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IUE observations of blue horizontal branch stars in the globular clusters M 3 and NGC 6752*

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Abstract. IUE observations of 3 blue horizontal branch (BHB) stars in M 3 and 4 stars in NGC 6752 are presented. In addition, unpublished IUE archive data have been used for 5 more BHB stars in NGC 6752. Using the most recent model atmospheres (Kurucz 1992) the physical parameters of these stars have been derived, and compared with the ZAHB evolutionary tracks by Dorman et al. (1993). All the stars, including those that appear to be evolved off the ZAHB, are consistent with the theoretical predictions. The present results are compared with those obtained in previous similar analyses: the possible presence of some low-gravity stars is confirmed in M 3, while no clear indication is found of multiple stellar populations on the HB of NGC 6752. However different populations, if any, would be difficult to identify in the $\log g$-$\log T_e$ plane because of the simultaneous effect of various parameters and the poor accuracy of the gravity estimates from IUE data.

Key words: clusters: globular: M3; NGC 6752 – stars: evolution of – stars: fundamental parameters – stars: horizontal branch

1. Introduction

The horizontal branch (HB) in a globular cluster HR (or colour-magnitude - CM) diagram is the locus of the stars which are burning Helium in their core after the Helium flash that occurs at the tip of the red giant branch phase. During this process there may be some amounts of core-envelope mixing and mass loss. These stars, which have all essentially the same age and chemical abundance, distribute themselves along the HB in a narrow range of luminosities and widely different temperatures (i.e. colours) according to their core and envelope mass. The general characteristics of the observed HB morphologies are therefore rather well understood. However there are some detailed features that cannot yet be easily explained by the current knowledge of the stellar evolution. In particular:

i) It is generally agreed that metallicity is the first parameter driving the stellar distribution along the HB, in the sense that most metal-poor clusters have blue HBs whereas relatively metal-rich clusters usually have red HBs. However there are clusters that do not follow this rule, and the non-monotonic relation between HB morphology and metal abundance introduces the need of a "second parameter" (or maybe even a "third parameter" or a combination of various parameters) in order to account for widely different HB morphologies in clusters with the same metal abundance (e.g. the case of M5, NGC362, NGC288 and NGC2808, see Rood et al. 1993). The most likely "second parameter" candidate has been suggested to be the age, but other parameters may play some rôle as well. For recent reviews we refer to Lee 1993; Fusi Pecci et al. 1993; van den Bergh & Morris 1993, and references therein.

ii) In several clusters the distribution of stars along the HB is discontinuous, producing "gaps" in the observed stellar population. Some of these clusters present also extended blue HBs, i.e. extremely hot (blue) "tails" reaching temperatures around 35,000K or more. No unquestionable explanation has been found yet for the presence of these gaps or tails (Fusi Pecci et al. 1993; Lee 1993; Lee 1994).

iii) Some non-genuine HB stars might fall in the HB area as a result of their evolution, for example the descendants of Blue Straggler stars (Fusi Pecci et al. 1992) and binary mergers (Iben 1990; Bailyn 1992), or because of colour saturation and large bolometric corrections at these high temperatures, for example supra-HB and post-AGB stars (Buzzoni et al. 1992).

iv) In addition, recent UV observations have revealed the existence of a hot and faint stellar population in some globular clusters, e.g. ω Cen (Whitney et al. 1994), M 79 (Hill et al. 1992), M 15 (De Marchi and Paresce (1994) and M 3 (Laget et al. 1994). Some of these stars may be HB or HB-related stars, most are probably not, as far as one can see from their still very poorly understood characteristics. Although they are not directly relevant and have not been considered for the present analysis, they should be kept in mind when discussing the general properties of the hot stellar components in globular clusters.

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* Based on observations obtained with the International Ultraviolet Explorer, ESA-Villafranca, Spain

A knowledge of the stellar population(s) on the HB is very important because of its impact on issues like: a) the parameters (e.g. helium abundance) that can be derived using the stellar population ratios between the HB and other evolutionary phases in the HR diagram (Buzzoni et al. 1983); b) the possible relation between the HB morphology and the structural and dynamical conditions of the clusters (Fusi Pecci et al. 1992, 1993); c) the contribution of the bluest HB stars to the integrated UV light of the clusters, which is relevant in population synthesis studies of unresolved stellar systems (Burstein et al. 1988; Greggio & Renzini 1990; Ferguson et al. 1991; Dorman et al. 1995).

We have started a program to study in detail the HB stellar population in a number of globular clusters, devoting special attention to the stars above and below the gaps and to the extended blue tails. Here we present the results obtained from IUE data in the clusters M 3 and NGC 6752, using both new observations and unpublished archive data, and compare them with previous analyses of this type. These clusters have been selected because they are among the most populous and nearby ones, and represent classical cases of a rather typical and "normal" HB morphology, albeit with the possible presence of a gap on the blue end (M 3), and of an extreme blue HB tail with gaps (NGC 6752).

A detailed study of the UV fluxes and optical spectral features for 9 BHB stars in NGC 6752 was performed by Caloi et al. (1986) and Heber et al. (1986, hereafter C 86 and H 86, respectively). The stellar physical parameters were derived using LTE and NLTE model atmospheres, and the evolutionary status of the sample stars above and below the gap was discussed. This study was continued by Moehler et al. (1994, hereafter MHB 94) in the clusters M 15 and NGC 6752 using visual spectroscopic and spectrophotometric data.

A previous study of HB stars in several globular clusters was also made by Crocker et al. (1988, hereafter CRC 88) using visual spectrophotometry. Our M 3 program stars are common to that sample and the results will be compared in Sect. 4.1.

2. The data

Three BHB stars in M 3 were observed with IUE in March 1992 using the low resolution mode (6 Å) in the wavelength range 1200-1900Å. Similar observations were taken of four BHB stars in NGC 6752 in September 1992. In addition, archive data have been used for 5 more stars in NGC 6752. The log of these observations is given in Table 1. In Fig. 1 we show the HB of M 3 and NGC 6752 where all these stars are marked as circles. They are also listed in Table 2; the identifications are from Buonanno et al. (1994) for M 3 (alternative identifications in column 2 are from Sandage 1953), and from Buonanno et al. (1986) for NGC 6752. Note that our star 5151 in NGC 6752 does not correspond to the star labelled 5151 in MHB 94 which is a misidentification of star 3118, as kindly pointed out by U. Heber (1994, private communication). Previous analyses in the UV range with IUE data had been performed for 3 UV-bright stars in M 3 (Buzzoni et al. 1992) and 8 BHB stars in NGC 6752 (C 86, H 86). The UV-bright stars in M 3, namely 156=I-II-57=vZ1128, 524=I-III-87 and 7561=I-V-37, are actually post-AGB and supra-HB stars and are not of the same type as those analysed in the present study.

The stars in NGC 6752 have been reanalysed using the archive data in order to treat all the available information on a homogeneous and uniform basis. These stars are indicated as squares in Fig. 1, and have been reported in Table 2 for completeness and convenience, although this information is already contained in the quoted papers.

Table 1. IUE spectra for the program BHB stars in M 3 and NGC 6752

Star	Image	Obs. Date	Exp.Time (min)
M 3			
621	SWP44258	28MAR92	402.00
352	SWP44273	31MAR92	348.00
843	SWP44280	01APR92	156.00
NGC 6752			
4951	SWP45779	26SEP92	180.00
2932	SWP30906	04MAY87	395.00
722	SWP25534	28MAR85	408.00
4548	SWP45780	26SEP92	162.00
534	SWP30897	03MAY87	370.38
5151	SWP45783	27SEP92	383.00
4009	SWP45773	25SEP92	383.00
491	SWP25522	26MAR85	294.00
	SWP30915	05MAY87	395.00
916	SWP25539	29MAR85	282.00
4719	SWP17053	27MAY82	413.00
1754	SWP19442	11MAR83	84.00
763	SWP17444	18JUL82	418.00
331	SWP23126	28MAY84	413.00
3986	SWP23120	27MAY84	411.00
3118	SWP19433	10MAR83	398.00

3. Analysis and results

In analogy with our previous work in M 3 (Buzzoni et al. 1992) and with de Boer (1985), we have estimated for each star the UV colours (13–18) and (18–V) as

$$(13\text{–}18)=-2.5(logF_{1300} - logF_{1800})$$

and

$$(18\text{–V})=-2.5(logF_{1800} - logF_V)$$

where F_{1300} and F_{1800} are the intrinsic fluxes at 1300 and 1800Å, averaged over a bandwidth of 100Å and 150Å respectively, and the flux at V has been obtained as $logF_V = -0.4V_0 - 8.41$ (Allen 1976). These are continuum bands, and in any case it is not possible to identify any absorption feature in our spectra, as expected in these metal-poor stars and relatively low S/N data. The data have been corrected for E(B–V)=0.01 and 0.04 for M 3 and NGC 6752 respectively (Peterson 1993) using the

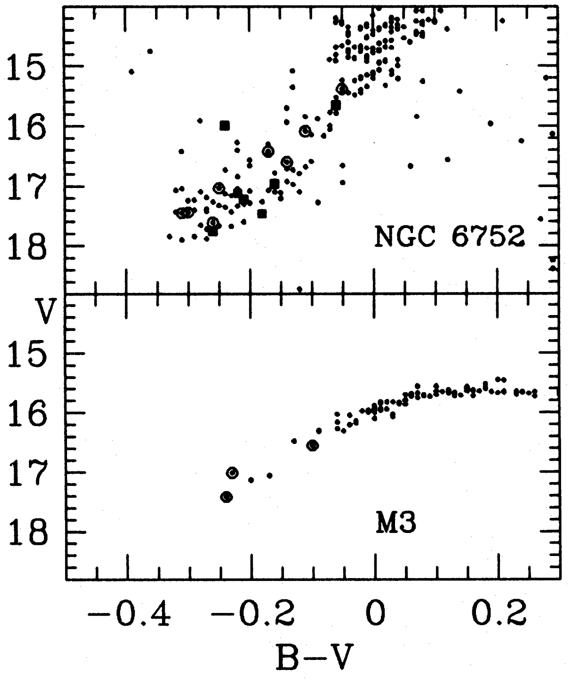

Fig. 1. The blue part of the horizontal branches of M 3 and NGC 6752. The program stars are marked as circles, the NGC 6752 stars previously analysed in the UV are marked as squares. Note the gaps at V ~ 16.7 in M 3 and V ~ 16.3 in NGC 6752

Table 2. V magnitudes and B–V colours for the program BHB stars in M 3 and NGC 6752. The identifications in column 1 and the photometric data are from Buonanno et al. (1994) and Buonanno et al. (1986) respectively, the alternative identifications in column 2 are from Sandage (1953) and C 86 respectively

Star	Star	V	B–V	Note
		M 3		
621	I-III-57	16.55	–0.10	
352	I-I-58	17.01	–0.23	
843	I-VI-54	17.42	–0.24	
		NGC 6752		
4951		15.38	–0.05	
2932	4287	16.08	–0.11	(1)
722	841	16.42	–0.17	(1)
4548		16.60	–0.14	
534	649	17.03	–0.25	(1)
5151		17.22	–0.21	
4009		17.44	–0.30	
491	602	17.45	–0.31	(1)
916	1112	17.61	–0.26	(1)
4719	2167	15.65	–0.06	(2)
1754	2128	15.99	–0.24	(2)
763	3781	17.13	–0.24	(2)
331	3675	17.12	–0.22	(2)
3986	3507	17.46	–0.18	(2)
	3118	17.76	–0.26	(2),(3)

(1): identification in column 2 from IUE Archive (same source as C 86);
(2): previous analysis of UV data by C 86 and H 86;
(3): photometric data from C 86.

Seaton's (1979) reddening law for the Galaxy and assuming A_V=3.2E(B–V). In addition, the data have been corrected by a correction function which takes into account the "low frequency ondulations" found by Finley et al. (1990) in their analysis of SWP low resolution spectra of white dwarfs. The latest version of this correction vector, that we have applied to our data, is shown in Chavez et al. 's (1995) Fig. 7, and was kindly provided by M. Chavez (1994, private communication). This is a significant correction at the shortest wavelengths (it decreases the flux by about 15% around 1300Å) while it has only a marginal effect at 1800Å. The dereddened and corrected fluxes and UV colours thus derived are listed in Table 3.

Typical errors in the observed colours are about ±0.1 mag due to the combined effect of the visual and UV photometric accuracy, the uncertainties in the reddening correction and the absolute calibrations on different spectral ranges.

In order to obtain an estimate of temperature and gravity for these stars, we have followed two procedures, albeit not quite independent.

3.1. The (18–V)-T_e and (13–18)-logg relations

The intrinsic colours have been compared with a grid of synthetic (13–18) and (18–V) colours that were constructed with the same procedure adopted for the observed spectra, using the most recent model atmospheres by Kurucz (1992, hereafter K92) at metallicity [m/H]=–1.50, which is appropriate for both clusters. We note, however, that the models are increasingly insensitive to metallicity as the temperature increases, and for stars hotter than about 10,000K the models at [m/H]=0.0 lead to essentially the same results within few hundred degrees (but see Dixon et al. 1994 for possible problems with very hot stars).

We show in Fig. 2a-c the grid of models (i.e. temperatures and gravities) in the (13–18) vs (18–V) plane. For the sake of clarity, the models have been plotted in three temperature groups, i.e. T=10,000-20,000K (Fig. 2a), T=20,000-30,000K (Fig. 2b) and T=30,000-50,000K (Fig. 2c), where the models at the top correspond to the highest gravity (log$g$=5.0) and scale down in steps of 0.5.

The (18–V) colour is considered to be a good temperature indicator, especially for the hottest stars, since it provides a long baseline and includes the contribution from the ultraviolet where these stars emit a large fraction of their energy. However it is extremely sensitive to reddening, an error ΔE(B–V)=0.01 corresponding to ΔlogT_e=0.006, without considering the inaccuracy of the reddening law.

The (13–18) colour is a gravity indicator, although its sensitivity to gravity is not very high (see Fig. 2) and the use of optical spectra in the blue range (i.e. Balmer continuum and lines) would provide more accurate estimates. Alternatively, a

Table 3. Logarithm of dereddened fluxes (*erg* $cm^{-2}\,s^{-1}\,Å^{-1}$) at 1300Å, 1800Å and V, and corresponding (13–18) and (18–V) colours, for the program BHB stars in M 3 and NGC 6752

Star	$logF_{1300}$	$logF_{1800}$	$logF_V$	(13–18)	(18–V)
M 3					
621	-14.43	-14.53	-15.02	-0.25	-1.23
352	-14.42	-14.45	-15.20	-0.08	-1.88
843	-14.42	-14.40	-15.37	+0.05	-2.43
NGC 6752					
4951	-13.64	-13.77	-14.51	-0.33	-1.85
2932	-13.62	-13.86	-14.79	-0.60	-2.33
722	-13.53	-13.85	-14.93	-0.80	-2.70
4548	-13.56	-13.81	-15.00	-0.63	-2.98
534	-13.54	-13.95	-15.17	-1.03	-3.05
5151	-13.55	-13.95	-15.25	-1.00	-3.25
4009	-13.44	-13.82	-15.34	-0.95	-3.80
491	-13.54	-13.93	-15.34	-0.98	-3.53
916	-13.64	-13.97	-15.40	-0.83	-3.58
4719	-13.61	-13.81	-14.62	-0.50	-2.03
1754	-12.77	-13.12	-14.75	-0.88	-4.08
763	-13.38	-13.77	-15.21	-0.98	-3.60
331	-13.44	-13.85	-15.21	-1.03	-3.40
3986	-13.55	-13.93	-15.34	-0.95	-3.53
3118	-13.79	-14.13	-15.46	-0.85	-3.33

good tool for this purpose would be far-UV data, as shown by a recent analysis of two UV-bright stars in M5 and M 3 by Dixon et al. (1994) using HUT spectrophotometry extending to the Lyman limit, which is more sensitive to both temperature and gravity and therefore provides a more precise determination of these parameters.

A possible problem of the (13–18) gravity index is its sensitivity to metallicity, as shown by the comparison of the energy distributions for field HB stars and Population I stars of the same spectral type (Huenemoerder et al. 1984). The excess flux for the field HB stars in the range between 1300Å and 1700Å is largely due to their lower metallicity. In the present analysis we have used theoretical model atmospheres for [m/H]=–1.5, which is appropriate for both clusters, however abundance anomalies due to radiative diffusion cannot be excluded in the hottest HB stars (Michaud et al. 1983; Altner & Matilsky 1993; Dixon et al. 1994), and some additional error due to this effect can further decrease the accuracy of the gravity determination.

As a result of this procedure and the errors discussed above, temperatures are estimated with an internal error of about 5%, whereas the error on the logarithm of the gravities is 0.5-1.0.

3.2. The comparison of energy distributions and model atmospheres

In order to exploit the full spectral information of the data, and for a consistent comparison with the results of H 86, we have also compared the SWP energy distributions with Kurucz (1992) models at [m/H]=–1.5. The spectra have been smoothed with a 24 Å running average to improve the S/N.

The values of temperature and gravity estimated from the (18–V) and (13–18) colours (see Sect. 3.1) have been used as initial assumptions. Then a grid of models at steps of 1000K in temperature and 0.5 in log$g$ around the initial assumptions has been compared to the observed spectra in order to find the best-fit set of parameters. We show in Fig. 3, as an example, the energy distributions of the stars 4951 and 5151 in NGC 6752 and 621 in M 3, compared to the bracketing models which have been normalized to the respective logF_V values listed in Table 3.

We have verified that for all stars the intrinsic energy distributions are consistent with the models corresponding to the initial assumptions within ±1000K. The models however are not very sensitive to gravity, and the most one can derive is some indication of high gravity (log$g$ $>$ 5.0) in those cases where the flux at 1300Å appears to rise more steeply than the remaining part of the energy distribution (see for example star 5151 in Fig. 3).

Therefore UV IUE data are important for estimates of temperature, but do not seem very adequate for estimates of gravity which are determined with better accuracy from the analysis of the Balmer line profiles and Balmer limit, or of the Lyman limit, if available.

As a result from the UV data alone, we have therefore adopted the mean of the temperatures estimated in Sect. 3.1 and 3.2, and the gravities estimated in Sect. 3.1. The values thus derived are listed in Table 4.

4. Discussion

4.1. Comparison with previous results

M 3: The three stars we have studied in M 3 had been previously analysed by CRC 88 using visual spectrophotometry. The temperatures, which were derived by comparison with Kurucz (1979 and unpublished) models using the continuum and the Balmer lines Hβ, Hγ and Hδ, result systematically hotter by approximately 1400K than the present estimates (see Table 4). Since zero reddening was assumed for M 3 by CRC 88, these values should actually be larger by an additional ΔlogT_e $\sim$ 0.006 in order to be homogeneous with our estimates. The different sets of theoretical models can only account for a temperature difference of approximately 2% in the range of temperatures of interest here, (K92 at [m/H]=–1.5 being cooler than K79 at [m/H]=0.0), so it appears that the temperatures estimated from the visual data (Balmer continuum and lines analysis) are systematically higher (by $\sim$ 1300K) than those derived from the UV data. The same effect is found also in NGC 6752, as discussed below.

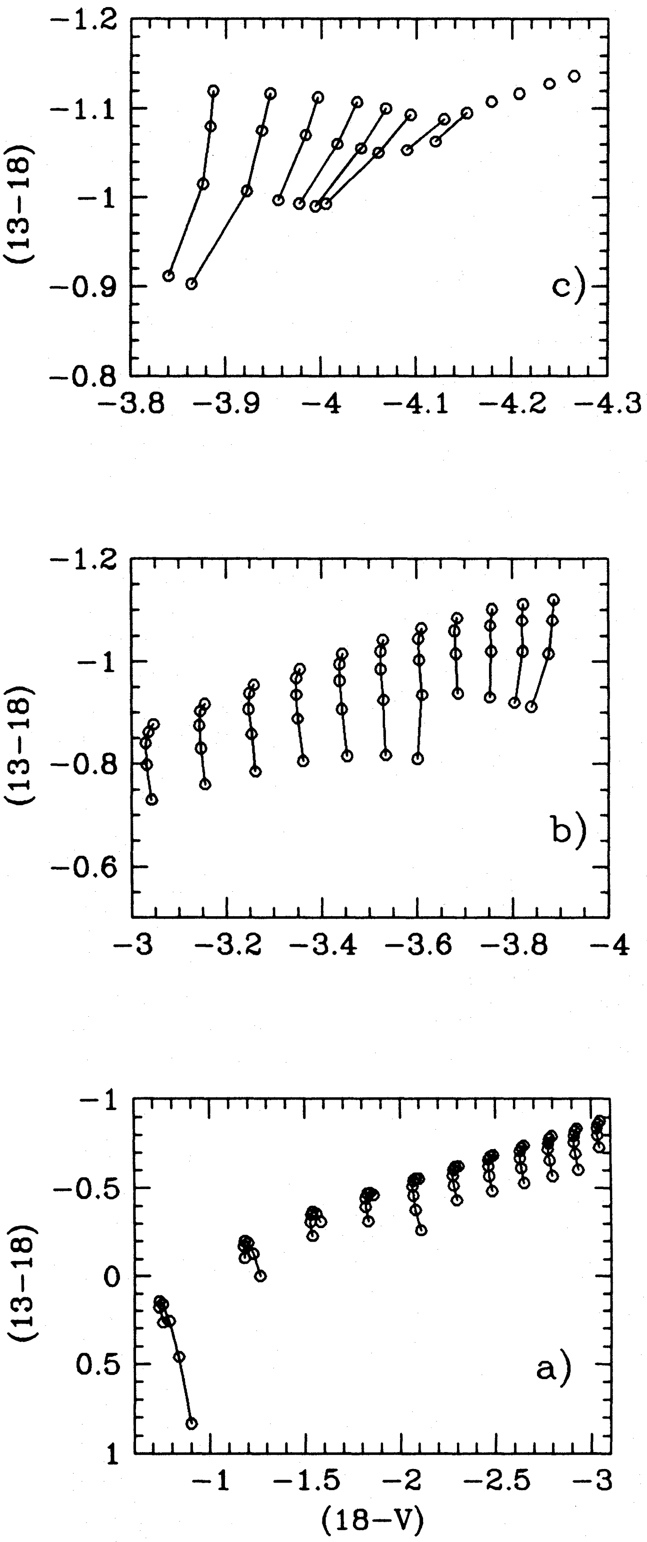

Fig. 2a–c. UV colours (13–18) vs. (18–V) from K92 model atmospheres with [m/H]=–1.5. The solid lines connect the models at a given temperature and different gravities decreasing from log$g$=5.0 (top dot) in steps of 0.5. For the sake of clarity the models have been plotted in three temperature ranges: **a** from 10,000 to 20,000K in steps of 1,000K, left to right; **b** from 20,000 to 30,000K in steps of 1,000K; **c** from 30,000 to 35,000K in steps of 1,000K, and from 35,000 to 50,000K in steps of 2,500K

Table 4. Effective temperature and gravity for the program stars in M 3 and NGC 6752, estimated from the colours (13–18) and (18–V) and the comparison with K92 models (see the text for comments on the accuracy of these estimates). The temperatures in parenthesis are from the empirical calibration by Gulati et al. (1989). The values on the second line are those derived from previous analyses, when available (i.e. CRC 88 for M 3, and H 86 for NGC 6752, see text)

Star	logT_e	log$g$
M 3		
621	4.041 (4.034)	3.5
	4.084	3.55
352	4.114 (4.140)	<2.5
	4.176	4.01
843	4.190 (4.233)	<2.5
	4.222	4.09
NGC 6752		
4951	4.114 (4.140)	2.8
2932	4.185 (4.216)	4.0
722	4.243 (4.273)	5.0
4548	4.284 (4.316)	3.0
534	4.301 (4.321)	>5.0
5151	4.342 (4.356)	>5.0
4009	4.461 (4.449)	3.5
491	4.398 (4.401)	4.0
916	4.408 (4.410)	3.0
4719	4.143 (4.169)	3.5
	4.176	4.0
1754	>4.602 (4.507)	4.0:
	4.602	5.0
763	4.414 (4.413)	4.0
	4.415	5.5
331	4.371 (4.377)	>5.0
	4.398	5.6
3986	4.398 (4.401)	4.0
	4.439	
3118	4.357 (4.369)	3.5
	4.371	5.2

The possible reasons we can think of in order to account for this discrepancy are:

a) A systematic difference between the two methods of deriving the temperatures, i.e. H lines analysis vs. UV-V continuum slope. This is supported by the recent results of Moehler et al. (1995) on BHB stars in M 15, where the temperatures estimated from the Balmer lines alone are on average about 3400K hotter than the temperatures estimated from the Balmer continuum alone. The combination of continuum and Balmer lines results still yields temperatures that are a few hundred degrees hotter than those derived from the continuum alone. We also note that Dixon et al. (1994) have fitted the UV spectrum of the M 3 star vZ1128 over the region from 830Å to 1850Å (HUT data) with the most recent Kurucz models, thus taking into ac-

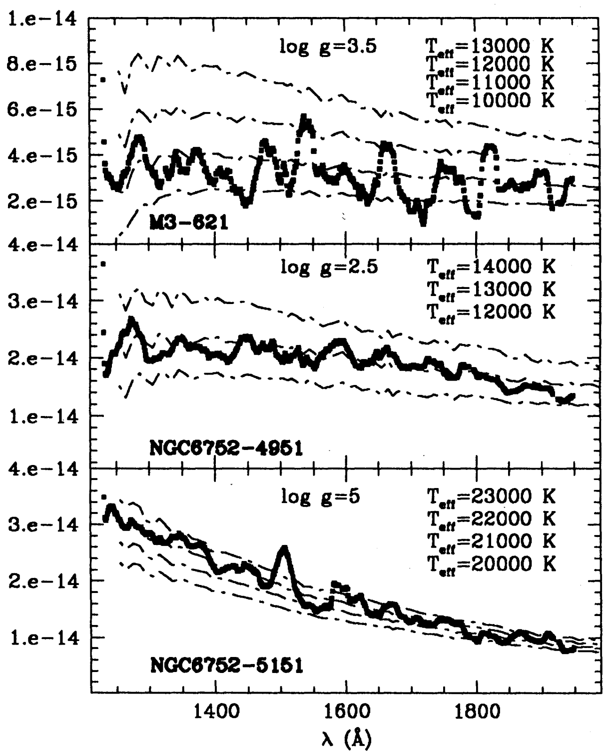

Fig. 3. Comparison of the spectral energy distributions of the stars 621 in M 3, and 4951 and 5151 in NGC 6752, with the Kurucz (1992) model atmospheres (dashed lines) corresponding to the values of gravity and temperature indicated in each panel

count the Lyman jump. They have derived a best-fit temperature of 35,000 K (albeit with a model at metallicity [m/H]=–3.5), which is significantly hotter than the value (30,000K) found by previous estimates using IUE data and the (18–V) colour (de Boer 1985; Buzzoni et al. 1992).

b) A systematic error in the absolute V calibration. This in principle cannot be excluded since few very blue standard stars are usually available, and the colour equation may have been extrapolated at the very blue end. In order to account for the observed temperature difference, the V magnitudes would have to be too bright by approximately 0.2 mag for stars of about 20,000K and 0.1 mag at 30,000K. The comparison of our photometric data with those from Sandage (1953) (see also the compilation by Hills 1971), however, does not support this explanation. In addition, the linear extrapolation of the photometric calibration would work in the opposite direction, as it would rather tend to overestimate the V magnitudes and make them fainter.

The gravities were estimated from the analysis of the Balmer lines, by assuming appropriate values for the temperature and the helium abundance in the atmosphere. These determinations of gravity are more accurate than those obtained from the UV data, which claim an error $\Delta \log g$=0.25 (Dixon et al. 1994) or worse (present analysis).

NGC 6752: the stars 4719, 1754, 763, 331, 3986 and 3118 had been previously studied by C 86 and H 86 using both ultraviolet and visual data and LTE and NLTE model atmospheres. The temperatures were determined by comparing the observed UV flux distributions with Kurucz and Kiel LTE models (NLTE models were used only for the hottest star 1754), after scaling the theoretical models to the observed V magnitudes, and assuming E(B–V)=0.05. The accuracy of these determinations is claimed to be 5%. These temperatures are in average about 1200K hotter than the present estimates (without considering the star 1754 for which our temperature determination is particularly uncertain), and again some of this difference can be accounted for by the smaller reddening value and by the cooler model atmospheres we have used, leaving however a residual discrepancy of about 700 K. Although this value is comparable to the 1σ error of these determinations, it seems to be systematic and in the same sense as the results found in M 3. Since for NGC 6752 the previous estimates of temperature were based on the same method we have used in the present analysis (in particular in Sect. 3.2), namely the comparison of UV and V continuum energy distributions, and again there is no support for a systematic difference in the V absolute calibration with respect to other independent photometric studies (i.e. Cannon as reported by C 86), it is not obvious what the cause of this discrepancy might be.

As a general comment, we note that the temperatures, which are certainly more accurate when obtained from ultraviolet and visual data together, do still suffer from some intrinsic uncertainty, due to the method used to derive them *and* to the intrinsic inaccuracies of the model atmospheres. This latter point may be quite important, especially in the ultraviolet range, as it was recognized for the cooler stars (e.g. Bell et al. 1994 and references therein), and deserves a careful analysis also for the hotter stars. In order to obtain a model-independent estimate of the temperatures, we have applied to the program stars the empirical temperature calibration for early-type stars by Gulati et al. (1989). The relation we have used is (from their Eq. 3): $logT_{eff} = 3.828 - 0.178(m1965 - V)_0$. The UV colour $(m1965 - V)_0$ has been obtained from our colour (18–V) plus a colour correction $-2.5(logF_{1965} - logF_{1800})$ as a function of temperature, derived from the model atmospheres. We have listed for comparison these "semi-empirical" temperatures in parenthesis in Table 4. It is interesting to note that, excluding the star 1754 which is off by more than 3σ, both our present estimates and those from the previous analyses define tight relations which differ by a small but systematic amount from the empirical results: our values are in average cooler by $\sim$3%, whereas the previous values are in average hotter by $\sim$4% over the entire temperature range.

The gravities were derived from Balmer line profile fits. The values of gravity are generally similar to the present estimates, except that the present values "saturate" at log$g$=5.0 (the highest gravity in K92 models) whereas the analysis of the Balmer lines can yield values larger than 5.0. In our analysis, the UV colours of the star 1754 are compatible with any value of temperature in the range 34,000 (with gravity $\sim$ 4.0) to 42,500K (with gravity $\sim$ 5.0). Therefore the values listed in Table 4 are very uncertain.

Table 5. Adopted values for the program stars. Temperatures are the mean values of those listed in Table 4, gravities are from previous analyses (second lines in Table 4) when available, otherwise from the present study. The error associated to the mass values is larger than 50% (see Sect. 3)

Star	$\log T_e$	$\log g$	B.C.	$\log\frac{L}{L_\odot}$	$\log\frac{M}{M_\odot}$
M 3					
621	4.054	3.55	-0.60	1.52	-0.54
352	4.144	4.01	-1.11	1.54	-0.42
843	4.215	4.09	-1.53	1.54	-0.62
NGC 6752					
4951	4.127	2.5	-1.01	1.42	-1.98
2932	4.201	5.0	-1.44	1.31	0.12
722	4.258	5.0	-1.78	1.31	-0.11
4548	4.300	2.5	-1.97	1.32	-2.77
534	4.311	5.0	-2.10	1.20	-0.43
5151	4.349	5.0	-2.32	1.21	-0.58
4009	4.455	3.5	-2.82	1.32	-2.39
491	4.400	4.0	-2.59	1.22	-1.77
916	4.409	3.0	-2.56	1.15	-2.88
4719	4.163	4.0	-1.22	1.40	-0.64
1754	4.573	5.0	-3.87	2.32	-0.36
763	4.414	5.5	-2.70	1.40	-0.15
331	4.382	5.6	-2.53	1.33	0.01
3986	4.413	4.0	-2.67	1.25	-1.79
3118	4.366	5.2	-2.42	1.03	-0.62

This star displays however AGB-manqué characteristics, and is not strictly relevant for our considerations on HB stars.

As a final result, summarized in Table 5, we have therefore adopted for the temperature the average value between the previous, present and empirical estimates of temperature, with an accuracy of approximately ± 5%, while for the gravity we have preferred the results from visual data when available.

In Table 5 we also list the bolometric corrections derived from the models (an offset of +0.11 has been applied to all B.C. values derived from K92 models, in order to scale to the correct value for the Sun BC(⊙)=–0.08), and the luminosities based on the assumptions that $M_{bol}(\odot)$=4.72 (Allen 1976), $(m-M)_0$(M 3)=15.00 (Buonanno et al. 1994) and $(m-M)_0$(NGC 6752)=13.07 (Buonanno et al. 1986). The masses have been estimated from the Stefan-Boltzmann law using the relation

$$logM/M_\odot = logL/L_\odot + logg - 4logT_e + 10.611$$

It is important to stress that the values of mass derived with this method are very inaccurate: assuming typical errors of ± 0.1 mag in the luminosity, ± 500K in the temperature and ± 0.5 in log$g$, the masses are determined with a ∼ 130% accuracy. This uncertainty would decrease down to ∼ 40% if the gravity could be determined with an error of ± 0.1, which is beyond the possibility of IUE data. The values of mass we list in Table 5 are therefore nothing more than simple indications. Somewhat more realistic results can be obtained if temperatures estimated from UV data are used along with gravities estimated from visual data.

4.2. The log$L$-logT_e diagram

The values listed in Table 5 for each star have been compared in the logL-logT_e plane (see Fig. 4) with the O-enhanced ZAHB models from Dorman et al. (1993) for [Fe/H]=–1.48, [O/Fe]=0.63, Y_{HB}=0.25 and core mass M_c=0.485 $M_\odot$. Comparison is made also with the canonical ZAHB models from Caloi et al. (1978) for Y=0.218, [Fe/H]=–1.63 and M_c=0.498 $M_\odot$, and with the models by Castellani et al. (1991) for Y_{HB}=0.24, Y_{MS}=0.23, [Fe/H]=–1.63 and M_c=0.498 $M_\odot$.

The stars above the gap (see Fig. 1) have been indicated as triangles, and the stars below the gap as circles. In M 3, all the stars appear to belong to the ZAHB or be at most slightly evolved. The same is true also for most stars in NGC 6752, with the exception of star 1754 which shows AGB-manqué characteristics. The star 3118, which appears to be underluminous by about 0.2-0.3 mag with respect to the other stars, can be affected by large photometric errors. This is the only star in our sample for which old photometric data have been used (see Table 2), as it lies near the edge of the field and is not included in the list of photometric data in Buonanno et al. (1986).

A population of underluminous hot HB stars has been found in some globular clusters, such as M 79 (Hill et al. 1992), NGC 1851 (Parise et al. 1994) and ω Cen (Whitney et al. 1994). It is not clear yet whether this arises from errors in the interior or atmosphere models, or from photometric errors, or if indeed it represents a special population of objects which are not true HB stars or alternatively are HB stars with smaller core masses than predicted from the evolution theory. In NGC 6752 a few slightly underluminous stars with respect to Caloi et al. 's ZAHB could be present. This effect, however, is not quite so evident if one considers the Dorman et al. 's ZAHB, therefore no conclusion can be derived about the existence of this type of stellar population in NGC 6752 from the present data.

5. Conclusions

We have analysed 3 BHB stars in M 3 and 9 BHB stars in NGC 6752 using UV IUE data, and reanalysed previously published IUE data for 6 more stars in NGC 6752. The values of temperatures and gravities have been derived by comparing the UV colours and energy distributions with the most recent model atmospheres (K92). The evolutionary status of these stars has then been estimated by comparison with Dorman et al. (1993) ZAHB models. From this analysis we may derive the following conclusions:

1. For these hot stars the temperatures derived from UV data are more accurate than those derived from visual data, as they are based on a much longer wavelength baseline. With respect to previous estimates which made use of visual data and

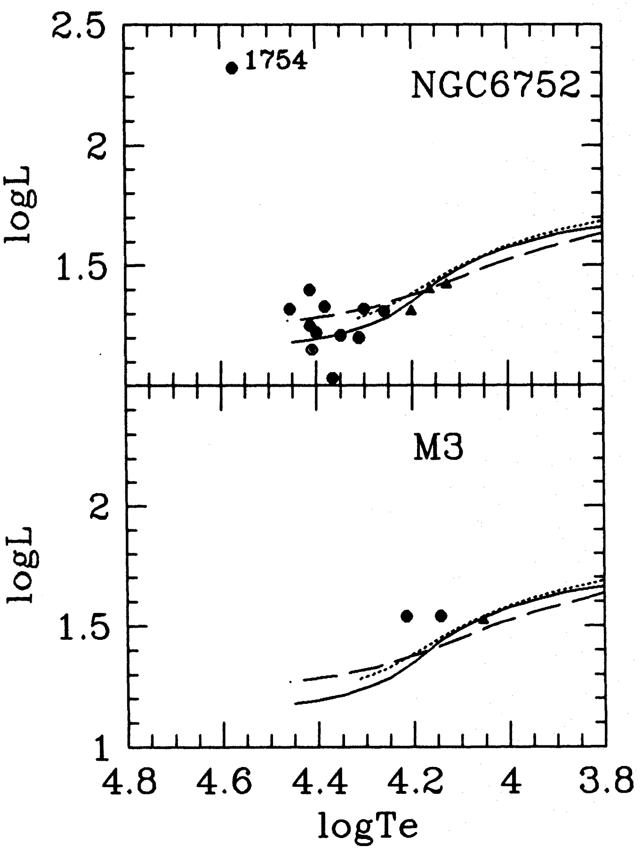

Fig. 4. The stars listed in Table 5 in the logL-logT_e plane. The circles and triangles indicate the stars below and above the gap, respectively. The solid line represents the O-enhanced ZAHB sequence from Dorman et al. (1993), the dashed and dotted lines show the ZAHB from Caloi et al. (1978) and Castellani et al. (1991), respectively

Kurucz (1979) model atmospheres, the present temperatures are approximately 1200K cooler. There may be (small) systematic differences in the temperature estimates, due to the method of deriving the temperature and to possible errors in the model atmospheres, as the comparison with the results obtained from the empirical temperature calibration by Gulati et al. (1989) seems to suggest.

2. The UV data in the IUE wavelength range are not very sensitive to gravity, and the values estimated from visual data (i.e. Balmer lines and Balmer limit), or from far-UV data if available (i.e. Lyman limit), are more accurate.

3. As previously suggested by CRC 88, there is some evidence of a low gravity tail on the HB in M 3. However the presence of multiple stellar populations, in M 3 or in other clusters, needs a considerable number of very accurate temperature and gravity determinations in order to be confirmed.

4. A few stars in NGC 6752 may (or may not, depending on the ZAHB models) be slightly underluminous with respect to the ZAHB, as it has been found also in other clusters (e.g. M 79, NGC 1851, ω Cen). It was suggested (H 86 and MHB 94) that the stars above the gap have lower gravities than the ZAHB, whereas the stars below the gap (i.e. the equivalent of the sdB stars in the field) lie well on the ZAHB. The present results neither support nor exclude this possibility, and we stress that more accurate temperatures and gravities are necessary in order to reach any firm conclusion on the presence of different stellar populations on the HB.

5. The values of mass estimated in the present analysis are affected by large errors and have to be taken only as indicative. Gravities as accurate as $\Delta\log g$=0.1 or better must be used in order to derive meaningful and reliable values for the stellar masses.

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