# Hot subluminous O stars from the SDSS

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## Abstract

The population of faint blue stars in the Galactic halo is dominated by hot subluminous stars. While those of B-type (sdB stars) have been studied in great detail, their hotter siblings (sdO stars) have not. Therefore we carried out quantitative spectral analysis of sdO stars taken from the Sloan Digital Sky Survey (SDSS) and we determined $T_{\rm eff}$, $\log g$ and the helium abundance. We find that the helium rich sdOs cluster in a narrow region at $T_{\rm eff} \approx 45\,000\,K$, $\log g \approx 5.8$ while the helium poor stars are widely spread. A comparison with evolutionary paths fails to explain the distribution of the former in detail, whereas the latter are most probably the progeny of the subluminous B stars. The helium enriched sdOs show carbon and/or nitrogen lines, but none of the helium deficient ones. We argue that the helium enriched sdO stars are formed from mergers of helium white dwarfs or via a delayed helium core flash.

## Introduction

Hot subluminous stars can roughly be divided into two classes: The hotter and in general helium rich subluminous O stars (sdO) and the helium deficient subluminous B stars (sdB). Since the work of Greenstein & Sargent (1974), the sdB stars are thought of as the progenitors of the sdO stars. The sdB stars have been identified as extended horizontal branch stars (EHB). They form a quite homogenous group of strongly helium deficient stars with effective temperatures between $\approx 20\,000\,K$ and $40\,000\,K$ (Heber, 1986). They consist of a helium burning core and a hydrogen shell of less than $0.02\,M_\odot$, too thin to sustain hydrogen shell burning. The unsolved question is, how the high mass loss necessary for a star to reach the EHB is accomplished. SdO stars on the other hand are poorly studied and therefore less well understood.

Following recent work on the sdO stars by Stroeer et al. (2007), we divide the sdOs in helium enriched and helium deficient sdOs, depending on wether they show sub- or supersolar helium abundances. Additionally, a classification based on the carbon and nitrogen line spectrum was introduced, that classifies sdOs into C, N, CN or 0, depending on the presence or absence of lines of carbon and/or nitrogen.

Our aim is to better understand the origin of sdOs and to search for possible links between them and the sdBs.

## Spectral analysis

The huge spectral database of the SDSS is a rich source for stellar astronomy. It provides spectra with a moderate resolution of $R \approx 1800$ from 3800 to 9200 Å. In order to study a large sample of sdO stars, we started an extensive search. We selected all stars within the colour range $(u-g) < 0.4$ and $(g-r) < 0.1$ included in the Data Release 5. This colour criterium excluded most stars showing composite spectra. Eventually we found 89 out of 156 sdO spectra of sufficient quality for spectral analysis. We performed a fit of synthetic spectra from state-of-the-art NLTE model atmospheres to the data using a $\chi^2$-routine (Napiwotzki, 1999), see Fig. 1. The model atmospheres contain hydrogen and helium only and take into account partial line blanketing. With the ionisation equilibrium beeing a formidable $T_{\rm eff}$-indicator, we always included He I 4472 Å into the fits.

The statistical errors are smaller than 2 000 K in $T_{\rm eff}$ and 0.14 dex in $\log g$ for 71% of the stars. The helium abundances are accurate to 0.3 dex or better. We regard these numbers as typical errors for our stars.

## Results

A search for metal lines revealed that while helium deficient stars show no or very few metal lines, the helium enriched ones show many and often very pronounced lines of carbon and nitrogen (Fig. 1). This is consistent with the findings of Stroeer et al. (2007), who used a sample of sdO stars drawn from the SPY survey. From here on, we will combine these 46 sdO stars from Stroeer et al. (2007) with our sample, in order to improve statistics.

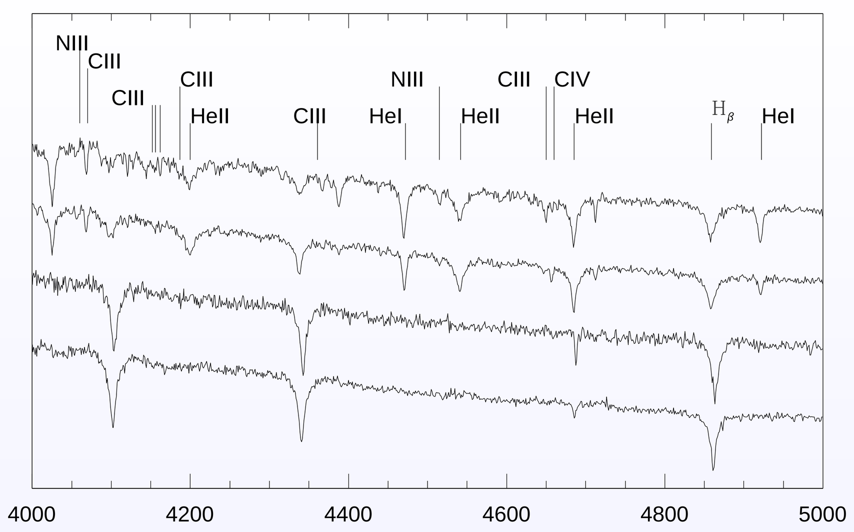


*Fig. 1. Some important lines for carbon and nitrogen. The top two stars are helium enriched, the bottom two are helium depleted.*

As shown in Fig. 2, we find no sdO star located on the EHB, and though there is an accumulation of stars near it, the stars are widely scattered in $T_{\rm eff}$ and $\log g$. This suggests that either they all are post-EHB stars, or they even may not be connected to the EHB at all and their location near the EHB is coincidence. Interestingly, the helium enriched sdO stars are concentrated in a narrow interval of $T_{\rm eff} = 40\,000\ldots50\,000\,K$, $\log g = 5.2\ldots6.3$, whereas helium deficient ones shun this region. Another point of interest are a few sdOs *below* the helium zero age main sequence (He-ZAMS). This is at variance with evolution theory, as such stars would not be able to sustain helium burning in their cores.

## Stellar Evolution

Canonical evolution theory sees the sdOs as progeny of the sdB stars. Dorman et al. (1993) have calculated accordant tracks, beginning with a star with minimal mass for helium ignition and a small envelope. The tracks lead from the zero age EHB (ZAEHB) to the terminal age EHB (TAEHB) and then through the sdO regime to higher temperatures and higher surface gravities. We present these tracks along with our sdOs in Fig. 2. They fail to explain the clustering of helium enriched sdOs, but reproduce the population of helium deficient sdOs well. Hence **the helium deficient stars form the progeny of the sdB stars** while the helium enriched ones do not.

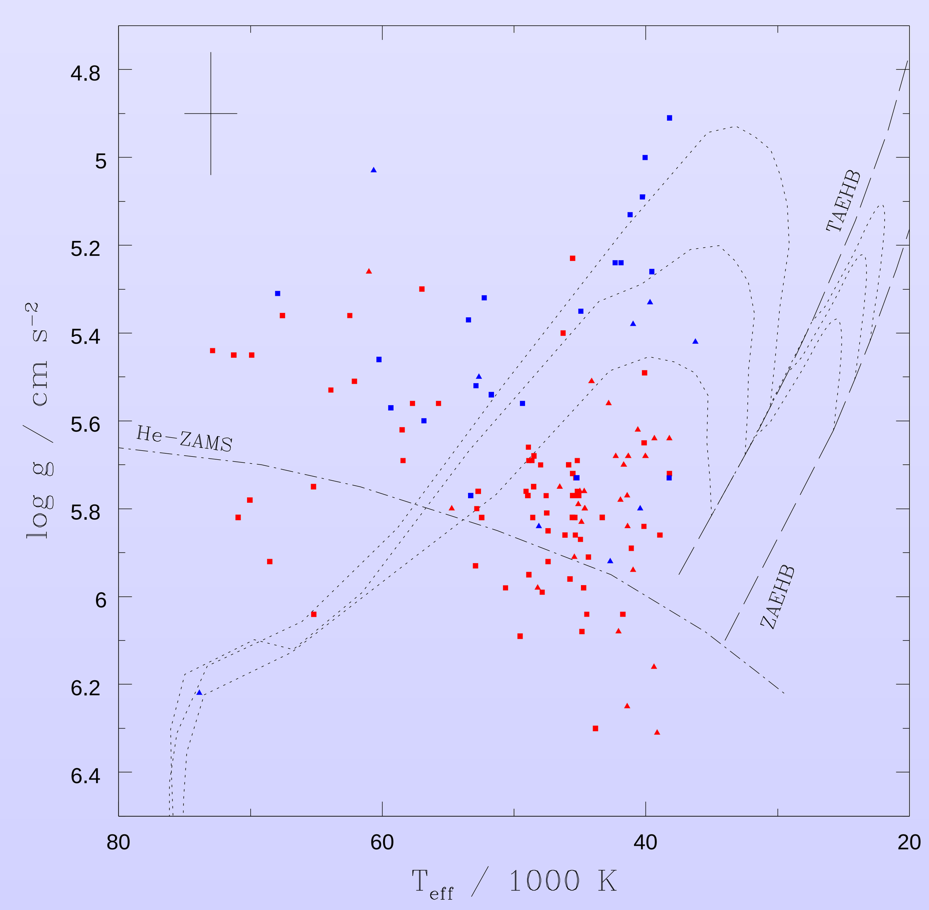


*Fig. 2. $T_{\rm eff}$-$\log g$-diagram of sdO stars from SDSS (squares) and SPY (Stroeer et al., 2007) (triangles). The red symbols represent helium enriched stars, helium deficient ones are blue. The EHB is marked by the zero age terminal age EHB (TAEHB) as well as the helium zero age main sequence (He-ZAMS). Shown are evolution paths for sdB stars on the EHB band and beyond (Dorman et al., 1993). The three paths represent stars with 0.471, 0.473 and 0.475 $M_\odot$ core masses (from bottom to top). A typical errorbar is drawn in the upper left corner.*

In order to explain the **helium enriched sdOs**, we invoke close binary evolution: Three channels leading to a helium burning star with a tiny hydrogen envelope have been discussed by Han et al. (2002, 2003). Such stars can be formed by **stable Roche Lobe overflow, common envelope ejection and the merging of two helium white dwarfs.**

In particular, the merging scenario is a promising option to explain helium enriched sdO stars. Short period binaries of two helium white dwarfs will loose energy through radiation of gravitational waves. Eventually, they will merge and the resulting star will ignite helium. Han et al. (2002) argue, that this merging process will mix the hydrogen shells into the helium burning regions where it will rapidly be consumed and bring up processed material to the surface. This would explain the richness in carbon and nitrogen lines observed in the spectra.

However, population synthesis simulations by Han et al. (2002, 2003) fail to explain the distribution of helium enriched sdOs in detail. The bulk of sdOs with $T_{\rm eff} = 40\,kK\ldots50\,kK$ seen in the observations is not present in the simulations. Further on, the sdOs in our analysis are significant bluer than in the simulations, where no star exceeds $T_{\rm eff} = 45\,kK$.

### Delayed helium core flash

Sweigart (1997) proposed a scenario for single stars. He argued that fast rotating RGB stars could mix helium into the shell. This will delay the helium flash until the star is already on the white dwarf cooling curve. The delayed flash induces mixing which will transport hydrogen into the core, resulting in a helium burning star with $T_{\rm eff} \approx 40\,000\,K$ on or near the He-ZAMS, enriched with carbon or nitrogen.

An example of this evolution is shown in Fig. 3 for a star with a resulting composition of $X = 0.154, Y = 0.814$. We see an excellent coverage of the area of the helium enriched sdOs. In spite of this promising prospect, one serious problem remains. From the evolutionay timescales we would expect many more stars near the He-ZAMS. This, however, is not observed.

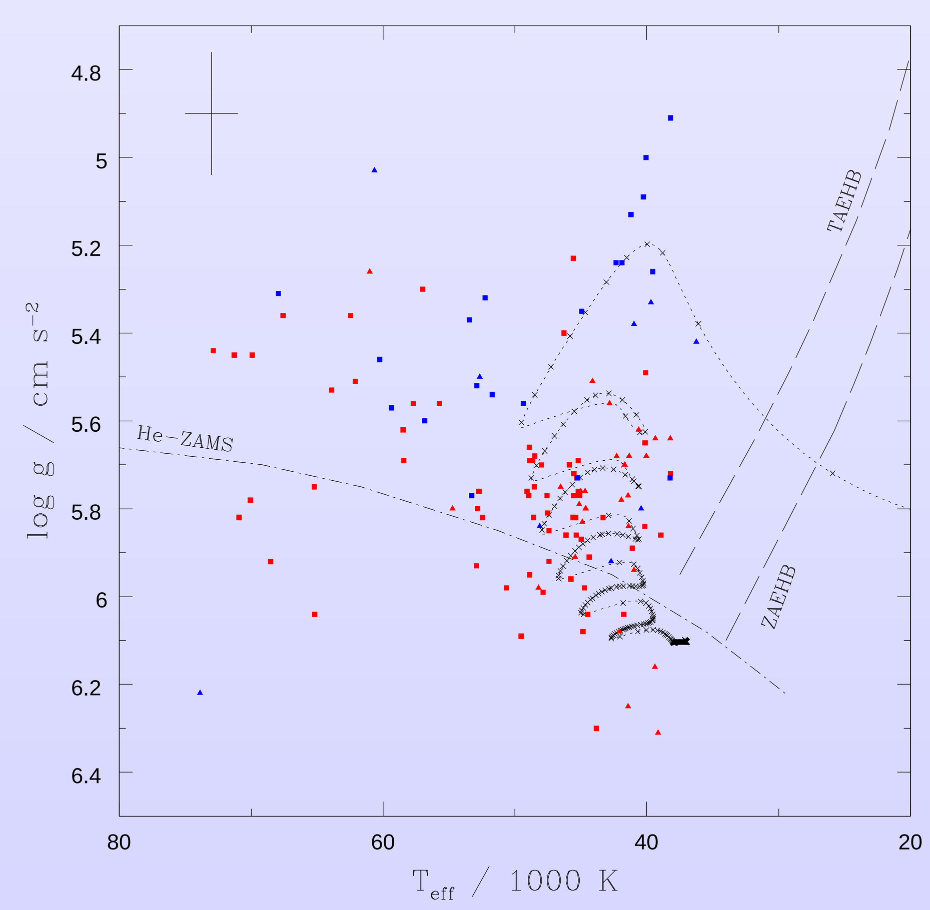


*Fig. 3. (to the left) The evolutionary path of a late hot flasher is shown. The track covers the cluster of helium enriched sdOs. We have marked the track with equidistant timesteps of 10 000 years, revealing a significant discrepancy of evolutionary timescales and the observed distribution.*

## Summary and conclusion

Faint blue stars dominate the population of faint blue stars in the Galactic halo. While the cooler sdBs have been studied in detail, the hotter sdOs have not.

We did a search for spectra of subluminous O stars in the SDSS database and performed a spectral analysis for 89 stars, fitting synthetic spectra to the observed ones via a $\chi^2$-technique. The analysis revealed a clustering of helium enriched sdOs in a small intervall at about 45 000 K, a region almost void of the helium deficient stars. A comparison of the sdOs in the $T_{\rm eff}$-$\log g$-diagram with different evolutionary tracks showed that the helium deficient sdO stars probably form the progeny of the sdB stars. The stars with helium enriched atmospheres still pose a problem: both the late hot flasher and the white dwarf merger scenario can explain the observations qualitatively, but fail to do so in the detail.

Further, we found the helium enriched sdOs also enriched in carbon and nitrogen. As the different formation channels predict different mixing in the atmosphere, a quantitative analysis of their abundances is the next step in our work. We have started a project to measure carbon and nitrogen abundances using hires spectra from the SPY survey, which will clarify the question of their formation process.

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