6 Field Horizontal Branch A-Type Stars

Field horizontal branch A-Type stars (FHB/A) are valuable tracers for the kinematics of the halo of the Galaxy. In the HES, they can be found at distances of up to ~ 20 kpc. Compared to carbon stars, they have the advantage that they are much more numerous, with surface densities of $\sim 2.5\,deg^{-2}$ in the HES. In the HES, A-type stars can be selected even at very low S/N, since the Balmer lines are so prominent. Therefore, the faintest objects have $V \simeq 17.5$.

For FHB/A stars, there is no such complication as a contamination with spectroscopically indistinguishable dwarfs, like for the C stars. Main-sequence A-type stars *are* found at high galactic latitudes, but they can easily distinguished from low gravity stars by UBV photometry (Wilhelm et al. 1999*a*).

Another application of FHB/A stars is distance estimation of High Velocity Clouds (HVCs). These are clouds of neutral hydrogen at velocities incompatible with Galactic differential rotation (for a recent review see Wakker & van Woerden 1997). With HVCs, we might observe a continuous infall of metal-poor ($\sim 1/10$ solar) gas into the Galaxy, which dilutes the enrichment of the interstellar medium (ISM) by heavy elements produced in stars (Wakker et al. 1999). The understanding of the nature of HVCs would therefore be important for modeling the chemical evolution of the Galaxy. However, there is an ongoing discussion on whether HVCs are really Galactic objects (van Woerden et al. 1998), or if they are extragalactic remnants of gas that formed the local group of galaxies, which would put them in distances in the order of Mpc (Blitz et al. 1999).

Distances to HVCs can be determined by using stars of known distance in the line of sight to the clouds (Wakker & van Woerden 1997). Provided that the HVC under consideration has a detectable metal content, we see absorption lines of these metals at the velocity of the cloud in the spectra of stars located *behind* the cloud, but do not see these lines in spectra of stars located *in front of* the stars. By using a sample of stars of different distances in the line of sight of the cloud, we can bracket it, provided the cloud is Galactic, and the most distant star used in the procedure is far enough away. If so, a distance range can be determined for the cloud. FHB/A stars are particularly suited for these purpose, because they are numerous, distant, and their spectra are almost free of intrinsic absorption lines of metals.

Finally, FHB/As can be used for the detection of possible "clumping" of the Galactic halo, which would prove that merger events have taken place during the formation of our Galaxy. In a first attempt, Doinidis & Beers (1989) have carried out a two-point correlation function analysis of a catalog of 4 400 *candidate* FHB/A stars and found evidence for an excess of stellar pairs with angular separations $\leq 10'$. However, at that time it was not yet clear that samples of high latitude A-type stars contain a considerable fraction ($\sim 1/3$) of main-sequence A-type stars. The distances of these stars were hence overestimated, and the detection of clustering is possibly an artifact. In Sect. 6.4 we outline how the fraction of high-gravity A-type stars can be reduced in HES FHB/A candidate samples.

Yanny et al. (1999) report on the isolation of a first set of 2 000 objects with colours of A-type stars in the SDSS commissioning data. Since the SDSS magnitude limit is $V \simeq 20$, these stars can be rather distant $d \lesssim 40$ kpc, which makes them particularly valuable for studying the outer regions of the Galactic halo. However, the SDSS has just started to produce data, and spectroscopic analysis of a large sample of FHB/A stars from that survey will likely not be available within the next few years.

6.1 Candidate Selection

For selection of candidate FHB/A stars we use automatic spectral classification. A learning sample of 654 spectra (see Tab. 19) has been compiled by classifying HES spectra by hand. We used the spectra of Jacoby et al. (1984), converted to objective prism spectra, for comparison. Note that *rectified* spectra were used in the comparison process. To the learning sample we add artificial noise, resulting in 5 S/N steps (5, 10, 15, 20, 25). $S/N = 30$ was not achievable since some of the learning sample spectra have a lower S/N than that.

i	Class	N
1	A5–8	39
2	A9–F2	67
3	F3–6	130
4	F7–G0	119
5	G1–K0	134
6	K1–3	65
7	K4–9	67
8	SdFearly	33

Table 19: Learning sample for selection of FHB/A star candidates. The sample size is 654.

We carried out a search for the best feature combination for compiling a complete sample of FHB/A stars on a set of 14 features, using the above learning sample. A complete search was done, i.e. all $2^{14} - 1$ feature combinations were evaluated, using the leaving-one-out method. The result is shown in Tab. 20. With exception of the original learning sample, without artificial noise added, there is a tendency to use more features for classification at lower S/N, and to use more continuum shape or broad band colour features.

Feature	S/N					
	orig.	25	20	15	10	5
`all5160eqw`	1	0	0	1	1	1
`all4861eqw`	0	1	0	0	1	0
`all4388eqw`	1	0	0	0	1	0
`all4340eqw`	1	1	1	1	1	1
`all4300eqw`	1	0	1	0	1	1
`all4261eqw`	0	0	1	1	0	0
`all4227eqw`	1	0	1	1	0	0
`all4102eqw`	1	1	1	1	0	0
`all3969eqw`	1	0	0	0	1	0
`all3934eqw`	1	0	0	1	0	1
`klcomp_1`	1	0	0	0	0	1
`klcomp_2`	0	1	0	1	1	1
`dx_hpp1`	0	0	0	0	1	1
`dx_hpp2`	0	1	1	1	0	0
$n =$	9	5	6	8	8	7

Table 20: Best feature combination for compilation of a complete sample of A-type stars.

Cost factors were selected by using the cost factor adjustment tool described in Sect. 3.6. They were chosen such that no spectrum of the classes A5–8 and A9–F2 (the target classes) were classified into one of the other classes, and such that the contamination of the sample is as low as possible.

We selected stars assigned to the classes A5–8 and A9–F2 having `dx_hpp2` > -100 as FHB/A star candidates.

6.2 Follow-Up Observations

BV photometry of 104 HES targets close to the SGP, and additional *UB* photometry of 58 of these stars was obtained by C. Flynn and B. Schuster in the nights October 6–11, 1998, with the ESO Danish 1.54 m telescope, with DFOSC. The accuracies obtained for $B-V$ and $U-B$ are $\sigma_{B-V} < 0.015^m$ and $\sigma_{U-B} < 0.03^m$, respectively.

Spectroscopy of HES FHB/A candidates was obtained with the CTIO 4 m telescope on December 12–15, 1998 by T. Beers and S. Rossi. The spectra have a dispersion of 0.5 Å/pixel, and a typical S/N of 20. 86 stars with available photometry from the ESO run were observed. In the direction of Galactic anti-rotation, additional 74 spectra were obtained, and in the Galactic anti-center direction, we obtained another 46 spectra, so that a total of 206 stars were observed.

The results of the follow-up campaigns for the 58 stars with available *UBV* photometry and spectroscopy are listed in Tab. 27 on pp. 110–111 in Appendix C. As is usual in high Galactic latitude samples of A-type stars (Wilhelm et al. 1999*b*), $\sim 1/3$ are main-sequence stars. In Sect. 6.4 we outline how an improved selection might be able to reduce this fraction considerably. However, the very good news is that 91 of 104 stars for which $B-V$ is available, or 88 %, are A-type stars, so that our selection by automatic classification works very well. The remaining stars are just too cool ($B-V > 0.3$). However, these stars, being main-sequence stars close to the turnoff, are interesting in themselves, since at those temperatures predominantly metal-poor stars are found.

In the next section we evaluate the FHB/A candidate selection in more detail.

6.3 Evaluation of the FHB/A Candidate Selection

For an evaluation of the automatic classification used for FHB/A candidate selection one has to compare the *real* classes with the classes automatically assigned. The problem then is: Where can we get the real classes from? It would be possible *in principle* to classify the available moderate resolution spectra with the classification criteria of the MK system, since the spectral resolution is high enough, and the S/N probably sufficient, if the spectra are smoothed to the spectral resolution used in the MK system (~ 2 Å). However, the MK system is not applicable to our spectra, since we are dealing with *metal-poor* stars. This would require to expand the two-dimensional MK system to a third dimension, i.e. [Fe/H], and to use different classification criteria for the two dimensions used in the MK system, since metallicity influences the strengths of the lines used.

In order to get a *rough* idea of the real classes of our stars, we derived a relation between $(B-V)_0$ and spectral type, by using the library of MK classified spectra of Jacoby et al. (1984). We used all 33 stars of class B9–F3 in that data set, and defined stars of class B9 to have class number $i = 1$, A0$= 2, \ldots$, F3$= 14$. By a straight line fit, we obtained the relation (see also Fig. 42:)

$$i = 2.65 + 29.5 \cdot (B-V)_0. \tag{42}$$

Spectral classes were computed for the 104 stars for which we have a $B-V$ measurement using the above relation. Note that *reddening* causes a systematic offset between the classification system used for automatic classification, and the classification system defined by Eq. 42. The average reddening in

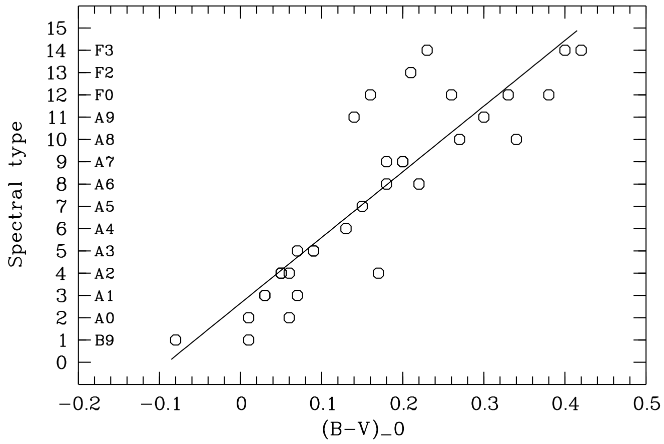

Figure 42: Calibration spectral type versus $(B-V)_0$, derived by using the data of Jacoby et al. (1984).

the sample of 1121 high latitude A-type stars of Wilhelm et al. (1999*b*) is $E(B-V) = 0.044$. Since it follows from Eq. 42 that

$$\sigma_i = 29.5\sigma_{B-V}, \tag{43}$$

the offset between both systems is expected to be ~ 1.3 classes. However, we are mainly interested in evaluating the *scatter* of the classes, and not zero point offsets. The result is shown in Fig. 43.

There is a systematic offset between the automatically assigned classes, and the classification from $(B-V)$. The direction of the offset is opposite to what is expected from the above reddening arguments: In the $(B-V)$-system, the stars are assigned to *earlier* types. In case of class A5–8, this can be explained by the fact that stars earlier than A5 are not represented in our learning sample (which was due to lack of objects). Since we have not applied a reject rule, stars of earlier spectral type have probably been assigned to A5–8.

In case of class A9–F2, there is an offset present between the $(B-V)$-system and the MK system already in the learning sample (see Fig. 44), which is in the same order of magnitude as the offset present in the test sample. Additionally, a few cooler stars might have been rejected from the candidate sample in the process of visual inspection.

The classification accuracy achieved with automatic classification is hardly better than could be achieved by applying the precise $B-V$ colours available *today* for all HES spectra: The error of the $B-V$ calibration for blue stars is $\sigma_{B-V} = 0.12$, which results in a classification error of 3.5 classes.

6.4 Identification of Main-Sequence A-Type Stars

Since we are interested in distant horizontal branch stars rather than main-sequence stars in the applications indicated above, it is desired to clean the sample of FHB/A candidates as much as possible from the latter stars. Therefore, we explored if this could be possible by using Strömgren c_1 coefficients.

As a test sample we used 45 unsaturated HES stars from the follow-up campaigns carried out in 1998, for which have UBV photometry and spectra, and 214 not saturated stars from Wilhelm et al. (1999*b*) present on HES plates. Both types of stars are not clearly separable by c_1 (see Fig. 45); however, it is possible to reduce the contamination with main-sequence stars at moderate cost of completeness. By using the simple selection criterion $c_1 > 0.9$ for FHB/A stars, a sample with 71 % com-

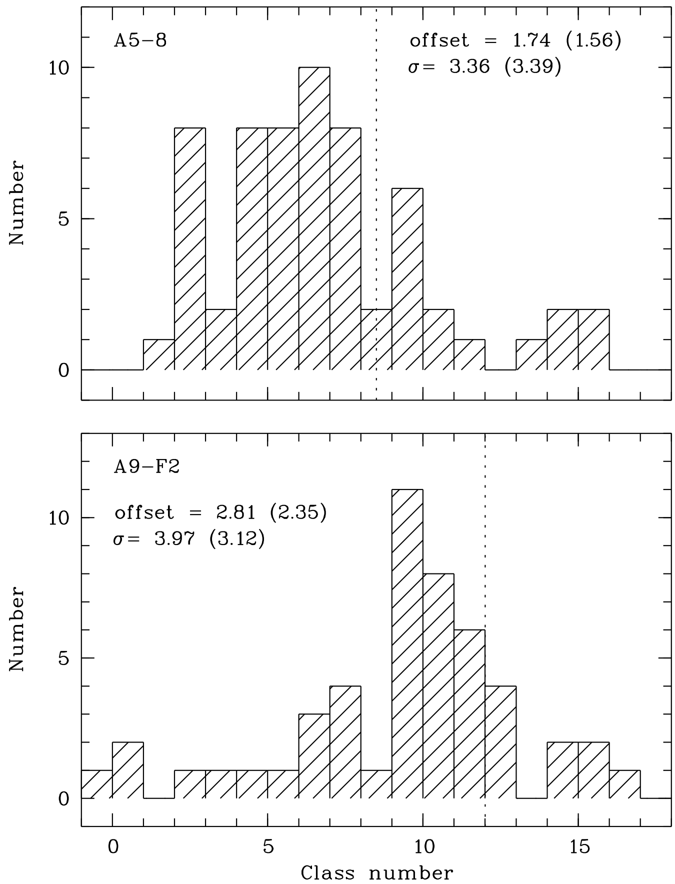

Figure 43: Evaluation of A-type star classification

pleteness can be generated, which has a contamination of 15 % only, compared to 35 % before. With a more sophisticated selection algorithm, e.g. automatic classification, it should be possible to decrease the contamination even more.

As can be seen from Fig. 49, the use of c_1 also allows to clean the *raw* sample from DA white dwarfs. Up to now, these objects have been rejected by visual inspection.

6.5 Outlook

Spectra of an additional set of 109 HES FHB/A candidates have been taken at the CTIO 4 m in October 1999, and spectra of 10 stars in January 2000 with the Kitt Peak 4 m telescope. The data are currently being reduced, and will be analyzed soon.

The author is founding member of the DIST (**D**istance to the **I**SM through **S**tellar **T**argets) consortium which aims at coordinating efforts of distance determinations of HVCs.

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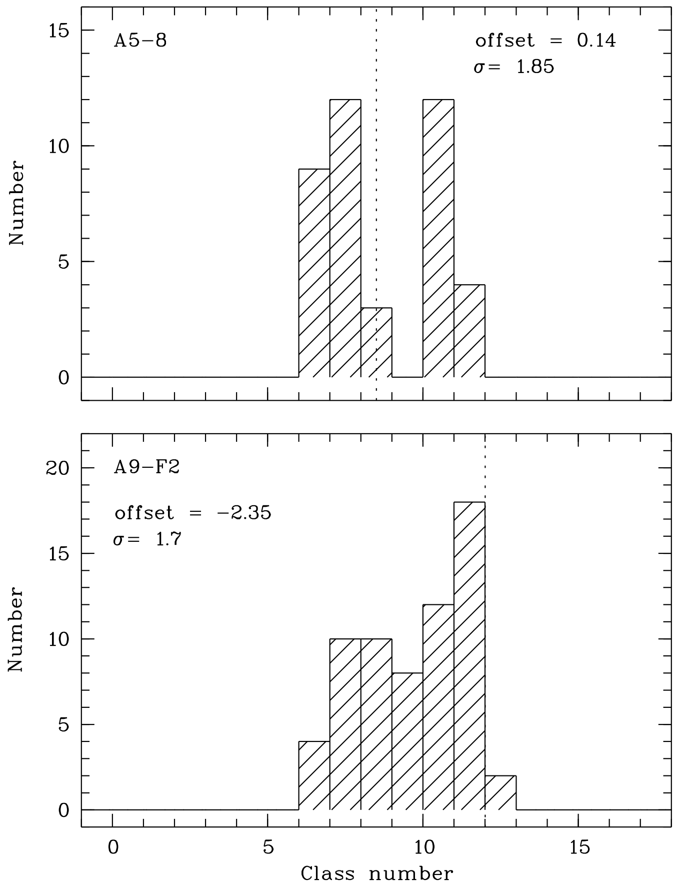

Figure 44: Class distribution of A-type stars in learning sample

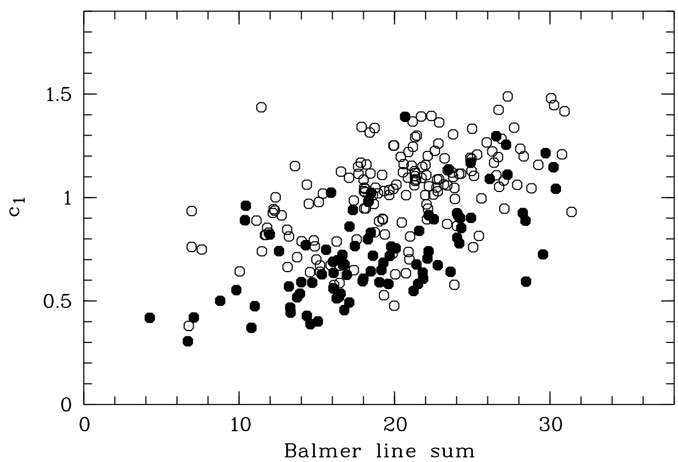

Figure 45: Separation of main-sequence A-type stars (filled circles) and FHB/A stars (open circles) by Strömgren c_1.

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