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CBS 78: A SECOND EXTREMELY RARE DBZ DEGENERATE STAR WITH ACCRETED CALCIUM

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ABSTRACT

We report the discovery of a second, extremely rare DBZ degenerate CBS 78 which reveals photospheric calcium in its nearly pure helium atmosphere. The presence of calcium strongly suggests accretion of interstellar matter as its origin, but hydrogen is not detected. Our synthetic spectrum analysis yields $T_e = 12{,}000$ K, $\log g > 8.0$, Ca/He $= 10^{-8.0 \pm 0.3}$, and a hydrogen abundance limit H/He $< 2 \times 10^{-5}$. The properties of CBS 78 are compared with other cool helium-rich degenerates with metals. We confirm the suggested existence of an empirical correlation between the hydrogen-to-calcium abundance ratio and effective temperature. This correlation shows that above a critical temperature $T_{\rm crit} \approx 11{,}000$ K, a screening mechanism is operative which prevents accretion of interstellar hydrogen onto white dwarfs; this mechanism apparently does not operate at lower temperatures.

Subject headings: stars: abundances — stars: accretion — stars: hydrogen deficient — stars: white dwarfs

I. INTRODUCTION

The detection of metals in the spectrum of any hydrogen- or helium-dominated white dwarf is uniquely important because it offers the possibility of gaining valuable insight into several poorly understood processes which can oppose the effects of gravitational diffusion to produce something other than a mono-elemental atmosphere with the lightest element exposed at the surface. In an accreting DB degenerate, the complex interplay of accretion, diffusion, and dilution in a deep convection zone remain to be fully understood. Until now, only one out of ~ 120 known DB degenerates was found to show metals, the star GD 40 (Wickramasinghe *et al.* 1975; Shipmen, Greenstein, and Boksenberg 1977; Shipman and Greenstein 1983). This object exhibited the usual He I lines along with H+K lines of Ca II. Analysis of its optical and near-ultraviolet, *International Ultraviolet Explorer* (*IUE*) spectra by Shipman, Greenstein, and Boksenberg (1977) and by Shipman and Greenstein (1983) yielded $T_e = 15{,}200$ K ± 500 K, $\log g = 8.2 \pm 0.5$, a calcium abundance $\log N(\mathrm{Ca})/\mathrm{N(He)} = -7.3 \pm 0.3$, and, from the *IUE* spectrum, abundances of detected iron and magnesium, $\log N(\mathrm{Fe})/N(\mathrm{He}) = -8$ and $\log N(\mathrm{Mg})/N(\mathrm{He}) = -8$. These authors concluded that their observed metal abundances were at variance with the predictions of gravitational diffusion theory, if accretion of interstellar matter in solar system ratios was occurring. Their work strongly suggested that processes other than diffusion must be fractionating the infalling material. Because GD 40 was the only DB star to show calcium, the only helium-rich metal line degenerates to which it could be compared were the cooler DZ stars whose effective temperatures were below $T_e = 10$ K. Subsequently, a somewhat hotter object—still too cool to show He I—was reported in Liebert, Wehrse, and Green (1986), and it (PG 2322+119) was assigned an uncertain temperature estimate of 12,000 K. Both Ca II and H lines appeared in that spectrum.

We report here the discovery of a second DB degenerate, CBS 78, which shows calcium lines twice as strong as in GD 40. As we will discuss below, this object provides a critically needed comparison of two different DBZ stars, which are widely separated in effective temperature. In § II we describe our observational techniques, data reduction, and analysis, while § III contains a discussion of our effective temperature/surface gravity determination and abundance analysis. We conclude with a comparison of CBS 78 with other metal-line degenerates in general and GD 40 in particular. Implications for both accretion of interstellar matter as the source of metals and for hydrogen screening of the accreting matter are discussed.

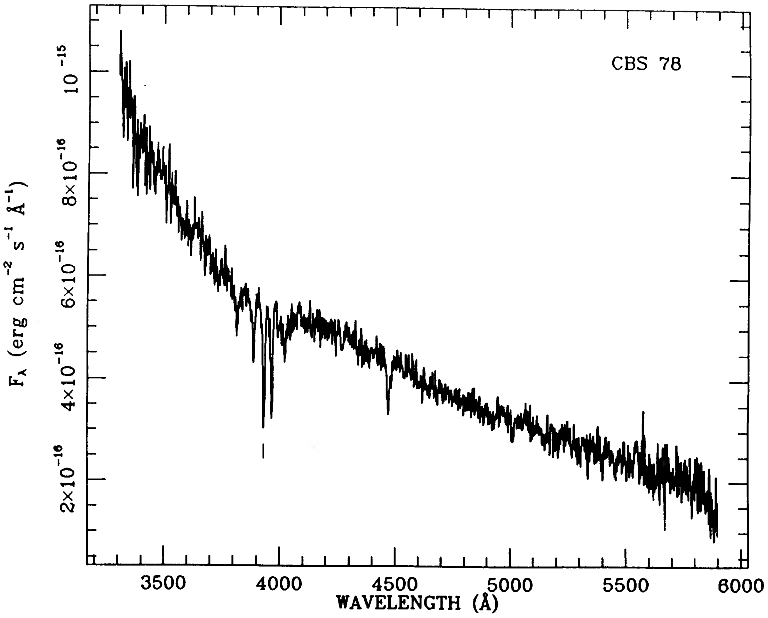

FIG. 1.—The Steward 2.3 m reticon spectrum of CBS 78 covering the wavelength range 3200–5800 Å at 5 Å resolution. Note the narrowness of the features and the absence of pronounced Stark-broadened wings characteristic of hotter DB stars. The Ca II K line is labeled with a tick mark.

II. OBSERVATIONS

Our observations were made as part of an ongoing program of follow-up spectroscopy of the Case Blue Stars (Pesch and Sanduleak 1983; Sanduleak and Pesch 1984; Pesch and Sanduleak 1986); CBS 78 ($M_B = +17$) was observed initially on the night of 1986 January 19 UT with the 2.3 m Steward telescope. The Cassegrain spectrograph was used with the blue-intensified, photon-counting Reticon system (Allen *et al.* 1984) as detector. We used a 600 lines mm^{-1} grating which yielded 5 Å resolution and a spectral coverage of 3300–5900 Å. The data were sky-subtracted, corrected for flat-field response and for atmospheric extinction using KPNO mean extinction coefficients for Kitt Peak National Observatory, resampled on a linear wavelength scale and placed on an absolute flux scale using observations of Oke (1974) standard stars.

Further observations of CBS 78 with an integration time of 7200 s were obtained on the night of 1986 March 7 UT with the same instrumental and reduction setup described above. The resulting final spectrum is displayed in Figure 1. The presence of the Ca II K lines (Ca II H is blended with He I 3964), the narrowness of the He I lines, and the marked weakness of He I 4388 are striking when compared with more typical (hotter) DB stars, especially the lack of pronounced Stark-broadened wings. The equivalent widths of the features in Figure 1 were measured with an estimated uncertainty of 10% and are listed in Table 1.

TABLE 1

He I AND Ca II LINE STRENGTHS

Feature	Equivalent Widths (Å) W_λ	Measured Wavelength Range ($\Delta\lambda_0$) = ±50 Å
He I 4471	2.49 Å	4421–4521
He I 4388	0.45 Å	4338–4438
He I 3888	3.71 Å	3859–3901
He I + Ca 3970 ...	5.12 Å	3947–3982
Ca II K 3933.......	6.10 Å	3912–4947
Hβ.................	< 1.5[a]	4811–4911
Hγ.................	< 1.0[a]	4290–4390

[a] 3 σ upper limit.

III. TEMPERATURE, GRAVITY, AND ABUNDANCE ANALYSIS

The measured equivalent widths in Table 1 can be compared with theoretical equivalent widths generated in two different DB model atmosphere grids (Wickramasinghe and Reid 1983; Shipman 1972). A comparison of He I 4471 + 4388 and 4388 with the theoretical equivalent widths in Table 3 of Wickramasinghe and Reid (1983) indicates $T_{\text{eff}} = 12{,}000$ K, log = 8 or 8.5. The Shipman models yield $T_e = 12{,}000$–$13{,}000$ K, log $g > 8$. Therefore, CBS 78 lies at the cool end of the DB sequence. The temperature of CBS 78 is strongly constrained by the line spectrum.

We determined the abundance of our calcium in CBS 78 by using the same model atmosphere grid as that described in Shipman, Greenstein, and Boksenberg (1977). The spectrum synthesis program, broadening parameters and all other details are described in Shipman, Greenstein, and Boksenberg (1977), Shipman and Auer (1979), and Shipman and Greenstein (1983). The calcium abundance we have derived assumes log $g = 8$ and no metal (or hydrogen) electron donors ($Z = 0$). The calcium abundance is found to be Ca/He = $10^{-8.0\pm0.3}$, where the uncertainty reflects the sparseness of the model grid, the uncertainty in log g, and allowance for the possible existence of invisible electron donors (H, C, N, or O). The absence of He I 4388 suggests a gravity of log $g = 8.0$ or greater based on the Wickramasinghe and Reid (1983) models; the Shipman (1972) models would suggest a higher gravity

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of roughly log $g = 8.5$. Because CBS 78 is too faint to obtain either an SWP or LWP spectrum with the *IUE* spacecraft, no other metal features (e.g., Fe, Mg) could be detected, unlike GD 40.

We have carefully inspected the data displayed in Figure 1 and find no evidence for the presence of any Balmer absorption features to the limit of $\sim 8\%$ of the continuum. A 3 σ upper limit on the strength of Hβ is $W(\mathrm{H}\beta) < 1.5$ Å. A somewhat more sensitive limit (3 σ limit) of $W(\mathrm{H}\gamma) < 1.0$ Å can be provided for Hγ. The models then allow us to set a limit of H/He $< 2 \times 10^{-5}$. The nondetection of hydrogen in CBS 78 is highly significant because of the fact that hydrogen abundances relative to calcium are therefore well below solar, as was found for GD 40. This contradicts the expected effect of envelope diffusion, which should only increase this ratio relative to the presumed solar value of the accreted gas. This "hydrogen screening" problem has led to the suggestion of at least two mechanisms that could eliminate hydrogen in the accreted matter: expulsion of protons by the electric fields of hot DB atmospheres (Fontaine and Michaud 1979) or a rotating, magnetic white dwarf "propeller" (Wesemael and Truran 1982) which could also screen ionized hydrogen. The effective temperature of CBS 78 places it near an empirical lower temperature boundary at 11,000–12,000 K below which the hydrogen screening mechanisms appear to break down (Liebert, Wehrse, and Green 1986). At the lower temperatures at least some of the DZ stars (e.g., R640, PG 1226 − 081) have hydrogen/metals ratios which are approximately solar.

IV. DISCUSSION

From the published abundances for DZ stars in Table 2 of Zeidler, Weidemann, and Koester (1986), our CBS 78 calcium abundance and upper limit H/He ratio, and those of Liebert, Wehrse, and Green 1986), we find a most interesting correlation, which is displayed in our Table 2. Here the [H/Ca] abundances are listed versus effective temperature for several well-analyzed DZA, DAZ, and DZ stars and the two known DBZ stars. The square brackets, [H/Ca], indicate ratios relative to solar, i.e., $[\mathrm{H/Ca}] \equiv [N(\mathrm{H})/N(\mathrm{Ca})/(N(\mathrm{H})/N(\mathrm{Ca})_\odot]$. Admittedly, inclusion in this short list required that an object have a derived H abundance or useful limit, which may somewhat bias the sample in favor of larger [H/Ca] especially for cooler stars. The inclusion of L745 − 46A illustrates the poor limits available for the coolest DZ stars.

TABLE 2

HYDROGEN TO CALCIUM ABUNDANCE RATIOS FOR DZA, DBZ, AND DZ STARS

Name	Type	T_e	[H/Ca]
GD 40	DBZ	15,000	$< 6 \times 10^{-4}$
CBS 78	DBZ	12,000–13,000	$< 3 \times 10^{-3}$
PG 2322 + 119 ...	DZA	12,000	5×10^{-3}
PG 1226 − 081 ...	DZA	9700	0.1–1
R640	DZA	8800	0.6
L745 − 46A.......	DZ	7800	< 20

While the number of stars in the sample is not large, the data in Table 2 suggest an abrupt decrease in [H/Ca] from of order unity (for at least *some* DZ stars) at $T_{\mathrm{eff}} < T_{\mathrm{crit}}$ to a lower value of order 10^{-3} or less for $T_{\mathrm{eff}} > T_{\mathrm{crit}}$. Our observations constrain T_{crit} rather tightly to be $10{,}000 < T_{\mathrm{crit}} < 12{,}000$ K. These results strengthen the suggestion of Liebert, Wehrse, and Green (1986), who were the *first* to identify an empirical correlation between [H/Ca] and T_{eff}. This correlation suggests that, if the metals come from accretion from the interstellar medium, a screening mechanism is operative for $T_{\mathrm{eff}} > T_{\mathrm{crit}}$ but does not operate at lower temperatures. While the propeller mechanism of Wesemael and Truran (1982) is one such possibility, any mechanism in which ionization of the circumstellar gas is an important factor are also intriguing. Moreover, the existence of the hydrogen screening mechanism strongly implies that the DBA phenomenon (Shipman, Liebert, and Green 1986) owes its origin to some process other than accretion: these stars show hydrogen but no trace of Ca II.

Finally, our results suggest that more sensitive searches for H absorption at Lyman-alpha (as well as for ultraviolet metal features) which could be done with the Hubble Space Telescope, are of high priority.

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