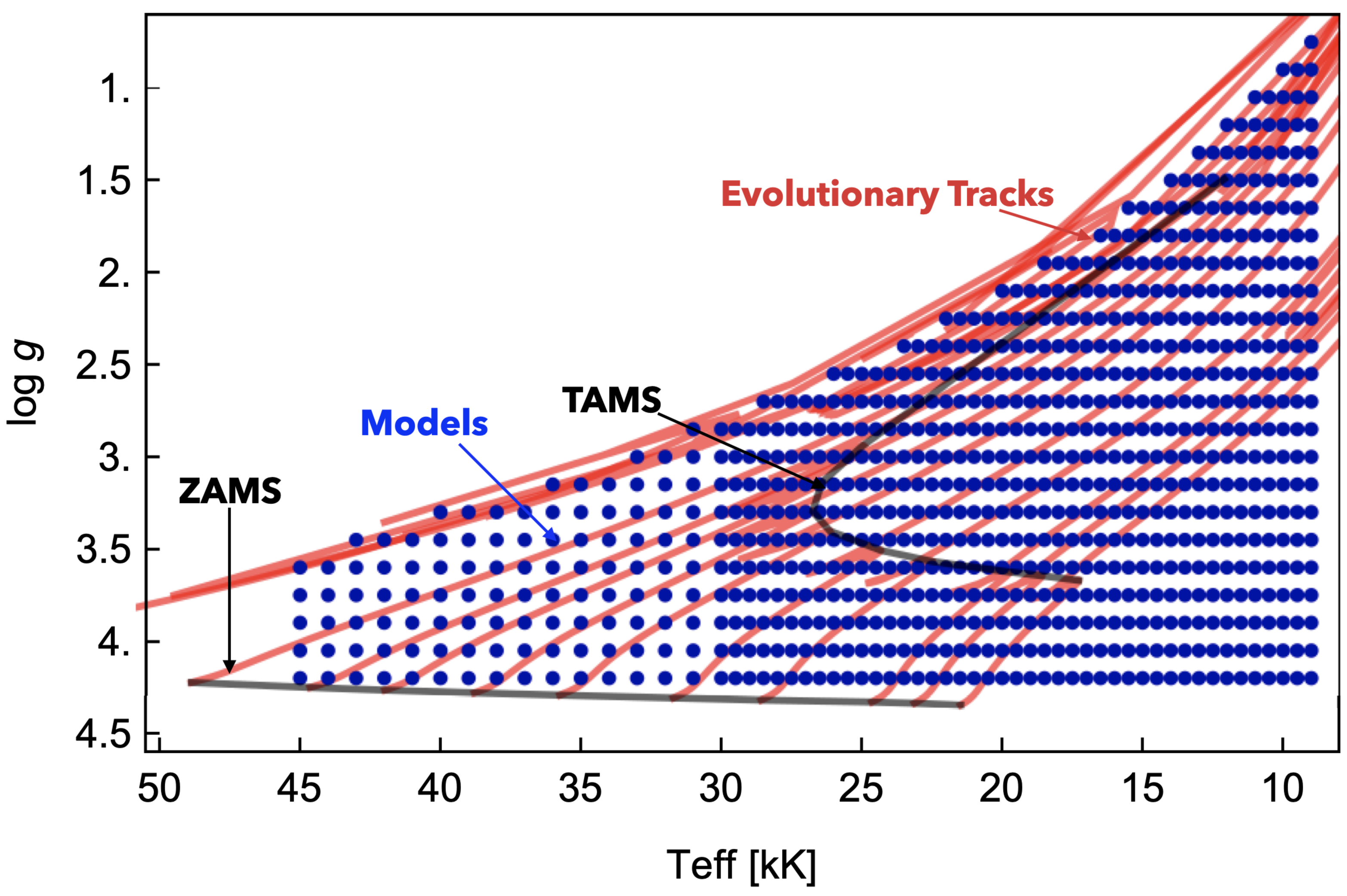


Figure 1: Location of ($T_{\rm eff} - \log g$) pairs (dots) considered in the grid of models. The red lines represent the evolutionary tracks from 7 $M_\odot$ to 60 $M_\odot$ without rotation (Ekström et al., 2008), while the black lines correspond to the zero age main-sequence (ZAMS) and the terminal age main-sequence (TAMS).

Table 2: Range of values considered in HYDWIND and FASTWIND grids

α:	0.45, 0.47 ,0.51, 0.53, 0.55, 0.57, 0.61, 0.65
k:	0.05 to 0.60 (step size 0.05)
δ:	0.00, 0.04, 0.10, 0.14, 0.2,0.24 , 0.3, 0.31, 0.32,0.33, 0.34, 0.35
$\log \epsilon_{\rm Si}$:	7.21, 7.36, 7.51, 7.66, 7.81
$v_{\rm micro}$:	1.0, 5.0, 10.0, 15.0, 20.0, 25.0 km/s

In the case of the FASTWIND grid, we calculated a total of $573\,433$ models. From these models line profiles of H, He, and Si elements were calculated in the optical and infrared range. Also, it is important to notice, that all our models are calculated without stellar rotation.

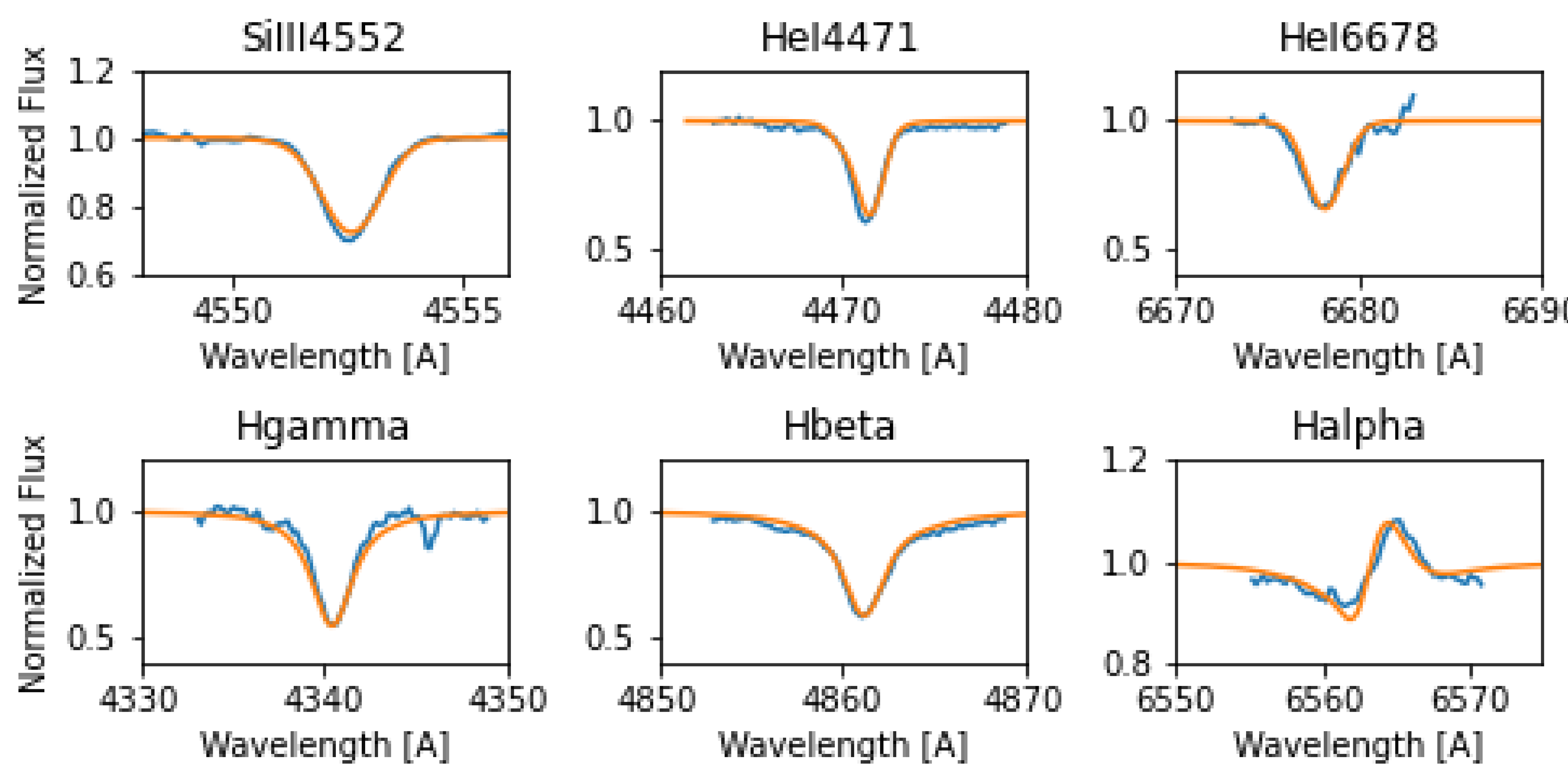
Method

The observational data was pre-processed using the *iacob broad* tool (Simón-Díaz & Herrero, 2014) to derive the projected rotational and macroturbulent speeds. Then, these values were used in our search code to perform the spectral fitting with the purpose to obtain stellar and wind parameters.

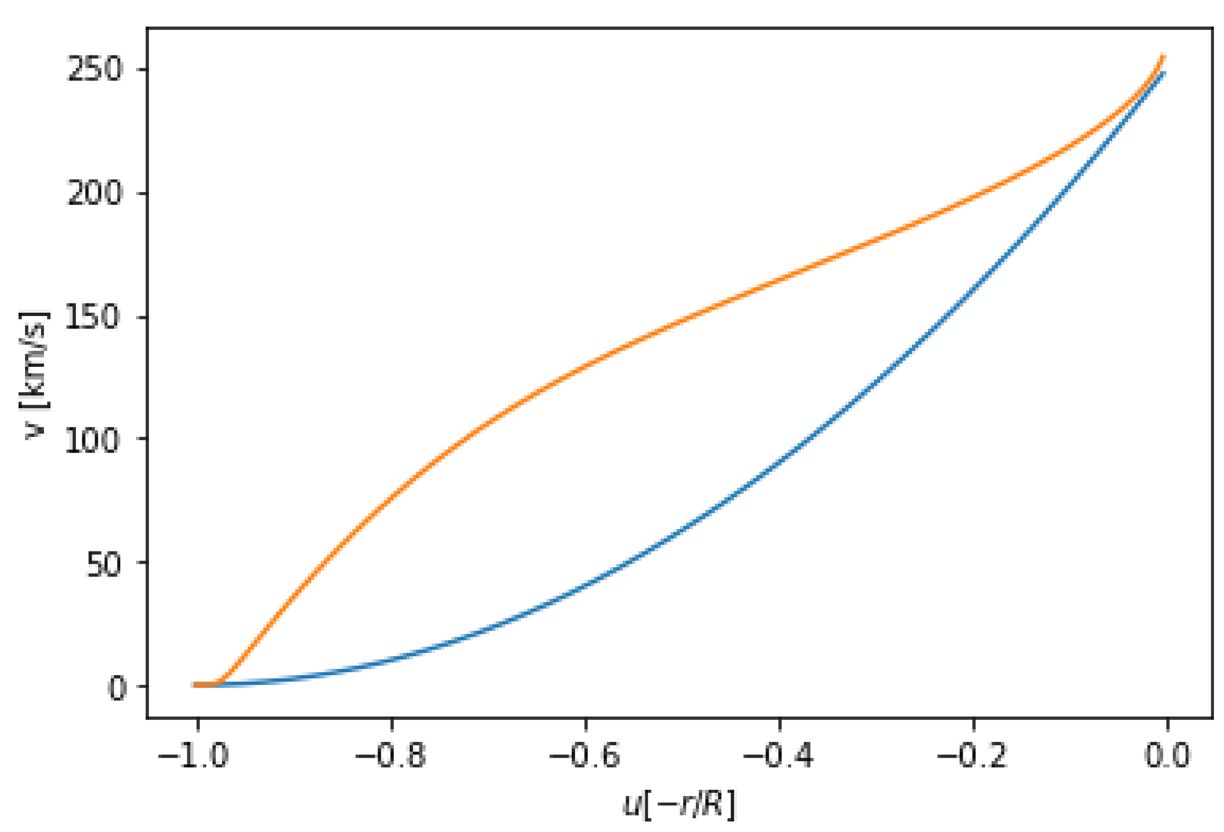
First, the code reads an input file that contains the information of the observational data, the convolution parameters and the type of solution we are searching for (optional). In a second step, it uses multiprocessing tools to search through the grid. The line profiles are rotationally convolved and interpolated with the observed line. Then a χ^2 test is performed. Finally, the code collect all these results and sort them from lower to higher χ^2 values, selecting and returning the one that most resembles to the observational data.

First Results

By way of example, we present the results for the star HD99953 considering 6 line profiles. Blue solid line shows the spectra retrieved from Haucke et al. (2018). Orange solid line corresponds to a model with the following parameters: $T_{\rm eff} = 185000\,{\rm K}$, $\log g = 2.4$, $\alpha = 0.45$, $k = 0.25$, $\delta = 0.32$, $v_{\rm micro} = 15\,{\rm km/s}$ and $\log \epsilon_{\rm Si} = 7.81$. These line force parameters correspond to a δ-slow solution with a $\dot{M} = 0.243 \times 10^{-6}\, M_\odot/{\rm year}$ and $v_\infty = 254\,{\rm km/s}$.



The stellar parameters are similar with the ones obtained by Haucke et al. (2018). Regarding to the wind parameters, they found a $\dot{M} = 0.08 \times 10^{-6}\, M_\odot/{\rm year}$ and $v_\infty = 250\,{\rm km/s}$ and a $\beta = 2$ for the velocity profile. From figure (below), we can observe the difference between the velocity profile used by Haucke et al. (2018) (blue solid line) and our hydrodynamic profile (orange solid line).



According to our experience in spectral line fittings, we predict that the models with values of $\beta \gtrsim 1.5$ can be properly reproduced with the hydrodynamic solution δ-slow.

Further studies using more stars and more spectral lines will give us more accurate results in the wind and stellar parameter estimation, leading us to find the WLR with accuracy parameters. As future work, we expect to analyze the χ^2 distributions and then use it to compute the uncertainties for each derived parameter.

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