HELIUM ABUNDANCE IN THE PHOTOSPHERES OF HOT DA WHITE DWARFS

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ABSTRACT

We have used optical and UV spectroscopy to determine He abundances and upper limits to He abundances in the photospheres of a selected sample of very hot hydrogen-rich white dwarfs. He abundances in the range log(He/H) -3 to -1.5 are observed in several of these DAs and upper limits of -3 determined for the remainder. In apparent contradiction to the relatively large He abundances inferred from soft X-ray observations for the hot DA G191 B2B, we find *no* evidence of He in the optical and UV.

INTRODUCTION

The issue of He abundance in the hottest H-rich degenerates is of interest for several reasons. First, in terms of the earliest stages of white dwarf evolution the observed pattern of H and He abundance with effective temperature is striking. The hottest degenerates all appear to be He-rich objects. Below 80,000 K, however, H-rich white dwarfs predominate with the white dwarf population becoming exclusively DA in the 45,000 K to 30,000 K region. He-rich stars reappear again as DBs below 30,000 K. This situation has prompted questions as to whether the composition of white dwarf photospheres change as these stars cool.

Second, soft X-ray observations of many DAs are currently interpreted as implying He abundances in the range log(He/H) -5 to -2. Is the observed opacity source due to He, or possibly other ions? If He is actually present, is it intrinsic to the photosphere of the DA, or is it the result of ongoing accretion from the interstellar medium? If it is intrinsic to the photosphere, how is He supported against the short gravitational settling times? Most of these questions lead directly to the issue of the thickness or the characteristic mass of the outer H envelope. Are DA envelopes predominantly thick ($M_H \sim 10^{-4}\ M_\odot$) as evolutionary calculations suggest? Or are they perhaps thin ($M_H < 10^{-8}\ M_\odot$) as implied by the existence of non-radial pulsations in the ZZ Ceti stars? These issues and questions have been the subject of numerous discussions in the literature (*e.g.* Fontaine and Wesemael, 1987; Koester, 1987; Liebert, Fontaine and Wesemael, 1986).

One approach to the question of He in the envelopes of DAs is to investigate the hottest such stars where He abundances are expected to be highest. A simple extrapolation of the empirical relation between soft X-ray inferred He abundance and effective temperature (Petre, Shipman and Canizares 1986) to temperatures above 60,000 K yields expected log(He/H) abundances of -3 to -2. At these levels He becomes spectroscopically detectible in the optical and UV (Wesemael, Liebert and Green 1984). In this paper we present UV and optical spectroscopy of six very hot DAs, selected from the the sample of Palomar-Green (PG) DAs studied by Fleming, Liebert and Green (FLG, 1986). These stars were assigned to the highest luminosity bin ($8.75 < M_V < 7.25$) by FLG. All show blue colors and narrow H Balmer profiles. Initial results for these objects are presented in Holberg (1987). Here we present preliminary results from the determination of the He abundances of these objects. A more detailed discussion of these data will be provided elsewhere (Holberg *et al.* 1988, in preparation).

OBSERVATIONS AND ANALYSIS

We have obtained optical and UV spectra for all the stars in our sample of six hot DAs. The optical spectra, covering the 3850 to 4950 Å range are shown in Fig. 2 of Holberg (1987). Spectral resolution is approximately 2.5 Å , sufficient to provide both H Balmer profiles suitable for detailed modeling and to seek evidence for the presence of He features such as He II λ4686 and He I λ4471. The low dispersion UV spectra obtained with the IUE SWP camera are shown In Fig. 1. In addition to the six hot DAs from the PG sample we also obtained similar observations for PG1210+533, a hot DAO white dwarf, and G191 B2B, a well-studied hot DA (T_{eff} ~62,500 K).

We take the following approach to the determination of He abundances. First we estimate T_{eff} and log g from detailed fits to the H Balmer profiles using a two dimensional grid of pure H model atmospheres. These temperatures and gravities are in turn used to estimate He abundance from a related grid of models having fixed gravity (log g = 8.0) but covering a range of He abundance. Due to the weakness of the He lines, our He abundance estimates are obtained from equivalent widths rather than detailed line fits.

We employ two related sets of model atmospheres. For the H Balmer profiles, we use an extensive grid of pure H model atmospheres which are the optical counter parts of the UV grid employed by Holberg, Wesemael and Basile (1986). For the determination of He abundances we employ a grid of models having H-to-He ratios covering the range log(He/H) = -4.0(0.5)-1.5 and T_{eff} = 50,000(10,000)100,000 K; all of which assume a fixed log g of 8.0. For this grid, detailed profiles of He II λ1640 and λ4686 and He I λ4471 are computed. Both sets of models are line blanketed, assume local thermodynamic equilibrium (LTE), plane parallel geometry, and hydrostatic equilibrium. The He/H models assume an unstratified *homogeneous* mixture of He and H. For the H Balmer profiles the unified stark broadening theory of Vidal, Cooper and Smith (1973) is used, while for the He line profiles the calculations follow Wesemael (1981) and employ the results of Griem (1974).

The equivalent widths presented in Table 1 were all obtained in the same fashion using the wavelength windows indicated in the column heading of each line. In an effort to minimize bias, similar equivalent widths were measured for the He I and He II lines in the He/H model grid using the same wavelength windows and techniques. Where only an upper limit is given in Table 1, the measurement corresponds to a 2σ upper limit.

The equivalent width of the He II λ4686 line was used to estimate He abundances. At T_{eff} above 60,000 K the equivalent width of the line becomes relatively insensitive to the temperature. In contrast the He I λ4471 line rapidly disappears for temperatures in excess of 50,000 K or 60,000 K. The He II λ1640 line is also insensitive to temperature, however, the relatively low S/N of our IUE data makes this line a

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poor primary indicator. The He II λ1640 and He I λ4471 lines serve mainly as consistency checks for the He abundances determined using He II λ4686.

The Paradox of G191 B2B

The relatively high S/N optical and UV spectra of G191 B2B can be used to place some rather restrictive upper limits on the He abundance in the photosphere of this star. The He II λ4686 (2σ) upper limit implies a corresponding upper limit of log(He/H) < -3.58. A similar but weaker upper limit of < -3.0 is obtained from the λ1640 line. Both results are in apparent conflict with the interpretation of the soft X-ray fluxes from G191 B2B obtained from *EXOSAT*. Assuming that the soft X-ray opacity of G191 B2B is due to He mixed homogeneously throughout the photosphere, Paerels *et al.* (1988) and Jordan *et al.* (1987), analyzing the same *EXOSAT* data, find consistent results, namely: log(He/H) > -2.49 and log(He/H) = -2.31 (+0.15 -0.27), respectively. These *lower limits* on He abundance are more than a factor of ten higher then our optical *upper limit*. In Fig. 2 we compare the observed G191 B2B optical and UV spectra in the vicinity of the He II λ4686 and λ1640 lines with synthetic profiles of these lines corresponding to a He abundance of log(He/H) = -2.5, the lowest value consistent with the soft X-ray data. It remains to be seen if model atmosphere calculations employing a chemically stratified photosphere are capable of explaining both the soft X-ray results and the optical and UV spectra.

DISCUSSION

In Table 2 we present results from the determination of He abundances for the stars in our sample of hot DAs. Three of these stars (PG0823+317, PG0846+249 and PG1305-017) exhibit detectible features due to He. For these stars we obtain He abundances in the range log(He/H) ~-2.5. The presence of He in the optical and the UV classifies these stars as DAOs (see Wesemael, Liebert and Green, 1985) and effectively doubles the number of known examples of stars in this class. In terms of effective temperature and He abundance, these stars would most closely resemble the central star of the low-surface brightness planetary nebula Abell 7. Wesemael, Liebert and Green (1985), in agreement with others, find T_{eff} = 65,000 ± 15,000 K and log(He/H) = -2.2 ± 0.15 for Abell 7. For the other stars which exhibit no detectible He features (PG1034+181, PG0950+139 and PG1108+325), we determine upper limits on He abundances of log(He/H) < -3.

This result can be contrasted with the results of Paerels *et al.* (1988), who find five out of the six stars observed in the soft X-ray with T_{eff} greater than 50,000 K exhibit inferred He abundances of a few times 10^{-3}. If our results are considered together with those for previously known DAOs and the soft X-ray results of Paerels *et al.*, a somewhat different more complex pattern of He abundance emerges. It would appear that hot (>50,000 K) H-rich degenerates exhibit a wide range of He abundance, extending from values below 10^{-5} for the well studied case of HZ 43 (Paerels *et al.* 1987) to values of $\sim 10^{-1.5}$ for obvious DAOs such as PG1210+533. The frequency with which high He abundance ($>10^{-3}$) is observed in such stars is clearly large, perhaps above 50%. Our results for G191 B2B, however, cast some doubt of the relevance of "He abundance" estimates obtained from homogeneously mixed He-H atmospheres. This would include optical/UV determinations as well as soft X-ray.

TABLE 1

EQUIVALENT WIDTHS (Å)

Name	He II λ1640	He II λ4686	He I λ4471	Hβ	Hγ	Hδ
EW Window	15Å	30Å	30 Å	100 Å	120 Å	100 Å
PG0134+181	2.1±0.4	<0.3	<0.3	2.8±0.2	4.2±0.3	3.2±0.3
PG0823+317	1.2±0.1	0.8±0.1	<0.2	3.6±0.1	4.8±0.2	2.9±0.2
PG0846+249	3.1±0.3	0.8±0.1	<0.2	2.7±0.2	4.8±0.2	2.5±0.2
PG0950+139	<0.5	0.8[a]	<0.2[a]	3.0±0.2[b]	3.2±0.2[b]	1.1±0.2[b]
PG1108+325	<0.7	<0.2	<0.3	2.8±0.2	5.1±0.2	2.7±0.2
PG1305-017	3.4±0.2	1.9±0.1	1.0±0.1	2.4±0.2	5.5±0.2	1.9±0.2
PG1210+533	2.4±0.1	1.9±0.1	0.9±0.1	4.8±0.1	9.0±0.2	5.0±0.1
G191 B2B	<0.8	<0.16	<0.16	3.4±0.1	6.4±0.2	2.7±0.2

a) Nebular contamination
b) Nebular emission components subtracted

Notes: all upper limits 2σ

TABLE 2

TEMPERATURES, GRAVITIES AND HELIUM ABUNDANCES

Name	T_{eff} (K)	log g	log (He/H)
PG0134+181	72,500 ± 5000	7.0 ± 0.5	< -3.3
PG0823+317	62,700 ± 4200	7.25 ± 0.25	-2.5 ± 0.25
PG0846+249	63,700 ± 5500	7.0 ± 0.35	-2.6 ± 0.25
PG0950+139	70,500 ± 5000	7.15 ± 0.5	< -2.2
PG1108+325	64,300 ± 5000	7.75 ± 0.35	< -3.5
PG1305-017	53,300 ± 3500	7.25 ± 0.35	~-1.0
PG1210+533	50,000[a]	8.0[a]	~-1.0
G191 B2B	62,250 ± 3520[b]	7.6 ± 0.4[b]	< -3.58

a) Wesemael, Liebert, and Green (1985)
b) Holberg, Wesemael, and Basile (1986)

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Considerable theoretical doubt has already been cast on the validity of a stable homogeneous He/H photosphere with the elimination of radiative forces as a possible support mechanism for He in DA atmospheres. Vennes *et al.* (1988) have shown that radiative forces fail by several orders of magnitude to account for observed abundances of He. An alternative model suggested by these authors which may be capable of explaining both the observed pattern of He abundance as well as cases such as G191 B2B is a thinly stratified envelope. In this picture the observed He abundance is due to the equilibrium diffusion tail from an underlying He-rich layer which extends into the thin hydrogen photosphere at the surface. The apparent dependence of He on T_{eff} is primarily an optical depth effect, due to the dependence of the $\tau = 1$ level on T_{eff} and wavelength. One important aspect of this mechanism is the requirement of a very thin (10^{-14} $M_{\odot}$) hydrogen envelope.

REFERENCES

Fleming, T. A., Liebert, J., and Green, R.: 1986, *Astrophys. J.*, **308**, 176 (FLG).

Fontaine, G., and Wesemael, F.: 1987, in *IAU Coll. No. 95 The Second Conference on Faint Blue Stars*, A. G. D. Philip, D. S. Hayes and J. Liebert, eds., L. Davis Press, Schenectady, p. 319.

Griem, H.R.: 1974, *Spectral line Broadening by Plasmas* (New York Academic Press).

Holberg, J. B.: 1987, in *IAU Coll. No. 95 The Second Conference on Faint Blue Stars*, A. G. D. Philip, D. S. Hayes and J. Liebert, eds., L. Davis Press, Schenectady, p. 283.

Holberg, J. B., Wesemael, F., and Basile, J.: 1986, *Astrophys. J.*, **306**, 629.

Jordan, S., Koester, D., Wulf-Mathies, C. and Brunner, H.: 1987, *Astron. Astrophys.*, **185**, 253.

Kahn, S. M., Wesemael, F., Liebert, J., Raymond, J. C., Steiner, J. E., and Shipman, H.: 1984, *Astrophys. J.*, **278**, 255.

Koester, D.: 1987, in *IAU Coll. No. 95 The Second Conference on Faint Blue Stars*, A. G. D. Philip, D. S. Hayes and J. Liebert, eds., L. Davis Press, Schenectady, p. 329.

Liebert, J., Fontaine, G., and Wesemael, F.: 1987, *Mem. Soc. Ast. Ital.*, **58**, 17.

Liebert, J., *et al.*: 1988, in preparation.

Paerels, F. B. S., and Heise, J.: 1988, *Astrophys. J.* (in press).

Petre, R., Shipman, H. L., and Canizares, C. R.: 1986, *Astrophys. J.*, **304**, 356.

Vennes, S., Pelletier, C., Fontaine, G., and Wesemael, F.: 1988, *Astrophys. J.* (in press).

Videl, C. R., Cooper, J., and Smith, E.W.: 1973, *Astrophys. J. (Suppl.)*, **25**,37.

Wesemael, F. 1981, *Astrophys.J. (Suppl.)*: **45**, 177.

Wesemael, F., Auer, L. H., Van Horn, H.M. and Savedoff, M. P.: 1980, *Astrophys. J. (Suppl.)*: **43**, 159.

Wesemael, F., Liebert, J., and Green, R. F.: 1984, *Publ. Astron. Soc. Pacific.*, **96**, 981.

Wesemael, F., Green, R. F., and Liebert, J.: 1985, *Astrophys. J. (Suppl.)*, **58**, 379.

FIGURE CAPTIONS

Fig. 1 A comparison of the *IUE* SWP spectra of the six hot DAs with those of PG1210+533 and G191 B2B. These spectra have been normalized to 1.0 at 1550 Å and off set vertically from each other. The flux scale is ergs cm^{-2} s^{-1} HZ^{-1}. Regions containing gross geocoronal Lyman α contamination and charged particle events have been deleted.

Fig. 2 UV (upper) and optical (lower) spectra of G191 B2B. These data indicate the lack of any features corresponding to He II λ1640 and λ4686. For comparison we show predicted He II features corresponding to log (He/H) = -3.6, our *upper limit* and -2.5, the *lower limit* found from soft X-ray observations.

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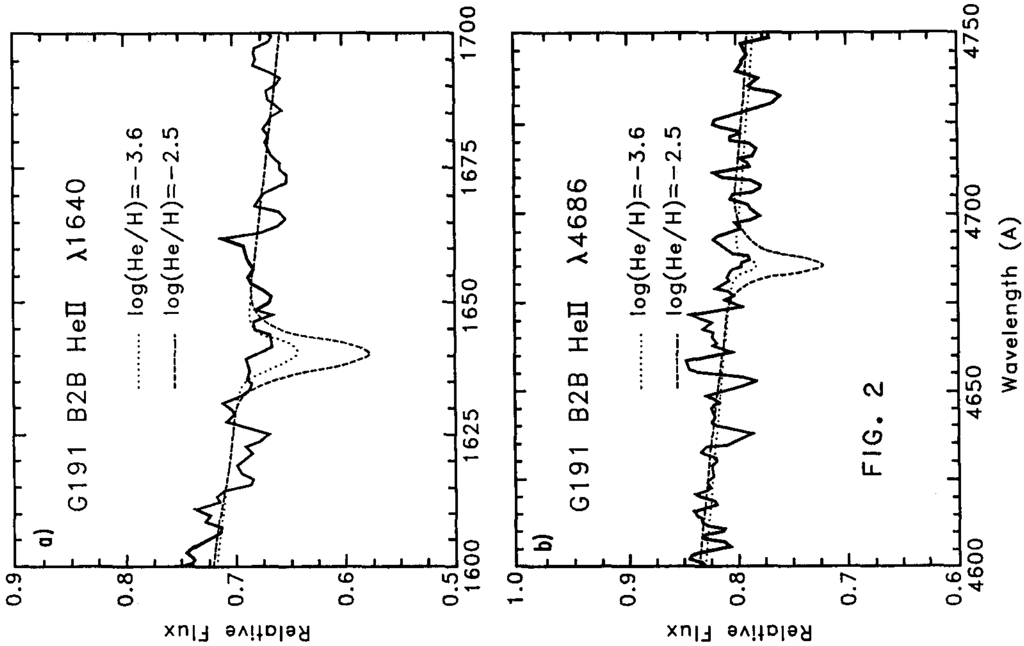

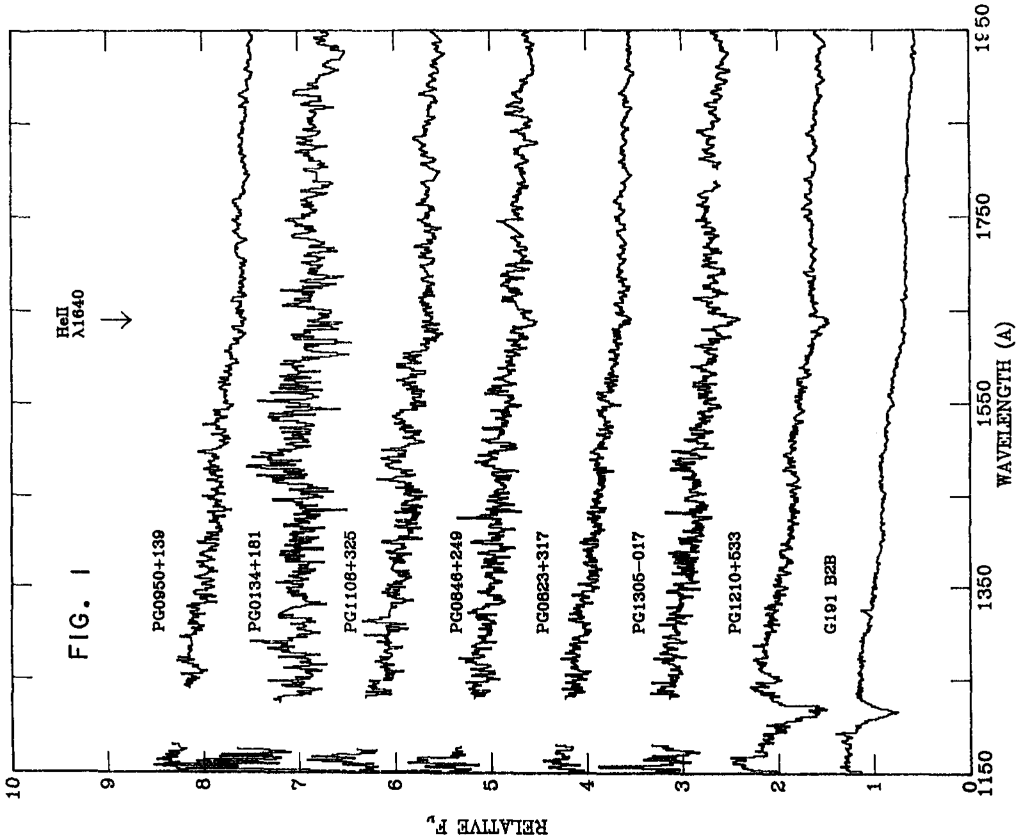

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