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METAL ABUNDANCES OF SDB STARS

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Abstract. The surface abundance patterns of four dozen bright sdB stars have been determined from high resolution, high S/N optical spectra. As typical in early B stars, the metal lines are few and weak. We searched for trends of the metal abundance patterns with the atmospheric parameters (effective temperature and gravity). It is remarkable that almost all metal abundances of sdBs with $T_{\rm eff} < 32\,000$ K stay at similar values, virtually independent of stellar parameters. The only exceptions are He and C which vary considerably from star to star. The hottest EHB stars lack O, Mg, Al and Si. Furthermore, all stars are rotating very slowly or not at all.

Key words: stars: abundances – stars: horizontal-branch – stars: rotation – hot subdwarfs

1. INTRODUCTION

The atmospheres of hot subdwarfs represent a huge puzzle in stellar physics: some chemical elements (such as helium) are highly depleted, whereas other elements (e.g., iron group elements) are enriched by factors up to a few 10 000 (Edelmann et al. 2001). Although these anomalies can probably be understood in terms of chemical layering processes in stellar envelopes (gravitational settling, radiative levitation and mass-loss), current models fail to explain the observed abundance patterns by orders of magnitudes. Also, the available sample of stars with well determined abundances is far too small to constrain diffusion theory. We present here the analysis for 49 sdB stars to determine their surface metal abundance patterns. This analysis has increased drastically (factor of ten) the number of detailed metal abundance analyses of sdB stars done so far.

2. OBSERVATIONS

Optical echelle spectra with high S/N were obtained at the German-Spanish Astronomical Center (DSAZ) on Calar Alto, Spain, with the 2.2 m telescope equipped with the FOCES spectrograph and at the ESO 1.5 m and 2.2 m telescopes equipped with the FEROS spectrograph. The observational dataset is homogeneous due to similar spectral resolutions (0.14Å at DSAZ and 0.09Å at ESO) and spectral coverage (3900 Å-6900 Å at DSAZ and 3600Å–8900Å at ESO) of all observed sdBs.

3. ANALYSIS

The atmospheric parameters (effective temperature, gravity and helium abundance) of all sdB's were derived simultaneously from the spectra by means of a χ^2 fit using fully line blanketed LTE model atmospheres (updated version of the code of Heber 1986). The results for all program stars are shown in Figure 1 in a theoretical ($T_{\rm eff}$ vs. log g) diagram.

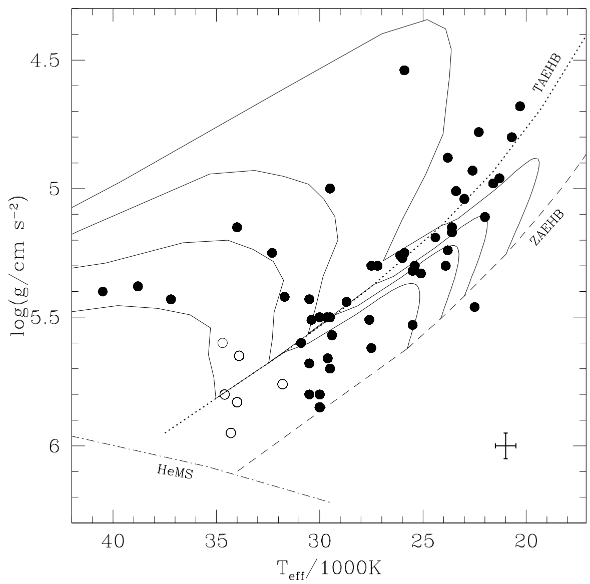

Fig. 1. Program stars in the $T_{\rm eff}$ vs.log(g) plane (stars denoted by open symbols lack of O, Mg, Al and Si).

LTE abundances were derived for all metals from measured equivalent widths using the classical curve-of-growth method. We generated model atmospheres, using the atmospheric parameters and solar metal abundances with the ATLAS9 code of Kurucz (1992). From these models we calculated curves-of-growth for the observed metal lines, from which abundances were derived. Blends from different ions were omitted from the analysis. Finally, the abundances were determined from a detailed spectrum synthesis for all lines measured before. The atomic data for the analysis were taken from the list of Wiese et al. (1996) for the CNO elements, from Kurucz (1992) and Ekberg (1993) for Fe and for all other elements from the table of Hirata & Horaguchi (1995).

4. TRENDS WITH ATMOSPHERIC PARAMETERS?

The chemical abundances observed in the atmospheres of sdB stars are very puzzling. There is now general consensus, that the peculiar abundance patterns are due to *diffusion*. Diffusion denotes the interplay between radiative acceleration (directly proportional to $T_{\rm eff}^4$) which levitates particles into upper regions, and the gravity which settles heavier particles into lower regions inside the envelope of stars. Therefore, we tried to identify possible trends of the chemical composition with $T_{\rm eff}$, log g and the luminosity (expressed in terms of the Eddington luminosity L_e).

Figure 2 shows the results for helium and for some (five) of the analyzed metal ions. Binarity and pulsations may influence the metal abundance patterns. Therefore we indicate known short period binaries (triangles) and pulsators (circles) in Figure 2. However, their metal abundance do not differ from those of apparently single, non-pulsating sdB stars (squares). Surprisingly, the abundances for most analyzed metal ions (especially for N II and Fe III) are constant irrespective of the stellar parameters. Only for S II and also for N III there seem to be a direct correlation with the stellar parameters: the larger the temperature and/or gravity, the larger the abundance for S II, and the lower the abundance for N III. However, this is most likely due to NLTE effects because the dominant ionization stages (N II and S III) do not show such trends.

For most of our program stars hotter than $\sim 32\,000$ K no absorption lines due to O, Mg, Al and Si can be detected in the optical wavelength range. This indicates that for the majority of sdB stars the abundances of O, Mg, Al and Si drop suddenly from a slightly subsolar value below $\sim 32\,000$ K to larger depletion for $T_{\rm eff}$ exceeding 32 000 K (see Figure 2). There are a few exceptions, though.

Those hot stars ($T_{\rm eff} > 32\,000$ K) that do show O, Mg, Al and Si are all of low gravity and, therefore, have evolved off the EHB. None of the hot sdB stars on or near the EHB show O, Mg, Al and Si lines (see Figure 1).

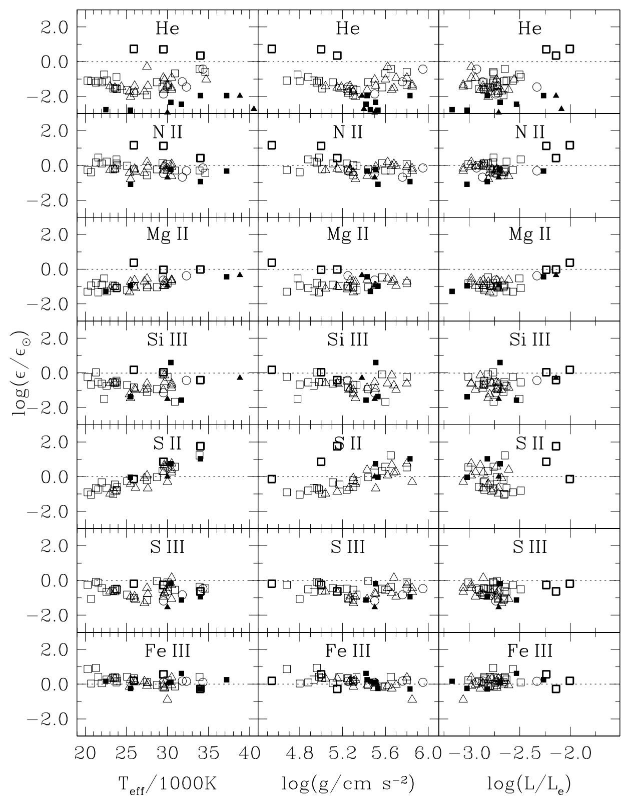

Fig. 2. Sample LTE abundances for all analyzed sdB stars relative to the solar values (dashed horizontal lines) versus $T_{\rm eff}$, log g and $L/L_{\rm e}$ (different symbols, see text).

Furthermore, three of those more luminous stars show a supersolar helium abundance (indicated by thick open symbols in Figure 2) and metal abundances which are almost solar or even higher in the case of N and Ar, which are enriched each by a factor or 3–10.

In a previous analysis of a large sample of low resolution spectra of sdB stars drawn from the Hamburg Quasar survey (Edelmann et al. 2003) we found a general trend of the helium abundances to increase with increasing $T_{\rm eff}$. Actually, sdB stars were found to separate into two distinct sequences. A small fraction (1/6) have much lower helium abundances at the same temperatures than the bulk of sdB stars. For the program stars presented here, we find also two distinct sequences with exactly the same fraction of stars (1/6) to show a helium "underabundancy" (indicated by filled symbols in Figure 2). The metal abundances of these helium underabundant sdB stars, however, do not differ from those of the others.

5. ROTATION

The projected rotational velocity can be measured by comparing synthetic line profiles, calculated for the given atmospheric parameters ($T_{\rm eff}$, log g, element abundance) of a star folded with an adopted rotational velocity, with the observed line profiles. The Mg II doublet at 4481.13 Åand 4481.33Åis most suitable for this purpose. The lines are very narrow and closely separated, and therefore very sensitive to rotational broadening. If the doublet is resolved into two components, the projected rotation velocity has to be very small. Only sdB stars that are known to be in short period binary systems show significant rotation. All others are slow rotators ($v_{\rm rot}\ \sin(i) < 3$ km s^{-1}) or do not rotate at all (unless seen pole-on).

6. CONCLUSION

With this work, the number of detailed metal abundance analyses of sdB stars has increased drastically (by a factor of ten). We have selected sdB stars for the abundance analysis covering a wide range of parameter space, which allowed us to search for trends of the metal abundances with these parameters. It is remarkable that for all program stars the abundances for many metals which are common in the atmospheres of sdB stars (C, N, S, Ar and Fe), are similar all over the parameter space. The same holds for O, Mg, Al and Si, but, only for stars with $T_{\rm eff} < 32\,000$ K. These metals practically vanish from the surface of most sdB stars with higher temperatures. Only for luminous (i.e., post-EHB) sdB stars the abundances of O, Mg, Al and Si are "normal", or become even larger than in the cooler EHB stars. No obvious differences for the abundances of pulsating or non-pulsating, and radial velocity variable or non-variable sdB stars became apparent. Our results represent a challenge for a theoretical interpretation.

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