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A library of IUE white dwarf spectra for stellar population analyses*

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Abstract. — We present high Signal to Noise ratio IUE spectra of different classes of white dwarfs, to be used as templates for stellar population analyses in the ultraviolet region. We present average stellar parameters associated to each group. The library contains 6 groups for DA's, 2 for DO's and 5 for DB's. We also present equivalent widths of spectral features, and continuum measurements. We call attention to the spectral characteristics which are promising indicators of the presence of white dwarfs in the spectra of composite stellar populations.

Key words: (stars): white dwarfs — ultraviolet: stars

1. Introduction

White dwarfs are not luminous objects, but they are very common: there are 1279 cataloged white dwarfs in McCook & Sion (1987, hereafter MS87). Many of them have trigonometric parallaxes indicating distances below 100 pc from the Sun. Since hot white dwarfs emit most of their light in the ultraviolet, it is in this spectral region where they can most probably be detected in spectra of composite stellar populations. In a recent paper, evidence was found of the presence of white dwarfs of type DA 5 in the spectra of early-type galaxies and globular clusters (Bica et al. 1996).

The *International Ultraviolet Explorer* (IUE) has been collecting spectra of white dwarfs for the last 17 years, and several of them already have a relatively large number of individual spectra stored in the IUE database.

Much information on stellar parameters have been derived from the IUE spectra of individual white dwarfs, just to mention a few: Wesemael et al. (1985) for DO's, Liebert et al. (1986) and Wegner & Nelan (1987) for DB's, and Kepler & Nelan (1993) and Bergeron et al. (1995) for DA's. A spectrophotometric atlas of individual white dwarfs was compiled from IUE archives by Wegner & Swanson (1991).

In order to further explore this database, in the present paper we group stars of similar spectral characteristics into distinct white dwarf classes, which can be very useful for, e.g., stellar population analyses. We obtain template spectra of much higher signal to noise ratio (S/N) than those of individual stars. This paper is structured as follows: in Sect. 2 we present the IUE white dwarf sample, gather information on individual stars from the literature, and measure fluxes in the present data; in Sect. 3 we build the groups and present the average parameters associated to them; in Sect. 4 we measure equivalent widths, continuum slopes and discuss the results; in Sect. 5 we present the concluding remarks of this work.

2. The white dwarf sample

We gathered the IUE spectra for the present sample from the IUE Uniform Low Dispersion Archive (ULDA Version 4.0) database as stored at the Instituto Astronômico e Geofísico of the Universidade de São Paulo (IAG–USP). Details on the ULDA calibration processes and access can be found in Courvoisier & Paltani (1992, and references therein). Some obvious réseau marks and bad pixels have been corrected by a linear interpolation. The population synthesis of composite spectra such as those of galaxies and/or star clusters, requires the knowledge of the observational and theoretical parameters associated to the different stellar types. With this in mind, we searched for white dwarfs which had information on spectral classification and/or atmospheric parameters from the literature. The sample contains 86 white dwarfs, and is not intended to be complete in any sense: we gathered enough spectra in order to achieve a good (S/N) for each group. We show the results for the individual early-type DA stars in Table 1 and for late-type DA's in Table 2, for DO's in Table 3 and DB's in Table 4. By Cols. (1) and (2)

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Table 1. Data on individual early-type DA stars

WD#	Other Names	Spectral Type	$T_{\rm eff}$(K) (Optical)	$T_{\rm eff}$(K) (UV)	log g	M_V	$10^{14}\times f_{\lambda}(2646)$ ($\rm erg\,cm^{-2}s^{-1}\AA^{-1}$)	$d_{\odot}$ (pc)
		WD_A1						
0136+251	PG 0136+251	DA 1	34 980			9.7	1.68	†
0346−011	GD 50	DA 2	43 102		9.09	11.4	12.10	29.9
	GR 228		40 540			11.8		
0548+000	GD 257	DA 1				9.0	3.67	162.9
	GR 289							
0549+158	GD 71	DA 1	33 753	32 800	7.76	9.3	21.90	56.5
	LTT 11733							
	EG 210							
	L1241-036							
0612+177	G104-27	DA 2	25 938		7.97	10.3	‡	42.6
	EG 46		24 660			10.4		
	LTT 11818							
	L1244-026							
1254+223	EG 187	DA 1	40 432	41 200	7.85	10.1	18.50	46.1
	PG 1254+223							
1314+293	HZ 43A	DA 1	38 200	50 000	7.90	8.7	31.70	65.2
	PG 1314							
	EG 98							
1615−154	G153-41	DA 2	29 833		8.08	10.2	16.60	44.0
	LTT 6497		29 730					
	EG 118							
1620−391	GR 274	DA 2	24 406	24 800	8.10	10.6	116.0	12.0
	CD-38 10980							
2014−575	L210-114	DA	28 373		7.88	10.0	11.60	40.2
2111+498	GD 394	DA 2	39 450	37 000		9.3	26.40	55.0
	EG 244	DA 1.5						
2309+105	GD 246	DA 1	57 990	54 000	7.91	11.1	28.20	25.1
	EG 233							
	BPM 97895							
		WD_A2						
0047−524	BPM 16274	DA 2	18 745	18 015	7.83	10.7	4.50	50.1
	L219-48							
0109−264	GD 691	DA 1					18.80	†
	PHL1003							
0134+833	GD 419	DA 2	18 730		8.07	11.1	12.80	24.9
	GR 308							
	LP2-534							
0214+568	EG 17	DA 2	21 180		7.83	10.5	‡	43.2
	H PER1166							
0227+050	FEIGE 22	DA 3	19 070		7.66	10.6	17.00	27.9
	EG 19							
0410+117	HZ 2	DA 3	20 790	19 575	7.81	10.7	6.57	42.8
	EG 31							
1042−690	BPM 6502	DA 3	21 380		7.86	10.5	17.80	32.5
	L101-80							
1337+705	G238-44	DA 2.5	20 230		8.05	10.7	15.60	26.2
	EG 102							
	LTT 18341							
2136+828	EG 147	DA 3	16 940	17 016	7.60	10.4	12.10	33.4
	G261-45					10.9		
2149+021	EG 150	DA 3	20 547		7.99	10.7	14.80	25.5
	G93-48		18 250			11.0		
			17 653					
		WD_A3						
0232+525	GR 314	DA 3	17 050		8.13	11.5	‡	28.2
	G174-5							
0310−688	EG 21	DA 3	16 181	15 546	8.06	11.3	41.90	10.5
	LB3303							
	CPD-69 177							
1105−048	EG 76	DA 3	15 576	16 720	7.80	11.0	9.33	24.2
	G163-50		15 300					
	LTT 4099		15 540					
			15 870					

Table Notes. (‡) - no LWP/R spectrum available; (†) - distance not available.

Table 2. Data on individual late-type DA stars

WD#	Other Names	Spectral Type	$T_{\rm eff}$(K) (Optical)	$T_{\rm eff}$(K) (UV)	$\log g$	M_V	$10^{14}\times f_\lambda(2646)$ ($\rm erg\,cm^{-2}s^{-1}\,Å^{-1}$)	$d_\odot$ (pc)
		WD_A4						
0352+096	EG 26	DA 4	14 420	15 000	8.10	11.5	2.32	40.2
	HZ 4		15 100	13 824				
0406+169	EG 29	DA 4	15 300	16 100	8.50	11.2	1.19	67.6
	LP414-101		15 740	15 077				
0954−710	BPM 6082	DA 4	13 915	13 876	7.72	11.1	5.48	29.9
	L64-27							
1327−083	G14-58	DA 4.5	14 350	15 520	7.82	11.3	16.60	13.8
	WOLF485A		12 800			11.9		
	EG 99							
	BD-07 3632A		14 670					
1919+145	GD 219	DA 4	15 080	15 700	8.08	11.5	9.37	19.7
	EG 201			14 632				
2047+372	EG 261	DA 4	14 660	15 100	8.16	11.6	9.33	20.2
	G210-36			14 001				
		WD_A4.5						
0133−116	ROSS 548	DA 4	11 830	12 400	7.97	11.6	‡	32.5
	EG 10		11 990	12 130				
	G271-106		10 000					
	ZZ Cet							
0231−054	GD 31	DA 4	12 840	12 910		11.9	‡	29.5
	EG 207							
0401+250	G8-8	DA 4	12 120	12 227	8.20	11.9	3.34	24.0
	EG 28		13 248					
			13 500					
0713+584	GD 294	DA 3.4		13 400			4.94	†
0858+363	GD 99	DA 4	11 100	12 000	8.08	11.8	1.24	35.5
	EG 219							
0921+354	EG 65	DA 4	11 620	13 150	7.97	11.7	‡	57.5
	G117-B15A		12 500	11 890		11.6		
			11 840					
1425−811	L19-2	DA 4	12 100	12 310	8.21	11.9	4.32	23.4
	EG 110		12 230	12 640				
	MY Aps							
1647+591	G226-29	DA 4	12 120	12 270	8.29	11.6	13.20	13.4
	GR 368		12 460	12 280				
	DN Dra							
1855+338	EG 127	DA 4.5	10 500	12 060		12.1	1.74	31.5
	G207-9		12 040					
1935+276	G185-32	DA 4	12 130	11 930	8.05	11.7	6.58	17.9
	GR 277		11 970	12 370				
	PY Vul							
		WD_A5						
1236−495	BPM 37093	DA 4.5	12 100	11 530	8.81	11.9	3.35	21.5
	LTT 4816		11 200	11 560		12.7		
			12 899					
1559+369	ROSS 808	DA 4.5	11 160	11 180	8.04	11.9	1.58	31.0
	G180-23		10 880	11 560				
	EG 115		11 200					
	TY CrB							
2326+049	G29-38	DA 4	11 820	11 650	8.14	11.9	5.93	16.8
	EG 159		11 900					
	ZZ Psc							

Table Notes. (‡) - no LWP/R spectrum available; (†) - distance not available.

designations following MS87; (3) optical spectral type from MS87; (4) optical effective temperature; (5) ultraviolet (UV) effective temperature; (6) surface gravity; (7) visual absolute magnitude from MS87; (8) observed monochromatic f_λ flux at $\lambda 2646$ Å; and finally (9) distance from the Sun. The sources for Cols. (4)-(6) and (9) are: Shipman (1979), Bergeron et al. (1992), Vennes (1992), Koester & Allard (1993), Kepler et al. (1995), Kepler & Nelan (1993), Bergeron et al. (1995) and Bragaglia et al. (1995) for DA's; Koester et al. (1981), Liebert et al. (1986), Oke et al. (1984), Wegner & Nelan (1987) and Thejll et al. (1991) for DB's; Wesemael et al. (1985), Liebert et al. (1989) and Werner et al. (1991) for DO's; for white dwarfs in general, we used information from Green (1980), Fleming et al. (1986), Liebert et al. (1988), Thejll et al. (1991), Werner & Heber et al. (1991), Bradley et al. (1993), Motch et al. (1993) and Wesemael et al. (1993). Stellar fluxes in Col. (8) were measured in our average spectra for individual white dwarfs. An asterisk in Col. (9) of Tables 3 and 4 indicates that the distance was not available in the literature above. In such cases, we assumed the average M_V of the corresponding group (see Table 5 in Sect. 3) to estimate the distance modulus. For a few stars, the apparent

Table 3. Data on individual DO stars

WD#	Other Names	Spectral Type	$T_{\rm eff}$(K) (Optical)	$T_{\rm eff}$(K) (UV)	$\log g$	M_V	$10^{14}\times f_\lambda(2646)$ (erg cm^{-2}s^{-1}Å^{-1})	$d_\odot$ (pc)
		DO 2						
0108+100	GR 900 PG 0108+100	DO 1	80 000		≥ 7.0	7.8	2.69	†
0109+111	GR 901 PG 0109+111	DO 1	80 000		≥ 7.0	7.8	3.24	†
1133+489	PG 1133+489	DO 1	47 500		≥ 7.0	9.0	0.74	†
1211+332	EG 295 HZ 21	DA 3	50 000		≥ 7.0	8.8	6.79	†
1707+427	V817 Her PG 1707+427	DO	100 000		≥ 7.0		0.38	461*
2131+066	IR Peg PG 2131+066	DO	85 000		7.5		1.36	470
		DO 1						
1034+001	PG 1034+001	DOZ 1	80 000		≥ 7.0	7.8	28.20	†
1151−029	PG 1151-029	DOZ 1					2.02	†
1159−035	GW Vir	DOZ 1	140 000		≥ 7.0		7.01	210*
1253+378	EG 93 HZ 34	DO	60 000		~ 7.0		2.53	†
1424+534	PG 1424+534	DOZ 1	100 000		7.0		2.40	393*
1520+525	PG 1520+525	DOZ 1	140 000		7.0		3.41	287*
1634−573	HD 149499B	DOZ 1					127.0	†
1821+643	DS Dra K1-16						5.79	230*

Table Notes. Data for PG 2131+066 are from Kawaler et al. (1995); (†) - distance not available.

visual magnitude was not available and consequently they lack distance estimates, as indicated in Tables 1-4.

To obtain the final spectrum for each object we first averaged individual spectra working separately in the short (SWP) and long (LWP and LWR) wavelength ranges. A few spectra were eliminated at this stage because they presented problems such as instrumental defects, discordant continuum distribution and/or spectral features. During this treatment of individual objects, the short and long wavelength domains were processed separately. The weights in the averages were given according to the square of the (S/N). This procedure allowed us to obtain the highest possible (S/N) spectra. Recently, this method has been applied to integrated spectra of star clusters in the IUE library providing new information from the derived templates (Bonatto et al. 1995). Since all the objects are nearby, and in no case was the λ2175 Å dust absorption feature evident, no reddening correction was applied to the spectra. The spectra have been corrected of the IUE réseau marks at λ1790 Å and λ3056 Å.

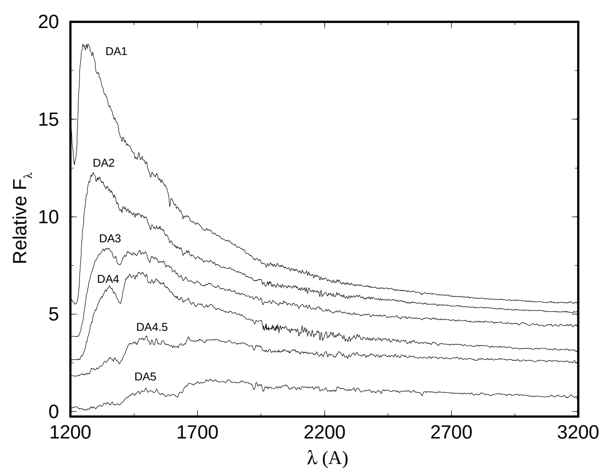

Fig. 1. The resulting templates for DA stars. Notice the Lyα wing and the wide features at λ1400 Å and λ1600 Å. The spectra are normalised at λ2646 Å and constants have been added to them, except for the bottom one

3. The templates and their properties

We used the optical spectral types for individual stars (Col. (3) in Tables 1-4) as a guide to create the groups, but the fundamental criterion was the similarity of the IUE spectra. Each average stellar spectrum contributed to its group formation with a weight proportional to the (S/N). The resulting DA groups are shown in Fig. 1, and those for DO's and DB's in Fig. 2. Notice the remarkable slope range, primarily a temperature effect. Differences in spectral features are also apparent (Sect. 4).

We present in Table 5 average properties for each group, by Cols. (1) group designation; (2) and (3) effective temperatures from optical and ultraviolet studies, respectively; (4) the adopted effective temperatures, which are averages of Cols. (2) and (3); (5) surface gravity ($\log g$); (6) and (7) absolute visual magnitudes (M_V) respectively derived averaging M_V's for individual stars from MS87, and theoretically predicted values using the adopted temperatures and surface gravities for the groups (Cols. (4) and (5)), and the models used in Bergeron et al. (1995); (8) luminosity in solar units ($\log(L/L_\odot)$); and finally (9) the intrinsic monochromatic flux F_λ at λ2646 Å, at the white

Table 4. Data on individual DB stars

WD#	Other Names	Spectral Type	$T_{\rm eff}$(K) (Optical)	$T_{\rm eff}$(K) (UV)	log g	M_V	$10^{14}\times f_\lambda(2646)$ (erg cm^{-2}s^{-1}Å^{-1})	$d_\odot$ (pc)
		WD_B2						
0111+104	GR 409	DB 2.5	28 900	30 000	8.07	11.0	2.12	77.3
	PG 0112+104			29 000				
0853+163	PG 0853+158	DB 2.5		22 000			1.11	†
	GR 904							
1115+158	PG 1115+158	DB 2	22 500	26 000			0.42	†
	DT Leo			25 000				
1149−133	PG 1149-133	DB 2		21 000			0.71	†
				20 000				
1326−037	PG 1326-034	DB 2		22 000			1.16	†
				21 000				
1346+082	PG 1346+082	DB					1.72	†
	CR Boo							
1351+489	PG 1351+489	DB 2	22 000	25 000			0.61	125.9*
	EM UMa			24 000				
1456+103	PG 1456+103	DB 3	22 500	24 000			0.90	100.5*
	CW Boo			23 000				
1645+325	V777 Her	DB 2	24 000	28 000	7.84	10.8	9.95	43.6
	GD 358			27 000				
1654+160	V824 Her	DB 2	28 500	26 000			0.65	113.2*
	PG 1654+160			25 000				
		WD_B3						
0100−060	G270-124	DB 3	19 000	25 000		10.9	5.94	37.3
	GR 513		23 000	22 000				
	BPM 70524		17 000					
	PHL 962							
0308−566	BPM 17088	DB 3	18 000	21 500		11.3	5.48	35.0
	L175-34			23 000				
0418−539	BPM 17731	DB 3	16 900	18 000		11.4	1.91	61.1
				20 000				
		WD_B3.5						
0017+136	EG 3	DB 3	13 100		8.01	11.3	1.60	63.1
	FEIGE 4		17 540					
0840+262	GR 291	DB 3	16 500	16 000		11.4	2.67	48.5
	TON 10		17 310					
0948+013	PG 0948+013	DB 2		18 000			‡	†
1445+152	PG 1445+152	DB 2		23 000			1.00	†
				19 000				
1940+374	EG 133	DB 3	15 820	17 000	7.71	11.5	3.31	39.8
	L1573-31		16 000					
2224−344	EG 153	DB 2	15 200	20 000			3.74	41.9*
	LTT 9031		19 000					
		WD_B4						
0300−013	GD 40	DBZ 4	18 000		7.85	11.4	0.87	67.3
	GR 384		13 730					
0615−591	BPM 18164	DB 4.5	15 300	14 600		11.4	4.89	34.2
	L182-61							
1333+487	GD 325	DB					4.69	33.0*
	GR 359							
1411+218	PG 1411+218	DB 4		14 000			2.97	†
1459+821	GR 393	DB 4	15 030		7.52	11.5	2.29	46.3
	G256-18							
	LP8-157							
		WD_B5						
0000−170	G226-32	DB 4	12 110	11 000	7.52	11.7	1.99	50.4
	LTT 11							
0002+729	GD 408	DB 4	13 310	13 000	7.69	11.4	2.88	38.2
	GR 305							
1129+004	BD 004234	DA					2.35	†
	L1002-16							
2147+280	GR 583	DB 4.5	14 000				‡	42.5*
	G187-27							

Table Notes. (‡) - no LWP/R spectrum available; (†) - distance not available.

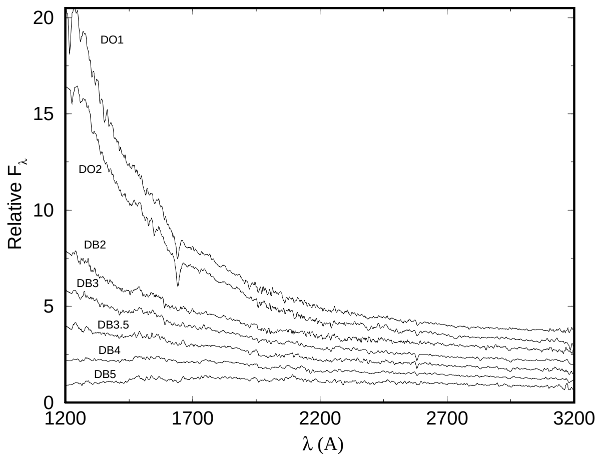

Fig. 2. The resulting templates for DO and DB stars. Notice the strong He II$_{\lambda 1640}$ in the DO templates, and the excess flux around 1430−1600 Å in the DB ones. The spectra are normalised at λ2646 Å and constants have been added to them, except for the bottom one

dwarf surface. The effective temperatures for each group were obtained by first averaging the available temperatures for each individual star and then averaging among stars in the group (Tables 1-4). Optical and UV determinations were treated separately. A similar approach was applied to derive the $\log g$ and M_V values. The intrinsic flux in Col. (9) is the average of those of the individual stars in each group, and was calculated with the observed flux in Col. (8) and distance (d) in Col. (9) in Tables 1-4, using $F_\lambda(2646) = 4\pi d^2 \times f_\lambda(2646)$, and then dividing this value by the typical white dwarf radius (Koester & Schönberner 1986) for each group.

A comparison of the optical and ultraviolet temperatures, shows that the latter are typically $\approx$ 600 K higher for DA 3 to DA 4.5, whereas for DA 5, the optical one is somewhat higher. For DB's, UV temperatures are typically $\approx$ 2000 K higher for the range DB 2 to DB 3.5, whereas for DB 4 and DB 5, the optical ones are typically $\approx$ 900 K higher.

A comparison of the M_V values for the groups in Cols. (6) and (7), shows that the mean differences are 0.10 and 0.25 respectively for DA and DB groups, in the sense that the theoretically predicted values are systematically brighter (except DA 5) than those observationally determined.

The standard deviations for temperatures in Cols. (2) and (3) of Table 5 in principle should reflect the internal dispersion of $T_{\rm eff}$ among the different stars making up the group. However, as can be seen in the tables for individual stars, the spread in temperature determinations in the optical or UV for a given star can be of the same order. Luminosities for DA and DB groups were calculated taking into account the models of Bergeron et al. (1995), using as input parameters the average $T_{\rm eff}$ and $\log g$ for each group (Table 5). For the group WD_B3, we adopted $\log g = 7.9$, which is the interpolated value from the DB groups. Luminosities for the DO groups were obtained from the models of Koester & Schönberner (1986).

4. Measurements and discussion

As shown in Figs. 1 and 2, the UV spectra of white dwarfs present few prominent spectral features. The main difference between DA's and DB's is the presence of the Lyα wing in the spectra of the former. Other characteristics appear in DA 3 to DA 5 stars, which are the wide absorption features centred at $\approx\lambda$1600 Å and λ1400 Å, which Koester et al. (1985) and Nelan & Wegner (1985) identified as, respectively, a resonance broadening of Lyα by the hydrogen quasi molecule, and a satellite line to Lyα arising from the hydrogen ion quasi molecule. Nelan & Wegner (1985) pointed out that the λ1400 Å feature appears for $T_{\rm eff}< 19\,000$ K, and the λ1600 Å for $T_{\rm eff}< 13\,500$ K. This is confirmed in our average spectra (Fig. 1) and properties (Table 5). In the DO's, a prominent line of He II$_{\lambda 1640}$ is present (Fig. 2). The most conspicuous feature in DB stars is the flux excess around 1430−1600 Å (Fig. 2). The origin of this feature is not clear, nor whether it arises from emission, or is caused by side absorptions. It also occurs in sdB stars with $T_{\rm eff}\approx 30\,000$ K, for which we also built templates from IUE spectra. This piece of evidence suggests that helium and/or other elements in common among these stars, may be responsible for the observed feature. It would be important to compute model spectra that can reproduce such features.

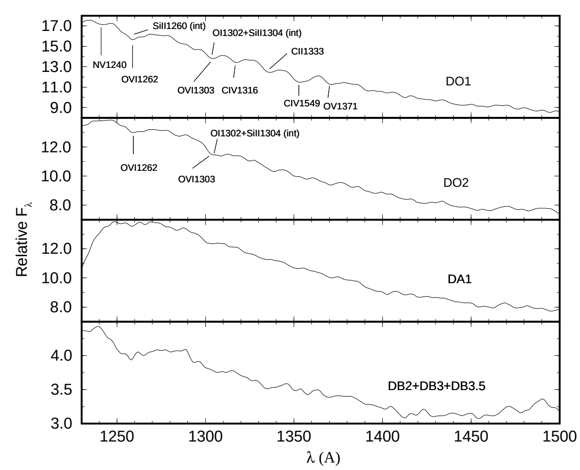

Fig. 3. Blow-up of the region 1230−1500 Å. Intrinsic absorption features are marked together with some possible interstellar absorptions

In Figs. 3-5 we present blow-ups of different spectral regions for particular templates in order to show in more detail weak absorption lines. In the DO stars, the He II$_{\lambda 1640}$ absorption line is prominent (Fig. 4), but some weaker lines are also evident, which arise from high ionization

Table 5. Properties of the white dwarf groups

Group	$T_{\rm eff}$(K) (Optical)	$T_{\rm eff}$(K) (UV)	$T_{\rm eff}$(K) (adopted)	$\log g$	M$_V$ (MS87)	M_V (theor.)	$\log(L/L_\odot)$	$10^{-9} \times F_\lambda(2646)$ (erg cm^{-2} s^{-1} Å^{-1})
WD_A1	35 862± 9 516	39 967±10 856	37 900	8.05±0.41	10.07	9.58	-0.53	5.51±4.45
WD_A2	19 446± 1 534	18 202± 1 290	18 800	7.86±0.16	10.69	10.64	-1.57	1.48±0.39
WD_A3	16 268± 743	16 133± 830	16 200	8.00±0.17	11.26	11.10	-1.97	0.64±0.75
WD_A4	14 646± 632	14 852± 682	14 750	8.06±0.28	11.35	11.35	-2.16	0.52±0.10
WD_A45	11 992± 671	12 428± 431	12 200	8.07±0.14	11.76	11.70	-2.56	0.26±0.04
WD_A5	11 669± 520	11 521± 141	11 600	8.33±0.42	11.93	12.21	-2.79	0.20±0.01
DO 1	104 000±35 777	—	104 000	≥ 7.0	8.23	—	1.50	11.3±8.74
DO 2	73 750±20 721	—	74 000	≥ 7.0	8.37	—	0.81	26.9±3.22
WD_B2	23 880± 2 945	24 750±2 964	24 300	7.96±0.16	10.88	10.40	-1.28	1.49±0.52
WD_B3	18 189± 1 393	22 000±2 598	20 100	7.90	11.21	10.50	-1.62	0.98±0.10
WD_B35	16 309± 840	17 875±1 750	17 100	7.86±0.21	11.39	10.76	-1.84	0.81±0.07
WD_B4	14 687± 839	14 300± 424	14 350	7.68±0.23	11.42	10.93	-2.06	0.66±0.09
WD_B5	13 140± 956	12 000±1 414	12 550	7.60±0.12	11.54	11.15	-2.25	0.61±0.07

species (Fig. 3) such as O VI and O V (Werner 1991); this is expected for temperatures in excess of 70 000 K (Table 5). Some interstellar absorptions may be present too, as indicated in the figures. In the LWP/R domain (Fig. 5), He II Paschen lines are present in DO stars, while in DB's, strong He I lines occur.

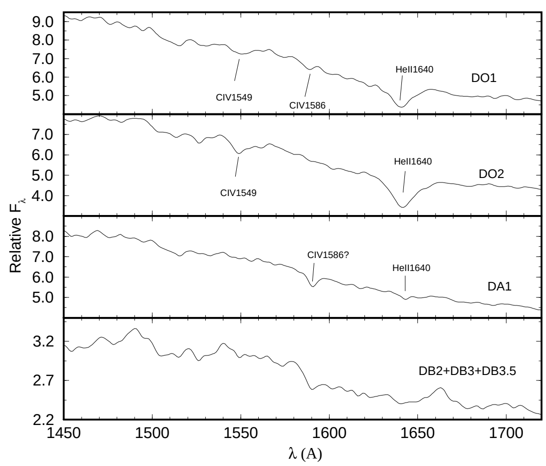

Fig. 4. Same as Fig. 3 for the region 1450−1720 Å

In Table 6 we show equivalent width measurements of the prominent features present in the templates. Since the He II$_{\lambda 1640}$ feature in DO's presents a conspicuous core and wing structure, we adopted continuum at λ1573 Å and λ1747 Å, while the spectral window for the core only, and core plus wings, are indicated in the table. We measured the excess flux at 1430−1600 Å in DB stars as an emission feature, by adopting adjacent continuum points. For the λ1400 Å and λ1600 Å absorption features in DA stars, the continuum points correspond to the window edges, as indicated in the table.

He II$_{\lambda 1640}$ is ≈ 30% stronger in the DO 2 template than in the DO 1 one. The excess at 1430−1600 Å in DB stars becomes stronger with decreasing temperature, except for the coolest group, DB 5. The λ1400 Å feature in DA stars increases with decreasing temperature, and is still detectable in the DA 2 template. The λ1600 Å feature also increases with decreasing temperature, but it is essentially absent in DA 3 or hotter groups.

We plot in Fig. 6 continuum ratios in the UV as a function of log($T_{\rm eff}$) for each group. Notice that despite the internal dispersion and/or errors in the $T_{\rm eff}$ values (as discussed in Sect. 3), the groups are well distinguished within each white dwarf class. Finally, in Table 7 we present continuum measurements relative to that at λ2646 Å. This spectral distribution, coupled to the absolute monochromatic fluxes at λ2646 Å (Table 5), can be used to scale the present white dwarf templates with respect to other stellar types, in view of stellar population syntheses.

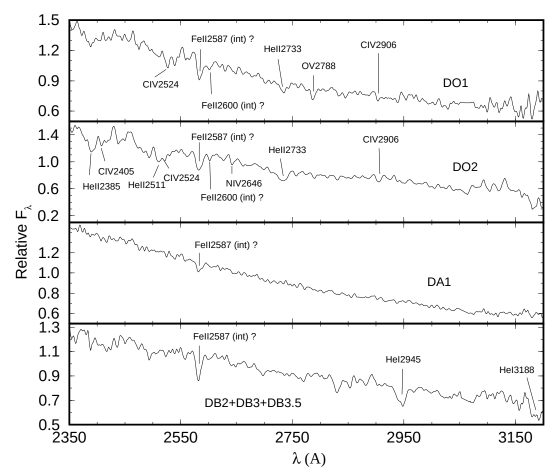

Fig. 5. Same as Fig. 3 for the region 2350−3170 Å

5. Concluding remarks

We built high (S/N) spectral templates for different classes of white dwarfs, using the IUE database. We obtained 6 groups for DA, 5 for DB and 2 for DO stars, for which we also derived average properties. We emphasise

Table 6. Equivalent widths of main features

Group	He II$_{\lambda 1640}$ 1625−1655 Å	He II$_{\lambda 1640}$ 1573−1747 Å	Excess 1430−1610 Å	λ1400 Å 1352−1430 Å	λ1600 Å 1493−1668 Å
DO 1	5.6±0.5	15.3±2.5	–	–	–
DO 2	7.8±0.5	19.1±2.5	–	–	–
WD_B2	–	–	−12.0±1.0	–	–
WD_B3	–	–	−14.0±1.0	–	–
WD_B3.5	–	–	−16.0±1.0	–	–
WD_B4	–	–	−20.7±1.0	–	–
WD_B5	–	–	−17.0±2.0	–	–
WD_A2	–	–	–	1.8±0.5	2.5±2.5
WD_A3	–	–	–	6.5±0.3	2.5±2.0
WD_A4	–	–	–	9.3±0.4	5.9±1.5
WD_A4.5	–	–	–	18.4±0.6	16.9±2.5
WD_A5	–	–	–	33.9±1.5	25.8±4.0

Table Notes. Equivalent widths are in Å; negative values indicate emission.

Table 7. Continuum measurements — C_λ/C_{2646}

λ (Å)	1242	1282	1348	1490	1587	1768	1830	2079	2123	2258	2466	2959	3122
WD_A1	14.09*	13.59	10.90	7.87	6.24	4.10	3.69	2.28	2.11	1.61	1.28	0.71	0.58
WD_A2	8.09*	7.69	6.92	5.49	4.56	3.09	2.83	1.86	1.75	1.50	1.22	0.73	0.63
WD_A3	4.73*	4.67	4.62	4.39	3.80	2.66	2.44	1.76	1.66	1.39	1.14	0.78	0.70
WD_A4	4.57*	4.57*	4.58*	4.57	3.87	2.82	2.61	1.72	1.64	1.41	1.17	0.77	0.69
WD_A4.5	1.74*	1.75*	1.77*	1.99	1.96	1.94	1.84	1.36	1.30	1.19	1.12	0.90	0.85
WD_A5	0.58*	0.66*	0.80*	1.10	1.31	1.63	1.57	1.26	1.23	1.19	1.07	0.86	0.80
DO 1	17.25	15.69	12.50	8.75	6.83	4.51	3.96	2.42	2.16	1.66	1.26	0.72	0.63
DO 2	13.82	13.03	10.25	7.57	6.00	4.09	3.61	2.12	1.89	1.52	1.25	0.70	0.58
WD_B2	5.61	5.24	4.43	3.73†/3.49‡	3.23†/3.00‡	2.47	2.30	1.61	1.56	1.33	1.13	0.75	0.65
WD_B3	4.34	4.05	3.68	3.34†/3.01‡	2.81†/2.68‡	2.34	2.18	1.69	1.60	1.40	1.15	0.79	0.73
WD_B3.5	3.00	2.87	2.60	2.53†/2.27‡	2.20†/2.11‡	1.95	1.90	1.47	1.36	1.20	1.06	0.76	0.73
WD_B4	1.72	1.76	1.69	1.85†/1.65‡	1.77†/1.62‡	1.64	1.61	1.35	1.31	1.16	1.07	0.81	0.74
WD_B5	1.00	1.06	1.07	1.32†/1.10‡	1.17†/1.16‡	1.33	1.28	1.25	1.18	1.11	1.07	0.88	0.82

Table Notes. (*) - extrapolated because of Lyα absorption wing; (†) - considering the 1430−1600 Å feature as emission; (‡) - considering the 1430−1600 Å feature as absorption. Errors are typically ±0.02, except in the extrapolated zones.

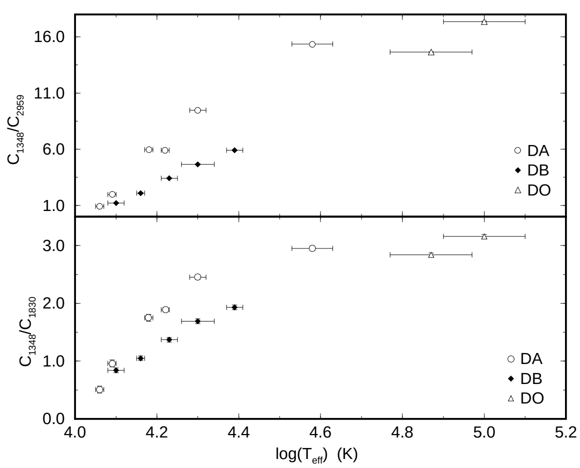

Fig. 6. Continuum ratios C_{1348}/C_{1830} and C_{1348}/C_{2959} plotted as functions of $T_{\rm eff}$

the most conspicuous spectral features in these templates which might be useful discriminators in the study of composite stellar populations. The DA templates are characterised by a strong Lyα absorption and, for some templates, by wide absorptions around λ1400 Å and λ1600 Å; the DO spectra present strong He II$_{\lambda 1640}$ absorptions; and the DB templates are characterised by an excess flux around 1430−1600 Å and by the presence of some He I lines. The DO 1, DO 2 and DA 1 templates present very steep slopes (in F_λ units) in the UV. This spectral library for the latest stages of stellar evolution will be a valuable tool in stellar population syntheses of galaxies and star clusters.

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