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THE X-RAY SOURCE MX 0513−40 AND THE GLOBULAR CLUSTER NGC 1851

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ABSTRACT

A hot low-gravity "UV-bright" star is found near the edge of the 1 σ error box of MX 0513−40 and about 0'.5 from the nucleus of the globular cluster NGC 1851. Its radial velocity is consistent with cluster membership and may be slightly variable. On some spectra a blueward emission component is found at Hβ.
Subject headings: early-type stars — globular clusters — X-ray sources

I. INTRODUCTION

Several globular clusters are known to lie within the boundaries of X-ray error boxes. These are NGC 6441 (3U 1746−37), NGC 6624 (3U 1820−30), M15 (3U 2131+11), and M92 (3U 1736+43). Only the two first identifications may be correct, since the corresponding X-ray error boxes are less than 0.02 deg^2. Both have a relatively high number of counts, and 3U 1820−30 is slighly varying (Giacconi *et al.* 1974) and pulsates on short time scales (Giacconi 1974). Recently, Markert and Clark (1975) announced the discovery of a new X-ray source located at $\alpha = 5^h13^m.4 \pm 0^m.7$, $\delta = -40°06' \pm 8'$, and suggested the globular cluster NGC 1851 as its optical counterpart. This new source is reported to vary by a factor as high as about 4 in 10 days. Thus it seems that there are now at least two *variable* X-ray sources which are relatively well identified with globular clusters, namely, 3U 1820−30 and MX 0513−40. However, the optical identification of Population II objects with X-ray sources seems to contradict the current belief (based on a sample of well identified objects) that variable X-ray sources are probably connected with binary systems in which the primary component is an early type star (see Jones, Chetin, and Liller 1974).

If the association of U Gem stars and novae is correct, then the discovery of three novae in globular clusters (Sawyer Hogg 1973) could suggest that U Gem stars in globular clusters may provide the observed X-ray emission. So far there is not much information about these stars; however, the three clusters with known novae (NGC 6093, NGC 6402, and NGC 6553) are not suspected X-ray sources. There is another well known class of stars which are definitely globular cluster members, exhibit many of the properties of early type stars, and may be binaries. These are the ultraviolet-bright (UV-bright) stars (see Zinn 1974) which may be highly evolved post-horizontal-branch objects. For one such star, Barnard 29 in M13, Stoeckly and Greenstein (1968) give some evidence of its binary nature. (For a more recent discussion of this star, see Auer and Norris 1974). Another example, although not a cluster member, is the halo UV-bright star HD 137569 (Danziger and Jura 1970): this star has well-established radial velocity variations and may be a highly evolved component of a Population II binary system. It is not clear yet whether this possible binary nature contributes significantly to the evolutionary state of these UV-bright stars themselves.

In an attempt to check whether UV-bright stars are connected with X-ray sources, we have chosen the most spectacular variable X-ray source in the globular cluster NGC 1851 for which no UV-bright stars have been reported until now (see Alcaino 1969, 1971). We undertook a photometric and spectroscopic search and found an outstanding hot UV-bright star with a varying emission line at Hβ and a possible variable radial velocity.

II. OBSERVATIONS

To make our search complete, we started with very short photographic *UBV* exposures such that (*a*) the nucleus of the cluster would be resolved as much as possible; (*b*) all outstanding UV-bright stars would show immediately. Figures 1 and 2 (plates L1 and L2) are reproductions of the *U* and *V* plates which show clearly three UV-bright stars of which the closest to the cluster nucleus (about 0'.5) is the bluest and brightest. No other UV-bright stars are found within the error box given by Markert and Clark. (Fig. 3 [Pl. L3]) is a reproduction of a longer exposure *V* plate which is given for identification purposes.) Obviously, crowding effects prevent any reliable photoelectric measurements of the magnitude and colors of this star. Therefore, we took several short-exposure *UBV* plates and established a photoelectric "sequence" of three blue stars in the vicinity of the cluster. All plates were measured on an iris photometer and calibrated with the aid of this sequence. However, many more stars (and especially blue ones) are needed to give a better accuracy. Several plates show some weak additional cluster background around the bluest star and were therefore corrected for this effect. We estimate our accuracy about ± 0.1 in *V* and ± 0.15 in both colors. Table 1 presents the results for the three UV-bright stars found. Their identifications are on Figures 1 and 3.

Since the colors of star 5 are the nearest to some of the well identified X-ray sources, it seemed appropriate

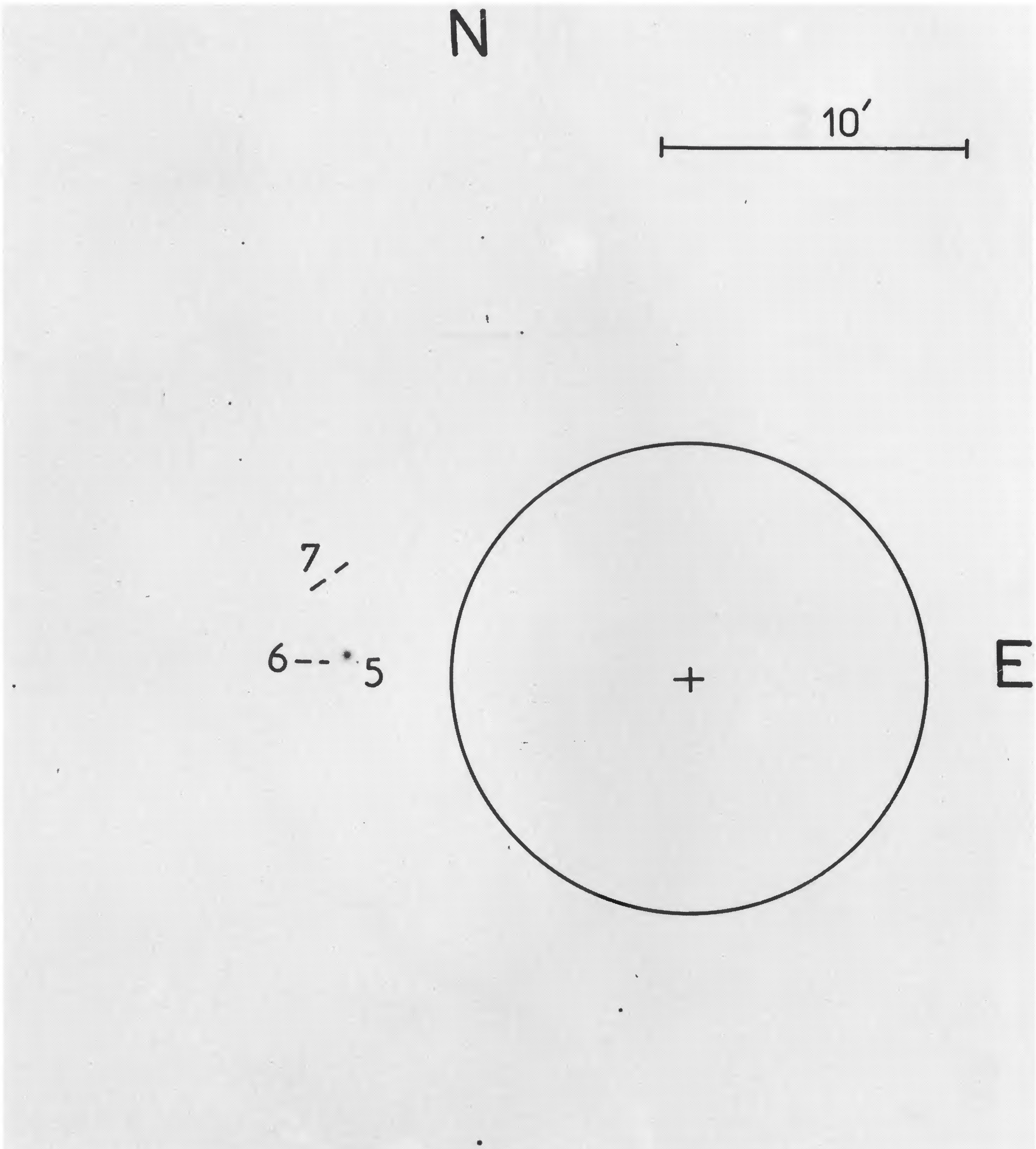

FIG. 1.—2.5 min exposure of NGC 1851 in the U band, taken with the 40-inch telescope at Siding Spring. Superposed is the approximate error circle of the X-ray source MX 0513−40 as given by Markert and Clark.

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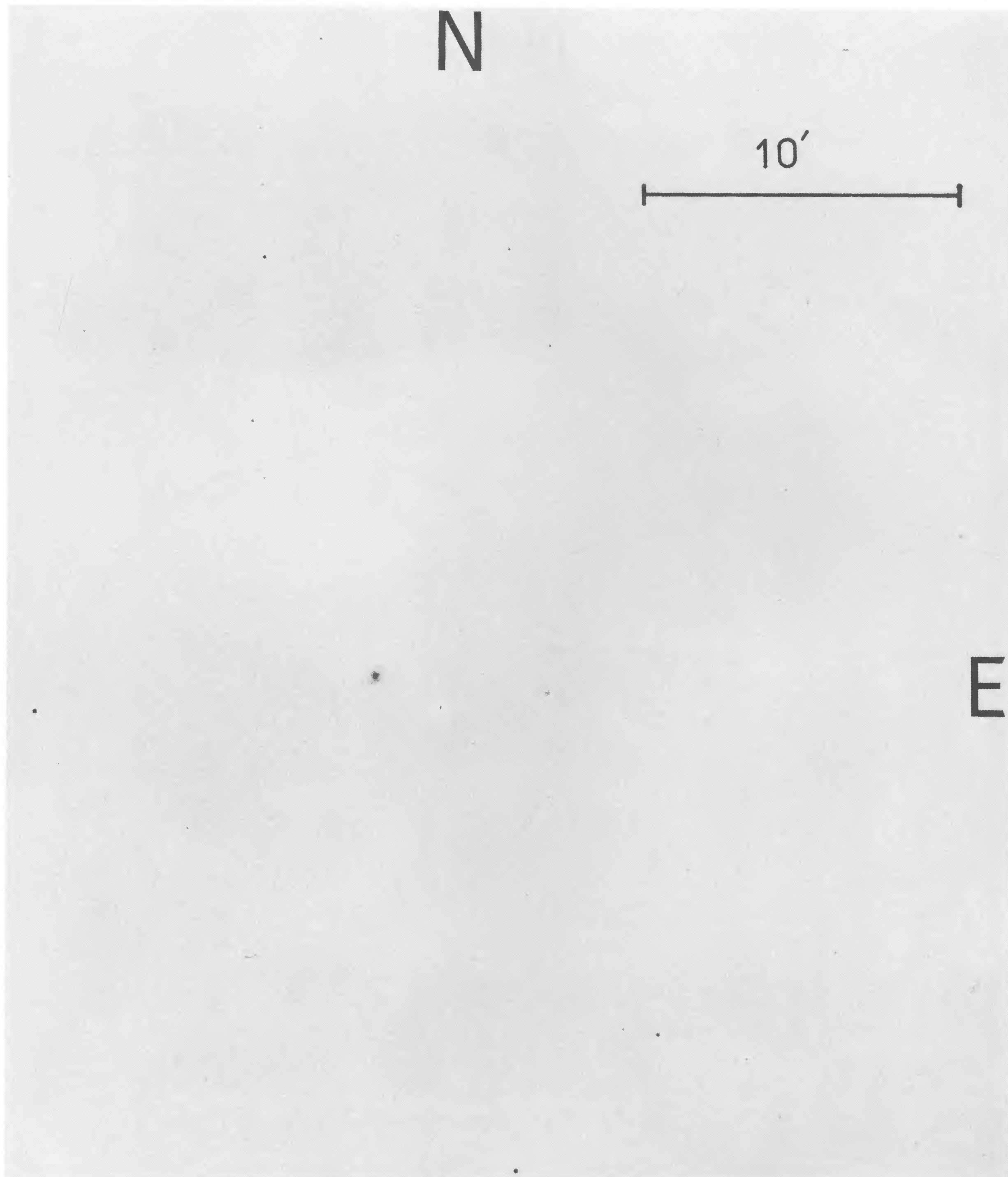

FIG. 2.—30 s exposure of NGC 1851 in the V band

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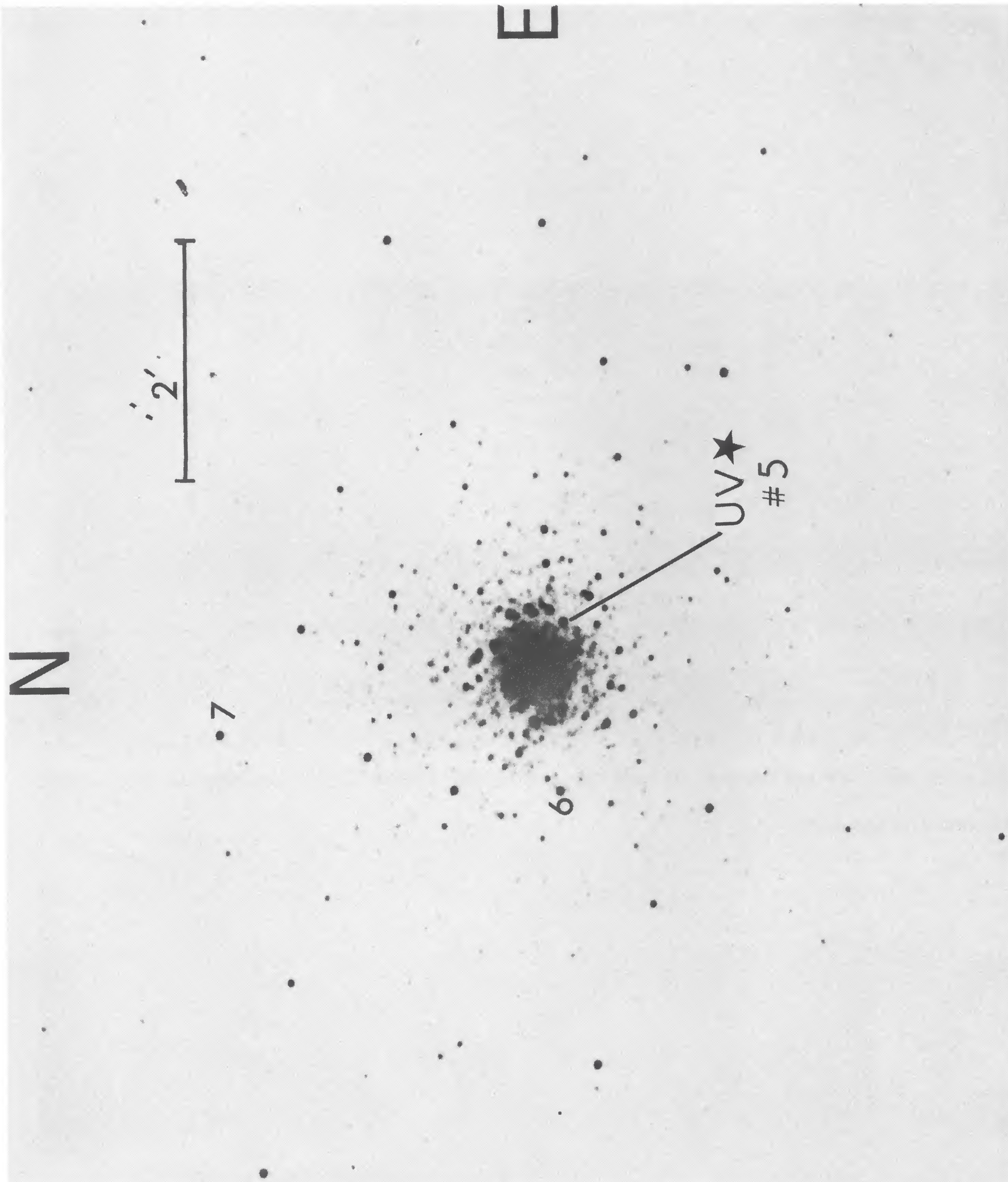

Fig. 3.—5 min exposure of NGC 1851 in the V band

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TABLE 1

Visual Magnitudes and Colors of the Three UV Bright Stars in NGC 1851

Star No.	V	$B-V$	$U-B$
5........	13.1	0.0	−0.7
6........	13.2	0.2	−0.2
7........	13.4	0.2	+0.2

* See Fig. 1 for identifications.

to concentrate our efforts to study it further. Several image tube spectra were taken on the 190-cm telescope at Mount Stromlo on nights of excellent seeing. We used the moonlight eliminator to minimize background contamination from the cluster: the slit length was 3″. The residual background contamination is obviously very small, because the G band of the integrated cluster spectrum is very weak or absent from our tracings. All spectra were taken at 100 Å mm^{-1} dispersion and widened to about 1 mm on the plate. Figure 4*a* (Plate L4) is a reproduction of one of the spectra and shows the Balmer series and the He I λλ3820, 4026, 4143, 4387, and a possible diffuse feature at 4471. Figure 4*c* shows a reproduction of the UV-bright star (classified B8 III by Feast and Thackeray 1960) in 47 Tuc taken consecutively and shows weaker He I lines and a steeper Balmer jump. We estimate a spectral type of about B6 III for star 5. However, this classification, based on the appearance of the He I and the Balmer lines, should be regarded with caution since abundance peculiarities may be present. Moreover, the Si II λ4128–He I λ4143 criterion cannot be used since Population II objects are metal-deficient. In this respect, it would be safer to rely more on the colors of the star previously discussed to derive any physical parameters.

Apart from the fact that this star seems to belong to the hottest group of UV-bright stars in globular clusters (see below), another outstanding feature is a variable emission line found at Hβ. Figure 4*b* shows a clear blueward emission line at Hβ while no such feature is seen on Figure 4*a*.

Four well exposed spectra and the spectrum of the UV-bright star in 47 Tuc were measured for radial velocities on an oscilloscope-setting-type machine. Balmer lines only were used. The agreement between lines on the same spectrum is within less than ±12 km s^{-1}. Table 2 shows the results (corrected for the Sun). The mean radial velocity is 340 ± 20 km s^{-1}, and it shows that the star is a member of the cluster (317 ± 3 km s^{-1} [Kinman 1959]).

The radial velocity measured for the UV-bright star in 47 Tuc agrees, within the accuracy, with the one published by Feast and Thackeray (1960). This fact gives some confidence in the zero point of our radial velocities in Table 2. The average radial velocity of the UV-bright star on 1975 January 19 was 356 km s^{-1} and on January 20 was 323 km s^{-1}. This difference may be significant when compared with the typical scatter of about ±12 km s^{-1} on individual nights. More radial velocity observations would be highly desirable.

TABLE 2

Radial Velocities of the Brightest UV Star in NGC 1851

Plate No.	Date 1975 Jan. (UT)	Radial Velocity (km s^{-1})
3680.......	19.49	+366
3681.......	19.50	+347
3684.......	20.49	+338
3685.......	20.51	+309
3683 (UV star 47 Tuc).....	20.46	− 30

III. THE MASS

To give an estimate for the mass of the star, we need, apart from its colors, an estimate for its gravity. This was done through a measurement of the Hδ and Hγ equivalent widths on two tracings. Both yielded an average of 3 ± 0.3 Å. Since relatively low dispersion (100 Å mm^{-1}) spectra were used, this value can be regarded as a safe upper limit (Underhill 1966). Taking the average colors given in Table 1, we derive a Q value of about −0.7. This corresponds to log $T_{\rm eff} \approx 4.35$ (Norris 1974). Comparing this temperature and equivalent widths with those from model atmospheres computed by Auer and Mihalas (1972), we derive a gravity of about log $g = 3$. Our inaccuracies in the colors and equivalent widths would not change substantially this relatively low value for the gravity.

For an apparent distance modulus of 15.5 (Illingworth 1974) the absolute visual magnitude of the star would be −2.4 mag. The inaccuracies in our derived colors do not permit a good estimate for the bolometric correction, which is known to be very steep in this range of temperatures. However, from its colors and gravity there is no doubt that this star belongs to the group of the hottest UV-bright stars found in other globular clusters, namely, Barnard 29 in M13, ROA 3596 and 5701 in ω Cen, and others (Auer and Norris 1974; Norris 1974; Zinn 1974). The derived mass for all these stars is less than 0.7 $M_\odot$, and it would be reasonable to attribute such a low mass to star 5 too.

IV. DISCUSSION

If star 5 is the correct optical identification and if it belongs to a binary system, then, according to the current accretion models of X-ray binaries, the unseen companion should be a white dwarf, a neutron star, or a black hole. In all three cases it would be difficult to draw a reliable picture of the evolution of the system, although the low mass derived above would probably restrict or eliminate some of the evolutionary pictures. In any case, mass loss from the present bright companion is essential for the X-ray emission mechanism

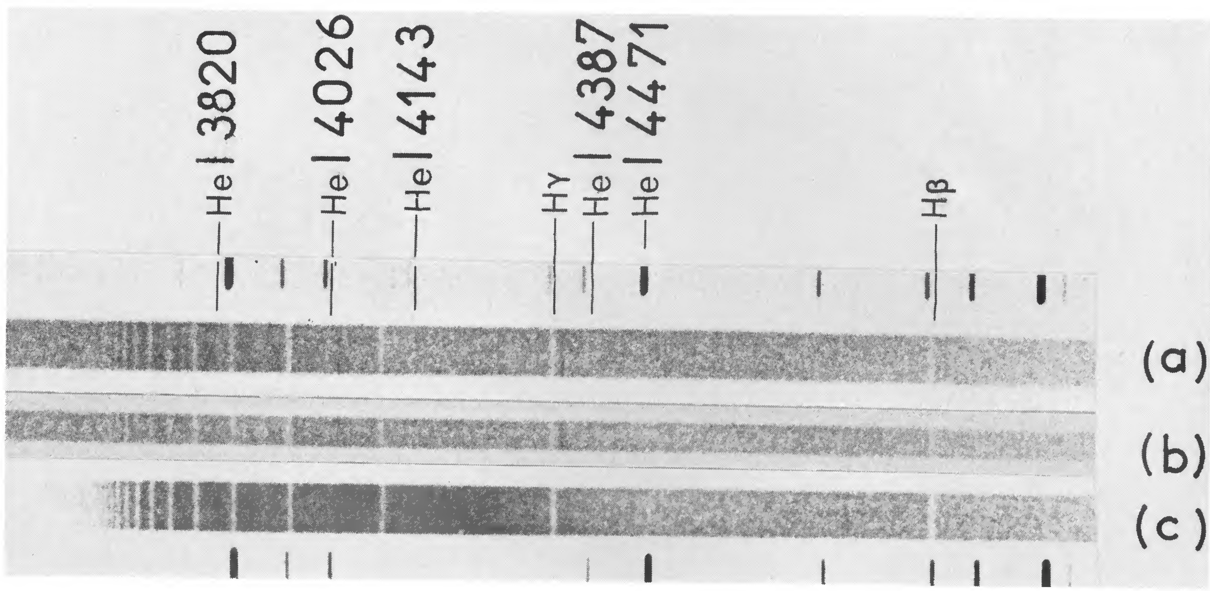

FIG. 4.—(*a*) and (*b*) spectra 3685 and 3680 of the UV-bright star 5 in NGC 1851; see Table 2. (*c*) spectrum 3683 of the UV-bright star in 47 Tuc.

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to operate; this could happen through a stellar wind or possibly through overfilling of its Roche lobe.

X-ray emission by the current accretion picture requires that the mass flux from primary to secondary be significantly less than 10^{-3} to 10^{-4} $M_{\odot}$ yr $^{-1}$ (Shakura and Sunyaev 1973). Although it seems very likely that globular cluster stars lose mass at several phases of their evolution, it may be that the corresponding mass flux is too high at most of these phases for the X-rays to escape. The UV-bright phase, with its high temperature and low gravity, seems a likely location for the steady and relatively low mass flux required.

A definitive proof that the UV-bright stars are the optical counterparts of X-ray sources in globular clusters can not be given unless an X-ray period is detected. However, the possibility that they belong to binary systems, their similarity to already identified X-ray sources, the apparent variable Hβ emission (for this star at least), and finally the *scarcity* of other interesting objects in globular clusters make it worthwhile exploring these identifications further.

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