# THE IMPACT OF HIPPARCOS ON THE CATALOGUE OF NEARBY STARS: THE STELLAR LUMINOSITY FUNCTION AND LOCAL KINEMATICS

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ABSTRACT

Investigating the properties of previous versions of the *Catalogue of Nearby Stars* great care was required to cope with often poorly determined distances of the objects. Now Hipparcos provides not only parallaxes but also proper motions and valuable additional information for almost 90 per cent of nearby stars in the magnitude range covered by the satellite.

In view of these extraordinary improvements the qualities of the new *Catalogue of Nearby Stars*, a version which takes the Hipparcos data into account, are discussed in comparison with the previous ground-based achievements. Though the number of stars within the chosen distance limit of 25 pc remained more or less the same, a considerable shift to larger distances took place. The new catalogue can be regarded as complete – in a statistical sense – for stars brighter than $M_V \sim 9$ mag, allowing therefore much more reliable studies of the stellar content in the solar neighbourhood. First results with on the local stellar luminosity function and the local kinematics are presented in more detail.

Key words: space astrometry; nearby stars; luminosity function; galactic kinematics.

## 1. INTRODUCTION

At present, our data base for the preparation of the new Catalogue of Nearby Stars, henceforth CNSH (Hipparcos version) and CNSG (ground-based version) contains more than 5 600 objects. This number includes also resolved companions of binaries and multiple stars. Due to their importance as kinematically unbiased samples also red dwarf stars found in objective prism surveys like the McCormick survey (Vyssotsky 1963) were included though considerable portions of these stars have larger distances than our *search limit*. Apart from astrometric data, photometric data (e.g. UBVRI colours) as well as radial velocities are constantly updated and are available in a uniform system. Likewise, additional information on duplicity, variability, etc. is kept up to date.

At our disposal were Hipparcos proper motions and parallaxes (ESA 1997) for althogether 5 532 stars comprising nearby stars, high-velocity stars, and red dwarf stars from spectroscopic surveys, mostly proposed in 1981 to be observed by Hipparcos. And very important for the present investigation, all remaining Hipparcos stars within 30 pc.

A cross-identification of the two files found 3 394 stars in common. An additional verification was advisable for the fainter stars of the sample in the case of very discrepant Hipparcos data. A more detailed look (finding charts, etc.) revealed indeed that 24 stars had erroneous identifications or wrong positions in the Hipparcos Input Catalogue. No astrometric results are given in the Hipparcos Catalogue for 13 additional stars. The identified 3 357 stars enclose almost 90 per cent of the CNS stars brighter than the magnitude limit ($m_V \approx 12$ mag) of the Hipparcos satellite.

Hipparcos attributed parallaxes larger than 40 mas to 217 stars not contained in our data base. Last but not least, Hipparcos detected also 37 previously unknown companions of nearby stars, and presumably even a brown dwarf companion (Bernstein 1997).

A closer examination of the new nearby objects gave the result that at least 39 of these Hipparcos parallaxes with standard errors usually exceeding 20 mas must be spurious. The standard errors of $\pi_h$ exceed 10 mas for only 48 stars of the Hipparcos sample available. A more detailed look on these stars, e.g. in the Digital Sky Survey, showed that such large errors were probably due to disturbing optical companions.

From the finally 119 new nearby stars kept there were among others some stars that have never been taken into consideration as nearby due to their small ground-based trigonometric parallaxes. The nearest star detected by Hipparcos HIP 103039 is a NLTT star at 5.5 pc. All other newly detected stars are beyond 10 pc, and with 85 stars the great majority lies between 20 and 25 pc.

## 2. HIPPARCOS VERSUS GROUND-BASED PARALLAXES

The fundamental data for the CNS-Catalogues are the trigonometric parallaxes. The fourth edition of the General Catalogue of Trigonometric Stellar Parallaxes (van Altena et al. 1995) represents the outcome of one century of ground-based parallax work. Since then only very few additions entered our data base. It contains 1973 *nearby* systems (altogether 2445 stars), i.e. stars with ground-based trigonometric parallaxes $\pi_g \geq 40$ mas. 1500 of these systems are brighter than 12 mag, the approximate magnitude limit of the Hipparcos satellite. The $\pi_g$ of 1452 systems can directly be compared with Hipparcos parallaxes $\pi_H$: The median standard error of the $\pi_H$ is 1.15 mas compared to a value of 8.8 mas for the $\pi_g$. The 10 mas error limit is exceeded by 40 per cent of

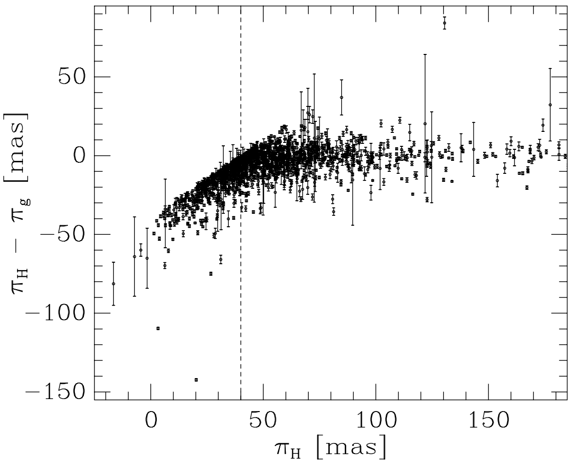


*Figure 1. Parallax differences $\pi_H - \pi_g$ versus the Hipparcos parallaxes for the 1452 stars with $\pi_g \geq 40$ mas. The dashed line marks the distance limit of the CNS.*

the $\pi_g$, but only by 2 per cent of the $\pi_H$. In Figure 1 the differences $\pi_H - \pi_g$ were plotted against the Hipparcos parallaxes $\pi_H$. The error bars represent Hipparcos errors. For the very nearby stars, not shown here, noticable differences occur only for a few souther stars without modern ground-based parallaxes. Figure 1 shows that there are only a very few stars with large Hipparcos errors. Since we are dealing with a volume limited sample defined by imprecise parallaxes the typical bias occurs that far too many stars are within the distance limit. According to Hipparcos only 66 per cent of the stars with $\pi_g \geq 40$ mas are really within 25 pc. With 45 per cent this percentage becomes even much smaller for the shell from 20 to 25 pc.

Establishing the series of nearby star catalogues in its present form, Wilhelm Gliese (Gliese 1957; Gliese 1969) realized very soon that he cannot rely only on the trigonometric parallaxes. Already in the 1969-version spectroscopic and photometric distance estimates were combined with trigonometric parallaxes to correct for the well-known bias in a volume limited sample caused by poorly determined trigonometric parallaxes. Since then the progress obtained in photometric and spectroscopic work offers a variety of improved distance estimates. In this sense the bias present in CNSG is less pronounced. This can be seen in Table 1 where for different distance intervals r the sample size of CNSG (column 4) and CNSH (column 5) are compared. Of course, these figures give only a superficial impression of the impact of Hipparcos, and may even be misleading: the drop from 65 to 61 stars within 5 pc, for example, is mainly due to the

*Table 1. Compilations of Nearby Stars 1957 – 1997.*

| r [pc] | 1957 | 1969 | CNSG | CNSH | $*/[pc^3]$ |
|---|---|---|---|---|---|
| 0 – 5 | 52 | 54 | 65 | 61 | 0.116 |
| 5 – 10 | 179 | 207 | 268 | 257 | 0.070 |
| 10 – 20 | 863 | 918 | 1593 | 1552 | 0.053 |
| 20 – 25 | | | 949 | 1126 | 0.035 |
| 0 – 20 | 1094 | 1179 | 1926 | 1870 | 0.056 |

fact that Hipparcos shifted the triple system $\epsilon$ Eri to 5.04 pc, just a bit outside the innermost sphere. The increase of the star numbers in the 20 to 25 pc shell may be surprising at a first glance. However, Hipparcos found not only 85 new stars belonging to this distance interval, but increased also the distances of many nearby stars (Figure 1).

## 3. TEST ON COMPLETENESS

The last column of Table 1 demonstrates the rapid decrease of the total star number density with increasing distance. Of course, the completeness of the CNSH is strongly correlated with absolute magnitude. The 25 pc distance limit of the catalogue corresponds to a distance modulus of M–m $\approx -2$ mag. Therefore, the Hipparcos Survey which is complete to a visual magnitude of about 7.5 mag provides completeness for $M_V \leq 5.5$ mag. An investigation of the the star number density for fainter magnitude bins as a function of increasing distance indicates that the CNSH should be complete up to its distance limit of 25 pc for absolute visual magnitudes brighter than 8 to 9 mag. This is supported by the search for additional nearby star candidates in the Tycho Catalogue where Makarov (1997) came to a similar conclusion.

This completeness means that the stars are rather homogeneously distributed in distance: the star numbers from 0 to 20 pc are more or less equal to the star numbers between 20 to 25 pc (to recall: with 20 pc the 25 pc sphere is separated pretty well into two half). It means further, also the distribution in declination is rather homogeneous. A formerly suspected small surplus of bright souther stars is no longer discernible.

## 4. THE STELLAR LUMINOSITY FUNCTION

In the previous section it could be stated that for the bright stars the CNSH is essentially complete up to 25 pc. Therefore the bright end of the luminosity function can be determined from twice the volume used in Wielen et al. 1983. For $M_V \geq 8$ mag a restriction to declinations north of –30° yields a significantly higher star density. A reduction of the distance limit to 20 pc is appropriate for $M_V \geq 9$ mag. This was already the case in Wielen et al. 1983, and also for the fainter magnitude bins the former completeness limits were applied. There were no strong reasons for a change of these limits. For $M_V = 18, 19$ mag the limit was extended to 10 pc, and for the very faint end $M_V = 20$ to 23 mag three stars within 25 pc determine a lower limit of the luminosity function.

The resulting luminosity function $\Phi(M_V)$ is presented in Table 2. Poisson errors give the statistical uncertainty $\varepsilon_\Phi$ (column 3). Figure 2 shows the new luminosity function (full line) together with the Wielen et al. (1983) function (dashed line). It is immediately evident that the bright end, $M_V \leq 7$ mag, is significantly lower than in 1983. Indeed, the present luminosity function yields about 15 per cent fewer bright stars. Only marginaly affected by Hipparcos, there seem also fewer stars around the maximum of the luminosity function indicating a flattening. Yet, in these faint magnitude intervals the scatter of the determination is rather high due to the small volume (5 pc sphere north of $\delta = -30°$) sampled.

*Table 2. The stellar luminosity function $\Phi(M_V)$ (number of stars within 20 pc in 1 mag bin).*

| $M_V$ | $\Phi(M_V)$ | $\varepsilon_\Phi$ | $\Phi_{ms}(M_V)$ |
|---|---|---|---|
| -1 | 1 | 1 | 0.5 |
| 0 | 4 | 2 | 3 |
| 1 | 11 | 3 | 8 |
| 2 | 16 | 3 | 14 |
| 3 | 41 | 5 | 37 |
| 4 | 57 | 6 | 53 |
| 5 | 98 | 7 | 98 |
| 6 | 100 | 7 | 100 |
| 7 | 98 | 7 | 98 |
| 8 | 112 | 9 | 112 |
| 9 | 140 | 14 | 140 |
| 10 | 235 | 50 | 235 |
| 11 | 300 | 57 | 277 |
| 12 | 427 | 191 | 427 |
| 13 | 341 | 171 | 256 |
| 14 | 341 | 171 | 256 |
| 15 | 427 | 191 | 427 |
| 16 | 341 | 171 | 341 |
| 17 | 171 | 121 | 171 |
| 18 | 75 | 28 | 75 |
| 19 | 43 | 21 | 43 |
| 20<br>21<br>22<br>23 | 0.4 | 0.2 | 0.4 |

The stellar luminosity function for the stars on or near the main sequence was obtained after separating the white dwarfs and the old giant stars. The result is given in column 4 of Table 2. It is in good agreement with the luminosity function derived by Murray et al. (1997) from Hipparcos parallaxes for the dwarf stars selected from the Michigan Spectral Survey. Their luminosity function samples a much larger volume up to 80 pc – at least for $M_V \leq 5$ mag.

## 5. LOCAL STELLAR MASS DENSITY

Taking the luminosity function of the main sequence stars and applying the mass-luminosity relation of Henry & McCarthy (1993) a new estimate of the local stellar mass density can be derived. In Table 3 the previously determined values (Wielen 1974) can be compared with the present result.

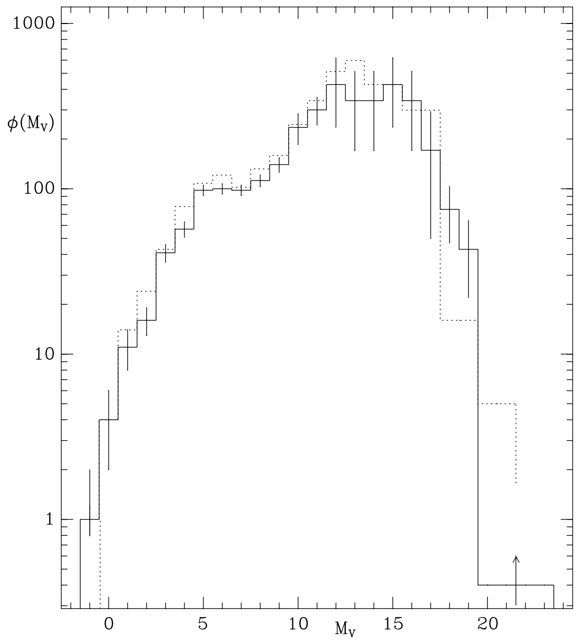


*Figure 2. Stellar luminosity function $\Phi(M_V)$. The units are number of stars within 20 pc per one magnitude bin. The dashed histogram shows the LMF from Wielen et al. (1983).*

*Table 3. Local stellar mass density (solar masses per $pc^3$).*

| source | old | new |
|---|---|---|
| main sequence: | | |
| $M_V \leq 9$ | 0.020 | 0.0178 |
| $10 \geq M_V \geq 13$ | 0.014 | 0.0112 |
| $M_V \geq 14$ | 0.003 | 0.0043 |
| no main sequence: | | |
| 27 giants (r $\geq$ 20 pc) | 0.001 | |
| 32 giants (r $\geq$ 25 pc) | | 0.0006 |
| 5 WD's (r $\geq$ 5 pc) | 0.007 | |
| 4 WD's (r $\geq$ 5 pc | | 0.0053 |
| total | 0.045 | 0.039 |

The decrease of the local stellar mass density to 0.039 $\mathcal{M}_\odot/pc^3$, can rather equally attributed to the contributions of the different star samples: The luminosity function yields fewer main sequence stars, the number of giants within 20 pc was almost reduced by a factor of two, and one white dwarf *left* the 5 pc sphere.

## 6. THE COLOUR-MAGNITUDE DIAGRAM

An inspection of the CM-diagram offers the best way to recognize the content of the CNS. Though it may be not the best choice, the B–V colour-index was taken because it is mostly available, i.e. for 85 per cent of the stars. In Figure 3 ground-based results are compared with the extraordinary improvements provided by Hipparcos. The CM-diagram Figure 3a is based on all ground-based trigonometric parallaxes. The large spread in the upper part shows very clearly how many poor parallaxes are involved.

A restriction to good parallaxes ($\sigma_\pi/\pi \leq 0.10$) produces a much clearer picture, but leaves only a sparsely crowded upper part of the diagram (Figure 3b). When introducing the Hipparcos parallaxes only 350 stars (practically all fainter than $M_V$ = 10 mag) are left from the 781 stars in Figure 3b. In other words, the upper part of Figure 3c is exclusively occupied by the 1411 Hipparcos stars.

Hipparcos provided us, for the first time, with a CM-diagram which is not only of unprecedented precision, but also essentially complete for all nearby stars brighter than $M_V$ = 9 mag. Therefore, Figure 3c represents the *real* distribution of the nearby bright stars.

## 7. KINEMATICS

In recent years radial velocities became available for practically all the nearby M dwarfs (Reid et al. (1995); Hawley et al. (1996)). Yet, we restrict the calculation of space velocity components to those stars with radial velocity errors smaller than ±8 km/s.

The space velocity components:
$U$ in the direction to the galactic center,
$V$ 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. After separation of old giants, white dwarfs, and subdwarfs, the remaining stars on or near the main sequence were divided into different B–V groups according to the division in Jahreiß & Wielen (1983). Of course, with very precise CM-diagrams at hand it may be possible to determine individual ages for most of the brighter stars. But, for the moment, only approximate mean ages $< \tau >$ were attributed to the individual B–V groups (column 11 in Table 4).

Because the nearby star sample is concentrated close to the galactic plane young stars are overrepresented. To get more representative values it is possible to average the quantities over z by weighting each star by the absolute value $|W|$ of its velocity perpendicular to the galactic plane. The resulting velocity parameters are presented in Table 4. For each group the axial ratio $\sigma_V/\sigma_U$ is given in column 10. For a flat rotation curve of our Galaxy a value of 0.71 is expected for this ratio.

The extension to 25 pc includes a few members of the UMa cluster. As is shown in Table 4 these stars affect especially the velocity parameters of the earliest group 6d ($B - V < 0.05$).

With the extension from 20 pc to 25 pc the number of stars should have been doubled. This is only partly the case. Obviously the cleaning effect of Hipparcos removed a considerable portion of the former group members. Moreover, in the later groups the lack of radial velocities becomes noticeable.

The velocity dispersions in Table 4 indicate that merely the faintest main sequence group 1 ($B - V \geq +1.40$) is kinematically biased, a consequence of the selection of faint nearby stars in high-proper motion catalogues.

In group 5–2, all main sequence stars are combined with $0.50 \leq B - V < 1.40$. It represents a rather complete and well mixed group of all ages. This becomes evident by comparing its velocity parameters with the corresponding values of the 516 stars from the McCormick K and M dwarf survey which should be free of kinematical bias. Metallicities could be determined for almost all stars of group 5–2 in the interval $0.22 \leq b - y \leq 0.59$ according to the precept of Schuster & Nissen (1989). The sample size of the different metallicity groups demonstrates the small amount of metal-poor stars in the immediate solar neighbourhood.

Many of the spectroscopically detected McCormick K and M dwarfs (Vyssotsky 1963) had only rough distance estimates. Therefore, the Hipparcos observations provided an enormous improvement to this sample. Especially, the number of stars in the complete sample and in the various age groups defined by the intensity of the CaII emission at the H and K lines could be significantly increased. Analogous to Jahreiß & Wielen (1983) the relative ages of the different HK groups were obtained under the assumption of a constant star formation rate. The results are presented in the lower part of Table 4.

Figure 4 shows the total velocity dispersion as a function of the mean age $< \tau >$ of the groups. Open

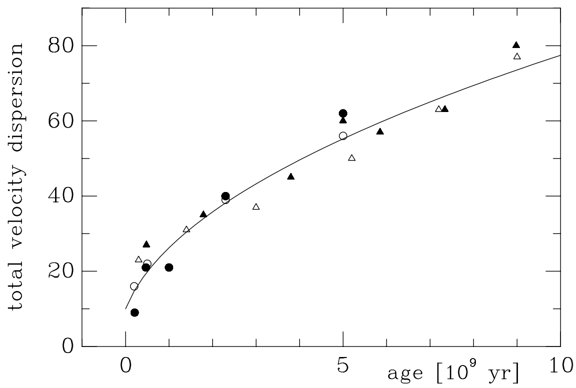


*Figure 4. Velocity dispersion as a function of age. Open symbols: CNS2-values (Wielen 1977); filled symbols: new results. Circles: main sequence groups; triangles: HK groups of the McCormick K and M dwarfs.*

symbols give the former values from Jahreiß & Wielen (1983), and filled symbols give the new values. The full line describes the increase of the velocity dispersion with age as a diffusion process under the assumption of a constant diffusion coeficient (Wielen 1977). As a result, it can be stated that the new values are still in good agreement with the former and the theory developed herewith.

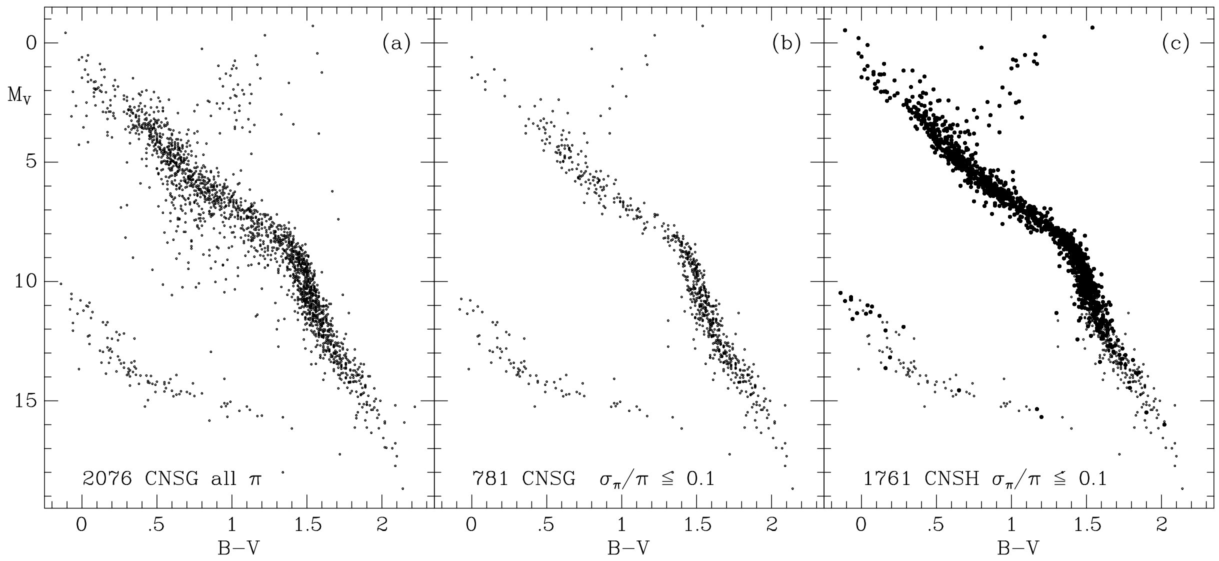


*Figure 3. CM-diagrams for nearby stars ($r \leq 25$ pc): (a) all CNSG stars with trigonometric parallaxes; (b) all CNSG stars with relative parallaxes better than 10 per cent; (c) all CNSH stars with relative parallaxes better than 10 per cent.*

*Table 4. Mean velocities and velocity dispersions for various CNSH groups ($|W|$-weighted).*

| n | group | $<U>$ | $<V>$ | $<W>$ | $\sigma_U$ | $\sigma_V$ | $\sigma_W$ | $\sigma_{tot}$ | $\sigma_V/\sigma_U$ | $<\tau>$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | [km/s] | | | | [km/s] | | | [$10^9$ yr] |
| 4 | group 6d* | −18 | −10 | −11 | 6 | 5 | 3 | 9 | .88 | 0.21 |
| 9 | group 6d | −7 | −6 | −10 | 16 | 7 | 3 | 17 | .43 | 0.21 |
| 15 | group 6c | −7 | −12 | −15 | 16 | 15 | 4 | 22 | .94 | 0.47 |
| 19 | group 6b | −10 | −2 | −1 | 16 | 11 | 9 | 21 | .70 | 1.0 |
| 78 | group 6a | −3 | −14 | −17 | 30 | 22 | 16 | 40 | .73 | 2.3 |
| 149 | group 5 | −23 | −29 | −3 | 46 | 33 | 25 | 61 | .72 | 5.0 |
| 104 | group 4 | −15 | −24 | −5 | 44 | 30 | 19 | 56 | .68 | 5.0 |
| 174 | group 3 | −10 | −21 | −8 | 44 | 27 | 20 | 55 | .61 | 5.0 |
| 173 | group 2 | −10 | −28 | −4 | 42 | 27 | 23 | 55 | .66 | 5.0 |
| 361 | group 1 | −7 | −27 | −14 | 50 | 33 | 28 | 66 | .66 | |
| 600 | group 5–2 | −14 | −26 | −5 | 44 | 29 | 22 | 57 | .66 | 5.0 |
| 230 | [Fe/H] (+0.4,−0.5) | −18 | −26 | −9 | 47 | 29 | 18 | 58 | .62 | |
| 15 | [Fe/H] (−0.5,−1.0) | −45 | −54 | 9 | 45 | 51 | 37 | 77 | 1.12 | |
| 6 | [Fe/H] (−1.0,−1.6) | 124 | −245 | −63 | 177 | 152 | 24 | 235 | .86 | |
| 30 | old giants | −9 | −31 | −10 | 29 | 31 | 21 | 48 | 1.05 | 7.0 |
| 15 | subdwarfs | 54 | −191 | 31 | 112 | 83 | 66 | 154 | .74 | 10.0 |
| 12 | white dwarfs | 5 | −21 | 6 | 41 | 25 | 13 | 49 | .61 | |
| 516 | Mc Cormick dwarfs | −7 | −26 | −7 | 45 | 32 | 24 | 60 | .71 | 5.0 |
| 37 | HK +8/+3 | −10 | −14 | −1 | 22 | 11 | 7 | 25 | .51 | .36 |
| 57 | HK +2 | −5 | −17 | −8 | 26 | 17 | 13 | 34 | .67 | 1.45 |
| 55 | HK +1 | 0 | −19 | −7 | 35 | 21 | 17 | 44 | .59 | 3.17 |
| 57 | HK 0 | −5 | −26 | −6 | 46 | 21 | 17 | 54 | .45 | 5.19 |
| 34 | HK −1 | −5 | −28 | 3 | 43 | 34 | 31 | 63 | .79 | 7.02 |
| 44 | HK −2/−5 | −2 | −34 | −11 | 65 | 35 | 28 | 79 | .54 | 8.91 |

* without UMa cluster stars

In an axisymmetric galaxy which is in a stationary state the mean motion $< V >$ is expected to be proportional to $\sigma_U^2$. Then for $\sigma_U \to 0$ km/s the mean motion $< V >$ should approach the circular velocity $V_L$. In Figure 6 the asymmetric drift is shown for the various CM groups (triangles) and HK groups (circles). A linear least-squares fit gives $7.7 \pm 2.4$ km/s for the circular velocity and for the slope $0.009 \pm 0.002$. This is in good agreement with a similar result presented in Binney et al. (1997) who investigated the Hipparcos proper motions of a sample of stars selected from the Michigan Survey.

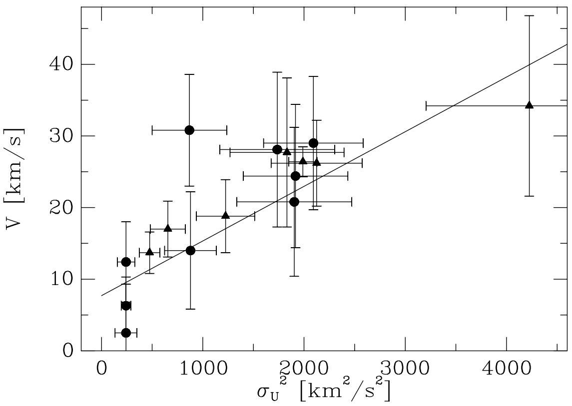


*Figure 5. Asymmetric drift. Circles: CM groups; triangles: HK groups of the McCormick K and M dwarfs. The full line is a least-squares fit.*

## 8. CONCLUSIONS

As was demonstrated the impact of Hipparcos on the research on nearby stars is enormous. The nearby star sample is now complete within a much larger volume for $M_V \leq 8$ mag with trigonometric parallaxes of unprecedented accuray. Consequently, the bright end of local stellar luminosity function could be determined with higher accuracy than before: the result is a 15 per cent decrease in star number density. Simultaneously, Hipparcos *cleaned* up the bright portion of the CM-diagram allowing now more precise studies of metallicity and age effects.

We could present here only a few examples how Hipparcos affected the nearby star sample, but, we are convinced that the true importance of Hipparcos will still show up in the near future.

Hipparcos detected almost 200 new nearby stars. On the other hand, since 1981, the deadline of Hipparcos proposals, quite a number of new promising nearby candidates were found. In additon, there are the candidates in the Tycho Catalogue. To proceed, new parallax work as well as photometry is required for relatively bright stars. But, for the moment, the interest in such stars seem to be rather low. DIVA or GAIA would be excellent possibilities for completing this work.

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This research has made use of the Simbad database, operated at CDS, Strasbourg, France.

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