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HOT SUBDWARFS IN THE GALACTIC BULGE

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Abstract. Recent observations and theories suggest that extreme horizontal branch (EHB) stars and their progeny should be the cause of the UV excess that many elliptical galaxies show in their spectra. Since the Galactic bulge is the closest representation of an old, metal-rich spheroid in which we are able to study the EHB scenario in detail, we obtained spectra of bulge EHB star candidates and we confirm their status as hot evolved stars. It is the first time that such stars are unambiguously observed in the Galactic bulge.

Key words: galaxies: elliptical – Galaxy: bulge – stars: hot subdwarfs

1. INTRODUCTION

The spectra of elliptical galaxies and bulge regions of spiral galaxies in many cases show a strong and unexpected increase in flux at wavelength shorter than 2500 Å. This feature, called "UV excess", was one of the most important discoveries of satellite-based UV astronomy (Code & Welch 1969) but also a puzzle, since it required the existence of hot stars in these old metal-rich systems (see Burstein et al. 1988 and references therein). After a long debate, most people agree that the observed UV radiation is mainly produced by very hot extreme horizontal branch stars (burning helium in their core) and their progeny, as Post-EarlyAGB and AGB-manqué stars (O'Connell 1999; Greggio & Renzini 1990, 1999; Dorman et al. 1995; Yi et al. 1998). This view is supported by spectroscopic (Ferguson et al. 1991; Brown et al. 1997, 2002) and photometric (Brown et al. 2002) UV observations of extragalactic systems. Near-UV HST observations of Brown et al. (2000) in M 32 detected for the first time individual EHB star candidates in an elliptical galaxy. The best fit to the observations is achieved with evolutionary tracks for helium- and metal-rich populations, since in this case EHB stars have the longest lifetimes in the temperature range required to reproduce the UV excess (cf. Bressan et al. 1994).

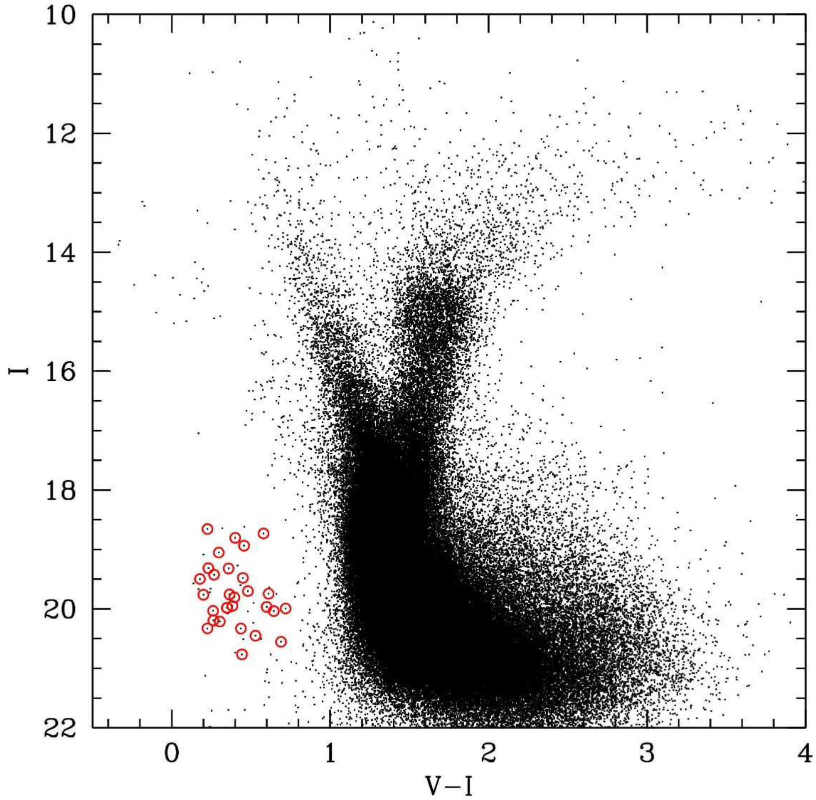

Fig. 1. Color-magnitude diagram of the Galactic bulge. Our targets are marked by circles.

The closest system similar to an elliptical galaxy with respect to age and metallicity for which it is possible to resolve stars is the Galactic bulge. The vast majority of EHB stars known in the Milky Way belongs however, to the metal-poor spheroid or to the disk population (where they show up as so-called subdwarf B (sdB) stars).

The only sdB candidates known in the bulge were found in the two massive globular cluster NGC 6388 and NGC 6441 (Rich et al. 1997; Busso et al. 2004), which are anyway not typical for the bulge population. The situation changed recently: Terndrup et al. (2004) found candidates in their survey for EHB stars in the Galactic bulge, and Wide Field Imager observations of a field toward the Galactic bulge (Zoccali et al. 2003) show a sequence of hot stars that are good candidates for EHB stars (see Figure 1). Using the values of Villeneuve et al. (1995) for scale height and space density of local field sdB stars, along a distance of 4.5 to 11 kpc within the field of view of WFI only less than 10 sdB stars are expected, while in our case about 140 candidates are found. Since they could be cool foreground stars (instead of reddened hot stars), we obtained spectroscopy of 29 candidates in order to derive effective temperatures and surface gravities and then, by means of comparison with HB models, to check their evolutionary status.

2. OBSERVATIONS

2.1. Target selection

Our spectroscopic targets were selected from the photometric catalogue of bulge stars obtained from Zoccali et al. 2003 (see Figure 1). We have chosen the stars with magnitude $18 < I < 21$ and color $0 < V - I < 0.8$ and among them we selected the most isolated ones.

2.2. VLT observations

We obtained medium-resolution spectra ($R \sim 1200$) of 29 candidates EHB stars at the VLT-UT1 (Antu) with FORS2. We used the multi-object spectroscopy (MXU) mode of FORS2 with the standard collimator, a slit width of $0.7''$ and grism B600, which allows to obtain spectra in the range between 3650 and 5200 Å(not all candidates though have spectra so extended because of the different positions on the CCD).

2.3. Data reduction

The data reduction was performed as described in Moehler et al. (2004) except for the following points. Due to the long exposure times (from 2700 s to 5400 s) the scientific observations contained a large number of cosmic rays and were therefore corrected with the algorithm described in Pych (2004). Regarding the subtraction of the sky background, we used two different methods depending on whether the target star in the slitlet was isolated or not. If the star was isolated, meaning any other stars in the slitlets were well enough separated from our target to identify regions uncontaminated by any stellar source, we approximated the spatial distribution of the sky background by a constant. If the slitlet showed severe crowding, meaning that the spectra of different stars were overlapping, we fitted each stellar profile with a Lorentzian function so that the whole spatial profile was reproduced by the sum of all the profiles; all the profiles but that one of the target were then subtracted (for details see Moehler & Sweigart 2006). With the extraction of the spectra, we saw that some (5 of 29) of our targets were actually cool stars. Therefore we did not proceed further with the reduction for these stars. The spectra were flux calibrated using standard stars spectra and corrected for any Doppler shifts determined from Balmer lines, as in Moehler et al. (2004).

3. ANALYSIS

Some examples of the spectra are shown in Figure 2. To fit the spectra (except for one He-rich one) we used ATLAS9 model atmospheres for solar metallicity (Kurucz 1993) to account for effects of radiative levitation (see Moehler et al. 2000 for details), from which we calculated spectra with Lemke's version of the LINFOR program (developed originally by Holweger, Steffen and Steenbock at Kiel University). The use of NLTE models or of LTE models with higher metallicity does not significantly change the results.

To establish the best fit, we used the routines developed by Bergeron et al. (1992) and Saffer et al. (1994), as modified by Napiwotzki et al. (1999), which employ a χ^2 test. The 1σ error necessary for the calculation of χ^2 is estimated from the noise in the continuum regions of the spectra. The fit program normalizes model spectra and observed spectra using the same points for the continuum definition.

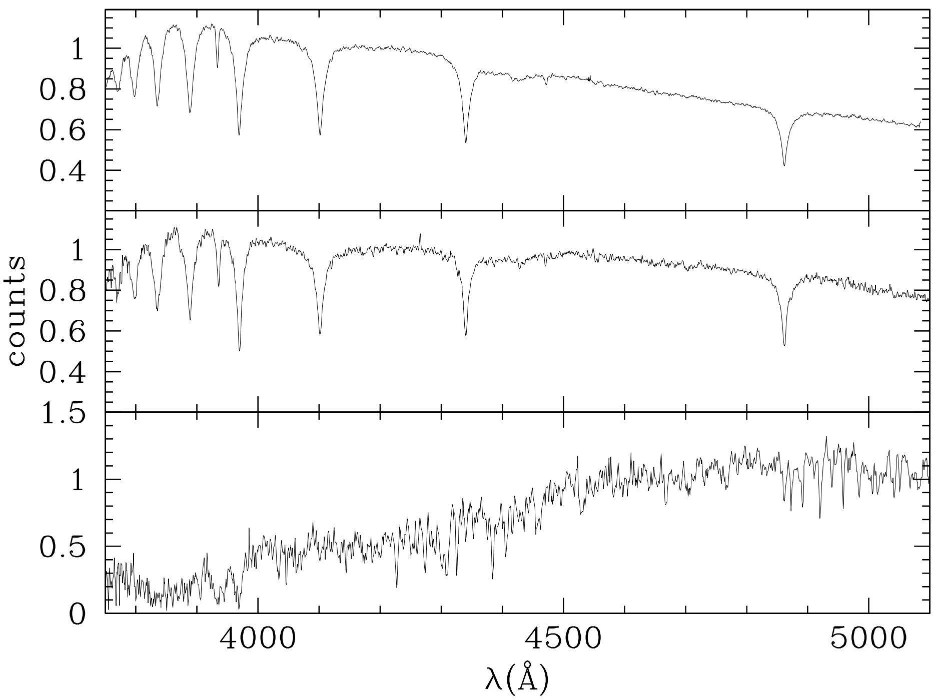

Fig. 2. Spectra of a few sdB star candidates. Top and central panel: typical spectra of newly detected hot stars with strong Balmer lines. Bottom panel: for comparison the totally different spectrum of a cool star.

We used the Balmer lines Hβ to H10 (excluding Hϵ to avoid the Ca II H line), the He I lines at 4026, 4388, 4471, 4921 Åand the He II lines at 4542 and 4686 Å.

We obtained the atmospheric parameters $T_{\rm eff}$, $\log g$ and helium abundances, and we calculated the absolute V and I magnitudes expected for these values, assuming $M_\star = 0.5\,M_\odot$. We left out one star because the fit was really bad. Considering a distance from the Galactic center of $\sim$ 8.5 kpc and a bulge radius of $\sim$1.5 kpc, we found that most of these objects are indeed bulge stars: of 23 hot stars, 13 stars are in the bulge within 1σ and 3 are in the bulge within 3σ.

This is also confirmed by the radial velocities found from the Doppler shift. The field we explored is centered at Galactic coordinates $\ell = 0°$, $b = $–$6°$, toward the Galactic center, so that the expected radial velocities for disk stars are around 0 km s^{-1}. Our velocities are distributed in a range between −200 and +300 km s^{-1}, in agreement with Terndrup et al. (1995).

Finally we compared our results with horizontal branch theoretical tracks: in Figure 3 we plotted in the $T_{\rm eff}$ vs. $\log g$ diagram the values found for those stars which belong to the bulge. The error bars are the formal errors from the fit procedure, but we are aware that the formal errors are underestimates (Napiwotzki, priv. comm.). The evolutionary tracks are from Yi et al. (1997) with metallicity $Z = 0.004$ and helium abundance $Y = 0.2416$. The Zero Age Horizontal Branch

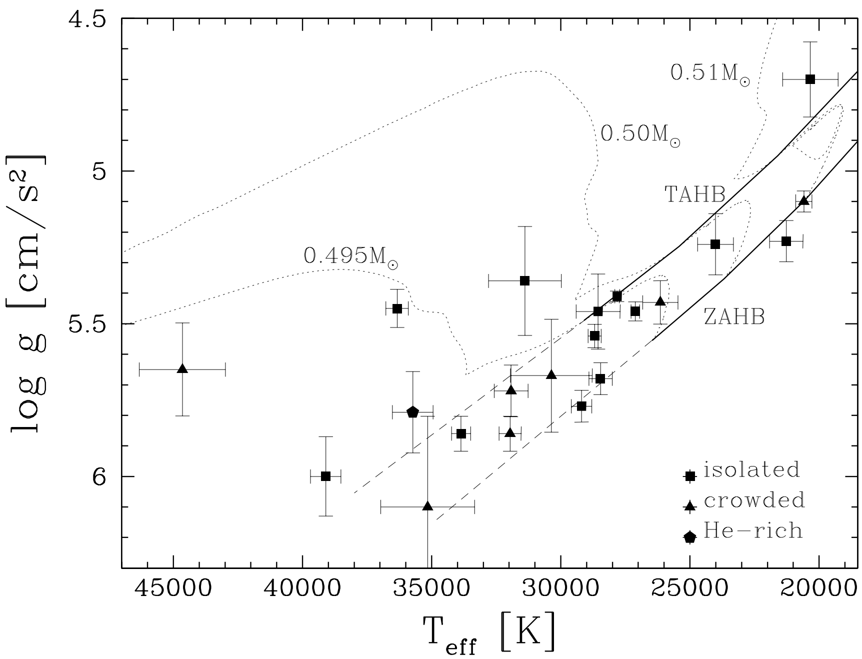

Fig. 3. $T_{\rm eff}$ vs. $\log g$) diagram. The squared symbols indicate the isolated stars; the triangles indicate the crowded stars and the pentagon is the He-rich star. The ZAHB and TAHB (Yi et al. 1997) and evolutionary tracks with metallicity $Z = 0.004$ and helium abundance $Y = 0.2416$ for 0.495, 0.50 and 0.51 $M_{\odot}$ are plotted. The dashed lines are extrapolated from the ZAHB and TAHB tracks.

(ZAHB), where the star starts to burn helium in its core quietly, and the Terminal Age Horizontal Branch, where the star burned the 99 % of the helium, are shown together with evolutionary tracks for stars with total masses of 0.495, 0.50 and 0.51 $M_{\odot}$. Since the theoretical lower limit for the mass of an EHB star is the core mass of the progenitor on the red giant branch ($\sim 0.45\,M_{\odot}$) while our tracks end at 0.495 $M_{\odot}$, we extrapolated the ZAHB and TAHB to lower masses (dashed curves in Figure 3). Proper models for lower masses will be calculated and used in a later paper. The observed points agree quite well with the theoretical tracks, therefore these objects are indeed EHB stars; some objects are above the TAHB meaning that they are in the post-HB phase and then evolving as AGB-manqué stars.

Finally we want to mention that all stars except one (which is helium-rich) are helium deficient as expected from diffusion.

5. CONCLUSIONS

We observed spectra of EHB star candidates in the Galactic bulge, from which we estimated the atmospherical parameters $T_{\rm eff}$ and $\log g$, confirming their evolutionary status. From the calculated radial velocities and distances we verified their membership to the bulge. This is the first time that such kind of stars are observed in the bulge, and with their spectra we are going to construct the integrated spectrum of the Galactic bulge from the UV to the optical, following the method described in Santos et al. (1995). The method consists in the construction of the integrated spectrum using a spectral library (in our case it will have to be a library extended to the UV) and the information contained in the spectroscopic and photometric observations. Regarding the spectral library, we will group the similar spectra, obtaining various groups of different spectral type, luminosity class and metallicity. For each group the average spectrum will be calculated, in order to obtain a better S/N. We will divide the color-magnitude diagram of the bulge in boxes, and each box will be associated to one of the library average spectra by means of the color index. The integrated spectrum will be the sum of the average spectra, scaling the contribute of each component keeping in account how many stars there are in each box.

This study will verify the role, so far only predicted, of EHB stars regarding the UV excess in elliptical galaxies.

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