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HOT SUBLUMINOUS STARS AND BLUE OBJECTS IN THE CASE LOW-DISPERSION NORTHERN SKY SURVEY. I.

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ABSTRACT

We present the results of moderate-resolution spectrophotometry of the Case blue star lists in the Case Low-Dispersion Northern Sky Survey. The Case blue star candidates have proved to be a rich source of new subluminous hot stars with 49% of the sample being comprised of hot degenerate stars. We have identified 42 DA white dwarfs, 11 DB white dwarfs including the second known DBZ degenerate (CBS 78), two DZ-type stars, one magnetic degenerate star (CBS 128), 35 sdO, sdB, and sdOB stars, eight HBB and HBA stars, seven sdF-G stars, five cataclysmic variables including a doubled-emission line object (CBS 31) for which there is evidence for a 1.5 hr period, a dwarf nova or nova-like (CBS 132) observed in a quiescent state, and a probable long-period cataclysmic variable (CW 1045+525) in which the secondary star is visible in the spectrum, a composite spectrum object (CBS 47), and 20 quasars and active galactic nuclei. The scientific objectives of our survey are discussed and preliminary abundance information, surface temperatures, and gravities are provided for most of the predegenerates and degenerates.

Subject headings: stars: early-type — stars: faint blue — stars: white dwarfs

I. INTRODUCTION

In order to understand the still uncertain final evolutionary channels linking the various types of planetary nebula nuclei, extended horizontal branch subdwarfs and white dwarfs, the data base of hot subluminous stars must continue to be increased. Objective prism and color selected surveys provide these enlarged samples and permit explorations of several critical areas: (1) crucial, still uncertain information is obtainable on the formation rates, space densities, lifetimes, temperatures, and luminosity functions of the various types of hot subluminous stars (sdB, sdO, DA, non-DA, planetary nebula nuclei, sdOB) and cataclysmic variables (dwarf novae, nova-like); (2) white dwarfs divide into several spectroscopic subgroups, some of which have only one or relatively few members (e.g., DZ, DO, DQ, DBA, DAZ, DAB, DBZ, magnetics). The spectroscopic properties of individual white dwarfs yield valuable information on those physical processes which might control and/or modify the flow of elements in high-gravity atmospheres: convection, accretion, diffusion, radiative forces, mass loss, nuclear burning, rotation, and magnetic fields; (3) the mix of spectral types in a complete sample, especially of hydrogen to helium-rich atmospheres over selected intervals of effective temperature or absolute magnitude, is critically important for understanding the evolution of white dwarf spectral subgroups as cooling proceeds (cf. Sion 1984; Fleming, Green, and Liebert 1986) and for testing the predictions of theoretical calculations (cf. Iben *et al.* 1983; Iben 1984; Michaud, Fontaine, and Charland 1984; Michaud and Fontaine 1984); (4) the hot helium-rich white dwarfs (DO stars) and their progenitors are exceedingly rare and thus more of them must be found. Between 45,000 K $\leq T_e \leq$ 80,000 K, only eight are known, practically all from the Palomar-Green (PG) sample (Green, Schmidt, and Liebert 1986). There is also a gap between 47,000 K and 30,000 K where no hot helium-rich stars have yet been found (cf. Wesemael, Green, and Liebert 1985; Liebert *et al.* 1986); (5) hot subdwarfs and hot degenerate stars with metals provide tests of radiative forces/diffusion theory, mass loss, tests of evolutionary models, and direct clues to prior evolutionary states; (6) serendipitous discoveries of new classes of objects (e.g., the PG 1159−035 stars, H 1504+65, KPD 0005+5106) are often the products of such surveys; (7) it is also especially important to build the data base of these classes of stars in a complete survey which extends to fainter limiting magnitudes and greater distances at higher galactic latitude since the scale heights of the different types of evolved, extended horizontal branch (EHB) subdwarfs and white dwarfs is rather uncertain at present. Our ultimate goal is to determine the scale heights by combining the results of the several surveys at low galactic latitude to high z distance above the galactic plane.

For all the above reasons, we have been observing the blue star candidates from the Case Low-Dispersion Northern Sky Survey (CBS; Case blue stars—List III) (Pesch and Sanduleak 1983; Sanduleak and Pesch 1984; Pesch and Sanduleak 1986; Pesch and Sanduleak 1987*a*), a large-scale objective prism survey of the entire northern sky bounded by $|\delta| > +30°$ and $|b| > +30°$. The limiting magnitude of $B \approx 18$ for the detec-

TABLE 1

CASE BLUE STARS SPECTRAL TYPE AND OBJECT CLASS

CBS	α(1950)	δ(1950)	m_B	Spectral Type or Object Class	CBS	α(1950)	δ(1950)	m_B	Spectral Type or Object Class
1..........	08h49m50s6	31′55″0	14	sdO–A sd (PG)	70..........	08h15m39s8	37′39″2	16	DA
2..........	09 01 45.4	31 44.9	15	sdOA/sdO	73..........	08 25 15.7	36 44.5	17	DB
3..........	09 02 39.2	29 18.2	17	DB	74..........	08 29 11.6	37 17.9	17	Sey $z = 0.0906$
4..........	09 06 19.6	29 41.7	16	DA	76..........	08 30 49.8	36 50.4	17	QSO $z = 0.9405$
5..........	09 20 15.5	29 40.0	14	sdB sdOA (PG)	77..........	08 35 25.1	36 39.7	17	DA
6..........	09 20 46.9	30 41.2	16	DA	78..........	08 38 42.1	37 34.0	17	DBZ
7..........	09 21 41.1	31 03.4	14	sdOB (PG)	79..........	08 39 05.4	37 59.9	16	DA
8..........	09 23 37.9	32 58.5	15	sdB–O (PG)	80..........	08 39 43.7	34 35.4	16	sdF–G
9..........	09 24 17.0	28 59.2	17	DA	81..........	08 39 57.4	33 38.7	14	sdB sd (PG)
10..........	09 27 08.	31 59.9	17	sdB (PG)	82..........	08 40 39.9	36 25.5	17	DB
11..........	09 27 17.2	31 04.0	14	sdB	83..........	08 41 09.0	33 40.3	16	DA
12..........	09 29 08.0	29 04.2	17	DA	84..........	08 43 35.0	35 49.8	14	DZ
14..........	09 32 14.4	31 23.6	15	sdB–O (PG)	86..........	08 47 05.9	35 24.0	17	DA
15..........	09 46 48.8	30 29.4	16	sdOC sdOC (PG)	87..........	08 55 31.6	36 34.0	16	HBB
17..........	09 59 01.8	30 32.9	15	sdB–O	90..........	08 59 05.3	33 47.2	16	DA
18..........	09 59 30.2	29 42.6	15	DA sd (PG)	91..........	09 00 13.3	35 25.0	17	DA
19..........	10 02 51.1	31 02.6	16	sdB	92..........	09 00 49.6	37 52.3	17	DA
20..........	10 07 27.1	30 35.5	15	sdB	93..........	09 01 50.2	34 50.7	18	DA (noisy)
21..........	10 28 13.2	32 50.5	16	DA	94..........	09 06 24.8	34 10.7	17	DB
23..........	10 32 54.8	32 34.7	17	sdF–G	95..........	09 08 31.6	35 43.0	17	sdB
24..........	10 37 06.9	29 54.6	17	QSO $z = 0.2436$	96..........	09 17 08.3	34 09.5	14	CV (PG)
25..........	10 37 12.1	32 02.3	14	HBA	98..........	09 20 49.6	36 36.7	16	sdB–O
26..........	10 38 06.	29 04.6:	16	DB	101..........	09 21 39.4	35 23.5	18	QSO $z = 1.3583$
27..........	10 46 47.	30 09.1:	16	DA	102..........	09 25 28.4	35 26.1	17	HBB
28..........	10 47 15.2	30 05.4	17	QSO $z = 0.3198$	103..........	09 26 34.1	37 55.5	16	QSO $z = 0.4410$
29..........	08 55 19.6	29 23.8	11	HBB (PG)	104..........	09 32 52.3	36 47.2	16	HBB
30..........	09 38 31.4	29 58.8	16	DA (PG)	105..........	09 34 00.9	34 38.8	16	QSO $z = 0.9083$
31..........	10 51 45.5	30 25.5	16	CV	108..........	09 41 26.6	36 22.7	17	QSO $z = 0.2270$
32..........	10 56 20.2	32 22.8	15	sdB	109..........	09 45 58.8	33 56.0	17	sdOB (noisy)
33..........	11 00 24.6	29 28.7	17	QSO $z = 0.3731$	110..........	09 46 15.8	36 17.4	14	HBB
34..........	11 04 07.9	29 51.9	15	sdB	111..........	09 48 50.9	34 21.7	14	CV (PG)
35..........	11 05 39.2	29 53.2	15	sdB	112..........	09 49 34.	35 26.7:	18	QSO $z = 1.8750$
36..........	11 07 38.7	31 03.9	17	sdB	113..........	09 52 48.	33 30.2:	18	DB
37..........	11 08 02.9	32 31.2	16	DA (PG)	114..........	09 54 52.6	34 14.0	17	DB
38..........	11 10 22.9	29 24.1	14	sdB (PG)	115..........	09 56 33.6	36 33.1	12	sdB
39..........	11 16 23.9	30 24.1	14	sdB (PG)	116..........	09 56 57.9	35 54.5	14	sdOC
40..........	11 17 19.4	31 13.5	14	sdB (PG)	117..........	09 58 17.6	35 19.8	16	DA
41..........	11 25 50.2	29 31.7	15	sdOA/sdOB (PG)	118..........	09 58 57.9	37 41.3	17	QSO $z = 0.8087$
42..........	11 28 39.8	29 20.9	17	QSO $z = 1.3189$	119..........	09 59 11.4	34 05.7	17	CV (PG)
43..........	11 31 44.7	32 09.9	16	DA	120..........	09 59 20.3	33 58.0	18	DB
44..........	11 31 57.3	31 35.5	17	DA	121..........	10 00 07.9	36 16.3	17	QSO $z = 0.4341$
45..........	11 33 36.2	29 18.3	15	DA (PG)	122..........	10 00 19.2	37 31.7	15	sdB (PG)
46..........	11 34 27.7	30 04.8	13	DA (PG)	123..........	10 00 32.3	36 11.2	16	sdOA
47..........	11 35 44.2	32 41.6	16	Composite	124..........	10 08 58.5	37 12.4	17	DA
48..........	11 35 20.6	32 06.5	14	DA (PG)	125..........	10 04 38.8	36 53.7	16	QSO $z = 1.0342$
49..........	11 52 28.9	32 05.1	17	DB	126..........	10 10 07.5	36 06.3	16	Sey $z = 0.0787$
50..........	11 56 17.6	29 10.3	16	DA	127..........	10 15 42.8	37 42.0	17	DZ
51..........	12 00 48.3	31 03.2	17	DA	128..........	10 17 59.5	36 41.9	16	Magnetic
52..........	12 02 51.8	30 51.5	15	DA (PG)	129..........	10 36 16.3	37 01.3	13	sdB
53..........	12 03 24.2	32 48.0	16	HBB	130..........	10 47 58.9	33 31.8	17	DA
54..........	12 11 04.8	32 05.1	16	DA	131..........	10 52 00.7	34 16.3	17	DA
55..........	12 13 25.4	30 42.2	17	sdF–G	132..........	10 52 19.0	37 15.8	14	CV
56..........	12 14 50.5	31 13.4	17	QSO $z = 0.3074$	135..........	11 03 06.3	36 36.7	17	sdO–A
57..........	12 15 02.8	32 21.8	17	HBB	141..........	11 29 09.7	34 57.6	16	sdB
58..........	12 17 24.6	31 56.6	17	sdOA	142..........	11 31 08.1	33 18.0	17	DA
59..........	12 19 16.9	30 25.5	17	sdF–G	143..........	11 34 21.4	35 25.8	17	sdB
60..........	12 24 01.6	30 55.6	16	DA (PG)	144..........	11 42 08.9	36 58.6	16	DA
61..........	12 27 55.3	30 44.3	17	DA	145..........	11 42 15.9	35 49.6	17	sdF–G
62..........	12 36 00.8	31 38.3	17	DA	146..........	11 47 30.6	36 17.0	16	sdB
63..........	12 40 30.3	29 40.0	17	QSO $z = 0.3966$	147..........	11 47 33.6	35 13.3	16	QSO $z = 0.2506$
64..........	12 46 20.5	29 59.0	17	DA	148..........	11 47 55.3	37 11.2	18	DB
65..........	12 49 10.2	29 37.3	17	DA	151..........	11 51 53.4	34 24.0	18	QSO $z = 0.4610$
66..........	12 50 54.0	30 23.0	15	sdB	152..........	11 52 23.9	37 07.6	17	DA
67..........	08 05 57.1	35 37.1	15	sdF–G	154..........	11 55 33.8	33 18.9	17	DA
68..........	08 10 45.	33 26.2:	17	DA	155..........	11 57 05.9	35 54.9	17	DA
69..........	08 12 36.	35 26.2:	13	sdF–G	156..........	12 00 10.1	37 52.7	18	QSO $z = 0.4969$
					158..........	12 10 21.3	34 10.8	14	sdB

tion of a stellar continuum may represent a deeper completeness limit than the PG survey ($B = 16.4$).

The CBS lists have proved to be an exceptionally rich source of new degenerate stars and hot subdwarfs. Preliminary spectral classifications of these objects have recently appeared elsewhere (Wagner *et al.* 1987; Sion *et al.* 1987). Also, results for CBS 78, the second known DBZ degenerate star which shows Ca II in addition to weak He I lines, have been published by Sion *et al.* (1986). In this paper, we will provide a more complete and detailed summary of our newly identified stellar objects together with some results of preliminary temperature, gravity, and abundance analyses. In § II, we describe our observational techniques, data reduction, measurements, and results. In § III, we discuss the various spectroscopic groups of CBS stars beginning with § III*a*, lower gravity, horizontal branch stars; § III*b*, the hot higher gravity, sdB, sdOB, and sdO stars along the extended horizontal branch; and in § IV, the white dwarf spectroscopic subgroups, including DA, DB, and DZ. In § V we discuss miscellaneous blue objects discovered during the course of the survey including cataclysmic variables, a newly discovered dwarf nova or nova-like, CBS 128—a new magnetic degenerate star, CBS 47—a composite spectrum star, active extragalactic objects including quasars, subdwarf F and G stars, and a probable active chromosphere star with strong and variable Ca II H and K emission.

II. OBSERVATIONS AND RESULTS

Our observations were made primarily with the Steward Observatory 2.3 m telescope on Kitt Peak. The Boller and Chivens spectrograph was used with the blue sensitive intensified, pulse counting Reticon system (PCR) as the detector (Allen *et al.* 1984). Dual 3" diameter entrance apertures were used. A 600 lines per mm grating blazed at 3800 Å in first order was employed which, when combined with these entrance apertures, gave a nominal resolution of 6 Å and a usable spectral range of 3140–6200 Å. Total integration times for most objects ranged from 240 to 480 s and in a few cases up to 7200 s. Spectra of a HeAr discharge source were obtained periodically during the night to provide wavelength calibration. Dispersion curves were determined from these spectra and for a fifth order polynomial fit the standard deviation was typically 0.1 Å. A quartz halogen lamp was observed before the night and at the end of the night to permit removal of pixel-to-pixel variations in response.

In addition, eight CBS objects (CBS 125, 126, 128, 129, 141, 144, 146, and 158) were observed with the Ohio State University image dissector scanner (IDS; Byard *et al.* 1981) on the Perkins 1.8 m telescope of the Ohio Wesleyan and Ohio State Universities at the Lowell Observatory. Dual 5" entrance apertures and a 600 lines per mm grating blazed at 5500 Å were employed which covered the spectral region 3700–6300 Å at 9 Å spectral resolution. Various lamp spectra and standard stars were observed with the IDS as with the PCR system for removal of instrumental effects. Two CBS objects (CBS 95 and 125) were observed using the 4.5 m Multiple Mirror Telescope (MMT) and Reticon spectrograph of the Smithsonian Institution and the University of Arizona. A 300 lines per mm grating blazed at 5000 Å and covering the spectral region 3200–6700 Å was used.

The data reduction procedure was the same for all of the objects reported in this work. Each integration in a given aperture was sky-subtracted, divided by the integration time, corrected for flat field response using the quartz halogen lamp spectra, corrected for the effects of atmospheric extinction assuming mean extinction coefficients for Kitt Peak, and resampled onto a linear wavelength scale. Before placing the spectra on an absolute flux scale, the reduced individual integrations in each aperture were co-added weighted by signal-to-noise ratio. The final reduced spectra in each aperture were then placed on an absolute flux scale by an instrument response function for that aperture determined by the observation of one or more standard stars from the list of Oke (1974) or Stone (1977). The flux calibrated spectra in each aperture were then added, weighted by their respective signal-to-noise ratios, to produce the final reduced spectrum. Reduction of the MMT spectra was similar to that of the PCR. The reduction of the IDS data was similar to that of the PCR data except that the spectra were not added weighted by signal-to-noise ratio.

For most of the CBS objects, we have measured approximate Johnson $U-B$ and $B-V$ colors by convolving our spectra with the UBV filter response functions as given by Allen (1973). We estimate that the $U-B$ and $B-V$ colors are accurate to approximately 0.15–0.20 mag and 0.05–0.10 mag, respectively. The chief uncertainties in the colors are the standard star flux calibration, the use of mean extinction coefficients, and differential atmospheric refraction, especially in the U band with our small entrance apertures. Most of the CBS objects were observed at air masses of less than 1.1. We have also measured the equivalent widths of absorption lines in the stellar spectra for diagnostic purposes. Lines measured include Hβ, Hγ, and Hδ; He I 4471, 4388, and 4921 Å; He II 4686 and 5411 Å. The equivalent widths are uncertain by approximately 5% to 10% with the error dominated by continuum placement.

The results of our observations are summarized in Table 1. For each CBS object, we tabulate the coordinates for epoch 1950.0, the photographic magnitude as estimated by Pesch and Sanduleak, and our derived spectral type or object class together with a PG designation for those objects also found in the PG catalog. In a few cases where our classification differs from that in the PG catalog, the PG classification is listed next to ours. Our classification of subdwarf spectra utilizes subtypes defined (arbitrarily) in the PG catalog. White dwarf classifications follow the scheme of Sion *et al.* (1983). We have defined QSO to be those objects of substantial redshift whereas those objects with broad emission lines and small redshifts have been defined as Sey (generally Seyfert 1–like objects). We did not find any objects with both narrow permitted and forbidden lines which might be classified as Seyfert 2 galaxies or LINERS. These objects are classified as Gal in the PG catalog.

The final summary of CBS objects by spectral type/object class is given in Table 2. Note that the percentage of white dwarfs in the CBS sample, 49% is considerably higher than that found in UV excess surveys at brighter limiting magnitudes and where prescreening of objective prism images was not a factor. In the UV excess surveys such as Kiso and PG, the stellar spectroscopic identifications are dominated by subdwarfs. However, the subdwarfs show shallower increases in the counts than the white dwarfs and quasars with increasing apparent magnitude (Green *et al.* 1986, Fig. 2), so that it is not surprising that they represent a smaller fraction of a sample at $B \geq 17$.

III. HOT SUBDWARFS

a) Low-Gravity Stars

We have identified eight low-gravity hot stars among the first four CBS lists. Their narrow Balmer profiles, Balmer series

TABLE 2

CASE BLUE STARS SUMMARY OF RESULTS

Type	Number
DA stars	42
DB stars	11
DZ stars	2
sdB stars	26
sdO stars	9
HBB/HBA stars	8
sdF–G stars	7
Cataclysmic variables	5
Magnetic degenerate stars	1
Composite spectrum stars	1
Quasars	18
Active galactic nuclei	2

visibility to principal quantum number $n = 12$–14, and Hγ equivalent widths place them at log $g = 3.5$–4 (cf. Fig. 2 of Greenstein 1980), while their positions in the two-color diagram based on our approximate colors (see Fig. 15 of Greenstein and Sargent 1974), their distinctively large Balmer jump, and very weak He I establish them as probable horizontal branch stars of type HBB and in one case, CBS 110, type HBA. The spectrum of CBS 110 is shown in Figure 1.

Two objects, CBS 20 and CBS 36, have large Balmer line equivalent widths, but peculiar energy distributions. CBS 20 appears far too blue to be an sdO or sdB star, while CBS 36 is unusually red and could be a composite blue (HBB or sdB) object plus a solar-type star. Both objects had noisy spectra and should be reobserved.

b) Hot Extended Horizontal Branch Subdwarfs

We have discovered or confirmed a total of 35 hot extended horizontal branch sdB and sdO subdwarfs. One object, CBS 8, appears to be helium-rich, but was classified sdB by Green, Schmidt, and Liebert (1986). Our spectrum fails to reveal He II 4686 Å but does show He I 4471 Å with an equivalent width of 5 Å (Table 3). Its provisional colors and Hβ and Hγ line strengths suggest $T_e \geq 30{,}000$ K with log $g \approx 5$.

Six stars on our discovery list appear to be very hot, higher gravity subdwarfs generally showing He II 4686 and 5411 Å with He I 4471 Å weak or absent and with Balmer line equivalent widths less than 8 Å (see Table 3). One object, CBS 109, which was classified sdOB by us, had a noisy spectrum and must be reobserved. The other objects, CBS 2, 7, 15, 41, and 116, appear to represent sdO stars near an empirical temperature boundary ($T_e \approx 40{,}000$ K) separating intermediate helium-rich and helium-poor sdO stars (Heber 1986), although Drilling and Schönberner (1985) have found some helium-poor stars well above 40,000 K. Of these five objects, CBS 41 (Fig. 1) has the steepest continuum and appears to be remarkably helium-deficient. The Balmer line strengths imply that $T_e \geq 40{,}000$ K and log $g \geq 5.5$. The He II features in CBS 41 have $W < 1$ Å.

The most helium-rich subdwarf of the group of six appears to be CBS 7 (Fig. 1) based upon the strengths of the He II features and the extreme weakness of H + He II relative to the other helium lines. The spectrum of CBS 7 resembles Slettebak-Brundage 705, an intermediate helium-rich sdO star analyzed by Hunger *et al.* (1981). The strength of He I and He II imply a helium abundance (by number) of $Y \approx 0.5$. The remaining objects CBS 2, 15, and 116 have log $g \approx 5.5$–6 and log $T_e \approx 4.5$–4.7. In the absence of a detailed non–LTE abundance fit, these objects would appear to have helium strengths that imply abundances between normal ($y = 0.12$) and intermediate helium-rich ($y = 0.5$). Their relative line strengths suggest a strong similarity to the sdO stars LS 630 and SB 884, the former being intermediate helium-rich and the latter having a normal helium abundance.

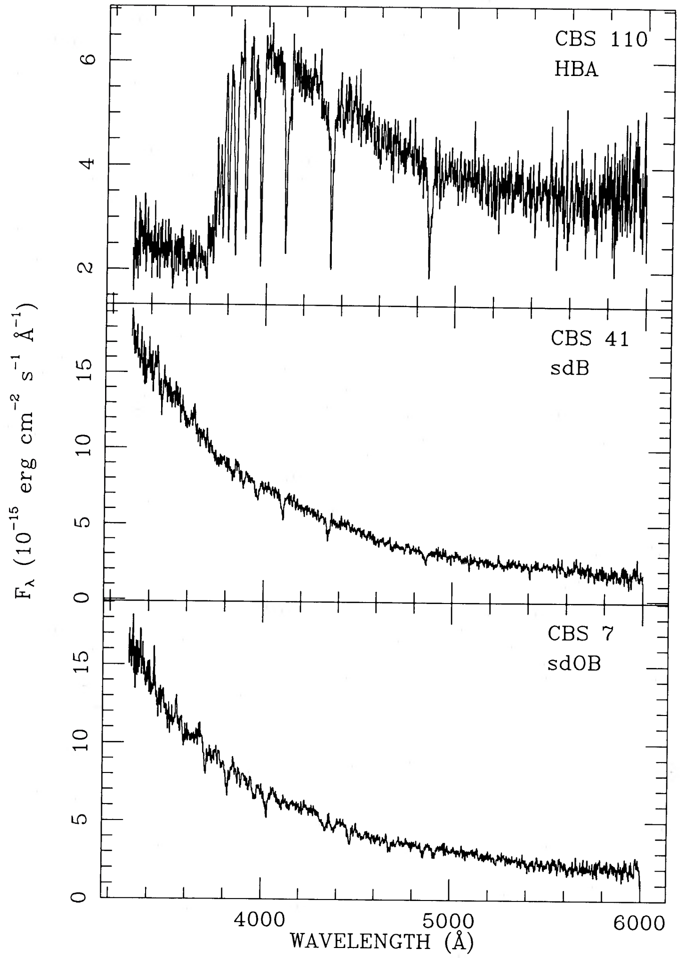

FIG. 1.—Spectra of subdwarf stars from the Case Low-Dispersion Northern Sky Survey. *Top:* CBS 110 (HBA); *middle:* CBS 41 (sdB); *bottom:* CBS 7 (sdOB). Note the distinctively large Balmer jump and narrow Balmer absorption lines in CBS 110. Note also the presence and strength of He I 4471 Å and He II 4686 Å in CBS 7 as compared with CBS 41.

The remaining hot subdwarfs are helium-poor sdB and sdOB stars, most showing weak He I 4471, 4388, 4026, 3888 Å and sometimes weak He II 4686 Å. Stark-broadened Balmer lines dominate and have distinguishable line members out to $n = 12$–14. These subdwarf stars are listed in Table 3 together with their provisional colors and equivalent widths. Temperatures may be estimated from the Greenstein and Sargent (1974) technique.

IV. WHITE DWARFS

a) DA Degenerates

We have classified a total of 55 degenerate stars of which we find 42 are DA, 11 are DB, and two are DZ. A total of seven DA stars were recovered from the PG survey, and several candidates were assigned a "DA?' designation by Pesch and

TABLE 3

CASE BLUE STARS SUBDWARF STARS

CBS	$U-B$	$B-V$	$W(H\beta)$	$W(H\gamma)$	$W(H\delta)$	W(He I) 4471	W(He II) 4686/5411	Type
1	−0.21	−0.12	8.2	8.3	10.8	...	...	sdO–A
2	−1.10	−0.26	8.1	6.3	5.2	0.7	1.4	sdOA/sdOB
5	−0.16	−0.07	8.1	11.4	...	...	...	sdB sdOA (PG)
7	−1.11	−0.18	3.7	...	...	3.5	3.4	sdOB
8	−0.95	−0.21	6.2	7.3	...	5.1	...	sdB–O
10	−0.90	−0.25	15.7	9.1	...	...	...	sdB
11	−0.86	−0.16	4.5	9.9	8.6	...	...	sdB–O
14	−0.88	−0.22	8.3	9.4	...	...	...	sdB–O
15	−0.98	−0.26	...	...	...	...	3.4/3.9	sdOC
17	−0.79	−0.19	10.7	8.6	...	...	...	sdB–O
19	−0.76	...	8.7	7.0	...	...	...	sdB
35	−0.92	−0.26	2.2	4.0	5.6	...	...	sdB
36	−0.53	0.22:	13.5	15.4	...	...	...	sdB
38	−1.05	−0.15	9.6	10.6	8.1	...	...	sdB
41	−1.16	−0.29	4.9	3.5	2.5	...	...	sdOA/sdOB
58	−0.95	−0.14	11.3	6.0	...	...	...	sdOA
81	−0.82	−0.25	7.9	8.6	9.1	...	...	sdB
95	−0.85	−0.20	...	...	...	...	...	sdB
98	−0.94	−0.20	5.5	9.9	...	...	...	sdB–O
115	−0.74	...	8.1	7.1	...	...	...	sdB
116	−1.13	−0.22	2.8	3.2	2.5	...	6.2/5.2	sdOC
123	−0.96	−0.38	7.6	4.4	2.1	...	...	sdOA
129	...	−0.08	6.2	7.3	...	...	...	sdB
135	−1.06	...	3.6	4.0	...	...	...	sdO–A
141	...	−0.18	6.3	9.8	...	...	...	sdB
142	−0.54	...	22.8	18.0	...	...	...	sdB
143	−1.01	...	5.5	5.9	...	...	...	sdB
146	...	−0.21	6.2	5.9	2.6	...	...	sdB
158	...	0.13	4.0	2.9	1.8	...	...	sdB

TABLE 4

CASE BLUE STARS DA WHITE DWARFS

CBS	$U-B$	$B-V$	$W(H\beta)$	$W(H\gamma)$	$T_e(K)/10^3$	Spectral Type
4	−0.77	−0.09	29.3	30.5	21	DA3
6	−0.66	−0.15	22.3	19.8	30	DA2
18	...	...	...	3.6	...	...
21	−0.50	−0.12	40.4	37.4	11.5	DA5
27	...	−0.69	33.8	31.6	...	...
37	−0.97	−0.20	7.3	7.9	42	DA1
43	−0.54	0.18	37.9	38.2	11	DA5
44	−0.57	−0.24:	31.3	35.4	...	DA/sdB
45	−0.86	−0.18	24.3	27.6	25	DA2
50	0.28	...	21.0	20.3	...	...
54	−0.40	0.26	36.9	38.8	11	DA5
61	−0.46	0.11	39.7	44.5	11.5	DA5
62	−0.95	−0.19	8.9	6.0	40–42.5	DA1
65	−0.49	0.11	32.5	34.3	10.5	DA5
68	−0.56	0.03	27.2	31.2	9–10	DA5
70	−0.50	0.12	16.8	27.8	8–10	DA6
77	−0.46	0.09	29.3	35.2	10–10.5	DA5
79	−0.53	0.14	32.8	30.3	10	DA5
83	−0.74	−0.02	27.3	26.6	24–25	DA2
86	−0.37	0.24	39.5	42.8	12	DA5
90	−0.64	0.04	24.2	23.2	9	DA5
91	−0.91	−0.22	12.8	13.8	36–37	DA1
92	−0.84	−0.18	16.4	13.0	34–37	DA1
98	−0.94	−0.20	5.5	9.9	37–43	DA1
117	−0.95	...	10.8	11.3	...	...
124	−0.40	...	35.2	31.4	...	...
130	−0.52	...	35.9	34.7	...	...
131	−0.51	...	31.8	32.5	...	...
144	...	0.12	34.7	32.1	...	...
152	−0.93	...	28.3	24.7	...	...
154	−0.28	...	36.9	35.1	...	...
155	−0.38	...	5.6	3.4	...	...

Sanduleak in the CBS lists based upon suspicion from their objective prism images.

In Table 4, we list for each identified DA star the estimated colors, $U-B$ and $B-V$, the equivalent widths of Hβ and Hγ, the derived effective temperature, and assigned spectral type on the new white dwarf classification system (Sion *et al.* 1983). The temperatures have been determined from the equivalent widths of Hβ and Hγ based upon the DA model grid of Shipman (1979). The white dwarfs in Table 4 range in spectral type from DA6 at the cool end to DA1; there are five DA degenerates having effective temperature between 30,000 K and 40,000 K. We have included in Table 4 only those stars for which we have measured equivalent widths and measured colors. We have identified nine other DA stars which either overlap with the PG survey or had noisy spectra. The spectrum of CBS 43 (DA5) is shown in Figure 2.

b) DB Degenerates

The discovery of additional DB white dwarfs in any complete survey holds special significance because of current intensive efforts to understand their formation, their evolutionary relationship if any to other spectroscopic subgroups, and their rarity relative to DA stars at the hot end of the luminosity function, and the searches for trace elements in their relatively transparent atmospheres. The possibility of finding new members of the very small class of hot DB pulsators (see recent reviews by Liebert 1986; Sion 1986; and Winget and Fontaine 1982) is also important. We have found 11 new DB degenerates among the CBS candidates including the second known DBZ star, CBS 78. This object reveals accreted photospheric calcium and is one of the coolest DB stars with $T_e \approx 12{,}000$ K and log $g \approx 8$ (Sion *et al.* 1986). In Table 5, we list a provisional $B-V$ color, the equivalent widths of He I 4921, 4471, and 4388 Å and our derived effective temperature and surface gravity. For the surface temperatures and gravities, we have used He I equivalent widths (below 20,000 K) and the singlet-to-triplet (4388/4471) ratio, respectively. The model grids of Wickramasinghe and Reid (1983) and Shipman (1972) were both employed and yielded similar results. One object, CBS 94, appears to be a DB star, but its spectrum is noisy and requires reobserving. The spectrum of CBS 113 (DB) is shown in Figure 2.

We estimate that the uncertainties in log g and log T_e are 0.5 and 0.02–0.03, respectively, and we do not attach high significance to the gravity determination. Oke, Weidemann, and Koester (1984) have analyzed Palomar 5 m multichannel spectra of excellent quality on a sample of bright DB stars and they find for their sample that log $g \approx 8$. Our data are poorer in quality than those of Oke, Weidemann, and Koester, since the objects are fainter and different models fit systematically different gravities to the same He I 4388 and 4471 Å ratio. Thus, those objects in Table 5 with log g of 7.5 or less are not necessarily low-gravity DB stars, and no mass difference is implied with DA stars.

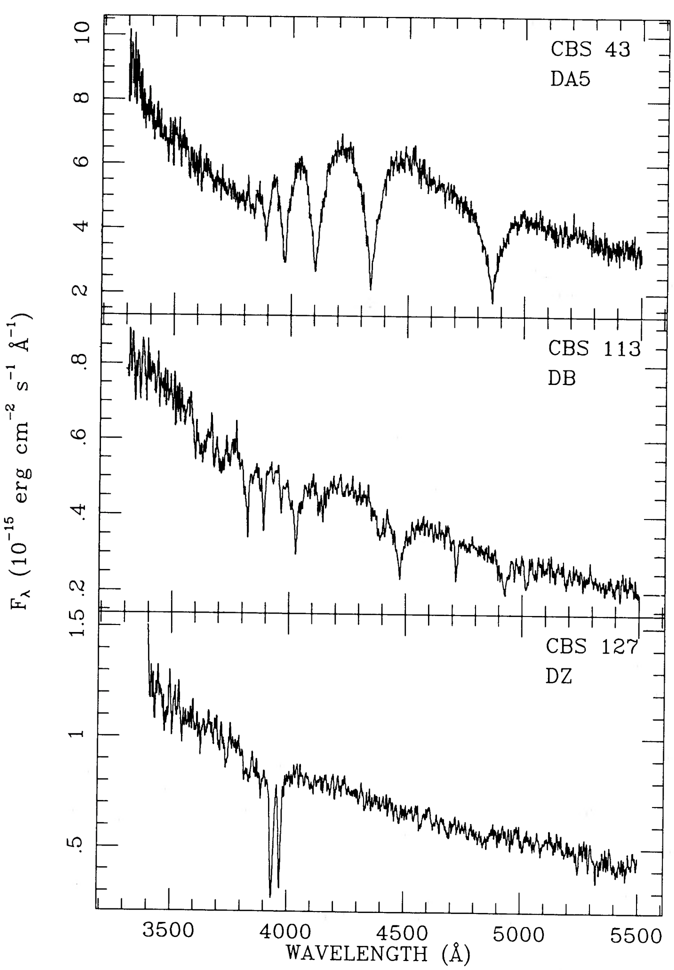

FIG. 2.—Spectra of white dwarf stars from the Case Low-Dispersion Northern Sky survey. *Top:* CBS 43 (DA5); *middle:* CBS 113 (DB); *bottom:* CBS 127 (DZ).

c) DZ Degenerates

Cool degenerates with quite blue continuua have been discovered in color-selected ultraviolet excess surveys as illustrated by PG 2322+119, PG 1225−079, Green, Schmidt, and Liebert 1986; Liebert, Wehrse, and Green 1987). A third DZ star, GD 95 (CBS 84), was first identified as a cool metallic line star by Pesch and Sanduleak (1986) who communicated the discovery to Liebert, Wehrse, and Green (1987) for analysis. Since the Case Northern Sky Survey has a redder color limit than the PG, we expected to find more cool degenerates among the Case blue stars. Thus far we have discovered one DZ white dwarf, CBS 127, in addition to the DBZ star, CBS 78, discussed previously. The spectrum of CBS 127 is shown in Figure 2 where the broad Ca II H and K absorption components are prominently revealed. The H and K equivalent widths are

TABLE 5

CASE BLUE STARS DB WHITE DWARFS

CBS	$B-V$	W(4388/4471)	W(4921)	$T_e/10^3$ (K)	log g
3	...	3.0/14.1	3.6	15	7.5
26	...	2.5/ 9.2	4.6	15	8–8.5
49	0.0	3.2/ 8.2	13.0	15	7–7.5
73	−0.02	3.4/10.7	5.4	15	7–7.5
78	−0.01	...	...	12	8
82	−0.02	5.5/16.8	12.1	≥18	7.5–8
94	0.10:	/11.7:	...	...	...
113	...	6.0/19.7	10.8	20	7.5
114	−0.03	8.2/17.5	...	≥18	7
120	...	3.6/11.3	...	15	7–7.5
148	...	3.7/ 9.8	...	15	7–7.5

8.7 Å and 12.6 Å, respectively, while the continuum is moderately steep into the blue. We note the absence of any other features beyond the possible presence of very weak Mg I 3830 Å and Fe I 3730 Å with equivalent widths of 1.6 Å and 2.6 Å, respectively. Our synthetic broad-band colors are $B-V=0.1$ and $U-B=-0.8$. Collectively, these spectral characteristics suggest that CBS 126 is probably hotter than 8000 K and resembles both PG 2322+119 and PG 1225−079. A more detailed analysis of this star will appear elsewhere.

V. MISCELLANEOUS BLUE OBJECTS

a) *Cataclysmic Variables*

We have discovered two new cataclysmic variables (CV) among the first four Case blue star lists. In addition, three CVs, CBS 96, 111, and 119, were recovered from the PG discovery list. One new cataclysmic variable, CBS 31, shows strong and broad double-peaked Balmer lines and weaker He I 4471 Å and He II 4686 Å emission. The spectrum of CBS 31 is shown in Figure 3. The emission lines of CBS 31, when compared with those of CBS 119, are considerably broader and double-peaked, suggesting that CBS 31 is observed at a much higher inclination than CBS 119 and may eclipse. The excitation of its spectrum suggests a U Geminorium system, but an AM Herculis or intermediate polar magnetic CV classification cannot be ruled out. Time-resolved CCD photometry in the V band over a 6 hr time interval and time-resolved spectroscopy of CBS 31 have been performed by Wagner *et al.* (1987). They find that the system undergoes a high state with an amplitude of 0.3 mag every 1.5 hr. Time-resolved spectroscopy of CBS 31 suggests that variations in the emission-line strengths may correlate with phase of the 1.5 hr period.

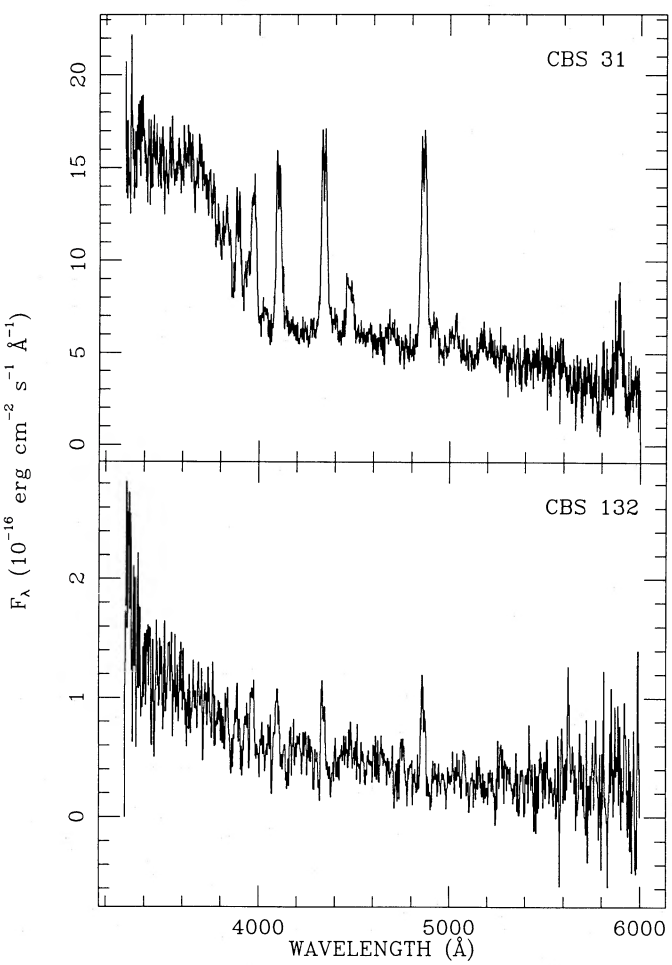

FIG. 3.—Two cataclysmic variables from the Case Low-Dispersion Northern Sky Survey, CBS 31 and CBS 132.

Another interesting CV discovered during the course of our follow-up spectroscopy is CBS 132. Pesch and Sanduleak (1987*b*) noted that on a plate taken on 1981 May 5, the spectrum was that of a 14th mag, moderately blue, early-type star with weak hydrogen absorption lines. However, the Palomar Sky Survey (POSS) prints show only a 19th mag object at this position. A spectrum of CBS 132 was obtained in 1987 March and is shown in Figure 3. The flux level is consistent with an object of 19th to 20th mag, but the spectrum reveals Balmer emission rather than absorption as noted on the objective prism plate when the object was 14th mag. We find that for Hβ emission an equivalent width of 53 Å and a full width at half-maximum (FWHM) of about 1800 km s^{-1} and for Hγ emission an equivalent width of 30 Å and a FWHM of 1450 km s^{-1}. The presence of broad Balmer emission lines at minimum brightness and Balmer absorption lines at maximum brightness suggests that CBS 132 is a dwarf nova or nova-like. The classification cannot be further refined as we do not know the precise form of the light curve based on only two epochs of observation. The widths of the emission lines suggest that on average the rotational velocity of the accretion disk is $v \sin i \approx 800$ km s^{-1}. If CBS 132 is a dwarf nova and reaches an absolute visual magnitude of +9 at minimum brightness, then it lies at a distance of perhaps 1 kpc assuming $A_V = 0$. The galactic latitude of CBS 132 is about 64° so that it, as well as other dwarf novae found through deep spectroscopic surveys at high galactic latitudes, may place additional constraints on the spatial density of these stars in the z-direction.

b) *CBS 128 = GD 116: A New Magnetic White Dwarf*

On 1987 March 26, a spectrum of CBS 128 was obtained with the IDS by RMW who noted the presence of absorption features at wavelengths roughly corresponding to the Balmer lines but with unusual structure. Later the same night, a spectrum was obtained using the 2.3 m telescope and PCR system at higher spectral resolution and signal-to-noise ratio by E. M. S. and J. L. who identified CBS 128 as a new magnetic white dwarf star. The spectrum of CBS 128 obtained with the IDS is shown in Figure 4. The field strength has been estimated to be about 10–30 MG by Gary Schmidt (private communication) assuming a hydrogen Zeeman pattern. A more complete analysis and discussion of CBS 128 as well as other magnetic white dwarfs is in preparation.

c) *CBS 47—A Composite Spectrum Star*

In Figure 5, we show the spectrum of CBS 47, a star with composite spectra discovered during the course of our follow-up spectroscopy. Note the rising continua to the red and blue suggesting the presence of both cool and hot objects in the system. From the spectrum in Figure 5, we find that $U-B=-0.42$ and $B-V=0.90$. The hot star shows only He I and this suggests a DB or high-gravity sdOB star. The following equivalent widths for He I absorption lines have been measured: 3888 Å, 6.7 Å; 4026 Å, 8.9 Å; 4388 Å, 5.6 Å; 4471 Å, 4.1 Å. The cool star is an early M type star. The equiv-

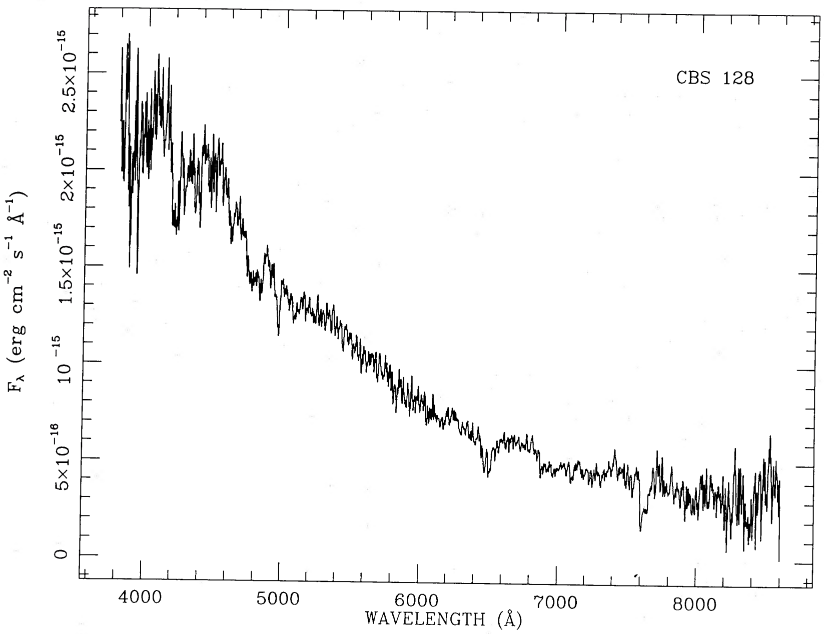

FIG. 4.—Spectrum of CBS 128, a new magnetic degenerate star. Note the difference between the Hα and Hβ line profiles.

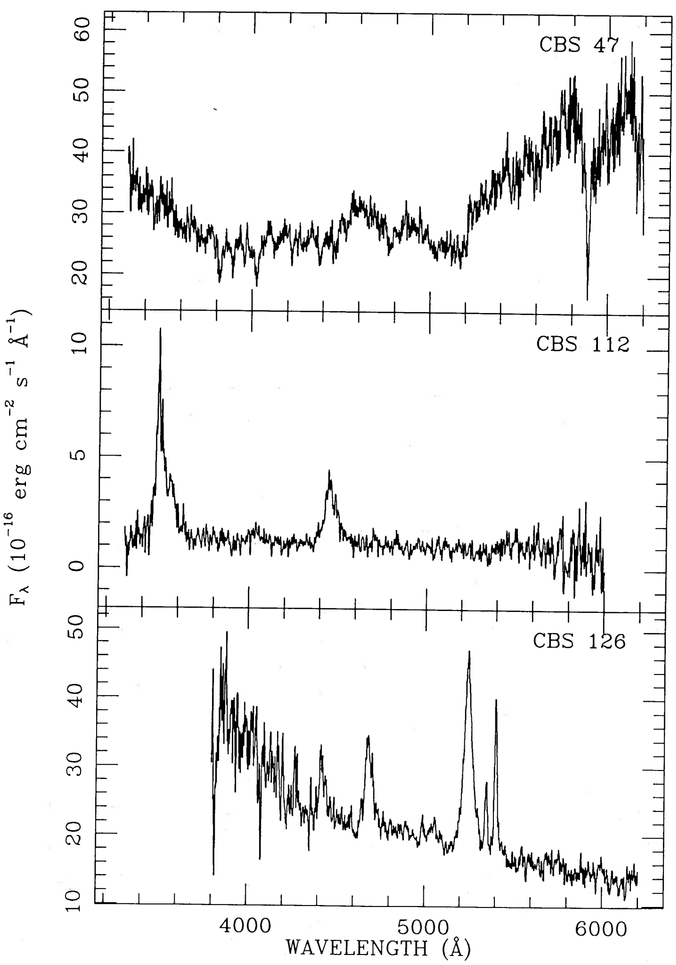

FIG. 5.—*Top:* CBS 47, a composite spectrum star. Note the rising red and blue continua and the presence of He I absorption lines at 3888, 4026, 4388, and 4471 Å; *middle:* the high-redshift quasar CBS 112 ($z = 1.8750$); *bottom:* the Seyfert 1 galaxy CBS 126.

alent width of NaD absorption is 11.8 Å and the spectrum shows some TiO redward of Na I. The comparison of the properties of CBS 47 with other similar composite systems will be an important area of future investigation.

d) Extragalactic Objects

Approximately 15% of the objects we observed in the first four CBS lists are extragalactic in nature. These objects contribute to information concerning the redshift, magnitude, and line strength distributions of QSOs and active galaxies as well as the surface and space densities of these objects. These objects are however "contaminants" in the CBS lists and should have been placed in either the CG (Case Galaxy) or CSO (Case Stellar Object) categories. Ambiguities in identification are however common to the objective prism technique. It is interesting to note that a higher percentage (> 50%) of extragalactic objects has been found in the CSO lists (Zotov 1985; Wagner 1987) as should be the case. In Table 1 we have listed the type of extragalactic object found and corresponding redshift. Two of the extragalactic objects found in the CBS lists, CBS 112 (QSO, $z = 1.8750$) and CBS 126 (Sey, $z = 0.0787$), are shown in Figure 5. A more complete analysis including line strength measurements for these objects as well as those found in the CSO lists is in preparation (Wagner 1987).

e) Subdwarf F and G Stars

Approximately 6% of the objects we examined in the first four CBS lists have sdF or sdG classifications. These stars have strong Ca II H and K absorption, the G band, and weak Hβ absorption. These subdwarf stars appear in a greater fraction in the CSO list where they dominate the galactic stellar sample (Wagner 1987). P. Pesch (private communication) remarks that such stars are systematically selected on the objective prism plates because the continua appear flat. More of these stars appear in the CSO lists than the CBS lists because of the additional requirement that CBS objects also show a darkening of the continuum toward the blue on the plate and these stars do not satisfy this requirement. CBS 55 may be a rather

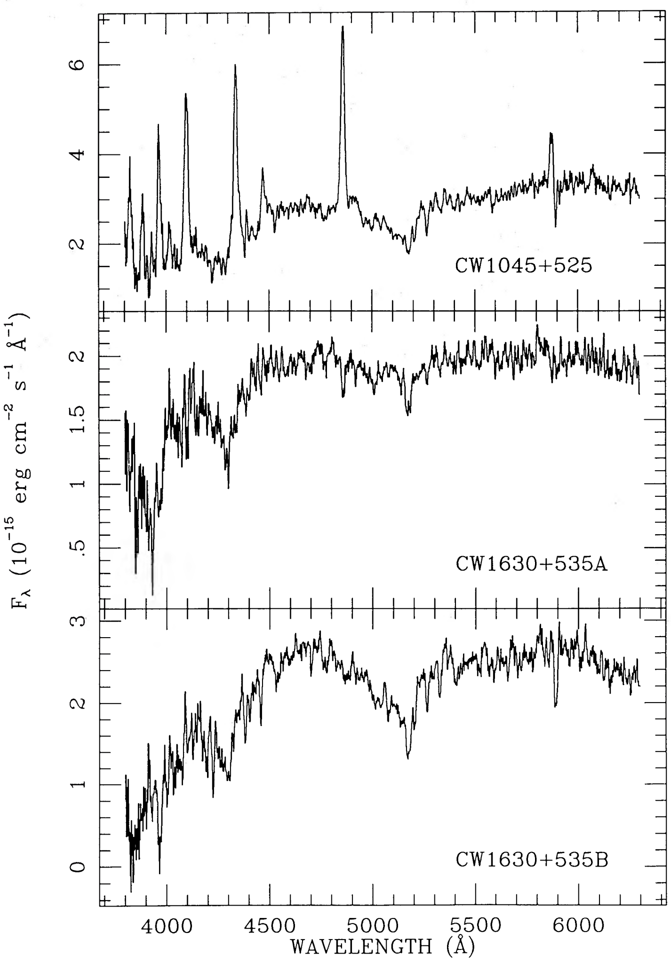

FIG. 6.—*Top:* the cataclysmic variable CW 1045+525. Note the presence of Balmer and He I emission and absorption from a late type stellar companion; *middle and bottom:* spectra of CW 1630+535 A and B. CW 1630+535A may be a RS CVn star as it exhibits strong and variable Ca II H and K emission (see text).

extreme sdG star and CBS 59 may have a composite spectrum, but additional spectra are required for confirmation. Some of these stars may be dG and sdB–O binaries (Ferguson, Green, and Liebert 1984).

f) Additional Case Survey Objects

Recently Pesch and Sanduleak (1987*b*) have published a short note on three variable stars discovered during the course of their spectroscopic surveys. One of these objects is CBS 132, described above. Spectra of the two remaining objects were obtained with the IDS during 1987 March and are described below.

CW 1045+525.—Pesch and Sanduleak note that on their objective prism plate the spectrum is that of a late K or M star with strong Balmer emission and a very strong UV continuum. They estimate that $B \approx 16.5$ and $B-V \approx -1.0$ after comparison with the POSS O and E prints. A spectrum of CW 1045+525 was obtained on 1987 March 25 and is shown in Figure 6. This spectrum confirms the objective prism results and reveals late-type stellar photospheric absorption lines due to NaD 5890, 5896 Å, MgH 5200 Å, and the G band in addition to strong Balmer, He I 4471 Å, and 5876 Å emission lines. We find from the spectrum that $B = 16.1$ mag and $B-V = +0.8$ mag, in excellent agreement with the photographic results. The composite spectrum suggests that CW 1045+525 is a cataclysmic variable containing a K star and a white dwarf surrounded by an accretion disk. Comparison with other cataclysmic binaries suggests that the orbital period is greater than about 6 hr since the companion star is visible in the spectrum. Radial velocity studies of this star may be valuable.

CW 1630+535.—Pesch and Sanduleak find that at this position are two comparable brightness late K or early M type stars ($B \approx 16$ mag) forming a physical double of about 3″ separation. On a plate obtained 1984 May 23, the easternmost star of the pair displayed at low dispersion the H and K lines of Ca II in emission at a strength never seen previously in any star by Pesch and Sanduleak (P. Pesch, private communication). Neither star showed any evidence of the Balmer series in emission nor a strong UV continuum. Spectra were obtained in 1987 March and are shown in Figure 6 where A refers to the easternmost star (that one with strong Ca II H and K on the objective prism plate) and B to the westernmost star. We find from the spectra the following photometric results: Star A: $B = 16.5$, $B-V = 0.8$; Star B: $B = 16.4$, $B-V = 0.9$. Examination of the spectrum of star A reveals no detectable emission at Ca II H and K at a strength which would have been easily visible on a low-dispersion objective prism plate. Weak persistent emission at Ca II H and K is not excluded on the basis of our IDS spectrum. CW 1630+535A is apparently then an active chromosphere star as these stars show strong and possibly variable Ca II emission. Ca II emission-line fluxes for 14 active chromosphere stars, many of them RS CVn binary systems, have been presented by Bopp (1984). CW 1630+535A may be similar to or more active than HD 8357 or BD+30°448, both RS CVn stars. HD 8357 is a transient X-ray source and this suggests flare activity and Ca II variability (Garcia *et al.* 1980; Bopp 1984).

We wish to thank Peter Pesch and Nick Sanduleak for performing the Case Low-Dispersion Northern Sky Survey and helpful discussions. The various types and numbers of objects discovered during the course of this follow-up survey are a tribute to their fine work. We would also like to thank Gary Schmidt, Harry Shipman, Ronald Kaitchuck, Robert F. Wing, and Pat Boeshaar for helpful discussions. Most of the reduction and measurements were performed at the Lowell Observatory computer facility and we thank the Lowell Observatory for the computer use and support. This research is supported by NSF grant AST-8517125 to Villanova University.

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