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HOT DEGENERATES IN THE MONTREAL-CAMBRIDGE-TOLOLO SURVEY. II. TWO NEW HYBRID WHITE DWARFS, MCT 0128−3846 AND MCT 0453−2933, AND THE NATURE OF THE DAB STARS

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ABSTRACT

We report the discovery, in the course of a survey for high-latitude, ultraviolet-excess objects in the southern hemisphere, of two new hybrid DAB stars. Both objects exhibit a weak He I λ4471 line superposed onto the usual Balmer line spectrum. Analyses of the Balmer series with both homogeneous and stratified models show these stars to have spectroscopic effective temperatures around 27,000 K. However, low-dispersion ultraviolet observations with the *IUE* reveal energy distributions considerably flatter than those of normal DA stars near that effective temperature. These energy distributions are inconsistent as well as those of stratified models calculated at the temperature and hydrogen-layer mass determined from the optical spectrum. We demonstrate instead that consistent fits to the optical and ultraviolet spectrum, as well as to the energy distribution, can be achieved if these objects are unresolved, composite systems consisting of a DA white dwarf together with a DB or DBA star. The DAB spectral class thus appears inhomogeneous, and may contain both composite systems and stratified stars.

Subject headings: stars: binaries — stars: individual (MCT 0128−3846, MCT 0453−2933) — ultraviolet: stars — white dwarfs

1. INTRODUCTION

On the basis of many studies which go back to Schatzman (1958), DA white dwarfs are now understood to have chemically pure atmospheres in the effective temperature domain where gravitational settling dominates over the physical mechanisms that could hinder the downward diffusion of heavy elements in the atmosphere. This purity disappears at high effective temperatures where studies in the X-ray (Vennes & Fontaine 1992; Barstow et al. 1993) and optical (Holberg et al. 1989; Napiwotzki & Schönberner 1993) regions reveal the presence of helium or metals, or both, in the stellar photosphere. It also vanishes at lower effective temperature, roughly below 11,000 K, when convective mixing destroys the element segregation established by gravitational settling (Bergeron et al. 1990b). Between these temperature extremes, however, it is generally believed that—barring any unsuspected competing mechanism—DA white dwarfs should possess pristine atmospheres.

Because of this expected purity, white dwarfs with spectra exhibiting features of more than one chemical element are of particular interest. Among those, the DAB stars represent the class of hybrid white dwarfs where weak neutral helium lines are superposed onto the classical hydrogen-line spectrum of DA stars (see, e.g., Wesemael et al. 1993b). Such stars are rare: until recently the only known DAB star was the prototype GD 323, a DAB2 star discovered independently by Oke, Weidemann, & Koester (1984) and Liebert et al. (1984). More recently, a second DAB star, G104-27, was discussed by Holberg, Kidder, & Wesemael (1990), but the exact nature of this object is still unclear, as the weak He I lines initially reported in data at high S/N were not seen in the later spectra of comparable quality (Kidder et al. 1992). It may be a true spectroscopic variable. A third object, HS 0209+0832 has recently been recognized in the Hamburg-Schmidt sky survey, and analyzed by Jordan et al. (1993).

The nature of these rare hybrid stars remains poorly understood. On the basis of their recent reinvestigation of the nature of GD 323, Koester, Liebert, & Saffer (1994) conclude that a stratified structure remains the "most promising" explanation of the properties of that object; according to these authors, GD 323 is a stratified, 28,750 K white dwarf, with a very thin ($\log q_H \equiv \log M_H/M_* = -16.8$) hydrogen layer floating on top of a helium envelope. In contrast, the weaker He I features and apparently normal Balmer lines of G104−27 can apparently equally well be fitted with homogeneous models or—perhaps a more reasonable alternative on physical grounds—stratified models near 26,000 K; for the latter, the hydrogen layer masses quoted have been $\log q_H = -16.6$ (Holberg et al. 1990), -16.2 (Vennes & Fontaine 1992), and -15.4 (Jordan et al. 1993). As far as HS 0209+0832 is concerned, its 36,000 K temperature places it within the DB gap, this temperature region between 28,000 and 45,000 K where no DB stars are observed. This is potentially an important clue, as some models of the spectral evolution of white dwarfs (e.g., Fontaine & Wesemael 1987)

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predict a changeover of some stars from DB to DA near that temperature range. Attempts at fitting its spectrum and energy distribution with stratified models (Jordan et al. 1993) yield an optimal fit near log $q_H = -15.2$, but also suggest that this object may not have a photosphere in complete diffusive equilibrium.

The current situation thus appears muddled; it may nevertheless be helpful to remember that the DAB class is, after all, only a spectroscopic class, with no guarantee that objects populating it form a homogeneous group. Clearly, much remains to be understood, and great progress can be made when the surface properties of additional objects with hybrid spectra are studied. In the course of our southern hemisphere survey of blue subluminous stars (the Montreal-Cambridge-Tololo, or MCT Survey; see Demers et al. 1986), we have discovered two new DAB white dwarfs, and we report here our observations and detailed analysis of these objects. A preliminary account of this work has been presented by Wesemael et al. (1993a).

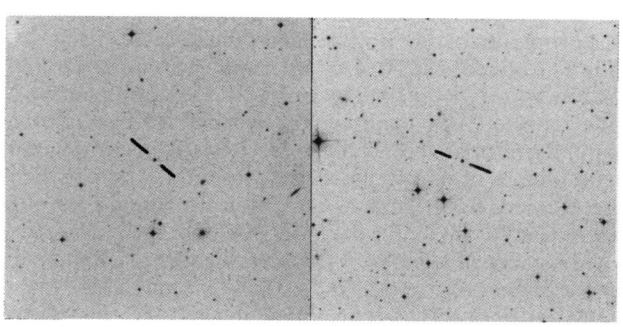
2. OBSERVATIONS

2.1. *Colorimetric Selection*

Both objects, MCT 0128−3846 and MCT 0453−2933, were discovered in the course of our southern hemisphere photographic survey for blue stellar objects currently being carried out at Cerro Tololo (the MCT survey). The selection of objects is performed on calibrated *U* and *B* Schmidt plates which are processed at the APM machine in Cambridge (UK). On the basis of their blue color ($[U-B]_{pg} = -0.80$ for MCT 0128−3846 and $[U-B]_{pg} = -0.62$ for MCT 0453−2933), both objects were retained for follow-up spectroscopic observations. Finding charts for both objects from the ESO Sky Survey J Film are presented in Figure 1, and positions, measured on the original APM plates and generally accurate to ±3″, are given in Tables 1 and 2.

2.2. *Optical Spectrophotometry*

Since their discoveries, which date back to 1986 November 16 (MCT 0453−2933) and 1989 October 9 (MCT 0128−3846), we observed both objects on several occasions at the CTIO 1.5 m and 4 m telescopes. MCT 0453−2933 was also observed at the Steward Observatory 2.3 m telescope on 1987 October 29. In addition, a red spectrum of MCT 0453−2933 only, covering the range 5200–6700 Å, was obtained in the course of a backup program on the CTIO 4 m telescope on 1988 September 25.



0128−3846 0453−2933

FIG. 1.—Finding charts for MCT 0128−3846 and MCT 0453−2933, reproduced from the ESO Sky Survey J Film. North is up, and east is left. The fields are 15′ × 15′.

TABLE 1

MISCELLANEOUS DATA ON MCT 0128−3846

Parameter	Value
α_{1950}	01^h28^m14.4^s
δ_{1950}	−38°46′06″
B_{pg}	15.72
$(U-B)_{pg}$	−0.80
V	15.32
$U-B$	−0.85
$B-V$	+0.04

TABLE 2

MISCELLANEOUS DATA ON MCT 0453−2933

Parameter	Value
α_{1950}	04^h53^m38.5^s
δ_{1950}	−29°33′41″
B_{pg}	15.41
$(U-B)_{pg}$	−0.62
V	15.12
$U-B$	−0.66
$B-V$	+0.03
y	15.03
$u-b$	+0.332
$b-y$	−0.057
m_1	+0.113
c_1	+0.220

We show, in Figure 2, blue 4 m optical spectra of both objects, together with the red spectrum of MCT 0453−2933. Shown as well is the blue spectrum of the normal DA2 star GD 14, recently analyzed by Bergeron, Saffer, & Liebert (1992a), and a 5 m spectrum of GD 323, analyzed by Koester (1989, 1991) and kindly made available to us by J. L. Greenstein and J. Liebert.

The blue spectra of the two new DAB stars differ from that of the ~25,630 K DA2 star GD 14 only by the presence of a weak He I λ4471 feature, and of an even weaker λ4026 line. The equivalent width of the former is ~1.8 Å in MCT 0128−3846, and ~1.1 Å in MCT 0453−2933. The blue spectrum of MCT 0453−2933 also shows clearly He I λλ4713, 4921, and 5015. Both the hydrogen and helium lines in the two new DAB stars appear deeper and stronger than those of the prototype GD 323. This is also true for Hα and the red He I features at 5875 and 6678 Å.

2.3. *Ultraviolet Spectrophotometry*

Both objects are sufficiently bright to be observed in the low-dispersion mode (~7 Å) with the *IUE* satellite in our program of follow-up observations of interesting degenerate stars in the MCT survey. All in all we obtained three images for MCT 0128−3846 (SWP 39692, SWP 39693, and LWP 18856) and six images for MCT 0453−2933 (SWP 31697, SWP 32195, SWP 32199, SWP 32203, LWP 11559, and LWP 11987).

Each spectra was reprocessed using the *IUE* Regional Data Analysis Facility (RDAF) at GSFC over the Internet Network. A Gaussian slit extraction technique, yielding more accurate fluxes for images at low S/N, was applied to the original two-dimensional low-dispersion spatially resolved line-by-line files. Absolute fluxes for SWP spectra are based on the new calibration of Finley, Basri, & Bowyer (1990), while LWP images are scaled with the flux calibration from Cassatella, Lloyd, &

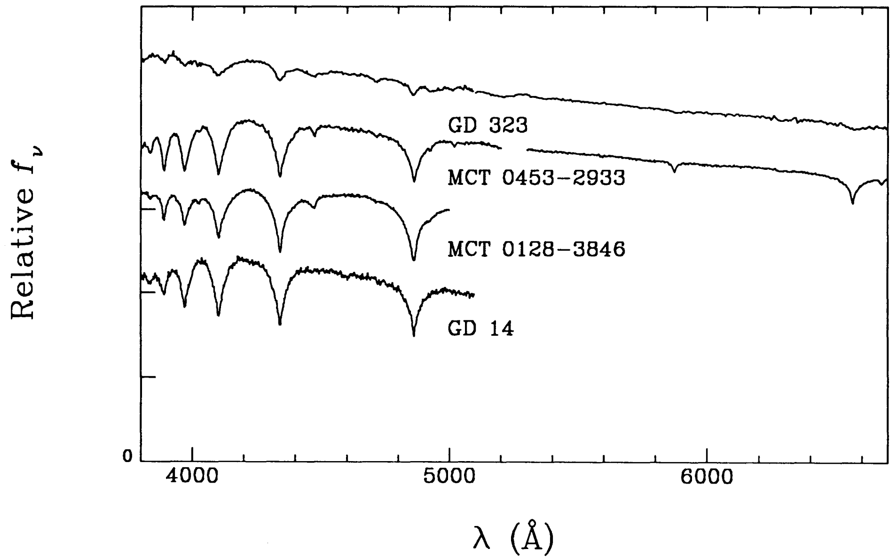


FIG. 2.—Blue optical spectra of MCT 0128−3846 and MCT 0453−2933, together with the red spectrum of MCT 0453−2933. Shown as well are the spectrum of the prototype GD 323 (*top*), kindly made available to us by J. L. Greenstein and J. Liebert, and that of GD 14 (Bergeron et al. 1992a), a normal DA2 star with an effective temperature of 25,630 K and Balmer line strengths comparable to those of the two newly discovered DAB stars (*bottom*). The resolution of the spectra of the MCT objects is ∼7–9 Å.

Gonzalez Riestra (1987). The time-dependent degradation was corrected following the prescription of Bohlin & Grillmair (1988) for SWP images, and Teays & Garhart (1990) for LWP images. Finally, the four SWP images and two LWP images of MCT 0453−2933 were averaged to increase the S/N; in the case of MCT 0128−3846, SWP 39692 was not used because of its low S/N due to a short integration time (60 minutes).

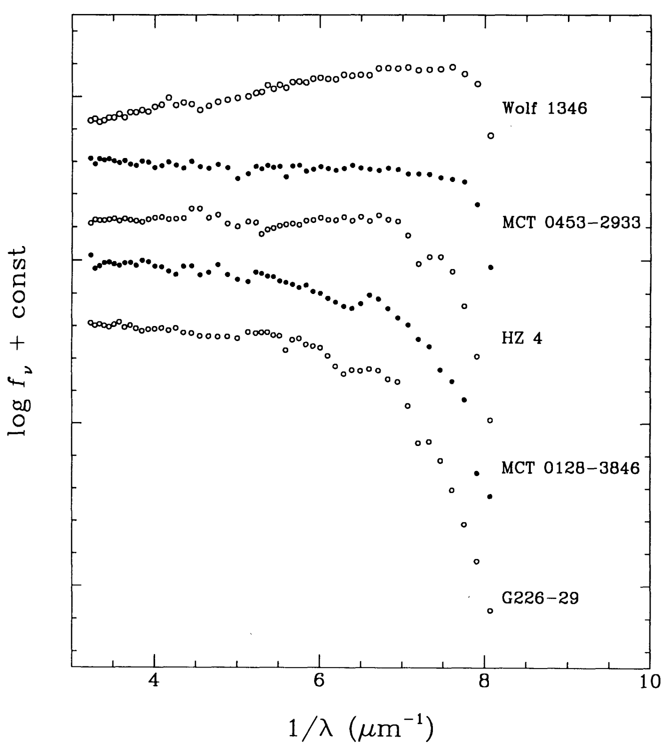


FIG. 3.—*IUE* energy distributions for the two DAB stars (*filled circles*) together with those of standard DA stars (*open circles*): Wolf 1346 ($T_{\rm eff}$ ∼ 20,680 K; Holberg et al. 1986), HZ 4 ($T_{\rm eff}$ ∼ 14,550 K; Koester et al. 1979), and G226-29 ($T_{\rm eff}$ ∼ 13,630 K; Fontaine et al. 1992).

The ultraviolet energy distributions of both objects are displayed in Figure 3. As was the case with GD 323, it is clear that the energy distributions of these stars are quite peculiar for objects with optical spectra characteristic of DA2 stars. We contrast these distributions with those of G226-29, a cool ZZ Ceti star ($T_{\rm eff}$ ∼ 13,630 K; Fontaine et al. 1992), as well as HZ 4 and Wolf 1346, two hotter DA stars with effective temperatures of 14,550 and 20,680 K, respectively (Koester, Schulz, & Weidemann 1979; Holberg, Wesemael, & Basile 1986). On the basis of this comparison alone, we find that the energy distributions of both DAB stars, were they to be fitted with homogeneous, hydrogen-rich atmospheres, would be characterized by fairly low effective temperatures, in the approximate range 13,000–18,000 K, in stark contrast to the temperatures which can be expected from the appearance of the optical spectrum, which hover around 25,000 K.

2.4. *Optical Broad- and Narrow-Band Photometry*

Single broad-band *U*, *B*, and *V* CCD frames were obtained for both objects with the CTIO 0.9 m telescope: MCT 0128−3846 was observed on the night of 1990 October 26–27 with the TI No. 3 chip with 2 × 2 on-chip binning, while MCT 0453−2933 was observed on the night of 1987 November 5–6 with the RCA No. 5 chip. The standard CTIO set of ***UBV*** filters was used, and extinction coefficients were determined from observations of several standard stars from the lists of Stobie, Sagar, & Gilmore (1985) and Graham (1982). In addition, a single photoelectric narrow-band photometric observation of MCT 0453−2933 was obtained on the night of 1988 September 15–16 on the CTIO 1 m telescope. The standard CTIO set of Strömgren filters was used here as well, and standard stars were selected from the lists of Crawford, Barnes, & Golson (1971) and Cousins (1987). The resulting magnitudes and colors are summarized in Tables 1 and 2.

3. MODEL ATMOSPHERE ANALYSES

We have derived atmospheric parameters for both objects by matching their energy distribution and line spectrum with those of various sets of model calculations.

3.1. *Homogeneous Models*

We first consider whether the optical spectra of both stars could be fitted in terms of homogeneous helium and hydrogen atmospheres. While the most simple, this solution is also physically perhaps the most unrealistic, as some mechanism would need to be invoked to maintain a homogeneous atmosphere at the effective temperatures characterizing these stars. Our homogeneous models are in LTE, and were calculated with an updated version of the code used by Wesemael et al. (1980) which includes, in particular, the improvements discussed by Bergeron, Wesemael, & Fontaine (1991). The fitting technique is similar to that used by Bergeron et al. (1992a), save for the fact that here the helium abundance, $y \equiv N(\mathrm{He})/N(\mathrm{H})$, is allowed to vary in the fitting procedure. For MCT 0128−3846, our fit makes use of the Balmer lines from Hβ up to H9, as well as of He I λ4471; for MCT 0453−2933, we used Hα up to H9, as well as He I $\lambda\lambda$4471, 5875, and 6678.

The results of our fits to the optical spectra based on homogeneous atmospheres are displayed in Figure 4. they are $T_{\mathrm{eff}} =$ 26,270 K, $\log g = 7.40$, $\log y = -2.1$ for MCT 0453−2933, and $T_{\mathrm{eff}} = 27{,}890$ K, $\log g = 8.37$, $\log y = -1.7$ for MCT 0128−3846. An estimate of the uncertainty on these parameters can be obtained from the individual analyses of two independent blue spectra of comparable quality obtained from MCT 0453−2933; the fitted parameters differ by 600 K in T_{eff}, 0.15 in $\log g$, and 0.1 in $\log y$. The unrelated uncertainty associated with the use of a different homogeneous model atmosphere grid would—on the basis of past experience—probably be of that order, or perhaps slightly greater in T_{eff}. An examination of Figure 4 reveals, however, that the overall quality of the fits to the Balmer lines is poorer than those carried out on normal DA stars in that temperature range (e.g., GD 310, GD 14, HZ 14) by Bergeron et al. (1992a). For MCT 0453−2933, the fit is simply not satisfactory, with the Balmer lines up to Hϵ as well as He I λ4471 predicted consistently deeper than observed, while H8 (which is in fact a blend of H I λ3889.05 and He I λ3888.65) is, in contrast, predicted shallower. In the red, He I λ5875 lacks the broad wings observed in the data. For MCT 0128−3846, the fit up to Hϵ is better, but He I λ4471 still is predicted deeper than is observed. Furthermore, the observed H8 line is predicted as a broader and much shallower feature than is observed.

Note that, within this interpretation of DAB stars as homogeneous objects, both stars have effective temperatures in the 26,000–28,000 K range, similar to the Koester et al. (1993) latest value for the effective temperature of GD 323, 28,750 K. Quite clearly, however, these spectroscopic effective temperatures are inconsistent with the ultraviolet energy distributions shown in Figure 3, which are characteristic of much cooler DA stars. This discrepancy is shown in some detail in Figure 5. There is clearly not much point, as was done by Liebert et al. (1984), in attempting to fit the energy distributions with much flatter ones which characterize homogeneous helium-rich stars in that temperature range, as the optical spectra of our DAB stars look decidedly like those of hydrogen-dominated stars. The inconsistency between the shape of the energy distribution and the optical line spectrum, when homogeneous hydrogen-dominated atmospheres are used, is clearly reminiscent of that encountered earlier by Liebert et al. (1984). This suggests that, despite the apparent differences between the optical spectra of those two new objects and that of the prototype, all three objects could perhaps share similar physical properties.

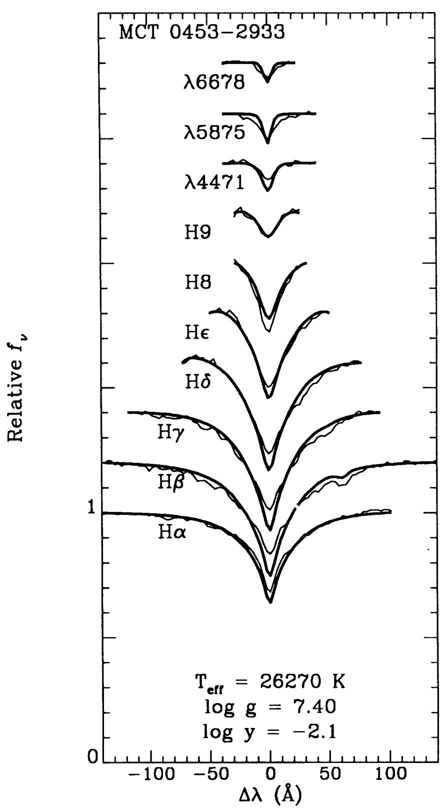


FIG. 4*a*

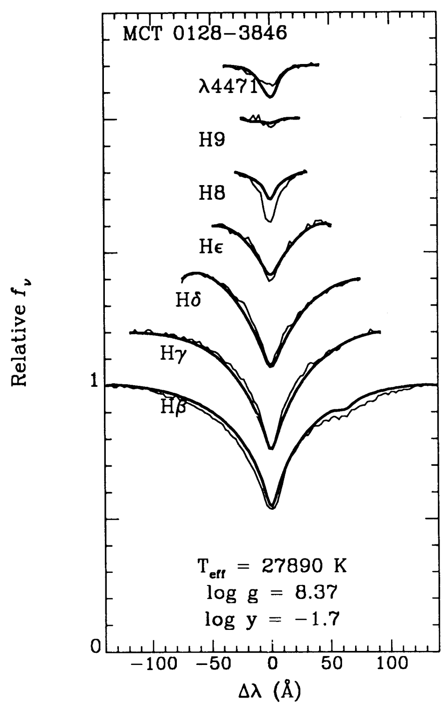


FIG. 4*b*

FIG. 4.—(*a*) Fit to the optical spectrum of MCT 0453−2933 with homogeneous models. (*b*) Same as (*a*), but for MCT 0128−3846.

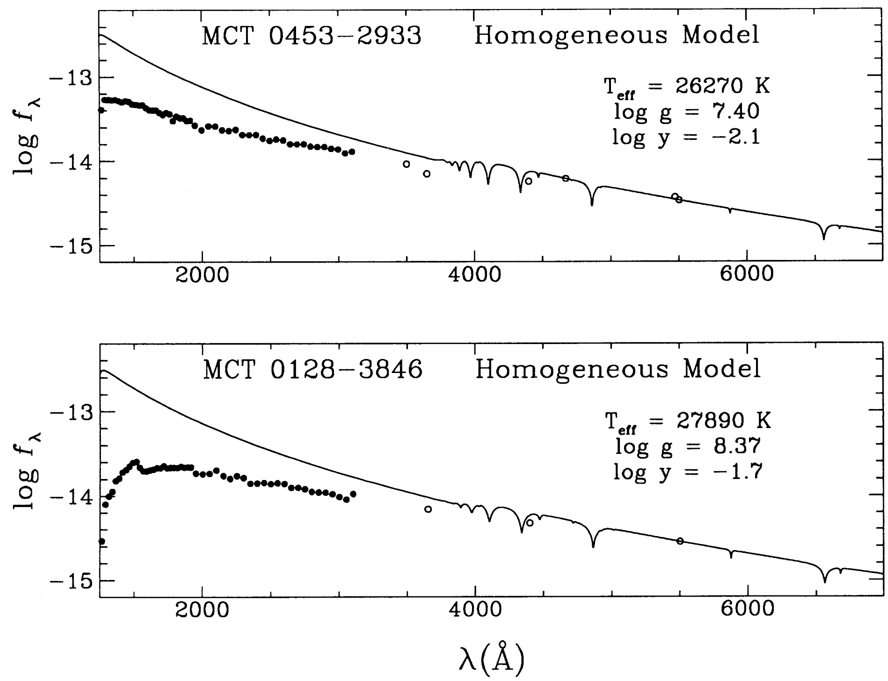


FIG. 5.—Comparison of the complete energy distribution of both stars with those of homogeneous models at the values of T_{eff}, log *g*, and log *y* derived from the optical spectrum. The filled circles are average SWP and LWP images, the open circles are the optical photometry (*U*, *B*, and *V* for MCT 0128−3846; *U*, *B*, *V*, *u*, *b*, and *y* for MCT 0453−2933).

This similarity clearly requires us to investigate next whether stratified model atmospheres can provide a match to the observed spectrophotometric and spectroscopic properties of these two new objects. The point is investigated in the following section.

3.2. *Statified* H/He *Models*

A more physically realistic model is that invoked by Liebert et al. (1984) and extensively developed by Koester (1989, 1991) and more recently by Koester et al. (1994) for GD 323, namely, that of a stratified atmosphere. In order to assess the adequacy of this model for these two new objects, we have attempted to fit the available data with a new grid of stratified models calculated especially for this work. These models, which are similar to those of Jordan & Koester (1986) and Vennes & Fontaine (1992), and which include variable ionization in the transition region as discussed by Koester et al. (1993), are parameterized by the fractional hydrogen mass floating on top of the helium envelope (i.e., q_H), as well as by the usual parameters T_{eff} and log *g*.

Our fits to the optical spectra of both objects are displayed in Figure 6. For MCT 0453−2933, the stratified fits to the Balmer lines are of quality comparable to that obtained with the homogeneous grid. The stratified fit to He I λ4471 line is superior to our earlier attempt, since that line is predicted—in the parameter range of interest—shallower than in the homogeneous models. However, the fits to the other two He I lines appear worse. For MCT 0128−3846, the quality of the stratified fits also appears comparable to that achieved earlier with the homogeneous models. The parameters of these optimal fits are $T_{eff} = 27{,}030$ K, $\log g = 7.40$, $\log q_H = -15.3$ for MCT 0453−2933, and $T_{eff} = 26{,}580$ K, $\log g = 8.53$, $\log q_H = -17.3$ for MCT 0128−3846. Once again, a minimal uncertainty in these parameters can be estimated from the two independent blue spectra obtained for MCT 0453−2933; the fitted parameters differ by 210 K in T_{eff}, 0.12 in log *g*, and 0.2 in log q_H. Note that, for stratified models, differences between independent grids of model atmospheres are likely to be larger than in the case of homogeneous models and could increase substantially the external error (see the summary in § 1 of the layer masses estimated for G104-27). In any case, while the two stars under study have very different surface gravities and fractional hydrogen layer masses, their effective temperatures are quite similar to that derived by Koester et al. (1994) for GD 323. Note also that the surface gravities determined for both objects within the stratified hypothesis are unusual: Bergeron et al. (1992a) found only two stars with $\log g > 8.5$ in their sample of 129 DA stars, and only 10 with $\log g < 7.5$.

One major obstacle remains, however: *the energy distributions of both objects cannot be fitted with stratified models at the optimal parameters given above, which were derived from the optical spectra.* This is illustrated in Figure 7, where we compare the complete energy distribution of both stars with those of models at the values of T_{eff}, log *g*, and log q_H previously determined from the optical spectra. This disagreement is somewhat disturbing particularly in light of the Koester et al. (1994) adequate match to the energy distribution of GD 323 with stratified models; the disagreement cannot rest with the grid of stratified models used here, as we can satisfactorily reproduce Koester's (1991) match to the complete energy distribution of GD 323 with his optimal parameters (T_{eff}, log *g*, and q_H) and our own stratified models; rather, it rests with the genuinely flatter energy distributions which characterize the two MCT objects.

3.3. *A Solution Based on Composite Spectra*

Given the apparent inadequacy of the stratified models in fitting the energy distributions, we are led to an alternative

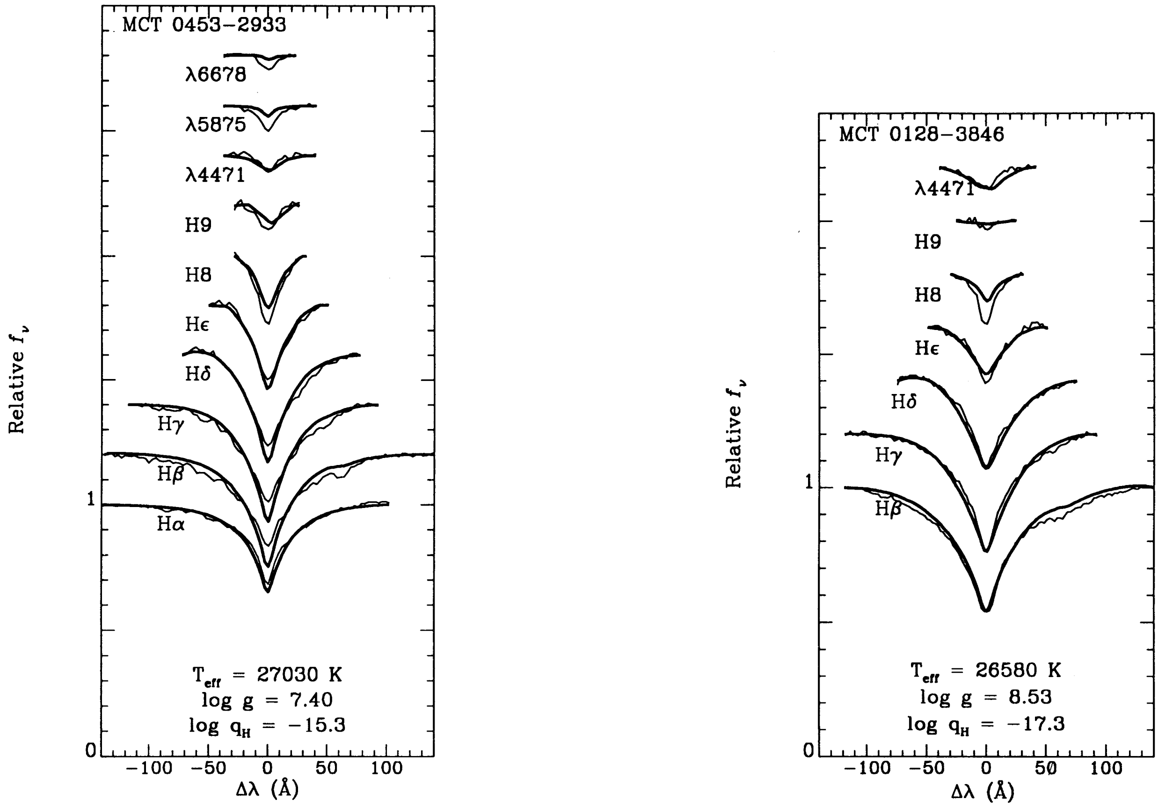


FIG. 6*a* FIG. 6*b*

FIG. 6.—(*a*) Fit to the optical spectrum of MCT 0453−2933 with stratified models. (*b*) Same as (*a*), but for MCT 0128−3846.

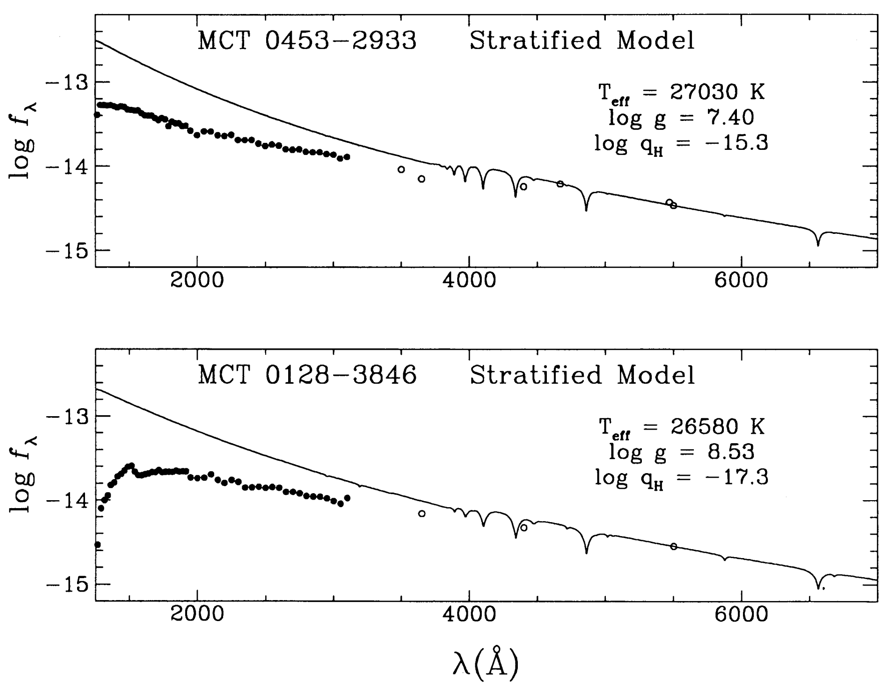


FIG. 7.—Comparison of the complete energy distribution of both stars with those of stratified models at the values of $T_{\rm eff}$, log *g*, and log $q_{\rm H}$ derived from the optical spectrum. The filled circles are average SWP and LWP images, the open circles are the optical photometry (*U*, *B*, and *V* for MCT 0128−3846; *U*, *B*, *V*, *u*, *b*, and *y* for MCT 0453−2933).

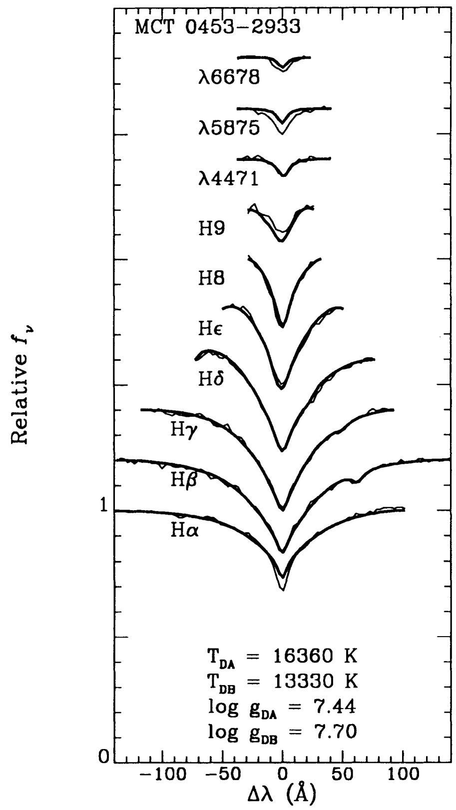


FIG. 8*a*

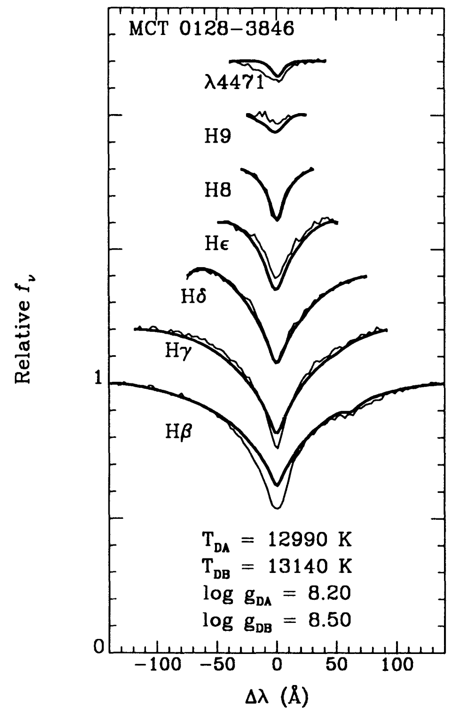


FIG. 8*b*

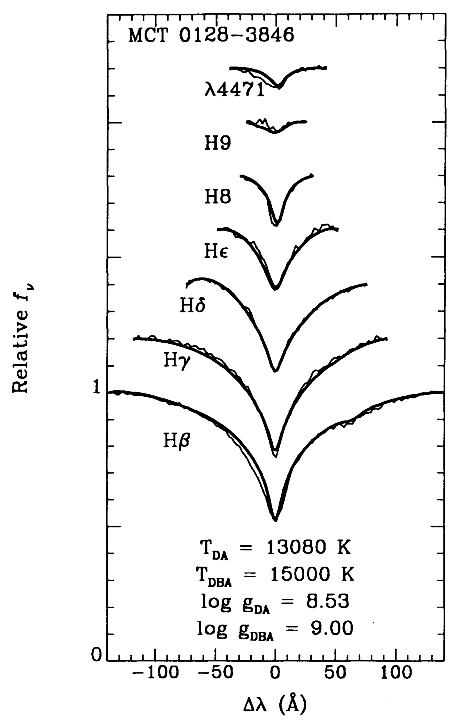


FIG. 8*c*

FIG. 8.—(*a*) Fit to the optical spectrum of MCT 0453−2933 with models representing a composite DA+DB system; (*b*) Same as (*a*) but for MCT 0128−3846; (*c*) Same as (*b*) but for a DA+DBA system. The helium abundance of the DBA star is log y_{DBA} = 4.

which had previously been considered, and rejected, in the case of GD 323, namely, that of a composite DA+DB spectrum. In the case of GD 323, the exploratory investigation of Liebert et al. (1984) had concentrated on systems composed of a DA and a DB star at equal gravities (specifically taken as log $g = 8$), but the recent reinvestigation of this model by Koester et al. (1994) confirms the earlier result. Denser model grids now permit the exploration of variations in stellar radius, or gravity, of both components. We first consider the possibility that the optical spectrum of both DAB objects is a combination of the spectrum of a DA star with that of a DB star. This is a four-parameter fit, with the effective temperature and gravity of both stars free to vary. Because of the increased number of free parameters, we now take into account in our fits the information contained in the stellar energy distribution. Our procedure thus consists in fixing the surface gravity of the DB star and carrying out a fit to the optical spectrum by adjusting the effective temperature of both stars and log g of the DA star. The quality of these fits, as well as their ability to match the observed energy distribution, is then checked and the final fit is found by interpolating in log g_{DB} within the model grid.

Let us first discuss our results for MCT 0453−2933. The match of our final solution in the optical is displayed in Figure 8*a*; it corresponds to the following combination: $T_{eff,DA}$ = 16,360 K; log g_{DA} = 7.44; $T_{eff,DB}$ = 13,330 K; log q_{DB} = 7.70. The uncertainties on these parameters are difficult to estimate; they are likely to be larger than in the case of homogeneous or stratified analyses and are estimated here to be of the order of 1500 K in T_{eff} and 0.25 in log g. The quality of the fit, while still found wanting for the He I λ5875, 6678 lines as well as at Hα and H9, is superior to anything obtained previously with homogeneous and stratified models of single stars (Figs. 4*a* and 6*a*). In addition, the predicted energy distribution matches the observed one well (Fig. 9). This is really the first time we have found a reasonable consistency between the optical spectrum

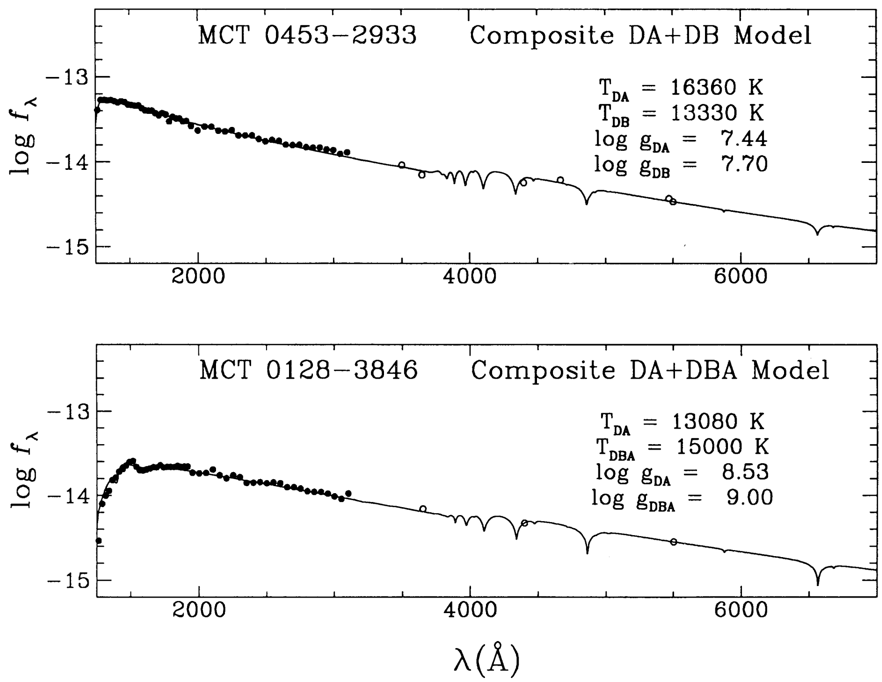


FIG. 9.—Match of the complete energy distribution of both stars with those of a composite DA+DB model (for MCT 0453−2933, *top*), or of a composite DA+DBA (for MCT 0128−3846, *bottom*) model at the optimal values of the stellar parameters. The *filled circles* are average SWP and LWP images, the *open circles* are the optical photometry (*U*, *B*, and *V* for MCT 0128−3846; *U*, *B*, *V*, *u*, *b*, and *y* for MCT 0453−2933).

and the complete energy distribution of this star. *This agreement—which is further strengthened below by the match to the observed* Lyα *profile— clearly demonstrates that the composite* DA+DB *model is the relevant one for MCT 0453−2933.*

For MCT 0128−3846, the fits are not as satisfying, in the sense that both the observed Hβ and Hγ profiles appear consistently deeper than predicted by the various possible combinations of DA + DB parameters. We show in Figure 8*b*, the best result obtained with a composite system of this nature, reached for the following combination: $T_{\rm eff,DA} = 12{,}990$ K; log $g_{\rm DA} = 8.20$; $T_{\rm eff,DB} = 13{,}140$ K; log $g_{\rm DB} = 8.50$. Although one would like to call upon a single model to explain both DAB stars, the match appears really too poor for this to be considered a satisfactory fit. One way out of this problem is to have the DB spectrum contribute some absorption at the center of the Balmer lines, i.e., to consider a DBA (a DB star with weak hydrogen lines) rather than a DB star as a companion to a normal DA star. DBA stars which constitute ~20% of the DB sample, are common enough for this idea not to be far-fetched. In such a fit, we now have, in addition to the individual effective temperatures and surface gravities of both components, an additional parameter in *y*, the N(He)/N(H) ratio in the DBA star. This parameter is not completely free, as all the DBA stars analyzed by Shipman, Liebert, & Green (1987) and Wegner & Nelan (1987) have log $y \gtrsim 3.4$, while the Lyα observation of GD 408 by Weidemann & Koester (1991) imposes log $y \lesssim 6$ for some hydrogen features (mostly Lyα) to remain visible; at larger values of *y*, DBA stars simply turn into garden-variety DB stars.

While the parameter space to be explored is quite large, we did consider DBA stars at gravities of 7.5, 8.0, 8.5, and 9.0, and abundances of log y = 4.0, 3.5, and 3.0. Above log y = 4.0, the contribution of the DBA star to the hydrogen line cores becomes insufficient to solve our hydrogen line problem. Our fitting procedure is similar to that described above, except that fits to the optical spectrum were carried out for both log $g_{\rm DBA}$ and log *y* kept fixed. Figure 8*c* shows our optimal fit to the optical spectrum of MCT 0128−3846 under the assumption of a DA+DBA composite; it is obtained for $T_{\rm eff,DA} = 13{,}080$ K; log $g_{\rm DA} = 8.53$; $T_{\rm eff,DBA} = 15{,}000$ K; log $g_{\rm DBA} = 9.00$; log $y_{\rm DBA} = 4.0$. The uncertainties should be comparable to those estimated earlier for MCT 0453−2933. Hβ still appears a bit too narrow, but the other Balmer lines fit well, much better than in the fits displayed in Figures 4*b*, 6*b*, or 8*b*; He I λ4471 is predicted somewhat narrow as well. However, the agreement with the observed energy distribution is quite good (Fig. 9).

We note that our successful fits to MCT 0128−3846 and MCT 0453−2933 point to unresolved systems containing a cool DA star with effective temperatures at or below 16,000 K. Such DA stars are known to exhibit satellite features in the red wing of Lyα, which have been attributed to the interaction of hydrogen atoms with H and H^+ perturbers (Koester et al. 1985; Nelan & Wegner 1985; Allard & Koester 1992 as well as Koester & Allard 1993, for recent work). We have searched for these features in the ultraviolet spectrum of MCT 0128−3846 which, of the two systems, contains the coolest DA component with, presumably, the strongest features. Figure 10 displays *IUE* SWP spectra of both MCT MCT 0128−3846 and G226-29, a well-known bright variable DA star already introduced in § 2.3. As a typical ZZ Ceti star, the latter displays the 1400 and 1600 Å troughs quite clearly (see also Wesemael, Lamontagne, & Fontaine 1986); in analogy with G226-29, MCT 0128−3846 shows a clear break in its energy distribution which most likely is associated with the 1600 Å feature in a cool, hydrogen-rich atmosphere. A weak 1400 Å feature seems present as well, but is marred by a cosmic-ray hit. Further quantitative comparisons of the relative strength of these features in G226-29 and MCT 0128−3846 must take into account the fact that, in the composite model, the light of the DA star is diluted by that of its equally bright unresolved DBA companion. But the ultra-

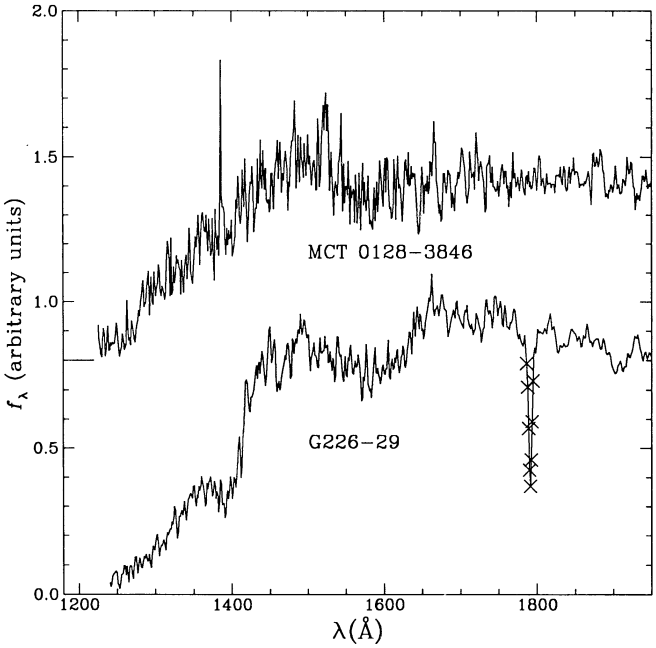


FIG. 10.—Ultraviolet spectrum of MCT 0128−3846 (unfiltered image SWP 39693; *top*) compared to that of the well-known ZZ Ceti star G226-29 (*bottom*). The quasi-molecular features at 1400 and 1600 Å are strong in the latter, while the 1600 Å feature is also visible in the former. The crosses indicate a reseau mark, and the spike near 1400 Å in MCT 0128−3846 is a cosmic-ray hit. The spectra have been cut below 1250 Å because of the presence of the geocoronal emission contribution. The spectra are offset vertically, and the long tick mark indicates the zero point of the top plot.

violet spectrum of MCT 0128−3846 provides us with a clear clue that the latter indeed contains a cool DA4—rather than a hotter DA2—star.

Finally, Figure 11 shows the match of our composite DA+DB or DA+DBA model described above to the Lyα region of both stars. While the contamination of the Lyα core by the geocoronal emission is significant, the line wings are sufficiently broad and extended that useful information can be extracted even from our large-aperture data. The parameters for both the DA and the helium-line component in each system are those derived above on the basis of the optical spectrum and energy distribution matches, and the fluxes are simply normalized to the observed V magnitude. The match is excellent for MCT 0453−2933 and suggests furthermore the existence of a weak 1400 Å feature, whose existence could be confirmed by higher S/N data. For MCT 0128−3846, our match to the ultraviolet spectrum appears equally good, despite the fact that this is a much more difficult object to model accurately. In this system, the temperature of the DA star is such that the optical spectrum and the Lα profile both are sensitive to the efficiency of the theory of convective mixing used in the modeling. This may well be the source of the residual discrepancies apparent in our fit to the optical spectrum (§ 3.3). Furthermore, the appearance of the satellite features of Lα complicates the synthetic spectrum calculations. We have used here the so-called ML2 convective efficiency (e.g., Bergeron, Wesemael, & Fontaine 1992b), and our current treatment of the 1400 and 1600 Å features. However, it is clear that the use of a different convective efficiency, or of a more sophisticated modeling of the satellite features (e.g., Koester & Allard 1993), will affect the quality of the match displayed in Figure 11. In addition, our fit is sensitive to the modeling of the van der Waals–broadened Lα profile in the DBA star model.

With these results in mind, it seems reasonable to conclude that our interpretation of both MCT objects as unresolved, composite systems provides us with a rather complete and simultaneous match to the optical spectrum, energy distribution in the 1200–5500 Å range, and Lα profile of these objects with an internal consistency which had previously eluded us.

4. CONCLUDING REMARKS

The ultraviolet and optical spectra, as well as the energy distribution, of both DAB stars can be accounted for if these objects are unresolved composite systems consisting of a DA together with a DB or DBA star. In MCT 0128−3846, the effective temperature of the DA star places the latter near the blue edge, but still within the instability strip of ZZ Ceti stars (e.g., Wesemael et al. 1991); on the basis of our current spectroscopic analysis of the ZZ Ceti sample, which builds on the work of Daou et al. (1990), the DA component in MCT 0128−3846 would be slightly cooler than G226-29 but slightly hotter than GD 165. A photometric detection of multiperiodic variations in MCT 0128−3846 would provide confirmation of the presence of a cool DA star in this system, and thus an important clue as to the correctness of our interpretation.

With the atmospheric parameters derived in this analysis, the predicted absolute visual magnitudes are $M_V = 10.0$ for MCT 0453−2933 and $M_V = 11.9$ for MCT 0128−3846, from which we obtain distances of 106 and 48 pc, respectively. Both objects appear perfectly stellar both on the saturated survey IIIaJ plates, and on our CCD frames. Our limits on the maximum component separation are $1''.15 \pm 0''.3$ for MCT 0128−3846, and $1''.45 \pm 0''.3$ for MCT 0453−2933, from which we derive upper limits on the physical separation of 55 and 154 AU, respectively. We remark also that, were MCT 0453−2933

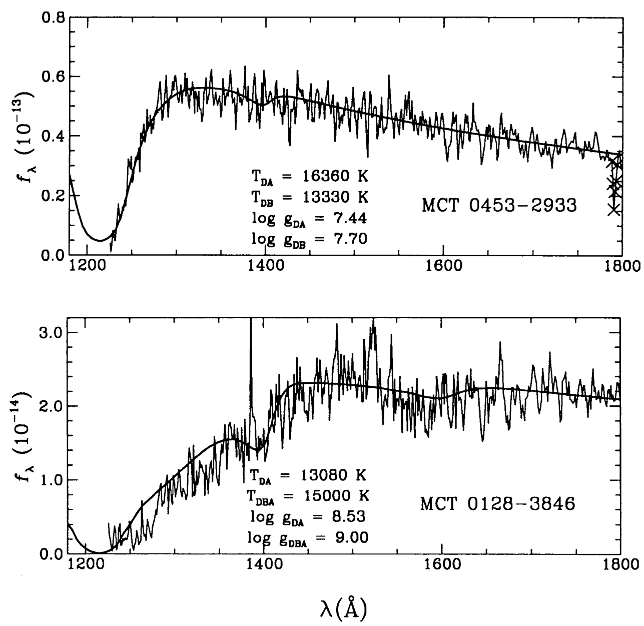


FIG. 11.—The Lα region in both systems. Superposed in each panel is the predicted profile of the composite model at the optimal values of the stellar parameters derived earlier, normalized at V. The *IUE* spectra are unfiltered and have been cut below 1250 Å because of the presence of the geocoronal emission contribution. The crosses indicate a reseau mark.

a "normal" DA star for its colors, its predicted M_V would be in the range 11.1–11.4 on the basis, respectively, of the relationships M_V versus $(b - y)$ and M_V versus $(B - V)$ given by McCook & Sion (1987); this object is thus predicted to be overluminous by 1.1–1.4 mag in the standard color-luminosity relation for DA white dwarfs (e.g., Greenstein 1985). On the other hand, the absolute visual magnitude of MCT 0128−3846, were it to be a normal DA star at $(B - V) = +0.04$, would be ~ 11.5, a value comparable to that predicted here within the composite model.

The discovery of these two objects in our southern-hemisphere colorimetric survey also strengthens the existence of the subclass of DAB stars as a true spectroscopic subclass of white dwarf stars. Interestingly, the two DAB stars reported here would have been detected easily in the spectroscopic analysis of Bergeron et al. (1992a). However, none of the 129 stars observed there showed any trace of He I λ4471. G104−27 was included in that survey, but the equivalent widths of its neutral helium features are too small to have been detected with medium-resolution spectra. Thus, although the number of stars of the DAB class is growing, the appearance of these hybrid spectra does remain a rare phenomenon.

This being said, it is now apparent that the DAB stars do not form a homogeneous group of objects and that different physical models will be relevant to different objects: hence the stratified model, whose relevance appears the most convincing in the case of GD 323, fails to account for the two new stars reported here. Furthermore, the extremely weak He I line in G104-27—detectable only at high S/N—is unlike the much stronger lines, observed at moderate S/N and resolution, in the two MCT stars, or the broad shallow features seen in GD 323. In addition, the problem of the disappearance of that line in G104-27 needs to be elucidated. It does not appear excluded, at this stage, that this star is a true spectroscopic variable, and follow-up spectroscopy of this peculiar object may clarify this issue.

In the case of the Hamburg-Schmidt object, HS 0209+0832, Jordan et al. (1993) found a fit with a homogeneous atmosphere at 36,000 K which is consistent with both the optical line spectrum and the energy distribution. However, because they find a stratified structure more physically reasonable for this star, they prefer to consider fits with stratified structures, *which do not yield a consistent answer*. They thus lean toward a disturbed atmospheric structure, not in diffusive equilibrium, perhaps associated with the presence of rotation-driven meridional circulation or accretion from the interstellar medium. In our view, however, the present analysis suggests that a composite nature, for this system as well, deserves careful consideration.

It seems also possible that the alternative to the stratified model of GD 323 developed by Beauchamp et al. (1993), namely, that of a chemically inhomogeneous stellar surface (see also Koester et al. 1993), might still be relevant to some DAB stars in much the same way it appears relevant to the magnetic DBA star Feige 7 (Achilleos et al. 1992). However, there seems to be no pressing need to call upon this more complicated model to account for the two MCT stars discussed here.

In retrospect, it is perhaps not surprising to find composite systems, such as those called upon here to model our DAB systems, in nature, as there already are several instances of such pairs in the literature: Liebert et al. (1993) report the recent discovery of an uresolved system containing a 14,500 K DA star together with a 16,000 K magnetic degenerate, most likely of helium-rich composition, while the work of Bergeron, Greenstein, & Liebert (1990a) and Bergeron, Ruiz, & Leggett (1993) has revealed, at cooler temperatures, the existence of several additional unresolved DA+DC pairs. On the basis of the frequency of both very close, velocity-variable pairs and wide common proper motion pairs, it appears that a few percent of all the field white dwarfs could be in the form of such unresolved double degenerate pairs. It seems reasonable to think that the progenitors of at least some of the Bergeron et al. (1990a) cool DA+DC pairs might be unresolved DA + DB systems, none of which had been found up to now. We note furthermore that the two MCT objects analyzed here appear to be unresolved analogs of the common proper motion pair L151-81A/B discussed by Oswalt et al. (1988). The latter has been shown to consist of a 12,000 K DA star together with—interestingly enough—a 16,000 K DBA (rather than DB) star; the physical separation of the components is of the order of 200 AU. Because of the relative temperature and brightness of the components, the spectrum of L151-81A/B remains unique, in that Hγ and He I λ4471 appear with similar strengths. One wonders how many white dwarf stars, with hybrid spectra less striking than that of L151-81A/B and not belonging to a wide pair, will actually turn out to be composite systems.

The masses of the components of each system can be evaluated using the pure carbon-core evolutionary models of Wood (1990). We obtain $M_{\rm DA} = 0.33\ M_\odot$, $M_{\rm DB} = 0.43\ M_\odot$ for MCT 0453−2933, and $M_{\rm DA} = 0.93\ M_\odot$, $M_{\rm DBA} = 1.20\ M_\odot$ for MCT 0128−3846. The inferred masses for the components of MCT 0453−2933 are smaller than, or close to 0.4 $M_\odot$. Such low-mass white dwarfs cannot have evolved from single main-sequence stars within the lifetime of the Galaxy, and close binary evolution needs to be invoked to account for their existence. The inferred masses thus imply that the system has undergone at least one phase of common envelope evolution through close binary evolution, as discussed, e.g., by Iben & Tutukov (1986) and Iben & Webbink (1989). In these scenarios, low-mass white dwarfs ($M \lesssim 0.4\ M_\odot$) are likely to have helium cores instead of carbon cores. If close binary evolution has indeed occurred, the distance between the components is probably much smaller than the upper limit obtained above.

Similarly, the masses derived for both components of MCT 0128−3846 are significantly larger than the average mass for white dwarfs (Bergeron et al. 1992a). As mentioned above, very massive stars are rare, although it would not be impossible to find field white dwarfs with such high masses. However, the fact that *both* stars in the system are unusually massive strongly suggests that close binary evolution has also occurred for MCT 0128−3846. If the separations between the components of both systems are small enough, time-resolved spectroscopy of both hydrogen and helium lines may reveal radial velocity variations.

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