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The Origin of Helium-Rich Subdwarf O Stars

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Abstract. The origin of helium-rich subdwarf O stars (He-sdO) is still unclear. Significant progress has been made recently in placing them in the Hertzsprung–Russell diagram. However, the question of their progenitors is still unsolved. It is unclear which types of stars evolve into He-sdOs and whether they are formed by all galactic populations. Here I will present results of a radial velocity (RV) survey of He-sdOs, which will be used to constrain the binary fraction and evaluate population membership.

1. Introduction

The zoo of hot subdwarf stars is divided into two main classes: the cooler subdwarf B (sdB) stars and the hotter subdwarf O (sdO) stars. The sdB class is relatively homogeneous with most members being hydrogen-rich and on or close to the extreme horizontal branch (EHB; Heber 1986). The sdO class on the other hand is very diverse, with luminosities spanning two orders of magnitude and atmospheric chemistry ranging from helium-poor to very helium-rich (Stroeer et al. 2007). A number of He-rich ($n_{\rm He}/n_{\rm H} \gtrsim 0.3$) sdO stars cluster in the parameter range $T_{\rm eff} = 37000\ldots55000\,{\rm K}$ and $\log g = 5.5\ldots6.2$. These will be called He-sdO further-on. They are clearly distinct from the hydrogen-rich sdOs, none of which has a He abundance in excess of the solar value ($n_{\rm He}/n_{\rm H} \lesssim 0.1$). Another interesting distinction between both types are the carbon and nitrogen abundances. Lines of carbon and/or nitrogen are present in every He-sdO, but in none of the hydrogen-rich sdO stars investigated by Stroeer et al. (2007).

He-sdO populate a region in the Hertzsprung–Russell diagram close to the hydrogen-rich sdBs, which are cooler and – on average – less luminous. Evolution calculations predict that sdBs evolving away from the EHB pass through the He-sdO region (Dorman et al. 1993). Thus a link between both classes appears plausible. Greenstein & Sargent (1974) were the first to point out that mixing by a helium convection zone below the surface could be responsible for the transformation of sdBs into He-rich objects, when they evolve to higher temperatures. However, detailed calculations by Groth et al. (1985) showed that this mechanism does not work. MacDonald & Arrieta (1994) argue that the hydrogen-rich envelope of sdBs could be stripped off by a combination of mass loss and mixing processes. Castellani & Castellani (1993) and D'Cruz et al. (1996) put forward the hot flasher scenario, in which the star leaves the red giant branch, because it lost most if its envelope, but suffers from a late helium core flash afterwards. The resulting subdwarfs are hotter than standard EHB stars. However, only the so-called late hot flasher scenario (Brown et al. 2001) predicts intensive deep mixing transforming the envelopes from hydrogen-rich to helium-rich. Another scenario proposes the formation of He-sdOs via a phase as extreme He stars after the merging of two He core white dwarfs (Iben 1990; Saio & Jeffery 2000).

Recent radial velocity (RV) surveys revealed that a large fraction ($> 30\%$) of all sdB stars resides in close binaries (Saffer et al. 1998; Maxted et al. 2001; Napiwotzki et al. 2004a; Edelmann et al. 2004). If He-sdO are the result of post-EHB evolution (including late flashers), a high frequency of close binaries is expected. The merger scenario on the other hand predicts that none of the He-sdOs should be part of a close binary system *now*.

2. Hot Subdwarfs in the SPY Radial Velocity Survey

SPY, the ESO **S**upernovae type Ia **P**rogenitor surve**Y** (Napiwotzki et al. 2001, 2003), is a programme dedicated to search for short period binary white dwarfs (double degenerates – DDs). The aim of SPY is the detection of DD progenitors of supernovae type Ia by means of a survey for RV variations. SN Ia progenitor candidates should be close enough to merge within one Hubble time due to gravitational wave radiation and the combined mass should exceed the Chandrasekhar limit for WDs. As a by-product, SPY produced high-resolution spectra of 75 sdB stars and 33 He-sdO stars, which were included in our sample because of misclassifications in the input catalogues. The He-sdO sample included in SPY is the first systematically checked for RV variations. This allows us to investigate the role of binarity for their formation and their possible link with the sdB stars.

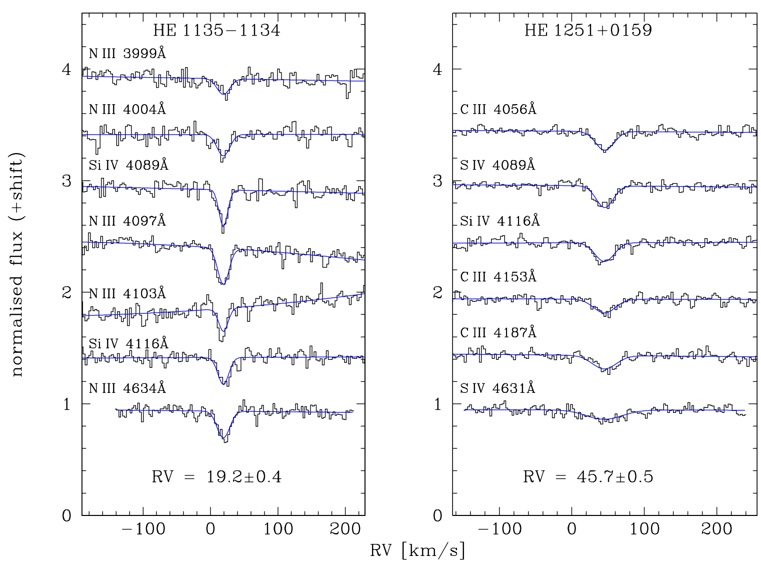

Figure 1. Sample fits demonstrating the RV measurement for the nitrogen-rich He-sdO HE 1135−1134 (left) and the carbon-rich HE 1251+0159 (right).

We measured RVs for the He-sdO by a simultaneous fit of Gaussian line profiles to selected isolated metal lines with the fit routine FITSB2 (Napiwotzki

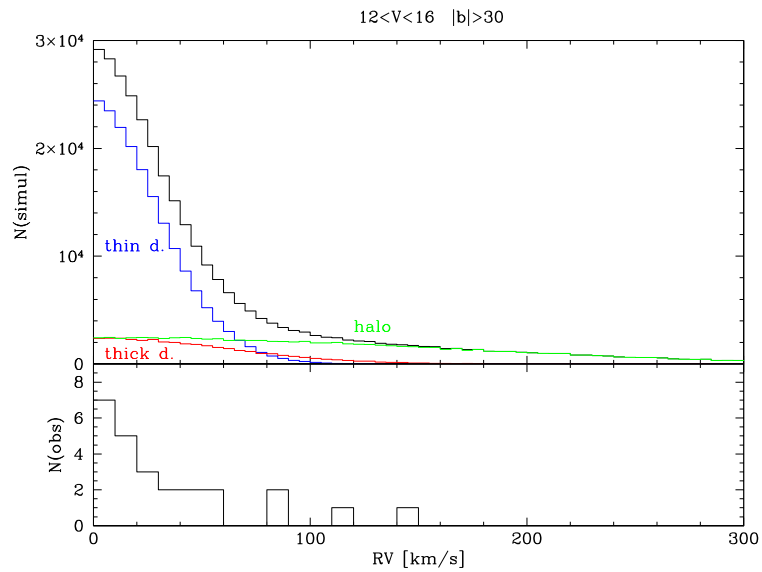

Figure 2. Distribution of He-sdO RVs. *Top panel:* Simulation of a sample with apparent brightness V and galactic latitude b approximately reproducing the SPY sample. He-sdO from the thin disk, thick disk and halo component of the Milky Way are distinguished. *Bottom panel:* Observed RV distribution of the SPY sample.

et al. 2004b). Two examples are shown in Fig. 1. Note that this method produces absolute RVs, different from the cross-correlation type method used in Napiwotzki et al. (2004a). Measurements accuracy is better than 1 km/s for most He-sdO spectra. A total of 31 single-lined He-sdOs was checked for RV variations. We detected *only one* RV variable close binary in this sample, and this is a peculiar object: a double-lined system apparently consisting of two subdwarfs (Lisker et al. 2004). The binary frequency among He-sdOs is much smaller than those found for sdBs (39% in the SPY sample; Napiwotzki et al. 2004a), which indicates that there is no direct evolutionary link between both classes.

For a quantitative comparison with other samples and an evaluation of the true fraction of binaries one needs to know the detection efficiency, i.e. the chance that a binary escaped detection, because of unfavourable inclination angles or phasing of the observations. We performed a set of Monte Carlo simulations for different period distributions and companion masses (see Napiwotzki et al. 2004a, for details). The detection probabilities for short period systems are quite high, larger than 90% even in the unfavourable case of a low mass ($0.2 M_\odot$) main sequence companion.

3. Discussion: The Origin of He-sdO Stars

The binary frequency of He-sdOs is very low, much lower than for the sdB sample. The detection efficiency of the RV survey is so high, that a significant number of "hidden" close binaries can be ruled out. Thus we can conclude that

He-sdO stars are *not* the progeny of sdBs. Additional support for this conclusion comes from the distribution in the HR diagram (Stroeer et al. 2007). The most plausible explanation is a merger origin of most He-sdOs. Computations by Saio & Jeffery (2000) showed that the product of the merger of two He-core white dwarfs passes through the region in the HR diagram occupied by He-sdOs.

If accurate proper motions are available these can be combined with the RV measurements and used to evaluate the membership in the galactic populations as described by Pauli et al. (2006) for white dwarfs from SPY. However, typical distances of He-sdOs in the SPY sample are too large to allow an unambiguous population classification for most individual objects (Richter 2006). However, some conclusions can be drawn from the RVs alone. Fig. 2 compares a theoretical simulation of He-sdOs from the different galactic populations with the observed sample (cf. Napiwotzki 2008). The four stars with the highest RVs are almost certainly halo objects. The case is less clear for He-sdO with lower RVs, but the low velocity peak indicates a significant thin disk contribution. We conclude that He-sdOs are produced by all galactic populations.

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