Synthetic spectra for O and B type subdwarf stars

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Abstract: We present a new NLTE grid of optical (3200–7200 Å) synthetic spectra calculated with Tlusty/Synspec. Our model atmospheres include the most recent hydrogen Stark broadening profiles; were calculated in opacity sampling but limited to pure H/He composition. The grid covers the observed parameter space of (He-)sdB and (He-)sdO stars, making it suitable for the homogeneous spectral analyses of such evolved stars.

Introduction

Hot subdwarfs are very important objects to understand the late stages of stellar evolution. These He burning stars connect the red giant branch to the white dwarf sequence and suffer a strong mass-loss before they settle on the extreme horizontal branch for about a 100 Myr. This way hot subdwarfs also give an insight into the horizontal branch morphology. The conditions and reasons of the extreme mass-loss are not easy to decipher, in particular for single stars. Current formation theories can explain the observed subdwarf populations, but extensive spectral libraries, that include all types of hot subdwarfs, would be welcome to separate the observed populations and find the relative contributions of the various formation channels.

Line blanketing and NLTE effects are strong and must be considered in subdwarf spectroscopy while the static plane-parallel atmosphere approximations are still valid. The NLTE model atmosphere code Tlusty is long used in subdwarf atmospheric analyses, libraries of synthetic spectra have been calculated and fitted successfully for numerous subdwarfs. However, recent improvements in the theoretical models and the lack of a homogeneous, publicly available reference library motivated us to calculate a new grid. Here we present a comprehensive spectral library, which is based on the observed distribution of hot subdwarf stars and suitable for their homogeneous analyses.

Model calculation

We used Tlusty 204 and Synspec 49 (Hubeny & Lanz 1995; Lanz & Hubeny 1995) in our work, which calculate plane–parallel, horizontally homogeneous, static stellar atmospheres in radiative and hydrostatic equilibrium treating metal line blanketing by means of opacity sampling. The most detailed model atoms of H and He were included from the BSTAR database (Lanz & Hubeny, 2007) giving altogether 61 explicit energy (super-)levels and 330 radiative transitions.

The grid was calculated in about 1400 CPU hours and consists of 11 396 grid points to which we were able to converge 10 887 spectra (95.5%) in the current version. The grid is complete between $\log g = 5.0$ and 6.1 (cgs), most of the slow converging models are either at low T_{eff} – high $\log g$ (the extremely low-mass white dwarf regime) or at high He abundance – high $\log g$, where no stars were observed in a sample of ∼170 hot subdwarfs selected from the GALEX survey (Németh et al., 2012). However, that analysis was done with Tlusty as well, which raises the concern of detectability of such stars. The atmospheres with a high helium abundance and low effective temperature are convectively unstable and a He convection zone is difficult to model.

The spectral energy distributions were calculated at 16 000–18 000 frequency points using 70 depth points in opacity sampling. The microturbulent velocity was set to zero and all models were converged to a relative change of 0.1% of the structural parameters. Synthetic spectra were then calculated in the range of 3200–7200 Å with 0.1 Å step size, ensuring that both the continuum and the line profiles are sampled well. Because the abundances were limited to H/He our models do not address the Balmer line problem. Due to this shortcoming the derived atmospheric parameters are not expected to be consistent with the more accurate photometric or asteroseismic constraints.

A sample of synthetic spectra near the Hβ line are shown in Figure 1. Effective temperature increases from bottom to top in the figure as well as the He abundance in each sequence. The shift in ionization balance is marked by the gradual decrease of the He I/He II line strength ratio towards higher temperatures. Also remarkable is the weakening of the Hβ line at higher temperatures and He abundances, while in the most extreme cases the He II Pickering series dominates the spectra.
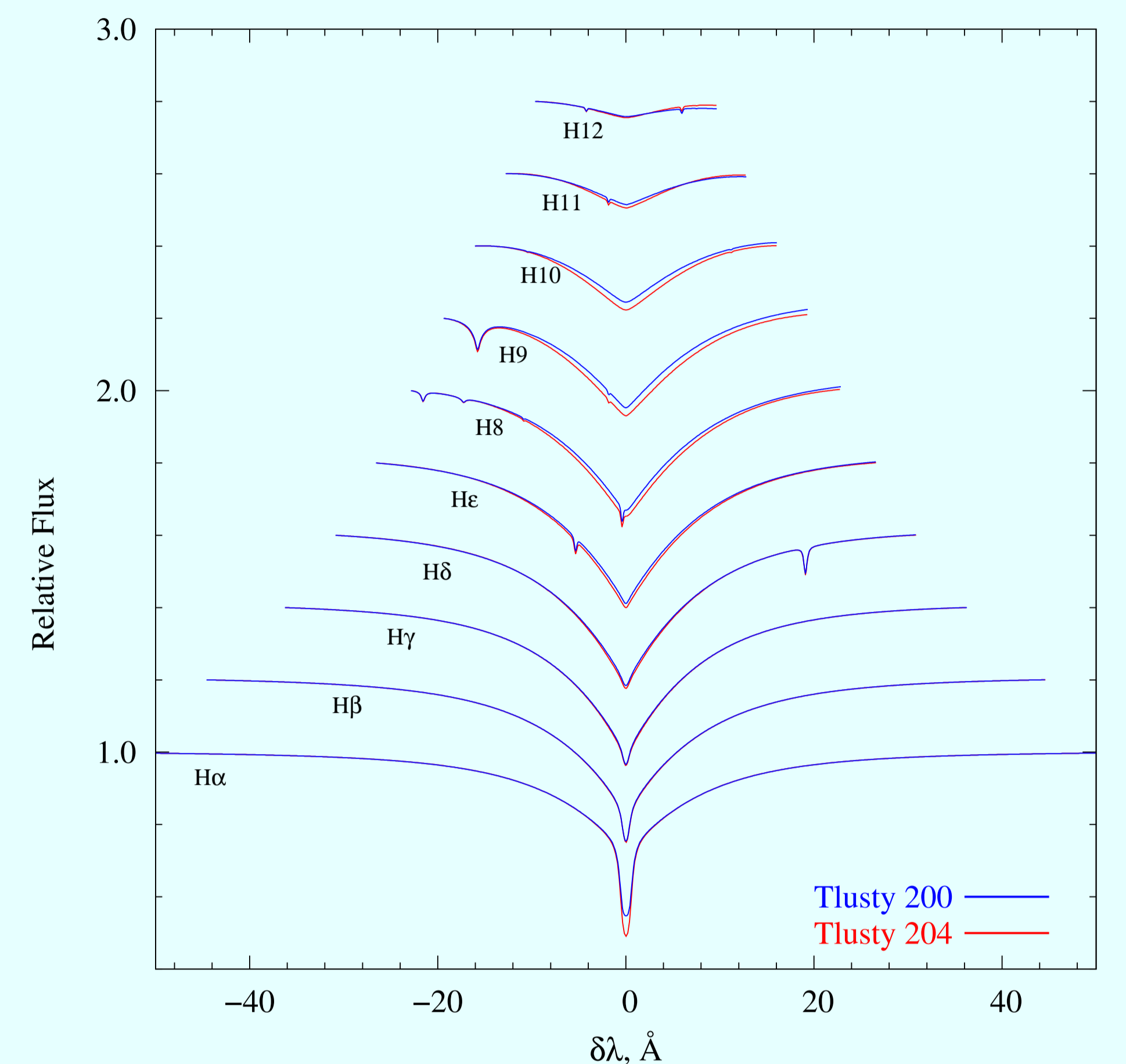
Line profiles

The new version of Tlusty makes it possible to include detailed H line profiles directly in the atmosphere structure calculations. We added the Stark broadening tables for the first ten lines of the Lyman and Balmer series of H from Tremblay & Bergeron (2009). A systematic line profile difference towards the high members of the Balmer series has been observed in white dwarfs and also notable for subdwarfs, in particular for the Hϵ – H10 lines in Figure 2. The differences in the line profiles are relatively small. However, because the surface gravity is constrained by the upper Balmer series, even such small differences can be responsible for about half of the discrepancy observed between spectroscopic and photometric surface gravities, also known as the $\log g$ problem (Rauch, 2012). We expect that the new profiles will increase the internal consistency of temperature and gravity determinations from various Balmer lines. Surprisingly, we found a deeper Hα line core. Although the new line profiles modify the atmospheric structure and the level populations, this change was unexpected and needs further investigations.

Beyond the H line profiles our models include detailed profiles for the overlapping forbidden components of four He I lines (4026, 4388, 4471, and 4922 Å) as well as detailed profiles for the He II Balmer, Paschen and Pfund series. The structure of the 4922 He I line can be seen in Figure 1.

The library

The parameters of our grid are listed in Table 1. The library consists of synthetic spectra and continuum flux in ASCII format and can be downloaded from:
http://www.ster.kuleuven.be/~petern/work/sd_grid/

Figure 2: Hydrogen line profiles of a typical sdB star with $T_{eff} = 32\,000$K, $\log g = 5.7$ (cgs) and He/H = 0.013 model. Lines were shifted for clarity and normalized at the short wavelength end.

**Table 1:** Boundaries of the spectral library.

Parameter	Lower limit	Step size	Higher limit
T_{eff} (K)	20 000	+1000	56 000
$\log g$ (cgs)	5.0	+0.1	6.3
nHe/nH	0.0005	×2	100

Before the final publication of our grid further efforts will be made to converge the missing model atmospheres and the continuum sampling will be increased to at least a few Ångströms in order to reduce the size of the database below 1 Gb.

References

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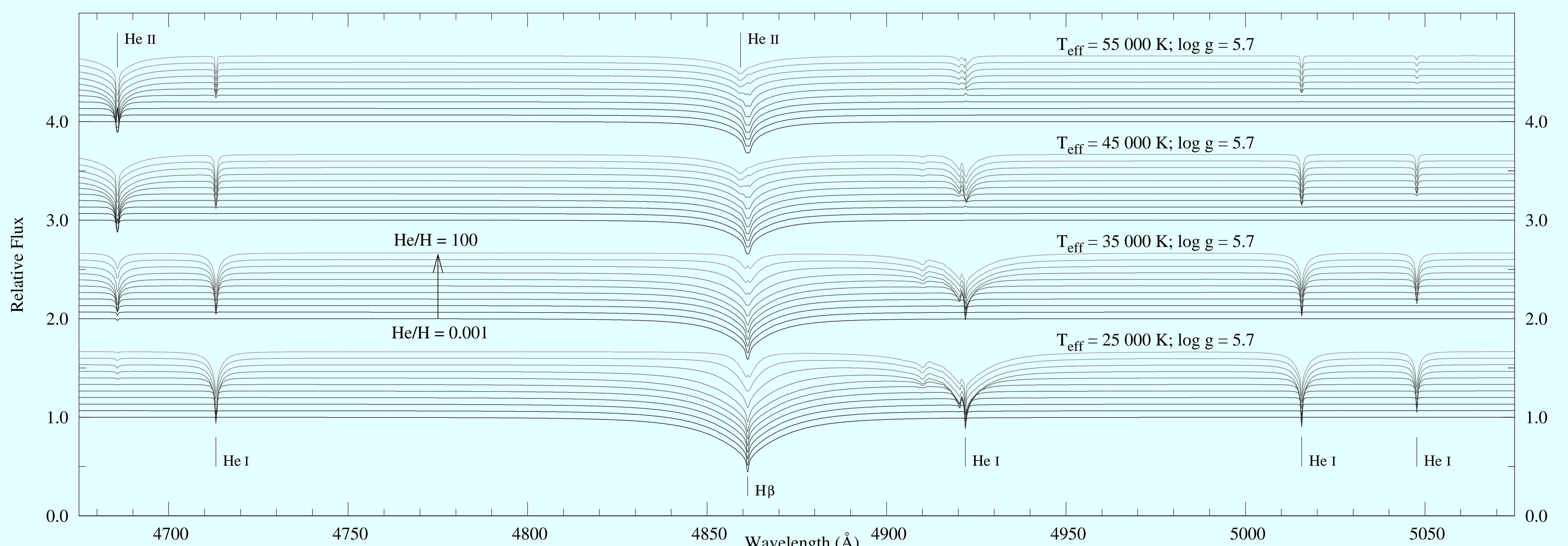
Figure 1: Spectral variations along increasing temperature and He abundances from bottom to top at $\log g = 5.7$ (cgs).