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A SPECTROSCOPIC SURVEY OF SOUTHERN HEMISPHERE WHITE DWARFS—V

DATA FOR FIFTEEN ADDITIONAL STARS AND THE NATURE OF THE W219 GROUP

Gary Wegner

Department of Astrophysics, University Observatory, South Parks Road, Oxford*

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SUMMARY

Spectroscopic data on 13 new southern white dwarfs are described. None of these stars have been previously observed spectroscopically. Spectral types, line profiles, and equivalent widths for the Hβ or K line of Ca II, depending on which is visible in the spectrum are given. Five new stars with peculiar spectra and which appear to belong to the W219 group are described. The kinematical and spectroscopic properties of these stars are discussed and it is concluded that the W219 group white dwarfs cannot be considered a comoving group, but take part in a more general property of the molecular band white dwarfs' motions directed toward the Southern Hemisphere due to their halo population characteristics.

1. INTRODUCTION

The observations, presently reported, are an extension of an investigation on the spectral classification of the southern hemisphere white dwarfs (Wegner 1973). The list of white dwarf suspects again is based primarily on the 158 stars given by Luyten & Smith (1958) for which broadband photometry has been given by Eggen (1969). Although not as extensive, this second set of observations fills a gap in the first series centred near $\alpha = 23^{\mathrm{h}}$ which arose from observing conditions experienced during the Australian winter and should therefore be a useful supplement.

In addition, this investigation was designed to provide new information on a subclass of the white dwarfs often called the W219 group which was first discussed by Bell (1962) and Bell & Rodgers (1964). These stars are characterized by two properties: (1) Similar space motions with respect to the Sun directed toward an apex near $A = 14^{\mathrm{h}}\,44^{\mathrm{m}}$, $D = -59°$, and (2) the presence of weak C_2 bands in many of their spectra. In earlier papers on the spectra of southern white dwarfs (Wegner 1973, 1974), two new suspects were accidentally found and since then, several additional stars with the properties of this group have been observed. Although it no longer appears that these stars can belong to a comoving group, they can be understood more generally in terms of their belonging to the halo population. White dwarfs of this type are undoubtedly important for understanding the physical processes governing the evolution of the degenerate stars because they appear to be old kinematically and cool, which makes them among the oldest observable of these objects.

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* Present address: South African Astronomical Observatory, P.O. Box 9, Observatory, C. P., South Africa, 7935.

TABLE I

Fundamental data for the observed stars

No./Name	α/δ	Sp./m_V	$B-V/U-B$	μ/θ	$W/w_{1/2}$	Notes
42	00 : 24·4	DAwk	+0·17	0·58	27·8	★
L170–27	−55 : 41	15·14	−0·66	214	16	
43	00 : 48·9	DA	−0·02	0·19	38·5	
BPM 16285	−54 : 29	15·29	−0·78	66	33	
44	01 : 38·7	DB	−0·12	0·16	—	
BPM 16571	−55 : 58	14·86	−1·06	100	—	
45	03 : 11·3	DF	+0·52	0·08	3·2	★
BPM 17113	−54 : 18	14·75	−0·42	163	9	
46	04 : 19·6	DAwk	+0·52	0·56	12·1	★
LFT 349	−48 : 46	14·36	−0·45	176	6	
47	04 : 46·5	DA	−0·105	0·04	33·1	
BPM 3253	−78 : 57	13·47	−1·205	257	22	
48	07 : 22·2	pec.	+1·34	0·86	—	★
LFT 526	−39 : 13	13·66	+1·04	154	—	
—	15 : 20·0	sd	+0·57	0·11	10·9	
BPM 9483	−68 : 47	14·68	−0·32	110	2·0	
49	16 : 27·0	pec.	+1·25	0·58	9·4	★
L411–46	−41 : 59	14·70	+0·90	222	8	
—	18 : 15·3	sd	+0·555	0·06	9·1	
BPM 11316	−62 : 35	14·86	−0·31	194	22	
50	19 : 53·2	DA	−0·01	0·22	24·3	
BPM 12843	−71 : 31	15·15	−0·99	180	30	
51	21 : 54·8	DB	−0·13	0·22	—	★
LDS 766A	−43 : 42	15·04	−0·85	144	—	
52	21 : 59·8	DAwk	+0·16	0·51	24·6	★
LFT 1679	−75 : 28	15·06	−0·63	279	22	
53	22 : 03·9	DA	−0·045	0·12	23·2	
BPM 44347	−48 : 34	15·55	−1·05	265	18	
54	23 : 37·7	DA	+0·045	0·26	38·1	
BPM 15727	−76 : 03	14·66	−0·69	241	22	

Notes to Table I

42. A W219 group member. This star's $H\beta$ line appears to be too weak for its $(U-V)$ colour. Additional faint features are suspected which include CH near λ 4300 and weak K line of Ca II.

45. The spectrum appears nearly continuous. Weak H and K of Ca II and possibly CH at λ 4300 are present.

46. A W219 group member, finding chart in Plate I. The spectrum contains several weak features which include the hydrogen Balmer lines and a shallow band near λ 5180 which is attributed to C_2, but could also be Mg I or MgH.

48. A W219 group member, finding chart in Plate I. The spectrum of this peculiar cool

1975MNRAS.171..637W

2. OBSERVATIONS

All stars, with the exception of No. 48, were observed 1973 September 4–8, in Pretoria with the 74-in. telescope of the Radcliffe Observatory using the Cassegrain image-tube spectrograph with an RCA Carnegie-type image-tube (Thackeray 1971) and baked Eastman Kodak IIa-O plates. One spectrum was obtained of each star. The reciprocal dispersion of these spectra was about 140 Å mm^{-1} and gave a projected slit width of 5·0 Å on the plate. The spectra were widened to 0·3 mm, cover the spectral range 3700–5900 Å, and are centred near $H\beta$. Intensity calibrations were provided by spectra from an auxiliary spectrograph, taken on pieces of the same photographic plates as used for the stars, and developed with the stellar plates.

The spectral classifications are given in Table I where the format is similar to the earlier paper (Wegner 1973). Column 1 gives the star's list number, if it appears to be a degenerate star, extended from the first series and a name for the star according to the following system: ' BPM ' stars have finding charts given by Eggen (1969), the ' L ' star can be found in Luyten's (1949) atlas of finding charts, and ' LFT ' stars have finding charts given in Plate I. Column 2 gives the star's 1950·0 right ascension and declination. Columns 3 and 4 give the spectral class of the star determined from the present series of observations and *UBV* data as given by Eggen (1969) for all stars except Nos 48 and 49 which were taken from Eggen (1968). Column 5 gives the yearly proper motion μ in arc seconds and the position angle θ taken from Luyten (1955, 1970). Column 6 gives the equivalent width W and half-widths $w_{1/2}$ of $H\beta$ for the DA stars as explained in Section 3 or the K-line of Ca II for some of the other stars, if visible. Unfortunately for the two DB stars, there is a defect on the photocathode of the image-tube which is at the position of the 4471 Å line of He I. The spectra of the non-DA stars are described in more detail in the notes at the end of Table I. No trigonometric parallaxes are available for any of these stars.

Two of the cool stars that were observed do not appear to be truly degenerate and were therefore left unnumbered. The present pair of stars lies in the same portion of the $(B-V)$–$(U-B)$ diagram as the red 'subdwarfs ' described by Greenstein (1971) in his study of the red subluminous star suspects and share the property of having weak metal lines. Greenstein interprets these stars to be of very low metal content because of their excessively large $\delta(U-B)$ and belonging to the extreme Population II.

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star was obtained at the author's request on 1974 March 1–2 by T. Lloyd Evans with the Radcliffe telescope. It shows molecular features which include MgH. Also visible are Ca I at λ 4226, Na, D, and weak H and K of Ca II. If TiO is present it is very weak.

49. A W219 group member. This cool star's spectrum contains a broad shallow depression centred near λ 5170 possibly due to C_2 or MgH. CH appears present as do H and K of Ca II. The hydrogen Balmer lines appear present.

51. This star has a common proper motion companion, Luyten colour class *m* and $m_{pg} = 15{\cdot}9$, 331 °, 9″. The *UBV* colours are peculiar for a white dwarf of this spectral type and would indicate an atmospheric composition differing from the normal DB stars.

52. A member of the W219 group. Finding chart is in Plate I. The hydrogen Balmer lines and H and K of Ca II are present in the spectrum. A weak feature near λ 5170 due to C_2 appears to be present.

3. SPECTROSCOPIC DATA

3.1 *Line profile data for the DA stars*

Direct intensity tracings of all spectra were made in Oxford using the Moll-type microphotometer which employs a Bryans X–Y curve follower for the conversion of plate transmission to direct intensity and a Varian chart recorder. Strong Hg I night sky lines are present in these spectra which render Hβ the only suitable line which can be satisfactorily studied in the DA stars. Table II gives the Hβ line profiles for the DA stars which were defined with the continuum located at $1-R = 1000$ and as a repeatable definition of the continuum, the points at $\Delta\lambda = \pm 150$ Å on each wing of Hβ were connected by a straight line. Since the present spectra are of a lower dispersion, narrower, and therefore noisier than the Mount Stromlo spectra, the blue and red wings of Hβ have been averaged. The differences between the wings of Hβ imply an internal error of about ± 5 to ± 10 per cent for the line profiles and therefore also the equivalent widths. Although there was no overlap with the Mount Stromlo observations due to the limited amount of observing time, systematic differences are not expected in the equivalent widths of Hβ given here and in Wegner (1973). This is because the spectral responses of the detectors were similar and care was taken to ensure that the continuum was defined identically in the two studies.

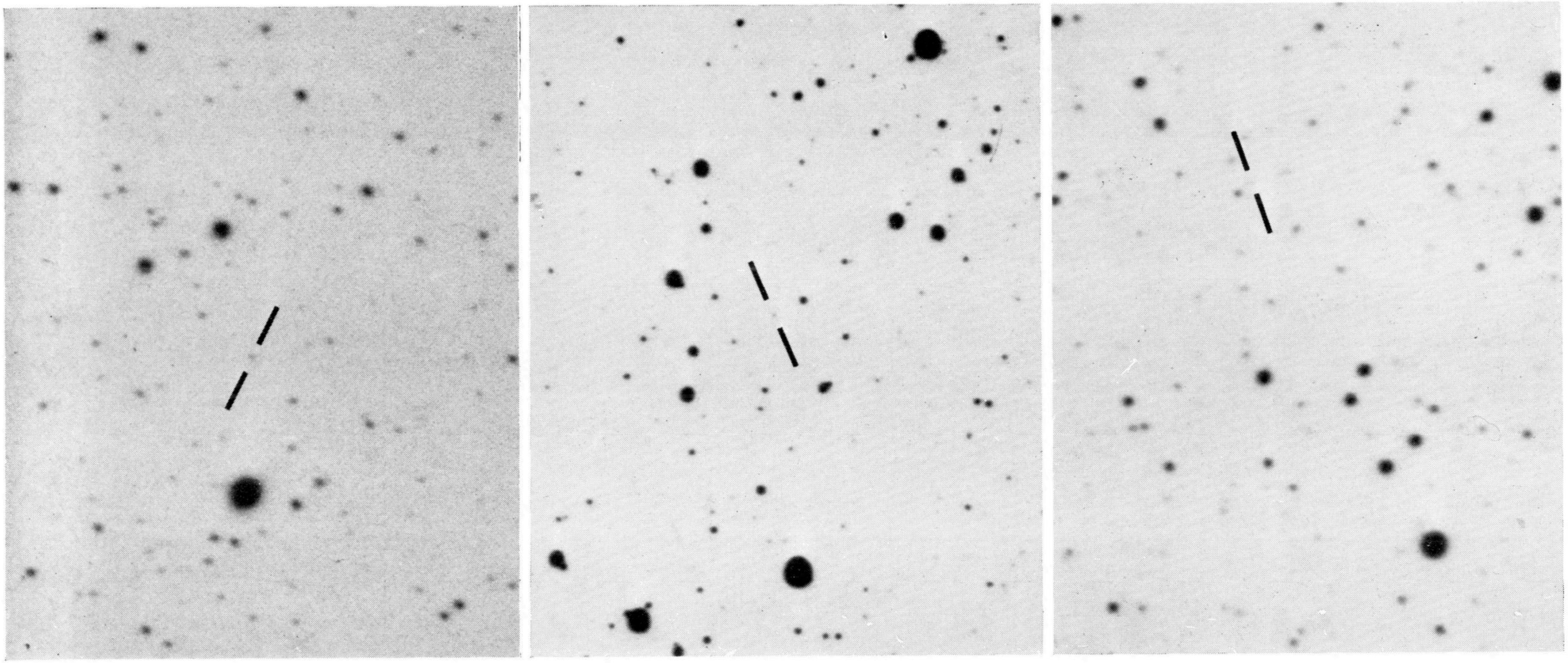
TABLE II

Hβ profiles for the DA stars

$\pm\Delta\lambda$ (Å)	(42)	(43)	(46)	(47)	(49)	(50)	(52)	(53)	(54)
0	565	525	683	582	750	725	645	652	530
4	670	605	812	621	825	762	700	700	585
20	802	725	922	778	921	828	815	832	752
40	875	808	950	855	962	885	892	905	837
60	921	878	965	903	990	930	931	943	882
80	946	918	981	936	1000	955	958	964	911
120	981	978	1000	976	1000	987	988	988	965

The plot of W against U–V using the equivalent width data for Hβ is shown in Fig. 1 which combines the results of Wegner (1973), this paper, and some unpublished measurements for a few northern DA stars. The solid curve is an eye estimate of the mean relation and shows the well known dependence of hydrogen line equivalent width on (U–V) for nerly constant $\log g$ and resembles the results for Hγ given by Eggen & Greenstein (1965). Even if the intrinsic scatter of points about this mean relation is taken to be ± 10 Å in W, there are four stars which clearly lie outside the relation for the DA stars that are shown by triangles. The fifth triangle at $(U–V) = +0{\cdot}07$ is the position of LFT 349 which also has a C_2 feature in its spectrum and is described in Section 4.2. Two of these stars (Nos 18 and 33) were known previously and classed DAwk in Wegner (1973). The remaining stars are members of the W219 groups, described in Section 4.

It is difficult to say much quantitatively about the atmospheric element abundances of these weak hydrogen line stars without continuum measurements and atmospheric models, but apparently they either have different atmospheric compositions or are composite. It is not clear with the present information whether the hydrogen line strengths are reduced, or if the U–V colours are shifted due to a



46 48 52

Plate I. *Finding charts for the stars in Table I for which no previously published charts exist. The pictures were prepared from the* Canterbury Sky Atlas (*Doughty, Shane & Wood* 1972). *North is top and east left. The bottom of each panel is approximately* 4 *arcmin in length.*

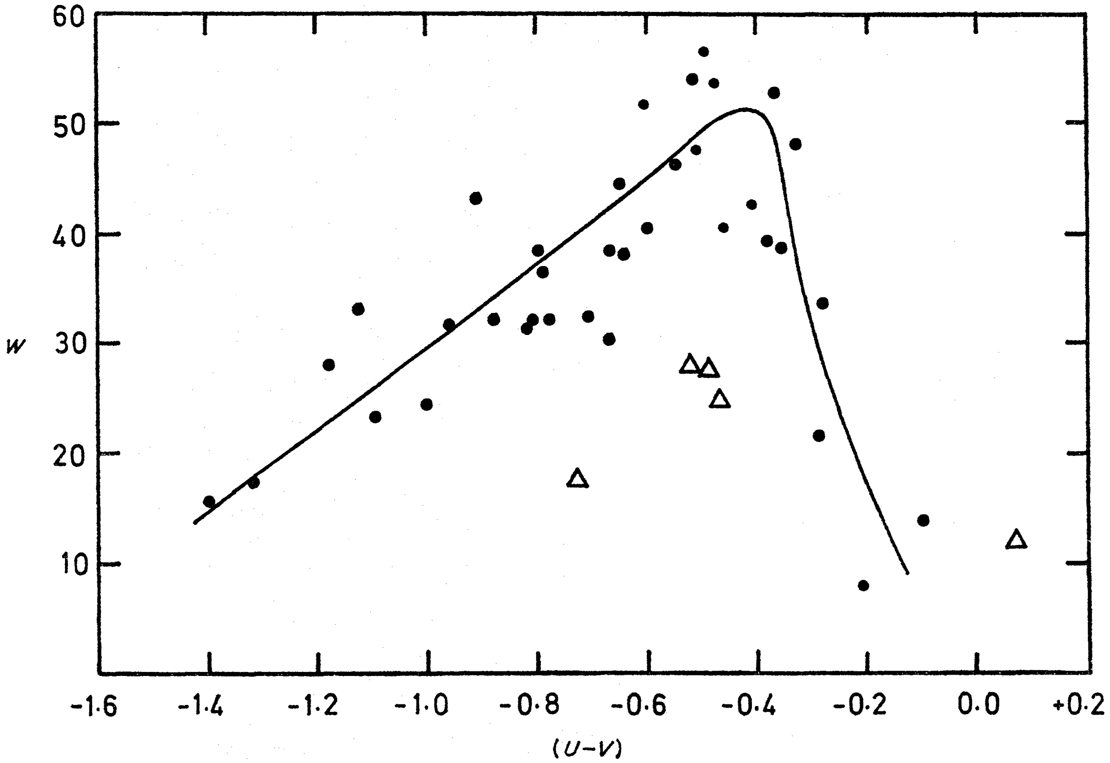


FIG. 1. *The equivalent width of Hβ as a function of U–V for the DA stars. Triangles denote DAwk stars.*

change in the emergent continuum flux because of differences in H, C, N, O and heavy metals. The work of Matsushima & Terashita (1969) and Fig. 10 of Bues (1970) indicate that appreciable variations in the hydrogen line strengths with H:He and metal content only occur for large changes in these quantities.

Another interesting feature of Fig. 1 is the presence of an apparent clump of points near $(U\text{–}V) = -0{\cdot}75$ on the sequence for the normal DA stars. There is some suggestion of its existence in the $W(\mathrm{H}\gamma)$ diagram in Fig. 8 of Eggen & Greenstein (1965).

4. THE NATURE OF THE W219 'GROUP' STARS

4.1 *Kinematical properties*

The remarkable phenomenon that several C_2 and DC white dwarfs have their proper motions directed toward a common apex in the southern hemisphere (Bell 1962; Bell & Rodgers 1964; Eggen & Greenstein 1965) has been noted for a long time. Since the white dwarfs of these spectral classes generally have high space velocities with respect to the Sun, they naturally have been regarded as Population II objects (Greenstein 1969). In Table I, five stars are given which were found in Luyten's (1955) ' LFT ' catalogue by comparing the observed θ_0 and computed θ_c position angles of the proper motion where:

$$\cot\theta_c = \cos\delta\tan D\csc(A-\alpha) - \sin\delta\cot(A-\alpha),$$

and (A, D) are the equatorial coordinates of the apex. Table III lists various stars which have observed proper motions in the direction of Bell's apex at $A = 221°$

TABLE III

Stars having proper motions that fit Bell's (1962) *convergent point for the W219 group*

Star No.	m_V	$(U–V)$	π_{trig}	μ	θ_0	θ_c	Spectrum
(a) Previously known stars							
	(mag.)	(mag.)	(″)	(″)	(°)	(°)	
EG 24	15·20	−0·22	0·068	1·25	162	162	4670
EG 41	14·10	−0·51	—	1·49	171	161	4670
11	14·09	+0·49	0·173	2·05	135	151	DC
20	11·50	−0·45	0·206	2·68	96	88	C2
EG 148	13·23	−0·54	0·074	0·67	199	213	DC
EG 156	17·2:	−0·90	—	0·31	220	205	4670:
(b) Newly observed stars							
EG 135	13·69	−0·35	0·076	0·84	213	211	DAs
12	13·92	−0·85	—	0·47	128	123	C2
42	15·14	−0·49	—	0·58	214	214	DAwk
46	14·36	+0·07	—	0·56	176	162	DAwk
48	13·68	+2·38	—	0·86	154	145	pec.
49	14·79	+2·15	—	0·58	222	220	pec.
52	15·06	−0·47	—	0·51	279	224	DAwk
(c) Stars rejected by Strand & Riddle (1970)							
USNO 22	14·64	+2·86	0·028	1·43	148	149	
USNO 40	13·62	+2·35	0·013	0·88	162	162	
USNO 66	13·70	+2·51	0·012	0·85	207	209	
USNO 74	12·89	+2·67	0·033	0·76	213	214	
EG 27	15·52	+2·97	0·015	1·20	164	162	DKp

and $D = -59^\circ$, of which 13 have been verified spectroscopically to be genuine white dwarfs or appear to be subluminous from their reduced proper motions.

When these stars' kinematics are scrutinized in detail, difficulties appear for the interpretation of them forming a comoving group. For this to be true, they should have nearly identical V—velocities covering a limited range in U and W. (In this paper, UVW denote the usual components of stellar velocity with respect to the Sun in left-handed coordinates.) (1) Strand & Riddle (1970) first demonstrated that a number of stars with proper motions fitting the W219 group convergent point show discordance between the predicted group and observed trigonometric parallaxes and thus do not appear to be physically related. Their objects are very red for white dwarfs, so they may be random dM stars. (2) The conclusion is further strengthened by the five stars with trigonometric parallaxes. Their trajectories in the UV-plane can be plotted with radial velocity as a free parameter. This exercise demonstrates that there is no well-defined area of convergence for any set of radial velocities.

Nevertheless, the fact that these stars have the same convergent point seems significant. Looking at the proper motions of all the known DC and λ 4670 stars (e.g. by simply plotting them on a celestial globe) shows that in addition to the number of those stars with proper motions directed at the convergent point near $A = 221^\circ$ and $D = -59^\circ$, there are additional stars just missing it and that in general, the proper motions of the DC, λ 4670 white dwarfs are predominantly directed toward the southern hemisphere. Furthermore, the above convergent point lies at $l^{\mathrm{II}} = 317^\circ$, $b^{\mathrm{II}} = 0^\circ$, which is in the region of the sky where it is well known that the high velocity stars have their apices. This appears to be consistent with the Population II interpretation of these white dwarfs.

Some additional information on these stars can be derived from their velocity ellipsoid obtained using their proper motions. The 40 candidate stars were taken from the lists of Eggen & Greenstein, Papers I–VII (see Greenstein 1974) if they are listed as spectral class DC or λ 4670, or from Table I and Wegner (1973). The luminosities for stars lacking parallaxes were obtained from the relation:

$$M_V = 13^{m}\cdot 15 + 10^{m}\cdot 85\,(U-V)$$

(Eggen & Greenstein 1965) which is consistent with the DC and λ 4670 stars that have parallaxes and seems sensibly single valued as is not the case for the DA's. The velocity ellipsoid's axes, σ_j (j = 1, 2, 3) and the asymmetrical drift, ΔV, were determined using a graphical method with the result:

$$\sigma_1 : \sigma_2 : \sigma_3 = 126 : 85 : 74 \text{ km s}^{-1},$$

and $\Delta V = 48 \text{ km s}^{-1}$, where the estimated errors are about ± 20 per cent of the derived parameters. These results are nearly the same as those of Iwanowska (1973) for stars classed as Population II on the basis of tangential velocities, but not homogeneous spectral type.

These velocity dispersions are high compared to other classes of stars which may, in part, be due to selection effects, for white dwarfs are generally found from large proper motions. Nevertheless, the value of 48 km s^{-1} for the assymetrical drift and the velocity dispersions of the DC and λ 4670 found above give a density gradient: $d \log \nu / d \log R = -2\cdot 6$, where ν and R are the star density and distance from the galactic centre respectively. This is near the value of -3, typical for halo stars (see Oort 1965).

4.2 *Spectroscopic properties*

The spectra of individual stars with proper motions consistent with the W219 group's apex are described in the notes to Table I, Eggen & Greenstein (1965) or Wegner (1973). In general, degenerate stars of this type show weak C_2 bands in their spectra, but some of the newly observed stars have additional molecular bands and hydrogen lines. Intensity tracings of two of these stars, LFT 349 (No. 46) and L411–46 (No. 49) are in Fig. 2, where spectral features of Hβ and C_2 and CH molecules appear, while L411–46 has additional metal lines of Ca I and Ca II. The spectrum of a third cool star, LFT 526 (No. 48) is particularly interesting in that it seems to contain MgH. Wehrse's (1972) model atmospheres for cool solar composition white dwarfs produce a strong MgH band near λ 5185. In the light of these results, the presence of MgH and H features in the spectra of these stars suggest that they are not as metal and hydrogen-poor as some white dwarfs.

One possibility is that these abundance differences may be a gravity effect. No parallaxes are available for the three stars above, but some information on their luminosities comes from Jones' (1972) calibration of the reduced proper motion, $H = m + 5 \log \mu + 5$ and $(B-V)$ where in the $(B-V)-H$ plane, degenerate and non-degenerate stars are clearly separated. This approach suggests that all but two of the W219 group stars discussed here are degenerates with $\log g \approx 8$. The two remaining stars, LFT 526 (No. 48) and L411–46 (No. 49) would be subluminous, lying between the main and white dwarf sequences and could thus be low mass degenerates or cool subdwarfs.

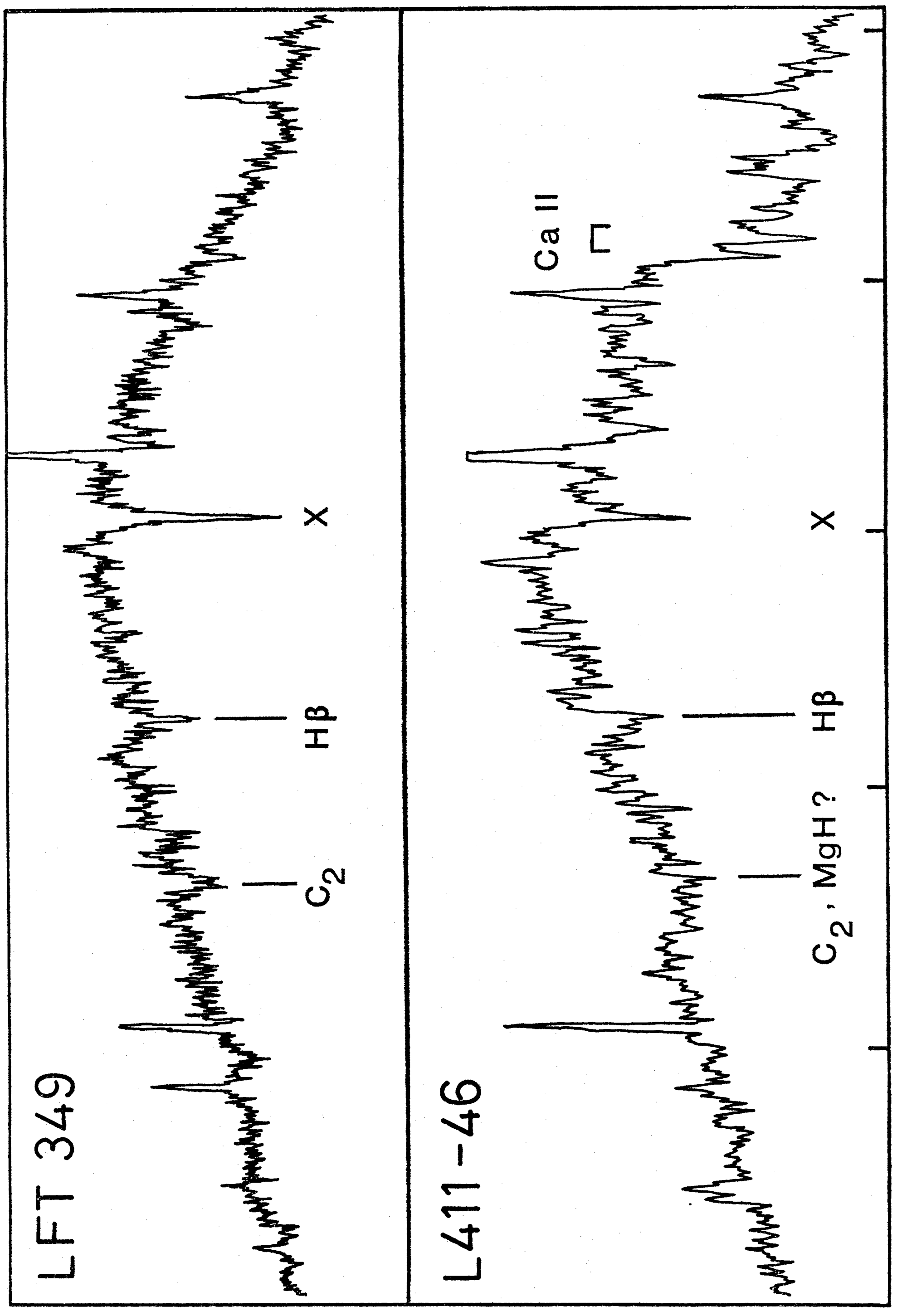


FIG. 2. *The spectra of two newly observed white dwarfs that have both atomic hydrogen and molecular features in their spectra. The feature 'X' is an image-tube defect.*

The stars in Section 3.1 with proper motions toward the W219 group apex could have weak hydrogen lines. A similar result, attributed to population membership, was found by Iwanowska (1973) as her Population II DA objects statistically show weaker hydrogen lines. Further studies of possible correlations between the kinematics and atmospheric abundances of white dwarfs should be undertaken.

4.3 *Conclusions about the W219 group and related stars*

The present investigation found that the stars previously referred to as members of the 'W219 group' are not really in a comoving group, but are examples of a more general kinematical property of the molecular band white dwarfs which is a consequence of their being in the Population II. However, the presently available limited data on these white dwarfs can only partially answer two fundamental questions which they seem to pose. First, what is their kinematical relationship to stars of the solar neighbourhood? Second, how do they fit in with current concepts on the evolution of white dwarfs? A clear picture of the relationship between the spectroscopic and kinematic properties is needed before far-reaching generalizations can be made about white dwarfs.

Evidence regarding the stellar population membership of different classes of white dwarfs has been discussed by Greenstein (1969), Strand & Riddle (1970) and Wegner (1974). The DA's appear to have high velocity dispersions than DB's and this could indicate a difference in the original parent star masses. Carbon molecule band white dwarfs (including spectral type DC) seem to be characterized by high space motions and apparent large age, or duplicity. This simple picture is, however, complicated for at least two reasons: (1) Some magnetic white dwarfs which appear to have carbon molecules have low space velocities (Greenstein, Gunn & Kristian 1971). (2) Some molecular white dwarfs such as BPM 27606 (No. 39) and LDS 678A (EG131) have dMe companions with low radial velocities, both indicating youth. These stars have spectra differing from other molecular band white dwarfs such as L145–141 (No. 20) which are clearly of the high velocity type (see Wegner 1973; Bues & Wegner 1975). The existence of the classes of stars described above suggests that further sub-divisions exist among the white dwarfs which depend on kinematical characteristics. This provides evidence against the presently popular hypothesis that all DA stars evolve into DB's which turn into DC's and suggests that other factors such as the parent mass of the star are important.

A range of ages and masses appears to be present because these stars have a spread in M_V and T_{eff}. For L145–141, $M_V = 13{\cdot}1$ mag. while for L97–12, $M_V = 15{\cdot}25$ mag. Using the recent detailed calculations of Lamb (1974) for a $1{\cdot}0\ M_\odot$ pure carbon white dwarf, the cooling ages would be 2×10^9 and 5×10^9 yr, respectively. Assuming a total age of 10^{10} yr would indicate parent stars in the mass range $1\ M_\odot$ to $1{\cdot}3\ M_\odot$.

With the above information, a crude estimate of the space density of these objects can be made. About 10 per cent of white dwarfs with known spectral types are DC and $\lambda\,4670$ stars, while Iwanowska (1973) estimates that Population II objects constitute about 25 per cent of the white dwarfs. Thus using Weidemann's (1967) estimate of the total white dwarf space density near the Sun, the space density of these objects would be of the order of $0{\cdot}002$ stars pc^{-3}, with a large range of uncertainty since the total white dwarf space density itself is only known to within a factor of about two. This is comparable to Oort's (1965) estimate of about $0{\cdot}005\ M_\odot\ \mathrm{pc}^{-3}$ for the other halo stars.

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REFERENCES

Bell, R. A., 1962. *Observatory*, **82**, 68.
Bell, R. A. & Rodgers, A. W., 1964. *Observatory*, **84**, 29.
Bues, I., 1970. *Astr. Astrophys.*, **7**, 91.
Bues, I. & Wegner, G., 1975. *Astr. Astrophys.*, submitted.
Doughty, N. A., Shane, C. D. & Wood, F. B., 1972. *The Canterbury sky atlas*, Mount John University Observatory, Christchurch.
Eggen, O. J., 1968. *Astrophys. J. Suppl.*, **19**, 57.
Eggen, O. J., 1969. *Astrophys. J.*, **157**, 287.
Eggen, O. J. & Greenstein, J. L., 1965. *Astrophys. J.*, **141**, 83.
Greenstein, J. L., 1969. *Astrophys. J.*, **158**, 281.
Greenstein, J. L., 1971. In *White dwarfs*, IAU Symposium No. 42, ed. W. J. Luyten, D. Reidel, Dordrecht.
Greenstein, J. L., 1974. *Astrophys. J.* (*Letters*), **189**, L131.
Greenstein, J. L., Gunn, J. E. & Kristian, J., 1971. *Astrophys. J.* (*Letters*), **169**, L63.
Iwanowska, W., 1973. *Studia Soc. Scient. Torunensis*, *Vol.* **V**, Section F, 11.
Jones, E. M., 1972. *Astrophys. J.*, **177**, 245.
Lamb, D. Q., 1974. *Evolution of pure* ^{12}*C white dwarfs*, Ph.D. Thesis, University of Rochester.
Luyten, W. J., 1949. *Astrophys. J.*, **109**, 528.
Luyten, W. J., 1955. *Catalogue of* 1849 *stars with* $\mu > 0''{\cdot}5$, Lund Press, Minneapolis.
Luyten, W. J., 1970. *White dwarfs*, University of Minnesota, Minneapolis.
Luyten, W. J. & Smith, J. A., 1958. *Magnitudes and colors of southern white dwarfs*, University of Minnesota Observatory.
Matushima, S. & Terashita, Y., 1969. *Astrophys. J.*, **156**, 183.
Oort, J. H., 1965. In *Galactic structure*, eds A. Blaauw & Schmidt, M., University of Chicago Press, Chicago.
Strand, K. Aa. & Riddle, R. K., 1970. *Publ. U.S. nav. Obs.*, *Vol.* **XX**, part IIIC, 33.
Thackeray, A. D., 1971. *Q. Jl R. astr. Soc.*, **12**, 320.
Wegner, G., 1973. *Mon. Not. R. astr. Soc.*, **163**, 381.
Wegner, G., 1974. *Mon. Not. R. astr. Soc.*, **166**, 271.
Wehrse, R., 1972. *Astr. Astrophys.*, **19**, 453.
Weidemann, V., 1967. *Z. Astrophys.*, **67**, 286.