EUVE and *ORFEUS* Observations of the Cool DO White Dwarf HD 149499 B

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We present the results of a recent spectroscopic investigation of the cool DO white dwarf HD 149499 B in the EUV and FUV ranges. Observations were performed with the spectrograph of the *EUVE* satellite and the Berkeley EUV/FUV spectrometer of the *ORFEUS* space experiment.† The analysis of the *ORFEUS* spectrum, performed with a grid of LTE model atmospheres, yielded the basic parameters $T_{\rm eff} = 49500 \pm 500$ K and $\log g = 7.97 \pm 0.08$. This result is confirmed by the *EUVE* spectra. The photospheric hydrogen Lyman lines in the FUV spectrum indicate the presence of hydrogen: $\log n_{\rm H}/n_{\rm He} = -0.65 \pm 0.12$. The implications of this finding for the spectral evolution of white dwarfs are discussed. A check of the LTE assumption was performed by a comparison with NLTE atmospheres calculated for appropriate parameters. The interstellar hydrogen column towards the HD 149499 system amounts to $N_{\rm H} = (7 \pm 2) \cdot 10^{18}\,{\rm cm}^{-2}$.

1. Introduction

The class of hot helium-rich white dwarfs (spectral type DO) is divided into three subgroups: cool DOs, hot DOs, and PG 1159 stars (Wesemael et al. 1985). In the last years spectral analyses of PG 1159 stars and hot DO white dwarfs have been carried out by the Kiel/Bamberg NLTE group (see Dreizler et al. 1995 for a review). The PG 1159 stars are very carbon- and oxygen-rich: He:C:O = 0.61:0.31:0.08 (by number). Analyses of hot DO stars resulted in C/He ranging from below the observational limit $< 10^{-3}$ to $\approx 10^{-2}$.

For an understanding of the probable evolutionary sequence PG 1159 → hot DO → cool DO, analyses of cool DO white dwarfs are needed. The primary candidate for the search for weak metal features in the FUV and EUV range is the DO HD 149499 B because it is by far the brightest star of this class ($V \approx 11\overset{\rm m}{.}7$). It is the secondary star of a binary system with a K0V primary (separated by only $1\overset{''}{.}5$; Holden 1977), dominating in the optical range ($3\overset{\rm m}{.}5$ brighter in V; Holden 1977). Therefore optical observations of the white dwarf are nearly impossible. However, in the FUV region the white dwarf flux is nearly uncontaminated, but The temperature determination remains controversial. From *IUE* data Wray et al. (1979) derived a temperature range 70000 K$\leq$ $T_{\rm eff} \leq 100000$ K, while Sion et al. (1982) determined $T_{\rm eff} = 55000^{+15000}_{-5000}$ K. The probably most reliable $T_{\rm eff}$ result was derived by Poulin et al. (1989) from combined *IUE* and *Voyager* spectra: $T_{\rm eff} = 54000$ K. However, more accurate data are highly desirable. In this paper we present the results of new observations of HD 149499 B in the EUV and FUV with the *EUVE* satellite and the *ORFEUS* telescope, respectively.

† Based on the development and utilization of *ORFEUS* (*Orbiting and Retrievable Far and Extreme Ultraviolet Spectrometers*), a collaboration of the Astronomical Institute of the University of Tuebingen, the Space Astrophysics Group, University of California, Berkeley, and the Landessternwarte Heidelberg.

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2. Observations and Data Reduction

EUV spectrograms of HD 149499 B were obtained with the *EUVE* satellite in pointed mode. *EUVE* provides three spectrometers covering the ranges 70 ... 190 Å (short wavelength; SW), 140 ... 380 Å (medium wavelength; MW), and 280 ... 760 Å (long wavelength; LW). A spectral resolution of $\lambda/\Delta\lambda \approx 300$ is achieved. Due to the strong He II 228 Å edge, HD 149499 B was not detected in the SW range. The MW and LW spectra are displayed in Fig. 2. The flux peak in the 500 ... 600 Å region is contaminated by second order flux.

HD 149499 B was observed for 1675 s with the Berkeley spectrometer of the *ORFEUS* (*Orbiting Retrievable Far and Extreme Ultraviolet Spectrograph*) experiment (Hurwitz & Bowyer 1995). *ORFEUS* was mounted aboard the free flying Astro-SPAS platform which was deployed from and later recovered by the space shuttle Discovery in September 1993. The Berkeley spectrometer covers the 390 ... 1170 Å band simultaneously, with an achieved spectral resolution of $\lambda/3000$. Because the column density of interstellar hydrogen is relatively high (see below), only the spectral range longward of the Lyman edge at 912 Å is useful for this target (for further details see Napiwotzki et al. 1995 and references therein).

3. Analysis

The LTE model atmosphere codes of Koester were used to calculate an extensive grid of H/He models around the expected parameters of HD 149499 B. The model code uses the classical assumptions of LTE models: plane-parallel stratification, hydrostatic equilibrium, radiative equilibrium. Convection is included, if the stratification is unstable, using the ML1 version of the mixing length approximation with $l/H_p = 1$. Line blanketing by hydrogen and helium (neutral and ionized) lines is fully included.

Since it was shown by Napiwotzki (1995a,b) from an investigation of optical lines that NLTE effects can be important even in cool DO white dwarfs, it is necessary to check the validity of the LTE assumption for our analysis. For this purpose we calculated a H/He NLTE model atmosphere for HD 149499 B with the ALI code developed by Werner (1986). It turned out that LTE and NLTE spectra are in very good agreement for the relevant parameter range and differences can be neglected for practical purposes. Only at $\lambda < 228$ Å moderate NLTE deviations occur. However, in the case of HD 149499 B the flux is essentially zero below the He II absorption edge.

Analysis of spectral lines in the spectral range covered by our *ORFEUS* spectrogram is hampered by a lack of up-to-date line broadening tables. New data based on recent theoretical developments are highly desirable. For our analysis we applied the line broadening tables for hydrogen of Edmonds et al. (1967; ESW) for the He II $2 \rightarrow n$ series.

The flux calibrated FUV spectrum of HD 149499 B was used for the determination of temperature, gravity, and hydrogen content. We scaled the model flux according to the observed flux at 1150 Å and performed a χ^2 fitting with the synthetic spectra. The final results are: $T_{\rm eff} = 49500 \pm 500$ K, $\log g = 7.97 \pm 0.08$, $\log n_{\rm H}/n_{\rm He} = -0.65 \pm 0.12$. The best fit is displayed in Fig. 1.

The error ranges are formal 1 σ errors provided by the fitting procedure. However, one has to be aware of possible systematic errors, especially those caused by the applied line broadening theory. The detection of hydrogen is of high statistical significance. On the other hand all hydrogen lines coincide with He II lines and our result depends on a correct description of the He II line broadening. Thus it is possible that the quantitative result might change, if an improved line broadening is applied. Independent of the exact

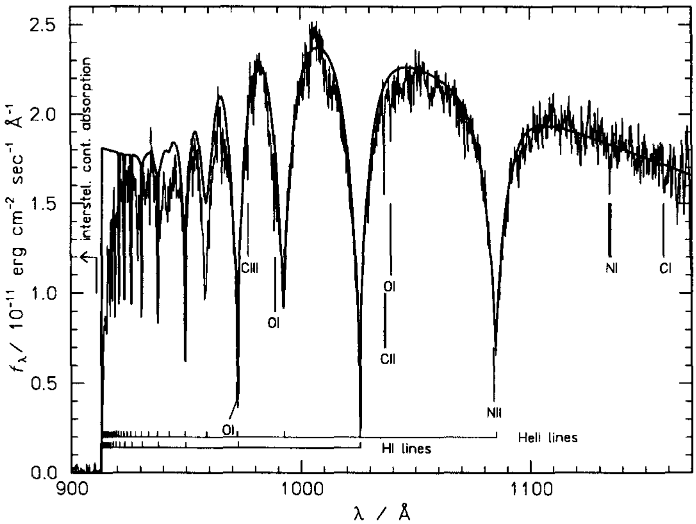

FIGURE 1. FUV spectrogram obtained with the Berkeley EUV/FUV spectrograph of *ORFEUS* compared to our best fitting model. Important photospheric and interstellar lines are indicated.

abundance, a comparison with a pure He model shows that the pure He II lines can be fitted exactly, while those possibly containing a hydrogen contribution are discrepant. We are therefore confident that the detection of hydrogen is real.

An independent check of the results can be performed with the *EUVE* spectra. We kept g and $n_{\mathrm{H}}/n_{\mathrm{He}}$ fixed at the values determined from the *ORFEUS* spectrum and varied T_{eff}. The optimum value of the interstellar hydrogen column density N_{H} was calculated for each model. The results are shown in Fig. 2. The derived limits $49000 \leq T_{\mathrm{eff}} \leq 51000$ are in excellent agreement with our *ORFEUS* results. The corresponding column density amounts to $(7 \pm 2) \cdot 10^{18}\,\mathrm{cm}^{-2}$.

The knowledge of the interstellar hydrogen column density is crucial for the temperature determination. In our analysis of the *EUVE* data it was determined simultaneously. However, the interstellar Lyman lines of hydrogen in the *ORFEUS* spectrum provide us with a further test. These lines are best fitted with $N_{\mathrm{H}} = 1 \cdot 10^{19}\,\mathrm{cm}^{-2}$. This result is accurate within a factor of two. It is in good agreement with the determination from our *EUVE* spectra.

4. Discussion

We have presented an analysis of FUV and EUV spectra of the cool DO HD 149499 B. The He II $2 \rightarrow n$ series and the coinciding Lyman lines are used for the determination of the basic parameters T_{eff}, g, and $n_{\mathrm{H}}/n_{\mathrm{He}}$ from the *ORFEUS* spectrum. The LTE analysis yields $T_{\mathrm{eff}} = 49500\,\mathrm{K}$, $\log g = 7.97$, and $\log n_{\mathrm{H}}/n_{\mathrm{He}} = -0.65$. An independent check of our T_{eff} determination is performed by means of the *EUVE* observations. NLTE effects

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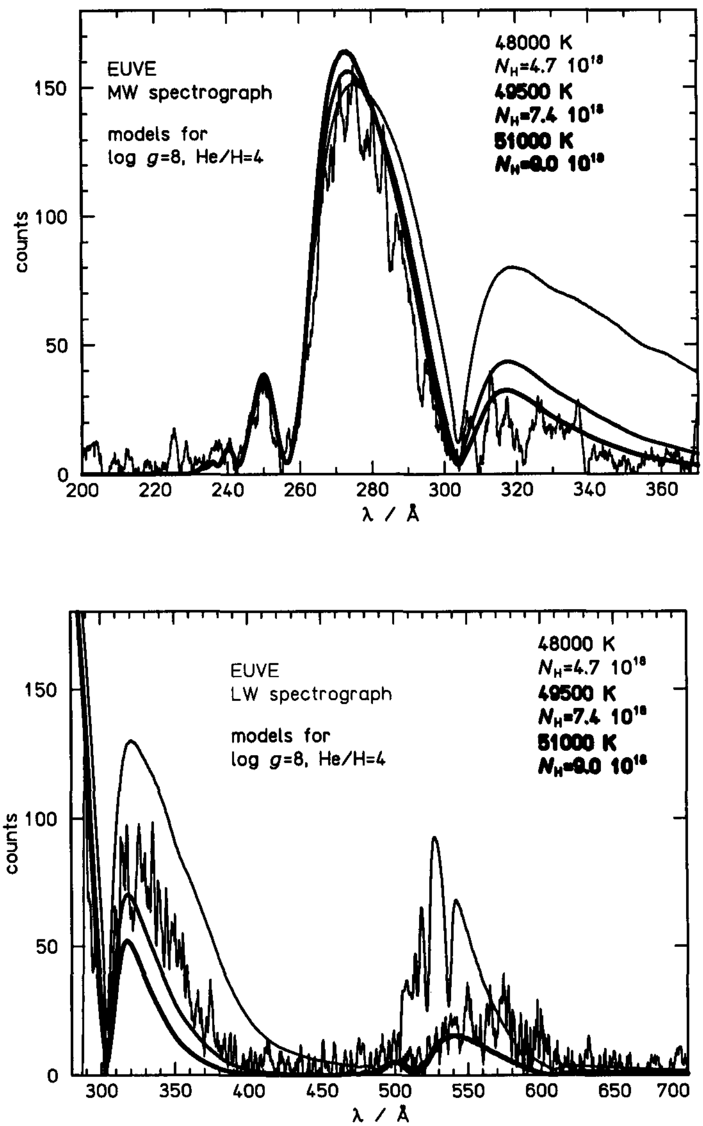

FIGURE 2. *EUVE* spectra of HD 149499 B and model spectra demonstrating the strong temperature dependence.

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on the investigated lines can be neglected for the parameters of HD 149499 B. This is the first accurate determination of the atmospheric parameters of this bright DO star. Only the FUV observations presented here allow to overcome the spectroscopic contamination by the main sequence companion.

The temperature of 49500 K places HD 149499 B at the cool end of the DO sequence, close to the so-called DB gap (28000 K $\leq T_{\rm eff} \leq$ 45000 K) in which no helium-rich white dwarf is known. This makes HD 149499 B an important object for an understanding of the processes responsible for this gap. The float-up hypothesis of Fontaine & Wesemael (1987; cf. MacDonald & Vennes 1991) predicts that hydrogen, which remained highly diluted in the helium envelope, floats up when the DO stars cool down and transform them into DA white dwarfs with a very thin hydrogen layer on top. Thus the detection of hydrogen in the atmosphere of HD 149499 B is of extreme interest.

The only other DO white dwarf with a hydrogen detection is HZ 21 (Koester et al. 1979; Wesemael et al. 1985) with a temperature similar to HD 149499 B ($\approx$50000 K). However, these analyses used much poorer observational material and for a quantitative confirmation a repeated analysis with new observations and up-to-date model atmospheres is needed. For all other DO stars only upper limits on the hydrogen abundance exist. In most cases, especially for the hot DO and PG 1159 stars, these are not very conclusive, because the limits are higher than or comparable to the hydrogen abundance detected in HD 149499 B, even with the use of good spectra and modern model atmospheres. The detection of hydrogen in cool DO white dwarfs supports the float-up hypothesis, but improved analyses of more DO stars are necessary before we can draw firm conclusions.

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