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BVI CCD Photometry of the Globular Cluster 47 Tuc[1]

by

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ABSTRACT

We present *BVI* photometry for about 16000 stars from a 220 square arcmin field centered 8 arcmin East of the center of 47 Tuc. We have identified eight likely blue stragglers located in the outer parts of the cluster. Four of these objects are easy targets for spectroscopic studies with ground-based telescopes. Six candidates for blue horizontal branch stars were identified. However, it is possible that all or most of them belong in fact to the SMC halo. One faint blue star being candidate for a cataclysmic variable was found close to the cluster center.

The average *I*-band magnitude for stars forming the red giant branch clump is determined at $I_0 = 13.09 \pm 0.005$ mag. This in turn implies distance modulus of the cluster $(m-M)_{0,47\mathrm{Tuc}} = 13.32 \pm 0.03 \pm 0.036$ mag (statistical plus systematic error), if we adopt $M_{I,m} = -0.23 \pm 0.03$ mag for the average absolute luminosity of Hipparcos-calibrated clump giants, following Paczyński and Stanek and Stanek and Garnavich. This distance modulus of 47 Tuc is lower by 0.2–0.25 mag than its recent estimates based on Hipparcos parallaxes for subdwarfs. We discuss possible reasons for this discrepancy. The photometric data are available through the *anonymous ftp* service.

Key words: *globular clusters: individual: 47 Tuc – techniques: photometric – Stars: distances*

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1. Introduction

47 Tuc (NGC 104) is a populous, metal rich, globular cluster located at relatively small distance from the Sun. In the recent compilation Harris (1996) lists for its metallicity $[\mathrm{Fe/H}] = -0.76$, absolute visual magnitude $M_V = -9.26$, distance modulus $(m-M)_V = 13.21$ and extinction $E(B-V) = 0.04$. The cluster belongs to the population of disk clusters (Zinn and West 1984). High galactic latitude of 47 Tuc ($b = -44.9$) along with its closeness make it particularly attractive object for detailed studies. The major, CCD based photometric investigations of 47 Tuc include *BV* photometry by Hesser *et al.* (1987) and *BVI* photometry by Alcaino and Liller (1987). The cluster was a subject of numerous projects conducted with the HST. The most recent contributions include identification of a population of eclipsing binary stars in the cluster center (Edmonds *et al.* 1996, Minniti *et al.* 1997), search for cataclysmic binaries (Shara *et al.* 1996), study of the luminosity function (Santiago *et al.* 1996) and spectroscopic study of a blue straggler located in the cluster center (Shara, Saffer and Livio 1997). Kaluzny *et al.* (1997, 1998) used ground-based data to identify several new variables, including 12 eclipsing binaries, in the outer parts of the cluster.

In this paper we report medium-deep *BVI* photometry for an eastern section of 47 Tuc. These observations were aimed at: a) derivation of a luminosity function for an upper main-sequence stars and subgiants; b) identification of blue stragglers in the outer parts of the cluster; c) search for candidates for blue horizontal branch stars. The luminosity function derived from our data will be published elsewhere (Wysocka 1998, in preparation). Below we concentrate on search for blue stragglers and other blue stars as well as on determination of the distance modulus of the cluster.

2. Observations and Photometric Reductions

The observations presented here were obtained using 1024×1024 Tektronix CCD (TEK2 camera) attached to the 2.5 m duPont telescope of the Las Campanas Observatory. The field of view of the camera was 4×4 arcmin with the scale of 0.235 arcsec/pixel. The data were collected on 4 nights of July 11–14, 1993. 18 partly overlapping fields covering eastern part of the cluster were imaged through *BVI* filters. A schematic chart showing location of these fields is shown in Fig. 1. The total surface of the observed area of the cluster equals to about 220 square arcmin. The following sequence of exposures was collected for each sub-field: *B* – 600 s, *V* – 300 s, *I* – 300 s. Additionally, shorter exposures were obtained for sub-fields F19 and F10.[3] The seeing ranged from 1.1 to 1.7 arcsec with a median

[3] The tables with the *BVI* photometry and equatorial coordinates for all stars detected are available in electronic form from *ftp://www.astro.princeton.edu/kaluzny/Globular/47Tuc_BVI* or *ftp://sirius.astrouw.edu.pl/pub/jka/Globular/47Tuc_BVI*.

value of about 1.5 arcsec. The instrumental profile photometry was extracted using DAOPHOT/ALLSTAR package (Stetson 1987). The point spread function varying linearly with coordinates was applied. The instrumental *bvi* photometry derived for sub-fields F1–20 was transformed to the common instrumental system defined by photometry of sub-field F4. The offsets of the zero points of the photometry obtained for individual sub-fields were determined from the stars in overlapping regions of adjacent sub-fields.

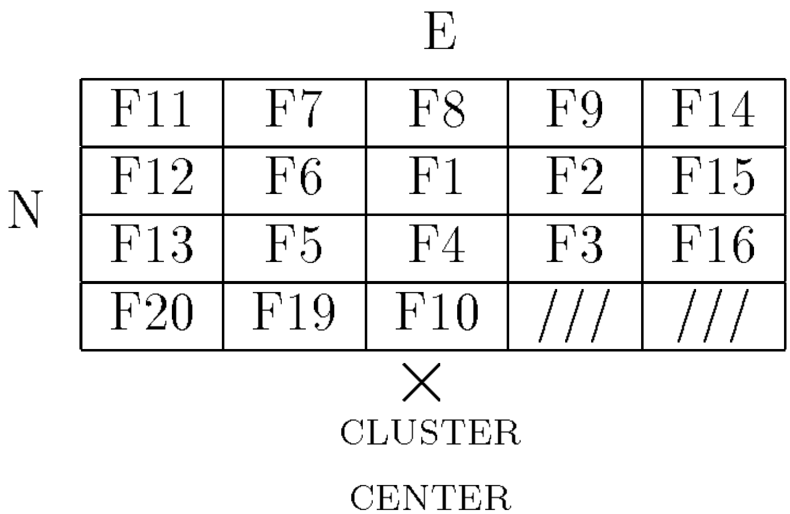

Fig. 1. A schematic finding chart showing location of observed sub-fields relatively to the cluster center.

Calibration to the standard BVI_c system was performed using photometry of Landolt (1992) fields, observed over the whole run. On the night of July 12, 1993, we observed three Landolt fields containing a total of 14 standards. These fields were observed at air-masses spanning the range 1.1–1.6. Based on the aperture photometry of the standard stars we adopted the following relations:

$$\begin{aligned} v &= 1.698 - 0.024 \times (B-V) + 0.172 \times (X - 1.25) \\ v &= 1.699 - 0.022 \times (V-I) + 0.170 \times (X - 1.25) \\ i &= 1.953 - 0.017 \times (V-I) + 0.067 \times (X - 1.25) \\ b-v &= 0.394 + 0.946 \times (B-V) + 0.060 \times (X - 1.25) \\ v-i &= -0.247 + 0.994 \times (V-I) + 0.083 \times (X - 1.25) \end{aligned} \tag{1}$$

where X is an airmass and lower-case letters refer to the instrumental magnitudes normalized to 1 sec exposures. The overall quality of the adopted transformation is illustrated in Fig. 2 where the magnitude and color residuals are plotted for the standard stars. The last step was the determination of aperture corrections for the

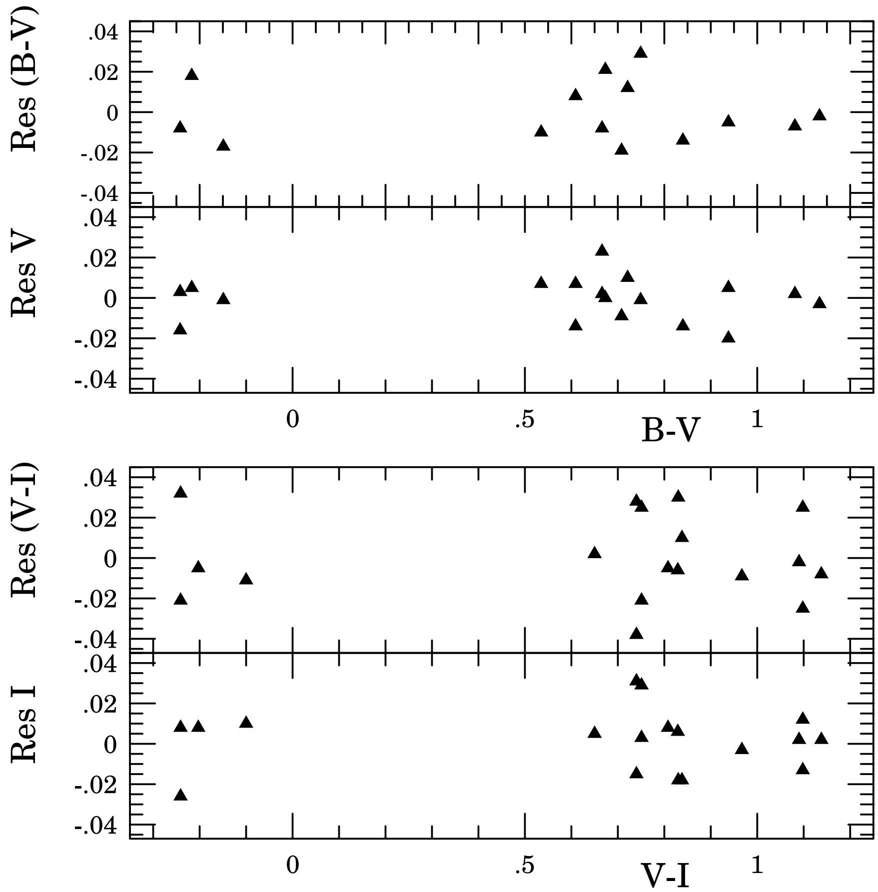

Fig. 2. Differences between our photometry of Landolt (1992) standards and the published values.

sub-field F4. We estimate that probable errors of the zero points of our photometry of 47 Tuc do not exceed 0.03 mag for magnitudes and colors.

The derived *BVI* photometry of 47 Tuc is presented in the form of color-magnitude diagrams (CMDs) in Figs. 3, 4 and 5. Fig. 3 shows data for all but two most crowded sub-fields F19 and F10. Photometry for sub-fields F19 and F10 is shown in Figs. 4 and 5, respectively. Presented CMDs are not complete in the sense that for each of sub-fields the objects with errors of photometry unusually large for their magnitude were discarded.

2.1. Comparison with Previous Photometry

The cluster region observed by us neither overlaps with the fields observed by Hesser *et al.* (1987) nor with the field observed by Alcaino and Liller (1987). Hence it is impossible to compare directly our photometry with the photometry published by these authors, but indirect comparison is possible. In Fig. 6 we show V *vs.* $B-V$ CMD based on our data for the sub-field F4 with overimposed fiducial

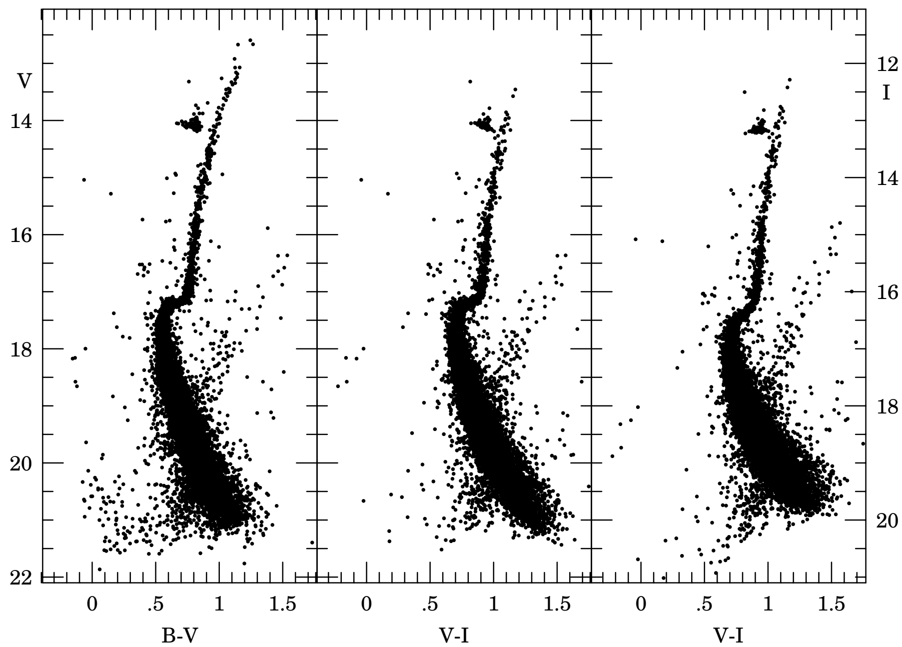

Fig. 3. V *vs.* $B-V$ (left), V *vs.* $V-I$ (center) and I *vs.* $V-I$ color-magnitude diagrams for all observed sub-fields but F10 and F19. Note the different vertical scale for the right panel.

relation published by Hesser *et al.* (1987, Table IX in their paper). It should be noted that parts of the fiducial relation describing location of the horizontal branch and main sequence are based on CCD data while the subgiants and lower giant branch are defined based on the photographic data. The overall agreement is good although a systematic discrepancy in color is visible at the bottom of the subgiant branch. The average color for RGB stars plotted in Fig. 3 is $\langle B-V\rangle = 0.796$ which is marginally bluer than the average color measured by Hesser *et al.* (1987) who obtained $\langle B-V\rangle = 0.800$ and $\langle B-V\rangle = 0.805$ for their fields F3 and F4.

Our photometry for main-sequence stars is consistent with results of Alcaino and Liller (1987) who obtained $(B-V)_t = 0.56 \pm 0.02$ and $(V-I)_t = 0.68 \pm 0.02$ for the colors of the main-sequence turnoff. Our data imply $(B-V)_t \approx 0.55$ and $(V-I)_t \approx 0.71$.

In Fig. 7 we compare our *VI* photometry for RGB and sub-giant branch with the data from Armandroff (1988) and Da Costa and Armandroff (1990). There are no noticeable systematic differences between these 3 sets of data.

3. Analysis of Photometry

3.1. Blue Stragglers

Most of the thoroughly investigated globular clusters are known to harbor more or less rich populations of blue stragglers (BSS) (*e.g.*, Ferraro, Fusi Pecci and Bel-

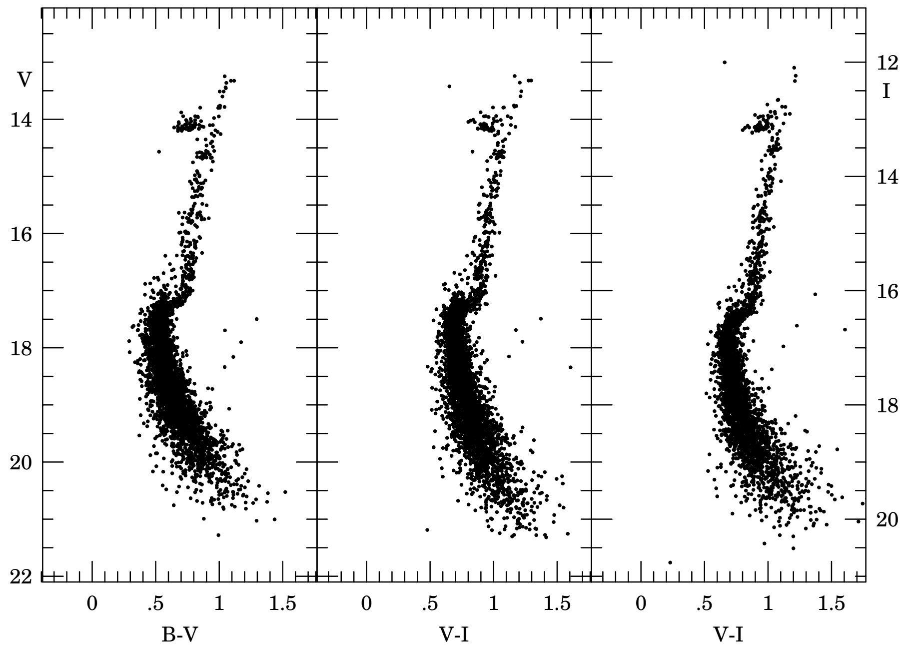

Fig. 4. V *vs.* $B-V$ (left), V *vs.* $V-I$ (center) and I *vs.* $V-I$ color-magnitude diagrams for sub-field F19.

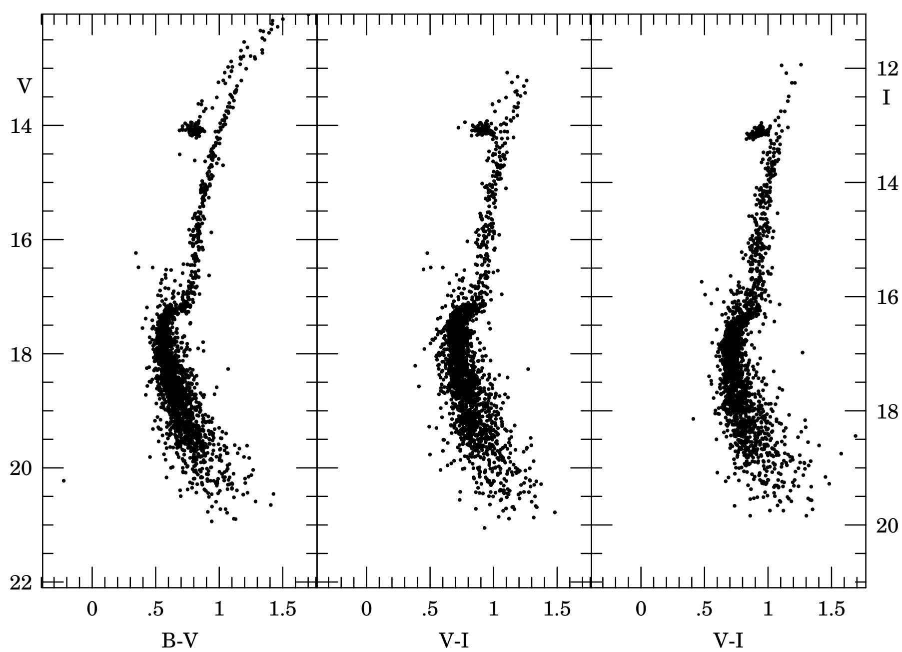

Fig. 5. V *vs.* $B-V$ (left), V *vs.* $V-I$ (center) and I *vs.* $V-I$ color-magnitude diagrams for sub-field F10.

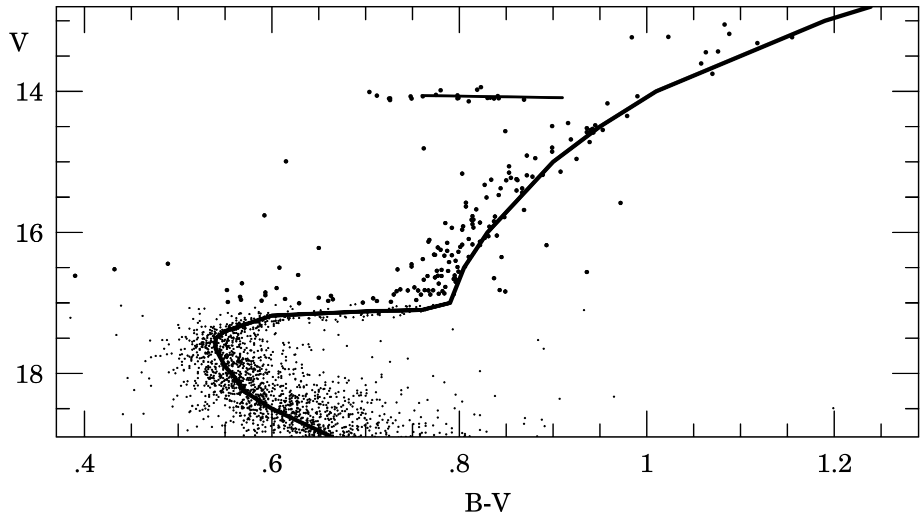

Fig. 6. The CMD for the sub-field F4, compared with the fiducial relation obtained by Hesser *et al.* (1987).

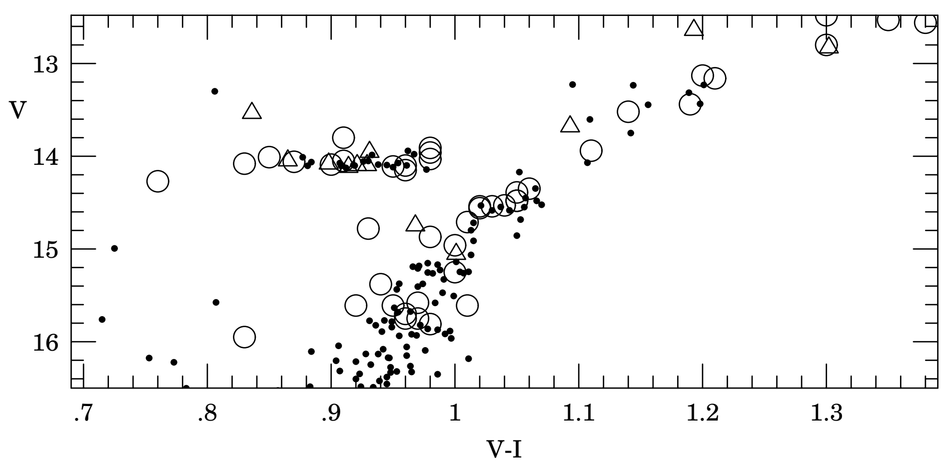

Fig. 7. Comparison of our *VI* data (dots) with Armandroff (1988; open circles) and Da Costa and Armandroff (1990; open triangles).

lazzini 1995). There seems to be a correlation between a given cluster concentration and the properties of its BSS population. In sparse clusters a substantial fraction of their BSS can be found in peripheral regions, although generally BSS are more concentrated than "ordinary" member stars (*e.g.,* subdwarfs). In clusters with very high central densities BSS have been observed almost exclusively in their central regions. Particularly interesting is the case of the nearby cluster M3 where there is an evidence for presence of two populations of BSS of different origin (Ferraro *et al.* 1997). It has been suggested that BSS observed in cores of globular clusters are formed preferentially by stellar collisions while BSS observed in loose clusters are formed by merging of primordial binaries (Ferraro, Fusi Pecci and Bellazzini 1995, Sandquist, Bolte and Hernquist 1997).

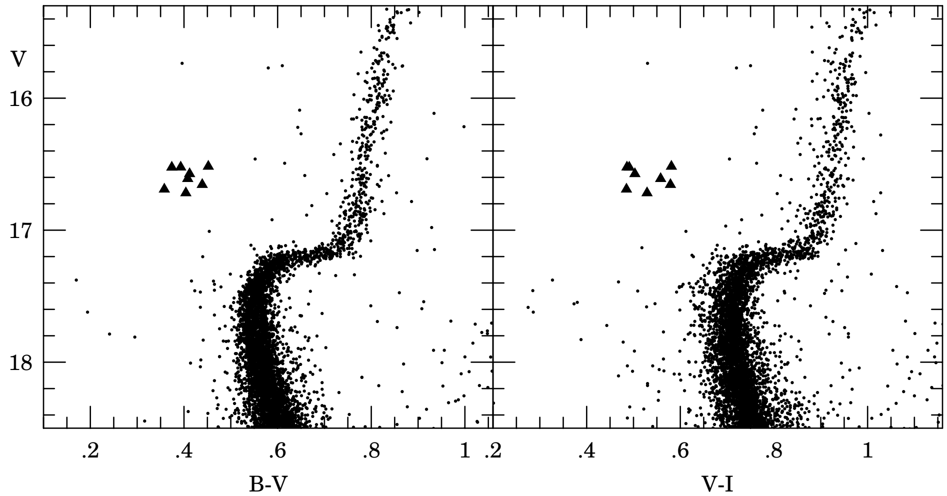

Fig. 8. An expanded view of the main-sequence turnoff region for data presented in Fig. 3. Eight likely BSS are marked with triangles.

Paresce *et al.* (1991) reported identification of 22 BSS in the core of 47 Tuc, the first detection of BSS in a globular cluster core by HST. In contrast Hesser *et al.* (1987) noted the complete lack of possible BSS in the out-of-core regions the cluster. Recently Kaluzny *et al.* (1998) surveyed a large fraction of the cluster and detected 12 eclipsing binaries of which most are likely BSS. Several candidates for BSS are visible in the CMDs presented in Figs. 3, 4 and 5. As photometry shown in Figs. 4 and 5 is relatively noisy we limited our attention to the data displayed in Fig. 3. An expanded view of that figure showing region around the main-sequence turnoff is shown in Fig. 8. One may note presence of an apparent BSS clump at $V \approx 16.6$ and $B-V \approx 0.40$. In Table 1 we list photometry and equatorial coordinates for eight stars forming that clump. Star BSS7 has been identified as a contact binary by Kaluzny *et al.* (1998; variable OGLE GC226). Hence it is a likely binary BSS. The finding charts allowing identification of the eight BSS candidates are shown in Fig. 9.

Recently Shara, Saffer and Livio (1997) used a spectrum obtained with the HST to derive absolute parameters for one of BSS located in the cluster core. We note in this context that four of our BSS candidates are relatively isolated, uncrowded objects. They are excellent objects for spectroscopic studies with ground-based telescopes. As one of the closest globular clusters, 47 Tuc is particularly well suited for studies aimed at comparison of properties of individual stars belonging to inner and outer BSS populations.

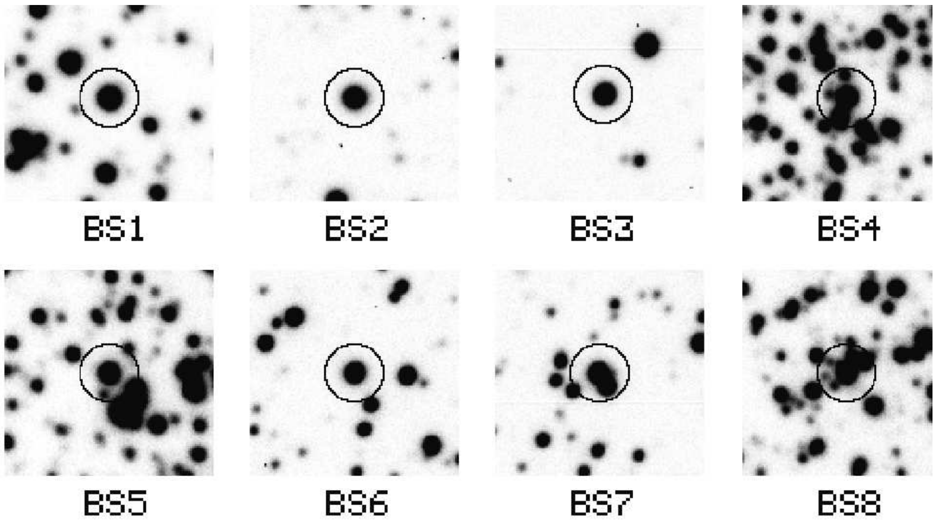

Fig. 9. The *V*-band finding charts for eight BSS candidates. Each chart is 60 arcsec on a side with North up and East to the left.

Table 1

Photometry and coordinates for blue straggler candidates

ID	V	$B-V$	$V-I$	RA(2000)	Dec(2000)
BS1	16.528	0.449	0.578	$0^{h}25^{m}38\overset{s}{.}51$	$-71^{\circ}57'43\overset{''}{.}9$
BS2	16.534	0.389	0.481	$0^{h}26^{m}54\overset{s}{.}25$	$-72^{\circ}03'02\overset{''}{.}6$
BS3	16.535	0.369	0.486	$0^{h}27^{m}07\overset{s}{.}87$	$-71^{\circ}57'35\overset{''}{.}0$
BS4	16.584	0.409	0.498	$0^{h}25^{m}14\overset{s}{.}88$	$-72^{\circ}06'05\overset{''}{.}8$
BS5	16.621	0.404	0.555	$0^{h}25^{m}19\overset{s}{.}22$	$-72^{\circ}05'47\overset{''}{.}9$
BS6	16.666	0.436	0.576	$0^{h}26^{m}02\overset{s}{.}37$	$-72^{\circ}10'16\overset{''}{.}3$
BS7	16.701	0.352	0.480	$0^{h}26^{m}11\overset{s}{.}21$	$-72^{\circ}11'06\overset{''}{.}3$
BS8	16.729	0.400	0.525	$0^{h}25^{m}15\overset{s}{.}29$	$-72^{\circ}00'47\overset{''}{.}4$

3.2. Distance Modulus of the Cluster

Hesser *et al.* (1987) derived the distance modulus of 47 Tuc $\mu_{0,47\mathrm{Tuc}}$=13.25 mag. Recently Gratton *et al.* (1997) derived a higher value of 13.44 mag, using Hipparcos calibrated subdwarfs and reddening of $E(B-V)=0.023$ mag. Reid (1998) also used Hipparcos calibrated subdwarfs and obtained distance modulus of 13.57 ± 0.15 mag, assuming $E(B-V)=0.04$ mag (which would become 13.50 mag had he used Gratton *et al.* value of reddening). Finally, Salaris and Weiss (1998) obtained an apparent distance modulus of 13.50 ± 0.05 mag what corresponds to $\mu_{0,47\mathrm{Tuc}}\approx13.35$ for adopted $E(B-V)=0.05$.

Following an approach developed by Paczyński and Stanek (1998), here we derive a distance to 47 Tuc by comparing red clump stars from the Hipparcos catalog with the red clump stars from our data set. This method was applied by Stanek and Garnavich (1998) to M31 galaxy, by Udalski *et al.* (1998) to the LMC and the SMC and by Stanek, Zaritsky and Harris (1998) to the LMC.

In the upper panel of Fig. 10 we show the red clump dominated part of the I_0 *vs.* $(V-I)_0$ color-magnitude diagram for 47 Tuc, corrected for extinction and reddening assuming a value of $E(B-V)=0.04$ mag used by Reid (1998). The dashed rectangle corresponds to the region of the CMD selected for comparison with the local red clump stars observed by Hipparcos (Paczyński and Stanek 1998). In the lower panel of Fig. 10 we show the distribution of 138 stars from the selected region as a function of extinction-corrected magnitude I_0. Following Stanek and Garnavich (1998), we fitted this distribution with a function

$$n(I_0)=a+b(I_0-I_{0,m})+c(I_0-I_{0,m})^2+\frac{N_{\rm RC}}{\sigma_{\rm RC}\sqrt{2\pi}}\exp\left[-\frac{(I_0-I_{0,m})^2}{2\sigma_{\rm RC}^2}\right] \quad (2).$$

The first three terms describe a fit to the "background" distribution of the red giant stars, and the Gaussian term represents a fit to the red clump itself. $I_{0,m}$ corresponds to the peak magnitude of the red clump population. We obtained the value of $I_{0,m}=13.089\pm0.005$ mag and $\sigma_{\rm RC}=0.026$ mag, *i.e.*, extremely narrow, well defined red clump.

We now proceed to obtain the 47 Tuc distance modulus using the red clump, by assuming that the absolute *I*-band brightness of the red clump stars is the same for the local stars observed by Hipparcos and those in the cluster. Combining $I_{0,m}$ with the distribution of local red clump stars, which have $M_{I,m}=-0.23\pm0.03$ (Stanek and Garnavich 1998), we obtain the distance modulus for the 47 Tuc, $\mu_{0,\rm 47Tuc}=13.319\pm0.030$ mag (statistical error only). After adding the systematic error of 0.02 mag due to the uncertainty in the extinction A_I determination, and 0.03 mag due to the zero-point uncertainty in our *I*-band photometry, we arrive at the final value of $\mu_{0,\rm 47Tuc}=13.319\pm0.030\pm0.036$ mag (statistical plus systematic error). This is about 0.2–0.25 mag below the value of Reid (1998) and Salaris and Weiss (1998), but in good agreement with the value of Hesser *et al.* (1987).

One possible explanation for this difference is that the intrinsic brightness of the red clump stars in 47 Tuc is higher than in the solar neighborhood. If following Reid (1998) we adopt $(m-M)_{0,\rm 47Tuc}=13.57$ mag for the cluster, then we obtain $M_I=-0.48$ for clump giants with $[\rm Fe/H]\approx-0.7$. However, note that the distance of Reid (1998) has a high statistical error of 0.15 mag, as it is based on only nine stars. Our comparison is based on about 600 Hipparcos red clump stars and about 100 red clump stars from 47 Tuc. This shows the great potential of the red clump method as a distance scale indicator.

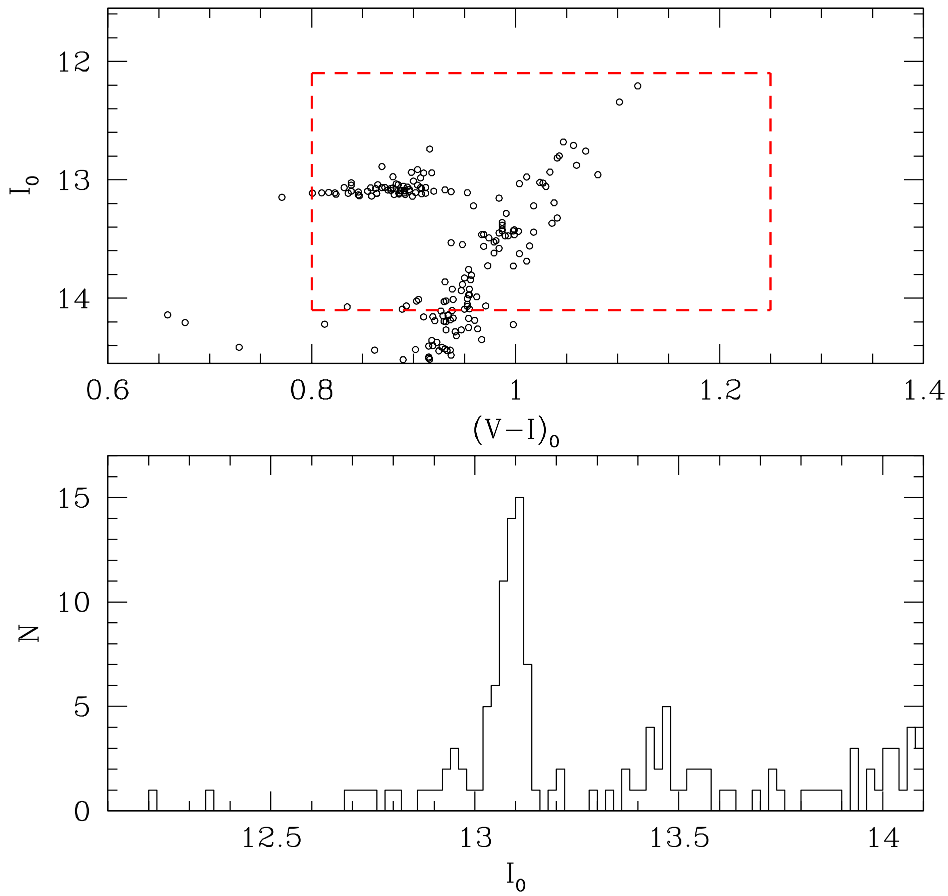

Fig. 10. The red clump dominated part of the I_0 *vs.* $(V-I)_0$ CMD, corrected for extinction and reddening assuming a value of $E(B-V) = 0.04$ mag (upper panel). The dashed rectangle surrounds the red clump region used for the comparison between the local (observed by Hipparcos) and the 47 Tuc red clump stars. In the lower panel we show the distribution of 138 stars from the selected region as a function of extinction-corrected magnitude I_0.

3.3. Blue Stars

It has been realized in recent years that some old stellar clusters with apparently red horizontal branches possess in fact populations of sdB/O stars. The most striking example is an extremely metal-rich old open cluster NGC 6791 in which about 30% of helium burning giants form an extended blue horizontal branch (Kaluzny and Udalski 1992, Kaluzny and Rucinski 1995). More recently Rich *et al.* (1997) discovered extended blue horizontal branches in two metal-rich globular clusters NGC 5927 and NGC 6388. Theoretical models aimed at explaining formation of UV-bright helium-burning stars in old metal-rich populations were discussed among others by Yi, Demarque and Kim (1997) and Sweigart and Catelan (1998). Existence of hot long-living stars in old metal-rich stellar systems may offer an attractive explanation of excessive UV flux in some giant elliptical galaxies (Code and Welch 1979, Burnstein *et al.* 1988, Brown *et al.* 1997).

Table 2

Photometry and coordinates for blue stars identified in the 47 Tuc field

ID	V	$B-V$	$V-I$	RA(2000)	Dec(2000)
B1	17.998	−0.053	−0.024	$0^h26^m00\overset{s}{.}65$	$-72°07'39''$
B2	18.159	−0.135	−0.162	$0^h26^m14\overset{s}{.}43$	$-72°03'58''$
B3	18.172	−0.154	−0.079	$0^h25^m30\overset{s}{.}03$	$-72°06'55''$
B4	18.577	−0.132	−0.156	$0^h24^m44\overset{s}{.}63$	$-71°57'19''$
B5	18.657	−0.120	−0.225	$0^h27^m00\overset{s}{.}15$	$-72°03'11''$
B6	15.040	−0.064	−0.042	$0^h25^m48\overset{s}{.}16$	$-71°58'09''$
B7	20.226	−0.224		$0^h24^m52\overset{s}{.}88$	$-72°03'27''$

The V *vs.* $B-V$ CMD shown in Fig. 3 includes five blue stars with $B-V \approx -0.1$ and $18 < V < 18.7$. Photometry and coordinates of these objects are listed in Table 2. That table includes also one relatively bright blue star from Fig. 3 (star B6) and one faint blue star identified in the sub-field F10 (star B7; see Fig. 5). Finding charts for stars B1–7 are shown in Fig. 11. Admittedly stars B1–5 lie on the extension of the upper main-sequence of the SMC which is clearly visible in the lower left part of the V *vs.* $B-V$ CMD shown in Fig. 3. Luminosities and colors of stars B1–5 are consistent with the hypothesis that they are dwarfs of spectral types B7-9 belonging to the SMC halo. Note however, that there is a ≈ 1 mag gap between these five stars and fainter candidates for the upper-main sequence stars from the SMC. On the other hand, it is striking that CMDs for sub-fields F10 and F19, which are located closest to the cluster center, are void of candidates for sdB/O stars. Sub-fields F10 and F19 covered about 1/9 of the total surveyed area. Their V *vs.* $B-V$ CMDs presented in Figs. 4 and 5 include 2941 stars with $17 < V < 19$ while corresponding number for the remaining sub-fields (see Fig. 3) is 6934. Hence, it would be reasonable to expect in Figs. 4 and 5 presence of 1–3 blue stars with properties similar to stars B1–5

Star B6 is much brighter than stars B1–5. If it were the SMC member then its absolute magnitude would be $M_V \approx -3.7$ what corresponds to a dwarf of spectral type B0 or B1. However, the observed color of the star is inconsistent with such a hypothesis.

The CMDs presented in Figs. 3, 4 and 5 contain a total of 226 stars located on the red horizontal branch of 47 Tuc. We have identified 6 candidates for stars from extension of the blue horizontal branch, but five of them are likely to be in fact upper main sequence stars from the SMC. The question about cluster membership of stars B1–6 can be easily resolved by measuring radial velocities of these objects.

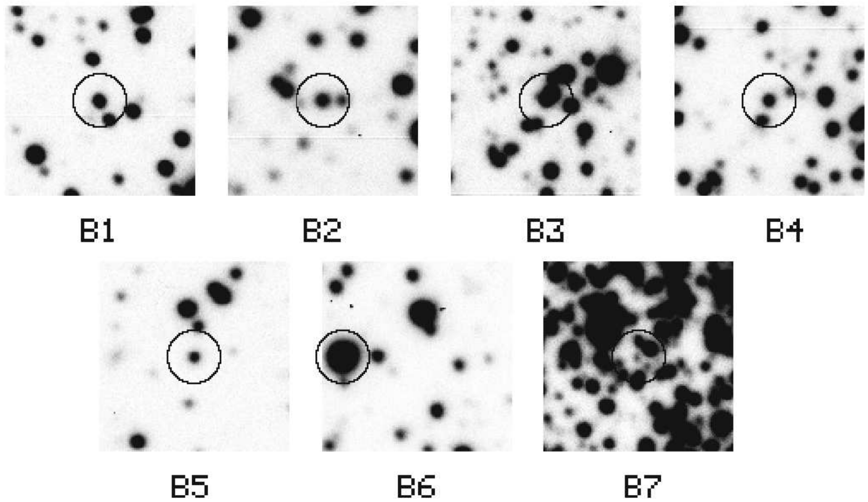

Fig. 11. The *V*-band finding charts for blue stars B1–B7 from Table 2. Each chart is 60 arcsec on a side with North up and East to the left.

In any case, our results confirm earlier findings about paucity or even lack of hot subdwarfs in 47 Tuc.

Object B7 is too faint to be a candidate for a hot subdwarf belonging to 47 Tuc. It was included in Table 2 because it is noticeably bluer than an upper-main sequence stars from the SMC which can be seen in Fig. 3. Although B7 is located in the densest surveyed sub-field its photometry is quite reliable as luckily that star is a relatively uncrowded object (see Fig. 11). The derived magnitude and color of B7 are consistent with a hypothesis that it is a cataclysmic variable belonging to 47 Tuc. So far only one cataclysmic variable was identified in the cluster (Paresce and De Marchi 1994; see also Shara *et al.* 1996). Given an unexpected paucity of cataclysmic variables in globular clusters (*e.g.,* Shara *et al.* 1996) it may be worth to examine closer nature of B7. The star can be monitored for possible variability and also its spectrum can be acquired with the ground-based telescopes.

4. Conclusions

We summarize our results as follows:

1. We have identified eight promising candidates for blue stragglers in outer parts of 47 Tuc. Four of these stars are uncrowded objects being easy targets for detailed spectroscopic studies with ground-based telescopes.
2. Five candidates for stars from the extended horizontal branch of 47 Tuc were identified in the surveyed field. However, these objects may be as well B-type main sequence stars belonging to the halo of the SMC. One relatively bright object being a candidate for blue horizontal branch star was also found.

3. A faint blue star was identified close to the cluster center. Its apparent magnitude and color are consistent with the hypothesis that it is a cataclysmic variable belonging to the cluster.
4. The average *I*-band magnitude for stars forming the red giant branch clump is determined at $I_0 = 13.09 \pm 0.005$ mag. This in turn implies distance modulus of the cluster $(m-M)_{0,47\mathrm{Tuc}} = 13.32 \pm 0.03 \pm 0.036$ mag.

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REFERENCES

Alcaino, G., and Liller, W. 1987, *Astrophys. J.*, **319**, 304.
Armandroff, T.E. 1988, *Astron. J.*, **96**, 588.
Brown, T.M., Ferguson, H.C., Davidsen, A., and Dorman, B. 1997, *Astrophys. J.*, **482**, 685.
Burnstein, D., Bertola, F., Buson, L. M., and Lauer, T.R. 1988, *Astrophys. J.*, **328**, 440.
Code, A.D., and Welch, G.A. 1979, *Astrophys. J.*, **228**, 95.
Da Costa, G.S., and Armandroff, T.E. 1990, *Astron. J.*, **100**, 162.
Edmonds, P.D., Gilliland, R.L., Guhathakurta, P., Petro, L.D., Saha, A., and Shara, M.M. 1996, *Astrophys. J.*, **468**, 241.
Ferraro, R.F., Fusi Pecci, F., and Bellazzini, M. 1995, *Astron. Astrophys.*, **294**, 80.
Ferraro, R.F., *et al.* 1997, *Astron. Astrophys.*, **324**, 915.
Gratton, R.G., Fusi Pecci, F., Carretta, E., Clementini, G., Corsi, C.E., and Lattanzi, M. 1997, *Astrophys. J.*, **491**, 749.
Harris, W.E. 1996, *Astron. J.*, **112**, 1487.
Hesser, J.E., Harris, W.E., VandenBerg, D.A., Allwright, J.W.B., Shott, P., and Stetson, P.B. 1987, *P.A.S.P.*, **99**, 739.
Kaluzny, J., and Udalski, A. 1992, *Acta Astron.*, **42**, 29.
Kaluzny, J., and Rucinski, S.M. 1995, *Astron. Astrophys. Suppl. Ser.*, **114**, 1.
Kaluzny, J., Krzemiński, W., Mazur, B., Wysocka, A., and Stępień, K. 1997, *Acta Astron.*, **47**, 249.
Kaluzny, J., Kubiak, M., Szymański, M., Udalski, A., Krzemiński, W., Mateo, M., and Stanek, K.Z. 1998, *Astron. Astrophys. Suppl. Ser.*, **128**, 19.
Landolt, A. 1992, *Astron. J.*, **104**, 340.
Minniti, D., Meylan, G., Pryor, C., Phinney, E.S., Sams, B., and Tinney, C.G. 1997, *Astrophys. J. Letters*, **474**, L27.
Paczyński, B., and Stanek, K.Z. 1998, *Astrophys. J. Letters*, **494**, L219.
Paresce, F., *et al.* 1991, *Nature*, **352**, 297.
Paresce, F., and De Marchi, G. 1994, *Astrophys. J. Letters*, **427**, L33.
Reid, I.N. 1998, *Astron. J.*, **115**, 204.
Rich, R.M., *et al.* 1997, *Astrophys. J. Letters*, **484**, L25.
Salaris, M., and Weiss, A. 1998, *Astron. Astrophys.*, **335**, 943.
Sandquist, E.L., Bolte, M., Hernquist, L. 1997, *Astrophys. J.*, **477**, 335.
Santiago, B.X., Elson, R.A.W., and Gilmore, G.F. 1996, *MNRAS*, **281**, 1363.
Shara, M.M., Saffer, R.A., and Livio, M. 1997, *Astrophys. J. Letters*, **489**, L59.
Shara, M.M., Bergeron, L.E., Gilliland, R.L., Saha, A., and Petro, L. 1996, *Astrophys. J.*, **471**, 804.
Stanek, K.Z., and Garnavich, P.M. 1998, *Astrophys. J. Letters*, **503**, L131.
Stanek, K.Z., Zaritsky, D., and Harris, J. 1998, *Astrophys. J. Letters*, **500**, L141.

Stetson, P.B. 1987, *P.A.S.P.*, **99**, 191.
Sweigart, A.V., and Catelan, M. 1998, *Astrophys. J. Letters*, **501**, L63.
Udalski, A., Szymański, M., Kubiak, M., Pietrzyński, G., Woźniak, P., and Żebruń, K. 1998, *Acta Astron.*, **48**, 1.
Yi, S., Demarque, P., and Kim, Y.-C. 1997, *Astrophys. J.*, **482**, 677.
Zinn, R., and West, M.J. 1984, *Astrophys. J. Suppl. Ser.*, **55**, 45.