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The Edinburgh–Cape Blue Object Survey – III. Zone 2; galactic latitudes $-30° > b > -40°$

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ABSTRACT

The Edinburgh–Cape Blue Object Survey seeks to identify point sources with an ultraviolet excess. Results for zone 2 of the survey are presented here, covering that part of the South Galactic Cap between 30° and 40° from the Galactic plane and south of about −12°.3 of declination. Edinburgh–Cape zone 2 comprises 66 UK Schmidt Telescope fields covering about 1730 deg^2, in which we find some 892 blue objects, including 423 hot subdwarfs (∼47 per cent); 128 white dwarfs (∼14 per cent); 25 cataclysmic variables (∼3 per cent); 119 binaries (∼13 per cent), mostly composed of a hot subdwarf and a main-sequence F or G star; 66 horizontal branch stars (∼7 per cent) and 48 'star-like' extragalactic objects (∼5 per cent). A further 362 stars observed in the survey, mainly low-metallicity F- and G-type stars, are also listed. Both low-dispersion spectroscopic classification and *UBV* photometry are presented for almost all of the hot objects and either spectroscopy or photometry (or both) for the cooler ones.

Key words: surveys – stars: early-type – stars: horizontal branch – subdwarfs – white dwarfs – quasars: general.

1 INTRODUCTION

Historically – and until relatively recently – most of the astronomical observatories, and most of the astronomers, have been located in the Northern hemisphere. This has resulted in a north–south imbalance in the numbers of catalogued objects, including the 'faint blue stars'. From the earliest systematic surveys (Humason & Zwicky 1947), it was realized that these objects were not a homogenous group and that the stars were generally subluminous relative to main-sequence stars of the same colour. Among this loose grouping, we now recognize white dwarfs, horizontal branch stars, hot subdwarf stars, cataclysmic variables (CVs) and even quasars. But the earliest surveys were substantially Northern hemisphere (one cannot consider this subject without thinking immediately of the extensive work done by Luyten over decades – see Luyten 1953, 1954, 1969; Haro & Luyten 1962, as examples) and even the more recent surveys such as the Palomar–Green (PG) survey (Green, Schmidt & Liebert 1986) and the overwhelming Sloan Digital Sky Survey (Abazajian et al. 2003) have been effectively northern.

An illustration of the effect this has had on the availability of southern research material is given by the pulsating white dwarf stars. Prior to the Sloan Digital Sky Survey (SDSS), out of approximately 80 known DA pulsators (DAV or ZZ Ceti stars) only about a quarter are in the Southern hemisphere – and many of those are equatorial. This imbalance has not significantly improved with new results – see Mukadam et al. (2004) and Mullally et al. (2005). Before the Sloan survey, of the nine known DB pulsators (DBV or V777 Her stars) only one is southern – and that was discovered by the Edinburgh–Cape (EC) survey (Koen et al. 1995). Nitta et al. (2009) doubled the number of known DBV stars but naturally the new SDSS discoveries are mainly northern. Of the five known DO pulsators (DOV or GW Vir stars), only the prototype, PG 1159−034 itself, is southern – and that was found by the northern PG survey.

A principal motivation behind the EC survey was thus to correct the very evident imbalance between the numbers of hot, interesting objects known to exist in the northern and southern hemispheres; in short, we wanted more southern sources for detailed study. From the outset, it was hoped that the EC survey would prove as successful in the south as the comparable PG survey has been in the north.

In the absence of any excess of modesty, we can claim several successes for the EC survey, including the following.

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(i) Publication of a description of the survey (Stobie et al. 1997b, hereafter Paper I) together with the first EC zone – the North Galactic Cap south of declination $-12^\circ\!.5$ (Kilkenny et al. 1997b, hereafter Paper II). The latter covered about 1560 deg^2 and contained some 955 objects brighter than $B = 16.5$ mag, of which 675 were genuinely hot (comparable to OB stars in temperature) and the remainder were F- or G-type stars.

(ii) The discovery of the first rapidly pulsating sdB stars (Kilkenny et al. 1997a; Koen et al. 1997; O'Donoghue et al. 1997; Stobie et al. 1997a). This led directly to a more widespread search for sdB pulsators among the survey stars and elsewhere, resulting in the discovery of several new pulsators, including PG 1605+072, a large-amplitude, multifrequency, evolved sdB pulsator (Koen et al. 1998), and PG 1336−018, the first sdB pulsator to be found in an eclipsing binary system (Kilkenny et al. 1998b).

(iii) The discovery of a number of unusual and rare objects, including the spectacular eclipsing DA+dM binary, EC 13471−1256 (O'Donoghue et al. 2003), in which the cool companion exhibits significant flares. A new member of the class of rare AM CVn variables was found (O'Donoghue et al. 1994) as were several new members of the rare pulsating DB white dwarf stars (Koen et al. 1995; Kilkenny et al. 2009).

(iv) Studies of selected classes of object have been carried out. Chen et al. (2001) reported work on new CVs found in the EC survey and a multiwavelength study was made of EC objects with essentially featureless spectra in the optical region (Sefako et al. 1999). A study of a significant sample of low-metallicity F- and G-type stars was carried out by Beers et al. (2001) and the apparently normal B stars found in the survey were resolved into post-asymptotic giant branch (AGB) stars (Lynn et al. 2005) and normal B stars at large distances from the Galactic plane (Magee et al. 2001; Lynn et al. 2004), which were additionally used to study the interstellar medium via the Ca II K line (Smoker et al. 2003).

2 SURVEY PLAN

The EC survey plan and the methods employed were laid out in considerable detail in Paper I. However, since that paper was written, some changes have been forced on to the survey for several disparate reasons, described in this section and the next.

A significant change is that the original survey was planned to cover the whole of the southern sky which had a Galactic latitude $|b| > 30^\circ$. This would have involved obtaining nearly 400 Schmidt plate pairs covering almost 10 000 deg^2. Early in the project, it was realized that this would be a massive undertaking – and would overlap substantially with the southern edge of the existing PG survey which extends to almost $\delta = -15^\circ$. It was thus decided to limit the survey to south of declination $\delta = -12^\circ\!.3$ (plate *centres* with $\delta \le -15^\circ$), essentially eliminating zone 7 from the survey (see table 4 of Paper I) and reducing the number of fields to 318, covering slightly less than 8000 deg^2 (although seven plate pairs with plate centres $= -10^\circ$ had already been taken and the fields were included in the zone 1 results, increasing the total number of fields to 325). This revised area effectively complemented the northern PG survey with only a small overlap and was divided into zones of Galactic latitude as listed in Table 1. (A brief summary of the statistics of the EC/PG overlap region is given in Paper II.)

A second issue arose over plate measurement. Although all the *U*, *B* plate pairs required for the survey were obtained by the UK Schmidt Telescope Unit (UKSTU), it proved impossible to measure them all before the SuperCOSMOS facility was closed and the measuring machine de-commissioned, leaving us some 66 fields short of a survey. The current (and final) situation is illustrated in the schematic in Fig. 1. The solid block of completed fields between right ascension 9^h and 16^h represents the zone 1 results published in Paper II. In the South Galactic Cap (right ascensions 0^h–6^h and 19^h–24^h), many fields remain white – most of them between declinations -30° and -60°. These are almost all fields which could not be measured before the decommissioning of SuperCOSMOS, although the fields covering the Large and Small Magellanic Clouds (LMC and SMC) are also omitted because they were never intended to be part of the survey (see also Fig. 3).

Table 1. Completeness of the EC survey zones.

Zone	Galactic latitude	No. of fields	No. measured	Per cent complete
1	$b > +30^\circ$	61	61	100
2	$-40^\circ < b < -30^\circ$	66	66	100
3	$-50^\circ < b < -40^\circ$	53	53	100
4	$-60^\circ < b < -50^\circ$	52	26	50
5	$-70^\circ < b < -60^\circ$	44	24	55
6	$-90^\circ < b < -70^\circ$	49	29	59

The completed area (filled in black in Fig. 1) totals 259 fields, results for some 61 of which were already published in Paper II. The rest are distributed as shown in Table 1. Essentially, zones 2 and 3 are 100 per cent complete and zones 4–6 only between about 50 and 60 per cent complete, in the sense of the plate pairs having been reduced and lists of blue stars extracted. (The number of fields in each zone is a little different from those quoted in table 4 of Paper I – the reason for this is lost in the mists of time.)

For all fields reduced, we have obtained low-dispersion (100 Å mm^{-1}) spectroscopy for the bluest objects; *UBV* photometry has been obtained for many, but not all, of these. As things stand, it seems impossible that any more plates will be reduced and unlikely that any further photometry will be completed. It is therefore our intention to publish what material we have as quickly as possible.

3 METHODS

The survey methods were described in substantial detail in Paper I, but it is worth recapitulating the main processes and indicating where small changes have occurred. Very briefly, we have regarded the survey as composed of three phases: phase 1 – obtaining and reducing the plate material, including selecting the blue objects; phase 2 – obtaining photometry and spectroscopy for classification and to establish a uniform faint magnitude limit to the survey; and phase 3 – detailed investigation of interesting objects and classes of object. In practice, the three phases overlapped in time significantly.

In phase 1, *U* and *B* plate pairs were obtained with the UK 1.2-m Schmidt telescope at the Coonabarabran site of the Anglo-Australian Observatory. The *B* plate exposures of 15 min reached ∼20 mag and allowed separation of stars and galaxies and the *U* plate exposures of 60 min set the ∼18 mag faint limit to the survey. Plate centres were separated by 5° and the area of each plate measured was $5^\circ\!.35 \times 5^\circ\!.35$, so that some small overlap existed between all adjacent plates. Plate pairs were measured at the Royal Observatory, Edinburgh, using the COSMOS facility (MacGillivray & Stobie 1984) and, after 1995, SuperCOSMOS (Hambly et al. 2001). These measurements produced lists of blue objects ordered by a natural system photographic magnitude, $B_{\rm pg}$, together with a natural system colour, $(U - B)_{\rm pg}$. The lists of stars produced for each area were then used as the basis for phase 2, comprising

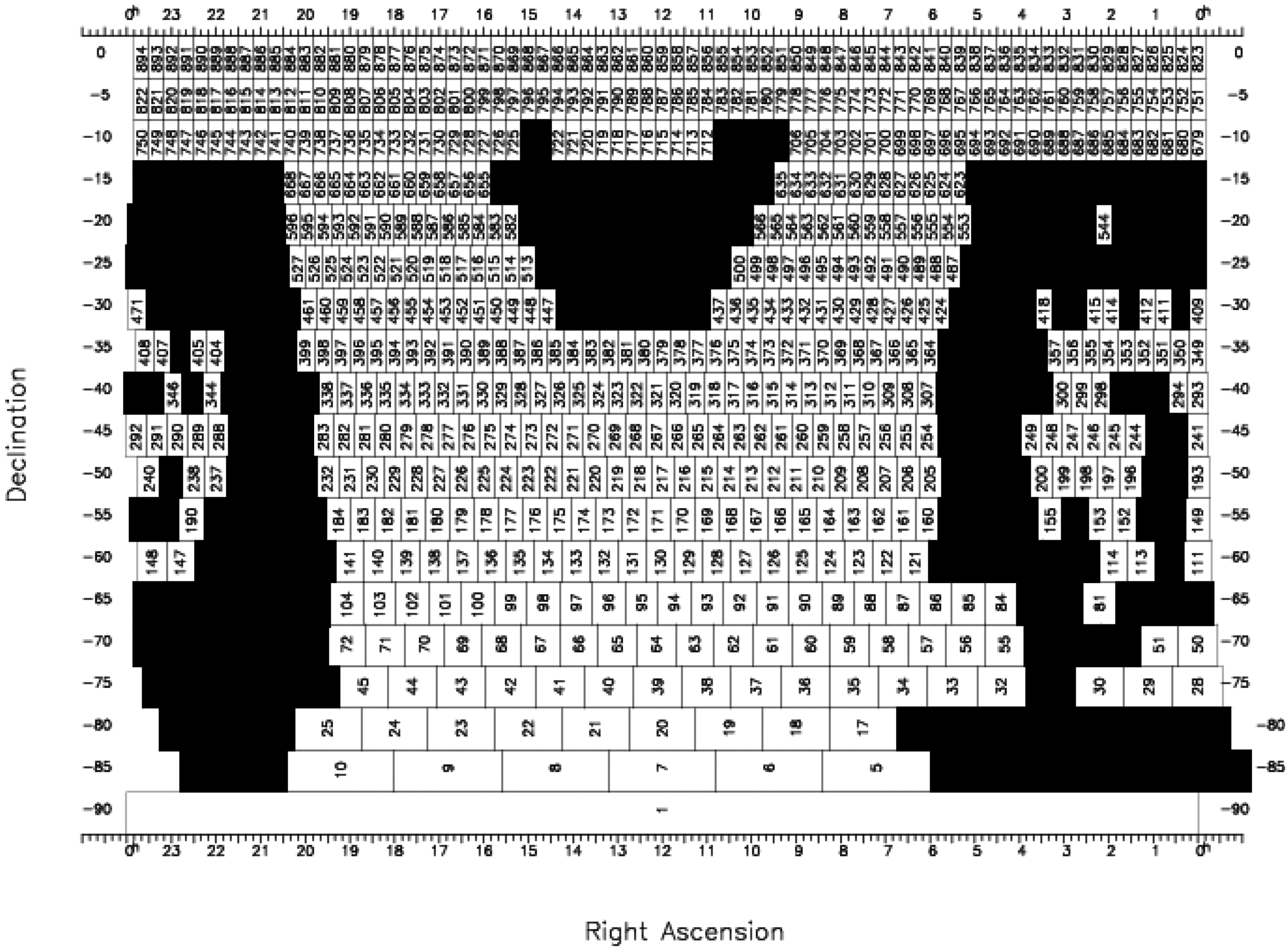

Figure 1. The EC survey: UKSTU fields actually scanned and reduced are black. Because this is only a schematic, the apparently large field at the south celestial pole (bottom of the figure) has the same area as the apparently tiny equatorial fields at the top. Some fields with $\delta > -15°$ were obtained before the decision was taken not to do the equatorial zone (zone 7). The holes at bottom right around fields 56 and 29 are the LMC and SMC areas, respectively, which were purposely excluded from the survey. Zone 1 is the solid area at top, centre and zone 7 would have extended the Galactic Caps to the equator. The South Galactic Pole is in UKSTU area 411.

a single photoelectric *UBV* measurement and low-dispersion (100 Å mm^{-1}) spectrogram for each blue object down to a consistent limiting magnitude of $B = 16.5$, carried out at the South African Astronomical Observatory (SAAO). Results from some of the phase 3 programmes have already been briefly noted in Section 1.

A change in the method of blue object selection (from the reduced photographic material) was made with the switch from COSMOS to SuperCOSMOS. The original selection was made in the photographic natural system using a $B/(U - B)$ colour–magnitude plot (see fig. 2 of Paper I). A polygon, fitted by eye, was used to separate the relatively small number of very blue objects from the vast numbers of redder ones. In the more recently reduced fields, a process was used of selecting objects starting with the bluest and proceeding redwards until a sharp increase in numbers was detected – effectively the onset of systematic detection of F- and G-type field stars. At the phase 2 stage – obtaining photometry and spectroscopy of the blue objects – we started observing each area at the brightest objects and progressed until the first object with B fainter than 16.5 mag was reached. Simultaneously, we observed the (photographically) bluest objects first and progressed towards redder objects until we began to detect FG-type stars – still somewhat blue because of varying degrees of low metallicity. In practice, because the photometry and spectroscopy proceeded in parallel, the FG stars could be detected by either photometry or spectroscopy and were not then observed further. The process is illustrated in Fig. 2 for UKSTU field 11. Although slightly different from the original method of selecting the blue objects, because we are moving from the bluest targets to FG stars by both methods, we should be collecting all the hot objects. Of course, blue objects could still be missed because of errors in the photographic photometry but that will affect both methods (for a substantial discussion of these errors, see Paper I and O'Donoghue et al. 1993).

A significant change in instrumentation occurred in early 1997, when the Reticon photon-counting system on the SAAO Cassegrain spectrograph was replaced with a SITe 1798 × 266 CCD detector. Although the latter gave some improvement in quantum efficiency and has required a shift to a totally different reduction software (IRAF; Tody 1993), other parameters in the spectrograph remained the same (grating 6, giving a wavelength range of about 3600–5400 Å at a dispersion of 100 Å mm^{-1} and a resolution ∼3.5 Å) so that the output spectra are very similar to those from the

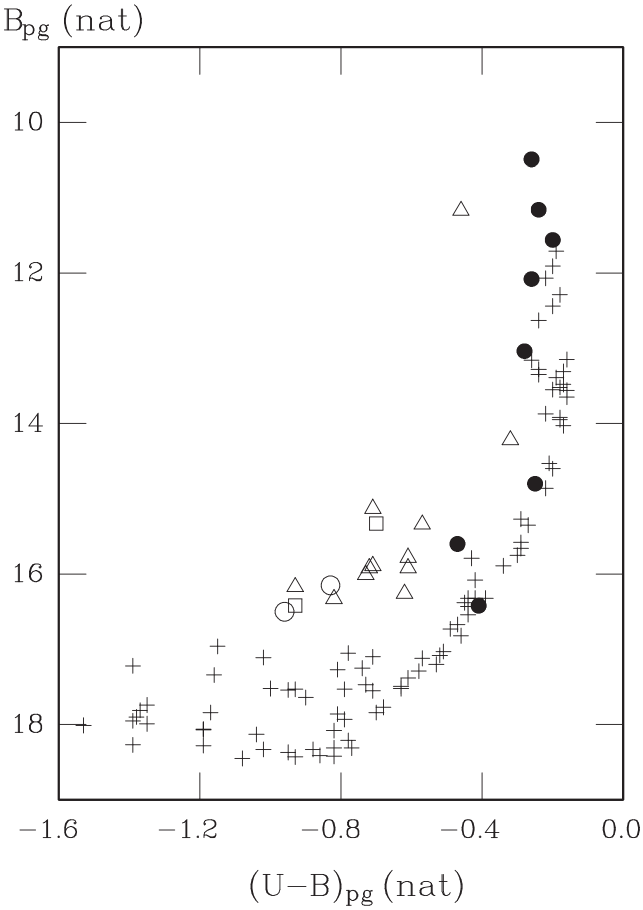

Figure 2. Blue object observations in UKSTU field 11 (as an example). The natural system photographic $B/(U-B)$ colour–magnitude diagram is plotted. Starting from the brightest objects and working towards fainter and redder objects, the red limit is set by the detection of FG stars (•) and the faint limit is set by the detection of the first star with a photoelectric B magnitude fainter than 16.5 mag. In this particular field, hot subdwarfs (△), white dwarfs (□) and AGN (◯) are found down to the $B = 16.5$ limit. The other objects (+) remain unclassified but, brighter than $B = 16.5$, are most probably F- and G-type stars.

Reticon and the spectral classification process should be essentially unaffected.

4 ZONE 2

As noted in Section 2, the survey is limited to plate centres south of declination $\delta = -15^\circ$ and thus to a northern declination limit of about $\delta = -12\overset{\circ}{.}3$. Zone 2 is additionally defined by selecting UKSTU field centres with Galactic latitudes in the range $-30^\circ < b < -40^\circ$. Because the fundamental planes of the equatorial and Galactic spherical coordinate systems are not coincident and because photographic plates are square and the sky is not, the area defined by our zone 2 has a rather ragged appearance – as illustrated schematically in Fig. 3. A full list of the UKSTU fields covered by zone 2 is given in Table 2.

The area of each field measured is about $5\overset{\circ}{.}35 \times 5\overset{\circ}{.}35$, but the field centres are 5° apart so that there is a small overlap between adjacent fields. This also means that at the edge of a zone, each field extends a little further than the nominal $2\overset{\circ}{.}5$ from the plate centre.

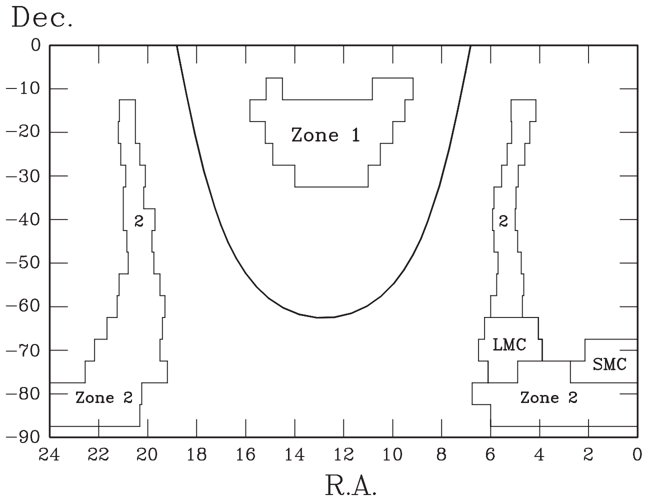

Figure 3. The EC survey: schematic of zones 1 and 2. The solid curved line indicates the Galactic equator. The areas around the LMC and SMC were explicitly excluded from the survey.

Table 2. The EC survey – zone 2 UKSTU fields.

Field centres (declination)	UKSTU fields (west)	UKSTU fields (east)
−15°	620–622	669, 670
−20°	551, 552	597, 598
−25°	485, 486	528, 529
−30°	422, 423	462, 463
−35°	362, 363	400, 401
−40°	305, 306	339–341
−45°	252, 253	284, 285
−50°	203, 204	233, 234
−55°	158, 159	185–187
−60°	119, 120	142–144
−65°	– (LMC)	105–107
−70°	– (LMC)	73–75
−75°	31, 32	46–48
−80°	12–16	26, 27
−85°	2–4	11

Allowing for this, we estimate that the 66 fields of zone 2 cover about 1730 deg^2.

5 RESULTS

A sample of the results from the EC survey, zone 2, is given in Tables 3 and 4 (the full results are only available on-line); Table 3 lists the genuinely hot objects and Table 4 the cooler objects – mostly F- and G-type stars. The latter might still be of interest if they are substantially metal weak – see e.g. Beers et al. (2001). The zone 2 tables contain the EC Survey object number, derived from the *truncated* 1950.0 coordinates in the format EChhmm.m-ddmm; 1950.0 coordinates; the date of the photometric observations (day/month/year); V, $(B-V)$ and $(U-B)$ data; a spectral type – where these exist; and any relevant comments. Some explanatory notes are given below.

5.1 Equatorial coordinates

The 1950.0 equatorial coordinates are determined from COSMOS and SuperCOSMOS measurements and have been quoted as

Table 3. Hot objects in zone 2 of the EC survey. This is a small sample of the data; the full table is only available on-line.

EC	α_{1950}	δ_{1950}	Date	V	$(B-V)$	$(U-B)$	Sp. type	Comments
00048−8631	0 04 49.6	−86 31 08	20/12/93	16.10	−0.15	−0.69	sdB(+F?)	JL 159; hsp
00276−7751	0 27 40.3	−77 51 55		15.83	−0.08	−0.92	DB	JL 190; hsp
00311−8215	0 31 10.6	−82 15 56	18/08/92	15.42	−0.18	−0.89	sdB/sdOB	
			01/11/94	15.32	−0.12	−1.00		
00325−7921	0 32 33.6	−79 21 52		14.94	+0.49	−0.82	AGN	6dFGS (Seyfert 1)
00342−7836	0 34 14.9	−78 36 55		16.77	+0.44	+0.12	AGN	Variable ?
				16.08	+0.46	−0.79		
00392−7922	0 39 15.7	−79 22 41	01/11/94	15.83	−0.29	−0.91	sdB	JL 204; hsp
00538−8121	0 53 50.2	−81 21 00	01/11/94	15.14	+0.28	−0.55	F5+sd?	Colours suggest binary
00539−8141	0 53 58.9	−81 41 41	01/11/94	15.15	+0.31	−0.64	sdB+F	
00573−7833	0 57 18.8	−78 33 50	01/11/94	15.55	−0.10	−1.08	sdOB	
01077−8047	1 07 42.6	−80 47 24	09/09/93	14.47	+0.50	−0.37	DA	
01112−8312	1 11 14.3	−83 12 43	27/09/00	16.66	−0.08	−0.87	DA	
01176−8233	1 17 37.0	−82 33 50		16.43	+0.16	−0.61	DA	
01200−8024	1 20 03.1	−80 24 30		15.99	−0.03	−0.38	B7/HBB	
01258−7842	1 25 52.8	−78 42 00		16.30	+0.00	−0.91	sdB+F	
01314−8544	1 31 28.2	−85 44 41	20/12/93	15.63	−0.10	−0.80	sdB	
			12/09/94	15.76	−0.28	−0.83		
01403−8340	1 40 19.0	−83 40 43	20/12/93	15.79	+0.27	−0.51	sdB+F	
01512−7726	1 51 12.2	−77 26 12		16.43	−0.12	−0.48	HBB	
02016−8122	2 01 40.7	−81 22 53	18/12/92	15.69	+0.00	−0.65	HBB/B5	hsp
			01/11/94	15.81	−0.05	−0.72		
02172−8410	2 17 15.0	−84 10 15		15.99	+0.00	−0.76	DA	
02268−8053	2 26 50.3	−80 53 33	18/12/92	15.20	−0.16	−0.97	sdB	
			01/11/94	15.28	−0.22	−0.97		
02322−7951	2 32 16.1	−79 51 25	19/12/92	16.17	−0.01	−0.50	DA	hsp
02344−7347	2 34 24.9	−73 47 06	12/11/93	15.54	−0.03	−0.94	CV	DI 1290; Hβ e
02396−8215	2 39 40.8	−82 15 51	25/08/00	16.72	−0.01	−0.84	sdBe	Hβ filled
02428−7229	2 42 53.3	−72 29 28	27/08/00	15.80	+0.46	−0.83	AGN	6dFGS (Seyfert 1)

Table 4. Late-type stars in zone 2 of the EC survey. This is a small sample of the data; the full table is only available on-line.

EC	α_{1950}	δ_{1950}	Date	V	$(B-V)$	$(U-B)$	Sp. type	Comments
00008−8250	0 00 51.2	−82 50 28	12/09/94	14.39	+0.89	+0.47		
00341−7725	0 34 07.4	−77 25 53	09/09/93	13.50	+0.54	−0.09	F6	
00347−7711	0 34 44.0	−77 11 28	01/11/94	14.54	+0.54	−0.06	F7	
00354−8055	0 35 28.2	−80 55 05		15.85	+0.75	+0.10	G8/K	
00433−7718	0 43 19.4	−77 18 19		15.27	+0.57	+0.04	F8	
01181−7826	1 18 10.5	−78 26 49	09/09/93	13.66	+0.52	−0.10	F6	
01508−8339	1 50 53.1	−83 39 33	27/08/00	15.89	+0.58	+0.02		
02023−7847	2 02 18.5	−78 47 10	18/12/92	14.19	+0.49	−0.17	F1	
02269−8626	2 26 58.9	−86 26 57	09/09/93	13.26	+0.48	−0.10		
02448−8535	2 44 50.4	−85 35 43	18/01/02	11.49	+0.47	+0.01	AF	
02520−8542	2 52 03.9	−85 42 41	18/01/02	11.25	+0.43	+0.03	A	
02555−7338	2 55 35.6	−73 38 14	12/11/93	14.89:	+0.78:	+0.36:		DI 1378
03144−8556	3 14 28.3	−85 56 17		11.93			AF	TX Oct (Algol-type EB)
03298−8239	3 29 48.8	−82 39 16		15.39	+0.61	−0.11	F9	
03327−7908	3 32 44.8	−79 08 09		~14.2			G3	
03330−7735	3 33 01.4	−77 35 14	11/08/93	14.94	+0.68	+0.11	G0	Poor spectrogram
03439−7214	3 43 54.8	−72 14 41		~13.0			F5	
03450−7213	3 45 01.1	−72 13 34		~13.1			G1	
03460−7231	3 46 04.3	−72 31 17	24/08/00	12.50	+0.53	+0.03	F6	

accurate to an arcsecond (Paper I) based on experience with the measuring systems. As a brief check, we have here compared the coordinates measured on different plates for the same star – this occurs for a few stars because of the small field overlap. (Occasionally a star was measured in three fields; this results in three measurement comparisons.) The mean differences are listed in Table 5 which indicate that a mean coordinate error of 1 arcsec is a conservative estimate.

5.2 *UBV* photometry

The photoelectric *UBV* photometry was obtained with the 0.75-m and 1-m telescopes (mainly the latter) at the Sutherland site of the South African Astronomical Observatory. All data were reduced to the Cousins' E-region system (as listed by Menzies et al. 1989) and the blue extension of Kilkenny et al. (1998a); the latter being required because of the paucity of very blue E-region standards. On

Table 5. Mean coordinate differences and standard deviations from stars measured on two or more plates. '*n*' is the number of comparisons in the mean.

Declination zones	$\overline{\lvert\Delta\alpha\rvert}$ (arcsec)	σ_α	$\overline{\lvert\Delta\delta\rvert}$ (arcsec)	σ_δ	*n*
−90° to −80°	0.6	±0.4	0.6	±0.9	34
−80° to −70°	1.1	±0.8	0.5	±0.7	19
−70° to −60°	0.5	±0.4	0.8	±1.0	14
−60° to −50°	0.4	±0.5	0.6	±0.9	16
−50° to −40°	1.0	±0.7	1.2	±1.4	10
−40° to −30°	0.3	±0.5	0.8	±1.1	4
−30° to −20°	0.4	±0.6	1.7	±1.7	3
−10° to −20°	1.2	±1.4	0.3	±0.5	7

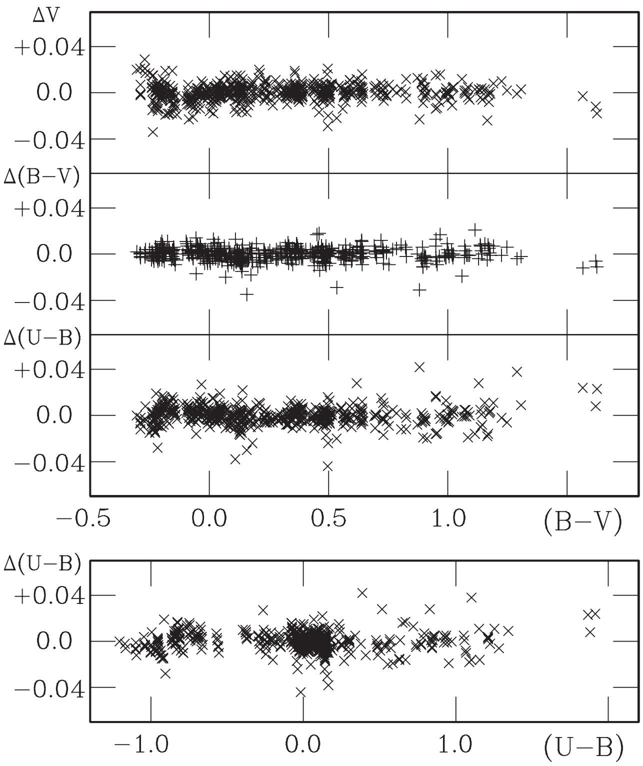

Figure 4. Residuals for the standards used in the EC *UBV* photometry obtained in 2000–2002. The differences (Δ) are standard *minus* observed, where the standards are from Menzies et al. (1989) or Kilkenny et al. (1998a). The blue standards are separated from the E-region standards near $(U - B) = -0.5$ and $(B - V) = -0.1$.

a full night, typically 15–20 standards might be observed; on part nights, usually fewer, depending on the available clear time. Colour equations were determined from several months of standard star observations – generally one observing season. Standards on each night were used to define the zero-points (which were allowed to vary in time) and to check the atmospheric extinction coefficients. Mean values for the latter were used unless different values were obviously indicated on a particular night. More details on the SAAO photometry reduction process are given in the appendix of Kilkenny et al. (1998a).

Fig. 4 shows the residuals for the standards, including the blue extension stars, for photometry obtained during 2000–2002 – the last of the EC photometry. The residuals for the blue extension

Table 6. Residuals for the EC *UBV* photometry of the blue extension stars observed in 2000–2001. The differences (Δ) are Kilkenny et al. (1998a) *minus* observed.

Star	$(U - B)$	ΔV	$\Delta(B - V)$	$\Delta(U - B)$	*n*
CD-31 4800	−1.207	0.020	0.002	0.000	1
HD 49798	−1.173	− 0.002	− 0.002	− 0.004	2
HD 149382	−1.108	0.009	0.000	− 0.008	3
CD-28 7246S	−1.098	0.005	0.004	− 0.001	1
BD-11 162	−1.043	− 0.010	0.002	− 0.002	4
HD 177566	−1.012	− 0.003	0.000	− 0.009	2
CD-35 15910	−1.004	0.023	0.000	− 0.001	4
HD 171141	−0.977	− 0.005	− 0.002	− 0.009	3
HD 57193	−0.961	− 0.001	0.002	− 0.004	1
HD 56094	−0.956	0.007	0.000	0.000	1
HD 18100	−0.954	− 0.004	− 0.001	− 0.003	8
HD 205805	−0.945	0.010	− 0.002	− 0.012	3
CD-38 222	−0.934	− 0.009	0.001	− 0.010	4
HD 31407	−0.862	− 0.004	0.001	0.001	5
HD 217505	−0.840	0.003	0.000	0.002	9
HD 220172	−0.834	0.005	0.004	0.005	1
HD 192273	−0.828	− 0.002	0.008	0.007	3
HD 188112	−0.813	0.002	0.003	− 0.008	1
HD 209684	−0.810	− 0.001	0.001	0.008	10
CD-44 1028	−0.799	− 0.002	− 0.003	− 0.009	3
HD 61193	−0.755	0.004	0.000	0.012	1
CD-33 2585	−0.751	0.003	0.002	0.009	3
HD 49260	−0.732	− 0.003	− 0.001	0.012	3
HD 173994	−0.708	− 0.010	0.000	0.005	2
CD-41 14294	−0.700	0.001	0.000	0.003	6
HD 171940	−0.687	− 0.009	0.003	0.004	3
HD 36733	−0.663	− 0.007	0.002	0.004	7

standards are also listed in Table 6 as a function of (standard) $(U - B)$ colour. It seems reasonable to assert that there should be no *systematic* errors greater than about 0.01 mag in any of *V*, $(B - V)$ or $(U - B)$.

In Paper II (the EC zone 1 results), the blue extension to the photoelectric *UBV* photometry was based on blue star photometry by Menzies et al. (1989). However, Kilkenny et al. (1998a) showed that there were small differences between the Menzies et al. (1989) photometry and later results. We have therefore corrected all the pre-1995 data in Table 3 according to the formulae given in sections 6 and 7 of Kilkenny et al. (1998a). Actually, since the corrections are significant only for the bluest stars, for most of the Table 3 objects (and all of the Table 4 stars), the corrections were zero. The post-1998 photometric results were already standardized at the blue end to the Kilkenny et al. (1998a) results. Note that the Paper II data will still contain these small systematic errors in the bluest stars (though these are, at worst, only +0.03 mag in *V*, −0.01 in $(B - V)$ and −0.02 in $(U - B)$ for the bluest objects).

Because of the unintentionally long time that this project has been underway, we have managed to lose some of the original photometric data from several nights. Since we are not in a position to repeat these observations, we have taken the data from our working logs which record preliminary on-line results. These were reduced at the telescope with appropriate colour equations but with mean extinction values. The latter are perfectly adequate for most nights but will not be correct on nights with higher extinction (this effect is mitigated by our strong tendency to observe near the meridian). Additionally, the on-line results have a fixed zero-point and so are not corrected for any nightly zero-point drifts. Nonetheless, they are better than no data at all, and some spot checks of results where we have both preliminary and final data, indicate that the vast majority of differences between these results are in the range 0.00–0.03 mag. However, occasionally larger residuals do occur, so that these preliminary data should be treated with appropriate caution. In the tables, such photometric data are indicated by the absence of a date of observation.

Where we have no photometry at all (with one exception, this applies only to the Table 4 stars), we have used SIMBAD to search for published *V* magnitudes and have included these in the tables, often with an indication of the source in the 'comments' column. (Note, however, that this might not be the original source, given that the SIMBAD data base is a compilation). If there is no magnitude to be found in the literature, we have estimated a magnitude from the photographic photometry. These estimates are indicated with a tilde (∼) in the tables and should be regarded as very rough; partly due to the inherent inaccuracy in photographic data and partly due to the fact that we cannot generally apply colour equations to these results.

5.3 Spectral types

As far as possible, we have obtained low-dispersion (100 Å mm^{-1}) spectrograms for all objects – with the particular exception of objects which appear to be F-type or later from the *UBV* photometry. Spectrograms were obtained with grating 6 (coverage about 3600–5400 Å and resolution ∼3.5 Å) in the Unit Spectrograph on the 1.9-m telescope at the Sutherland site of the SAAO. In the early days of the survey, the spectrograph was equipped with a Reticon detector but since about 1997 has used a CCD detector. Figs 9–14 in Paper I give examples of some of the Reticon spectra. In a few cases, particularly with poor signal-to-noise ratio (S/N) and/or spectra which appear to show no features in the grating 6 spectrograms, we have also obtained grating 7 data (210 Å mm^{-1}, with a coverage of about 3600–7200 Å and resolution of ∼7 Å).

Paper I also describes the basis of our classification process – which we have tried to maintain in this paper. In brief, we have used the scheme proposed by Moehler et al. (1990) for the hot subdwarf stars. These are usually obvious by their relatively broad (high-gravity) spectral lines: sdB types show hydrogen and weak (or no) He I; sdOB stars have hydrogen and weak He I *and* He II; and sdO stars show hydrogen and He II. In addition, the helium-rich subdwarfs are typified by having no (or very weak) hydrogen: He-sdB stars are indicated by strong He I and perhaps weak He II; He-sdO types typically have strong He II and weak He I (if Balmer series lines were present, they would be blended with He II features). A blue horizontal branch (HBB) type is indicated by moderately strong H lines and weak He I (4471) and perhaps Mg II (4481). We have often found it difficult to decide whether a star should be classified as a normal B star or an HBB (and it is sometimes hard, when classifying, to fight off the prejudice that normal B stars should be much less likely in high-latitude surveys). Poor S/N of the spectrograms compounds this problem – and sometimes results in a classification of the type Bn/HBB (or HBB/Bn), when we cannot decide.

Our spectra extend to well below the Balmer discontinuity and that has been a useful classification indicator. In the hot subdwarfs, the Balmer lines are typically seen only to about $n = 10$–12, whereas in normal B stars, they are often visible to $n = 13$–14 (depending, of course, on the S/N of the spectrograms). The HBB stars might have even more lines visible; the white dwarfs will have far fewer visible lines, typically only to $n = 8$.

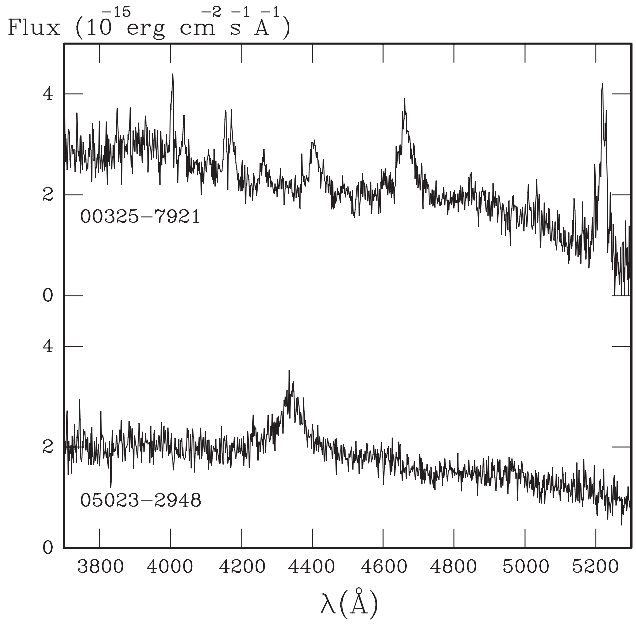

Figure 5. Example spectrograms of objects classified 'AGN'. The upper object, EC 00325−7921, clearly shows redshifted Balmer series – at least Hβ to Hϵ can be identified. The lower object, EC 05023−2948, only shows one obvious feature which is thus unidentified. [Note that the ordinate scale (flux) is approximately correct in a relative sense, though more inaccurate in absolute terms because these are slit spectrograms in the blue, obtained in a system with no atmospheric dispersion corrector.]

White dwarf stars are generally easy to classify because of their very broad spectral features (due to high gravity). We have followed the scheme described by Sion et al. (1983) with the well-known types (DA, DB and so on).

Resolved extragalactic objects were deliberately excluded from the survey using a surface brightness criterion (see Paper I). However, a number of point source extragalactic objects have wriggled through this filter. Following Paper II, we have classified these into two groups, based on their general spectral appearance – 'AGN' for objects which show significant continuum flux and broad, usually strong, emission features (see Fig. 5)–and 'eGal' for objects which show relatively sharp emission features and often little or no continuum flux. We have also used a classification 'cont' for objects which show no clear spectral features. In some cases, these might be extragalactic objects with no emission features in the region covered by our spectrograms (∼3600–5400 Å); others might be CVs or very weak-line white dwarfs (see Fig. 6 and also Sefako et al. 1999 for other examples and a more rigorous discussion). Poor S/N spectrograms obviously compound classification problems for these objects and the classification 'cont' is not uniform in the sense that we label objects as such if they have no features stronger that a certain percentage of the continuum; rather the classification will depend on the S/N of an individual spectrogram.

Cataclysmic variables (generally, objects with strong, non-redshifted emission lines) have simply been classified 'CV' without any attempt to subdivide, though sometimes we attach a modifying comment in the final column of Table 3.

Apparently normal B, A, F and G stars have been classified by comparison with high S/N spectrograms of bright stars with well-determined spectral types. We have not attempted luminosity classification. It is very likely that some, if not most, of the 'normal'

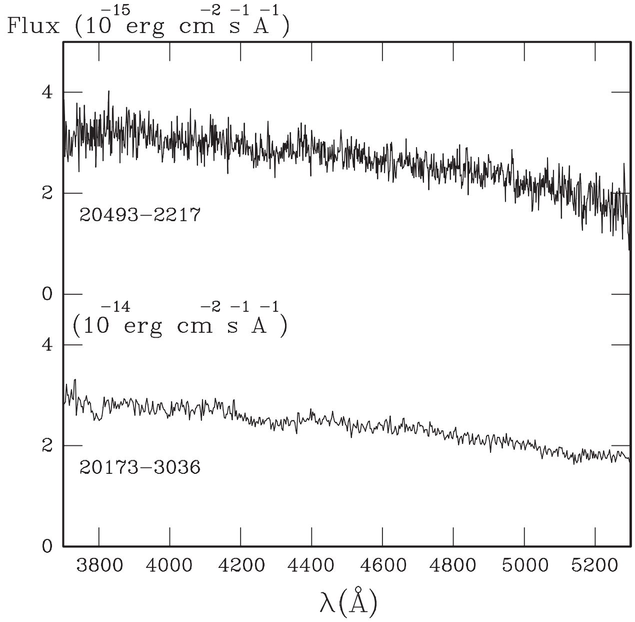

Figure 6. Example spectrograms of objects classified 'cont'. In the lower spectrogram of EC 20173−3036, a relatively bright object at $V \sim 13.7$, it is fairly easy to see that there are not really any significant features in the spectral region covered. In the upper spectrogram of EC 20493−2217, still not particularly faint at $V \sim 15.1$, weak features might well be hidden in the noise. Comments on the ordinate scale are as for Fig. 5.

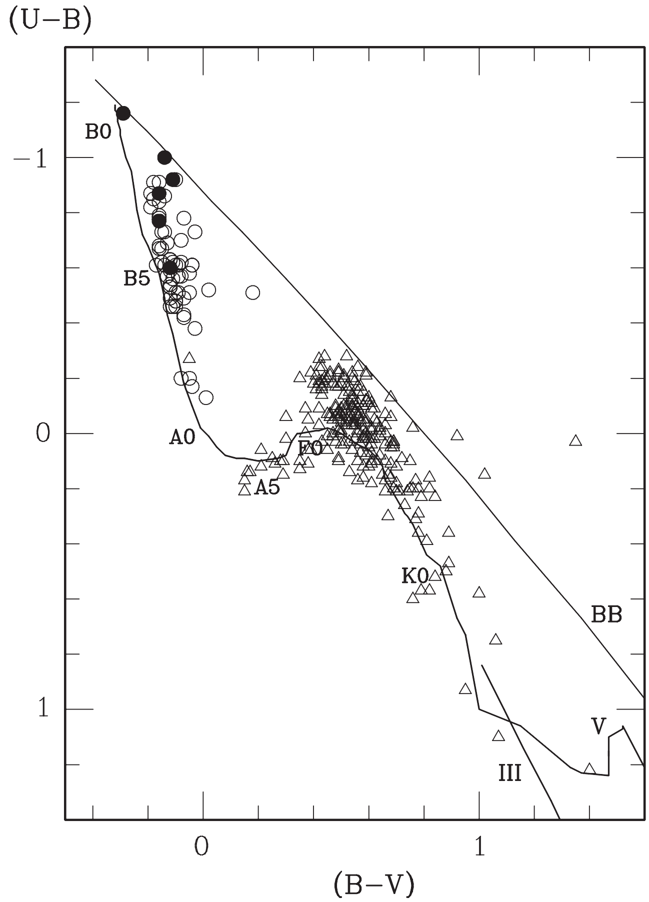

Figure 7. Two-colour diagram for apparently normal stars. Open circles (○) represent B stars; filled circles (•) represent B stars which appear to be significantly helium rich or hydrogen deficient; open triangles (△) represent stars of type ~mid-A and later. The intrinsic colour lines are from FitzGerald (1970) and the blackbody (BB) line from Straizys, Sudzius & Kuriliene (1976). The approximate locations on the intrinsic colour line of a few typical main-sequence types are indicated.

F- and G-type stars picked up by the survey will be somewhat metal deficient [note the obvious $(U - B)$ 'excess' for many of these stars in Fig. 7]; this could certainly lead to classification errors using the methods described below.

Composite spectral types have generally been given to objects which show features which are extremely unlikely to arise from a single object. Common among our types are (for example) 'sdB+F' which will usually denote a spectrum which appears to be an sdB star but which also shows the Ca II K line and perhaps other late-type features – the *G* band is not uncommon. A type 'F+sd' would be given to an F star which had evidence of He I lines.

We note that the spectrograms obtained for the EC survey are sometimes rather noisy, notably for the faintest stars observed. A good fraction of the work was done with a Reticon detector which had a photocathode quantum efficiency, rather than that of a CCD. For classification, therefore, we generally relied on strong spectral features – the growth of the Ca II K line in progressively cooler A stars or the *G* band in F stars, for example. As noted above, deciding between HBB and 'normal' B types was difficult (in any case, this often requires detailed spectral analysis using higher spectral resolution – see Magee et al. 2001; Lynn et al. 2004, 2005). Detecting weak He II 4686 to discriminate between sdB and sdOB types (for example) was sometimes difficult. This has resulted in classifications of the type HBB/B5 or sdB/sdOB where we cannot easily decide between two types; in such cases, the first classification should be considered the more likely.

5.4 Comments

The final column of the survey tables contains necessarily brief comments of varying nature. These fall into four main categories.

(i) Terse comments on the quality of the photometry or spectroscopy, including comments on the spectral classification – such as 'He I strong' and 'Hβ emission' – and indicating where variability might be present, for example.

(ii) Comments such as 'hsp' or '2hsp' indicate that 'high-speed' (continuous) photometry has been obtained on one or more occasions. This would be continuous photometry with a typical resolution of 10–30 s and a time base of 1–2 h. Where more than one run has been obtained these would almost always have been on different nights. Where any significant variation has been found and published, a reference is given.

(iii) References from some collaborative projects on apparently normal B stars and CVs which give additional photometry, spectroscopy or analyses (temperatures, gravities, abundances etc.). These references are abbreviated as follows: Ch01 for Chen et al. (2001); Ma98 and Ma01 for Magee et al. (1998, 2001); Ro97 for Rolleston et al. (1997) and Ly04, Ly05 for Lynn et al. 2004, 2005).

(iv) Some alternative designations are listed, including spectral types from the literature, where these are available. Dr Roy Østensen very kindly, and unasked, carried out searches of his on-line subdwarf catalogue (see Østensen 2006, for a description) and the SIMBAD data base for correspondences within 30 arcsec of our EC zone 2 catalogue positions. We also did a similar

SIMBAD search within 15 arcsec of the EC positions, obtaining similar results.

With regard to the last category, an important caveat to keep in mind is that these alternative designations are in no way complete or exhaustive. Some stars, particularly the brighter ones, can have many names, having been detected in different ground-based surveys (going back as far as the *Durchmusterungen* of the late 19th century) as well as in modern satellite surveys. The available space permits only one or two alternatives – and, in any case, the SIMBAD data base is so widely used and so catholic in scope that this is hardly a serious deficiency.

Our particular choices for alternatives might seem eclectic, even whimsical, but were decided on the basis of two main considerations: first, to select sources which contained additional information such as spectral types. These include the BPS CS stars (Beers, Preston & Schectman 1985), the 6-degree Field Galaxy Survey (6dFGS; Jones et al. 2004), the Hamburg–ESO survey (HE; Wisotzki et al. 1996, for example), the white dwarf catalogues (WD; McCook & Sion 1999 – later versions are available on-line) and the catalogues of quasars and AGN (VV; Véron-Cetty & Véron 2010, for example). We note that some of these references are compilations and often not the source of the spectral types – the HD stars in our table, for example, have MK types from the extensive work of the Michigan group (Houk 1978; Houk & Cowley 1975 etc.). Our second consideration was to select alternative designations from surveys which overlapped significantly with ours and were the original discovery sources. These include the JL stars (Jaidee & Lyngå 1969) and the DI objects found in the Magellanic Cloud bridge (Demers & Irwin 1991).

We have not generally referred to satellite data bases in the tables; there are quite a few EC objects which have been observed by *International Ultraviolet Explorer* (*IUE*), *Extreme Ultraviolet Explorer* (*EUVE*), *Galaxy Evolution Explorer* (*GALEX*) and so on, as well as many included in the ground-based Two Micron All Sky Survey (2MASS) survey, but it would be impossible to include all these in a systematic and consistent way. As it is generally the actual measurements which are important, the reader is referred to SIMBAD for these data.

Finally, we note that the correlations we have made with other sources (using SIMBAD) are generally in good positional agreement. From 256 identifications, we find that 42 per cent agree to better than 1 arcsec (the accuracy claimed for our coordinates; see Table 5) and 73 per cent to better than 2 arcsec. A few are as bad as 5 or 6 arcsec and any correspondence worse than that has been excluded from the comments column (although significant proper motion could be an issue for the nearest objects, such as white dwarf stars). A small number of EC objects are close to *ROSAT* objects (1RSX; Voges et al. 1999) but, in general, the separations are of the order 10 arcsec or more and we have not included these, although it could be that for an extended object the X-rays come from a different region than the optical radiation. Again, the scrupulous reader should check SIMBAD for such coincidences.

6 TWO-COLOUR DIAGRAMS

In a similar fashion to the zone 1 results (our Paper II), we present two-colour diagrams for the principal classes of objects found in zone 2. Since most of the photometry presented here is only a single observation per target, estimating the errors is not easy. In Paper I, from a small number of objects with more than one observation, typical errors were estimated to vary from about 1 per cent for the brightest stars ($V < 13.5$) to about 5 per cent for the faintest ($V > 16.5$) – see table 2 of Paper I.

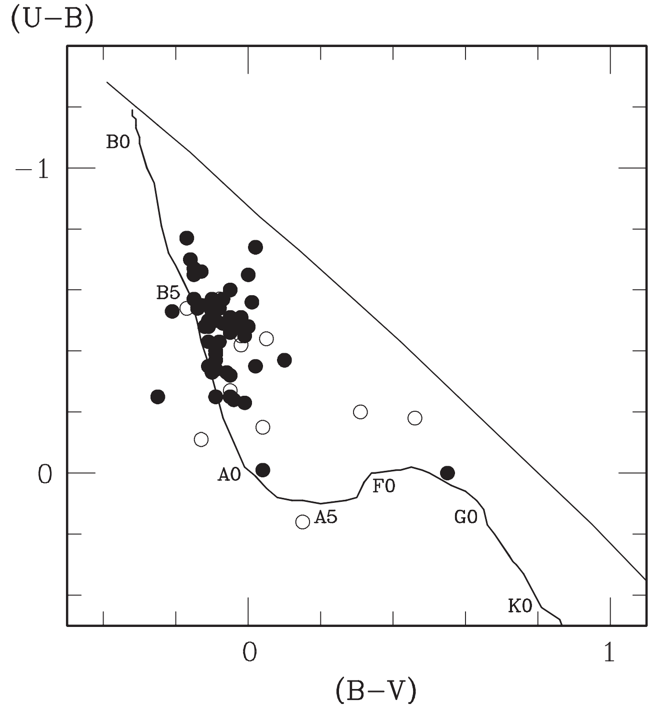

Figure 8. Two-colour diagram for horizontal branch stars. Filled circles represent stars classified HBB and open circles represent stars classified HBA. The intrinsic colour and blackbody lines are as for Fig. 7, though the scale and range of this figure are different.

Fig. 7 shows the apparently normal stars – those classified B, A, F or even later types, and including objects classified B/HBB and similar, as long as the 'normal' classification is the first. As noted in Paper II, the F- and G-type stars were probably included in the survey as the long 'tail' in the error distribution of the photographic photometry and show the classical distribution of late-type subdwarfs – extending well above the intrinsic colour line as a result of varying metal deficiency – see e.g. Sandage & Luyten (1969). Although initially regarded as contamination of the main survey, these stars have proved a useful source of low-metallicity stars (Beers et al. 2001).

The early-type stars which look normal spectroscopically, also look photometrically like slightly (or very slightly) reddened B stars with equivalent spectral types ∼B1–B9. As noted above, at the dispersion and S/N of our spectra, it is very difficult to distinguish between normal B stars and some horizontal branch stars.

The helium-rich stars – among the bluest of the B star sample – are not hydrogen deficient in the sense of the extreme helium stars but show significantly stronger He I lines than normal.

Fig. 8 plots the horizontal branch stars. The HBB stars appear photometrically the same as B stars and, as noted above, are often difficult to distinguish spectroscopically.

Figs 9 and 10 show the sdB and sdO/sdOB stars, respectively. The He-sdB stars all lie among the hottest of the sdB stars which – as with zone 1 – dominate the zone 2 sample. The sdO stars of all types are also unsurprisingly very blue. A few stars in both the sdB and sdO samples are rather redder than might be expected and are probably unrecognized binaries.

Fig. 11 plots the stars with obviously composite spectra – presumably binary systems. We have divided these into systems where

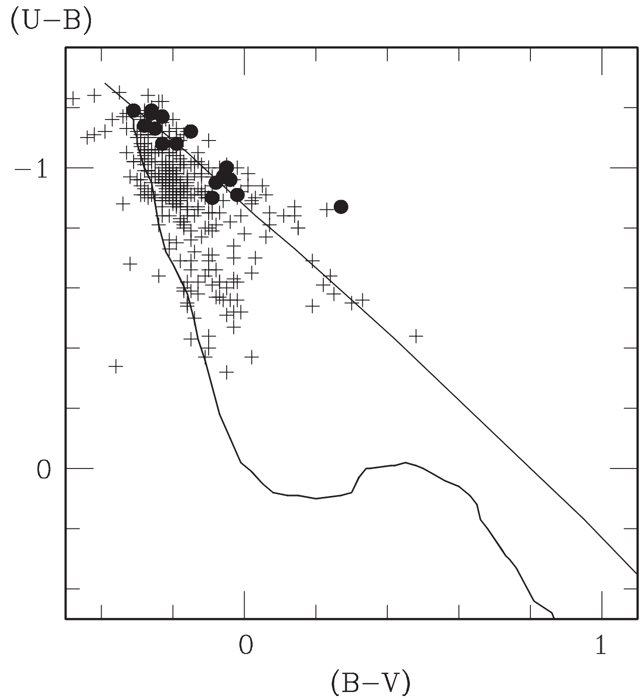

Figure 9. Two-colour diagram for sdB stars. Crosses represent stars classified sdB and filled circles represent stars classified He-sdB. The intrinsic colour and blackbody lines are as Fig. 8.

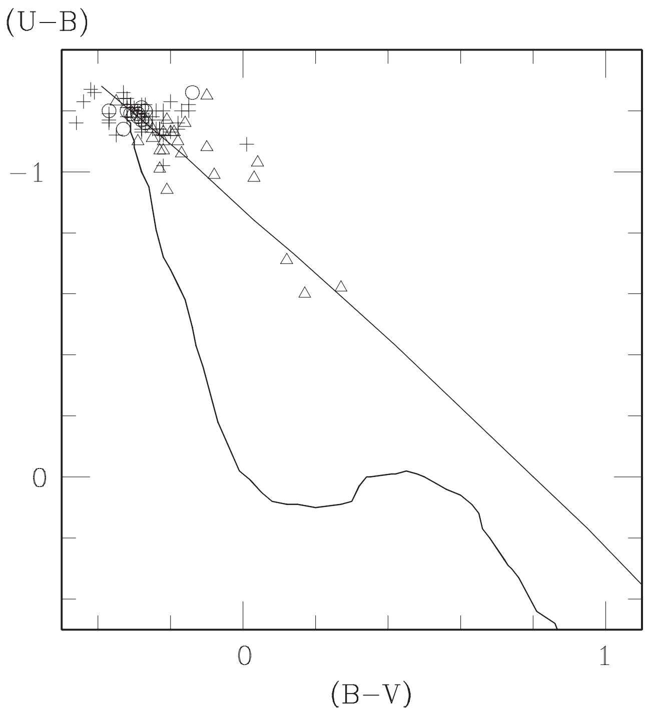

Figure 10. Two-colour diagram for sdO stars. Open circles represent stars classified sdO; crosses represent stars classified He-sdO; triangles represent stars classified sdOB. The intrinsic colour and blackbody lines are as Fig. 8.

the hot subdwarf is obvious, but late-type features are visible (Ca II K and *G* band, for example) and systems where the star appears to be of F- or G type but early-type features are present (usually He I). Clearly, the former would be expected to be bluest and this is borne

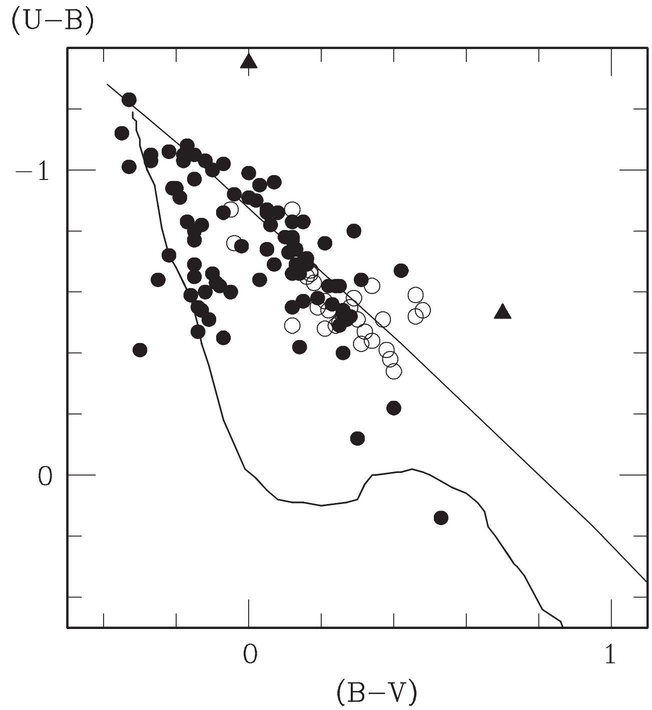

Figure 11. Two-colour diagram for composite stars. Filled circles represent classifications such as sdB+F and sdO+G, where the hot subdwarf dominates the spectrum; open circles represent stars where the cooler star dominates (F5+sd, F+sd? and so on). The filled triangles represent the DA+dM system, EC 20246−4855 and (near the top of the figure) Nova Tel 1948 (EC 20003−5552). The intrinsic colour and blackbody lines are as Fig. 8.

out by Fig. 11. It is certain that we have not detected all the binaries in the sample; the strays in Figs 9 and 10 suggest as much and, in addition, systems with a hot subdwarf and a K- or M-type companion would not be detected by us as spectroscopically binaries – and a single observation per star will not uncover eclipsing systems.

Fig. 12 plots the CV systems and white dwarf stars – with the exception of EC 05089−5933, for which the apparent colours, $(B - V) = +0.89$, $(U - B) = +0.70$, suggest strongly that the wrong star was observed photometrically! Otherwise, the presumably unreddened white dwarf stars are close to the blackbody line. Some of the CVs have odd colours as a result of strong spectral emission lines which can substantially distort the colours.

Fig. 13 shows the extragalactic objects and spectra for which we can see no obvious absorption or emission features (‘cont’). Perhaps unsurprisingly, the latter all lie close to the blackbody line whilst the AGN and eGal types mainly lie well above it but with a broad scatter of colours – again a result of the interaction of the filter transmission characteristics with the relatively strong spectral emission features which can be in different locations, depending on the redshifted velocity.

Finally, a brief summary of the statistics of the hot objects in zone 2 of the survey is given in Table 7 .

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The EC survey is based on data obtained with the UK Schmidt Telescope at the Anglo-Australian Observatory. All plate reductions were carried out by the COSMOS/SuperCOSMOS facility at the Royal Observatory, Edinburgh, and all phase 2 photoelectric and

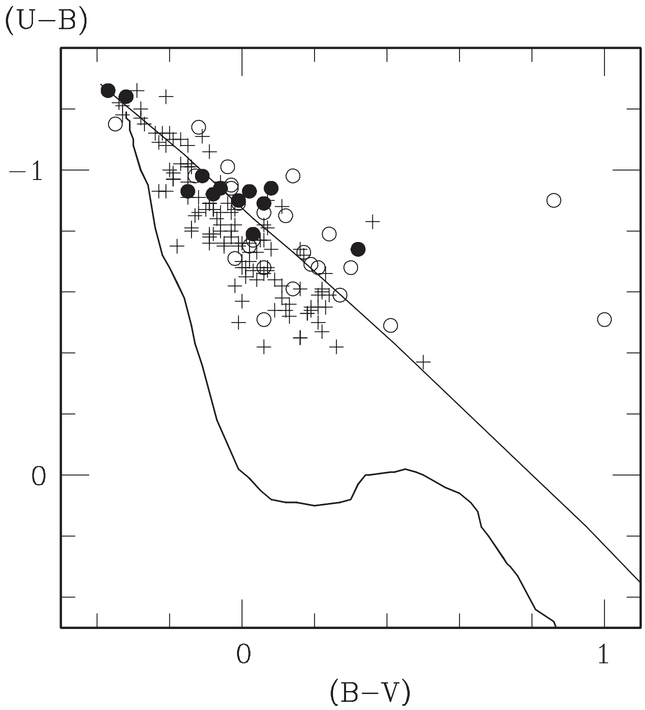

Figure 12. Two-colour diagram for white dwarf stars and CV systems (including symbiotics). Crosses represent DA stars; filled circles represent other types of white dwarf, mainly DB stars; open circles represent CV systems. The intrinsic colour and blackbody lines are as Fig. 8.

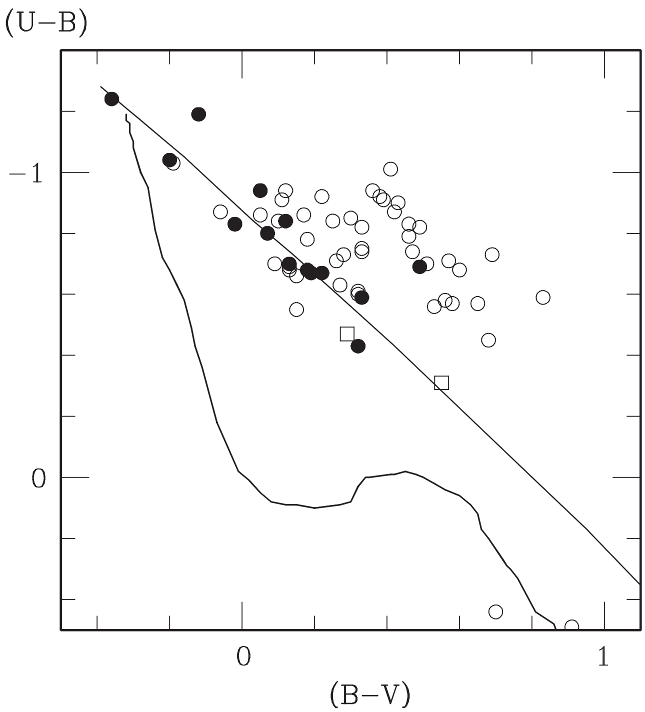

Figure 13. Two-colour diagram for extragalactic objects and for objects which show no discernible spectral features in the range of our spectrograms. Open circles represent objects we have classified 'AGN'; the two open squares represent objects we have called 'eGal'; filled circles represent our 'cont' classification. The intrinsic colour and blackbody lines are as Fig. 8.

Table 7. Numbers/percentages of hot objects in EC zone 2.

Genus	Species	*n*	Per cent
Apparently normal	B	58	6.5
	BHe	6	0.1
Horizontal branch	HBA	14	1.5
	HBB	52	5.8
Subdwarf	sdB	319	35.7
	He-sdB	16	1.7
	sdOB	26	2.9
	sdO	11	1.2
	He-sdO	51	5.7
White dwarf	DA	116	13.0
	Others	12	1.3
Cataclysmics		25	2.8
Extragalactic	AGN	46	5.1
	eGal	2	0.02
Binaries	Subdwarf+	88	9.9
	FG+	29	3.3
	Others	2	0.02
Others	Cont	14	1.5
	Unknown	5	0.06

spectroscopic data were obtained at the South African Astronomical Observatory. We are immensely grateful to those organizations for allocations of vast amounts of telescope, instrumentation and personnel time. We are grateful to Mike Read (Royal Observatory, Edinburgh) and Martin Kilkenny for making Fig. 1 possible and to Roy Østensen (KU Leuven) for searches of his hot subdwarf catalogue and the SIMBAD data base for existing correspondences to our catalogue.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Table 3. Hot objects in zone 2 of the EC survey.
Table 4. Late-type stars in zone 2 of the EC survey (http://mnras.oxfordjournals.org/lookup/suppl/doi:10.1093/mnras/stt158/-/DC1).

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