KINEMATICS OF SUBDWARFS BASED ON HIPPARCOS PARALLAXES AND PROPER MOTIONS

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ABSTRACT

Hipparcos parallaxes and proper motions were combined with radial velocities and metallicities from Carney et al. (1994). As a result a sample of 237 high-velocity stars was obtained having highly accurate space velocities and uniformly determined metallicities.

Hipparcos parallaxes show: (a) the Carney et al. (1994) sample is still contaminated by subgiants and giants. (b) the photometric distances in Carney et al. (1994) were underestimated by about 16 per cent.

The kinematical properties of these subdwarfs are discussed as a function of their metallicities. From an enlarged sample of subdwarfs, 93 halo subdwarfs could be selected indicating that a possible rotation of the galactic halo is improbable.

Key words: space astrometry; subdwarfs; photometric distances; kinematics.

1. INTRODUCTION

Hipparcos parallaxes and proper motions (ESA, 1997) became available for a predetermined sample of 731 high-velocity stars proposed in 1981 for observation by the Hipparcos satellite. Since then an extensive list of publications illustrates the enormous progress achieved in obtaining metallicities and radial velocities for high-velocity stars.

A rather complete compilation of such data in a uniform system were recently published by Carney et al. (1994), hereafter CLLA. In their paper kinematical parameters are given for 1269 stars and metallicities for 1261 stars of the complete survey comprising altogether 1464 stars. According to the authors their survey should contain roughly all of the A, F, and early G, many of the late G, and some of the early K stars in the *Lowell Proper Motion Catalogue*. The precision of their newly determined radial velocities lies in the order of 0.7 km/s. In addition, most of the sample stars were carefully checked for binarity. The typical accuracy of the metallicities was estimated to ± 0.13 dex.

A cross-identification of both samples yields 364 stars in common. But, not for all these stars the complete set of required data was available. The CLLA compilation contains stars with missing [Fe/H]'s or missing radial velocities. On the other hand, the Hipparcos parallaxes are rather poor ($\pi/\sigma_\pi < 3$) for some of the stars with large distances.

It must be emphazised that the present investigation was carried out with a limited Hipparcos sample. Very probably, a search in the complete Hipparcos Catalogue must yield a considerably larger number of stars in common.

2. TEST OF THE PHOTOMETRIC DISTANCES

The photometric distances in the CLLA sample were calibrated with ground-based trigonometric parallaxes. The individual distances, reddenings, and metallicities were determined by comparing synthetic spectra to the low-signal-to-noise spectra obtained for radial velocities (Laird et al. 1988). The authors tried to remove as far as possible all giants and subgiants since their procedure works only properly for dwarfs and subdwarfs. The color-magnitude diagram in Figure 1 shows all the 305 CLLA stars with photometric distances (if no distance was given the star was already recognized as subgiant by the authors). In Figure 1 the absolute visual magnitudes and their standard errors are based on Hipparcos parallaxes and errors. The $B-V$ colour indices were taken from the Hipparcos Catalogue. They are in good agreement with the colours given in CLLA (except HIP 64386 for which the HIP colours $B-V$ and $V-I$ are much too large).

From the CM-diagram it becomes obvious that the CLLA sample is still contaminated by previously undetected subgiants and giants. For the presently investigated subsample this contamination amounts to about 10 per cent.

Removing all stars lying considerably above the mean main sequence leaves 275 stars for which the photometric distance determination should be appropriate. For these stars the differences of the Hipparcos parallaxes minus the photometric parallaxes are plotted over the CLLA parallaxes in Figure 2. Adopting the method outlined and applied in Wielen et al. (1997) a

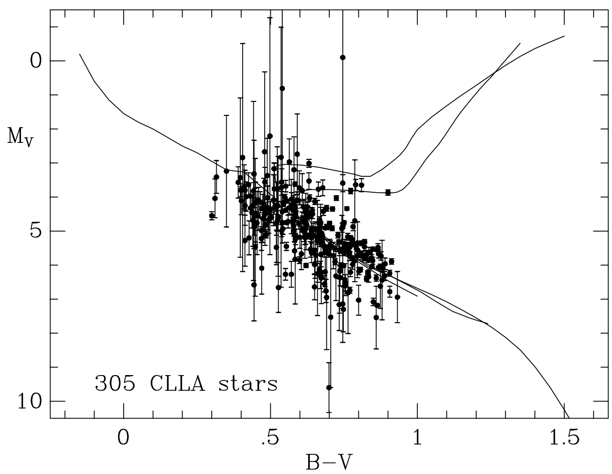

Figure 1. CM-diagram for all identified CLLA stars. Hipparcos parallaxes were used to determine M_V and its standard error. The full lines indicate the mean main sequence and the old open clusters M 67 and NGC 188.

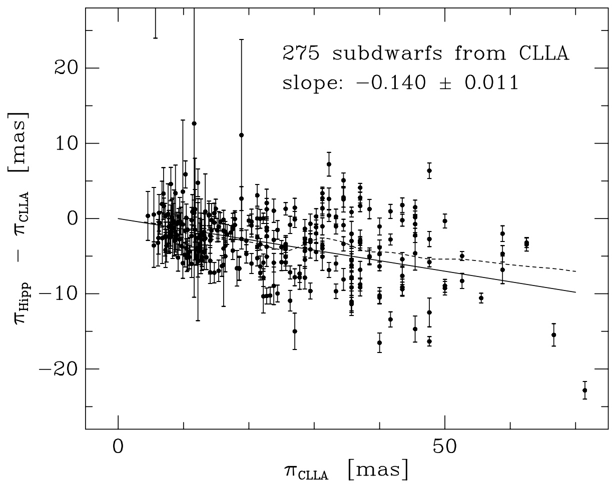

Figure 2. Parallax differences $\pi_{\rm Hipp} - \pi_{\rm CLLA}$ versus the photometric parallaxes of CLLA. Full line: linear least-squares fit. Dashed line: locally weighted regression. The CLLA parallaxes should be corrected by a factor (1 + slope).

linear least-squares fit was carried out yielding –0.140 ± 0.011 for the slope of the regression line (full line). This indicates that the distances given in CLLA were systematically underestimated by about 16 per cent.

The locally weighted regression curve (dashed line) proposes an even larger correction for the more distant stars, that are dominated by the more metal-poor subdwarfs. And, indeed, separating the sample into 86 metal-poor ([Fe/H] $\leq$ –1.20) stars and 189 more metal-rich stars ([Fe/H] $\geq$ –1.20) yields for the slope of the regression line –0.247 ± 0.024 and –0.113 ± 0.012, respectively, i.e. the CLLA distances of the more metal-poor stars require an even larger correction. A similar finding was noticed in Ryan & Norris (1991) whose distances for the more metal-poor stars ([Fe/H] $\leq$ –1.20) were typically 25 per cent larger than those determined by the method applied in CLLA.

Because the determination of reddening, distance, and metallicity are interdependent (Laird et al. 1988) also the metallicities may be slightly affected by the systematic error of the photometric distances. Yet, for the moment, we must assume that this effect is negligible for the following investigation of the kinematical properties.

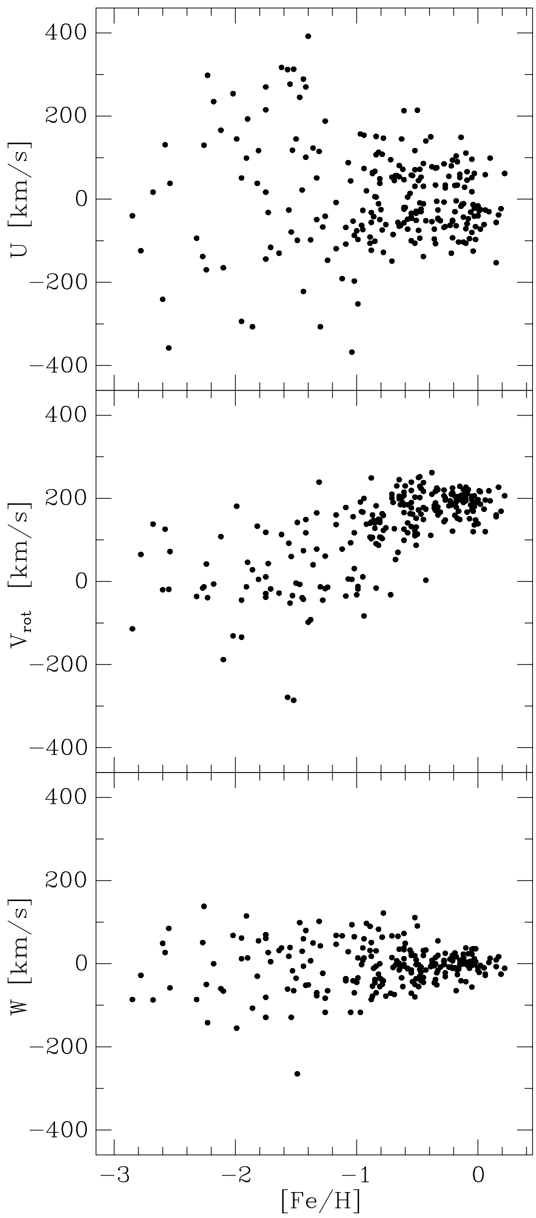

Figure 3. Space velocity components U, $V_{\rm rot}$, and W versus metallicity [Fe/H]. The typical increase of the velocity dispersion and a decrease of the mean rotational velocity $V_{\rm rot}$ towards smaller [Fe/H] becomes evident.

3. KINEMATICAL PROPERTIES

Removing all subgiants and giants detected by Hipparcos and a few questionable Hipparcos parallaxes there remain finally 237 stars that should have reliable metallicities, velocity components, and distances. Carney et al. (1994) used Luyten's NLTT proper motions for the calculation of the space velocity components. These proper motions have typical errors of 20 to 25 mas/year, notwithstanding their unknown systematic errors (only the brighter part of the NLTT should be in the system of the SAO, i.e. FK4). Therefore, the Hipparcos proper motions provide an enormous improvement in the accuracy of the tangential velocities.

Using the proper motions and parallaxes supplied by the Hipparcos Catalogue, and radial velocities given in Carney et al. (1994), the space velocity components

U	in the direction to the galactic center,
$V_{\rm rot}$	in the direction of galactic rotation, and
W	in the direction to the north galactic pole

have been calculated with respect to the Sun and then reduced to the LSR (local standard of rest). For the latter Delhaye's (1965) values were adopted: + 9, + 12, + 7 km/s for *U, V, W,* respectively. Finally, the velocity components were transformed into a frame rotating with circular velocity V_c = –220 km/s relative to the LSR, i.e. the expected rest frame of our Galaxy (e.g. Wielen 1986).

In Figure 3 the resulting velocity components are plotted with respect to the metallicity index [Fe/H] given in Carney et al. (1994). The expected increase of the velocity dispersion as well as the decrease of the mean rotational velocity $V_{\rm rot}$ with decreasing metallicity from [Fe/H] = 0.0 dex to [Fe/H] = –1.0 dex becomes obvious. But also another feature can be recognized: Especially the *U*-distribution seems to indicate that the present sample was kinematically selected: for small *U*-values the diagram is sparsely populated. Due to their position at least three objects in Figure 3 are prominent. In the $V_{\rm rot}$ panel it is the common proper motion pair HD 134 439/40 near $V_{\rm rot}$ = –290 km/s and [Fe/H] = –1.55 dex. In the *W* panel it is the blue straggler candidate BD –12°2669 (Carney et al. 1996) showing up at (–1.49 dex, –265 km/s).

Mean motions with respect to the LSR and velocity dispersions were calculated for different groups in [Fe/H], after HD 134 440 (the fainter component of the CPM pair) as well as BD –12°2669 (which presumably does not belong to the ordinary subdwarfs) were removed. The results are presented in the upper part of Table 1. A comparison with other findings as for example compiled in Table 6 of Ryan & Norris (1991) shows that especially the velocity dispersion in the *U*-component is rather high, pointing to the selection of the stars out of a proper motion catalogue. Nevertheless, the velocity parameters are fairly well comparable with the corresponding values for the RR Lyrae stars (Wielen et al. 1997).

It is possible to supplement the CLLA sample with additional subdwarf stars from Norris (1986). This is a compilation of stars with [Fe/H] less than –0.50 dex from various sources and with metallicity determinations of varying accuracy. For a considerable portion of the latter sample improved metallicities depending on the K16 index were determined in Ryan & Norris (1991). A total of 283 stars from Norris (1986) could be identified with the Hipparcos sample.

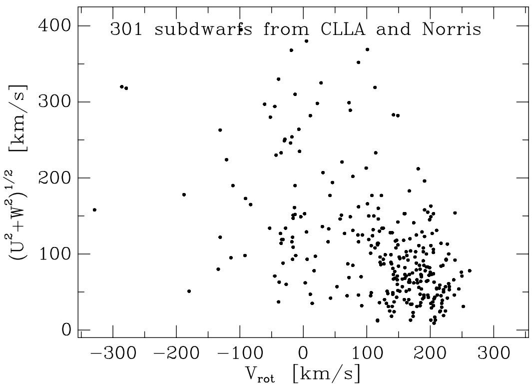

Figure 4. Toomre diagram: $(U^2+W^2)^{1/2}$ versus $V_{\rm rot}$ distribution for altogether 301 subdwarf stars selected from CLLA and Norris (1986).

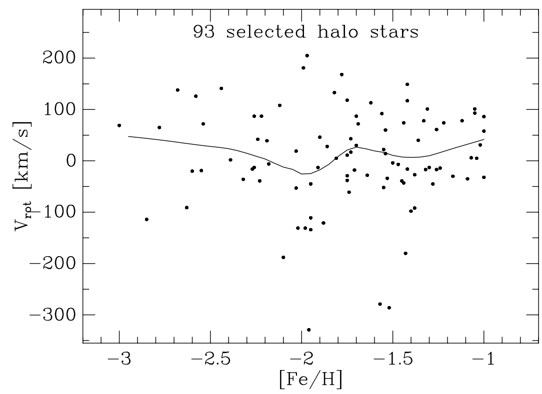

Figure 5. $V_{\rm rot}$ versus [Fe/H] distribution of 93 halo stars: selected from stars with [Fe/H] ≤ –1.00 and additional restrictions in the Toomre-diagram (see text).

After removal of duplicate entries and subgiants (∼30 per cent) another 64 stars could be added to the CLLA sample. For some of the 64 stars questionable metallicities have been replaced by more reliable values from Edvardsson et al. (1993), Axer et al. (1994) or from Stroemgren photometry according to the precepts given in Schuster & Nissen (1989). As noted in Appendix B of Carney et al. (1996) the latter metallicities should be comparable to their own ones. The kinematical parameters of the enlarged sample are shown in the lower part of Table 1. The resulting values are in fair agreement with the values determined from the CLLA sample alone.

Table 1. Parameters of the velocity distribution.

[Fe/H]	n	$< U >$	$< V >$	$< W >$	σ_U	σ_V	σ_W
[dex]			[km/s]			[km/s]	
CLLA							
–2.6 to –2.0	16	–13 ± 49	–234 ± 24	–22 ± 20	187 ±23	89 ± 14	75 ± 10
–2.0 to –1.5	22	+45 ± 39	–225 ± 21	–16 ± 16	177 ±22	95 ± 20	72 ± 9
–1.5 to –1.0	29	–19 ± 34	–182 ± 17	–9 ± 13	176 ±22	87 ± 9	66 ± 6
–1.0 to –0.5	73	–5 ± 11	–91 ± 8	–8 ± 6	89 ± 8	66 ± 8	51 ± 4
–0.5 to +0.4	95	–18 ± 8	–44 ± 4	–11 ± 3	70 ± 5	36 ± 6	23 ± 2
CLLA + Norris							
–2.6 to –2.0	25	–3 ± 34	–221 ± 18	–8 ± 16	162 ±19	84 ± 11	76 ± 8
–2.0 to –1.5	35	+23 ± 32	–231 ± 20	–10 ± 14	185 ±17	112 ± 17	79 ± 8
–1.5 to –1.0	43	–5 ± 26	–179 ± 15	–8 ± 12	164 ±18	91 ± 9	74 ± 6
–1.0 to –0.5	101	–20 ± 10	–89 ± 7	–7 ± 6	90 ± 7	62 ± 7	52 ± 4

4. THE HALO SUBDWARFS

For a selection of proper halo stars contained in the enlarged subdwarf sample (CLLA + Norris) not only a metallicity criterion was applied but also the kinematical properties of the stars were taken into account. Figure 4 shows the Toomre diagram for the complete sample of 301 stars. In such a diagram concentric half circles around the zero point of $(V_{\rm rot}, (U^2 + W^2)^{1/2})$ represent curves of constant kinetic energy with respect to the galactic center. The clustering near $V_{\rm rot} \sim 200$ km/s for $(U^2 + W^2)^{1/2} <$ 160 km/s becomes obvious, and shows the high portion of thick disk stars in our sample.

In the following all stars with [Fe/H]< -1.40 dex are regarded as halo stars, plus stars with [Fe/H]$<$ -1.00 dex if they didn't fall in the panel of the Toomre diagramm defined by $V_{\rm rot} > 100$ km/s and $(U^2 + W^2)^{1/2} < 160$ km/s, i.e. the region dominated by thick disk stars.

The $V_{\rm rot}$ versus [Fe/H] distribution of the 93 halo stars extracted in this way is presented in Figure 5. It shows a rather smooth behaviour over a wide range of metallicities. This impression is supported by the full line which is the result of a parameter free (locally weighted) regression analysis, and should be a rather strong argument against a possible rotation of the galactic halo.

5. CONCLUSIONS

On the basis of Hipparcos parallaxes it could be demonstrated that the subdwarf sample of Carney et al. 1994 is still contaminated by subgiants. Furthermore, Hipparcos parallaxes suggest, a systematic increase of the photometric distances by about 16 per cent.

Obviously, the kinematical properties are influenced by the selection of the sample from a high-proper motion catalogue. Nevertheless, a possible rotation of the galactic halo is not indicated.

It would be advisable to repeat a similar investigation as soon as the complete Hipparcos Catalogue becomes available.

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REFERENCES

Axer, M., Fuhrmann, K., Gehren, T., 1994, A&A, 291, 895

Carney, B.W., Latham, D.W., Laird, J.B., Aguilar, L.A., 1994, Astron. J., 107, 2240

Carney, B.W., Laird, J.B., Latham, D.W., Aguilar, L.A., 1996, Astron. J., 112, 668

Delhaye, J., 1965, in: Galactic Structure, Stars and Stellar Systems 5, 61

Edvardsson, B., Andersen, J., Gustafsson, B., Lambert, D.L., Nissen, P.E., Tomkin, J., 1993, A&A, 275, 101

ESA, 1997, The Hipparcos and Tycho Catalogues, ESA SP–1200

Laird, J.B., Carney, B.W., Latham, D.W., 1988, Astron. J., 95, 1843

Norris, J.E., 1986, ApJS, 61, 667

Ryan, S.G., Norris, J.E., 1991, Astron. J., 101, 1835

Schuster, W.J., Nissen, P.E. 1989, A&A, 221, 65

Wielen, R., 1986, Transactions Intern. Astron. Union 19B, 93

Wielen, R., Fuchs, B., Dettbarn, C., Jahreiß, H., Rockmann, J., 1997, ESA SP–402, this volume