A Spectroscopic Survey in the EUV of the "Coolest" Hot DA Stars

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We present an analysis of the extreme ultraviolet (EUV) spectroscopy of a sample of 10 DA white dwarfs observed by the *Extreme Ultraviolet Explorer* (*EUVE*). We have selected white dwarfs cooler than about 50,000 K and with presumably low heavy element abundances. The goal of this study is to determine the fundamental atmospheric parameters, namely the effective temperature and chemical composition, of these stars by fitting their continua with synthetic spectra computed from pure hydrogen LTE/line-blanketed model atmospheres. The question of the presence (or absence) of trace elements is explored by comparing EUV-determined effective temperatures to the one obtained from a fit of hydrogen balmer lines. It is found that the majority of the DA in the sample are consistent with having a pure hydrogen atmosphere. One of the star, MCT0027-634, is another possible example of a HZ 43-type white dwarf, having an effective temperature above 50000 K and a low heavy element abundance, i.e., much lower than predicted by diffusion theory.

1. Introduction

The spectra of white dwarfs in the extreme ultraviolet (EUV) are generally more complex than their optical and ultraviolet spectra traditionally used in the determination of their fundamental atmospheric parameters. EUV spectra of hot DA ($T_{\rm eff} \geq 50000$ K) often show evidences for the presence of heavy elements as indicated by strong absorption features and a notable flux depression at wavelengths shorter than about 200 Å. It was initially recognized by Vauclair, Vauclair, & Greenstein (1979) that selective radiative pressure could defeat gravitational settling in hot white dwarfs atmospheres and they predicted that small abundances of C, N, and O should be present. In general, the metal rich spectra cannot not explained by simple mixtures of He, C, N, O, and Si, but other trace elements such as Fe are likely to be dominant source of photospheric opacity in the EUV (Vennes et al. 1989, 1991). Chayer, Fontaine, & Wesemael (1995), in their comprehensive study of radiative pressure in hot white dwarfs, are indeed predicting substantial abundances for many more heavy elements. The interpretation of hot DA spectra is further complicated by continuum absorption by hydrogen and helium in the interstellar medium. However, it is possible to separate the effect of interstellar absorption when fitting the EUV white dwarfs spectra. In fact, it turns out that white dwarfs EUV continua are excellent background sources against which to measure column densities of H I, He I, and He II in the local interstellar medium (see Bowyer 1995) permitting then to gain information on its morphology and ionization state (Vennes et al. 1993, 1994; Dupuis et al. 1995).

We have selected a sample of 10 DA with effective temperatures ranging from 25000 K to 50000 K and therefore more likely to have lower metal abundances according to Chayer, Fontaine, & Wesemael (1995). Even then, the predicted abundances are in some case sufficiently high to be detected in *EUVE* spectra. It is an important test of the diffusion to search for trace of heavy elements in the somewhat cooler white dwarfs considered here. There is indeed a class of hot DA characterized by a low metallicity with HZ 43

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being a prototypical case. Until now, HZ 43 has been a rather unique object, one of our objective is to determine how unique it is. Most of the stars we have selected are cooler than HZ 43 but are hot enough for theory to predict detectable heavy element abundance in their EUV spectra. Instead of trying to identify individual spectral features from heavy elements, we consider the effect of the metallic opacity on the shape of the continua in the EUV. Metals cause deviations from the pure hydrogen ideal case and attempt to fit the EUV spectra will result in effective temperature and gravity that disagree with optical results. The effect is that a consistent fit is obtained for a cooler temperature. We have therefore determined effective temperature obtained by fitting pure hydrogen spectra for all the stars in the sample and made a comparison with temperature based on optical spectroscopy (balmer lines).

2. Analysis

The group of stars analyzed in this paper were either observed as part of our own guest observers program with *EUVE* or obtained from the *EUVE* public archive. All observations were reprocessed with the most recent calibration data and the spectra were re-extracted, corrected for overlapping spectral orders, and converted to flux units using effective areas in the first order only. The spectra were binned by 4 pixels or more to improve the signal-to-noise ratio.

Our analysis is based on fitting pure hydrogen model, which is equivalent to assuming no contribution from heavy elements to the photospheric opacity. The synthetic spectra are computed from pure hydrogen LTE-blanketed white dwarf models described in Vennes (1992). In this paper, we have not attempted to fit the gravity, instead values obtained from fitting optical spectra were used. In several cases, determinations are available in the literature as indicated in Table 1. In other cases, we have made determinations based on our database of optical spectra (Vennes et al. 1995). Therefore, we are left with 4 parameters, the effective temperature and the H I, He I, and He II interstellar column densities, to be determined using *EUVE* spectroscopy. Fortunately, in many cases, the He I column density is directly measurable from either the 504 Å photoionization edge or the 206 Å auto-ionization transition (Vennes et al. 1993; Rumph, Bowyer, & Vennes 1994). Similarly, the He II column density can be determined from the photoionization edge at 228 Å. In the few cases for which that cannot be done, we set He I/H I to 0.07 and He II/H I to 0.03. The effective temperature and the H I column density is determined by performing a χ^2 minimization. The model spectra are normalized to the flux at 5500 Å (V magnitude) and convolved with the spectrometer response. The best fit effective temperatures are given in Table 1 along with the gravity and the effective temperatures obtained from optical spectroscopy. Table 2 is listing the interstellar column densities we have determined. Figure 1 shows a mosaic of the spectra for the stars in the sample along with the best fit models.

3. Results

Deviations between optical and EUV spectroscopy determinations of the effective temperatures are good indicators of additional heavy element opacities in atmospheres of DA white dwarfs. We find, in Table 1, that for most of the stars in the sample, the two effective temperature determinations agree within the assigned uncertainties meaning these stars are consistent with having pure hydrogen photospheres. Several stars (EUVE0715-704, EUVE1032+534, EUVE2009-604, and EUVE2156-546) have effective temperature in excess of 40000 K and appear not to be contaminated by a significant heavy element

TABLE 1. Effective temperatures and gravities

EUVE J	Name	$T_{\rm eff}$(EUV) (K)	$T_{\rm eff}$(Optical) (K)	log g (cm s^{-2})
0029−634	MCT	49000	55000	7.90
0053−330	GD 659	34550	35500	7.95
0552+158	GD 71	32560	33000	7.85
0715−704	EUVE,RE	42358	42500	7.90
1032+534	EUVE,RE	44200	45000	7.80
1257+220	GD 153	39125	39000	7.55
1316+290	HZ 43	51015	49000	7.70
1623−392	CD−38°10980	24387	25000	8.10
2009−604	EUVE,RE	42100	...	8.00
2156−546	MCT	44320	45753	7.98

TABLE 2. Interstellar column densities of hydrogen and helium

EUVE J	$N_{\rm H\,I}$ (10^{18} cm^{-2})	$N_{\rm He\,I}$ (10^{17} cm^{-2})	$N_{\rm He\,II}$ (10^{17} cm^{-2})
0029−634	20.0	14.0	6.0†
0053−330	2.9	2.6	1.9
0552+158	0.56	0.52	$\leq$ 5.0
0715−704	21.0	15.0	6.4†
1032+534	5.8	4.0	1.7†
1257+220	0.80	.66	$\leq$ 0.30
1316+290	0.82	0.55	$\leq$ 0.50
1623−392	3.2	2.2	0.96†
2009−604	18.0	12.0	3.2
2156−546	9.6	2.3	4.1

† He I/H I and He II/H I assumed equal to 0.07 and 0.03

abundance. Previous analysis of EUV/soft X-ray photometry of hot DA indicated that below 35000–40000 K, no EUV flux deficiency is observed (Vennes & Fontaine 1992; Barstow et al. 1993; Finley 1995; Wolff et al. 1995). In addition to HZ 43, we find several other hot white dwarfs that, contrary to diffusion theory predictions, have very low metallicity in spite of their high temperature and normal gravity. As pointed out by Chayer, Fontaine, and Wesemael (1995), this probably indicates that other physical processes, such as weak mass loss, are determining the heavy elements pattern in the atmospheres of hot white dwarfs. It might also be that the metallicity of hot white dwarfs photospheres depend on whether or not the atmosphere of the white dwarfs progenitors were already depleted of heavy elements.

The remaining stars in the sample are cooler than 40000 K (GD 659, GD 71, GD 153, and CD-38) and it less a surprise that their atmospheres are of pure hydrogen composition. However, the excellent agreement obtained between EUV effective temperature determinations and optical determinations is remarkable. The EUV continuum is very sensitive to the effective temperature and gravity, especially at short wavelengths where

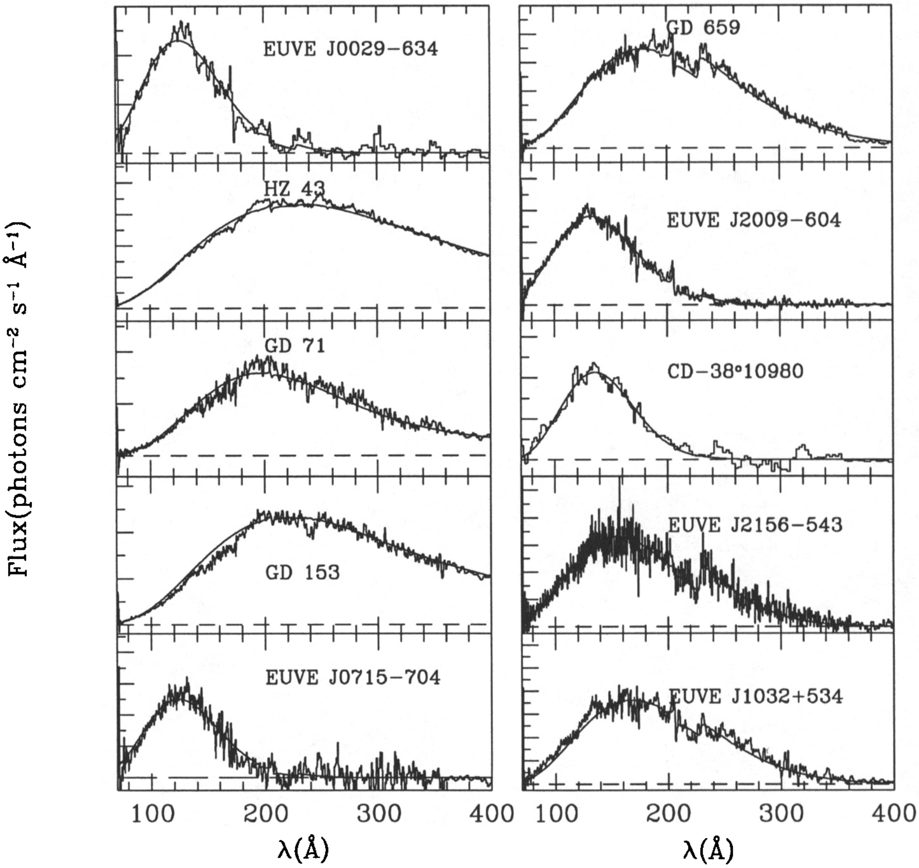

FIGURE 1. *EUVE* Spectra of hot DA Stars

the effect of interstellar absorption is less important. This explain the relatively small uncertainties of our temperature determinations. EUV spectroscopy therefore provides an independent determination of the temperature scale for hot DA stars.

EUVE 0029−634 is the only star for which its EUV effective temperature is significantly cooler than its optical temperature by about 5000 K. It is by far the hottest star in our sample with an effective temperature approximatively equal to 55000 K. At such a high temperature, radiative pressure is certainly able to support relatively high metal abundances. In this case, we infer that their must be a certain level of contamination by heavy elements, but not as high as in hot DA like Feige 24 and G191-B2B. In fact, if it would have been the case, considering EUVE 0029−634 has a much higher column density of interstellar hydrogen, it would not have been detected by *EUVE*. Therefore, this object also shares some resemblance with HZ 43.

HZ 43 is, as expected, well reproduced by a pure hydrogen model. In addition to the usual interstellar features (possibly the 228 Å photoionization edge of He II), the HZ 43 spectrum show several absorption features that could either possibly due to a low level of metal abundances or detector features. Dupuis, Vennes, & Pradhan (1995) presented a preliminary analysis showing that these features could not be attributed to C, N, or O.

Column densities of H I, He I, and He II are derived for all the stars in the sample. It is very interesting that several white dwarfs exhibit the interstellar 228 Å photoionization edge as first observed by *EUVE* in the spectrum of GD 246 (Vennes et al. 1993). These measurements provide estimates of the ionization fractions of hydrogen and helium in the nearby interstellar medium. At this point, we can rule out high ionization fraction of hydrogen in most of the directions. These stars also cover a wide range of column densities, and unlike the low columns stars like HZ 43 (Dupuis et al. 1995), they are probing other clouds in addition to the so-called local cloud. It is not quite clear whether these ionization fractions are representative of the physical conditions of the local interstellar medium or of clumps of partially ionized matter distributed along the line of sight.

4. Conclusions

We have determined the effective temperatures and the interstellar column densities of H I, He I, and He II for 10 hot DA stars with effective temperatures ranging from 25000 K to 55000 K. By comparing the effective temperatures derived from a fit of pure hydrogen model to the extreme-ultraviolet spectra with temperatures derived from optical spectroscopy, we conclude that most of these stars are consistent with having pure hydrogen photospheres. A fraction of these stars have temperatures in excess of 40000 K and in which detectable level of contamination by heavy elements are expected theoretically. The lack of heavy elements in these stars stress the need to consider competing physical processes to selective radiative pressure. Several of these stars are useful probes of the local interstellar medium since they provide a direct measurements of He I and He II column densities.

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