WHITE DWARF CANDIDATES IN
THE GLOBULAR CLUSTER NGC 6752

Harvey B. Richer*

Department of Geophysics and Astronomy
University of British Columbia
Vancouver, Canada

*Visiting Astronomer, Cerro Tololo Interamerican
Observatory which is supported by the National
Science Foundation under contract NSF-C866.

In a recent paper (Richer 1978, hereafter Paper I) the results of a search for faint blue objects in and around the globular cluster NGC 6752 were reported. The aim of the program was to isolate a sample of white dwarf candidates in this cluster which could then be studied in further detail. The plate material for this survey consisted of a set of deep UBV plates (only one in each color) obtained at the prime focus of the Cerro Tololo Interamerican Observatory 4-meter telescope. Limiting magnitudes reached by the plates were about U=22.4, B=23.0, V=22.0. A reanalysis of the photometry presented in Paper I (using a reduction program supplied by W. Harris [see Stetson and Harris 1977]) has now yielded a total of 68 candidate objects within 20' of the cluster center having $B \leq 22.7$ and $(U-B) \leq -0.4$. Although the accuracy of the photometry is low (about ±0.2 magnitudes), it seems clear that the preponderance of the objects do not have UBV colors typical of white dwarfs. Of the 68 candidate objects, 36 had a measurable V magnitude, and only 11 of these lay in the area of the color-color diagram known to be occupied by white dwarfs (Eggen and Greenstein 1965). The remaining 25 were generally well above the black body line in the two-color diagram and are probably QSO's or peculiar blue stellar objects. Among these 11 good candidates, 7 are within 14' of the cluster center and hence have a probability of greater than 50% of being cluster members according to the star counts of King et al (1968) assuming that white dwarfs have a radial distribution in NGC 6752 similar to other cluster members.

In early July 1979, an effort was made to obtain spectra of some of the best candidate white dwarfs. The CTIO 4-meter telescope was used in conjunction with the SIT vidicon spectrograph. A dispersion of 376 Å/mm was used giving a resolution of 13 Å per pixel. However, the reading beam of the vidicon is slightly defocused so that the actual resolution of the spectra is somewhat poorer than this. The observations were very difficult for the following reasons. (1) None of the candidate objects could be seen on the finder TV screen so that blind offsets were necessary. (2) The fields were generally very crowded so that no orientation of the slit could completely eliminate the presence of nearby stars. In the reduction of the spectra, these contaminating stars were subtracted off as best as possible, but the procedure was not always entirely successful. (3) In order to be able to properly calibrate the spectra in terms of fluxes using Oke (1974) standards, a moderately large slit width (4".5) was needed to insure no loss of light. This allowed more sky than was desireable to contaminate the spectra. The result of all these difficulties is that there is some contamination present on all spectra, and they are all rather noisy as typical signal strengths were only about 20% that of the sky contribution giving an average signal to noise ratio of about 10.

Five spectra were obtained in the 1½ clear nights from this observing run. The stars observed are listed in Table 1 where the first column gives the star name from Paper I (a finding chart is located there also) and the next three columns contain photographic photometry (somewhat revised from Paper I) of these objects. Figure 1

Table 1
Observations of White Dwarf Candidates
In NGC 6752

STAR	B	U-B	(B-V)	Distance From Cluster Center (min. arc)	Spectral Type
WD 1	20.36	-1.23	-0.22	4.7	DC?
WD 2	20.70	-0.72	-0.08	13.7	DA
WD 12	21.49	-0.75	0.0:	4.9	DA ?
WD 18	21.67	-0.98	-0.1:	7.8	DA?
WD 21	21.71	-0.67	+0.21	10.8	QSO Z≃2

locates these objects in a B, (U-B) color-magnitude diagram constructed from the present plate material. This diagram was not obtained from

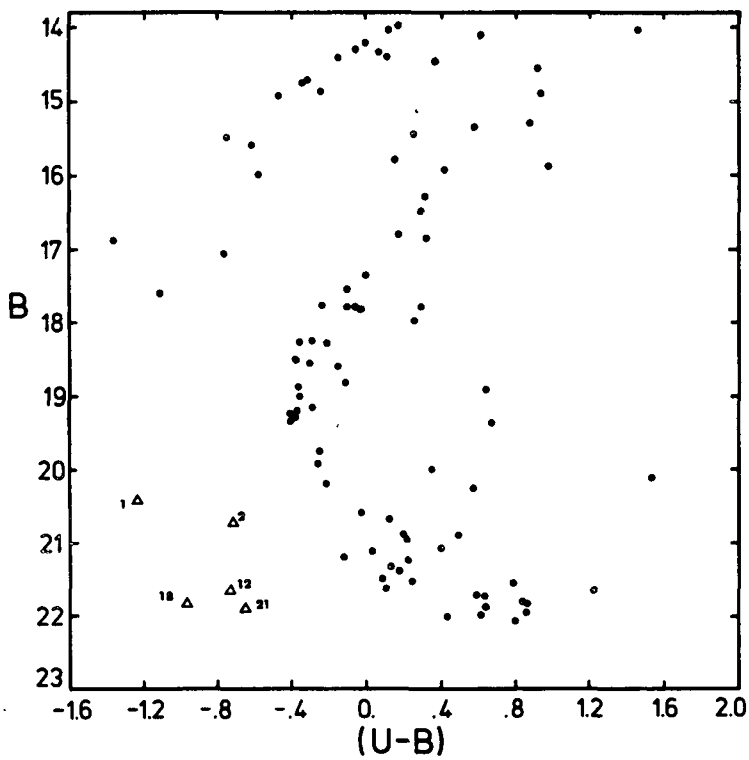

Figure 1.
The B, (U-B) color-magnitude diagram for the globular cluster NGC 6752. The five white dwarf candidates for which spectra have been obtained are indicated as triangles.

https://doi.org/10.1017/S0252921100076016 Published online by Cambridge University Press

measuring all stars in some annulus centered on the cluster but is intended simply to illustrate the major features of the color-magnitude diagram of NGC 6752. Hence many stars were preselected (particularly the horizontal branch stars) from the lists of Cannon and Stobie (1973), Wesselink (1974), or Carney (1979).

Figures 2 and 3 illustrate 3 of the spectra secured together with standard spectra. In Figure 2, F110 is a very hot DO or subdwarf O star with colors similar to WD1. Even at the present low resolution, the sharp H lines seen by Eggen and Greenstein (1965) in F110 are prominent. In the spectrum of WD1, no clear absorption lines are observed superimposed on its very blue continuum. We shall tentatively classify this spectrum, then, as DC. The comparison spectrum in Figure

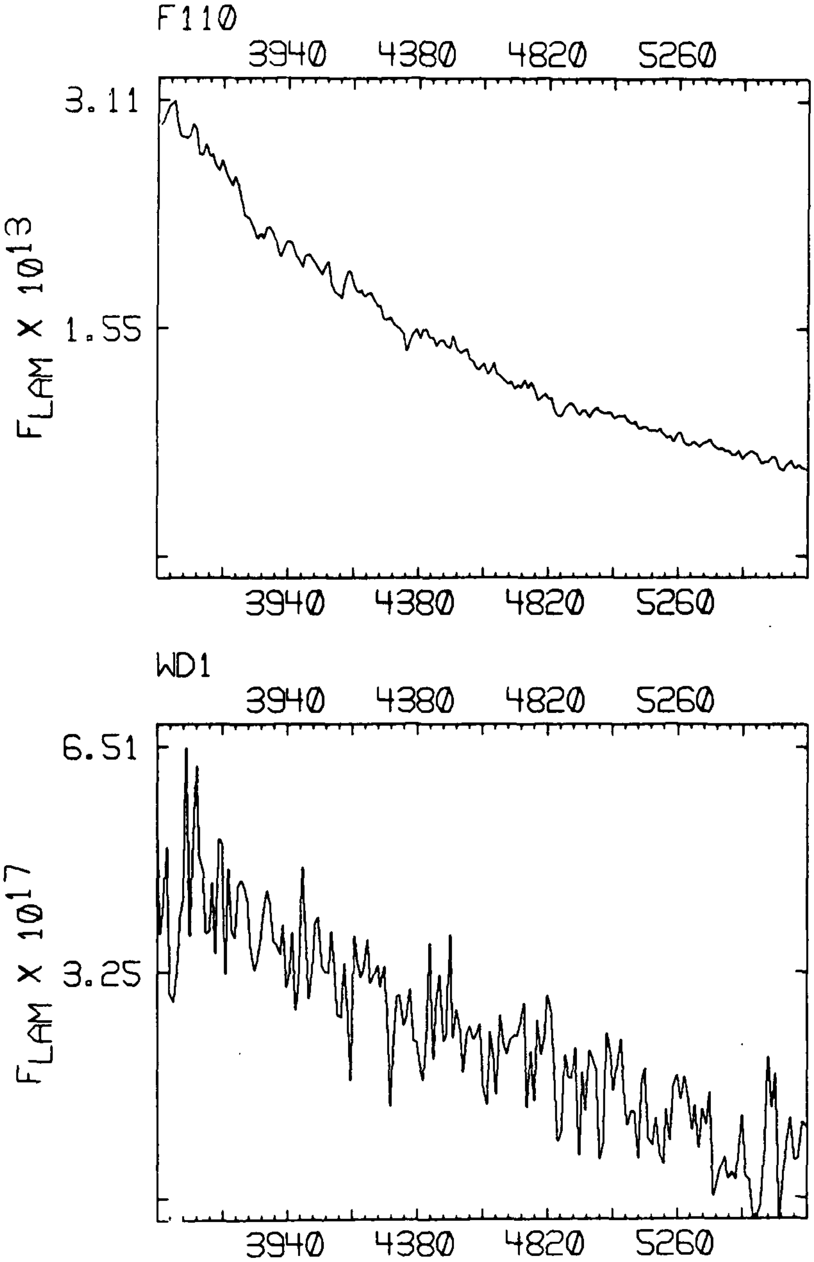

Figure 2. CTIO 4-meter SIT vidicon spectra of F110, a hot DO or subdwarf O star, and WD1, the brightest white dwarf candidate found in NGC 6752.

https://doi.org/10.1017/S0252921100076016 Published online by Cambridge University Press

3 is W485; a classic DA white dwarf. WD2 shows very broad Hβ and clear Hγ, Hδ and Hε. It also appears to exhibit a strong absorption line at λ4600 and λ3720. There are no features at these wavelengths in known white dwarfs so we must assume that they are due to a combination of noise, and improper sky and contaminating star subtraction. The final spectrum in Figure 3 is that of WD18. This star is very faint (B=21.7), and there were several contaminating close by stars on the slit (causing, no doubt, the upturn in the spectrum longward of about 5000 Å). Nevertheless it does exhibit quite a blue continuum shortward of λ5000 and a very broad absorption line at the expected location of Hβ. Until a better spectrum is secured, we will classify this star as a DA. The spectra of WD12 and WD21 are not illustrated here. WD12 appeared similar to WD18; a blue continuum and a single broad absorption line at Hβ, while WD21 was a QSO with a redshift near Z=2 based on three broad emission lines.

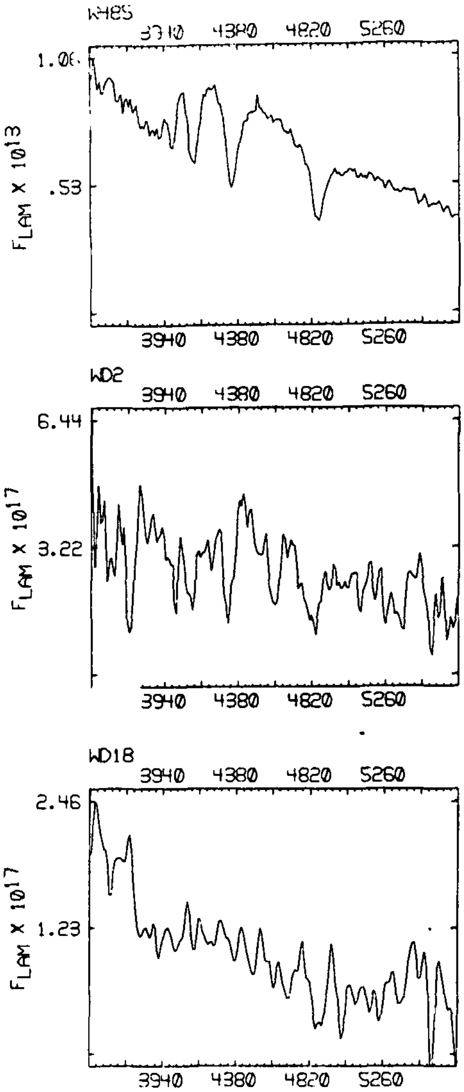

Figure 3. CTIO 4-meter SIT vidicon spectra of W485, WD2, and WD18. The former is a typical DA star. All spectra have been smoothed with a three-point triangular filter.

https://doi.org/10.1017/S0252921100076016 Published online by Cambridge University Press

In Table 2, I have listed the measured equivalent widths in 3 white dwarf standards and 2 program stars. The numbers in parentheses are values from Greenstein (1960), so the results for Hγ from these low resolution spectra are reasonable. In general, the Hβ equivalent widths seem inordinately large; perhaps the noisy character of the data causes an overestimate of their values. From a comparison with the presently measured value for W485 and Greenstein's (1960) value, the true width

Table 2
Equivalent Widths of Balmer Lines
In Standards and White Dwarf Candidates

STAR	E.W. Hγ(Å)	E.W. Hβ(Å)
L870-2	5.1 (6.0)	8.8
HZ43	10.9 (9.1)	...
W485	34.9 (31.9)	41.4
WD2	32.8	50.3
WD18	...	45.9

of Hγ for both WD2 and WD18 is probably in the range 30-40 Å, very reasonable white dwarf values and numbers not inconsistent with their colors (see Fig. 6 in Greenstein 1960).

Table 3 contains the properties of the 4 white dwarfs of Table 1 assuming that they belong to NGC 6752. All column headings are self explanatory and the numbers have been derived in the following manner.

Table 3
Properties of White Dwarfs
Assuming Cluster Membership

STAR	M_v	θ_e	M_{bol}	$\log R/R_\odot$	$\log g\ (M = .7\ M_\odot)$
WD 1	7.4	.11	3.5	-1.57	7.4
WD 2	7.6	.25	5.9	-1.33	6.9
WD 12	8.3	.27	6.8	-1.44	7.1
WD 18	8.6	.19	6.2	-1.63	7.6

The value of M_v comes from a distance modulus of 13.2 (Cannon and Stobie 1973) for NGC 6752, while θ_e (= $5040/T_e$) was obtained from the calibration of (U-V) in terms of T_e given by Shipman (1972) and amended by Trimble and Greenstein (1974). The bolometric correction used was for a black body at the derived T_e. The value of log $(R/R_\odot)$ is then directly calculable from the expression

$$\log (R/R_\odot) = 2 \log \theta_e - 0.2M_{bol} + 1.05 \qquad (1)$$

given by Weidemann (1968) and log g assumes $M = 0.7\ M_\odot$.

The data of table 3, although of low accuracy, seems to suggest that WD2 and WD12 are unlikely to be cluster members if they are typical white dwarfs; the radii seem too large and hence log g seems too small-they are most likely foreground objects. However, both WD1 and WD18 have properties typical of the very hot white dwarfs discussed by Greenstein and Sargent (1974). Since such objects are very rare in space (Greenstein and Sargent 1974), the appearance of two so close to the cluster center is strongly suggestive that they belong to NGC 6752. Only one other object over the entire .35 square degrees surveyed by the plates seemed to be a white dwarf as hot as WD18. This star, WD11 from Paper I, has V=21.52 and (U-V)= -1.16 but is found at about 20' from the cluster center and on this basis alone it may be argued that it is likely to be a field star.

In conclusion, the photometry, spectroscopy, derived properties, and location of WD1 and WD18 close to the center of the globular cluster NGC 6752 argue strongly in favor of them being cluster members. If correct, these two stars are the first white dwarf candidates to be found in a globular cluster. It is of some interest to compare the expected number of white dwarfs found with that predicted. Hills (1974) has shown that for white dwarfs in a globular cluster of total luminosity 10^5 $L_\odot$ (a reasonable approximation for NGC 6752: Arp 1965), the expectation is that about 22 should exist brighter than M_v=8.5 at M=0.7 (±.1) $M_\odot$ if there is no neutrino emission via the plasma process. For models including neutrino emission, the number is about 4. From the star counts of King et al (1968) one can estimate that the central 5' radius of the cluster inaccessible to a blink survey due to excessive crowding should contain about 30% of the stars in the cluster. Hence the expected <u>observed</u> numbers should be about 15 (no neutrino emission) and 3 (plasma process operating). For the remaining 6 white dwarf candidates for which no spectra yet exist, only 3 have log $(R/R_\odot) \leq -1.44$ if they are at the distance of NGC 6752. The best candidate is WD11 (log $(R/R_\odot)$= -1.68, M_{bol}=5.1, θ_e= .14) but it lies a full 20' from the cluster center and on this basis it is unlikely to be associated with the cluster. WD16 has log $(R/R_\odot)$= -1.51, M_{bol}= +6.4 and θ_e=.23 if it is a cluster member. It is located at 15' from the center of NGC 6752. WD19, at 11' from the cluster center has, log $(R/R_\odot)$ = -1.57, M_{bol}= +6.5 and θ_e=.22 if a member. Hence it is unlikely that among the 6 remaining good candidates, more than 1 or at most 2 are associated with NGC 6752. Hence, unless large numbers of blue stellar objects were missed by the blink survey, we can expect about 3 or 4 likely white dwarf members of NGC 6752 brighter than M_v = 8.5. That many blue objects were missed seems very unlikely as the blink survey was done twice under totally independent conditions and slightly over 90% of the sample was common to both efforts. The numbers of white dwarfs found as probable members of this globular cluster seem to suggest that the plasma neutrino process is operating in nature.

This research was supported by grants from the National Science and Engineering Research Council of Canada. Telescope time at CTIO is gratefully acknowledged.

REFERENCES

Arp, H.C. 1965, in <u>Galactic Structure</u>, eds. A. Blaauw and M. Schmidt (Chicago: University of Chicago Press), chap. 19.

Cannon, R.D., and Stobie, R.S. 1973, M.N.R.A.S., <u>162</u>, 227.

Carney, B.W. 1979, A.J., <u>84</u>, 515.

Eggen, O.J., and Greenstein, J.L. 1965, Ap.J., <u>141</u>, 83.

Greenstein, J.L. 1960, in <u>Stellar Atmospheres</u>, ed. J.L. Greenstein (Chicago: University of Chicago Press), chap. 19.

Greenstein, J.L., and Sargent, A.I. 1974, Ap.J.Suppl., <u>28</u>, 157.

Hills, J.G. 1974, Ap.J., <u>190</u>, 109.

King, I.R., Hedemann, E., and Hodge, S.M. 1968, A.J., 73, 456.
Oke, J.B. 1974, Ap.J.Suppl., No. 235, 27, 21.
Richer, H.B. 1978, Ap.J. (Letters), 224, L9.
Shipman, H.L. 1972, Ap.J., 177, 723.
Stetson, P.B., and Harris, W.E. 1977, A.J., 82, 954.
Trimble, V., and Greenstein, J.L. 1972, Ap.J., 177, 441.
Weidemann, V. 1968, Ann. Rev. Astr. and Ap., 6, 351.
Wesselink, A.J. 1974, M.N.R.A.S., 168, 345.