

The DB and DBA white dwarfs: epitomes of hydrogen-deficient stars¹

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Abstract.

White dwarfs of spectral type DB are known to have photospheres composed almost exclusively of helium with, occasionally, only minute traces of hydrogen and heavy elements. While progress in our understanding of DB stars has been considerable over the past 25 years, our knowledge of some of their properties — above all their mass distribution and their luminosity function — lags behind that secured for their more numerous, and better-studied, hydrogen-line counterparts, the DA stars.

Here, we review results of earlier analyses of DB stars based on Strömgren photometry, spectroscopy, multichannel spectrophotometry, as well as ultraviolet spectrophotometry from the *IUE*, and outline some of the problems inherent to analyses of DB stars. We then present some preliminary results of an ongoing spectroscopic analysis of these objects; it is based on optical spectra secured for close to 80 DB white dwarfs, and used jointly with ultraviolet spectrophotometry of 25 DB stars culled from the *IUE* archives. A new generation of synthetic spectra, which incorporates the best description currently available of the helium plasma at the physical conditions characteristic of the photospheres of DB stars, is also briefly presented. The He I line profiles include Stark, resonance, and van der Waals broadening, and take into account forbidden components.

The new synthetic spectra reproduce well all He I lines observed in DB stars in the optical range, including gravity-sensitive lines. Two new forbidden components of the helium atom observed in the red part of the spectrum are also satisfactorily modeled. We show that the requirement of a good correlation between the effective temperatures determined independently from the *IUE* energy distributions and from the He I line profiles provides some constraint on the efficiency of atmospheric convec-

¹A review dedicated to the memory of Albrecht Unsöld (1905–1995)

tion. Finally, we present the first mass distribution for the DB white dwarfs, and compare it to that of the DA stars.

1. The DB and DBA Degenerates as Hydrogen-Deficient Stars

With their atmospheres of nearly pure helium, most of it in neutral form, the DB white dwarfs must represent, to an unbiased eye, the best example of hydrogen-deficient stars nature has to offer. Far from being oddities, they represent nearly 20% of all the white dwarfs in the range of effective temperature where DB stars are found, i.e., between about 10,000 and 30,000 K.

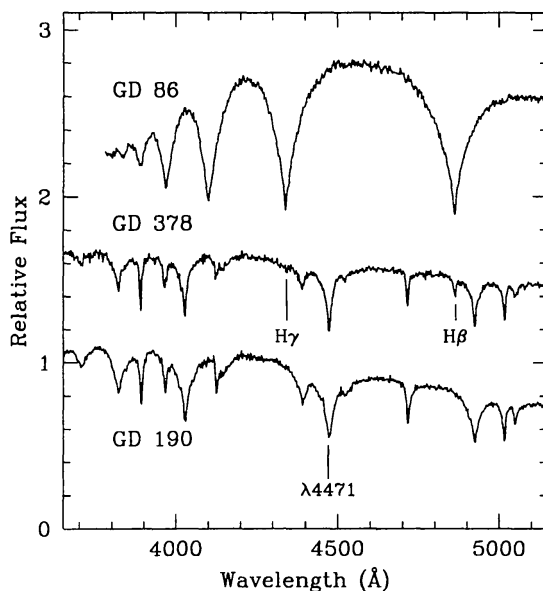


Figure 1. Optical spectra of GD 190 ($T_{\text{eff}} \sim 21,000$ K) and GD 378 ($T_{\text{eff}} \sim 16,000$ K), typical DB and DBA stars, respectively. Weak $H\beta$ and $H\gamma$ are visible in the latter. GD 86 is a 15,500 K DA star, shown for comparison.

These temperature boundaries have distinct origins: the lower boundary simply reflects the fact that the helium atom is predominantly in its ground state at low effective temperatures. Optical transitions, which originate from the $n = 2$ level, thus cannot be excited, and helium becomes spectroscopically invisible at low effective temperatures even though it is the main constituent of the atmosphere. In contrast, no white dwarf with strong neutral helium lines is known to be hotter than 30,000 K. This is not a consequence of ionization or excitation equilibrium, as models show the He II lines strengthening appreciably only near 40,000 K. This result must thus be considered a true cutoff in the distribution of DB stars, and a fundamental property of these objects. This dearth of hot DB white dwarfs, when combined to the absence of DO stars below about 45,000 K (Wesemael, Green, & Liebert 1985), implies that essentially all white dwarfs in the 30,000–45,000 K range, often called the DB gap, have a hydrogen-rich atmosphere.

A small group of objects, called the DBA stars, is closely related to the DB spectral class, and completes this picture. These are white dwarfs that show strong lines of He I — similar to those encountered in the DB stars — but also weaker hydrogen lines. Additional minor groups include the DBZ and the DBAZ stars (e.g., Sion, Aannestad, & Kenyon 1988), which exhibit weak to moderately strong lines of heavy elements, most frequently calcium, occasionally together with hydrogen. Illustrations of these many subtypes are shown in Wesemael et al. (1993). In Figure 1, we display spectra only for the dominant DB and DBA classes, together with the spectrum of a typical hydrogen-line DA star near 15,000 K. The complex optical spectrum of DB stars, with its numerous, weak He I transitions, departs from the elegant simplicity of the spectrum of DA stars, and is an accurate reflection of the increased challenge encountered in attempting to model the atmospheres of helium-rich degenerates.

2. A Review of Past Studies of DB and DBA Stars

While the first model atmospheres of DB stars already included a pure helium composition (Kolesov 1964), the high photospheric purity of these stars was first revealed by the work of Bues (1970) and Strittmatter & Wickramasinghe (1971), who succeeded in reproducing quite well the strongest lines in the observed spectra of a handful of DB stars. To obtain these results, they required an abundance of $N(\text{H})/N(\text{He}) \sim 10^{-5}$, and a metallicity at least 100 times lower than the solar value. The low gravity determined by Bues for four DB stars, $\log g \sim 7.0-7.5$, has subsequently been attributed to her neglect of convective energy transport.

Progress in the treatment of the atmospheres of DB stars continued over that decade with the inclusion of two significant improvements in the models: convection in the atmospheric layers (starting with Wickramasinghe & Strittmatter 1970), and the use, in line profile calculations, of the best available Stark profiles for transitions in the helium atom (e.g., Liebert et al. 1976; Wickramasinghe 1979). Increasing confidence in the models, and the availability of high-quality Palomar data, subsequently led to the first direct gravity determination in a DB star, GD 40 (Shipman, Greenstein, & Boksenberg 1977). This was later followed by the detailed spectroscopic study of a sample of seven DB degenerates by Wickramasinghe & Reid (1983), and by the analysis (Koester et al. 1985) of both *IUE* and optical data on the bright, variable DB star GD 358. The GD 358 analysis showed that, in the case of a rather hot ($\sim 24,000$ K) DB star, it was possible to reproduce fairly well the profiles of the neutral helium lines for which detailed line opacities were tabulated. This success, by providing confidence both in the basic structure of the model atmospheres (including the main continuum opacity sources) and in the Stark broadening theories, paved the way for our own renewed attempt at spectroscopic modeling of the DB stars.

Radius or gravity determinations in DB stars do not hinge on the availability of optical spectroscopy, and thus became available as soon as realistic model atmospheres for helium-rich stars were computed. Shipman (1972, 1979) included several DB stars in his extensive determinations of white dwarf radii from photometry and parallaxes, and found no significant differences between the radii of DA and DB stars. Updating earlier work by Koester (1979), Koester, Schulz, &

Wegner (1981) subsequently analyzed a large homogeneous sample of DB stars observed spectroscopically and photometrically. Even though the Strömgren photometry proved of little use, they succeeded in determining effective temperatures and surface gravities for a subsample of 18 objects. Their mean gravity was $\langle \log g \rangle = 7.78$, with a standard deviation $\sigma = 0.18$. This range corresponds to a small scatter on individual masses ($\langle M \rangle = 0.44 M_{\odot}$, $\sigma_M = 0.10 M_{\odot}$), a result which hinted at the mass distribution of DB stars being fairly narrow. Wickramasinghe & Reid (1983) later obtained $\langle M \rangle = 0.58 M_{\odot}$ from their limited sample of seven stars. Finally, Oke, Weidemann, & Koester (1984), using multichannel observations of 30 objects, determined the effective temperature and surface gravity for most stars in their sample. Their mean mass is $\langle M \rangle = 0.55 \pm 0.10 M_{\odot}$. These earlier studies conclusively demonstrate that narrow-band colors cannot be used for gravity determinations in DB stars, but that optical spectroscopy and/or MCSP spectrophotometry can be put to profitable use. Furthermore, existing analyses do hint at the mass distribution of DB stars being quite narrow — to an extent comparable to that of the hydrogen-line DA stars.

The existence of the DB gap along the cooling sequence of helium-rich degenerates, the development of models of spectral evolution of white dwarf stars, as well as the existence of pulsating DB white dwarfs all underscored the requirement for a more accurate knowledge of the temperature scale of DB stars. Thus, more recent studies of large samples of DB stars have largely focused on this particular aspect, and made significant use of *IUE* energy distributions in order to determine effective temperatures of DB degenerates. Studies of this kind were carried out by Wickramasinghe (1983), Liebert et al. (1986), Wegner & Nelan (1987), and Thejll, Vennes, & Shipman (1991). In particular, the work of Thejll et al., which updates and corrects the earlier analysis of Liebert et al. of a sample of about ten hot DB stars observed with the *IUE*, confirms that none of the DB degenerates known to date is hotter than about 30,000 K.

It is useful to return briefly to the DBA stars, if only to sort out their relationship to the normal DB degenerates. After the discovery of hydrogen lines in two objects which appeared otherwise to be normal DB stars (Liebert & Strittmatter 1977; Wickramasinghe & Whelan 1977), it was unclear whether these objects were isolated oddballs, or a new class of white dwarfs. Since that time, however, many new DBA stars have been found (e.g., Shipman, Liebert, & Green 1987; Wegner & Nelan 1987), and about 20% of all helium-rich white dwarfs between $\sim 12,500$ – $20,000$ K are DBA stars with typical abundances of $N(\text{H})/N(\text{He}) \sim 10^{-5}$ – 10^{-3} . It is currently believed (e.g., Weidemann & Koester 1991) that the DB and DBA stars represent a fairly homogeneous group of objects, characterized by a continuum of hydrogen abundances. In most stars, there is too little hydrogen for it to be detectable in the optical at the effective temperature which characterizes them, and these objects are classified DB. The DBA stars tend to cluster at the low temperature end — where the helium continuum opacity is relatively low — and have hydrogen abundances above the detection threshold at those temperatures. Given the constraints imposed by current models of the DB gap (see below), accretion of hydrogen from the interstellar medium appears the only possible way of accounting for the presence of small quantities of hydrogen in DB stars (Pelletier 1986; Liebert, Fontaine, & Wesemael 1987).

3. Some Unresolved Issues Concerning DB Stars

While most DB stars are likely to originate from cooled-down DO stars, Nather, Robinson & Stover (1979, 1981) have suggested that DB stars could represent the end-state of hydrogen-deficient, double-degenerate (AM CVn-like) systems. The issue of what fraction of DB stars originate in this way has not been addressed beyond the initial estimate of Nather et al. On the other hand, the DO→DB scheme and the existence of the DB gap require that all DO degenerates be converted into DA stars at 45,000 K and, furthermore, that about 20% of the DA stars turn into DB degenerates at about 30,000 K. To accomplish these conversions, a mechanism has been proposed whereby the DO→DA conversion would be associated with the building up of a hydrogen layer in DO stars through upward hydrogen diffusion; the DA→DB changeover, on the other hand, would be accomplished by convective mixing of a suitably thin ($\sim 10^{-15} M_{\odot}$) hydrogen outer layer into the underlying, massive helium convection zone (Liebert et al. 1987; Fontaine & Wesemael 1987; MacDonald & Vennes 1991).

Further observational studies can help address the issues of the origin and chemical evolution of DB degenerates by providing answers for several fundamental questions. For example, is there any evidence of different mass distributions for the DA and DB stars? Is there any sign of, say, a bimodal mass distribution for the DB white dwarfs, which could be indicative of distinct evolutionary paths leading to these stars? Is there any statistical evidence for differences between the DB and DBA samples? Are the atmospheres of the hottest DB stars peculiar in any way, thus affording possible evidence for a recent episode of convective mixing? Do the pulsating DB stars define an instability strip along their cooling sequence, as is expected on theoretical grounds? If so, is the strip pure, and what are its boundaries? Given the number of unresolved issues surrounding the DB degenerates, the time appears right for a new spectroscopic study of DB stars.

4. A New Spectroscopic Study of the DB and DBA Degenerates

Progress in the spectroscopic study of DB stars has been somewhat slower than in the study of DA stars. This can be attributed to three reasons: firstly, DB stars generally tend to be faint, as a result of their relative rarity, and high-quality observations of these objects have thus — historically — been more difficult. Secondly, spectroscopic determinations of the atmospheric parameters of DB stars depend on our understanding of the helium atom. While recent progress has been made in the treatment of the continuum opacity of neutral helium (Koester et al. 1985; Seaton et al. 1992), the broadening theories necessary to compute the detailed line opacity have not evolved for nearly 25 years. Finally, there are concerns associated with the appropriate treatment of convection. This is an important problem, since almost all the DB stars have a convective atmosphere, and since many of the bright DB white dwarfs are in the effective temperature regime in which the derived atmospheric parameters could depend on the chosen convective efficiency.

The observational material which forms the basis for our reanalysis of the DB sample consists of high S/N optical spectra (3700–5200 Å) of now close to 80

DB stars. We also have *IUE* spectra for 25 of those stars from the *IUE* archives, as well as a handful of red spectra in the 5200–7100 Å range. In parallel, we have considerably improved the broadening data for optical lines of the neutral helium atom. An earlier summary of this work was presented by Beauchamp et al. (1995b).

4.1. Temperature- and Gravity-Sensitivity of He I Line Profiles

The temperature sensitivity of the He I lines in synthetic spectra of hot DB stars, shown in Figure 2, underscores the need for accurate calculations of the profiles of neutral helium lines. The details of the variation with effective temperature of the strength of the He I lines differ whether one is on the cool or the hot side of the temperature where the lines reach their maximal strength, near $T_{\text{eff}} = 20,000$ K. For cool DB stars, the intensity of the lines is very sensitive to effective temperature, and increases smoothly from nearly zero near $T_{\text{eff}} \sim 10,000$ K to its peak value, near 20,000 K. On the hot side, the intensity shows but a slow decrease with increasing T_{eff} . Because of this weakened sensibility, spectroscopic temperature determinations of the hottest DB stars clearly require detailed broadening calculations for as many optical He I lines as possible.

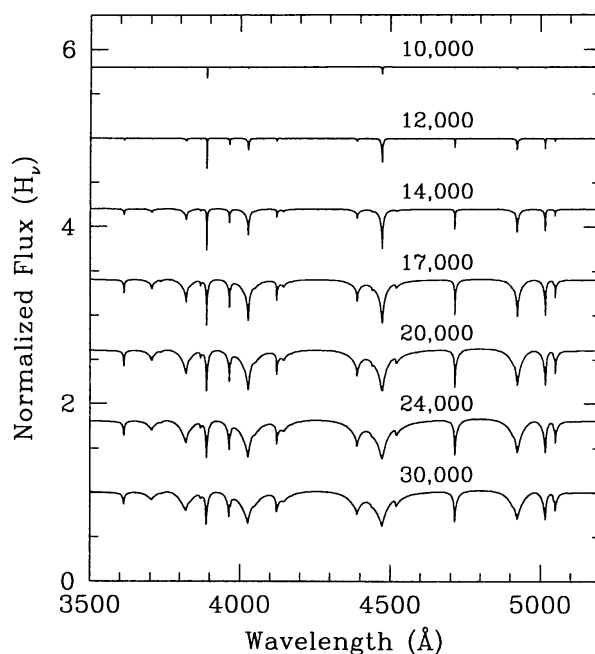


Figure 2. Optical synthetic spectra of DB white dwarfs at $\log g = 8.0$.

Gravity determination in these stars is not as problematic, since many of the He I lines are quite sensitive to $\log g$ at all values of T_{eff} . In particular, some of the gravity-sensitive lines near the strong He I $\lambda 4471$ transition have been used before as gravity indicators (Shipman et al. 1977; Wickramasinghe & Reid 1983). In addition, Wickramasinghe (1979) has demonstrated that many other lines, mainly in the 3700–4200 Å range, are also very sensitive to gravity. This new window has never been truly used, however, since no detailed broadening calculations are available for lines below 4200 Å, save for He I $\lambda 4026$.

4.2. Broadening Theories for Neutral Helium Lines

The major source of line broadening for DB stars hotter than $\sim 15,000$ K is Stark broadening by ions and electrons. Two main theories are available for the calculation of Stark profiles at a given density and temperature. That of Barnard, Cooper, and collaborators includes the three following effects: transition from quadratic to linear Stark broadening, transition from impact to quasi-static regime for electrons, as well as forbidden components. These different effects affect, among other things, the asymptotic behavior of the profile in the far wings. The second theory available simply describes the profile as a Lorentzian shape, which is derived assuming only quadratic Stark broadening and impact regime for the electrons. This Lorentzian profile can be quite different from the detailed profile calculated with the first theory since the transition from quadratic to linear Stark broadening occurs, for some lines, near the core, and the transition from impact to quasi-static regime for electrons typically occurs a few tens of Angströms from the core.

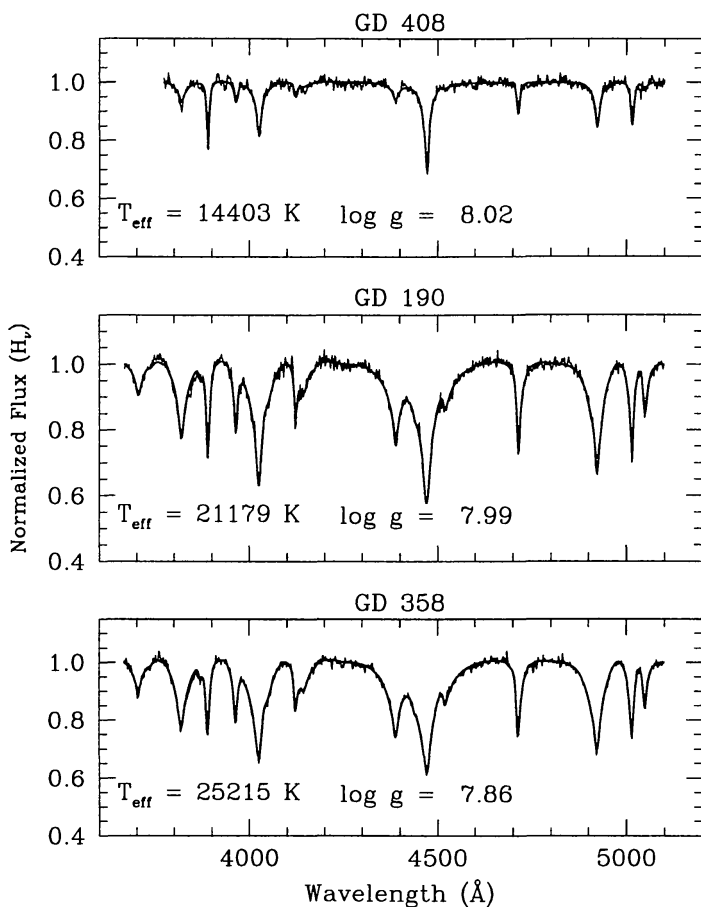


Figure 3. Optical fits to the DB stars GD 408, GD 190, and GD 358. The thick line represents a spectrum interpolated on our grid of synthetic spectra at the optimal values of T_{eff} and $\log g$.

Since detailed profiles from the more accurate theory have been tabulated for five neutral helium lines only (He I $\lambda 4026$, $\lambda 4388$, $\lambda 4471$, $\lambda 4922$, and $\lambda 5016$; Shamey 1969; Barnard & Cooper 1970; Barnard, Cooper, & Smith 1974, 1975),

we have calculated our own tables of detailed profiles for all the observable lines in DB spectra that require such a treatment, that is for nearly twenty lines. For each line, this involves the computation — for an ensemble of values of the electric microfield due to quasi-static ions — of a grid of electron-broadened profiles. A weighted average of these profiles over the ionic electric field, with the Holtsmark distribution as the weight function, yields the final profile at a given temperature and electronic density.

4.3. New Model Atmosphere and Synthetic Spectrum Calculations

These new broadening data have been incorporated in our calculations of a new generation of LTE model atmospheres and synthetic spectra. Models also include the effects of the He_2^+ molecule (Stancil 1994), which is one of the main sources of continuum opacity in cool DB stars, and the Hummer-Mihalas (1988) equation of state, along with their treatment of pseudo-continuum opacity (Däppen, Anderson, & Mihalas 1987).

It turns out that these new ingredients greatly improve the quality of the fits. Figure 3 shows fits for our optical spectra of GD 358 and GD 190. In each spectrum, each line or group of lines is suitably normalized by the local continuum. We were already able to obtain such a good fit longward of 4200 Å without using our broadening calculations because the lines there are well described by the Lorentzian shape, or have tabulated profiles from the Barnard et al. theory. However, the quality of the fit shortward of 4200 Å has now been greatly improved. Almost all lines there require the detailed treatment, which was previously available only for $\lambda 4026$. Furthermore, problems noted with the fit to the red wing of $\lambda 4026$ (Koester et al. 1985) have now been solved with our new broadening data.

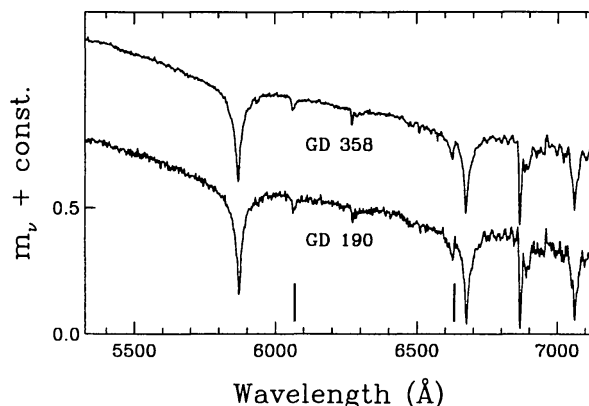


Figure 4. The forbidden components of the He I atom observed in spectra of GD 190 and GD 358 near 6068 Å and 6632 Å are indicated by tick marks.

In general, we find it difficult to match spectra of cool DB stars, such as GD 408, with the same success as in the hotter objects (Fig. 3). There, broadening by neutral particles becomes important, and one has to convolve the Stark profiles with their van der Waals counterparts. However, all the effects included in the more sophisticated theory of Stark broadening are neglected in

van der Waals broadening theories, which predict a Lorentzian profile. This deficiency is likely to be at the origin of the poorer fits to some of the helium lines, especially to $\lambda 3889$, which has the highest sensitivity to broadening by neutral particles.

Forbidden components are essential ingredients in calculations of Stark profiles. In the blue, for example, almost all the lines turn out to be a blend of a permitted component and typically 4 or 5 forbidden ones, of roughly the same strength as the permitted one. A well-known example of this is the $\lambda 4471$ line, which has a strong forbidden component at $4470 \text{ \AA}$. From all the forbidden components included in our synthetic spectra, that is more than one hundred, only three are simultaneously strong and far enough from any other lines, including their respective associated component. One is the well-known feature at $4517 \text{ \AA}$, associated with the strong $\lambda 4471$ line (Liebert et al. 1976). Two other forbidden components are predicted by our models at $6068 \text{ \AA}$ and $6632 \text{ \AA}$. As shown in Figure 4, the presence of these forbidden components in the red spectra of DB stars, first suggested by Greenstein & Liebert (1990), has now been confirmed by Beauchamp et al. (1995a), who successfully modeled them.

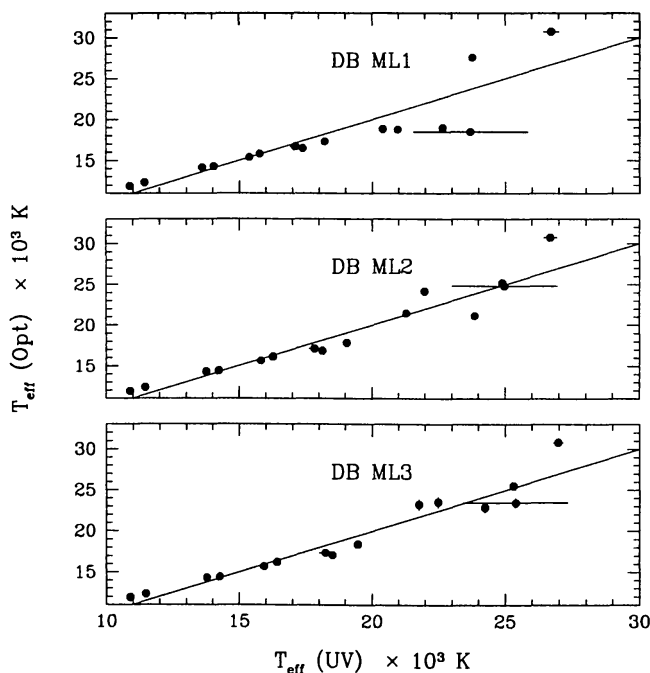


Figure 5. Correlation between ultraviolet and optical temperatures for different convective efficiencies.

As a final point, it is useful to study the correlation between the effective temperatures obtained from the *IUE*, and those derived from optical data. Figure 5 shows this correlation for a subsample of DB stars for which both data sets were available. The correlation is shown for three different convective efficiencies, within the framework of the mixing-length theory: ML1, ML2, and ML3, in order of increasing convective efficiency (e.g., Bergeron, Wesemael, & Fontaine 1991). It is interesting to note that the correlation is worse when ML1 is used, whereas both ML2 and ML3 provide satisfactory correlations between

the temperatures secured on the basis of different techniques. For ML2, which we adopt — for now — as a compromise, the standard deviation around the solid curve is $\sigma = 1600$ K, with the hotter stars the dominant contributors to that figure. It has not escaped our attention that, for ML2 or ML3 convection, the star which departs the most from the 1:1 correspondance is PG 0112+104, the hottest DB star, and the object closest to the cool end of the DB gap.

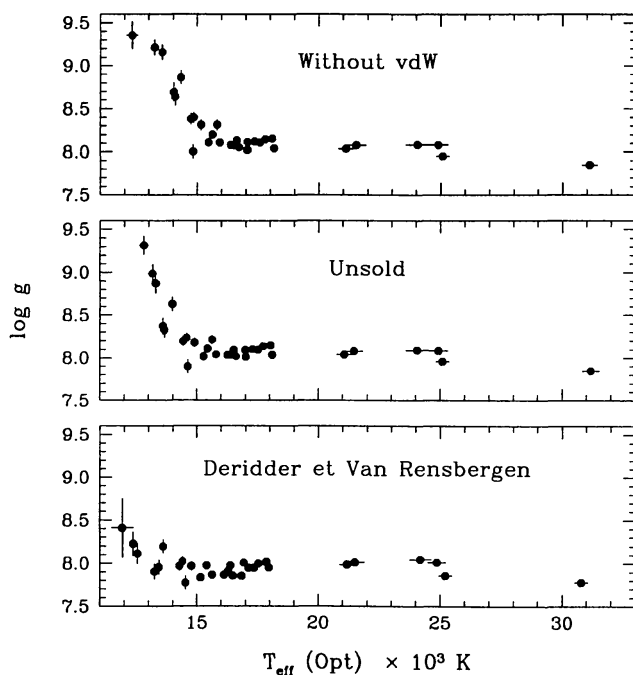


Figure 6. Correlation between optical effective temperature and gravity for different treatments of the van der Waals broadening.

Another useful diagram is the relation between effective temperature and surface gravity shown in Figure 6. Because white dwarfs cool at nearly constant radius, the surface gravity should be independent of effective temperature. In Figure 6, we show that correlation for three distinct situations: no van der Waals broadening included; van der Waals broadening described with the Unsöld (1955) approximation; and van der Waals broadening described with the more recent prescription of Deridder & Van Rensbergen (1976). Figure 6 shows that, while above 15,000 K $\log g$ is indeed independent of T_{eff} , the situation is more complicated at cooler temperatures. Indeed, the $\log g$ vs. T_{eff} relationship found depends sensitively on the treatment of the van der Waals broadening. Not unexpectedly, the Deridder & Van Rensbergen treatment of that broadening appears to provide the most satisfying correlation. Even then, in cool DB stars, the sensitivity of individual surface gravities to the exact treatment of broadening by neutral particles seems a little too high for comfort.

4.4. The Mass Distributions of the DB and DBA Degenerates

The surface gravities determined on the basis of our fits to the optical spectra can be transformed into masses through the use of the mass-radius relationship for degenerate stars of Wood (1990). Figure 7 shows our preliminary results on

the mass distribution of the DB and DBA white dwarfs which, in accordance with the issues discussed in §3, are best considered separately here. Our analysis is currently restricted to a small subsample of 41 DB stars and 13 DBA stars, all above 15,000 K, and the results displayed here are for ML2 convection. Our preliminary values for the mean mass and dispersion of the various samples are $\langle M \rangle = 0.567 M_\odot$, $\sigma_M = 0.043 M_\odot$ for the DB sample; $\langle M \rangle = 0.642 M_\odot$, $\sigma_M = 0.062 M_\odot$ for the DBA sample; and $\langle M \rangle = 0.585 M_\odot$, $\sigma_M = 0.063 M_\odot$ for the combined DB+DBA sample.

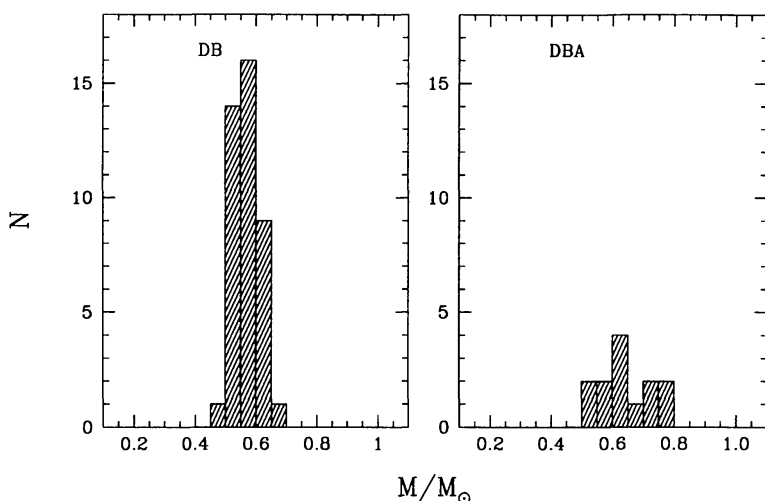


Figure 7. Mass distributions of the DB and DBA white dwarfs, under the assumption of a ML2 convective efficiency.

The mass distribution of the DB stars appears quite narrow: 73% of the stars analyzed have masses between 0.50 and $0.60 M_\odot$. A similar result is also seen if the ML3 parameterization is adopted in the determination of surface gravities. While it is based on a considerably smaller sample, the shape of the mass distribution of DBA stars appears distinctly different, with five out of 13 objects (38%) characterized by masses above $0.65 M_\odot$. Put differently, our results show that — in our combined sample of 54 objects — the four most massive objects are DBA stars. It thus appears that a larger stellar mass may favour the presence of hydrogen, perhaps through an increased hydrogen accretion from the interstellar medium or through a decreased dilution of the accreted hydrogen throughout a thinner helium convective zone.

The combined mass distribution we have obtained is compared to that of DA stars in Figure 8. There, we plot the combined DB+DBA sample, together with the mass distribution for DA stars of Bergeron, Saffer, & Liebert (1992), updated by Bergeron et al. (1995) for stellar models with the thick hydrogen layers (Wood 1995) currently thought to be representative of normal DA stars. As mentioned earlier, the mean mass of the combined DB+DBA sample is $\langle M \rangle = 0.585 M_\odot$, $\sigma_M = 0.063 M_\odot$, whereas it stands at $\langle M \rangle = 0.590 M_\odot$, $\sigma_M = 0.134 M_\odot$ for the DA stars with thick layers. Thus, *the mean mass of the helium-line degenerates does not differ in any significant way from that of the DA stars.* The larger standard deviation of the DA distribution reflects the fact that the main distinction between the DA and DB distributions appears in the wings of

the histograms: whereas DA stars have extensive wings at both low and high stellar masses, which account altogether for 20% of the DA sample, such is not the case in the DB stars. The extension of the DA distribution below $0.4M_{\odot}$ is

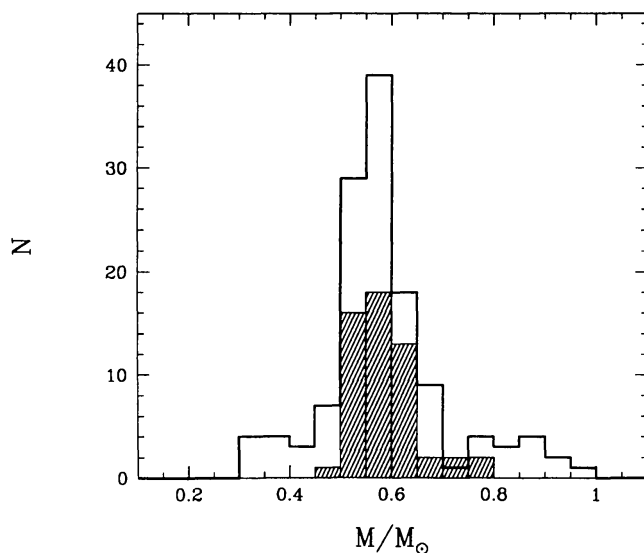


Figure 8. Comparison of the combined DB+DBA mass distribution (shaded area) with that derived for DA stars with thick hydrogen layers.

associated with the existence of low-mass, double degenerate systems (Iben & Tutukov 1987; Marsh, Dhillon, & Duck 1995), while high-mass objects are thought to be formed through mergers (Iben 1990). It appears that these particular evolutionary channels do not contribute significantly to the pool of DB white dwarfs, perhaps because the objects which go through one of these binary phases end up with hydrogen layers too massive to allow the postulated DA→DB conversion to occur near the cool edge of the DB gap.

5. Concluding Remarks

The narrow mass distribution of the DB and DBA degenerates presented in §4.4 represents but a first step toward an improved understanding of this important class of hydrogen-deficient stars. In the process, however, our investigation has already raised many more questions than have been answered — as should be. For example, is our difficulty in securing a consistent fit to the hot DB star PG 0112+104 symptomatic of a perturbed atmosphere, having just undergone an episode of convecting mixing and a DA→DB conversion? Despite the absence of Balmer lines in the optical spectra of the hot ($T_{\text{eff}} \gtrsim 20,000$ K) DB white dwarfs, to what extent is the hydrogen abundance a “hidden parameter” in our spectroscopic analyses of these stars? If the study of DB stars over the next few years is as fruitful as it has been over the past quarter century, answers to these, and many more, questions will undoubtedly be forthcoming.

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