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# HYDROGEN AND CALCIUM IN DB WHITE DWARFS: A CASE FOR INTERSTELLAR ACCRETION[1]

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## ABSTRACT

We report detections of calcium in two DBA stars and in two DB stars as well as possible detections of calcium and/or hydrogen in three additional DB degenerates, from moderate-resolution spectra obtained at the Multiple Mirror Telescope. We have derived calcium and hydrogen abundances and abundance limits which are close to the cosmic abundance. This finding would appear to indicate that accretion of interstellar hydrogen and grains can effectively occur in some single helium-rich degenerates up to effective temperatures of at least 20,000 K. If a "propeller" mechanism is operative in DB stars, our results would suggest that the mechanism may break down or be less efficient in a significant fraction of these objects.

*Subject headings:* stars: abundances — stars: accretion — stars: white dwarfs

## I. INTRODUCTION

The essentially pure helium atmospheres of the DB white dwarfs continue to pose a fascinating puzzle when seeking an understanding of their formation and evolution, principally because of two long-standing difficulties: (1) how it is possible that they avoid hydrogen pollution of their atmospheres due to interstellar accretion (Greenstein 1960); and (2) how it is possible to achieve their degree of helium purity in view of the remnant hydrogen theoretically expected to remain following post–AGB mass loss (cf. Iben and Tutukov 1984). Complicating this picture are the still unsettled possibilities that the DB stars and their cooler non-DA descendants evolve from a formation channel (or channels) distinct from that of DA stars or that the DA and DB white dwarfs transform into each other through various physical processes which can alter their surface abundances (cf. Liebert 1980, 1984; Sion 1986; Wegner and Nelan 1987; Shipman, Liebert, and Green 1987; and Liebert, Fontaine, and Wesemael 1987 for useful summaries and discussions of the above questions). Among these poorly understood processes are convective mixing, accretion, diffusion-induced burning (Michaud, Fontaine, and Charland 1984; Michaud and Fontaine 1984), and mass loss.

In recent years important spectroscopic exceptions to the majority of DB stars have been found within the DB temperature range (12,000 K < $T_{\rm eff}$ < 30,000 K). The discovery of the first DBZ star, GD 40, which exhibits calcium in addition to the usual He I lines (Wickramasinghe *et al.* 1975; Shipman, Liebert, and Green 1977; Shipman and Greenstein 1983) and a second such case, CBS 78 (Sion *et al.* 1986) was followed by the remarkable recent finding that about 20% of the 50 or so DB stars in the complete Palomar-Green survey have detectable hydrogen and thus comprise a statistically significant subset (Shipman, Liebert, and Green 1987). By implication the so-called hybrid DBA stars formerly regarded as isolated "freaks" (G200−39, LDS 785A) are members of an important subsample of DB degenerates. But, is the hydrogen in DBA stars primordial, i.e., remnant amounts from prior progenitor evolution, or is the hydrogen accreted as the DB degenerate plows through interstellar matter during its galactic orbit? The difficulties and prospects for both of these possibilities are discussed in detail by Shipman, Liebert, and Green (1987) who do not rule out or favor either choice. However, recent MMT moderate resolution spectroscopy by Kenyon *et al.* (1988) has provided a new lead with the discovery of photospheric calcium in the prototype DBA, G200−39. In G200−39 the calcium-to-hydrogen abundance ratio is consistent with the solar abundance which provides some support for the role of accretion in that object. Note, however, that if the DBA phenomenon is due to interstellar accretion, then it is difficult to reconcile this with the apparent empirical lower temperature boundary ($T_{\rm eff} \approx 11{,}000$ K ± 1000 K) above which hydrogen accretion seems to be prevented in helium-rich degenerates as suggested by Liebert, Wehrse, and Green (1987) and confirmed by Sion *et al.* (1986).

In this *Letter*, we present new observations with potentially important implications for the questions and difficulties cited above. A close examination of our co-added spectra of 34 proper motion–selected DB stars observed for radial velocity with the MMT spectrograph at generally high signal-to-noise ratios has revealed the presence of weak Ca II in two additional DBA stars and in four otherwise normal DB stars, bringing to six the number of known DBZ degenerates and to three the number of known DBAZ degenerates. Following a description of the observational technique (§ II) and a summary of physical parameters and abundance information (§ III), we conclude with a brief discussion of possible implications (§ IV).

[1] Research reported herein used the Multiple Mirror Telescope, a joint facility of the Smithsonian Institution and the University of Arizona.

## II. OBSERVATIONAL TECHNIQUE AND SPECTROSCOPIC DATA

Spectroscopy of the white dwarfs reported here was obtained on various observing runs during 1985–1986 with the MMT spectrograph and the 832 lines $mm^{-1}$ grating. A detailed description of the observational techniques can be found in Kenyon *et al.* (1988). Our data cover a 900 Å bandpass centered near 4200 Å and have a spectral resolution of 1 Å.

In total we obtained MMT spectra for 34 DB stars of which 15 were observed at least 3 times and 19 were observed twice. Out of this sample we have isolated seven stars which appear to have definite or probable detections of Ca II K features and/or hydrogen. Three of these seven were previously recognized and classified DBA (GD 61, Wegner and Nelan 1987; GD 84 and GD 378, Greenstein 1984). The other four stars were previously classified DB3, DB4, or DB5 (see McCook and Sion 1987 for the original references). Although the nature of our selection process and the incompleteness of the proper motion–selected white dwarf sample heavily biases any statistical conclusions on the frequency of DBZ or DBAZ stars, it is nonetheless worth noting that roughly 20% of our "sample" revealed evidence for calcium.

## III. ANALYSIS

The co-added spectrum of GD 303 is presented in Figure 1 (*top left*) and reveals the typical strong He I features of a DB4 star except for the apparent presence of a very weak absorption feature due to Ca II K. There is little to indicate the presence of Hγ at the limit of 0.1 Å. The Ca II K line has EW = 0.2 Å. Figure 1 (*bottom left*) presents the co-added spectrum of GD 61 previously recognized as a DBA star by Wegner and Nelan (1987). We confirm their classification with our rather clear detection of Hγ, but in addition we note the presence of a weak Ca II K line with an EW = 0.2 Å. In Figure 1 (*top right*) the spectrum of still another star previously classified as DBA (Greenstein 1984), GD 378, reveals confirmatory Hγ and Hδ features but also has a weak absorption feature at Ca II K with an EW = 0.2 K and a possible extremely weak Ca I 4226 line. If these calcium detections in GD 61 and GD 378 are real, they bring to three the number of known DBAZ stars including G200−39 reported in Kenyon *et al.* (1988). The spectrum of the previously classified DB4 star, GD 408, in Figure 1 (*bottom right*), similarly reveals Ca II K with EW = 0.2 Å and a possible weak Ca I 4226 feature but little evidence for hydrogen features. In Figure 2 the co-added spectra of the same four

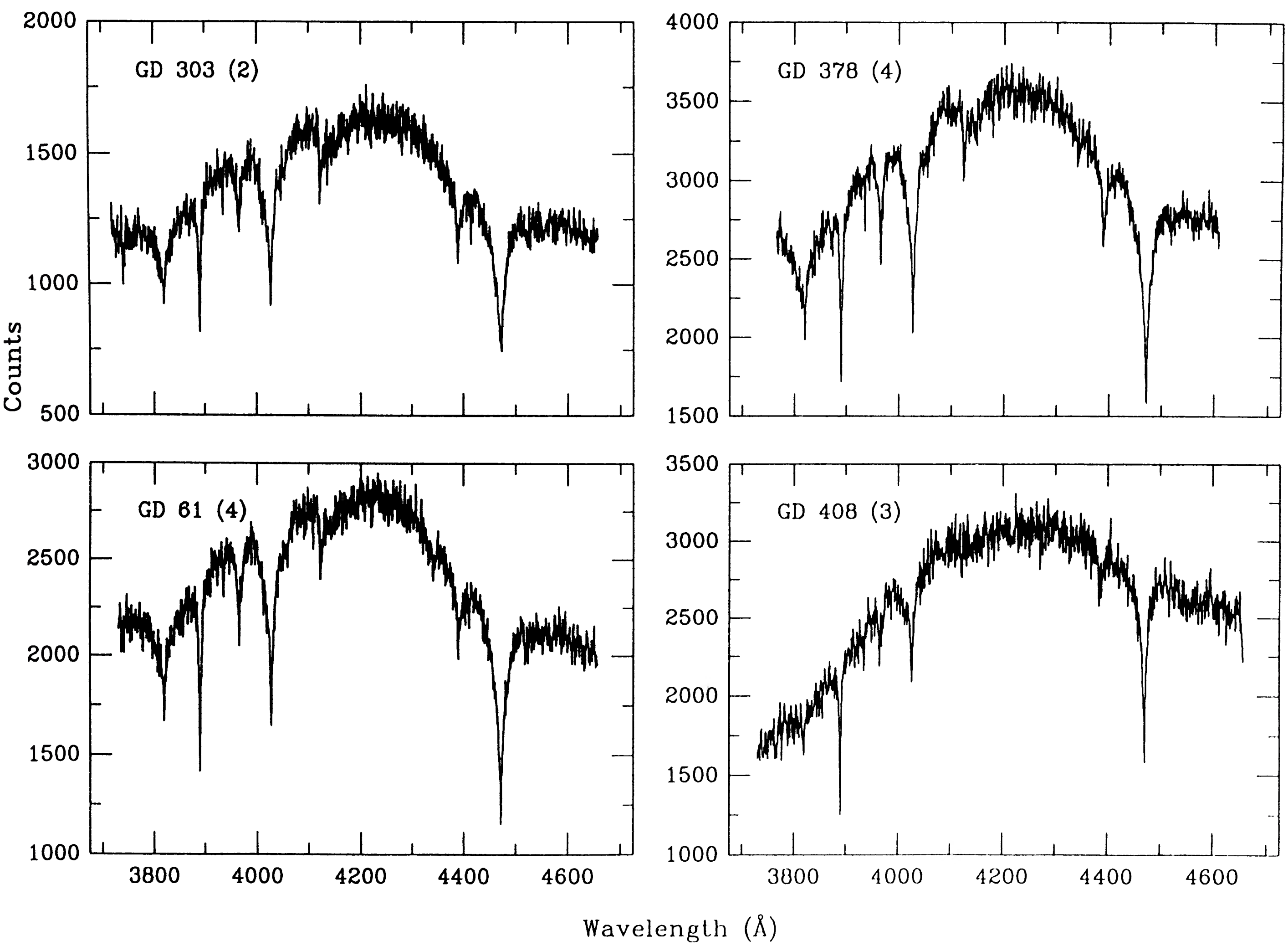


FIG. 1.—The co-added spectra of GD 303, GD 61, GD 378, and GD 408, respectively. The number in parentheses following the name of the star is the number of individual spectra co-added.

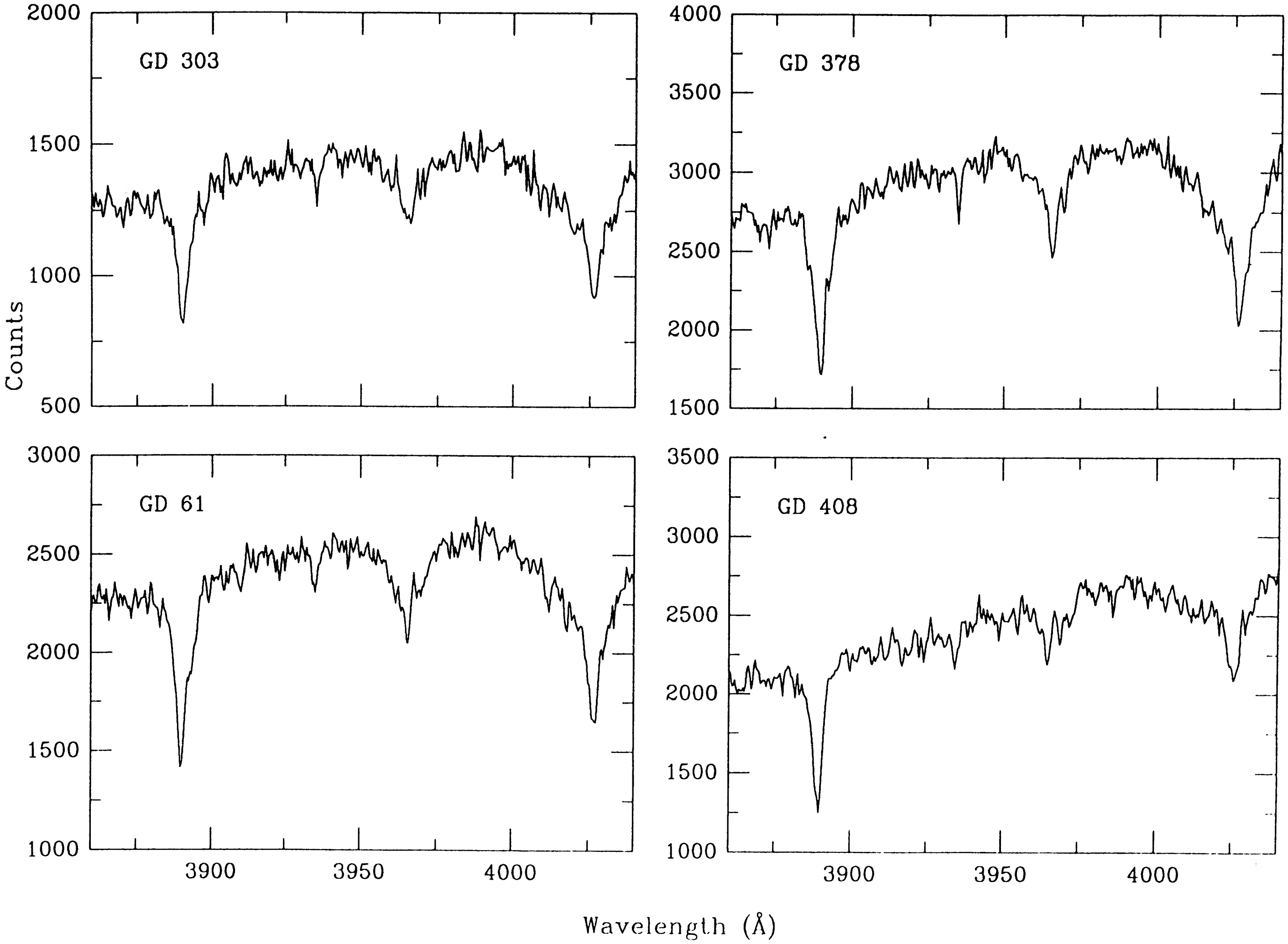


FIG. 2.—The same as Fig. 1 except plotted on an expanded scale in the region of Ca II K

stars are shown on an expanded scale around the region of Ca II K.

The three remaining stars, GD 84, GD 85, and GD 124 present considerably weaker, but nonetheless possible, detections of Ca II K features at the 0.1 Å level. The co-added spectra are displayed in Figure 3 as expanded plots in the region of Ca II K, each the sum of three spectra. The first object, GD 84, has a noisy spectrum, but Greenstein (1984) classified it DBA6 on the basis of an unpublished scan. Our spectrum reveals ill-defined features presumably of He I but with EW < 0.2 Å for He I 4026, 4388, and 4471. There is a hint of Ca II K present but little to suggest hydrogen lines. The DB3 star, GD 85, reveals a possible Ca II feature with EW < 0.1 Å, but this must be confirmed with further observations. Our co-added spectrum of GD 124, which was classified DB5 by Greenstein (1984), reveals possible Hγ and (considerably weaker) Hδ absorption which, if confirmed, would add another DBA star. Any Ca II K feature in this star has EW < 0.1 Å. There is a slight depression at 3933 Å difficult to distinguish from the noise.

The equivalent widths (EWs) have been determined using an interactive analysis program developed by one of us (S.K.) as described in Kenyon *et al.* (1988). They were measured using the continuum limits defined in Wickramasinghe and Reid (1983); namely, 4320−4560 for He I 4471+4388, 4320−4420 for He I 4388 and 3985−4100 for He I 4026+4009. The gravity-sensitive singlet-to-triplet ratio 4388/4471 was used to roughly estimate gravities using the same grid due to Wickramasinghe and Reid (1983).

The basic observational data and derived physical parameters and are summarized in Table 1. The revised spectral types are listed, and the effective temperatures and gravity estimates are tabulated from several sources.

The calcium features in GD 408, GD 303, GD 378, and GD 61 are comparable in strength to that of G200−39 which had EW (Ca II) = 0.15 ± 0.05 Å but are considerably weaker than those detected in the two previously known DBZ stars, GD 40 and CBS 78. The observed velocity widths of the Ca II features and the close spectroscopic and temperature/gravity similarity of our objects to the earlier DB and DBA stars with demonstrably photospheric calcium make it exceedingly unlikely that the calcium is interstellar (cf. Kenyon *et al.* 1988). The possibility that the features are due to He I 3936 pressure-shifted to the blue can also be rejected because of its low transition prob-

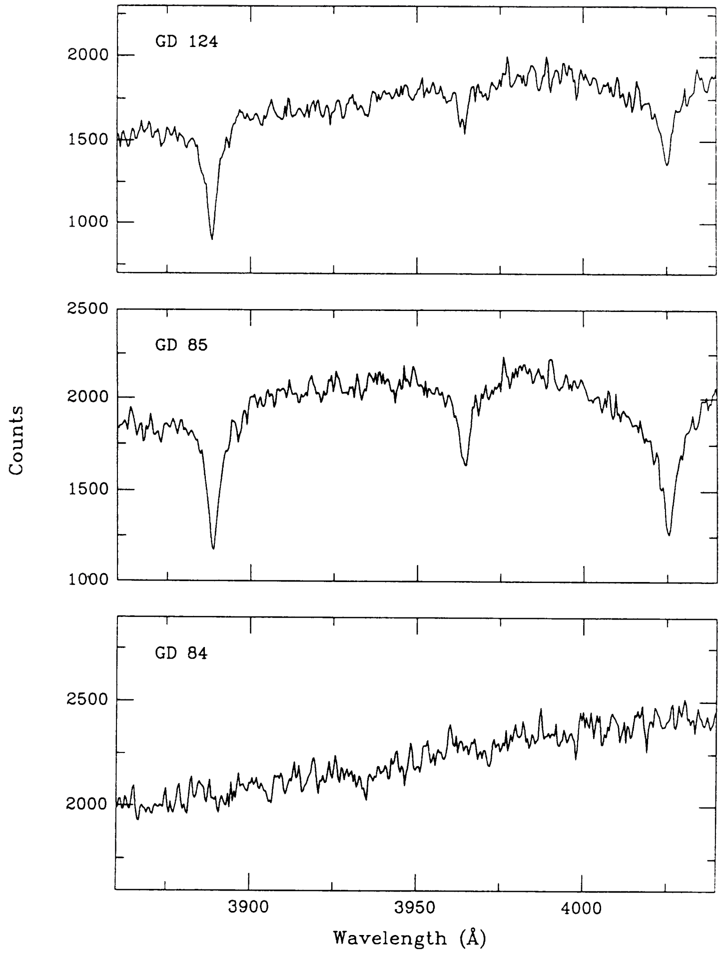


FIG. 3.—The same as Fig. 2 but for GD 124, GD 84, and GD 85

TABLE 1

DBZ, DBAZ STARS: PHYSICAL PARAMETERS AND ABUNDANCES

| Name/WD Number | Spectral Type | $T_{eff}$ | log *g* | Ca/He | H/He | Ca/H |
|---|---|---|---|---|---|---|
| GD 408/0002+729 ...... | DBZA?4 | 13,310[a]<br>13,000[b] | 7.69[a] | −10 | ≤−5.0 | ≥5.0 |
| GD 61/0435+410 ....... | DBAZ3 | 15,000[c]<br>19,000[b]<br>16,410[a] | 8.05[a]<br>8[c] | −10 | −3.8 | −6.2 |
| GD 84/0714+458 ....... | DBAZ?6 | 10,800[c] | 8[c] | ... | ... | ... |
| GD 85/0716+404 ....... | DBAZ?3 | 16,280[a]<br>15,000[c]<br>14,500[b] | 7.86[a]<br>7.5–8[c] | ≤10 | ≤−5.0 | ... |
| GD 303/1011+570 ...... | DBZ4 | 17,180[a]<br>19,000[c]<br>17,000[b] | 7.79[a]<br>8[c] | −10 | ≤−5.5 | ≥−4.5 |
| GD 124/1046−017 ...... | DBZ5 | 10,626[b]<br>13,730[a]<br>12,000[c] | 8.0[a]<br>7[c] | ≤10 | ≤−5.0 | ... |
| GD 378/1822+410 ...... | DBAZ4 | 15,875[b]<br>15,590[a]<br>16,000[c] | 7.93[a] | −10 | −4.0 | −6.0 |

[a] Oke, Weidemann, and Koester 1984.
[b] Wegner and Nelan 1987.
[c] This *Letter*, using the grid of Wickramasinghe and Reid 1983.

ability and absence or extreme weakness in spectroscopically normal DB stars including the many "pure" DB stars for which we have spectra.

The approximate calcium-to-helium abundances can be extracted using the procedures outlined in Sion *et al.* (1986) and Kenyon *et al.* (1988). Using our adopted gravities in Table 1, the detection (or nondetection) of H$\gamma$ yields a hydrogen-to-helium abundance ratio (or upper limit of same) from consideration of the DB model grid of Wegner and Nelan (1987), computed specifically for the case of hybrid composition atmospheres. In particular, Figure 12 in Wegner and Nelan presents the behavior of the H$\beta$ EW as a function of $T_{\rm eff}$ for several assumed abundances. Since a similar behavior is expected for H$\gamma$ with only minor differences due to excitation and broadening, the H$\gamma$ line strengths provide approximate but useful abundance information. The results of our abundance analysis are listed in Table 1 with the following abundance notation: Ca/He $\equiv$ log [$N$(Ca)/$N$(He)], H/He $\equiv$ log [$N$(H)/$N$(He)], Ca/H $\equiv$ log [$N$(Ca)/$N$(H).

It is not surprising that the calcium abundances we derive are considerably lower than the DBZ stars GD 40 and CBS 78 which had much stronger Ca II features. For example, the Ca II K feature in CBS 78 had EW = 6 Å corresponding to a calcium abundance, for log $g = 8$, $T_{\rm eff} = 12{,}000$ K, of $-8.0 \pm 0.3$. For our sample of DBZ and DBAZ stars the calcium abundances corresponding to our tabulated effective temperatures, gravities, and Ca II EW are approximately log [$N$(Ca)/$N$(He)] $= -10 \pm 0.5$. This Ca abundance, coupled with the H/He abundances and limits in Table 1, indicates calcium-to-hydrogen abundances in our stars near the solar value of log [$N$(Ca)/$N$(H)] $= -5.66$. The implications of this general result for the group of stars in Table 1 is discussed below.

## IV. IMPLICATIONS AND DISCUSSION

The detection of calcium in the DBA and DB stars reported here as well as in G200−39 (Kenyon *et al.* 1988), together with the derived Ca/H abundances being close to the solar value, lend mounting support to the hypothesis that the hydrogen and calcium in the DBA stars and DBZ stars like GD 40 is accreted from the interstellar medium. The nearness to solar of our Ca/H abundances cannot be coincidental. Rather it may indicate that either (1) the propeller mechanism of Illiaronov and Sunyaev (1975) and Wesemael and Truran (1982), which requires only modest $10^3$ or $10^4$ G magnetic fields and rotational velocities of 100 km s$^{-1}$, breaks down in the DBAZ stars or (2) the hydrogen missing in GD 40 and other DBZ stars was destroyed via diffusion-induced burning (Michaud, Fontaine, and Charland 1984). In this connection Wickramasinghe and Reid (1983) have already pointed out that the propeller mechanism must be 100% efficient in order prevent accretion in the hot DB stars (with the shallowest convection zones) where the accretion efficiency is expected to be higher (cf. Alcock and Illiaronov 1980). All of the DB/DBA stars suspected of accreting have thus far been cooler than 20,000 K.

It is clear that further high signal-to-noise ratio observations and abundances of trace metals and hydrogen in DB stars are needed as well more extensive information on DB rotational velocities and their individual masses. If most DB stars have higher than average magnetic fields, angular momentum or lower than average individual masses (i.e., deeper convection zones), it may become possible to understand how their photospheres can usually remain hydrogen-free and when exceptions can occur. If, as our results indicate, interstellar accretion is responsible for the DBA phenomenon manifested in roughly 20% of the DB stars, it seems probable that some fraction of DA stars owe their hydrogen to interstellar accretion.

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