Detection of Heavy Elements in the *EUVE* Spectrum of a Hot White Dwarf

S. JORDAN,[1] D. KOESTER,[1] AND D. FINLEY[2]

[1]Institut für Astronomie und Astrophysik, Universität Kiel, D-24098 Kiel, Germany

[2]Center for EUV Astrophysics, 2150 Kittredge Street,
University of California, Berkeley, CA 94720-5030, USA

Observations with the *ROSAT* satellite have already indicated that metal absorbers must be present in the atmosphere of the hot DA white dwarf PG 1234+482. This is now confirmed by strong absorption features found in the short and medium wavelength *EUVE* spectrum of the star. With fully blanked model atmospheres, taking into account several million lines of heavy elements, we could attribute the strongest features to absorption by FeVI and FeVII. Since the spectrum has not been dithered during the observation other elements could not be identified with the same level of confidence, but upper limits could be determined. These are in general lower than predicted by models, which attempt to explain the presence of the metals by theoretical calculations of radiative forces in hot DA white dwarf atmospheres.

1. Introduction

Observations in the EUV and soft X-ray region of the electromagnetic spectrum have revealed that hot white dwarfs of spectral type DA, showing only the Balmer series of hydrogen in the optical, can possess significant amounts of heavier elements. This conclusion has been reached since in many objects the energy flux measured in the EUV and soft X-ray by the *EINSTEIN* and *EXOSAT* satellites turned out to be smaller than predicted by pure hydrogen atmospheres (Kahn et al. 1984, Petre et al. 1986, Jordan et al. 1987, Paerels & Heise 1989) It is believed that radiative levitation is responsible for the presence of heavy elements in the atmospheres of white dwarfs, since these ions would otherwise sink down into deeper layers due to the strong gravitational acceleration. The recent results from the *ROSAT* observations (Barstow et al. 1993; Jordan et al. 1994; Wolff et al. 1994, 1995) have shown that the ensemble of hot DA stars ($\gtrsim 25,000$ K) can be divided into two groups: all stars with $T_{\rm eff} \lesssim 38,000$ K are compatible with pure hydrogen atmospheres while at higher temperatures most objects contain additional opacity.

With X-ray and EUV photometry only, the presence of these absorbers could be established, but not their nature. Vennes et al. (1989) analyzed one of the very few EUV spectra obtained by *EXOSAT* and concluded that a mixture of several heavy elements is necessary to explain the observed energy distribution of the hot DA Feige 24. In some case metal absorbers have also been found in *IUE* high resolution and HST GHRS spectra of the bright DA star G191-B2B (Bruhweiler & Kondo 1991; Vennes et al. 1992; Holberg et al. 1993, 1994; Werner & Dreizler 1994; Vidal-Madjar et al. 1994). Now the *EUVE* satellite provides a unique tool to obtain high resolution spectra in a spectral region where strong absorption edges and lines of several elements can directly be detected.

2. Observations and Model Atmosphere Analysis

PG 1234+482 was identified as a hot DA by Jordan et al. (1991). From the optical and UV (*IUE*) spectrum we determined an effective temperature of $55,600 \pm 1,500$ K with a pure H model atmosphere. However, the soft X-ray flux measured by *ROSAT* is about a factor of 12 lower than predicted by such a model. Moreover, the PSPC pulse height

S. Bowyer and R. F. Malina (eds.), Astrophysics in the Extreme Ultraviolet, 235–240.

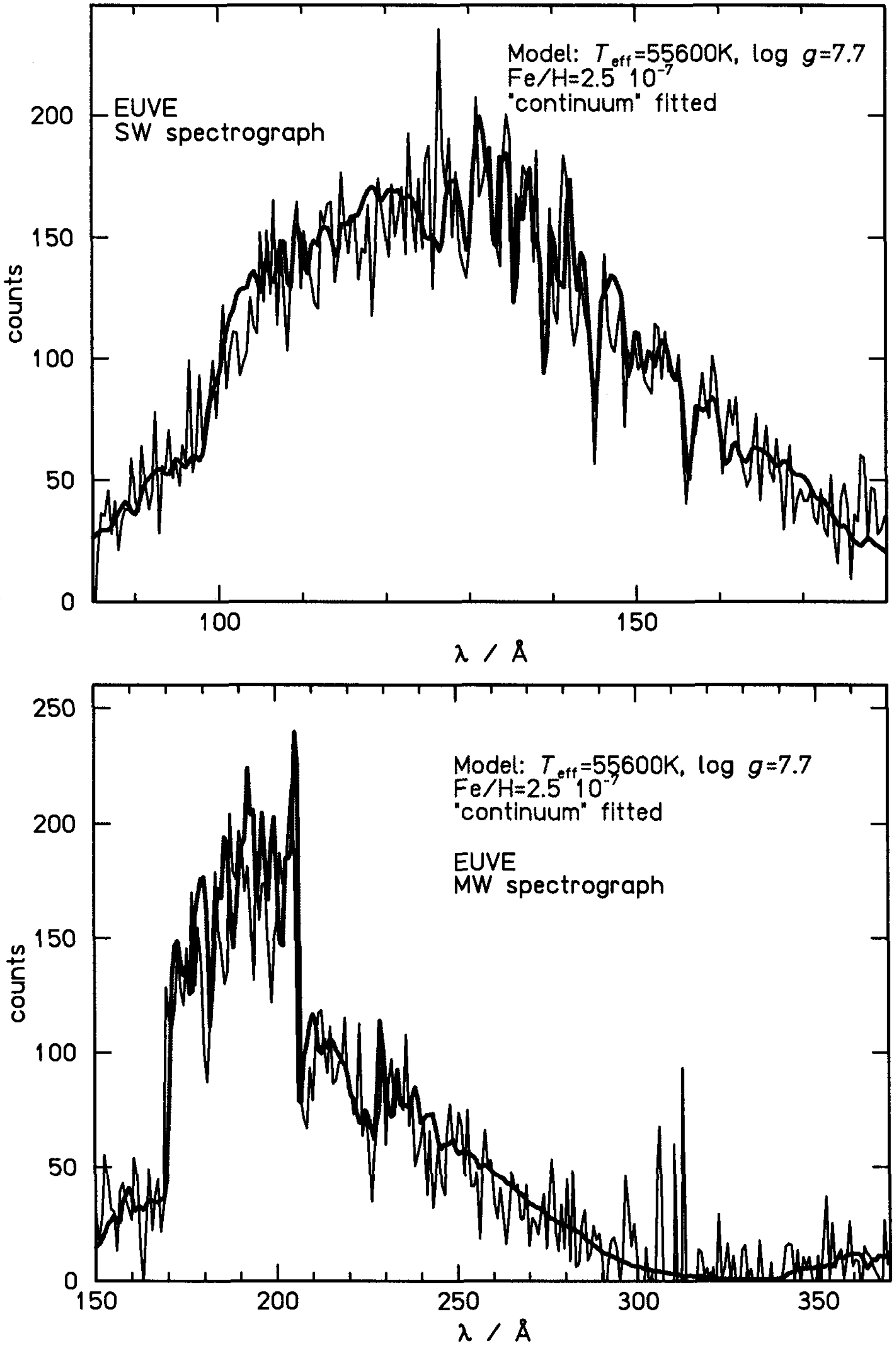

FIGURE 1. The SW (top) and MW (bottom) spectrum of PG 1234+482 is compared to a synthetic spectrum for $T_{\rm eff} = 55,600\,\rm K$, $\log g = 7.7$, and Fe/H=$2.5 \cdot 10^{-7}$

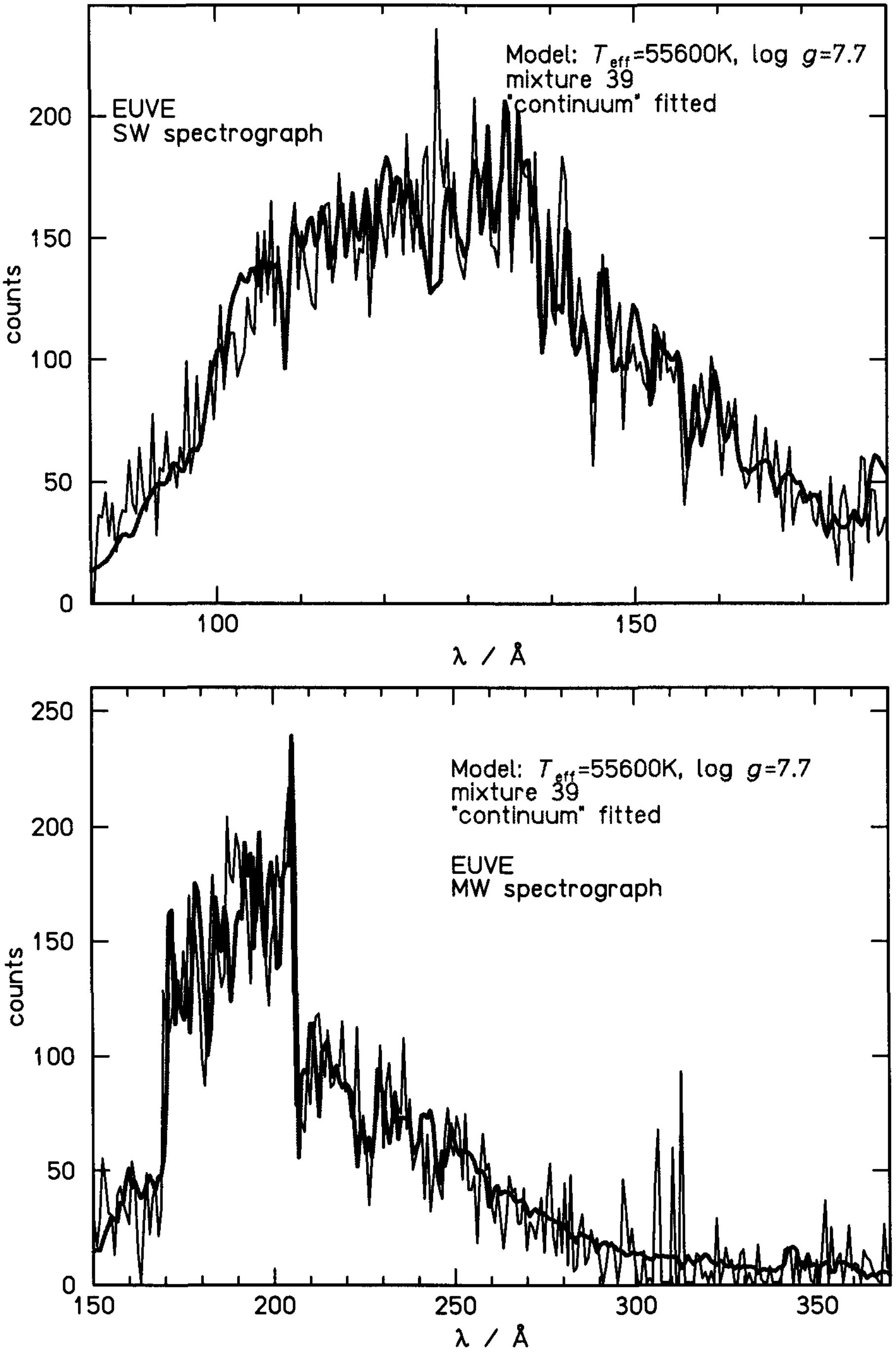

FIGURE 2. Comparison of the *EUVE* spectra of PG 1234+482 to a model spectrum for $T_{\rm eff} = 55,600$ K, $\log g = 7.7$, and a chemical composition listed in the table

distribution could not be reproduced by any model atmosphere containing H and He only, so that the opacity in the short wavelength region must be due to metals (Jordan 1993). This is now confirmed by the high resolution *EUVE* spectrum (exposure time: 99 ksec). No strong HeII photoionization edge at 228 Å but many strong absorption features were detected with the short (SW) and medium (MW) wavelength spectrographs.

The interpretation of such a spectrum with model atmospheres has become possible just recently (Koester, these proceedings). For our analysis we used the Koester model atmosphere code which now takes into account blanketing by typically 10^7 metal lines listed in the Kurucz (1991) tables. For the photoionization cross sections Opacity Project data (Seaton et al. 1992) were used with the exception of nickel, for which the hydrogenic approximation had to be applied. The model flux is folded with the detector response matrix of the spectrograph and and normalized at the V magnitude of $14\overset{\mathrm{m}}{.}38$; the interstellar absorption is calculated according to Rumph et al. (1994) and Morrison & MacCammon(1983).

In order to find out which absorbers may be responsible for the observed features we calculated model atmospheres and synthetic spectra for a mixture of hydrogen and at each time one of the following elements: Fe, Ni, Ca, C, N, O, and Si. The flux level predicted by these bielemental mixtures cannot be expected to agree with the observed spectra, so that we had to artificially reduce the theoretical *EUVE* spectrum with respect to the observed one (typically by a factor of 2 or 3 in the SW, and some 10% in the MW). The overall shape was also adjusted by multiplication with a quadratic function.

Fig. 1 shows that many of the dominant absorption features (especially in the SW) can be reasonably fitted with a theoretical spectrum for an atmosphere consisting of H and Fe with Fe/H$= 2.5 \cdot 10^{-7}$ by numbers. The conclusion that iron ions (FeVI, FeVII) are the most important absorbers in this spectral region could already be reached by comparing the *EUVE* spectrum to opacities for a temperature and pressure representative for the line forming region in the atmosphere (see Fig. 1 in Jordan et al. 1995).

None of the other bielemental compositions led to equally convincing results, although there are indications that nickel and calcium are the next strongest absorbers. However, observational uncertainties may result from the fact that the spectrum of PG 1234+482 has not been dithered during the observation so that part of the structure may be due to fixed pattern noise.

Mixture used for Fig. 2:

number ratio	predictions
Fe/H $= 2 \cdot 10^{-7}$	$1.5 \cdot 10^{-5}$
Ni/H $= 2 \cdot 10^{-8}$	$2.0 \cdot 10^{-6}$
Ca/H $= 2 \cdot 10^{-8}$	$2.0 \cdot 10^{-6}$
C/H $= 1 \cdot 10^{-5}$	$1.8 \cdot 10^{-4}$
N/H $= 2 \cdot 10^{-6}$	$2.5 \cdot 10^{-4}$
O/H $= 3 \cdot 10^{-8}$	$1.3 \cdot 10^{-4}$
Si/H $= 1 \cdot 10^{-8}$	$< 10^{-8}$

Nevertheless, we tried to calculated upper limits by increasing the abundance of the metals until the predicted features became stronger than observed. After this procedure was performed for each element individually, we calculated a synthetic spectrum for the full mixture of metals (listed in the Table). The result is shown in Fig. 2. Compared to the calculation with H and Fe only, there is a slight improvement of the overall fit, but there is still a significant flux discrepancy in the SW region of the order of 50%. Therefore we have to conclude that other elements, not yet included in our calculations, are probably present.

However, the abundances can be regarded as upper limits; to be more careful the values may be multiplied by a factor of 2. Even then the abundances are in general lower than predicted by Chayer et al. (1995, for $\log g = 7.5$), who performed detailed calculations of the radiative forces in hot DA white dwarf atmospheres. Currently, these models neglect the influence of the metals on the temperature and pressure structure of the atmosphere, and do not include the effects on each trace element of the flux blocking by the other elements that are present.

The flux distribution in the MW spectrum is relatively well reproduced by our mixture of heavy elements under the assumption of an interstellar hydrogen column density of $N_{\rm H} = 10^{19}\,{\rm cm}^{-2}$. Modeling of the HeI autoionization transition, first detected in the spectrum of GD 246 by Vennes et al. (1993), we estimated $N_{\rm He} = 10^{18}\,{\rm cm}^{-2}$, meaning that the ISM is mostly neutral. A careful determination of the helium ionization fraction will be performed when a final model for PG 1234+482 is found.

3. Future Prospects

PG 1234+482 will be reobserved with *EUVE* in the dithered mode and with an exposure time of 200 ksec. This will result in a high quality spectrum so that we may be able to find a unique chemical composition reproducing both the strength of the absorption features and the overall flux distribution. We may then arrive at a somewhat lower effective temperature since up to now we have neglected the blanketing effect of the metals on the optical temperature determination. Finally, since NLTE effects cannot be excluded at temperatures above 50,000 K, we plan to repeat our analysis with NLTE atmospheres which also account for the large number of metal lines (Dreizler & Werner 1993).

Work on *ROSAT* data in Kiel was supported by the DARA (grant 50 OR 9302 4).

REFERENCES

BARSTOW, M. A., FLEMING, T. A., DIAMOND, C. J., ET AL. 1993, MNRAS, 264, 16

BRUHWEILER, F. C., & KONDO, Y. 1981, ApJ, 248, L123

CHAYER, P., FONTAINE, G., & WESEMAEL, F. 1995, ApJ, in press

DREIZLER, S., & WERNER, K. 1993, A&A, 278, 199

HOLBERG, J. B., BARSTOW, M. A., BUCKLEY, D. A. H. ET AL. 1993, ApJ, 416, 806

HOLBERG, J. B., HUBENY, I., BARSTOW, M. A., ET AL. 1994, ApJ, 425, L105

JORDAN, S. 1993, in Advances in Space Research, 13, no. 12, Pergamon Press, 319

JORDAN, S., KOESTER, D., WULF-MATHIES, C., & BRUNNER, H. 1987, A&A, 185, 253

JORDAN, S., HEBER, U., & WEIDEMANN, V. 1991, in White Dwarfs, ed. Vauclair & Sion, 121

JORDAN, S., WOLFF, B., KOESTER, D., & NAPIWOTZKI, R. 1994, A&A, 290, 834

KOESTER, D., WERNER, K., FINLEY, D. S., & DREIZLER, S. 1995, Lecture Notes in Physics, 443, 332

KAHN, S. M., WESEMAEL, F., LIEBERT, J., ET AL. 1984, ApJ, 278, 255

KURUCZ, R. L. 1991, in, NATO ASI Series, 341, 441

MORRISON, R., & MACCAMMON, D. 1983, ApJ, 270, 119

PAERELS, F. B. S., & HEISE, J. 1989, ApJ, 339, 1000

PETRE, R., SHIPMAN, H. L., & CANIZARES, C. R. 1986, ApJ, 304, 356

RUMPH, T., BOWYER, S., & VENNES, S. 1994, AJ, 107, 2108

SEATON, M. J., ZEIPPEN, C. J., TULLY, J. A., ET AL. 1992, Rev. Mexicana Astron. Af., 23, 19

VENNES, S., CHAYER, P., FONTAINE, G., & WESEMAEL, F. 1989, ApJ, 336, L25

VENNES, S., CHAYER, P., THORSTENSEN, J. R., BOWYER, S., & SHIPMAN, H. L. 1992, ApJ, 392, L27

VENNES, S., DUPUIS, J., RUMPH, T. ET AL. 1993, ApJ, 410, L119

VIDAL-MADJAR, A., ALLARD, N. F., KOESTER, D. ET AL. 1994, A&A, 287, 175

WERNER, K., & DREIZLER, S. 1994, A&A, 286, L31

WOLFF, B., JORDAN, S., BADE, N., & REIMERS, D. 1994, A&A, 294, 794

WOLFF, B., JORDAN, S., & KOESTER, D. 1995, A&A, submitted