Carbon abundances of sdO stars from SPY

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Abstract. Ströer et al. (2007) recently suggested a classification of sdOs according to supersonar and subsolar helium abundances, with only the helium-enriched stars showing signs of carbon and/or nitrogen in their optical spectra. We aim to derive reliable carbon and nitrogen abundances by fitting synthetic spectra to data obtained with the UVES spectrograph at ESO. Here we present our first results of the analysis of carbon abundances in hot subdwarf O stars. By constructing a grid of model atmospheres consisting of hydrogen, helium and carbon we were able to derive atmospheric parameters of nine carbon rich sdOs. We find log(N_C/N_total) up to ten times higher than the solar value, while the mean value for the effective temperature and the surface gravity is slightly lower than derived by helium-hydrogen models only. Surprisingly, we also find three fast rotators among our program stars.

1. Introduction
Subdwarf O stars (sdO) and their cooler siblings, the sdBs, form what is called the “Extended Horizontal Branch (EHB)” in the HRD. They are core helium burning stars with virtually no hydrogen envelope. While the sdBs are quite homogeneous, showing low helium abundances and their metal abundances are explainable by diffusion, the sdO stars show a wide variance in T_{eff}, log(g) and log(N_{He}/N_H). Ströer et al. (2007) divide them into helium-enriched and helium-deficient stars with the dividing line being the solar helium abundance, log(N_{He}/N_H)⊙ = −1. The helium-enriched sdOs are clustered in a narrow region in the T_{eff} − log(g)-plane at T_{eff} ≈ 45 000 K and log(g) ≈ 5.6.

2. Evolution
Comparison between observed parameters of sdOs and theoretical evolutionary tracks (see Fig. 1) show that the helium deficient stars (open symbols) most likely are the progeny of the sdB stars. The helium-enriched stars (filled symbols) however are not so easily explained as their overdensity strongly disagrees with the timescales of the post-EHB stracks.

3. Beyond hydrogen and helium
Ströer at al. (2007) find that the helium-enriched sdOs can further be divided into C-, N-, and CN-types, depending on their spectra showing nitrogen or carbon or both. Two scenarios for the origin of He-enriched sdOs have been proposed. a) Late hot flashers (Sweigart et al., 1997; Lanz et al., 2004) are stars that undergo a delayed helium core flash when they are already on the WD cooling curve. This scenario comes in two different flavours, “deep” and “shallow” mixing.
Figure 1. Data from SPY (triangles) and SDSS (squares). Filled symbols are helium-enriched stars, open symbols are helium-deficient. Also shown are the locations of the EHB and the main sequence for helium burning stars. The two evolutionary tracks in the upper left are post-AGB stars (Schönbener et al., 1983). Evolutions from the EHB towards the White Dwarf graveyard are shown by three tracks on the right (Dorman et al., 1993).

In the former, the hydrogen envelope will be mixed into the star’s interior and will be burned completely, while in the latter case the mixing will take place without the hydrogen being burnt.

b) He-WD mergers (Han et al., 2002; Saio & Jeffery, 2002) result from the coalescence and eventual merger of He-WDs due to radiation of gravitational waves. These scenarios may become distinguishable by the predicted abundances.

4. Spectral analysis
To further investigate this issue, we are doing an analysis of sdO stars from the SPY survey (Napiwotzki et al. 2001), which provides the necessary resolution and SNR for this analysis. The spectra were observed with the UVES spectrograph at ESO and cover the wavelength range from 3,300 Å to 6,600 Å at high resolution.

As a first step in this direction we identified all elements present in SPY sdO stars. While the helium-deficient sdOs spectra are virtually void of any element other than helium and hydrogen, we find the C-type helium enriched ones to show traces of nitrogen, silicon and oxygen besides carbon. In the N-type spectra we find neon, sulfur, titantium, silicon, oxygen and carbon besides the dominant nitrogen.

Using model atoms of H, HeI, HeII, CIII and CIV we constructed an extensive model grid of \( \log(N_{\text{He}}/N_{\text{H}}) = -1 \cdots + 2 \), \( T_{\text{eff}} = 40000 \cdots 60000 \text{K} \), \( \log(g) = 5.00 \cdots 6.40 \) and \( \log(N_{\text{C}}/N_{\text{total}}) = -2 \cdots - 6 \). The atmospheric structure was calculated using the PRO2 code by Werner & Dreizler (1999) and Dreizler (2003) under consideration of lineblanketing of the present model atoms. The model spectra were folded to the instrument profile taking the seeing
 Figure 2. An example of a fit of $\log(N_C/N_{\text{total}})$ and $v_{\text{rot}} \sin i$. The best fit model here is $T_{\text{eff}} = 44200$ K, $\log(g) = 5.64$, $\log(N_C/N_{\text{total}}) = -2.8$ and $v_{\text{rot}} \sin i = 12$ km s$^{-1}$. All lines shown are CIII with the exception of their blend with HeII $\lambda$3889 Å and HeI $\lambda$4121 Å. All fitted ranges shown are shifted to $\lambda = 0$ with their original central wavelength given on their left side.

Spectral line fitting was performed by interpolating in $\log(N_{\text{He}}/N_{\text{H}})$ to the value obtained by Ströer et al. (2007), then simultaneously fitting $T_{\text{eff}}$ and $\log(g)$ using the H- and He-lines. Care was taken that no contamination of carbon lines did occur in the broad line wings. Fixing $T_{\text{eff}}$ and $\log(g)$, a new fit using only CIII-lines was done to determine $\log(N_C/N_{\text{total}})$ and $v_{\text{rot}} \sin i$, see Fig 2.

With one exception, for every star two or more spectra were available. We use these multiple results to get a crude error estimate of $\Delta T_{\text{eff}} = 500$ K, $\Delta \log(g) = 0.1$ and $\Delta \log(N_C/N_{\text{total}}) = 0.3$.

5. Results

Atmospheric parameters: For all nine C-type helium-enriched sdOs in the SPY-sample we determined new $T_{\text{eff}}$ and $\log(g)$. The results are plotted in Fig. 3. The new model atmospheres lead to some changes of parameters compared to the values by Ströer et al. 2007. The mean $T_{\text{eff}}$ is lowered by 1300 K, the mean $\log(g)$ by 0.14 dex. Whether these differences are due to additional lineblanketing of the carbon or to different analysing methods is still open for investigation.

Carbon abundances: We find the carbon abundances to lie between $\log(N_C/N_{\text{total}}) =$
Figure 3. Filled symbols are the new values for $T_{\text{eff}}$ and $\log(g)$, the values from Ströer et al. (2007) are open symbols. The origin of this difference still has to be investigated.

$-2.3\cdots -3.1$, that is up to ten times to the solar value ($\log(N_C/N_{\text{total}}) = -3.5$), but no trends in $T_{\text{eff}} - \log(N_C/N_{\text{total}})$ or $\log(N_{\text{He}}/N_{\text{H}}) - \log(N_C/N_{\text{total}})$ can be seen. These first measured abundances enable us to compare the observations with theoretical late hot flasher calculations, Miller Bertolami, M., this proceedings.

Rotational velocity: Surprisingly, we find three out of nine sdOs to be “fast” rotators with $v_{\text{rot}} \sin i = 23$, 23 and 28 km s$^{-1}$ — fast compared to sdBs which mostly show $v_{\text{rot}} \sin i < 10$ km s$^{-1}$ (Geier et al., in prep.). This discovery seems to favour the WD-merger theory.

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References
Dorman B Rood R T and O’Connell R W 1993 ApJ 419 596-614
Dreizler S 2003 ASP Conf. Ser. 288 69-82
Han Z Podsiadlowski Ph Maxted P F L Marsh T R and Ivanova N 2002 MNRAS 336 449-66
Lanz T Brown T Sweigart A Hubeny I Landsman W 2004 ApJ 602 342-55
Miller Bertolami M M Althaus L G 2007 Preprint ArXiv:0711.0140
Napiwotzki R et al. 2001 Astronomische Nachrichten 322 411-18
Saio C H and Jeffery C S 2002 MNRAS 333 121-132
Schönberner D 1983 ApJ 272 708-14
Ströer A Heber U Lisker T Napiwotzki R Dreizler S Christlieb N and Reimers D 2007 A&A 462 269-80
Sweigart A 1997 Third Conference on Faint Blue Stars, L. Davies Press 3
Werner K and Dreizler S 1999 Preprint ArXiv: astro-ph/9906130