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Letter to the Editor

Helium line profile variations in the DAB white dwarf HS 0209+0832

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Abstract. HS0209+0832, the only white dwarf known to show helium lines in the DB gap region, is reported to display profile variations of helium lines. A quantitative spectroscopic analysis using NLTE model atmospheres reveals that the line profile variations are consistent with a constant $T_{\rm eff}$ = 36100 K and log g = 7.91 but with a varying helium abundance. It decreased from a high abundance state (He/H=0.012, by number) by a factor of 2 to 3 in 1995 and recovered back to the high abundance state in 1996. The previously suggested possibility that HS 0209+0832 is a composite spectrum (DA+DB) object is ruled out by the spectral analysis. Hence HS 0209+0832 is the first DAB star to be unambigously near the middle of the DB gap and appears to be explainable by a homogeneous He/H atmosphere with the helium abundance lower by a factor of 2–3 in one observation.

Key words: stars: white dwarfs – stars: atmospheres – stars: abundances – stars: variables: other – stars: individual: HS0209+0832 – Diffusion

1. Introduction

White dwarfs are separated in two distinct spectroscopic sequences, the DA and non–DA white dwarfs. The former ones display a pure hydrogen spectrum and can be found from the hottest effective temperatures all the way down the white dwarf cooling sequence. Amongst the hottest DAs a few stars are found to show traces of helium and are therefore classified as DAO or DAB if He II or He I, respectively, is present.

The helium–rich sequence comprises DO ($T_{\rm eff} > 45\,000$ K), DB (11 000 K $< T_{\rm eff} <$ 30 000 K) and DC ($T_{\rm eff} <$ 11 000 K) white dwarfs. The helium-rich sequence is obviously interrupted by the so–called "DB-gap" between 30 000 K and 45 000 K (Liebert et al. 1986), which poses a fundamental problem in the understanding of the white dwarf evolution. No helium–rich white dwarf is known to exist in the temperature range of the "DB gap". According to Fontaine & Wesemael (1987) the DB gap can be explained by the interplay of diffusion and convection along the white dwarf cooling track. As a DO white dwarf cools, traces of hydrogen (originally hidden in the deeper layers of the stellar envelope) float to the stellar surface until at 45 000 K the spectrum of the white dwarf is turned into a DA spectrum. Below $\approx$30 000 K a helium convection zone develops and the small hydrogen mass layer would be completely diluted again turning the star back into a helium rich white dwarf (DB, with H/He$< 10^{-5}$, MacDonald and Vennes 1991).

Jordan et al. (1993) discovered that HS 0209+0832, a DAB star from the Hamburg-Schmidt-survey, has an effective temperature of $T_{\rm eff}$=36 000 K and, therefore, lies well within the DB gap. Its spectrum displays weak He I lines in addition to the Balmer sequence and from a quantitative spectral analysis a helium abundance of 2% was derived. However, Jordan et al. (1993) were unable to exclude the possibility that the object is a spectroscopic binary. Their observations could almost as well be fitted by a combination of a DA at 32 000 K and a DB of 15 000K as by their DAB model of 36 000K. The spectra of Jordan et al. were obtained with the grism mode of the focal reducer at the Calar Alto 3.5m telescope and therefore had rather low spectral resolution (7Å). Since HS 0209+0832 is the only white dwarf in the DB gap regime known to show helium lines it was considered worthwhile to reobserve the star at improved spectral resolution.

2. Observation and data reduction

HS 0209+0832 was observed at the German-Spanish Astronomical Center on Calar Alto, Spain, using the TWIN spectrograph at the 3.5m telescope and gratings with 72 Å mm^{-1}reciprocal dispersion in both channels resulting in a spectral resolution of 3.6Å. Three spectra of HS 0209+0832 were taken in December 1995 and in 1996 (see Table 1) and reduced in Bamberg using the MIDAS program package. The normalized spectra are reproduced in Fig. 1 and compared with the (lower resolution)

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grism spectra of Jordan et al. (1993). The new spectra confirm the presence of the He I λ4471 line beside the Balmer line spectrum and hence the classification of HS 0209+0832 as a DAB white dwarf. In addition, He I 5875Å and 6678Å are detected in the red channel spectra. Surprisingly, the helium line spectrum is clearly variable: He II 4686Å and additional He I lines (4713Å, 4922Å, and 5017Å) are present in the spectra taken in August 1996 but are absent in the spectra taken earlier. Most remarkable is the weakness of the He I lines in the spectrum taken in December 1995 when compared to the spectra taken earlier and later. The He I 4471Å line profile is notably asymmetric. Intercomparison of the two spectra taken in August 1996 does not reveal any differences. Hence we presume that the helium line spectrum of HS 0209+0832 is invariable on the timescale of days but varies in strength on longer timescales.

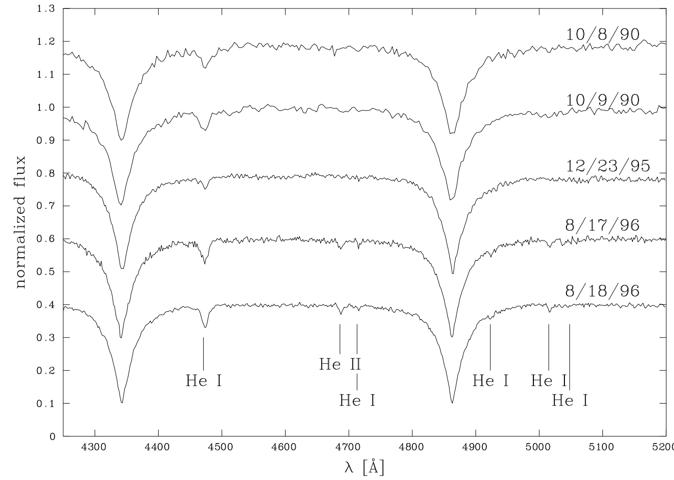
Cross correlation of the 1995 and 1996 spectra against each other did not show a radial velocity variation beyond the detection limit ($\pm$40km/s).

3. Model atmosphere analysis

The observed spectra are analysed using model atmospheres that include line blanketing and non-LTE effects selfconsistently as described by Napiwotzki (1997). The models are plane-parallel and chemically homogeneous, composed of hydrogen and helium. We use the latest version of the NLTE code of Werner (1986) which is based on the Accelerated Lambda Iteration (ALI) technique (Werner & Husfeld 1985). A detailed description of the code can be found in Werner & Dreizler (1996). We want to point out that the occupation probability formalism for excited levels of the hydrogen atom (Hummer-Mihalas, 1988) is important in order to obtain accurate results (see Bergeron, Liebert & Fulbright 1995). We extended the grid of models of Napiwotzki (1997) by calculating additional models with $T_{\rm eff}$ = 35 000, 37 000 and 40 000 K and with gravities ranging from $\log g$ = 7.5 to 8.5 in steps of 0.25 dex. The following helium abundances (by number) were adopted: He/H = 10^{-3}, 3×10^{-3}, 10^{-2} and 3×10^{-2}.

The atmospheric parameters $T_{\rm eff}$, $\log g$ and helium abundance are determined simultaneously from the observed spectra by calculating the χ^2 deviations using a modified version of Bergeron and Saffer's computer program (Saffer et al. 1994). Table 1 summarizes the results for all five epochs. Systematic errors due to the observation and data reduction (flatfielding, relative flux calibration and spectrum normalisation) dominate over statistical ones. We estimate errors for $T_{\rm eff}$ from the repeated optical analyses of Bergeron, Liebert & Fulbright (1995) and Bergeron, Saffer & Liebert (1992) to be 2.5% and adopt an error of $\pm$0.1 dex for the gravities derived from individual spectra. Within these limits all individual temperature and gravity determinations agree.

Fig. 2 displays the fit of the Balmer lines for one epoch and Fig. 3 shows the helium line profile fits for all epochs. Note that the asymmetry of the He I 4471Å profile is reproduced well by our model profiles. The asymmetry is caused by the forbidden component of the line transition.



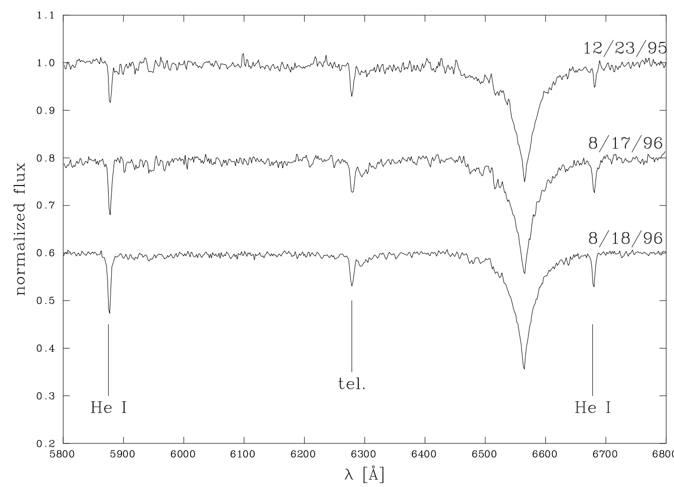


Fig. 1. Top: Blue spectra of HS 0209+0832, taken at five epochs. Note that in the spectrum taken in December 1995 He II 4686Å is absent and the He I lines are considerably weaker. Bottom: Red spectra of HS 0209+0832, taken at three epochs. Note that the He I lines 5875Å and 6678Å are considerably weaker in the spectrum taken in December 1995.

Wesemael et al. (1994) analysed two DAB stars, MCT 0128-3846 and MCT 0453-2933 and found that a composite spectrum fit of a combined DA and DB model spectrum could reproduce the fit of the optical line spectrum as well the UV flux distribution much better than any DAB model spectrum. They concluded that the two MCT stars are DA+DB spectroscopic binaries. This urged us to repeat the fits for HS 0209+0832 but excluding the helium lines as a test. Fitting Hγ to Hϵ and keeping He/H = 0.01 fixed did not improve the fit and resulted in temperatures and gravities entirely consistent with the three dimensional fits listed in Table 1.

The results from the August 1996 spectra are consistent with those from the 1990 data. All spectroscopic differences can be attributed to the lower spectral resolution of the 1990 data. In December 1995, the helium abundance is two to three times lower than at the other epochs while $T_{\rm eff}$ and $\log g$ remain un-

Table 1. Times of observation (start of exposure) and atmospheric parameters for HS 0209+0832 for all available epochs.

date	time (UT)	exp. time	$T_{\rm eff}$ K	log g	log (He/H)
10/8/90	$1^{\rm h}\ 17^{\rm m}$	1200s	35950	7.94	-1.88
10/9/90	$1^{\rm h}\ 20^{\rm m}$	1200s	36080	7.94	-2.00
12/23/95	$21^{\rm h}\ 03^{\rm m}$	1800s	36450	7.88	-2.33
8/17/96	$4^{\rm h}\ 00^{\rm m}$	1800s	36020	7.93	-1.92
8/18/96	$3^{\rm h}\ 54^{\rm m}$	1400s	35970	7.84	-1.95

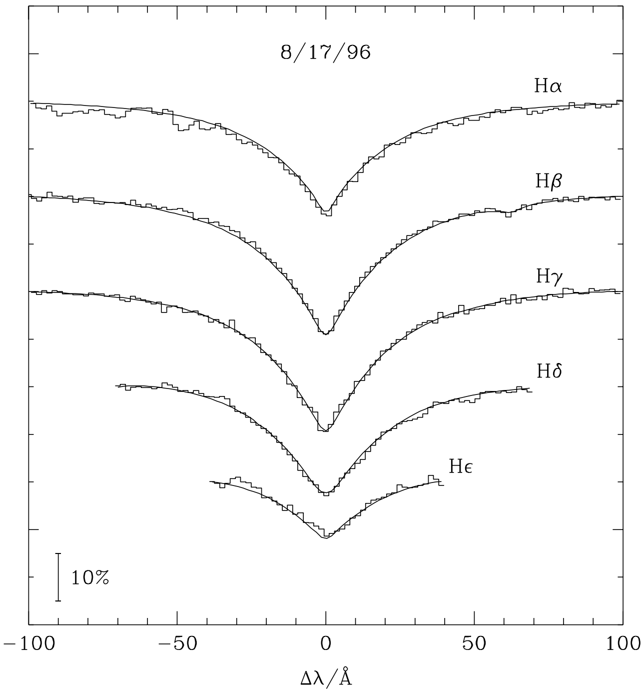


Fig. 2. Fit of the Balmer lines for the spectrum taken on August 17$^{\rm th}$, 1996.

changed. Hence the helium line profile variations can be traced back to a change in helium content.

The mean effective temperature $T_{\rm eff}$=36 100±200 K is in perfect agreement with the result of Jordan et al. (1993, $T_{\rm eff}$=36 000 K), which is based on Balmer line fitting and the UV flux distribution. The helium abundance (He/H=0.012, by number) is slightly lower than that determined by Jordan et al., probably due to NLTE effects. Jordan et al. did not attempt to derive the gravity of the star. Our result log g= 7.91±0.05 is quite typical for a white dwarf.

4. Discussion

Spectral variations of the helium lines have been observed previously in the unique magnetic white dwarf Feige 7 (Achilleos et al. 1992). The weakening of helium lines has also been observed in two hydrogen-rich white dwarfs, the DAB G104-27 and the DAO PG 1210+533. However, the recovery of the helium line strengths witnessed in HS 0209+0832 is unprecedented.

The DAB star G104-27 lies just below the red edge of the DB gap ($T_{\rm eff}$=26 000 K, Holberg et al. 1990). The strength of the 4471 Å line indicated a helium abundance of about 0.3%. Surprisingly the helium feature was not detected anymore in spectra taken 21 months later (Kidder et al. 1992).

The DAO star PG 1210+533 showed a similar dramatic spectral change (Bergeron et al. 1994): He I 4471Å and to a lesser extend also He II 4686Å weakened significantly between February 1989 and April 1992. All spectra are consistent with the same $T_{\rm eff}$ and log g but with varying helium abundances (by a factor of two). The spectral changes observed in PG 1210+533 are considered not to be secular, but appear to be modulated in time.

Kidder et al. (1992) discussed two models to explain the spectral change observed in G104-27: (i) In the cap model it is assumed that helium is not uniformly distributed over the surface but enriched in caps. Slow rotation of the white dwarf then leads to a modulation of He I line strength. (ii) Since G104-27 lies close to the red edge of the DB gap, the interplay of diffusion and convection may lead to oscillations, resulting in a disappearing and reappearing of the helium lines. Since HS 0209+0832 is hotter than G104-27 its atmosphere is not convective and, therefore, the second model does not apply. Hence we regard the helium cap model as a reasonable explanation for HS 0209+0832.

The cap model is successfully used to model the spectral variations of some chemically peculiar stars of the upper main sequence, both for helium poor stars (e.g. Farthmann et al. 1993) and for helium rich ones (Groote & Hunger 1982). Amongst the white dwarfs it was applied to model the spectrum variable Feige 7 (Achilleos et al. 1992) and the non-variable DAB GD 323 (Beauchamp et al., 1993; Koester et al. 1994). Since magnetic fields are present in many of the chemically peculiar stars of the upper main sequence and in Feige 7, it is worthwhile to search for a magnetic field of HS 0209+0832. Our Hα spectra (see Fig. 2) set an upper limit of about 0.5 MG to the magnetic dipole field strength if we assume that a Zeeman splitting of ± 10Å should be detectable in our spectra. Further spectroscopic monitoring of HS 0209+0832 has to show whether the line profile variations are periodic or not.

HS 0209+0832 lies in the middle of the DB gap whereas the DAB GD 323 and the DAO star PG 1210+533 mark the low and high temperature ends of the gap, respectively. While the observations of HS 0209+0832 can be well reproduced with homogenous H/He models (see also Jordan et al., 1993), the two other stars cannot. Bergeron et al. (1994) found that in the case of PG 1210+533 neither stratified nor homogeneous models can provide a satisfactory fit to the helium line profiles. Koester et al. (1994) analysed GD 323 and considered in addition He spots on the surface of the star and the possibility that GD 323 could be a DA+DB binary. Neither model perfectly reproduced the observation but the stratified model was regarded as the closest match.

A binary model (DA + DB) for HS 0209+0832 has also been discussed by Jordan et al. (1993). The DB would have to be considerably cooler ($T_{\rm eff}$=15 000 K) than the DA. Such a DB model is far too cool to produce any He II lines. The detection of

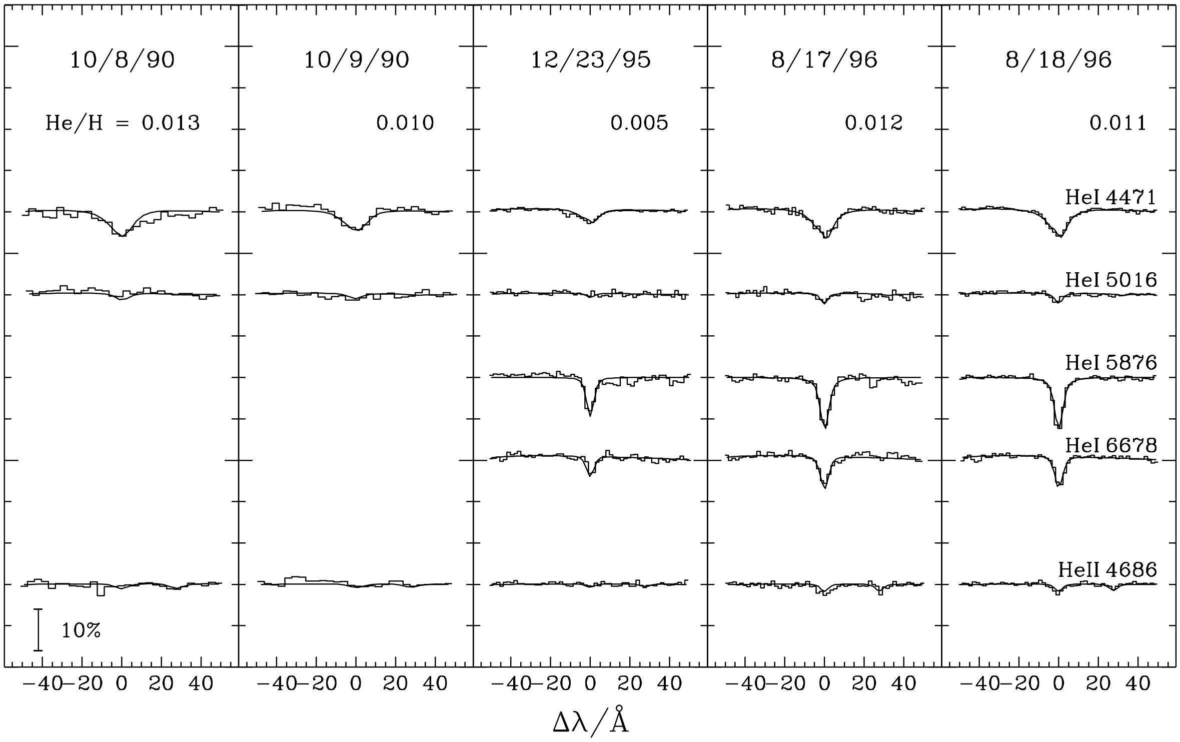


Fig. 3. Fit of the helium lines for all five epochs.

He II 4686Å in the 1996 spectra, therefore, rules out the DA+DB model since the NLTE model spectrum reproduces 4686Å well at $T_{\rm eff}$=36 000K in perfect agreement with fits of the Balmer line profiles and the UV energy distribution (Jordan et al. 1993).

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