TOWARD A DETERMINATION OF THE HELIUM ABUNDANCE IN COOL DA WHITE DWARFS

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Convective mixing between the thin superficial hydrogen layer and the more massive and deeper helium layer is generally believed to be responsible for the increased number of non-DA white dwarfs relative to the number of DA below 10000K (see Sion 1984 and references therein). However, because of the spectroscopic invisibility of the helium lines at effective temperatures below 13000K, the true atmospheric composition of these cool stars remains somewhat uncertain. On theoretical grounds, studies of the evolution of white dwarfs on the cooling sequence have shown that if the hydrogen layer is thicker than $\sim 10^{-6} M_{\odot}$, convective mixing does not occur (Tassoul, Fontaine, and Winget 1988). Furthermore, the exact amount of helium pollution is very sensitive to the thickness of the hydrogen layer. It seems therefore imperative to evaluate to what extent DA stars below 13000K truly are hydrogen-rich. In line with our previous efforts geared toward an understanding of the atmospheric properties of the cool DA white dwarfs, we present new insights into the spectroscopic modelling of these cool stars, and also demonstrate, for a particular object, how the helium abundance might be determined.

Despite its spectroscopic invisibility, the helium abundance can be inferred from its effect on the Balmer lines through increased pressure ionization (Wehrse 1977; Liebert and Wehrse 1983; Bergeron, Wesemael, and Fontaine 1987, Paper I hereafter). In order to evaluate properly this spectroscopic diagnostic, a detailed model of pressure ionization is required. As discussed briefly in Paper I, Hummer and Mihalas (1988) have recently developed such a model where the pressure ionization is treated with an occupation probability formalism. For each atomic level of the hydrogen atom, an occupation probability w is assigned: the electron has a probability w of being bound to the atom, and a probability 1-w of being ionized. In the Hummer-Mihalas formalism, this occupation probability is governed by two

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different types of perturbers: the charged and neutral particles. The combined occupation probability can be expressed as the product of both perturbations, $w = w_{charged} w_{neutral}$.

Within this occupation probability framework, some care must be taken in calculating the bound-bound opacity, or the bound-free opacity from dissolved atomic levels (Däppen, Anderson, and Mihalas 1987). In particular, these dissolved levels will produce a smooth pseudo-continuum opacity similar to the Inglis-Teller prescription. The inclusion of the Hummer-Mihalas formalism in the context of the spectroscopy of cool DA white dwarfs is illustrated in Figure 1, where synthetic spectra of two characteristic models at log g=8.0 are displayed.

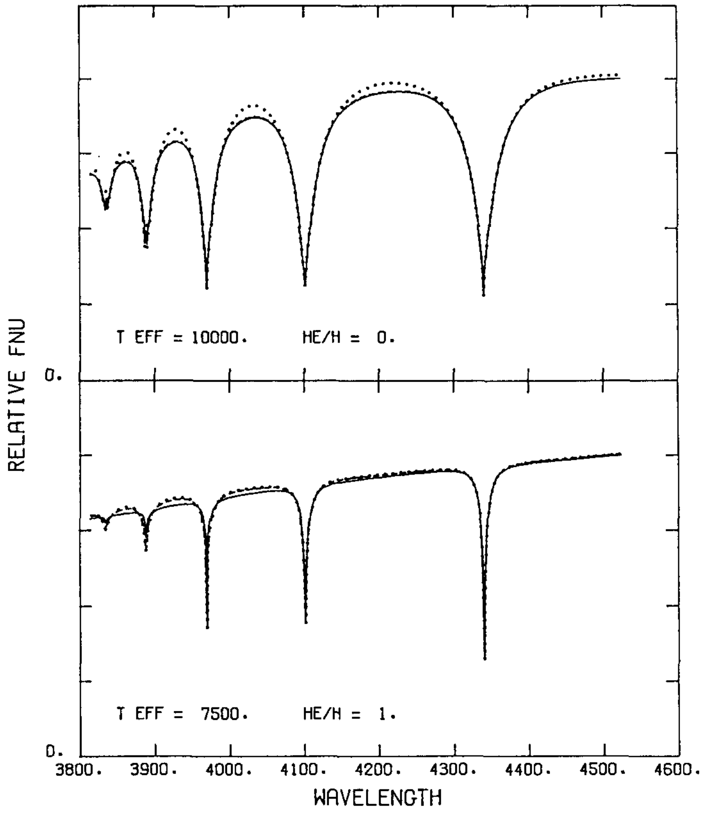

Fig. 1. Comparison of synthetic spectra using an occupation probability unity (dotted line), the full occupation probability including perturbations from both charged and neutral particles (solid line), and from charged particles only (dashed line).

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Spectra at both temperatures have been calculated with different versions of the occupation probability. The dotted line is calculated with an occupation probability unity for each atomic level. This approximation corresponds to a large extent to previous spectroscopic analyses. The solid line represents the calculation obtained with the full occupation probability w, while the dashed line takes into account only the contribution from the charged particles (e.g. $w_{neutral}=1$).

In the hotter pure hydrogen model (top panel), the solid and dashed lines are superposed, thus showing that the main contribution to the occupation probability comes from the charged particles. The neutral particle density of hydrogen is too low to modify significantly w. We note also that the full occupation probability treatment does not affect the line centers, even for the higher Balmer lines. What is dramatically modified however, is the increased contribution of the pseudo-continuum opacity produced by dissolved upper atomic levels, in spectral regions where the line opacity is relatively unimportant. Spectroscopic analyses of DA stars using this newer formalism, particularly *in the region of ZZ Ceti stars*, could shift temperatures to higher values than estimated from previous studies (e.g. Daou *et al.* 1988).

In the cooler model with an increased helium abundance (lower panel), the contribution from the charged particles is completely negligible (the dashed and dotted lines are superposed). Once again, the pseudo-continuum between the Balmer lines is affected by the Hummer-Mihalas formalism but, this time, through the perturbations from the neutral particles. However, in cool pure hydrogen models where the photospheric pressure and the neutral particle density are decreased, the pseudo-continuum contribution is significantly reduced, and does not affect the determination of effective temperatures (Bergeron *et al.* 1988). In the particular model presented on the lower panel, the helium signature is clearly noticeable from a close examination of the higher Balmer lines, when the perturbation from the neutral particles is included.

These considerations can be used to infer the helium abundance, as first suggested by Wehrse (1977), and Liebert and Wehrse (1983). The sensitivity of the predicted line profiles on the helium abundance is clearly illustrated in Figure 2 where the spectrum of the DA white dwarf GD25 (Gr312) is displayed, along with three synthetic spectra at log g=8.0 and different helium to hydrogen ratios. For each model, the effective temperature was obtained from the best fit to H_γ and H_δ as these lines are less sensitive to the presence of helium (or to a variation of gravity) than H_ϵ or higher Balmer lines. It is obvious that a fit to the whole spectrum requires a helium to hydrogen ratio in GD25 of the order of ~1.

One particular aspect that has not been considered yet is the effect of the assumed surface gravity. Despite the analytical arguments considered by Liebert and Wehrse (1983), a careful reanalysis (Bergeron, Wesemael, and Fontaine 1989) clearly demonstrates that *helium abundance and gravity effects cannot be separated*; this conclusion is independent of the exact treatment of the occupation probability. Therefore, the GD25 spectrum could as well be fit with a pure hydrogen spectrum, but with an increased surface gravity. One way of avoiding this uncertainty is to look at a large sample of cool DA white dwarfs, and assume a mean surface gravity of log g=8.0. Such a large sample of objects is currently under investigation using this technique.

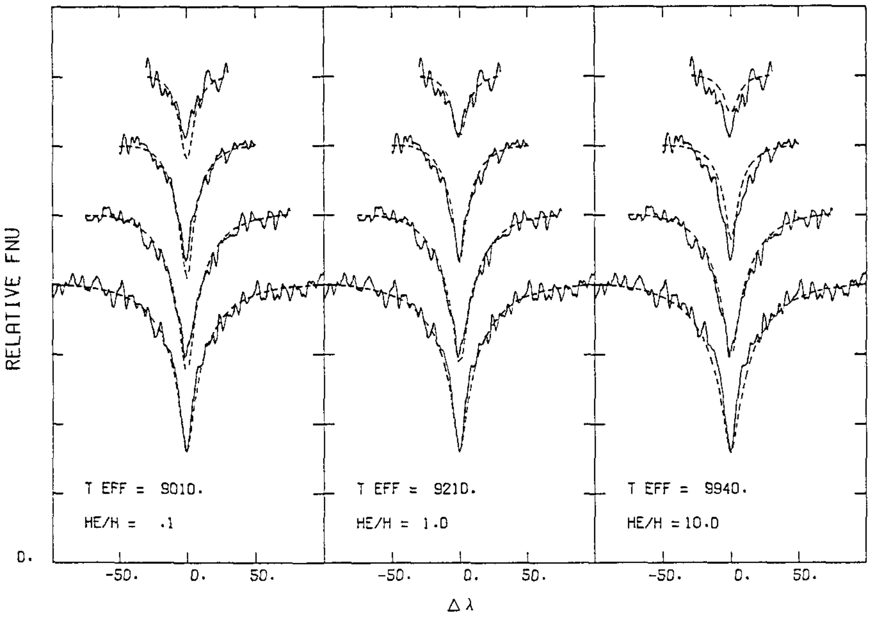

Fig. 2. Comparison of the spectrum of GD25 (from top to bottom H_B to H_γ) with our best fit at different helium to hydrogen ratios.

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Preliminary results indicate that the fit obtained for GD25 is not a unique occurence, and that a fair number, and probably most of the cool DA white dwarfs below ~10000K are best fit with atmospheres with helium abundances He/H~0.1, with a few objects as high as He/H~10. Because the surface gravity distribution of DA white dwarfs is expected to be very narrow (Weidemann and Koester 1984), this result opens up the tantalizing possibility of actually measuring the thickness of the hydrogen layer in DA stars through abundance analyses.

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