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Hot stars in globular clusters

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Abstract. Globular clusters are ideal laboratories to study the evolution of low-mass stars. In this review, I shall concentrate on two types of hot stars observed in globular clusters: horizontal branch stars and UV bright stars. The third type, the white dwarfs, are covered by Bono in this volume. While the morphology of the horizontal branch correlates strongly with metallicity, it has been known for a long time that one parameter is not sufficient to describe the diversity of observed horizontal branch morphologies. A veritable zoo of candidates for this elusive "2^{nd} parameter" has been suggested over the past decades, and the most prominent ones will be briefly discussed here. Adding to the complications, diffusion is active in the atmospheres of hot horizontal branch stars, which makes their analysis much more diffcult. The latest twist along the horizontal branch was added by the recent discovery of an extension to hotter temperatures and fainter magnitudes, the so-called "blue hook". The evolutionary origin of these stars is still under debate. I shall also give a brief overview of our current knowledge about hot UV bright stars and use them to illustrate the adverse effects of selection bias.

Key words. Stars: horizontal branch – Stars: UV bright Stars: atmospheres – Stars: Population II – Galaxy: globular clusters

1. Introduction

Globular clusters are the closest approximation to a physicist's laboratory in astronomy. They are densely packed, gravitationally bound systems of several thousands to about one million stars. The dimensions of the globular clusters are small compared to their distance from us: half of the light is generally emitted within a radius of less than 10 pc, whereas the closest globular cluster has a distance of 2 kpc, and 90% lie more than 5 kpc away. We can thus safely assume that all stars within a globular cluster lie at the same distance from us. With ages in the order of 10^{10} years globular clusters are among the oldest objects in our Galaxy. Contrary to the field of the Galaxy, most globular clusters formed stars only once in the beginning. Because the duration of that star formation episode is generally short, as compared to the current age of the globular clusters, the stars within one globular cluster are essentially coeval. In addition, all stars within one globular cluster (with few exceptions) show the same initial heavy element abundance pattern (which may differ from one cluster to another).

As we know today that Galactic globular clusters are old stellar systems, people are often surprised by the presence of hot stars in these clusters, since hot stars are usually associated with young stellar systems. The follow-

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ing paragraphs will show that hot stars have been known to exist in globular clusters for quite some time:

More than a century ago, Barnard (1900) reported the detection of stars in globular clusters that were much brighter on (blue-sensitive) photographic plates than they appeared visually: *"Of course the simple explanation of this peculiarity is that these stars, so bright photographically and so faint visually, are shining with a much bluer light than the stars which make up the main body of the clusters."*

ten Bruggencate (1927, p. 130) used Shapley's data on M 3 and other clusters to plot magnitude versus colour (by replacing luminosity and spectral type in the Hertzsprung-Russell diagram) and noted the presence of a horizontal branch that parted from the red giant branch and extended far to the blue at constant brightness. Greenstein (1939) observed a colour-magnitude diagram for M 4 and noticed that – while hot main-sequence stars were completely missing – there existed a group of bright stars above the horizontal branch and on the blue side of the red giant branch. These two groups of stars are known today as **horizontal branch** (**HB**) and **UV bright** stars, respectively. Their areas in a typical colour-magnitude diagram are marked in Fig. 1.

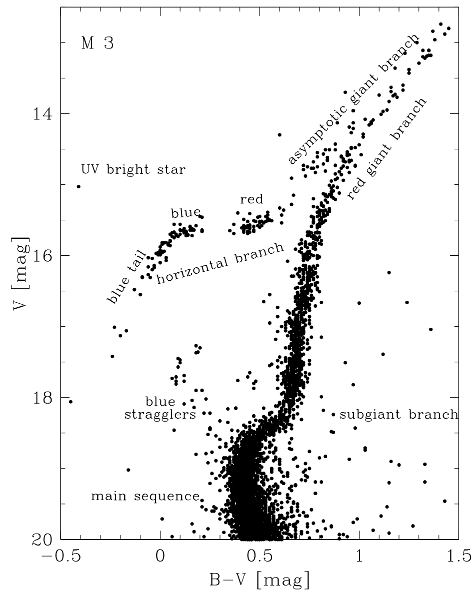

Fig. 1. Colour-magnitude diagram of the bright stars in M 3 from data by Buonanno et al. (1994) with the evolutionary phases marked.

2. Horizontal branch stars

It took quite some time before the evolutionary status of horizontal branch stars was understood (for details, see Moehler 2001). Nowadays there is a general agreement that horizontal branch stars consist of a helium-burning core of about 0.5 $M_\odot$ and hydrogen-rich envelope of up to 0.3 $M_\odot$. The less massive this envelope is, the hotter is the resulting HB star (at a given metallicity). The distribution of stars in colour (i.e. temperature) along the horizontal branch (at a given metallicity) can therefore be understood as a spread in envelope mass. This, in turn, requires a spread in the mass loss on the red giant branch. The true nature of this mass loss, unfortunately, is still not understood (see Catelan 2000, for a discussion of the effects of various mass loss parametrizations), which puts a definite question mark to many statements about horizontal branch stars.

If the mass of this hydrogen-rich envelope exceeds roughly 0.02 $M_\odot$, hydrogen-shell burning is active and the stars will evolve to the asymptotic giant branch (**AGB**) after the helium in the core is exhausted. If the hydrogen envelope is less massive, hydrogen shell burning cannot be sustained, and the stars evolve directly to the white dwarf domain. These least massive (i.e. hottest) horizontal branch stars are also called extreme horizontal branch (**EHB**) stars and have effective temperatures above 20,000 K. The transition from hot to extreme HB stars takes place towards the fainter part of the blue tail at $M_V \geq 3$[1].

[1] The change in slope of the horizontal branch towards higher temperatures is caused by the decreasing sensitivity of $B - V$ to temperature on one hand and by the increasing bolometric correction for hot-

2.1. The second parameter problem

Metal-poor globular clusters generally show bluer horizontal branches than metal-rich ones. This behaviour can be reproduced by current models, assuming that the mass loss does not depend on the metallicity and that the clusters have similar ages. Then the HB stars should have envelopes of similar mass, but the lower opacity in the envelopes of metal-poor HB stars provides less shielding of the hot core, resulting in a higher effective temperature for the star. However, more than 40 years ago, Sandage & Wildey (1967) discovered that there are globular cluster with similar metallicities, but quite different HB morphologies. Since then, many more examples have been found, with some extreme cases, like NGC 6388 and NGC 6441, two metal-rich bulge globular clusters which show blue tails in their colour-magnitude diagrams (Rich et al. 1997). Also a so-called "internal" 2nd parameter has been observed, which describes globular clusters showing HB stars over an extremely wide temperature range (i.e. from the red HB to the extreme HB region). An excellent example for this effect is NGC 2808 (e.g. Bedin et al. 2000).

Despite many efforts over the past decades, the problem of the 2nd parameter remains unsolved, and there is of course no reason why there should be just one 2nd parameter, and not also a 3rd and 4th one. One should also keep in mind that the horizontal branch morphology is strongly influenced by the mass loss on the red giant branch, which we still do not understand. Below, I give a list of candidates for the 2nd parameter, which is very probably not complete despite my best efforts. Since most of the scenarios have been discussed by many authors, I decided not to provide references for individual scenarios, as it is impossible to do that in an appropriate way in the limited space available here[2].

ter stars (i.e. the maximum of stellar flux is radiated at ever shorter wavelengths for increasing temperatures, making stars fainter at *V*) on the other hand.

[2] Just requiring the words `second parameter globular cluster` in the abstract and restricting the search to refereed papers yields almost 200 references in ADS.

Age With increasing age the turnoff mass of a stellar population decreases. Thus, a given mass loss will result in HB stars with less massive envelopes, i.e. hotter HB stars. This would mean that, at a given metallicity, globular clusters with blue horizontal branches are older than those with red horizontal branches. The age differences required range from one billion years to several billion years, and also depend on the absolute ages of the globular clusters. This scenario cannot explain the internal 2nd parameter effect, as the required age differences would also affect the observed turnoff region.

Dynamical Effects Due to their high density, globular clusters provide a good environment for dynamical interactions. Such interactions may enhance mass loss, e.g. by close encounters of red giant stars with main sequence stars or compact objects. If dynamical interactions were the 2nd parameter, one would expect that more concentrated globular clusters show bluer horizontal branches, and/or that the ratio of blue vs. red HB stars shows a gradient across a given globular cluster. Evidence for such effects remains inconclusive. A more extreme case of the dynamical interactions scenario would be the existence of a black hole, which would enhance mass loss for stars passing by. The existence of black holes in globular clusters, however, is still under debate.

Binary Evolution As a special case of dynamical interactions, close binary evolution can also enhance mass loss. However, while the field extreme horizontal branch stars show a rather high binary frequency, the ones in globular clusters show a very low one. Also in the case of close binary evolution, one would expect a radial gradient in the HB morphology, as the binaries would tend to sink to the center of the globular cluster.

Rotation High rotational velocities will delay the helium core flash, thereby increasing the time for mass loss on the red giant branch. So far, however, no evidence for fast rotation has been observed on the red giant branch. The distribution of rotational velocities along the horizontal branch itself is puzzling: Almost all HB stars hotter than 12,000 K show $v \sin i \leq 10\,\mathrm{kms}^{-1}$, while some of the cooler blue HB stars can show $v \sin i$ of up to $40\,\mathrm{kms}^{-1}$. Neither the change in rotational velocities, nor the high rotational velocities observed for some cooler blue HB stars are currently understood.

Helium Abundance For a given age an increase in helium abundance decreases the turnoff mass of a stellar population. This is due to the combination of the higher luminosity (caused by increased energy production and reduced opacity) and the reduced hydrogen content of helium-enriched stars. Thus, like an increase in age, an increase in helium abundance will result in bluer HB stars. At the same time, helium-enhanced horizontal branch stars should also be more luminous, as the efficiency of the hydrogen-shell burning increases with increasing helium abundance. While this scenario has been revived by the discovery of multiple main sequences, which can best be explained by sub-populations enriched in helium, it faces severe problems due to the fact that the helium enrichment needs to be achieved with little or no enrichment in metals.

Mass There is observational evidence that the blueward extension of the horizontal branch correlates with the total mass of the globular cluster (see also Sect. 2.3). It is, however, unclear how the total mass of the cluster influences the evolution of individual stars, especially since mass and concentration do not go hand in hand (i.e. the more massive globular clusters are not necessarily more concentrated). More massive globular clusters, however, stand a better chance to keep elements produced by their stars, so that self-enrichment becomes possible.

2.2. Diffusion, rotation, and atmospheric parameters

Most of the discussion so far relied on photometric observations. Recent years, however, provided also a wealth of spectroscopic observations of hot HB stars at various resolutions. Early analyses found discrepancies between the effective temperatures and surface gravities derived from observations and those predicted by stellar evolutionary theories. The observed values placed the stars predominantly at the end of their HB evolution, where they should spend at most about 10% of their time on the HB (e.g. Moehler et al. 1995, 1997b). The observations by Grundahl et al. (1999) pointed toward a possible solution: In their Strömgren colour-magnitude diagrams, they observed a jump of HB stars toward brighter *u* magnitudes at effective temperatures between 11,000 K and 12,000 K. They suggested the onset of radiative levitation of heavy elements (as predicted by Michaud et al. 1983) as the cause for this sudden change in *u* brightness, as an increase in atmospheric metallicity would decrease the flux in the far-UV region and by flux-redistribution increase the flux in the *u* band. Behr et al. (1999) independently observed a sudden increase in the atmospheric metallicity of HB stars in M 13 at effective temperatures of about 11,500 K, thereby confirming the earlier results of Glaspey et al. (1986) and supporting the Grundahl et al. scenario. A study by Moehler et al. (2000) showed that a crude accounting for the increase in atmospheric metallicity indeed brought a much better agreement between the parameters derived from spectroscopic observations and those predicted by the canonical stellar evolution theory. Remaining discrepancies might be due to the fact that diffusion affects different elements differently (e.g. enriching iron, but depleting helium), while the model spectra used for the analysis were calculated with scaled-solar abundances.

It is so far not understood why diffusion starts very suddenly at effective temperatures of around 11,500 K, whereas theoretical calculations predict diffusion effects to be active already at a significantly cooler temperature (Michaud et al. 2008). This temperature region coincides with a change in the observed rotational velocities of the HB stars: Almost all HB stars hotter then the diffusion threshold temperature show $v \sin i \leq 10\,\mathrm{km s^{-1}}$, while some of the cooler blue HB stars can show $v \sin i$ of up to $40\,\mathrm{km s^{-1}}$ (Behr 2003; Recio-Blanco et al. 2004; Fabbian et al. 2005, and references therein).

2.3. Blue hook stars

By using HST observations of ω Cen, D'Cruz et al. (2000) discovered a group of stars forming a hook-like feature below the hot end of the zero-age horizontal branch in an $m_{160} - V, V$ colour-magnitude diagram. Accordingly, they dubbed these stars "blue hook stars"[3]. In an optical colour-magnitude diagram, these stars lie at very hot (and faint) end of the horizontal branch. Candidate blue hook stars have been found in M 15 (Moehler et al. 1997a), NGC 2808 (Brown et al. 2001), M 54 (Rosenberg et al. 2004), NGC 2419 (Ripepi et al. 2007), NGC 6388 and possibly NGC 6441 (Busso et al. 2007). Thus, five or six of the seven most massive globular clusters show evidence for such stars (47 Tuc being the sole exception).

These stars cannot be produced by canonical evolution, as they are hotter and fainter in the UV than the hottest canonical horizontal branch stars. Since the effective temperature of a horizontal branch star correlates with its envelope mass, higher temperatures require lower envelope masses, i.e. higher mass loss. If one increases the mass loss on the red giant branch beyond the value required for the hottest extreme HB stars, however, the result is not a hotter EHB star, but a helium-core white dwarf, because the star will leave the red giant branch without igniting helium in its core.

[3] Unfortunately, this name can provoke to some confusion, as the white dwarf cooling sequence also forms a hook like feature extending to the blue, when collision-induced absorption of hydrogen becomes important.

Already 15 years ago, however, Castellani & Castellani (1993) studied the evolution of such stars, and found that a star can ignite helium later while on the white dwarf cooling curve. Since the ignition takes place when the star is hot (as opposed to the helium-core flash on the red giant branch), these stars are called "hot flashers". Such stars can populate the hot end of the extreme HB. Brown et al. (2001) extended this scenario to even higher mass-loss rates, and found that if the helium-core flash happens sufficiently late on the white dwarf cooling curve, the hydrogen burning shell is so weak that it no longer prevents mixing between the core and the envelope during the helium core flash. In that case, helium and carbon from the core are mixed into the envelope (increasing the carbon abundance to up to 1–3% by mass), while hydrogen from the envelope is transported to the core and burnt. The change of the envelope composition from hydrogen-rich to helium-rich causes severe changes in the envelope opacity, and results in stars that are brighter shortward of the Lyman edge, due to the missing hydrogen absorption. Flux redistribution then makes them fainter at longer wavelengths, and thereby explains their position below the zero-age HB. In addition, they should be hotter than the early hot flashers described by Castellani & Castellani (1993).

Another possible explanation for the blue hook stars lies with the helium-enrichment, recently suggested to explain the split main sequence observed in ω Cen (Norris 2004) and NGC 2808 (D'Antona et al. 2005). Lee et al. (2005) have suggested that the blue hook stars are the progeny of these proposed helium-rich main sequence stars. In this case, their helium abundance should not exceed $Y \approx 0.4$. Spectroscopic observations of the blue (and supposedly helium-rich) main sequence stars in ω Cen yield a carbon abundance of [C/M] = 0.0 (Piotto et al. 2005). This carbon abundance will decrease further as the stars ascend the red giant branch, due to the extra-mixing process which occurs in metal-poor red giants. Thus, the helium-enrichment scenario predicts a carbon abundance by mass in the blue hook stars of less than 0.1%, i.e., at least a factor of 10

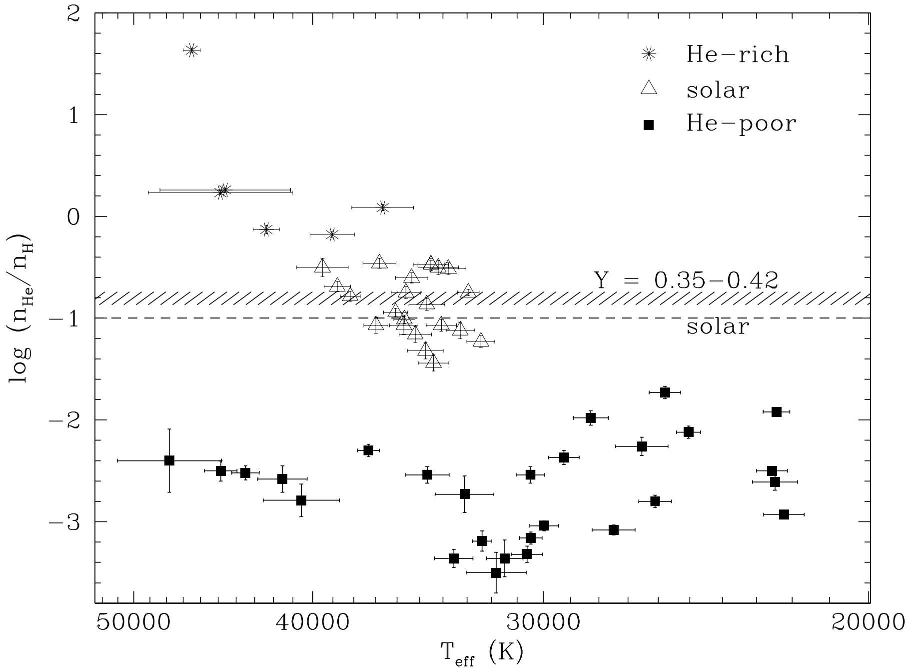

Fig. 2. Effective temperatures and helium abundances for the hottest HB stars in ω Cen (Moehler et al. 2007). The dashed line marks solar helium abundance, the hashed area marks the range for the helium-enrichment scenario of Lee et al. (2005).

smaller than the carbon abundance predicted by the late hot flasher scenario. In addition, the simulations by Lee et al. (2005) predict the stars at the very hot end of the HB to be about 0.5 mag brighter than they are observed.

Recent analyses of the hottest HB stars in ω Cen by Moehler et al. (2007, cf. Fig. 2) showed three groups of stars in the temperature range from 30,000 K to 50,000 K with different helium abundances: helium-poor ($\log \frac{n_{He}}{n_H} < -2$), solar helium abundance within a factor of 3 ($-1.5 \leq \log \frac{n_{He}}{n_H} \leq -0.5$) and helium-rich ($\log \frac{n_{He}}{n_H} > -0.4$). There is a strong correlation between visual brightness and helium abundance with the most helium-rich stars being the visually faintest. Only the helium-rich stars show evidence for carbon in their spectra, indicating carbon abundances of at least 1% by mass. However, even the helium-rich stars still show hydrogen in their spectra. This might be due to diffusion effects, which would cause any residual hydrogen to float to the top (see Unglaub 2005, for details).

Such effects would also explain the trend of helium abundance with effective temperature seen for the solar-helium stars in Fig. 2, as the effective temperature decreases with increasing hydrogen abundance (see Moehler et al. 2002, for details).

More than 30% of the stars above 30,000 K show helium abundances in excess of the values discussed by Lee et al. (2005). D'Antona & Ventura (2007), however, recently presented models in which helium-enriched stars suffer extra-mixing on the red giant branch, which enhances their helium abundance even further, possibly into the range observed for blue hook stars. Therefore, the evolutionary status of the blue hook stars will most probably continue to be hotly debated.

3. UV bright stars

Already Shapley (1930, p. 30) remarked that *"Occasionally, there are abnormally bright blue stars, as in Messier 13, but even these are faint absolutely, compared with some of the galactic B stars"*. This statement refers to stars like those mentioned by Barnard (1900), which in colour-magnitude diagrams lie above the horizontal branch and blueward of the red giant branch. This is also the region where one would expect to find central stars of planetary nebulae, which are, however, rare in globular clusters: Until recently (Jacoby et al. 1997) Ps1 (Pease 1928), the planetary nebula in M 15 with its central star K648, and IRAS18333-2357 in M 22 (Cohen & Gillett 1989) remained the only such objects known in globular clusters.

Apart from analyses of individual stars like vZ1128 in M 3 (Strom & Strom 1970, and references therein) and Barnard 29 in M 13 (Traving 1962; Stoeckley & Greenstein 1968) the first systematic work on these bright blue stars was done by Strom et al. (1970). All stars analysed there appear close to solar helium content, contrary to the hot and extreme horizontal branch stars, which, in general, are depleted in helium. Strom et al. identified the brightest and bluest UV bright stars with models of post-AGB stars (confirming the ideas of Schwarzschild & Härm 1970) and the remaining ones with stars evolving from the horizontal branch towards the AGB. This means that all of the stars in their study are in the double-shell burning stage. Zinn et al. (1972) performed a systematic search for such stars by taking advantage of the fact that they are brighter in the U band than all other cluster stars. This also resulted in the name **UV Bright Stars** for stars brighter than the horizontal branch and bluer than the red giant branch[4].

[4] As the flux maximum moves to ever shorter wavelengths for increasing temperatures, hot UV bright stars may be rather faint not only in V, but also in the U band. Thus UV bright stars will appear brighter than the HB in optical colour-magnitude diagrams only if they are cool and/or luminous.

Zinn (1974) observed spectra of 38 optically selected UV bright stars in 8 globular clusters. He found that – at a given age and metallicity – different HB morphologies result in different UV bright star populations: The presence/absence of "supra-HB" stars is correlated with the presence/absence of hot HB stars in M 13, M 15, and M 3. This agrees with the theoretical expectation that hot HB stars evolving away from the HB show up as "supra-HB" stars. The more luminous UV bright stars in all three globular clusters are consistent with post-AGB tracks. Also the existence of a planetary nebula and the presence of red HB stars in M 15 (which is unusual for such a metal-poor globular cluster) are linked to each other: The red HB stars in M 15 have masses of 0.8 – 0.9 $M_\odot$, which favour the creation of planetary nebulae (compared to less massive blue HB or blue tail stars). Schönberner (1983) discusses the theoretical evolution of post-AGB stars with a special emphasis on the production of planetary nebulae: The 0.546 $M_\odot$ model, which leaves the AGB before thermal pulses start (post-early AGB), evolves so slowly that its age at 30,000 K (the temperature for planetary nebula ionization) exceeds the age of the oldest known planetary nebulae. Thus the lower mass limit for central stars of planetary nebulae is taken to be 0.55 $M_\odot$.

de Boer (1985) used IUE spectra of 10 hot UV bright stars in 7 globular clusters to estimate their contribution to the integrated UV light of the respective globular clusters: hot post-AGB stars contribute less than 3% to the total cluster light at 3300 Å, increasing to about 15% at 1500 Å and further increasing towards even shorter wavelengths. de Boer (1987) gives a compilation of 45 luminous hot UV bright stars ($M_V < 0$, $(B-V)_0 < 0.2$) in 36 globular clusters.

Most of the UV bright stars found in ground based searches are cooler than 30,000 K, although theory predicts stars with temperatures up to 100,000 K (e.g., Schönberner 1983; Renzini 1985). Hot post-(extreme)HB and post-(early) AGB stars, however, do not necessarily fulfill the original definition of UV bright stars: As stars get hotter the maximum of their flux distribution moves to ever shorter wavelengths and especially the less luminous UV bright stars evolving away from the extreme HB can be quite faint at visual and near-UV wavelengths. The early lists of hot UV bright stars are thus certainly incomplete, since they are based on optical searches, which favour luminous hot UV bright stars and are also limited in their spatial coverage due to crowding in the cluster cores. As hot UV bright stars shine up in far-UV images of globular clusters the Ultraviolet Imaging Telescope (UIT, Stecher et al. 1997) was used to obtain ultraviolet (≈1620 Å) images of 14 globular clusters. The solar-blind detectors on UIT suppress the cool star population, which allows UV-bright stars to be detected into the cluster cores, and the 40′ field of view of UIT is large enough to image the entire population of most observed clusters. Thus, the UIT images provide a complete census of the hot UV-bright stars in the observed clusters, which is well suited to test post-(extreme)HB and post-(early) AGB evolutionary tracks. Such a test is especially important, as hot UV bright stars probably make a significant contribution to the UV-upturn observed in elliptical galaxies (Greggio & Renzini 1990; Dorman et al. 1995; Dorman 1997; Brown et al. 1997; Greggio & Renzini 1999; Brown et al. 2000).

The need for further information on these evolutionary stages has also been illustrated by the results of Jacoby et al. (1997) for planetary nebulae in globular clusters. In their O III imaging survey of 133 globular clusters, they found only four planetary nebulae, two of which were previously known (Ps1 in M 15, and IRAS 18333-2357 in M 22, see above). Based on the planetary nebula luminosity function for metal-poor populations, they expected to find 16 planetary nebulae in their sample. However, their O III search may have missed some old, faint planetary nebulae. And – even more important – their assumption that all stars in a globular cluster will eventually go through the AGB phase is not valid for globular clusters like NGC 6752, where about 30% of the HB population consist of EHB stars (with $T_{\rm eff} > 20{,}000$ K), which evolve into white dwarfs without ever passing through the thermally pulsing AGB phase. While such globular clusters are expected to be deficient in post-AGB stars, they should show a substantial population of less luminous ($1.8 < \log(L/L_\odot) < 3$) UV-bright stars, which can be either post-EHB stars or post-early AGB stars, neither of which would produce a planetary nebula.

All this emphasizes the need for spectroscopic analyses of hot UV bright stars to compare their parameters to evolutionary calculations. Most analyses so far, however, have been limited to the use of IUE spectra. While IUE spectra allow a good determination of $T_{\rm eff}$ for hot stars they are not very suitable to determine log g (see Cacciari et al. 1995). Analyses that also used hydrogen lines (line profile fits or equivalent widths) or the shape of the far-UV continuum were performed for 14 optically selected hot (effective temperature above 10,000 K) UV bright stars (in some cases only the most recent analysis is given): M 22–II-81 (Glaspey et al. 1985); NGC 6712–C49 (Remillard et al. 1980, only lower limit for $T_{\rm eff}$); NGC 6397–ROB162 (Heber & Kudritzki 1986); NGC 1851–UV5, M 3–vZ1128 (Dixon et al. 1994); 47 Tuc–BS (Dixon et al. 1995); M 13–Barnard 29, ω Cen–ROA5701 (Thompson et al. 2007); M 5–ZNG1 (Dixon et al. 2004); M 13–ZNG4 (Ambika et al. 2004); M 10–ZNG1, M 15–ZNG1 (Mooney et al. 2004); NGC 6712–ZNG1 (Mooney et al. 2004; Jasniewicz et al. 2004); and M 15–K996 (Jasniewicz et al. 2004). Moehler et al. (1998, ground-based observations, ten stars) and Landsman (priv. comm., HST observations, three stars) observed and analysed spectra of UV-bright stars identified as such solely on the UIT images. The derived effective temperatures and gravities of all these stars are plotted in Fig. 3, along with evolutionary tracks.

Obviously, the dominance of post-AGB stars among optically selected hot UV bright stars is due to the heavy bias of the selection towards the most luminous stars. The analysis of optically selected hot UV bright stars thus gives a wrong impression of the importance of the various evolutionary phases which contribute to the UV flux of old stellar populations. The lack of classic post-AGB stars among hot

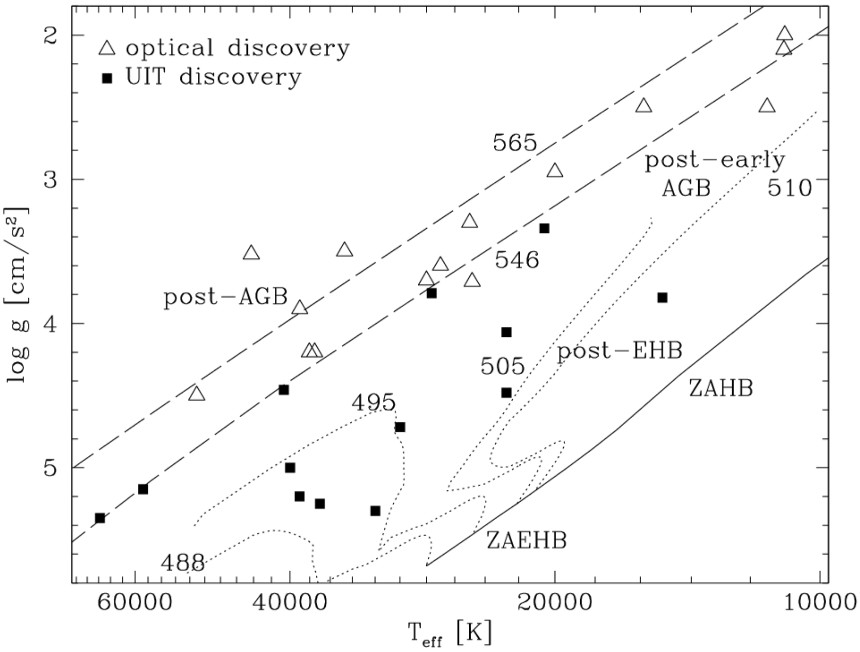

Fig. 3. The atmospheric parameters of hot UV bright stars compared to evolutionary tracks. The solid and dotted lines mark the ZAHB and post-ZAHB evolutionary tracks for [Fe/H] = −1.48 (Dorman et al. 1993). The dashed lines give post-AGB (0.565 $M_\odot$) and post-early AGB (0.546 $M_\odot$) tracks (Schönberner 1983). All tracks are labeled with the mass of the stars in units of $10^{-3} M_\odot$. The filled symbols mark UV bright stars identified as such only by UIT, while the open symbols mark UV bright stars already known from optical searches (see text for references).

UV bright stars in globular clusters may be understood from the different lifetimes: The lifetime of Schönberner's post-early AGB track is about 10 times longer than his lowest mass post-AGB track. Thus, even if only a small fraction of stars follow post-early AGB tracks, those stars may be more numerous than true post-AGB stars. Due to their relatively long lifetime, post-early AGB stars are also unlikely to be observed as central stars of planetary nebulae (see above).

Theoretical simulations would be useful to determine whether the relative populations of post-AGB and post-early AGB stars can be accommodated by using existing post-HB evolutionary tracks or if additional process (e.g. additional mass loss) are necessary. Possible discrepancies have been indicated by Landsman et al. (1996), who find only 4 post-EHB stars in UIT observations of NGC 6752, whereas 11 would be expected.

4. Some open questions

This section provides my personal view of the currently open questions with respect to hot stars in globular clusters – any comments or answer are most welcome!

- What is the correct description of the mass loss on the red giant branch?
- Is there *a* 2nd parameter or are there several ones?
- What causes the observed correlation between the mass of a globular cluster and the extension of its horizontal branch to high effective temperatures?

- What causes the high rotational velocities observed for some cool blue HB stars and why does the distribution of rotational velocities change abruptly with the onset of diffusion?
- Can the remaining discrepancies between observed and predicted atmospheric parameters of hot horizontal branch stars fully be ascribed to an incorrect description of diffusion effects in their atmospheres?
- What is the true nature of the blue hook stars and why have they so far been found almost exclusively in the most massive globular clusters?
- Do the observed numbers of hot UV bright stars agree with theoretical predictions?
- How would helium enrichment affect the number of UV bright stars?

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