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AN ULTRAVIOLET-VISIBLE INVESTIGATION OF THE GLOBULAR CLUSTER NGC 1851

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ABSTRACT

Two-color ultraviolet images of the globular cluster NGC 1851 were obtained with the Ultraviolet Imaging Telescope (UIT) during the 1990 December Astro-1 Spacelab mission. A total of 133 stars are detected at 2490 Å and 74 stars at 1520 Å. An ultraviolet color-magnitude diagram based on the 46 well-photometered stars that appear in both images is presented. Thirty-nine of the 45 horizontal branch (HB) stars fall below the zero-age horizontal branch (ZAHB) of $Z = 0.001$ and $Y = 0.23$ predicted by Sweigart by as much as 0.6 mag if the interstellar reddening to the cluster is $E(B-V) = 0.02$. Supporting ground-based V and B observations, however, show excellent correlation with the same model ZAHB. A newly detected hot subdwarf star with $T_{\rm eff} \sim 26{,}000$ K appears to be an extreme horizontal branch star. The measured flux for this star also falls approximately 0.6 mag below the position on the CMD predicted by parameters derived from ground-based spectroscopy by Landsman. The far-ultraviolet image is dominated by the ultraviolet-bright member star UV 5, which contributes 30% of the total flux at 1520 Å. The UIT photometry is consistent with the classification of UV 5 as a post–asymptotic giant branch (PAGB) star. To a limit of 16.5 mag at 1520 Å we find no ultraviolet counterpart within 6″ of the position of the X-ray source MX 0513−40.

Subject headings: globular clusters: individual (NGC 1851) — Hertzsprung-Russell (HR) diagram — stars: AGB and post-AGB — stars: horizontal branch — ultraviolet: stars

1. INTRODUCTION

Observations with the Ultraviolet Imaging Telescope (UIT; Stecher et al. 1992) during the Astro-1 mission of the Space Shuttle Columbia in 1990 December provided an excellent opportunity to apply the techniques of ultraviolet imaging and photometry to several globular star clusters (Hill et al. 1992; Landsman et al. 1992). These methods facilitate the systematic study of low-mass stars in the later stages of evolution. The solar-blind characteristics of the UIT suppress emission from main-sequence and red giant stars, allowing the much rarer horizontal branch (HB) and post-asymptotic giant branch stars to appear very distinctly in the images. As a result, they can be accurately photometered, their effective temperatures and relative (or absolute) magnitudes can be obtained, and their statistical characteristics can be compared with the predictions of stellar evolution theory, as expressed, for example, in tracks on color-magnitude diagrams (CMDs). This paper reports on the UIT observations of NGC 1851. NGC 1851 is a globular cluster (optical center, R.A. = $05^{\rm h}12^{\rm m}28\overset{\rm s}{.}1$, Decl. = $-40°06'07''$ [equinox 1950; Shawl & White 1980]) with intermediate metallicity, [Fe/H] = −1.29, and a relatively bright HB, $V_{\rm HB} = 16.05$ mag, according to the parameters adopted by da Costa & Armandroff (1990). The cluster is also associated with the bright X-ray source MX 0513−40 (cf. Jernigan & Clark 1979). NGC 1851 also contains the ultraviolet-bright star UV 5, discovered by Vidal & Freeman (1975), who suggested that it is a binary system. Although Bolton & Mallia (1977) appeared to confirm that UV 5 is both a binary and the likely optical counterpart of MX 0513−40, later work seems to demonstrate that it is neither (Grindlay 1982; da Costa 1982).

2. OBSERVATIONS

2.1. *Ultraviolet Observations*

The UIT, a 38 cm Ritchey-Chrétien telescope with two cameras and 11 filters, obtained ultraviolet images with full width at half-maximum intensity (for stellar sources) of $2\overset{''}{.}3$ and $2\overset{''}{.}5$ in the near- and far-ultraviolet, respectively, over a 40′ field of view (Stecher et al. 1992). Six images of NGC 1851 were acquired during the 1990 December 2–10 Astro-1 mission. One of us (Parise) served on board Columbia as a crew member. Three observations were made with the A1 filter ($\lambda_{\rm center} = 2490$ Å, $\Delta\lambda = 1150$ Å) and three with the B1 filter ($\lambda_{\rm center} = 1520$ Å, $\Delta\lambda = 350$ Å). The exposure times for each set were 21, 109, and 543 s. The UIT images of NGC 1851 were digitized and calibrated by the methods of Stecher et al. (1992). Point-spread photometry was accomplished with an adaptation of the DAOPHOT algorithm (Stetson 1987), which takes into account the noise properties of the film and the non-Gaussian characteristics of the sky background. With the exception of measurements of the ultraviolet-bright object UV 5, a star that contributes 30% of the total flux of NGC 1851 in the 1520 Å images, all photometric data reported here are from the two 543 s exposures, no. FUV 0419 (1520 Å frame, obtained on 1990 December 9 at 02:06 UT exposure midpoint) and no. NUV 0342 (2490 Å frame obtained on 1990 December 9, 01:55 UT [Fig. 1, Pl. 3]). Errors introduced into the photometry by image overlap are minimized through the point-spread fitting function available in DAOPHOT. Point-spread photometry

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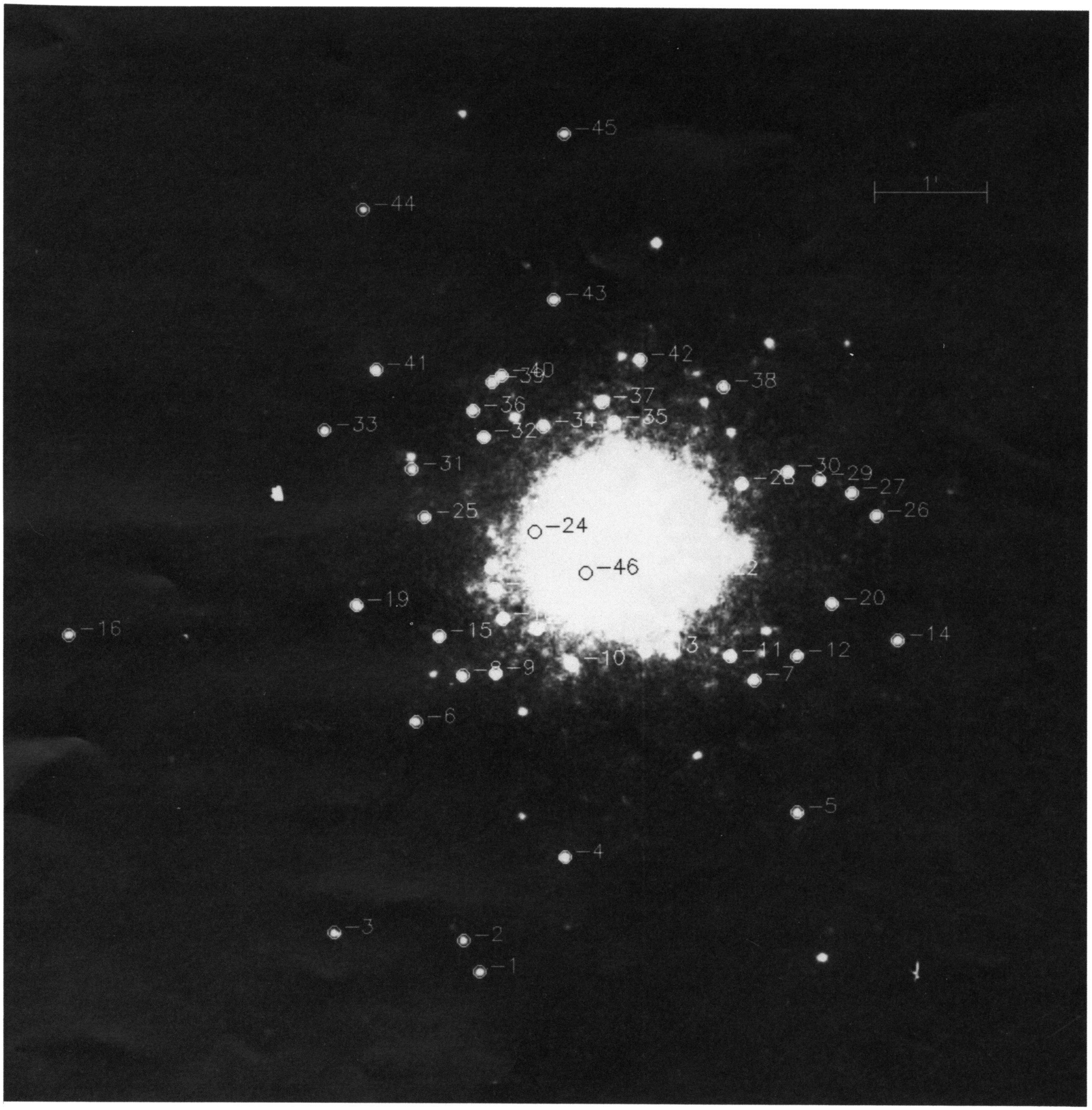

FIG. 1.—This 10′ field was extracted from a 543 s exposure through the A1 filter (λ = 2490 Å, $\Delta\lambda$ = 1150 Å). The 46 program stars which have good photometry and are detected in both UV images are identified. North is up.

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was conducted through a 3 pixel (3".6) radius aperture; the fluxes were then corrected with aperture corrections calculated from the mean of 10 isolated stars. The mean corrections for stars measured with the three-pixel aperture are −0.76 mag ± 0.05 (2490 Å images) and −0.87 mag ± 0.05 (1520 Å images). Although 133 stars were measured on the 2490 Å image, the extreme crowding made it necessary to reject all sources within 40" of the cluster center. This reduced the number of reliably measured stars to 46. Of the 74 stars measured on the 1520 Å image, 46 corresponded to the 46 uncrowded stars in the 2490 Å image and the remaining 28 were inside the 40" area which was saturated on the 2490 Å image. Photometry and positions for these 46 stars are presented in Table 1 and as a UV CMD in Figure 2.

2.2. *Ground-based Observations*

To support the UIT research, V (Fig. 3, [Pl. 4]) and B images of NGC 1851 were obtained on 1991 July 12 with the Thomson 1024 CCD camera on the 0.9 m reflector at Cerro Tololo Inter-American Observatory. The observing conditions, however, were not photometric, and it was not possible to consistently calibrate the data against standard star observations taken on the same night. Therefore, CCD photometry by Walker (1993), which correlates well with previous photographic work by Stetson (1981), was adopted to calibrate the V and B images. The transformations from the observed magnitudes as measured by DAOPHOT through a 3 pixel (1".8) radius aperture to Walker's magnitudes are

$$V_{\rm Walker} = V_{\rm observed} - 0.53$$

and

$$B_{\rm Walker} = B_{\rm observed} - 0.34 + 0.10(B-V)_{\rm observed} .$$

A total of 680 stars were measured in both B and V, with an rms scatter in the residuals of ±0.07 mag. Thirty of the 46 stars observed in the 10' UV images are also identified in the 5' V and B images and listed in Table 1. The remaining 16 stars are either outside the V and B field of view (nos. 1, 2, 3, 4, 16, 33, 44, 45), crowded with other brighter, cooler stars (nos. 13, 15, 31, 34), or saturated (nos. 22, 23, 24, 46). A $B-V$ versus V CMD with all 680 stars plotted is shown in Figure 4.

TABLE 1

PHOTOMETRY OF THE 46 PROGRAM STARS[a]

UIT No.	1520 Å	2490 Å	B	V	R.A.(1950)	Decl.(1950)
1.........	16.49	17.04	...	...	05h12m36s.8	−40°09′51″
2.........	16.78	17.22	...	...	05 12 37.4	−40 09 32
3.........	16.28	17.00	...	...	05 12 43.5	−40 09 21
4.........	15.94	16.65	...	...	05 12 32.2	−40 08 54
5.........	16.25	16.93	15.82	14.77	05 12 21.2	−40 08 44
6.........	16.26	16.98	16.84	16.93	05 12 38.5	−40 07 33
7.........	16.58	16.76	16.61	16.71	05 12 22.5	−40 07 31
8.........	16.30	16.91	16.75	16.78	05 12 36.1	−40 07 12
9.........	16.23	16.94	16.92	16.99	05 12 34.6	−40 07 13
10.........	16.03	16.09	16.50	16.50	05 12 31.0	−40 07 11
11.........	16.35	16.81	17.09	17.20	05 12 23.6	−40 07 16
12.........	16.39	16.88	16.79	16.81	05 12 20.3	−40 07 21
13.........	17.26	16.27	...	...	05 12 27.5	−40 07 10
14.........	16.19	16.85	16.70	16.75	05 12 15.5	−40 07 19
15.........	17.35	16.91	...	...	05 12 37.1	−40 06 49
16.........	16.30	17.04	...	...	05 12 54.4	−40 06 27
17.........	16.59	16.54	16.75	16.05	05 12 32.5	−40 06 51
18.........	16.41	16.67	15.66	14.54	05 12 34.0	−40 06 44
19.........	16.14	16.71	16.72	16.78	05 12 40.8	−40 06 28
20.........	16.49	16.87	16.97	17.04	05 12 18.5	−40 06 54
21.........	16.32	16.38	16.82	16.28	05 12 34.2	−40 06 29
22.........	16.00	16.21	...	...	05 12 24.2	−40 06 31
23.........	16.87	16.83	...	...	05 12 34.2	−40 06 17
24.........	16.80	16.07	...	...	05 12 32.0	−40 05 59
25.........	16.71	17.15	16.50	16.50	05 12 37.1	−40 05 45
26.........	16.46	16.91	16.43	16.41	05 12 16.0	−40 06 10
27.........	16.28	16.83	16.94	17.01	05 12 17.0	−40 05 57
28.........	16.66	16.62	18.81	17.85	05 12 22.0	−40 05 47
29.........	16.49	16.87	16.74	16.75	05 12 18.5	−40 05 48
30.........	16.42	16.64	17.24	17.42	05 12 19.9	−40 05 42
31.........	16.13	17.12	...	...	05 12 37.5	−40 05 19
32.........	16.64	16.84	16.60	16.62	05 12 34.0	−40 05 06
33.........	16.35	16.93	...	...	05 12 41.4	−40 04 54
34.........	16.39	16.75	...	...	05 12 31.1	−40 05 04
35.........	16.33	16.42	16.47	16.43	05 12 27.8	−40 04 51
36.........	16.37	16.88	16.77	16.83	05 12 34.4	−40 04 51
37.........	16.22	16.56	15.48	14.37	05 12 28.3	−40 04 53
38.........	16.55	17.07	16.66	16.68	05 12 22.5	−40 04 53
39.........	16.02	16.74	16.54	16.54	05 12 33.4	−40 04 38
40.........	16.10	16.73	16.81	16.86	05 12 33.0	−40 04 34
41.........	16.31	16.67	16.00	14.99	05 12 38.7	−40 04 25
42.........	16.22	16.75	16.52	16.55	05 12 26.3	−40 04 34
43.........	16.29	16.93	16.69	16.74	05 12 30.0	−40 03 57
44.........	15.87	17.28	...	...	05 12 38.5	−40 02 58
45.........	16.21	16.94	...	...	05 12 28.7	−40 02 29
46.........	10.42	11.13	...	...	05 12 29.9	−40 06 24

[a] With corresponding B and V magnitudes from the supporting observations at CTIO.

2.3. *UIT Observations of UV 5*

UV 5 was measured on the two 21 s UIT exposures of NGC 1851, no. FUV 0420 (1990 December 9, 02:16 UT) and no. NUV 0343 (1990 December 9, 02:04 UT). The image of UV 5 at 2490 Å, however, was saturated even in the 21 s exposure. An estimate of the 2490 Å flux of UV 5 was determined by fitting a Gaussian function to the wings of the saturated image, a procedure that unavoidably introduces some uncertainty. Accordingly, the ultraviolet color of UV 5, shown in Figure 2, is suspect. Calculation of an expected 2490 Å UIT magnitude for UV 5 from an *IUE* spectrum (LWP 22607), however, yields a value of 11.40 mag which differs from the estimate by only 0.28 mag. The 1520 Å flux reported here differs from that found from HUT observations of UV 5 by only 5% (W. Dixon 1992, private communication).

3. DISCUSSION

3.1. *The Reddening*

The interstellar reddening toward NGC 1851, a quantity crucial to interpreting ultraviolet observations, has been a controversial parameter. Recent work by Stetson (1981), later confirmed by Walker (1992), gives a value of $E(B-V) = 0.02 \pm 0.02$. However, other methods, which depend on intrinsic cluster properties, yield estimates in the range $0.07 < E(B-V) < 0.24$ (Zinn 1980; Alcaino 1969; Burstein & McDonald 1975; Harris 1976). A full discussion of the reddening toward NGC 1851, which discounts the higher values, is given by Walker (1992). The extinction in each of our wavelength bands is calculated from the parameterization of Cardelli, Clayton, & Mathis (1989) using $R_V = 3.1$. Although an ultraviolet extinction corresponding to an $E(B-V) = 0.12$ would place our photometry of the ultraviolet stars in NGC 1851 at or above a model ZAHB of $Z = 0.001$ and $Y = 0.23$, a reddening so large produces a very poor fit in the $B-V$ versus V CMD, which is consistent with $E(B-V) = 0.02$. The presence of anomalous ultraviolet extinction in the direction of NGC 1851 is also contradicted by the Hopkins Ultraviolet Telescope (HUT). A HUT spectrum of UV 5 taken contempo-

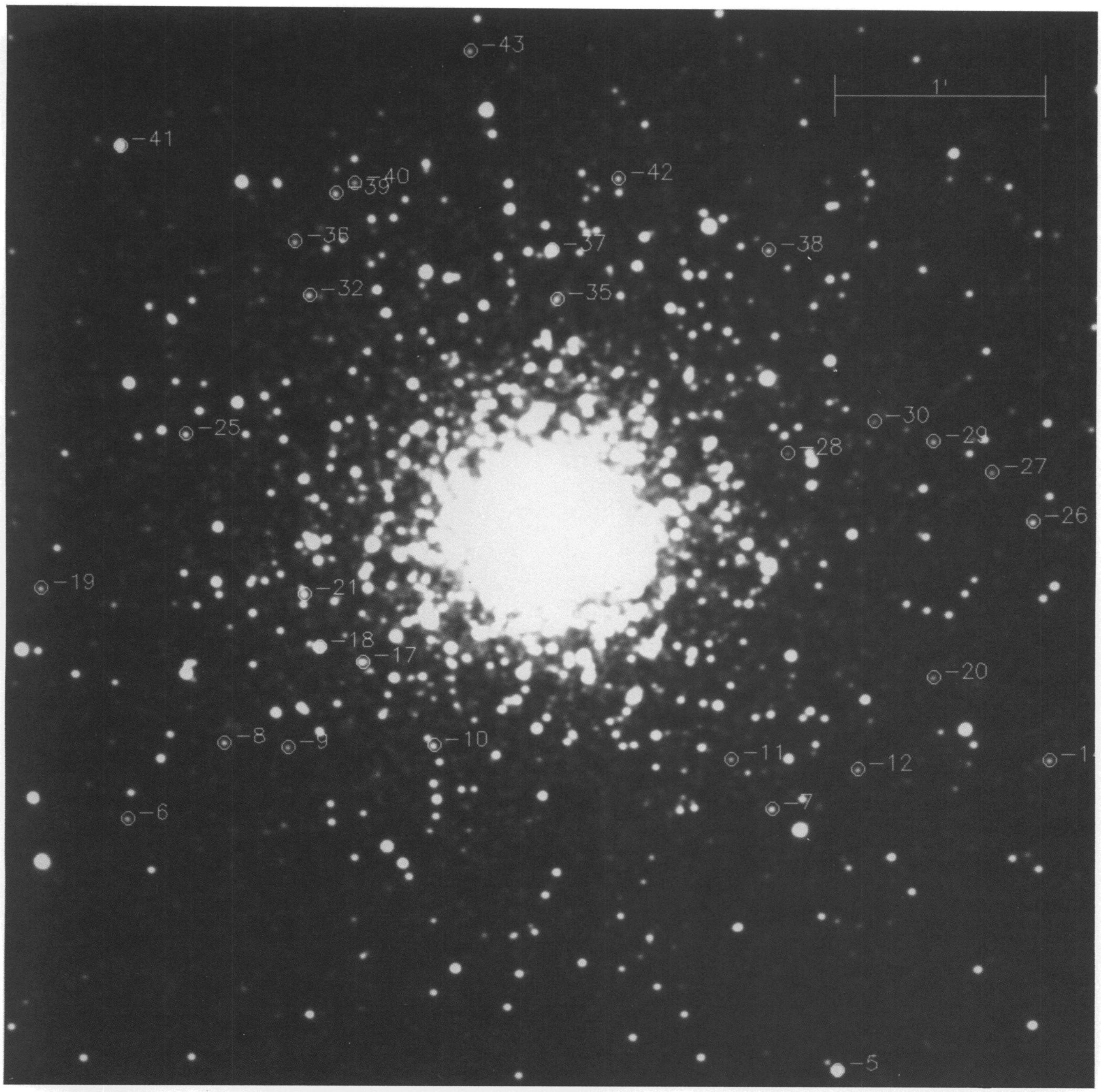

FIG. 3.—This 5′ field was extracted from a 300 s exposure in V. The image was taken with the CTIO 0.9 m telescope with a Thomson 1024 CCD. The 30 identified stars are those with counterparts in the UIT images. North is up.

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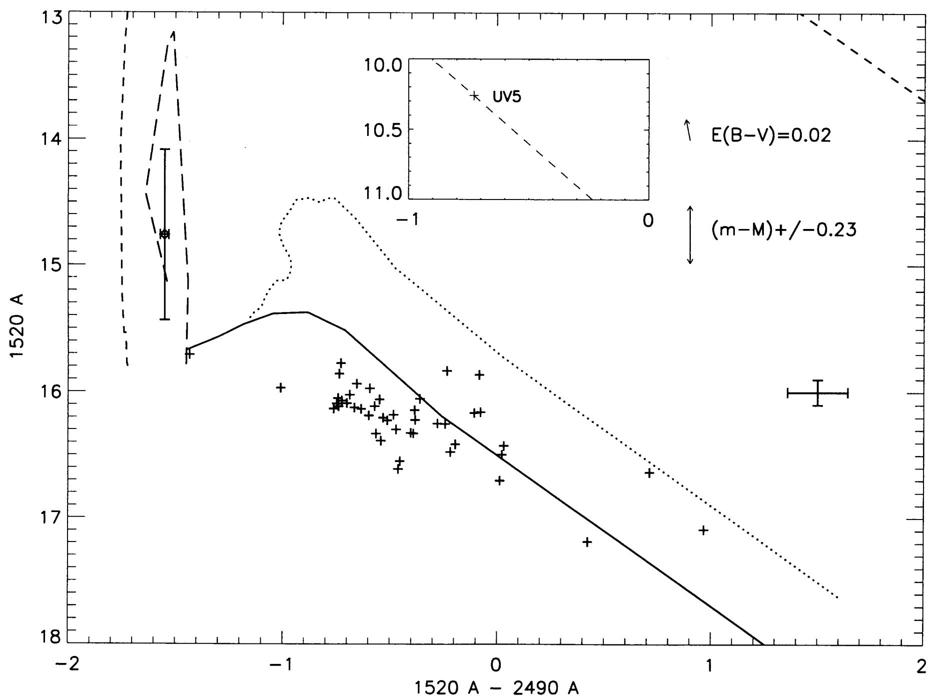

FIG. 2.—The points represented by the +'s are 46 stars which are detected in both the A1 (2490 Å) and B1 (1520 Å) filters. The solid line is a ZAHB from Sweigart (1987) for $Z = 0.001$, and $Y = 0.23$. The distance modulus used is $(M - m) = 15.49 \pm 0.23$. The observations were dereddened assuming $E(B-V) = 0.02 \pm 0.02$ utilizing the parameterization of Cardelli et al. (1989). The short-dashed line is a representative PAGB track from Schönberner (1983) for $m = 0.565 M_{\odot}$. The dotted line is an evolutionary track from Castellani et al. (1991) for a HB star of $m = 0.55\ M_{\odot}$. The long-dashed line is an evolutionary track from Caloi (1989) of an extreme HB star. The star at the blue end of the ZAHB line is the hot subdwarf star (UIT 44). The diamond-shaped point with error bars at a color of -1.55 is the predicted position of the hot subdwarf star from ground-based spectra of Landsman et al. (1993). The inset at the top depicts the position of the UV 5 PAGB star in relation to the Schönberner model track.

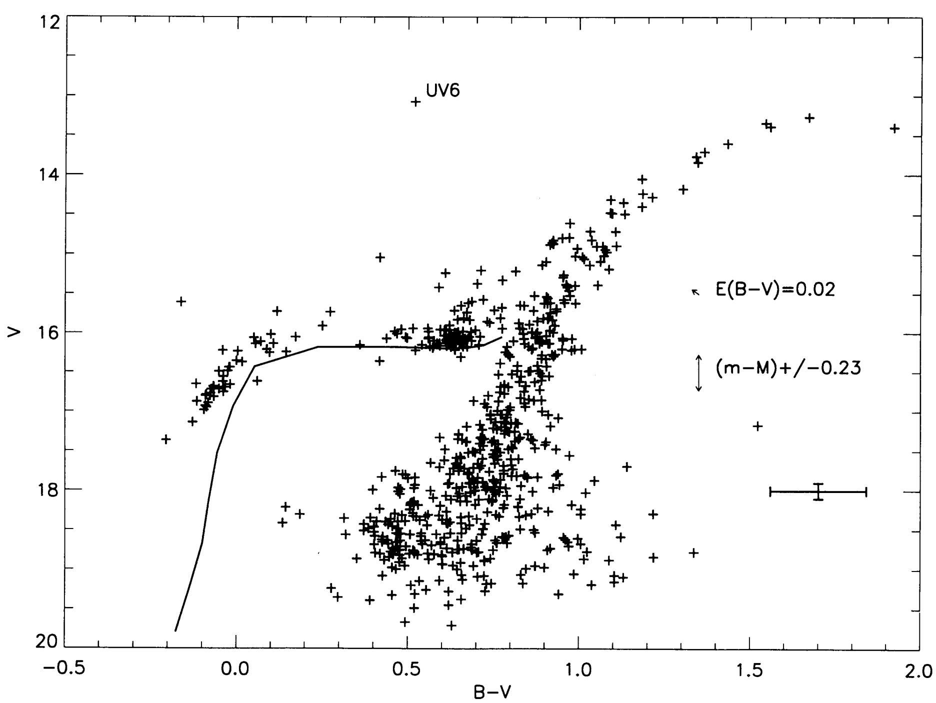

FIG. 4.—V and B CCD observations of 680 stars, as obtained with the CTIO 0.9 m telescope. A distance modulus of $(M - m) = 15.49$ was used to position the model ZAHB, and an $E(B-V) = 0.02 \pm 0.02$ (Walker 1992) was used to deredden the stars according to the parameterization of Cardelli et al. (1989). UV 6, which had been a good candidate for a PAGB star, has since been shown by da Costa & Armandroff (1990) not to be a cluster member.

raneously with our images yields an $E(B-V)=0.06$. Further, there is no obvious absorption at the wavelength of the interstellar 2200 Å feature in our *IUE* spectrum of UV 5 (LWP 22607), a finding that is again consistent with very low reddening. Based on these arguments, we have adopted Stetson's (1981) reddening, $E(B-V)=0.02$, with the corresponding absolute extinctions to NGC 1851 of $A_{2490}=0.145$ mag and $A_{1520}=0.164$ mag.

3.2. *Evolutionary Status*

We used several models to investigate the evolutionary status of the stars in Figure 2. The ZAHB, which represents the locus of HB stars of varying mass and equal evolutionary age, is generated with the stellar models of Sweigart (1987) and is represented by the solid line. A metallicity of $Z=0.001$, which corresponds to $[\mathrm{Fe/H}]=-1.33$, is adopted from Zinn (1980), and a helium abundance of $Y=0.23$. Stetson (1981) found a distance modulus of $(m-M)=15.39\pm0.23$ for NGC 1851. Stetson compared the mean observed m_V of the HB with a value of $M_V=0.6$ which corresponds to the theoretical ZAHB (Sweigart 1987). The ZAHB, however, should be at the lower luminosity limit of the HB, not the mean. Taking the HB to be 0.2 mag thick (Sandage 1990), we therefore adopt $(m-M)=15.49$. The dotted line in Figure 2 represents an evolutionary track (Castellani, Chieffi, & Pulone 1991) for a star of $m=0.55\ M_\odot$ over a period of approximately 120 Myr. Many of the stars to the right of the large group centered at a color of $m_{1520}-m_{2490}=-0.7$ probably originated near that group and are now evolving along tracks parallel to the Castellani track. Figure 2 also contains an evolutionary track (Caloi 1989) for an extreme HB star of $M=0.503\ M_\odot$ that does not evolve toward the AGB. Our star UIT 44, with an ultraviolet color $m_{1520}-m_{2490}=-1.44$, seems to be a good candidate for such an object. However, at the corresponding high temperature ($T_{\mathrm{eff}}\sim26{,}000$ K), this color is not a very good temperature discriminator. Landsman et al. (1993) observed UIT 44 spectroscopically with the CTIO 4 m telescope. The spectrum shows only weak Balmer absorption lines and is similar to the spectra of some helium-poor field sdB stars. The measured radial velocity of 333 km s^{-1} confirms cluster membership, and Balmer line fitting gives $T_{\mathrm{eff}}=29{,}700\ \mathrm{K}\pm1630$ and $\log g=5.39\pm0.27$.

3.3. *Nature of UV 5*

The post-asymptotic giant branch (PAGB) evolutionary phase is difficult to investigate empirically. The duration is typically less than 0.5 Myr, so few PAGB stars exist at one time in a single cluster. Renzini (1985) suggests that a galactic globular cluster of age 1.5×10^{10} yr and total luminosity L_T will have $n_j=(2\times10^{-11})L_T t_j$ stars in evolutionary phase j where t_j is the time spent in that phase. The total luminosity can be estimated from the published $M_V=-8.1$, and $B-V=+0.78$ ($T_{\mathrm{eff}}\sim5300$ K) from Harris & Racine (1979). Using the Kurucz (1992) models we find a total luminosity of $L_T=1.7\times10^5\ L_\odot$ is required to reproduce these values. According to this argument, if we assume a maximum PAGB lifetime of 5×10^5 yr (Schönberner 1983) we should find one or two PAGB stars in NGC 1851. A PAGB track by Schönberner (1983) for $M=0.565\ M_\odot$ is shown in Figure 2. It is clear from the position of UV 5 in Figure 2 (see inset) that its ultraviolet color and magnitude are consistent with those of a representative PAGB star. If da Costa (1982) is correct in reporting that prior indications of substantial radial velocity variations in UV 5 were mistaken, then this classification would appear to be the simplest interpretation of UV 5. A similar conclusion was reached from the far-ultraviolet spectrum observed at 3 Å resolution by Dixon et al. (1991) with the Hopkins Ultraviolet Telescope. The "apparent variable H-beta emission" in UV 5 reported by Vidal & Freeman (1975) and seemingly confirmed by Bolton & Mallia (1977), if real, might be a manifestation of residual mass loss in the PAGB pl.ase.

3.4. *The X-Ray Source*

Bailyn et al. (1988) summarized the optical identification situation for MX 0513−40: although it is well off-center in the cluster, at a projected distance of two core radii (Grindlay et al. 1984), which should facilitate identification, they found no blue object "in or near the error ellipse." We have examined our 1520 Å image for evidence of an ultraviolet counterpart for MX 0513−40 and find no star above the detection limit of 16.5 mag within 6″ of the position reported by Grindlay et al. (1984). The latter authors suggested that binary interactions in a collapsing cluster subcore may have ejected this object to its present large radial offset.

3.5. *Comparison with M79 and ω Cen*

NGC 1851 and M79 (Hill et al. 1992) are the two globular clusters for which ultraviolet CMDs are now available. There are pronounced differences between these two CMDs, which may provide clues to the different evolutionary histories of the two clusters. In M79, Ferraro et al. (1992) see a heavily populated HB in V and B which extends to their detection limit. In the UV, Hill et al. found that the well-populated HB extends blueward to at least $m_{1520}-m_{2490}=-1.4$, while in NGC 1851, we find that the HB extends from about $m_{1520}-m_{2490}=0.6$ ($T_{\mathrm{eff}}=8500$ K) to about $m_{1520}-m_{2490}=-0.7$ ($T_{\mathrm{eff}}=10{,}700$ K). M79 also exhibits lower than predicted UV fluxes by several tenths of a magnitude. There is a star that very likely is a PAGB object (UV 5) in NGC 1851, and a somewhat less strong PAGB candidate (UIT 1) in M79. Omega Cen was imaged in only one color with the UIT during Astro-1 but has been compared with models using V observations (Landsman et al. 1992) and found to produce lower than predicted UV fluxes also. Both M79 and ω Cen have several stars which are located well above the extreme blue end of the HB whereas NGC 1851 has only one (UIT 44). The fact that M79 and ω Cen also have more heavily populated extreme horizontal branches (EHBs) than NGC 1851 supports the conclusion that these stars are in fact EHB stars that have evolved upward from the ZAHB along tracks such as those computed by Caloi (1989).

4. CONCLUSIONS

From a comparison of the first UV CMD for NGC 1851 with published evolutionary models, it appears that the stars detected on both of the UIT 543 s exposures (at 1520 Å and 2490 Å) fall significantly below the UV flux predicted by a model ZAHB. We also see this effect in M79 and ω Cen, which were observed by UIT. This suggests that the HB stars in globular clusters may have a source of UV opacity in their atmospheres which is not accounted for in the Kurucz (1992) model atmospheres that are used to compute their fluxes. The newly found hot subdwarf star UIT 44 appears to be an isolated EHB star with small envelope mass based on both the UV photometry and visible spectroscopy. Both M79 and ω Cen have several stars in similar positions above the extreme blue end of the HB. Both clusters also have well-populated EHBs supporting the hypothesis that these stars are evolved EHB stars. The UV-bright star UV 5 has ultraviolet colors and magnitudes consistent with classification as a PAGB star.

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REFERENCES

Alcaino, G. 1969, ApJ, 156, 853
Bailyn, C. D., Grindlay, J. E., Cohn, H., & Lugger, P. M. 1988, ApJ, 331, 303
Bolton, A. J., & Mallia, E. A. 1977, A&A, 59, L23
Burstein, D., & McDonald, L. H. 1975, AJ, 80, 17
Caloi, V. 1989, A&A, 221, 27
Cardelli, J. A., Clayton, G. C., & Mathis, J. S. 1989, ApJ, 345, 245
Castellani, V., Chieffi, A., & Pulone, L. 1991, ApJS, 76, 911
da Costa, G. S. 1982, PASP, 94, 769
da Costa, G. S., & Armandroff, T. E. 1990, AJ, 100, 162
Dixon, W. V., et al. 1991, BAAS, 23, 912
Ferraro, F. R., et al. 1992, MNRAS, 256, 391
Greggio, L., & Renzini, A. 1990, ApJ, 364, 35
Grindlay, J. E. 1982, in IAU Colloq. 68, Astrophysical Parameters for Globular Clusters, ed. A. G. D. Philip & D. S. Hayes (Schenectady: L. Davis Press), 17
Grindlay, J. E., et al. 1984, ApJ, 282, L13
Harris, W. E. 1976, AJ, 81, 1095
Harris, W. E., & Racine, R. 1979, ARA&A, 17, 241
Hill, R. S., et al. 1992, ApJ, 395, L17
Jernigan, J. G., & Clark, G. W. 1979, ApJ, 231, L125
Kurucz, R. L. 1992, in The Stellar Populations of Galaxies, ed. B. Barbuy & A. Renzini (Dordrecht: Kluwer), 225
Landsman, W. B., et al. 1992, ApJ, 395, L21
———. 1993, BAAS, 25, 884
Renzini, A. 1985, in Horizontal-Branch and UV-Bright Stars, ed. A. G. Davis Philip (Schenectady: L. Davis Press)
Renzini, A., & Fusi Pecci, F. 1988, ARA&A, 26, 199
Sandage, A. 1990, ApJ, 350, 603
Schönberner, D. 1983, ApJ, 272, 708
Shawl, S. J., & White, R. E. 1980, ApJ, 239, L61
Stecher, T. P., et al. 1992, ApJ, 395, L1
Stetson, P. B. 1981, AJ, 86, 687
———. 1987, PASP, 99, 191
Sweigart, A. V. 1987, ApJ, 65, 95
Vidal, N. V., & Freeman, K. C. 1975, ApJ, 200, L9
Walker, A. R. 1992, PASP, 104, 1063
Zinn, R. 1980, ApJS, 42, 19