FAINT BLUE OBJECTS AT HIGH GALACTIC LATITUDE. VI. PALOMAR SCHMIDT FIELD CENTERED ON SELECTED AREA 82

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ABSTRACT

Starlike objects with both blue and ultraviolet excess have been selected from a seventh Palomar 1.2 m Schmidt field centered on Kapteyn Selected Area 82, at high galactic latitude. The method of selection is identical to that used in previous papers of this series. Objects having color excesses greater than halo F and G subdwarfs are listed to magnitude $B = 16.9$. The sample is complete to that magnitude, within the limits imposed by photometric error and the method of selection. The primary goal of this work is to increase areal coverage of the combined surveys of this series at the brighter limits, in order to improve the number-count statistics there. We list color classes, color subclasses, approximate positions, and $B$ magnitudes for 22 objects whose colors suggest that they are not F or G subdwarf stars. Spectra for 13 of the objects have been obtained with the NOAO 2.1 m telescope, and preliminary spectral types are given. The spectroscopic sample of the bluest (CC1) objects is complete to $B = 16.5$ mag over $24.85 \, \text{deg}^2$; it contains no new quasars, but three new white dwarf stars are reported. The results are briefly discussed.

Subject headings: high-latitude objects — quasars — stars: faint blue — stars: white dwarfs

I. INTRODUCTION

Halo subdwarfs are a natural means by which to determine whether objects at high galactic latitude have a blue and/or ultraviolet color excess ($B$-$UVX$). Their incidence relative to bluer objects at high Galactic latitudes is quite high, and relative colors of blue objects are readily apparent when the broadband colors of all objects are compared. This concept is the basis of the three-color Tonantzintla selection method devised by Haro (1956) and Haro and Luyten (1962). According to this method, three exposures of the same field are recorded on the same photographic plate, with each subsequent exposure offset by a small angle from the previous one. Each triple image corresponds to two independent color indices. Since the final system advocated by Haro and Luyten mimics the Johnson $UBV$ system, the two independent color indices may be taken to be $U - B$ and $B - V$.

In the $UBV$ two-color diagram, quasars and hot stars occupy regions distinctly separate from the ubiquitous halo F and G stars (Sandage 1965), and the selection of candidate objects can be made solely on the basis of color. The selection criteria are therefore well defined, which in turn promotes confidence when deciding issues of statistical completeness. As a consequence of the tight and quantifiable selection criteria of the two-color method, Sandage suggested that a survey of fields at high galactic latitude be undertaken.

Jaidee and Lynga (1969) were the first to realize that if selection by color is to proceed quantitatively, then absolute photometry is unnecessary; rather, it suffices merely to establish the existence of color excess by uncalibrated photometry relative to the halo subdwarfs. A secondary benefit of this approach is that both systematic and random photometric errors incurred in the process of selection are bypassed. Jaidee and Lynga were concerned only with color excess in $U - B$, but the principle can be extended to any number of color indices.

Lists of objects having both $U - B$ and $B - V$ excess have been compiled and published in previous papers of this series (Usher, Mitchell, and Warnock 1988, and references therein). Unreduced colors $"u - b"$ and $"b - v"$ are sufficient to establish color excess relative to subdwarfs, where $u$, $b$, and $v$ are raw, uncalibrated magnitudes determinable directly from the plate with an absolute minimum amount of processing. Throughout the survey, likely candidates were initially selected by eye after three independent scans of each field. In this field, no attempt is made to include any objects which appear to be resolved.

Completeness is claimed for objects that satisfy (1) the color criterion (ultraviolet-excess), and (2) the morphological criterion (starlike). With this paper, such designated "US" objects of all CC now total 3987 in seven fields.

Labels may be attached to each selected object as a rough guide to the degree of color excess (Usher 1981). Objects of prime interest have the greatest empirical color excesses relative to F and G subdwarfs and are called Color Class 1 (CC1). The formal definition of CC1 objects is that they are expected to have $U - V < 0$ or to lie above the blackbody cooling curve. Objects with halo subdwarf colors have been designated CC3. Owing to random photometric errors of measurement, and perhaps also for reasons intrinsic to the sources themselves, the boundary of the CC3 objects is not absolutely sharp; thus, ob-
objects that lie between CCI and CC3 are called CC2. The CCI
objects are further subclassified: the designation “CC1” itself is
reserved for objects with $U - V < 0$ that are estimated to lie
near the blackbody cooling curve; objects above the curve are
designated as CC1A, those below the curve as CC1B, while
those that are even further below the curve, and which may
therefore be nondegenerate blue stars, are designated CC1BS.
Objects with $U - V > 0$ but still above the blackbody curve,
are classified as CC1C.

II. SELECTION IN THE SA 82 FIELD

In order to improve statistics on the incidence of color-ex-
cess objects at the bright end of the US survey, we have studied
a field centered on SA 82 to a completeness limit of about $B$
= 16.9 mag. This extends the search area by 24.85 deg$^2$. Selection
has proceeded by the methods outlined above. Objects
were selected from Palomar 1.2 m Schmidt plate PS 28496
(1981 June 1/2; 103a-D; UG-1, 90 minutes; Wr45, 36 minutes;
and Wr12, 9 minutes). This emulsion/filter combination
is similar to the original Tonantzintla prescription, but pro-
vides slightly better color leverage between the U and B re-
mutes; and WR12, 9 minutes). This emulsion/filter combination
were selected from Palomar 1.2 m Schmidt plate PS 28496
a field centered on SA 82 to a completeness limit of about B
was based only on the bluest available standards, but since
these are not as blue as the bluest objects cataloged, there is
probably a systematic tendency for CCI objects to be slightly
fainter than the values tabulated. Random errors of $\sim 0.1$ mag
are estimated from the scatter in the calibration curve.

All selected CCI1 and CC2 objects are listed in Table 1. Col-
umn (1) lists the running number of the survey. Column (2)
gives the magnitude, uncorrected for galactic extinction be-
cause any correction is likely to be small compared to the pho-
metric uncertainty (Burstein and Heiles 1982). Column (3)
contains the color class and subclass. Columns (4) and (5) give
approximate positions, with finding charts given in Figure 1;
these positions were determined by triangulation from known
positions of stars listed in the SAO catalog. Column (6) gives a
preliminary spectral identification (§ IV), and column (7)
contains notes for individual sources, with “C” connoting a
confused source as observed during selection. Previously iden-
tified objects are given in the final column, with associated
spectral types in parentheses.

Not all selected CC3 objects are listed in Table 1, because the
primary goal of this work is to augment CCI and CC2 selection
at bright magnitudes. The three CC3 objects that are listed in
Table 1 were included because their empirical colors showed
up to lie blueward of the edge of the distribution of halo F
and G stars in the two-color diagram; preliminary spectral identifications suggest that they are A stars (§ IV).

III. COMPLETENESS

Three objects identified in other surveys are listed in Table
1. A fourth object (the sdB star PG 1420+16; Green, Schmidt,
and Liebert 1986) is not listed. As it happens, it was selected by
us because it is blue enough to be at least a potential color calibrator. But both the iris-photometric colors and visual in-
spection placed it in the CC3 category, with empirical $(b - v)$
colors that suggest that it might be an early F star. It was there-
fore assigned a color class of 3, and so is omitted from Table 1.
As to the possibility that it might be a variable, we derive a
magnitude 16.0 virtually the same as that of Green et al.
(1986).

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<th>B (mag)</th>
<th>CC</th>
<th>$\alpha$ (1950)</th>
<th>$\delta$ (1950)</th>
<th>Sp.</th>
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REFERENCES.—(1) Eggen and Greenstein 1965; (2) Green, Schmidt, and Liebert (1986).
Fig. 1.—Finding charts for selected objects in the Palomar 1.2 m Schmidt field centered on SA 82
On the basis of the spectroscopic identifications done so far, only US 3977 has turned out to be a halo subdwarf, and this object was included in the list only because a confusing source rendered its CC uncertain. On the other hand, a more satisfactory result would have been for more sdF/G stars to have been assigned bluer color classes, thereby ensuring a higher level of completeness in the CC1 and CC2 selection. Preliminary spectroscopic results from all US survey fields for B brighter than \(-18.0\) mag, indicate a 10%-15% incidence of sdF/G stars among all CC1 categories, so the present results can mean either that the color selection has been accurate, or that there is some degree of incompleteness among the CC1 categories. The high incidence of white dwarfs identified in the field (§ V) suggests the former alternative is the case. Concerning the possibility that there is a selection bias against objects that are relatively quite bright (Warnock et al. 1986), we know of no object that should have been selected but was not.

IV. SPECTROSCOPIC IDENTIFICATIONS

As part of a larger spectroscopic survey of the US lists, spectroscopy for 13 of the US objects selected in SA 82 was obtained at the KPNO 2.1 m telescope on the nights of 1986 December 30 through 1987 January 3. The Intensified Image Dissector Scanner and Gold Spectrograph were employed, along with a 300 1 mm\(^{-1}\) grating, to obtain spectra with a wavelength coverage between 3500 and 7000 Å. Circular entrance apertures with diameters of 8''5 provided a spectral resolution of \(-19\) Å. Typical integrations lasted until \(-250\) to 500 sky-subtracted counts per channel were obtained in that part of the continuum where the raw-energy distribution peaked. The spectra were flux and wavelength calibrated by use of KPNO’s mountain reduction software and IRAF.

The spectroscopic identifications presented in Table 1 are derived from visual inspection of the calibrated spectra. The combination of moderately good signal-to-noise (S/N) and spectral resolution, with coverage wide enough to include the rest wavelengths of all Balmer lines and the Balmer jump, is adequate to identify quasars and to distinguish accurately between the major types of hot stars. Objects classed as DA white dwarfs have Balmer line strengths that indicate large surface gravities (log \(g\) > 7) and moderate temperatures, so that identification should be unambiguous at 19 Å resolution. The S/N and spectral resolution do not permit the A and B stars to be further subclassified as normal or horizontal-branch stars as defined by Greenstein and Sargent (1974). Only US 3977 has an uncertain spectroscopic identification owing to a low S/N spectrum contaminated by morning twilight; it appears to be a hot star with Balmer lines probably weaker than a DA white dwarf, and with a Balmer jump sufficiently strong to suggest a normal or horizontal-branch B star (as distinct from an sdB star).

V. THE INCIDENCE OF BRIGHT COLOR-EXCESS OBJECTS

a) Quasars

The spectroscopic completeness limit of the CC1 objects listed in Table 1 is \(B = 16.5\) mag. The Medium-Bright Quasar Survey (MBQS) of Mitchell, Warnock, and Usher (1984) has identified five quasars of this magnitude or brighter with \(M_B < -23.0\) mag (Schmidt and Green 1983) over an area of 108.6 deg\(^2\). The fact that no quasars were found to \(B = 16.5\) mag over the 24.85 deg\(^2\) of the SA 82 survey means that the cumulative surface density of quasars at this magnitude or brighter that have been discovered in the US survey must be lowered slightly. Five quasars with \(M_B < -23.0\) mag are now found over 133.45 deg\(^2\), for an average incidence of \(N(B < 16.55) = 0.037 \pm 0.017\) per deg\(^2\). This brings about only a slight change in the best-fit estimate of cumulative incidence \(N\) per deg\(^2\) derived by Mitchell, Warnock, and Usher (1984):

\[
\log N(<B) = 0.84(B - 18.25) \tag{1}
\]

Equation (1) predicts that \(-2 \pm 1.5\) quasars should be found from the list in Table 1 to the survey completeness limit of \(B \leq 17.0\) mag. To the spectroscopic completeness limit of \(B = 16.5\), less than one quasar is expected, and the fact that none is found is therefore within the bounds of normal expectation.

b) Hot Blue Stars

The spectroscopic identifications of Table 1 include five DA white dwarfs, four A stars, two B stars, and one sdB star, all with \(B \leq 16.5\) mag. Three of the DA white dwarfs are newly identified. These stars have been included in the recent discussion by Mitchell, Howell, and Usher (1987) of the number counts of hot blue stars selected in the US survey.

The incidence of five DA white dwarfs with \(B \leq 16.5\) mag over \(-25\) deg\(^2\) is the highest yet found in any similarly sized US survey field. The number expected can be estimated from:

\[
N(B < B_{lim}) = \sum_{M_B} \Omega \phi_0(M_B) \int_0^{r_{max}} r^2 \rho(z) dr, \tag{2}
\]

where \(5 \log r_{max} = B_{lim} - M_B + 5\). Equation (2) is the density-weighted volume integral over the local luminosity function \(\phi_0(M_B)\) of DA white dwarfs, with the summation taken over the magnitude bins of the luminosity function. For \(\phi_0(M_B)\) we use values by Fleming, Leibert, and Green (1986) for the PG survey (Green, Schmidt, and Leibert 1986), with their \(M_V\) converted to \(M_B\) through the \(M_V\) versus color relation of Sion and Leibert (1977). The density-weighting factor is taken to be \(\rho(z) = \exp (z/z_0)\), where \(z = r \sin b\) is the perpendicular height above the galactic plane, and the scale height \(z_0 = 250\) pc (Green 1980).

For the SA 82 field, \(\Omega = 24.85\) deg\(^2\), \(B_{lim} = 16.55\) mag, and the galactic latitude is \(b = +66.2\)°. These numbers and equation (2) predict that \(-1.2\) DA white dwarfs would be expected in the SA 82 field to the spectroscopic limiting magnitude of \(B = 16.5\). This prediction is a factor of 4 lower than the number actually found, while preliminary spectroscopic results from the other US survey fields indicate that this factor is \(-1.3\) to 2 depending on the magnitude limit. A useful future course of study would be to obtain an independent determination of the DA white dwarf luminosity function from the US survey in order to investigate their local space density further.

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REFERENCES


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