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Oswalt, Terry D.; Sion, Edward M.; Hammond, Gordon; Vauclair, Gerard; Liebert, James W.; and Wegner, Gary, "UV Observations of the Cool DBQA5 White Dwarf LDS 678A - Limits on the Atmospheric Composition, Pressure Shift, and Gravitational Redshift Derived from C I 2479" (1991). *Open Dartmouth: Peer-reviewed articles by Dartmouth faculty*. 2126.
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1991AJ....101..583O

THE ASTRONOMICAL JOURNAL VOLUME 101, NUMBER 2 FEBRUARY 1991

UV OBSERVATIONS OF THE COOL DBQA5 WHITE DWARF LDS 678A: LIMITS ON THE ATMOSPHERIC COMPOSITION, PRESSURE SHIFT, AND GRAVITATIONAL REDSHIFT DERIVED FROM C I 2479

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Received 26 June 1990; revised 20 December 1990

ABSTRACT

We present a high-resolution ultraviolet spectrum of the helium-rich degenerate LDS 678A, obtained with the *International Ultraviolet Explorer* (*IUE*) satellite. LDS 678A is the coolest metallic line degenerate (DQ or DZ) yet observed with the *IUE* echelle. These observations provide a detailed line profile of the strong C I 2479 absorption line and equivalent width $W_{2479} = 2.35 \pm 0.06$ Å from which theoretical profile fits yield a carbon abundance of log C/He = (-6.7 ± 0.2). The presence of carbon in a He-rich atmosphere lends credence to the notion that LDS 678A is a transitional case between the DB white dwarfs with nearly pure helium atmospheres and the helium-rich DQ white dwarfs which exhibit carbon bands. Corrected for an inferred pressure shift $V_p = +38 \pm 4$ km/s for the C I 2479 line, a gravitational redshift of $V_{rs} = +26 \pm 13$ km/s is deduced from which a most probable mass of $0.55\mathscr{M}_\odot$ is derived.

1. INTRODUCTION

LDS 678A = EG131 = WD1917 − 07 is the bright component ($V_E = 12.24$) of a common proper motion binary (CPMB) discovered by Luyten (1949). Oswalt *et al.* (1988) provide a finding chart. The object was originally classified by Eggen & Greenstein (1965) as DAwk. Low resolution *IUE* and ground-based spectra obtained by Wegner (1981b) revealed C I lines in the UV and only broad weak He I lines in the optical; from the equivalent width of He I 4471 he estimated $T_{\rm eff} = 10\,600$ K. It should be noted that both these references refer to the white dwarf primary as LDS 678B, contrary to Luyten's original designation. Recently Greenstein & Liebert (1990) detected Hα absorption of equivalent width $W\alpha \approx 3$ Å in LDS 678A. Thus, on the revised spectral classification system introduced by Sion *et al.* (1983), it is now classified as a DBQA5. LDS 678A appears to be a transitional case between the DB white dwarfs with nearly pure helium atmospheres, and the helium-rich DQ white dwarfs which exhibit carbon bands.

With the much greater number and mix of ion transitions in the UV, the high sensitivity detection limit and extremely accurate wavelength scale of the *IUE* echelle, metal features undetectable at low *IUE* resolution and not accessible in the optical are more easily detected (cf. Vauclair & Liebert 1987). The search for such features provides a more stringent upper limit on metal/helium ratios in the DB–DQ transition region than can be derived from the absence of Ca II H and K in the optical or from the unexpected detection of C I features in low-resolution *IUE* spectra.

2. OBSERVATIONS

UV spectra of LDS 678A were obtained with the *IUE* on 28–29 August 1989. One LWP low-resolution spectrum and

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 0004-6256/91/020583-04$00.90 © 1991 Am. Astron. Soc.

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one SWP low-resolution spectrum were obtained to provide identifications for the most prominent features. A single 17 hr high dispersion LWP exposure (~1 Å resolution) was obtained using contiguous European2 low background and US1 shifts plus time from a preceding 1/2 US2 shift during which the radiation background level was below 1.5 volts. The observed high resolution spectrum near C I 2479 is presented in Fig. 1. Although a complete search for other weak features was performed over the entire high resolution spectrum, C I 2479 was the *only* stellar feature seen in the entire high resolution *IUE* spectrum and it has been used for the abundance analysis and radial-velocity determination discussed below.

Two blue region (3800–5000 Å) photographic spectra of each component of LDS 678A/B were obtained on nitrogen-baked Kodak IIa-J plates exposed during the night of 20 July 1980 using the Carnegie image tube spectrograph and the 2.1 m telescope at Kitt Peak National Observatory. This spectrographic system has been fully described by De Veny (1979). Seeing constraints allowed a slit width of 0.2 mm (~2 arcsec on the sky). Exposure times for the four spectra ranged from 5 to 30 min at a reciprocal dispersion of ~38 Å/mm. During this program, four or five spectra usually were recorded on each plate, including at least one spectrum of a bright radial-velocity standard from the list by Wilson (1963). At the reciprocal dispersion of the plates, the WD component LDS 678A exhibited no measurable features, in accord with earlier observations by Wickramasinghe et al. (1978). The companion, LDS 678B, is classified as a dM6.

Additional spectra of both components were obtained with the Arizona/Smithsonian Multiple Mirror Telescope and echelle spectrograph on 8 October 1990. The detector was a dual 2048 diode Reticon. The 8 min exposure of the dM6 component (LDS 678B) consists of one echelle order centered on the Hα line, covering nearly 70 Å at a spectral resolution of 0.2 Å (~9 km/s at Hα). A 10 min exposure at the same setting on the white dwarf (LDS 678A) failed to detect any non-LTE core to the weak Hα line previously reported by Greenstein & Liebert (1990). This is not surprising given the weakness of the line, but no independent radial-velocity measurement could be made for this object. Observations of the dusk twilight sky and an IAU radial velocity standard BD + 28° 3402 implied a small zero-point correction of + 2.3 km/s which was applied to the program objects.

3. DISCUSSION

Though gravitationally bound, most common proper motion binaries (CPMBs) have orbital velocities which are less than typical measurement uncertainties. Thus radial-velocity measurements for the dM6 companion provide an intrinsic velocity for the system against which the gravitational redshift (and therefore mass) of the white dwarf primary can be measured (cf. Eggen & Greenstein 1965 *et seq.*; Greenstein & Trimble 1967; Wegner 1973, 1981a; Koester 1987; Wegner *et al.* (1989).

Our estimate of the radial velocity of the system is based upon all available observations of the dM6 component. The two Kitt Peak plates were measured by Marcum (1989) using the Grant oscilloscope measuring machine at The Ohio State University; a complete discussion of this instrument is given by Arenz (1979). The raw measurements, recorded to the nearest 0.5 micron, were reduced using the KPNO program RADVEL. The 8 min MMT integration of LDS 678B yielded ~2000 photons per resolution element at the peak of the spectrum and ~1200 photons at the bottom of the Hα core. In addition, an even stronger absorption line due to Ca I 6572 could be measured. Both lines were fitted using pseudo-Gaussian profiles following numerical procedures for MMT reductions described in Liebert *et al.* (1989).

Following corrections for solar motion, Earth orbital velocity, barycentric motion, and diurnal rotation, the radial velocity of the dM6 component was determined to be

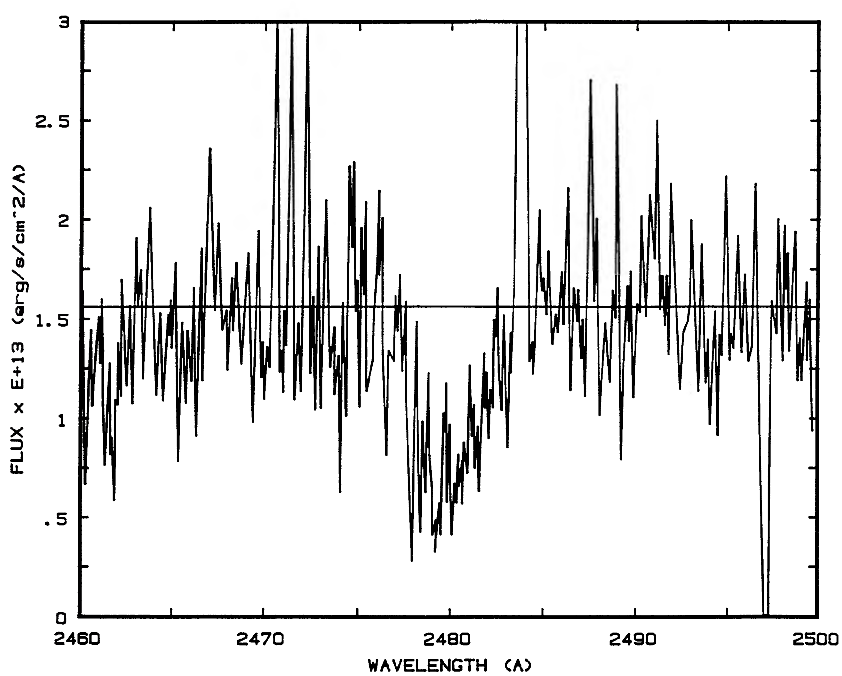

FIG. 1. LWP line profile of C I 2479 obtained with the IUE on 28–29 August 1989. Equivalent width is 2.35 ± 0.06 Å. As discussed in the text, this feature was used to derive a carbon abundance of log C/He = − 6.7 ± 0.2 and estimate a gravitational redshift of V_{rs} = + 26 ± 13 km/s.

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$V_{ms} = +22 \pm 9$ km/s and $+11 \pm 3$ km/s from the KPNO and MMT spectra, respectively. Both are in good agreement with earlier measurements by Wegner (1981a; $V_{ms} = +10 \pm 4$ km/s). The KPNO radial velocity was determined using a method of "weighted mean wavelengths" which Marcum (1989) has shown gives more consistent results than conventional reduction methods for very late-type main-sequence stars and white dwarfs—neither of which are well represented in lists of radial-velocity standards. On the other hand, both the MMT and Wegner's velocities were derived from red region spectra (6000-6900 Å) where line blending is less of a problem and both instrumental systems are well studied and specifically calibrated for velocities. We therefore assigned equal weight to all three determinations and adopted a mean velocity $V_{ms} = 14 \pm 10$ km/s for LDS 678B.

Our analysis of the C I 2479 line profile in LDS 678A uses recent models computed by Koester (1989) for the wavelength interval 2475–2483 Å which include the effects of quadratic Stark broadening and classical van der Waals broadening. These models yield $T_{eff} = 10\,200 \pm 500$ K for LDS 678A which, with our measured equivalent width for C I 2479 ($W_{2479} = 2.35 \pm 0.06$ Å), implies a carbon abundance of log C/He $= -6.7 \pm 0.2$. The uncertainty in W_{2479} was determined using several different choices of continuum. It should also be noted that the carbon abundance estimate is little affected by the uncertainty in temperature. These results are in good agreement with Wegner's (1981b) estimates of $T_{eff} \simeq 10\,600$ and log C/He < -3.

In determining the apparent radial velocity of LDS 678A from the *IUE* profile of C I 2479, least-squares Fourier series fits were applied to the entire profile and to the core region to determine smoothed line profiles. Lines of constant residual intensity were then constructed upon which vertical bisectors were drawn in order to identify the line center. The extent to which these bisectors agreed was used to estimate the precision of the radial-velocity measurements; they also identified a modest asymmetry in the wing regions, but extrapolated vertically through the cores. The central wavelengths of both fits agree to within 0.03 Å and correspond to an apparent radial velocity of 78 ± 9 km/s. The quoted uncertainty includes both the precision of the *IUE* wavelength scale and the fitting procedure.

The apparent velocity of the WD primary is the sum of the systemic velocity V_{ms}, its intrinsic gravitational redshift V_{rs}, and any processes which influence the shape of the line profile V_p. Thus, the *IUE* velocity of LDS 678A, corrected for the systemic velocity provided by its main-sequence companion is $78 - 14 = 64 \pm 13$ km/s. Unfortunately, DB and cooler He-rich degenerates are known to exhibit troublesome line profile asymmetries and pressure shifts that can seriously affect the determination of WD radial velocities. Our *IUE* line profile of C I 2479 appears to exhibit a slight red asymmetry and initially we suspected a weak additional feature contaminating the red wing. Multiplet tables provided no good candidate for such a blend, however Zeidler *et al.* (1986) have reported a very weak Si I line which contaminates the red wing of C I 2479 in WDs that are somewhat cooler and more metal rich than LDS 678A.

Hammond (1989) has reported excellent agreement between his laboratory width/shift measurements (Hammond 1975) and the theoretical work of Monteiro *et al.* (1986) on the broadening of Ca II H and K lines by helium. These lines are still the only transitions with reliably known width/shift ratios at cool white dwarf atmospheric conditions and although they are not good spectroscopic analogs of the C I transition, we use them only to explore the range of width/shift ratios that yield reasonable pressure shifts in model atmospheres appropriate for LDS 678A. Two models ($\log g = 8$ and 9) were computed for $T_{eff} = 10\,200$ K, log H/He $= -5$, log C/He $= -6$, log Ca/He $= -8.6$, using the improved cool degenerate model atmosphere code by Hammond (1990). These "helium-rich metal-poor models" yielded weak unblended Ca II H and K lines which would be undetectable in our optical spectra of LDS 678A. They also exhibit weak Hα absorption, which has recently been detected in LDS 678A by Greenstein & Liebert (1990); best agreement with the observed strength ($W\alpha \approx 3$ Å) was obtained by increasing the H abundance in these models by about a factor of two (log H/He ≈ -4.7), with no substantial change in the other parameters.

The two models have identical temperature runs with depth, but the gas pressures differ by a factor of four. Typical width/shift ratios at $\tau_{std} = 0.1$ and $T_{eff} = 8000$ K are -47 and -12.5 for the Ca II K and H line, respectively, compared to -2.8 for the classical van der Waals broadening used by Koester. Shift measurements for the H and K line profiles produced by these models were made with the same bisector techniques as for the *IUE* spectra. An additional model was run with the shifts switched off to check the accuracy of the shift measurement scheme. Pressure shifts for the K line were too small to measure in all cases. The least-squares fits for the Ca II H line and their bisectors yielded pressure shifts for $\log g = 8$ of $+15$ km/s; results for $\log g = 9$ were $+57$ km/s.

We arrived at our best estimate for the pressure shift in LDS 678A by applying several firm constraints, i.e., radial velocity, parallax, temperature, radius, and the range of plausible width/shift ratios derived from the helium-rich metal-poor models. If the true pressure shift is zero, as indicated by the $\log g = 8$ model for the Ca II K profile, and a Hamada–Salpeter C/O core is assumed, the observed residual velocity of $+64$ km/s is *entirely* due to gravitational redshift, implying a mass of $0.85\mathscr{M}_\odot$, $\log R/R_\odot = -2.06$, $\log g = 8.4$. Alternatively, the canonical average white dwarf mass of $0.6\mathscr{M}_\odot$ (Weidemann & Yuan 1989) requires a gravitational redshift $V_{rs} = +30$ km/s and, therefore, a pressure shift $V_p = 64 - 30 = +34$ km/s. This is reasonable in view of the helium-rich metal-poor models for $\log g = 8$, and it implies that $\log R/R_\odot = -1.90$ and $\log g = 8.0$. On the other hand, Koester *et al.* (1982) derive a mass of $0.42\mathscr{M}_\odot$ from the photometric colors and M_v derived from a trigonometric parallax which requires $\log R/R_\odot = -1.83$, $\log g = 7.75$, and a redshift $V_{rs} = +21$ km/s, hence an implied pressure shift $V_p = +43$ km/s.

Neither line broadening theory nor laboratory data alone give enough guidance to choose the appropriate pressure shift from the above range of reasonable values (0–43 km/s). However, an additional constraint is set by the photometric mass determined from the best-known parameter T_{eff} and bolometric magnitude. The multichannel, Strömgren, and *UBV* colors of Hammond's helium-rich metal-poor models with $T_{eff} = 10\,200$ K agree well with those of LDS 678A and predict a bolometric correction BC $= -0.75$. The models with log H/He $= -4.7$ also predict the Hα of equivalent width ($W\alpha \approx 3$ Å) observed by Greenstein & Liebert (1990). Using the relation

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TABLE 1. Models yielding reasonable shift/width ratios.

$\mathcal{M}/\mathcal{M}_\odot$	$\log R/R_\odot$	$T_{\rm eff}$	$\log g$	$V_{\rm p}$	Width/shift
0.85	− 2.06	12 300 K	8.4	0.0 km/s	< − 18
0.55	− 1.88	10 200	7.9	38	∼ − 6
0.42	− 1.83	9900	7.8	43	∼ − 3

TABLE 2. Summary of physical data for LDS 678A.

Parameter	Value	Mean error	Notes
$T_{\rm eff}$	10 200	500	(a),(b)
W_{2479}	2.35 Å	0.06	
log C/He	− 6.7	0.2	(a)
log H/He	− 4.7	0.2	(b),(c)
$\log g$	7.9	0.1	
$\log R/R_\odot$	− 1.88	0.02	
$\mathcal{M}/\mathcal{M}_\odot$	0.55	0.05	
$V_{\rm rs}$	26	13	
$V_{\rm p}$	38	4	
Width/shift	− 7	2	(b)

Notes to TABLE 2

(a) From equivalent width of C I 2479, models by Koester (1989).
(b) From helium-rich metal-poor models by Hammond (this paper).
(c) From detection of Hα by Greenstein & Liebert (1990).

$$\log(R/R_\odot) = 0.2(M_v + {\rm BC}) - 2\log(5040/T_{\rm eff}) - 1.059,$$

where the final constant contains $T_{\rm eff\odot} = 5780$ K, and $M_{\rm bol\odot} = 4.78$ (Hayes 1985), we derive $\log R/R_\odot = -1.88$ (assuming $M_v = 12.24$; McCook & Sion 1987), corresponding to a mass of 0.55 $\mathcal{M}_\odot$, $\log g = 7.93$, and a gravitational redshift of + 26 km/s. The implied pressure shift $V_{\rm p} = 64 - 26 = 38$ km/s, is consonant with the width-/shift ratios typical of the helium-rich metal-poor models.

As a final consistency check, we can invert the equation used to derive the photometric radius and solve for $T_{\rm eff}$ using the $\log R/R_\odot$ values derived above for the high and low masses which yielded reasonable width/shift ratios. These ranges are summarized in Table 1. The effective temperatures for both the high and low mass examples in this table are clearly excluded by the He I 4471 strengths predicted by Koester's models. It seems, therefore, that all the above estimates are best satisfied by a mass $\mathcal{M} = 0.5$–$0.6\mathcal{M}_\odot$ for LDS 678A. Using this range of masses and $T_{\rm eff} = 10\,200 \pm 500$ K, we derive the results summarized in Table 2 and conclude that the most reasonable width/shift ratio for the C I 2479 in LDS 678A is -7 ± 2.

Our analysis of LDS 678A indicates that much work remains to be done towards achieving a theoretical understanding of the pressure shifts in helium-rich WDs; in LDS 678A the assumption of only classical van der Waals broadening implies pressure shifts which are overestimated by at least a factor of 2. However, there is cause for optimism. We have shown that the existence of a nondegenerate common proper motion companion provides an intrinsic radial velocity which, when combined with spectroscopic and photometric data, is capable of setting empirical constraints on computed pressure shifts, and hence gravitational redshifts, for helium-rich WDs.

This work was supported by NASA Grant No. NAG5-343 and NSF Grant No. AST-8802689 to Villanova University, NSF Grant No. AST-8802687 to the Florida Institute of Technology and NSF Grant No. AST-8814711 to Louisiana State University. One of us (G.H.) is grateful to the College of Natural Sciences, University of South Florida, for generous grants of computer time. We also gratefully acknowledge our referee, H. Shipman, whose comments measurably improved this paper.

REFERENCES

Arenz, R. 1979, M.S. thesis, The Ohio State University
De Veny, J. 1979, Kitt Peak National Observatory Facilities Handbook
Eggen, O., and Greenstein, J. 1965, ApJ, 141, 83
Greenstein, J., and Liebert, J. 1990, ApJ, 360, 662
Greenstein, J., and Trimble, V. 1967, ApJ, 149, 283
Hammond, G. 1975, ApJ, 196, 291
Hammond, G. 1989, in White Dwarfs, IAU Symposium No. 114, edited by G. Wegner (Springer, Berlin), p. 346
Hammond, G. 1990, in preparation
Hayes, D. S. 1985, in Calibration of Fundamental Stellar Quantities, IAU Symposium No. 111, edited by D. S. Hayes, L. E. Pasinette, and A. G. D. Philip (Reidel, Dordrecht), p. 225
Koester, D. 1987, ApJ, 322, 852
Koester, D. 1989, unpublished
Koester, D., Weidemann, V., Zeidler, E. M. 1982, A&A, 116, 147
Luyten 1949, ApJ, 109, 528
Marcum, P. 1989, M.S. thesis, Florida Institute of Technology
McCook, G., and Sion, E. 1987, ApJ, 65, 603
Monteiro, T., Cooper, I., Dickinson, A., and Lewis, E. 1986, J. Phys. B, 19, 4087
Oswalt, T., Hintzen, P., and Luyten, W. 1988, ApJ, 66, 391
Sion, E., Greenstein, J., Landstreet, J., Liebert, J., Shipman, H., and Wegner, G. 1983, ApJ, 269, 253
Vauclair, G., and Liebert, J. W. 1987, in Exploring the Universe with the *IUE* Satellite, edited by Y. Kondo (Reidel, Holland), p. 355
Wegner, G. 1973, MNRAS, 165, 271
Wegner, G. 1981a, AJ, 86, 264
Wegner, G. 1981b, ApJ, 245, L27
Wegner, G., Reid, N., and McMahan, R. 1989, in White Dwarfs, edited by G. Wegner (Springer, Berlin), p. 378
Weidemann, V., and Yuan, J. W. 1989, IAU Colloquium No. 114, edited by G. Wegner (Springer, Berlin), p. 1
Wickramasinghe, D. T., Bessell, M. S., and Whelan, J. A. J. 1978, MNRAS, 182, 53P
Wilson, R. E. 1963, General Catalogue of Stellar Radial Velocities, Carnegie Institute of Washington
Zeidler, E. M., Weidemann, V., and Koester, D. 1986, A&A, 155, 356

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