NLTE-ANALYSIS OF THREE EXTREMELY HELIUM-RICH O-TYPE SUBDWARFS

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ABSTRACT. Three extremely helium-rich sdO stars (LSE 153, LSE 259 and LSE 263) were analyzed spectroscopically by means of detailed NLTE model atmospheres. These stars are very hot, with effective temperatures ranging from 70000 to 75000 K and gravities between log g = 4.4 and 4.9. Upper limits for the hydrogen abundance were also derived. The evolutionary status of the sdO stars is discussed and it is concluded that they evolve from the asymptotic giant branch towards the white dwarf stage. A possible evolutionary link between these hot stars and the extreme helium stars of spectral type B is discussed.

1. INTRODUCTION

Drilling (1983) discovered 12 hot sdO stars at low galactic latitudes. Three of them (LSE 153, 259 and 263) were classified as helium-rich from low resolution spectra. Subsequently, high resolution spectra were taken which revealed no trace of hydrogen (Heber et al., 1986). Presented here is a NLTE analysis of the visual high resolution spectra described by Heber et al. (1986).

2. MODEL ATMOSPHERES

NLTE model atmospheres were constructed using the complete linearization approach as described by Mihalas (1972). The statistical equilibrium equations (for hydrogen and helium) and the radiative transfer equations can be solved simultaneously with the constraints of hydrostatic and radiative equilibrium. Plane-parallel geometry is assumed. The computer code has been newly written (Husfeld, 1986) and is an extended version of the code described by Kudritzki (1976). It allows any chemical mixture of hydrogen and helium in the atmosphere (metals are not included in the calculations). The hydrogen model atom used consists of 16 levels for H I and one level for H II; 16 levels of He I, 32 levels of He II and one level of He III are considered for the helium model atom. All these levels contribute to the continuous

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opacity. The lowest 5 levels of H I and He I, respectively, and the lowest 10 levels of He II are treated in statistical equilibrium, whereas the others are held in LTE, relative to the respective continuum state. Radiative bound-bound rates are neglected in the model atmosphere calculations.

Line formation calculations were subsequently carried out using more detailed model atoms for hydrogen and helium in the statistical equilibrium calculations. At this stage the radiative bound-bound rates were taken into account and, using the best broadening theories available, accurate line profiles for H I, He I and He II were calculated (for details see Kudritzki and Simon, 1978).

3. ANALYSIS

A large grid of NLTE model atomospheres and emergent line profiles was computed for a helium abundance $\varepsilon_{He} = n_{He}/(n_H + n_{He}) = 0.99$ (number fraction). The grid covered the following parameter range: 30000 K $\leq T_{eff} \leq$ 140000 K and $3.5 \leq \log g \leq 7.0$.

The above grid allows the construction of "fit curves" which represent lines of constant equivalent width in the $(g - T_{eff})$-plane. By plotting the "fit curves" for the observed equivalent widths of several lines, their intersection in the $(g - T_{eff})$-plane defines a first estimate for the model parameters. We used the follow-ing lines: He II,λ4200 Å,λ4542 Å,λ4686 Å and He I, λ 4471 Å. Note that no He I, λ4471 Å can be measured in the spectrum of LSE 259. An upper limit of 50 mÅ was assumed for the equivalent width. Figure 1 displays the fit diagram for LSE 153 as an example. Comparing the observed and the theoretically predicted line profiles, additional models with slightly modified temperature and gravity were calculated until a satisfactory match for all lines was achieved. Results are given in Table 1.

The effective temperatures of LSE 153 and LSE 263 can be determined very precisely (error margin 2.2% and 3.5%, respectively; see Table I). This is due to the fact that He I λ 4471Å is measurable in both spectra. The strength of this line is very sensitive to effective temperature. No He I line is present in the spectrum of LSE 259 and T_{eff} and log g have to be determined exclusively from He II lines, these being less sensitive to T_{eff}. Thus, the error range for LSE 259 is larger. Figure 2 displays the line profile fit for LSE 153.

To check the influence of the chemical composition, further models were computed with increased hydrogen abundance (ε_H = 0.10 ... 0.20). This increase always left the profiles of the unblended He II and He I lines - and therefore the adopted parameters T_{eff} and log g - unchanged, but distorted the He II λ 4339 Å and λ 4100 Å line profiles. Since the observed profiles of these lines appear symmetric, upper limits to the hydrogen abundance and, consequently, lower limits to the helium abundance were derived (see Table I).

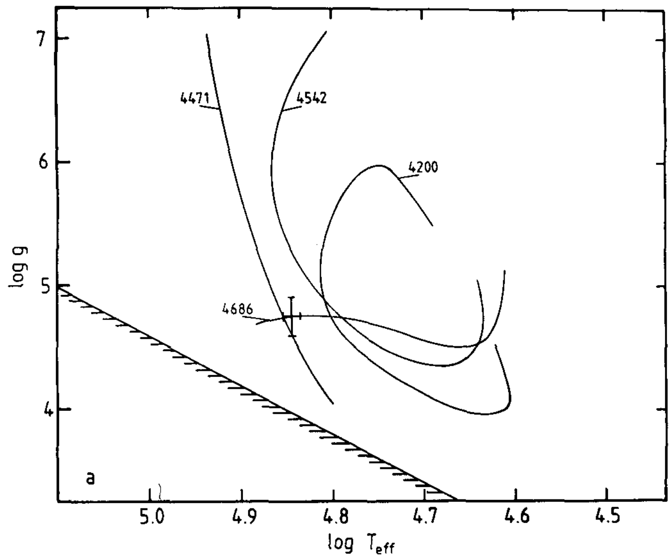

Fig. 1:

Fit curves for the observed equivalent widths (LSE 153). Also plotted is the finally adopted location together with the error limit. The hatched line represents the Eddington limit.

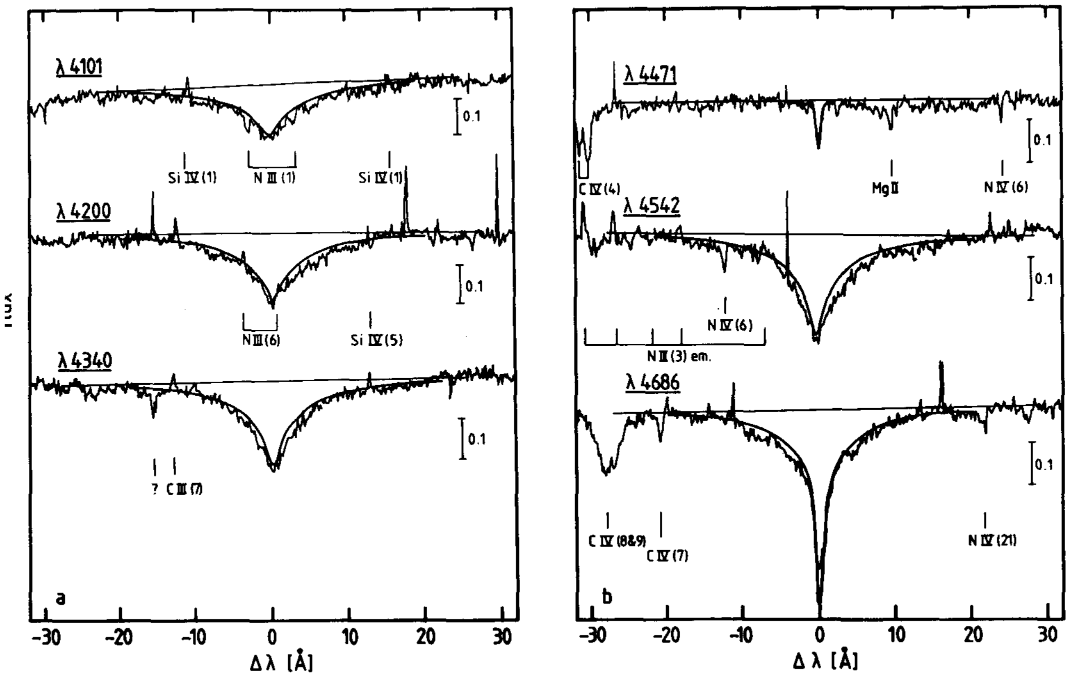

Fig. 2:

Comparison of the observed line profiles with the theoretically predicted profiles of the final model of LSE 153. The bars on the right represent 10% continuum height.

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TABLE I: Atmospheric parameters of the program stars

Error limits indicate the parameter region in which an equally good fit to the line profiles can be achieved.

Object	T_{eff} [K]	log g [cgs]	ϵ_{He}
LSE 153	70 000 $\pm$ 1 500	4.75 $\pm$ .15	$\gtrsim$.90
LSE 263	70 000 $\pm$ 2 500	4.9 $\pm$ .2	$\gtrsim$.90
LSE 259	75 000 $^{+10\,000}_{-5\,000}$	4.4 $\pm$ .2	$\gtrsim$.95

4. DISCUSSION

In Figure 3 the atmospheric parameters for LSE 153, LSE 259 and LSE 263 are compared to those of other sdOs (filled and open circles), to the central stars of planetary nebulae (CPN; squares), and to extreme helium stars of spectral type B (triangles). All stars have been analyzed previously using model atmosphere techniques. As can be seen from Figure 3, LSE 153, LSE 259 and LSE 263 do not lie in the region in the (g - T_{eff})-plane where the other sdOs can be found (Hunger et al., 1981), with the notable exception of BD+37^{o}442. The latter is also extremely helium-rich (Giddings, 1980). Instead, these stars lie close to some CPNs in Figure 3.

Also shown in Figure 3 is an evolutionary track for a helium star of 0.7 $M_{\odot}$ (Schönberner, 1977). The latter starts at the tip of the asymptotic giant branch (AGB) and leads through the observed region of both the extreme helium stars of spectral type B and the four extremely helium-rich sdOs, as can be seen from Figure 3. This suggests an evolutionary link between these two groups; thus, the helium-rich sdOs would be the immediate successors of the extreme helium stars of spectral type B. If this were the case, these sdOs would need to have metal abundances similar to those of their progenitors. The carbon abundance is of particular interest since the extreme helium stars are known to be carbon-rich. LSE 153, LSE 259 and BD+37^{o}442 are indeed carbon-rich but LSE 263 is not and, thus, the latter cannot have evolved from a B-type extreme helium star.

Detailed abundance analyses are under way in order to test the possible relationship to the B-type extreme helium stars.

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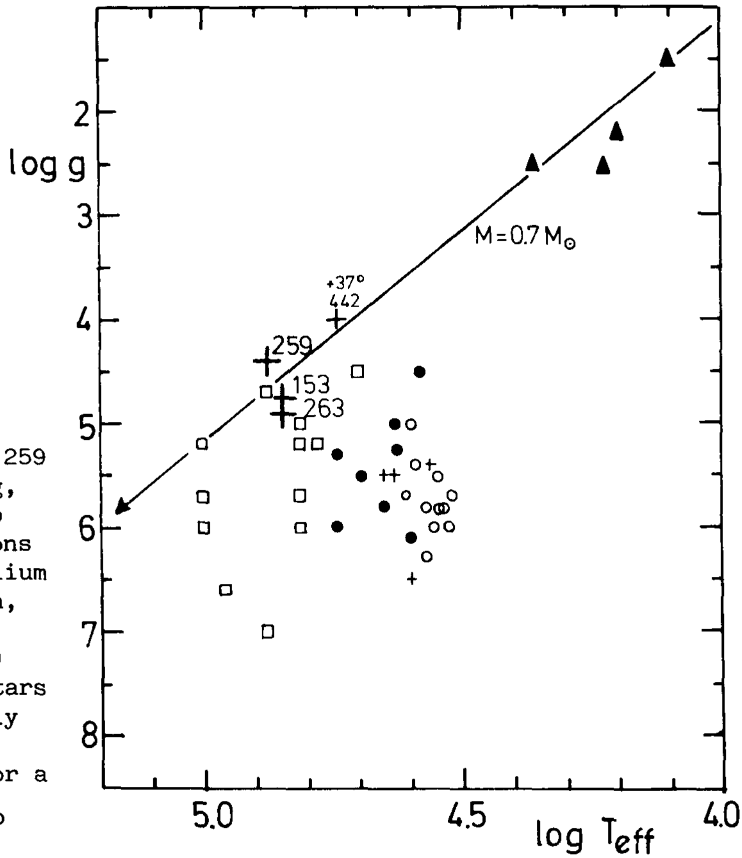

Fig. 3:

Position of LSE 153, 259 and 263 in the (log g, log T_{eff})-plane. Also shown are the positions of sdO stars (o = helium poor, ● = helium rich, + = extremely helium rich), CPNs (squares) and extreme helium stars (triangles). The fully drawn line is an evolutionary track for a helium star of 0.7 $M_{\odot}$ (Schönberner, 1977).

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