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SPECTRA OF WHITE DWARFS

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ABSTRACT

Results of a spectroscopic survey of white dwarf candidates from the Lowell Observatory lists are reported. *UBV* photometry is shown to be effective in enhancing the detection rate of DB white dwarfs. The spectrum of GD 40 contains lines of Ca II H and K in addition to those of He I; it is the first DB to show lines of any element other than helium.

Subject heading: white dwarf stars

I. INTRODUCTION

The purpose of this note is to report spectroscopic observations of candidate white dwarfs selected from the various Lowell Observatory lists (Giclas *et al.* 1972, and references contained therein). Our observations have been made at various times between 1970 and 1974 and may be regarded as a modest addition to Greenstein's work in this field (Greenstein 1974, and references therein). Special consideration has been given to the possibility of enhancing the detection rate of DB white dwarfs using available *UBV* photometry. The method, which relies on the insensitivity of *UBV* colors to atmospheric parameters in DB white dwarfs, proved remarkably effective in practice. We have also made an unsuccessful attempt to detect in DB spectra the forbidden ($^3P^o\,2p$–$^3P^o\,4p$) He I λ4517 transition, the presence of which was predicted by Wickramasinghe and Strittmatter (1970) using Griem's (1968) broadening theory.

II. THE OBSERVATIONS

Spectrograms of candidate white dwarfs have been obtained using the Cassegrain image-tube spectrograph at the Steward Observatory 2.3-m telescope. A dispersion of 90 Å mm^{-1} was used, giving an effective resolution of $\sim$4 Å and a spectral range 3500–5100 Å. A small number of spectrograms were previously obtained with the prime-focus spectrograph at the Lick Observatory 3-m telescope at a dispersion of 208 Å mm^{-1}, giving a comparable resolution and slightly reduced spectral cover. A summary of the observational material, together with assigned spectral types, is given in Table 1. Also listed are the equivalent widths W, the full width at half-depth $W_{0.5}$, and the central depths D. Superscripts 1 and 2 refer respectively to Hγ and Hδ for DA white dwarfs, and to the He I $\lambda\lambda$4472 and 4026 lines in the case of DBs. These measures are based on microdensitometer tracings and are of rather low accuracy, due partly to the modest information content on these low-dispersion, fairly narrow (0.2–0.4 mm) spectrograms, and to the inevitable systematic errors due to calibration. If no data are given for DA or DB classifications, it is because the available spectrograms were of insufficient quality. The final column of Table 1 contains comments on individual spectra (see also discussion below). An asterisk in this column indicates that *UBV* photometry has been provided by Eggen (1968).

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III. DISCUSSION

a) *Photometric Criteria for DB White Dwarfs*

The present sample was biased toward stars assigned by Giclas *et al.* to color classes -1 or 0, and inevitably, therefore, consists mainly of types DA and DB. It has been noted by Eggen and Greenstein (1967) that the *UBV* color indices of DBs tend to cluster around $U - B = -0.95$ and $B - V \sim -0.05$. This is due in the main to the temperature insensitivity of the *UBV* colors of helium-rich white dwarfs for temperatures $T_{\rm eff} \gtrsim 12{,}000$ K. There is, however, also some evidence from the He I line strengths of a real concentration of DB white dwarfs to the range $15{,}000 \lesssim T_{\rm eff} \lesssim 18{,}000$ K (Strittmatter and Wickramasinghe 1971). We have, therefore, attempted to use this photometric property to increase the detection rate of DB stars. In Table 2 we list all stars from Eggen's (1968) compilation which have *UBV* colors in the range $-1.10 \leq U - B \leq -0.85$ and $-0.14 \leq B - V \leq 0.0$. Only two previously known DBs lie outside this range; they are (i) HZ 29 (EG 91), which may be a binary and, in any case, has peculiar line profiles (Greenstein and Matthews 1957), and (ii) L1002–62 (EG 146), for which Eggen (1968) gives $B - V = -0.05$ and $U - B = -0.73$. The spectral types listed in Table 2 have either been taken from Greenstein (1969) or have been obtained by us. Of the 27 stars of known type,

TABLE 1

SPECTROGRAPHIC RESULTS FOR THE WHITE DWARF CANDIDATES

Star	α	δ	SpT	W^1	$W_{0.5}^1$	D^1	W^2	$W_{0.5}^2$	D^2	Notes
G158–100....	00°31′22	−12ʰ24ᵐ.4	DC?	...	...	...	...	...	...	
GD 9........	00 58 24	−04 27.5	DA	19	40	0.39	15	41	0.33	*
G2–40.......	01 26 46	+10 07.9	DA	28	33	0.51	10	48	0.37	*
GD 14.......	01 27 19	+27 00.9	DA	22	39	0.40	12	36	0.28	
GD 19.......	01 50 26	+09 34.8	sd	...	...	...	...	...	...	*
GD 423......	02 08 23	+63 15.8	dF	...	...	...	...	...	...	
GD 25.......	02 13 13	+39 37.6	DA	...	...	...	...	...	...	1, Gr 312*
GD 29.......	02 30 05	+36 05.9	sd	...	...	...	...	...	...	*
GD 30.......	02 30 37	+34 20.2	DA	28	46	0.48	...	...	...	
GD 38.......	02 59 20	+37 49.3	DA	15.6	36	0.32	9.6	28	0.24	Gr 287*
GD 40.......	03 00 21	−01 20.2	DB	11	18	0.44	5	21	0.17	2, 3*
GD 47.......	03 39 24	−03 32.3	DA	42	60	0.50	28	56	0.38	*
GD 52.......	03 48 48	+33 58.6	DA	26	45	0.47	16	32	0.43	*
GD 56.......	04 08 33	−04 06.1	DA	40	58	0.53	25	46	0.45	*
GD 60.......	04 16 57	+33 28.5	DA	34	33	0.50	18	36	0.38	*
GD 61.......	04 35 10	+41 03.7	DBs	10	30	0.30	4.6	20	0.20	Gr 315*
GD 66.......	05 17 25	+30 45.5	DA		...	...	...	...	...	1*
GD 69.......	05 32 48	+41 28.2	DAs	9.3	18	0.30	5.3	19	0.24	Gr 319*
GD 73.......	06 10 47	+20 51.5	sd	...	...	...	...	...	...	*
GD 74.......	06 25 30	+41 32.8	DA	23	37	0.39	12	37	0.27	*
GD 78.......	06 48 51	+36 49.4	DC	...	...	...	...	...	...	*
GD 294......	07 13 20	+58 29.8	DA	17	22	0.52	13	20	0.54	
GD 84.......	07 14 23	+45 53.4	DC	...	...	...	...	...	...	EG 215*
GD 86.......	07 30 44	+48 47.9	DA	29	47	0.46	17.0	36	0.40	*
GD 89.......	07 43 54	+44 16.3	DAn	38?	64?	0.45	23	53	0.41	Gr 343*
GD 90.......	08 16 31	+37 40.9	WDpec	...	...	...	...	...	...	Gr 368*
GD 111......	10 00 24	+43 02.6	DA	...	...	...	...	...	...	1*
GD 303......	10 11 17	+57 03.5	DB	9.9	34	0.25	...	...	...	
GD 122......	10 29 16	+32 55.6	DC	...	...	...	...	...	...	4*
GD 124......	10 46 00	−01 45.3	DB	...	.....	...	...	...	...	1*
GD 151......	12 49 54	+18 13.0	DA	13?	23?	0.32?	13	33	0.33	1*
GD 318......	12 37 59	+48 56.5	sd	...	...	...	...	...	...	
G61–29......	13 03 16	+18 17.0	DBe	...	...	...	...	...	...	*
GD 268......	13 04 56	+15 00.5	DC?	...	...	...	...	...	...	3*
G64–43......	14 03 46	−01 05.3	DB	...	...	...	...	...	...	1, 5 Gr 272*
G166–14.....	14 13 26	+23 10.6	DA	27	52	0.42	19	43	0.40	Gr 326*
GD 173......	14 51 17	+00 37.7	DA	25	39	0.47	...	...	...	Gr 297*
GD 196......	16 10 46	+16 39.6	DA	34?	...	...	32?	45?	0.56?	*
GD 354......	16 30 23	+61 48.7	DA	29	52	0.48	21	40	0.46	
GD 202......	16 36 25	+16 00.1	DA	32	38	0.52	19	33	0.47	*
GD 357......	16 41 19	+38 46.7	sd	...	...	...	...	...	...	
GD 360......	17 13 44	+33 16.4	DA	15	37	0.33	10	28	0.26	
GD 367......	17 47 26	+47 12.1	sd	...	...	...	...	...	...	
GD 218......	19 18 14	+11 05.0	DA	26	50	0.45	...	...	...	*
GD 228......	20 05 01	+05 43.7	sd	...	...	...	...	...	...	8
GD 393......	20 58 56	+50 39.4	DAs	23	26	0.56	18	28	0.51	
G126–18.....	21 36 28	+22 55.7	DA	28	38	0.51	22	29	0.56	
GD 396......	21 43 16	+35 18.3	DA	...	...	...	...	...	...	1
G18–34......	22 07 21	+14 14.9	DAs	8	14	0.38	6	14	0.31	6*
GD 242......	22 50 45	+23 41.6	sd?	...	...	...	...	...	...	1, 8
GD 248......	23 23 36	+15 43.8	DC	...	...	...	...	...	...	7, Gr 335*
GD 251......	23 31 53	+29 02.1	DA	16	30	0.40	15	23	0.44	
GD 407......	23 34 16	+59 41.6	sd	...	...	...	...	...	...	

NOTES.—(1) Plate not of adequate quality for microdensitometry—usually due to a narrow or irregular trail. (2) H and K present, fairly sharp. (3) See discussion in text. (4) The star is blue but our spectrum contains no lines of H or He. There may be weak features around λ3800, but further observations are required. (5) This is Gr 272 which Greenstein lists as a DC. The He I lines are clearly present on our spectrogram. (6) This is Gr 302. Greenstein classifies this star as a DC. However, the Balmer Lines are present, although they are fairly sharp and weak. (7) This is Gr 335, which was classified DC by Greenstein. (8) Assigned spectral type sdG by Eggen and Greenstein 1967.

* *UBV* photometry provided by Eggen (1968).

one, GD 122, is a DC; one, G5–32 is a λ4670 star; GD 268 is uncertain; 13 are DAs; and 12 are DBs, including the DBe star G61–29 (Burbidge and Strittmatter 1971). This represents a very substantial increase in the finding rate for DBs (~44%) compared with previous results (~10%). If the color criteria are strengthened so that only stars satisfying $-1.00 \leq U - B \leq -0.90$ and $-0.12 \leq B - V \leq -0.04$ are chosen, only one DB is lost but the number of other spectral types is reduced to five, corresponding to a DB detection rate of better than 66 percent. With the two exceptions already listed above, no previously

TABLE 2

White Dwarfs with Available Photometry

Star	$B - V$	$U - B$	SpT	Notes
GD 38........	−0.03	−1.06	DA	Gr 287
GD 40........	−0.05	−0.92	DB	
GD 61........	−0.09	−0.99	DB	Gr 315
G87–7........	−0.08	−0.92	DA	
GD 85.	−0.11	−0.99	DB	EG 216
GD 98........	−0.13	−0.94	DA	EG 218
G47–18.......	0.00	−0.89	λ4670	EG 182
GD 111.......	−0.08	−0.87	DA	
GD 122.......	0.00	−0.88	DC	
GD 124.......	−0.03	−0.88	DBwk	
GD 125.......	−0.08	−0.98	DAn	EG 221
GD 128.......	−0.07	−0.99	DB	EG 77
GD 140.......	−0.06	−0.98	DA	EG 184
GD 151.......	−0.08	−0.85	DA	
GD 267.......	−0.09	−0.88	DA	Gr 293
G61–29.......	−0.10	−0.97	DBe	
GD 268.......	−0.05	−0.99	DC?	
G64–43.......	−0.05	−0.99	DB	Gr 272
G166–14......	−0.10	−0.95	DA	
GD 173.......	−0.14	−0.96	DA	
GD 190.......	−0.10	−1.00	DB	EG 193
GD 198.......	−0.11	−0.94	DB	EG 194
GD 218.......	−0.11	−0.86	DA	
GD 222.......	−0.12	−0.88	DA	EG 226
G142–50......	−0.06	−0.86	DA	EG 134
G26–10.......	−0.07	−0.92	DB	EG 145
G26–31.......	−0.06	−0.96	DB	EG 149

known DB white dwarf would have escaped detection using this more stringent color condition. We therefore conclude that *UBV* color indices provide an excellent means of isolating DB white dwarfs. It is unfortunate that the property which permits this selection process renders the photometry useless for the purpose of deriving atmospheric parameters for these stars (cf. also Wickramasinghe and Strittmatter 1973). The photometry would thus be useful only for finding DBs. The sharp drop in number of DAs with virtually no change in the number of DBs as the color criteria are narrowed strengthens the hypothesis that virtually all DBs ($\geq 90\%$) are confined to the range $-1.00 \leq U - B \leq -0.90$ and $-0.12 \leq B - V \leq -0.04$.

b) Strength of He I *λ4517*

Wickramasinghe and Strittmatter (1970) had predicted from model-atmosphere calculations based on Griem's (1968) line-broadening theory that the He I λ4517 line arising from the forbidden $^3P^o\ 2p$–$^3P^o\ 4p$ transition should be detectable in DB spectra. (This may be thought of as high-pressure counterpart to the appearance of the He I 4469 $^3P^o\ 2p$–$^3F^o\ 4f$ line which appears in main-sequence B-star spectra.) In Figure 1 we show theoretical profiles for the He I λλ4469, 4471, and 4519 line region. The strength of the λ4517 feature at least at higher temperatures (20,000 K) suggests that the line may be detectable even if only as an asymmetry in the He I λ4471 line. Microdensitometer tracings have been made of all spectrograms of DB white dwarfs for which we have data. In no case did we find a clear feature at λ4517. Since we would expect to see a 10–15 percent feature in our data, this suggests that the strength of the line is significantly less than that predicted. While this may be due to errors in the model atmospheres or in ascribing atmospheric parameters, it seems to us more plausible that the strength of this transition has been overestimated by Griem. In support of this view, (*a*) the He I λ4471 broadening theory of Barnard *et al.* (1969) does not predict such a strong feature at λ4517; (*b*) the atmospheric parameters derived by us are in good agreement with those given by Shipman (1971) using spectrophotometric data; (*c*) according to Shipman (1971), the Griem theory, if applied to a main-sequence B star, predicts an equivalent width of ~30 milliangstroms for the λ4517 feature; no such line has been noted so far. Further attempts to detect the λ4517 feature using the more accurate UCSD Digicon system are currently in progress.

c) Remarks on Individual Spectra

The spectra of two stars, GD 40 and GD 90, require some additional comment. Most white dwarfs seem to have monoelemental atmospheres. Thus most DA white dwarfs have only hydrogen lines in their spectra, although a handful of stars, classified DA, F by Eggen and Greenstein (1965), show both the Balmer series

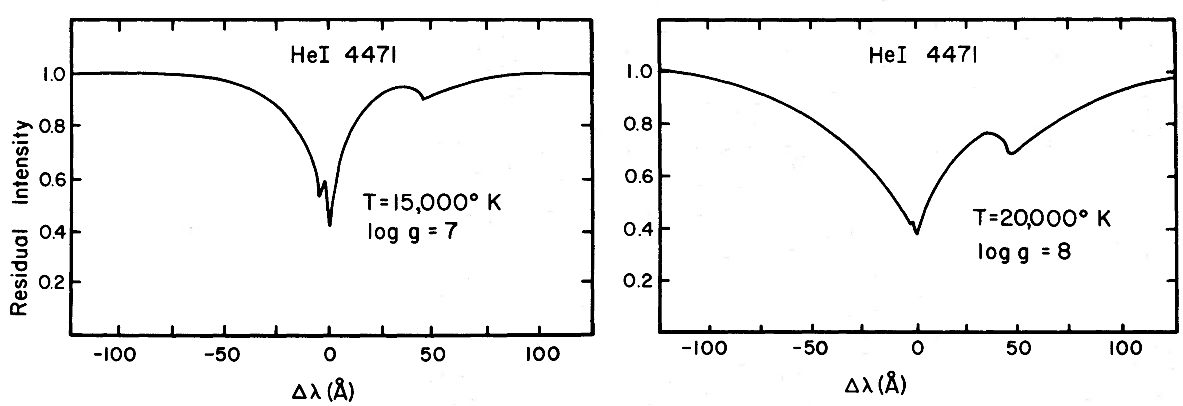

Fig. 1.—Profiles of the He I λλ4469, 4471, 4517 feature predicted from model-atmosphere calculations using Griem's (1968) broadening theory.

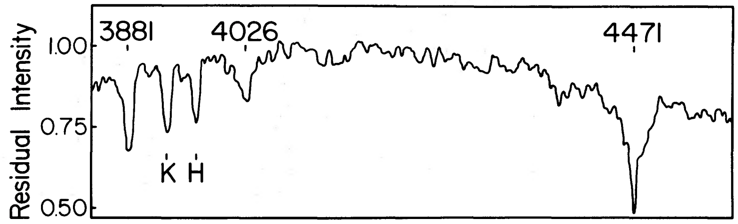

FIG. 2.—Microdensitometer trace on an intensity scale of a portion of the spectrum of GD 40

and H and K of Ca II in absorption. So far, only He I lines have been observed in the spectra of DB white dwarfs. GD 40 is noteworthy in that it has, in addition to the usual broad-winged He I lines, strong but relatively sharper lines at H and K. The spectrum is shown in Figure 2. The character of the He I lines leaves little doubt that this is indeed a white dwarf. Unfortunately no clear-cut proper-motion measurements exist with which to confirm this conclusion. The H and K lines must presumably arise in the upper (cooler) atmospheric layers, which would account for their comparative sharpness. (The strength and breadth of H and K rule out an interstellar origin of these lines.) No lines from other elements have been noted in the spectrum, although presumably Mg II, Si II, Fe II, etc., should be detectable if present in their normal abundances relative to calcium (Strittmatter and Wickramasinghe 1971). If confirmed, this result is rather surprising, since it implies that calcium behaves differently from other metals in white-dwarf atmospheres. The appearance of Ca II could not then be due to the onset of convection, as suggested by Strittmatter and Wickramasinghe (1971), to account for the DA, F stars, since this mechanism would presumably mix all elements back into the surface layers. Further studies of GD 40 are currently in progress.

The spectrum of GD 90 is unlike any other that we have seen. There is an extremely broad, highly structured absorption feature between 4250 and 4400 Å, several broad discrete absorption features between 4750 and 4920 Å, and further structure between 4050 and 4100 Å. The star has been subject to extensive study both spectroscopic and polarimetric, and appears to be a magnetic DA. A full discussion of the results has been given elsewhere (Angel *et al.* 1974).

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REFERENCES

Angel, J. R. P., Carswell, R. F., Strittmatter, P. A., Beaver, E. A., and Harms, R. 1974, *Ap. J.* (*Letters*), **194**, L47.
Barnard, A. J., Cooper, J., and Shamey, L. J. 1969, *Astr. and Ap.*, **1**, 28.
Burbidge, E. M., and Strittmatter, P. A. 1971, *Ap. J.* (*Letters*), **170**, L39.
Eggen, O. J. 1968, *Ap. J. Suppl.*, **16**, 97.
Eggen, O. J., and Greenstein, J. L. 1965, *Ap. J.*, **141**, 83.
———. 1967, *ibid.*, **150**, 927.
Giclas, H. L., Burnham, R., Jr., and Thomas, N. G. 1971, *The Lowell Proper Motion Survey.*
Greenstein, J. L. 1969, *Ap. J.*, **158**, 281.
———. 1974, *Ap. J.* (*Letters*), **189**, L131.
Greenstein, J. L., and Matthews, M. S. 1957, *Ap. J.*, **126**, 14.
Griem, H. 1968, *Ap. J.*, **154**, 111.
Shipman, H. L. 1971, Ph.D. thesis, California Institute of Technology.
Strittmatter, P. A., and Wickramasinghe, D. T. 1971, *M.N.R.A.S.*, **152**, 47.
Wickramasinghe, D. T., and Strittmatter, P. A. 1970, *M.N.R.A.S.*, **150**, 435.
———. 1973, *ibid.*, **160**, 421.

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