THE ASTROPHYSICAL JOURNAL, **328**:L65–L68, 1988 May 15

THE DETECTION OF PHOTOSPHERIC CALCIUM IN A DBA WHITE DWARF[1]

SCOTT J. KENYON
Smithsonian Astrophysical Observatory
HARRY L. SHIPMAN
Physics Department, University of Delaware
EDWARD M. SION
Department of Astronomy and Astrophysics, Villanova University
AND
PER A. AANNESTAD
Department of Physics and Astronomy, Arizona State University

Received 1987 October 28; accepted 1988 February 12

ABSTRACT

We report the detection of photospheric calcium absorption lines in the white dwarf star G200−39 (DBAZ4). The abundance of calcium relative to that of hydrogen is approximately solar, a result which lends support to the hypothesis that accretion of interstellar matter is responsible for hybrid composition white dwarfs.

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

I. INTRODUCTION

The sample of Palomar-Green white dwarfs (Green, Schmidt, and Liebert 1986) has provided the statistical basis for the remarkable discovery that many DB white dwarfs have trace amounts of hydrogen in their essentially pure helium atmospheres (Shipman, Liebert, and Green 1987, hereafter SLG). These hybrid composition DBA stars, of which G200−39 was among the first known examples (Liebert *et al.* 1979), comprise ∼20% of known DB stars with effective temperatures of $T_{\rm eff} = 14{,}000$–$19{,}000$ K, and have hydrogen to helium number ratios of $N(\mathrm{H})/N(\mathrm{He}) \equiv \mathrm{H/He} \approx 0.3$–$4 \times 10^{-4}$. The source of the hydrogen in these stars may provide a clue to resolving a longstanding controversy, namely do DA and DB white dwarfs originate and evolve from distinct formation channels, or do white dwarfs evolve from one spectroscopic subgroup into another as a result of physical processes which alter their surface compositions? If the latter possibility is the correct one, then it is important to identify the physical process(es) responsible for altering a white dwarf's surface composition as it evolves.

The usefulness of high S/N spectra for detecting weak, "contaminant" hydrogen features in DB white dwarfs (SLG) suggests that progress in understanding the source of trace elements in white dwarf atmospheres might be made by searching for metallic features, such as Ca or Mg, in the hybrid stars. In this *Letter*, we report the detection of photospheric calcium absorption lines on spectra of the DBA white dwarf G200−39. We find that the abundance of calcium relative to that of hydrogen is close to solar, consistent with the hypothesis that accretion of material from the interstellar medium is responsible for the unusual elemental abundances found in some white dwarfs.

II. OBSERVATIONS

Moderate resolution (1 Å) spectra of G200−39 (WD1425+540 [DBA4]; McCook and Sion 1987) covering λλ3750–4650 were obtained during 1985–1986 with the MMT spectrograph and 832 lines mm^{-1} grating. Simultaneous star and sky observations were made through 12 apertures of 2″.5 diameter, and the star was periodically beamswitched to minimize differences between the two halves of the Reticon array. A 90 s He-Ar comparison scan preceded and followed each integration; residuals in the polynomial fit to ∼30 strong comparison lines are ∼0.15 Å (10 km s^{-1}). The spectra have been sky-subtracted and divided by observations of a quartz lamp but have not been flux-calibrated.

Individual scans of G200−39 have continuum levels of 500–1000 counts per pixel and are too noisy to search for weak absorption features. We determined velocity offsets of each scan relative to our best exposure using a cross-correlation technique (Tonry and Davis 1979; Hartmann *et al.* 1986) and found the radial velocity of G200−39 to be constant at the 10–20 km s^{-1} level. Thus, our eight exposures were co-added in the heliocentric rest frame and are presented with similarly constructed spectra of a DA3 star (G244−36 = WD 0148+641) and a DB4 star (G26−10 = WD 2129+000) in Figure 1. The prominent He I and somewhat weaker H I lines which characterize a DBA white dwarf are well-marked on our spectrum, and the He I line profiles are similar to those of G26−10, a white dwarf with a comparable $G-R$ color ($G-R$[G200−39] = −0.44; $G-R$[G26−10] = −0.40 to −0.47; Greenstein 1984 and references therein).

It is apparent from Figure 1 that G200−39 possesses absorption features not present in "standard" stars. In Figure 2, we compare our spectrum on an expanded scale with data for the DBZ4 star GD 40 (WD 0300−013) and G26−10. A weak, isolated Ca II K line is obviously present in G200−39, while the doubled nature of the absorption feature at 3965 Å suggests the presence of Ca II H and He I λ3964. Equivalent widths for these and other absorption features are listed in Table 1.

Velocity information is important for associating the Ca features in G200−39 with the white dwarf photosphere, and observed offsets of lines from their rest wavelengths were derived as follows. Weak lines with EW ≲ 0.5 Å are symmetric

---

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

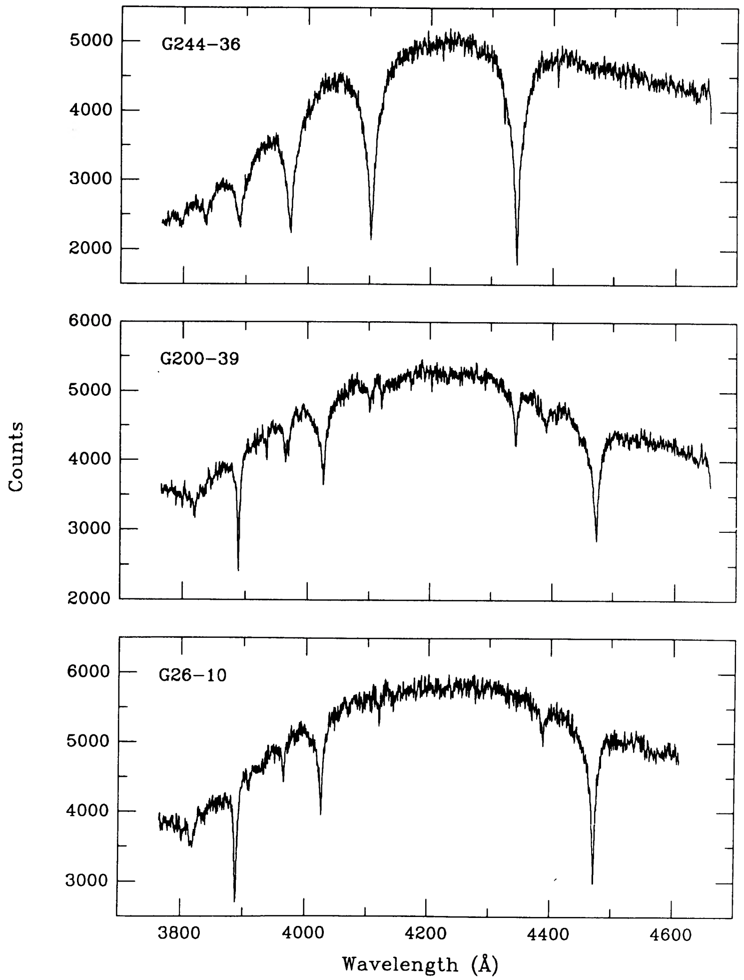

FIG. 1

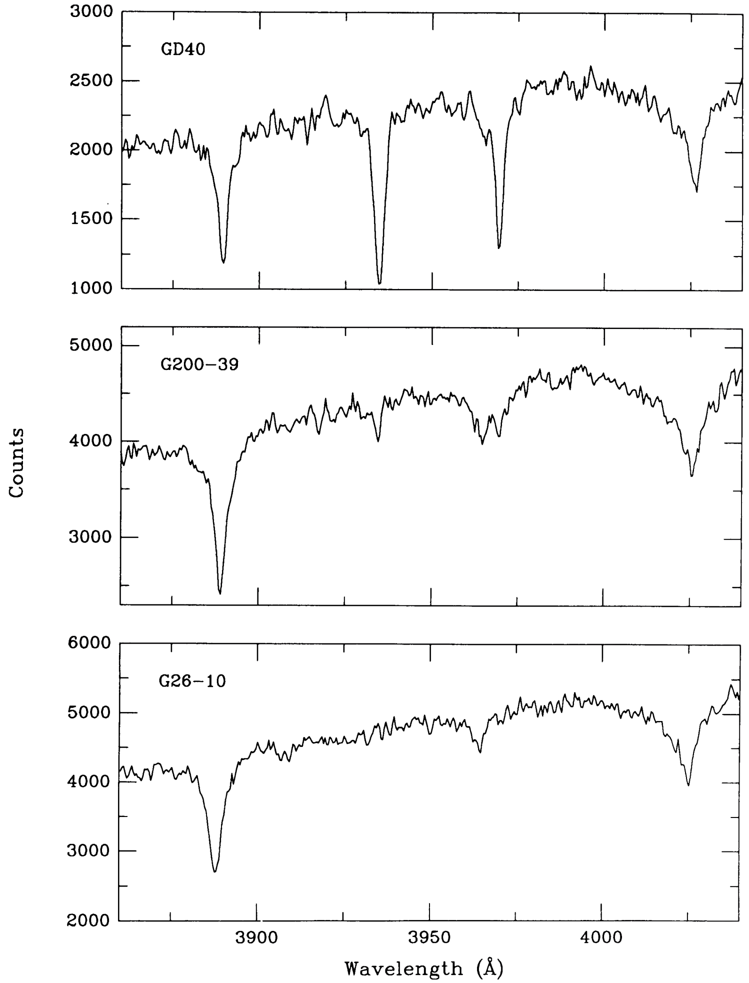

FIG. 2

FIG. 1.—Co-added spectrum of the DBAZ star G200 – 39, a normal DA star, G244 – 36, and a normal DB star, G26 – 10.

FIG. 2.—Calcium lines in G200 – 39 and in GD40 (DBZ4). An expanded spectrum of a DB star without Ca features, G26 – 10, is shown for comparison purposes.

TABLE 1

ABSORPTION-LINE EQUIVALENT WIDTHS IN G200 − 39

Identification	EW (Å)
He I λ3819	0.5 ± 0.1
He I λ3889	2.3 ± 0.2
He I λ3927	<0.1
Ca II λ3934	0.15 ± 0.05
He I λ3964	0.5 ± 0.1
Hε + Ca II λ3969	0.4 ± 0.1
He I λ4009	<0.1
He I λ4026	3.0 ± 0.25
Hδ	0.03 ± 0.05
He I λ4121	0.2 ± 0.05
He I λ4144	<0.1
Ca I λ4226	<0.1
Hγ	1.3 ± 0.15
He I λ4388	1.4 ± 0.3
He I λ4471	6.6 ± 0.35

on our spectra and can be well fitted by single Gaussians. Stronger lines are asymmetric, and we assume that such lines can be approximated by a narrow Gaussian which fits the central core of the line plus the sum of one or more Gaussians to fit the broad wings. In both cases, the central wavelength of the narrow Gaussian was assumed to represent the velocity of the line in question. The absolute velocity scale has been checked by similar measurements of absorption features on spectra of red dwarfs with known velocities. We found that the measured wavelengths were within ~10 km s^{-1} of the expected wavelengths, so we can be confident that the coadded spectra are on a good wavelength scale.

The velocities derived from the He I and Ca II absorption features present in G200−39 are consistent within the measurement errors of ~10–15 km s^{-1}. There is a significant disagreement in the velocity derived for Hγ (~70 km s^{-1}), although Hδ is very close to the stellar velocity. This result might be caused by pressure shifts of H in the helium-dominated atmosphere of G200−39. We estimate a velocity of +40 ± 15 km s^{-1} from He I and Ca II absorption lines, which is somewhat different from the −25 ± 40 km s^{-1} estimated by Liebert *et al.* (1979) using a poorer quality spectrum.

III. ANALYSIS

a) The Source of Calcium: Interstellar or Stellar?

Before we can associate the Ca detection in G200−39 with the white dwarf, it is essential to rule out the possibility that the calcium lines are interstellar in origin. The column density of H I projected onto the Galactic plane is $N_H \approx 5 \times 10^{18}$ to 10^{20} cm^{-2} toward G200−39 ($l = 91°$, $b = 55°$; $d = 60$ pc), and the H I maps of Frisch and York (1983) and of Paresce (1984) suggest there are not any foreground isolated clouds in this direction. The physical conditions in the local material are probably similar to the warm ($T \approx 10{,}000$ K), tenuous ($n_H \approx 0.1$ cm^{-3}) gas observed along various lines of sight within ~50 pc of the Sun (see Paresce 1984). The nearby gas has a velocity relative to the local standard of rest of ~15 km s^{-1} at $l = 165°$, $b = 10°$ (Crutcher 1982), so the heliocentric absorption velocity of material in the direction of G200−39 should be ~ −7 km s^{-1}. The observed velocity of calcium absorption lines in G200−39 is very different from the expected ISM velocity but agrees with those derived for strong, stellar He I lines.

The observed velocity *widths* of the Ca features in G200−39 are FWHM ~ 2 Å (two resolution elements) and are much larger than the ~0.1 Å width expected if the velocity dispersion in this portion of the interstellar medium is similar to that observed for Ar I within galactic quadrants III and IV (York and Frisch 1984).

We thus conclude that the Ca features observed in G200−39 are unlikely to be of interstellar origin and are produced in a stellar photosphere.

b) Calcium Abundances

An estimate for the Ca abundance in a white dwarf relies on accurate knowledge of the effective temperature, $T_{\rm eff}$, and the gravity, log *g*. The equivalent width of He I λ4471 is not sensitive to log *g* in a pure helium atmosphere, so we can determine $T_{\rm eff}$ fairly precisely since H/He is small (SLG). The measured equivalent width of λ4471 implies $T_{\rm eff} = 14{,}750 \pm 400$ K using the models described by SLG, while those presented by Wickramasinghe and Reid (1983) suggest $T_{\rm eff} = 13{,}500 \pm 500$ K. Our derived temperature for G200−39 is slightly lower than the temperature Shipman (1979) used to determine the stellar radius (see also SLG). The adjusted radius of this star is $R = 0.0132\ R_\odot$, which implies a gravity of $\log g = 7.9 \pm 0.4$ if G200−39 obeys the Hamada-Salpeter (1961) mass-radius relation for carbon white dwarfs.

Our estimate for the Ca abundance in G200−39, Ca/H, follows the procedure outlined by Sion *et al.* (1986). We adopt $\log g = 8$ and derive $\log\,[\mathrm{Ca/He}] = -10.3 \pm 0.3$. Recalling the SLG measurement for $\log\,[\mathrm{H/He}] \approx -4.15$, we find a calcium abundance of $\log\,[\mathrm{Ca/H}] \approx -6.15 \pm 0.5$. This calcium abundance is very close to the cosmic value, $\log\,[\mathrm{Ca/H}] = -5.66$ (see Table 11-3 of Aller 1984).

The high quality of the data presented here would in principle allow for more precisely determined abundances, because model profiles could be fitted in detail to the data. Such fits require a more extensive grid of models than is presently available, in particular one with more values of H/He. We have adopted a simpler analysis for this paper so Ca/H for G200−39 can be compared to those from the literature (e.g., those in Sion *et al.* 1986). A detailed comparison of models and high-quality MMT spectra of the hybrid stars is in progress and will be presented in a subsequent paper.

IV. DISCUSSION

The various hypotheses suggested to account for the atmospheric abundances in white dwarfs have been summarized by SLG and by Liebert, Fontaine, and Wesemael (1987, hereafter LFW), and can be divided into two general categories: (1) the elements are primordial and the relative abundances of atomic species are determined by atmospheric processes; or (2) the photospheric abundances are set by the composition of material accreted from the interstellar medium. LFW concluded that the relative numbers of DA and non-DA white dwarfs as a function of effective temperature can be understood qualitatively by the interplay between gravitational settling and convective mixing, while accretion provides the additional material needed to account for the hybrid stars. The detection of Ca in G200−39 eliminates one of SLG's objections to the accretion theory, namely that metallic absorption lines are not observed in any DBA stars. Additional support for the accretion picture is provided by our estimate of a solar Ca/H, although it is possible that Ca/H in G200−39 is merely coincidentally near solar and that accretion is not responsible for the atmospheric H. In this case, H/He may be determined by some interior mixing process, while accretion sets Ca/He.

Whatever the source of the solar Ca/H in G200−39 is, our results complicate the interpretation of other white dwarfs with detectable Ca features. Liebert, Wehrse, and Green (1987) and Sion *et al.* (1986) have noted a correlation between Ca/H and effective temperature, with Ca/H ∼ solar for $T_{\rm eff} < T_{\rm crit}$ and Ca/H ≫ solar for $T_{\rm eff} > T_{\rm crit}$. Sion *et al.* estimated $T_{\rm crit} \approx$ 10,000–12,000 K based on observations of six white dwarfs and suggested that some mechanism is responsible for screening hydrogen from accreting white dwarfs with $T_{\rm eff} \gtrsim 12{,}000$ K. Our result for G200−39 contradicts these conclusions, because we find a solar Ca/H abundance for a white dwarf with $T_{\rm eff}$ substantially larger than 12,000 K.

Popular mechanisms for modifying the H abundance in accreting white dwarfs include the propeller mechanism (which prevents H from accreting; see Wesemael and Truran 1982 and references therein) and diffusion-induced nuclear burning (which destroys accreted H; see Michaud, Fontaine, and Charland 1984). The correlation found by Liebert, Wehrse, and Green (1987) and by Sion *et al.* (1986) provided some support for a unique process which is very effective for $T_{\rm eff} \gtrsim$ 10,000–12,000 K and weakens considerably at lower effective temperatures, but our observations demonstrate that the physical situation is not so simple. Given the small number of hybrid objects with observed calcium lines and the large number of physical processes which potentially can change the photospheric abundances (see SLG and LFW), it is pointless to speculate further on the mechanism which produces DBAZ stars until more observations are collected. If accretion is responsible for the atmospheric H and Ca in hybrid stars, then these elements have not been fractionated in the accretion process and other cosmically abundant elements like C should be present in solar ratios. A search for ultraviolet resonance lines such as C II λ1335, Si II λ1265, and Mg II *h* and *k* with *IUE* or the Hubble Space Telescope thus would be a significant test of the accretion model. Additional high *S/N* observations are needed to search for metallic absorption lines in other DBA stars discovered by SLG and in the only known DAB degenerate, GD 323 (Liebert *et al.* 1984), to determine if these features are common or rare among hybrid stars. Finally, better limits on the H abundance in DBZ stars like GD 40 and CBS 78 can be used to compare these objects with G200−39.

The authors would like to thank L. Hartmann for discussions on cross-correlation analysis; C. Heller, J. McAfee, and J. Robertson for their cheerful, efficient operation of the MMT during data acquisition; D. Ouellette and the rest of the MMT staff for assistance with the spectrograph; S. Tokarz for performing the initial data reductions; and an anonymous referee for helpful comments on the original manuscript. Portions of this project were supported by the NSF through grants AST 85-17125 to Villanova University (E. M. S.) and NSF 85-15747 to the University of Delaware (H. L. S.).

REFERENCES

Aller, L. H. 1984, *Physics of Thermal Gaseous Nebulae* (Dordrecht: Reidel).
Crutcher, R. M. 1982, *A.J.*, **89**, 1022.
Frisch, P. C., and York, D. G. 1983, *Ap. J.* (*Letters*), **271**, L59.
Green, R. F., Schmidt, M., and Liebert, J. 1986, *Ap. J. Suppl.*, **61**, 305.
Greenstein, J. L. 1984, *Ap. J.*, **276**, 602.
Hamada, T., and Salpeter, E. E. 1961, *Ap. J.*, **134**, 683.
Hartmann, L., Hewett, R., Stahler, S., and Mathieu, R. D. 1986, *Ap. J.*, **309**, 275.
Liebert, J., Fontaine, G., and Wesemael, F. 1987, *Mem. Soc. Astr. Italiana*, **58**, 17 (LFW).
Liebert, J., Gresham, M., Hege, E. K., and Strittmatter, P. A. 1979, *A.J.*, **84**, 1612.
Liebert, J., Wehrse, R., and Green, R. F. 1987, *Astr. Ap.*, **175**, 173.
Liebert, J., Wesemael, F., Sion, E. M., and Wegner, G. 1984, *Ap. J.*, **277**, 692.
McCook, G. P., and Sion, E. M. 1987, *Ap. J. Suppl.*, **65**, 603.
Michaud, G., Fontaine, G., and Charland, Y. 1984, *Ap. J.*, **280**, 247.
Paresce, F. 1984, *A.J.*, **89**, 1022.
Shipman, H. L. 1979, *Ap. J.*, **228**, 240.
Shipman, H. L., Liebert, J., and Green, R. F. 1987, *Ap. J.*, **315**, 239 (SLG).
Sion, E. M., Shipman, H. L., Wagner, R. M., Liebert, J., and Starrfield, S. G. 1986, *Ap. J.* (*Letters*), **308**, L151.
Tonry, J., and Davis, M. 1979, *A.J.*, **84**, 1511.
Wesemael, F., and Truran, J. W. 1982, *Ap. J.*, **260**, 807.
Wickramasinghe, D., and Reid, N. 1983, *M.N.R.A.S.*, **203**, 887.
York, D. G., and Frisch, P. C. 1984, in *IAU Colloquium 81, Local Interstellar Medium*, ed. Y. Kondo, F. C. Bruhweiler, and B. D. Savage (NASA CP-2345), p. 51.

P. A. AANNESTAD: Physics Department, Arizona State University, Tempe, AZ 85281

S. J. KENYON: Smithsonian Astrophysical Observatory, Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138

H. L. SHIPMAN: Physics Department, University of Delaware, Sharp Laboratory, Newark, DE 19716

E. M. SION: Astronomy Department, Villanova University, Mendel Hall, Villanova, PA 19085