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A test of B-type star $H\beta$ photometric distances via the Hipparcos parallaxes*

N. Kaltcheva[1] **and J. Knude**[2]

[1] School of Physics and Astronomy, University of St Andrews, North Haugh, St Andrews, Fife, KY16 9SS, UK (ntk@st-andrews.ac.uk)
[2] Niels Bohr Institute for Astronomy, Physics and Geophysics, Juliane Maries Vej 30, DK-2100 Copenhagen Ø, Denmark (indus@astro.ku.dk)

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Abstract. We test the photometric *uvby*β distances for B III, IV and V type stars, with an emphasis on the effect of rotation on the M_V determination. From the M_V(*uvby*β) calibration of Balona & Shobbrook (1984), we have derived the absolute visual magnitudes for 176 stars with *v sin (i)* measurements and have compared them to M_V values derived via the parallaxes, measured by Hipparcos. For the luminosity classes IV and V there is a good agreement between the photometric and trigonometric distances and no dependence on rotation. The photometric M_V values for luminosity class III show a tendency to be slightly larger than the corresponding Hipparcos determination. Probably this is due to the photometric calibration itself and it is not connected to the stellar rotation. Using the Hipparcos data, we also test the Crawford's (1978) $M_V(\beta)$ reference line and the Philip & Egret (1980) and Schönberner & Harmanec (1995) $M_V((b-y)_0)$ reference lines. The last one shows disagreement with the trigonometric luminosities at the bright star end.

Key words: techniques: photometric – stars: distances – stars: early-type – stars: rotation

1. Introduction

The knowledge of individual B-type star distances is the only tool to reveal a reasonable information about the structure of some parts of the Milky Way. There are regions, where a projected spatial overlap of the different young groupings exists, and a considerable number of early-type background and foreground stars can be found in the same field. In these cases the spatial separation of the young stellar groups is more obvious than their photometric distinction. It is known, also, that for the young groups with a vertical main sequence or containing only evolved stars, a huge uncertainty could be involved applying the method of cluster fitting for determination of the distances. In these cases only obtaining the precise spatial distribution of the individual stars is helpful to define the membership and the characteristics of their groups as a whole (Kaltcheva 1998). Another item where accurate distances to the B stars are required is the derivation of the volume filling factor of the diffuse interstellar dust clouds illuminated by B stars that have left the molecular clouds in which they were formed (Knude 1992). A third example where B star accurate distances are critical is in the study of the local ISM structure from the combination of sodium D absorption lines and photometric distances (Génova et al. 1997, Corradi et al. 1998).

The calculation of the early-type star distances, obtained using both spectroscopic parallaxes and photometry, is a crucial problem. An examination of the M_V calibrations in the UBV, UBVβ and *uvby*β systems reveals an enormous scatter in the mean absolute magnitudes, both between various authors and within a given calibration. In general, using *uvby*β photometry, we expect to obtain reliable estimates of the distances, because Hβ is a sensitive luminosity indicator for B-type stars and the intrinsic scatter in the M_V(*uvby*β) calibrations is about three times less than in the calibrations using UBV or UBVβ photometry. When *uvby*β measurements are available, a M_V calculation is possible via β and c_0 indices using the $M_V(\beta)$ calibration of Crawford (1978) or $M_V(c_0,\,\beta)$ calibration of Balona & Shobbrook (1984) for class III, IV and V stars, and that of Zhang (1983) for Supergiants. In the calibration presented by Balona & Shobbrook (1984), attempts to correct the main uncertainties in the curve fitting method, due to the width of the main sequence and the evolution away from the main sequence of stars at the high-mass end are made. The errors in M_V values derived in this way are expected to be about 0.2 mag. In this sense, a test of the M_V values, derived via the Balona & Shobbrook (1984) calibration, comparing them to the values of M_V, obtained from the parallax measurements of the Hipparcos satellite will be useful. Note, however, that the β photometry alone is not able to make a differentiation of emission in the Balmer H_β line and evolution away from the ZAMS. We also remark that Balona & Shobbrook's calibration includes the Pleiades which recently have been shown to display an unexpected location in the M_V - (B_2-V_1) diagram (Mermilliod et al. 1997). For a similar (B_2-V_1) color the Pleiades stars are systematically ≈0.5 magnitude fainter than e.g. Praesepe stars. This of course adds to the scatter in Balona & Shobbrook's calibration.

When examining the reliability of the $M_V(c_0,\,\beta)$ calibration, it is important to estimate the influence of the effect of rotation on the M_V determination. Recently, also based on the

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Send offprint requests to: Jens Knude

* Based on data from the ESA Hipparcos astrometry satellite

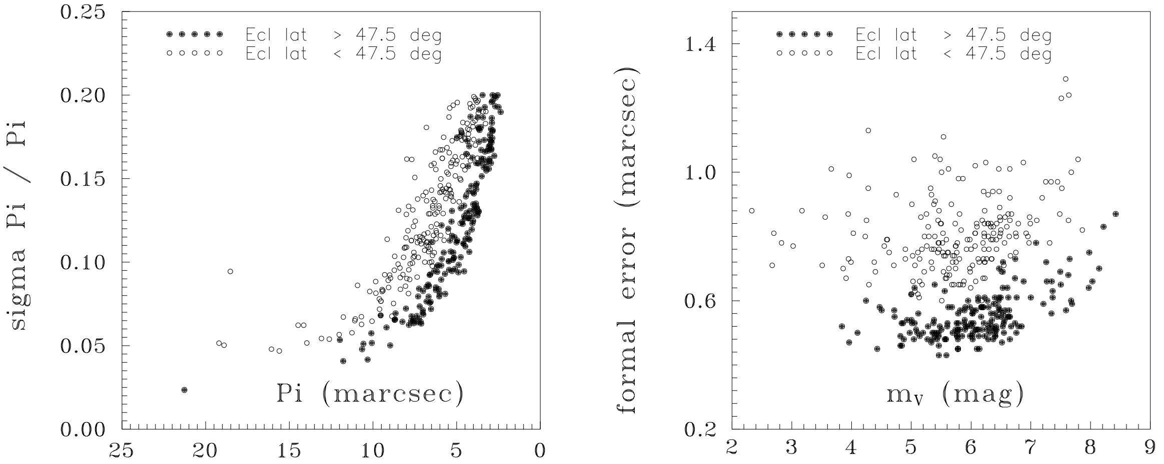

Fig. 1. The σ_π/π vs π and σ_π vs m_V diagrams

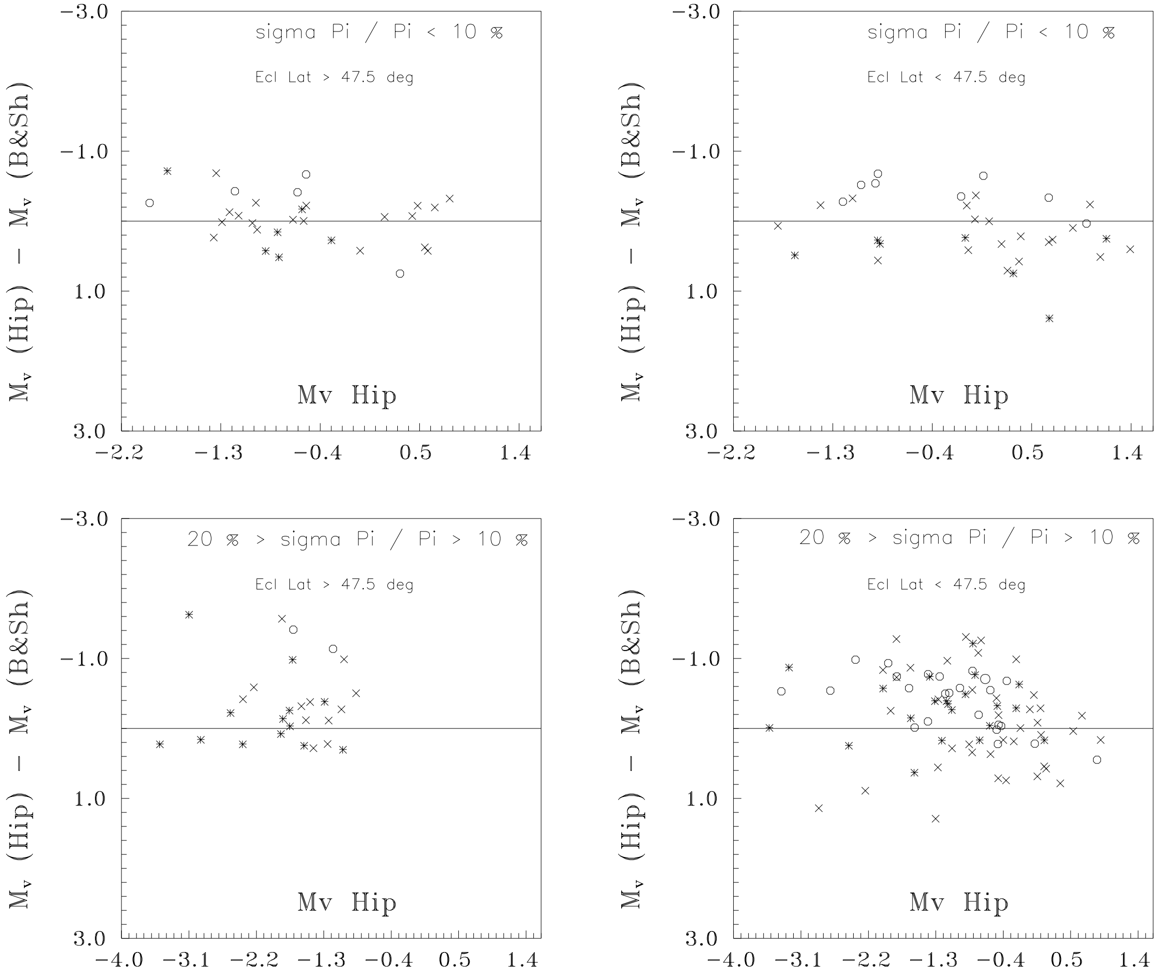

Fig. 2. The difference between the values of M_V from the Hipparcos parallaxes and from the photometry as a function of $M_V(Hip)$. The solid lines are the zero-lines. The different symbols indicate the different LC classes: open circles - LC III, crosses - LC V and asterisks - LC IV and IV-V.

data of the Hipparcos satellite, Lamers et al. (1997) noticed that for the O-B4 spectral subtypes slow rotators show a tendency to be fainter than the fast rotators and this influences the spectroscopic distance determination. They interpret this effect as a systematic misclassification of the fast rotating stars. Their sample contains 14 O-B4 III, IV and V type stars, selected to

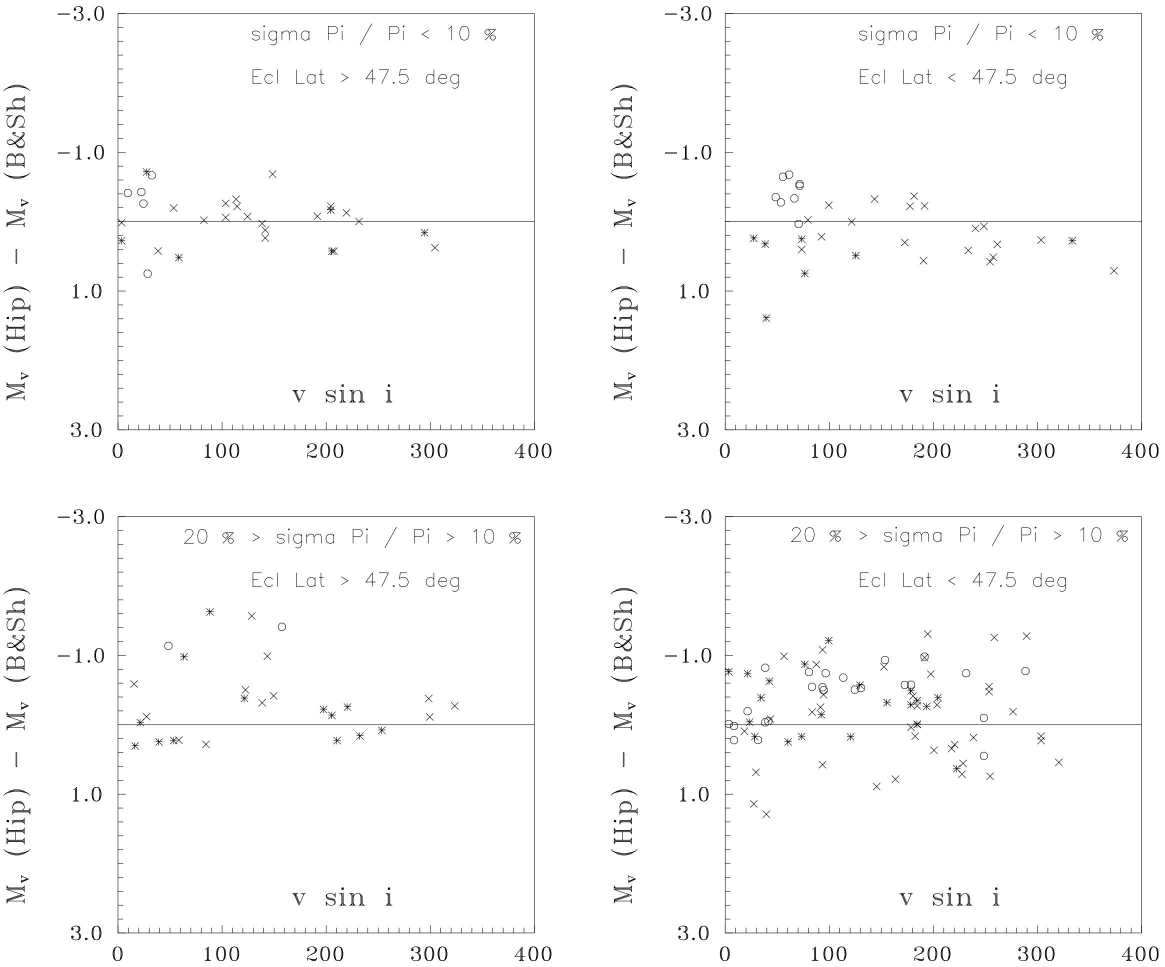

Fig. 3. The difference between the values of M_V from the Hipparcos parallaxes and from the photometry as a function of *v sin i*. The solid lines are the zero-lines. The symbols are the same as in Fig. 2

be optically bright, with $V < 5$ mag. Jaschek & Gomez (1998) also investigate the relation between M_V and spectral type for 30 B2-B9 III, IV and V type stars, selected only among those with absolute magnitude errors < 0.3 mag. Their sample does not show any rotation tendency, but they show that a unique relation between luminosity class and state of evolution may be absent for individual stars but seems valid in a statistical sense.

The main emphasis in this paper is a study of the influence of rotational velocity on the photometric $M_V(c_0,\,\beta)$ distance determination. This is the first item that should be checked before investigating the calibration in details.

2. The sample

From the Hipparcos catalogue (ESA, 1997) we have selected all B0-B9 III, IV and V type stars with relative errors σ_π/π in the parallax measurements smaller than 20 % and with *uvby*β photometry existing in the literature. For our present purpose we use the homogenized *uvby*β data from the compilation of Mermilliod et al. (1997). Then we have rejected all variable and multiple stars and stars with peculiarities and emission indicated in the spectra. The resulting sample is 392 stars. Following Arenou et al. (1995), we expect that the accuracy in the parallax determination will vary both with visual magnitude m_V and ecliptic latitude. In Fig. 1 we present the plots of the relative errors (σ_π/π) vs π and formal errors (σ) vs m_V for the stars from the sample. Different symbols are used for stars at high (filled symbols) and low (open circles) ecliptic latitude. It can be seen that both the relative and formal errors are smaller for high ecliptic latitude and a clear separation regarding the accuracy of the measured parallaxes occurs at ecliptic latitude 47.5 deg. Then we have selected stars with *v sin(i)* measurements. The *v sin(i)* data are taken from the Bright Star Catalogue (Hoffleit & Warren 1991). All these conditions brought the sample to 176 stars. The *v sin(i)* values range from 0 to 300 km/s. This last sample does not contain stars fainter than 7th mag, fainter stars apparently do not have *v sin(i)* measurements.

In order to examine the influence of the relative and formal errors, we have divided the sample into 4 parts, defined as follows:

1. stars at ecliptic latitude > 47.5 deg and $\sigma_\pi/\pi < 10\%$,
2. stars at ecliptic latitude < 47.5 deg and $\sigma_\pi/\pi < 10\%$,

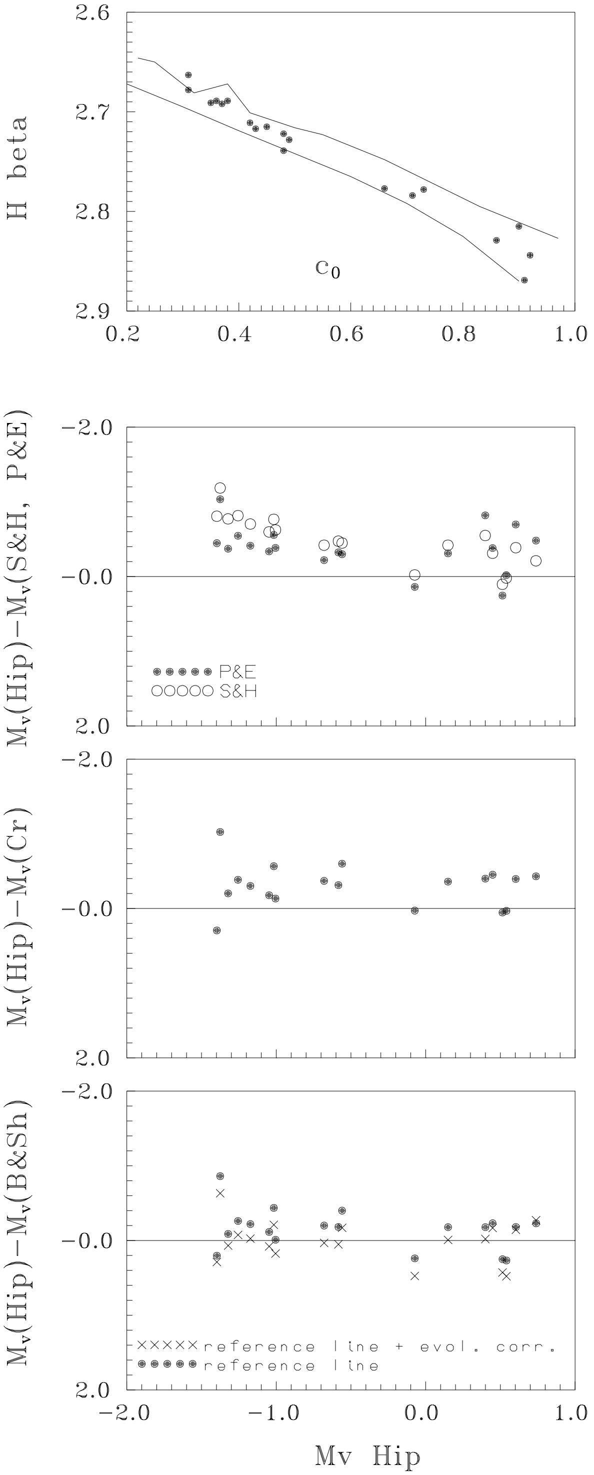

Fig. 4. The difference between the values of M_V from the Hipparcos parallaxes and from the calibrations of Schönberner & Harmanec (1995), Philip & Egret (1980), Crawford (1978) and Balona & Shobbrook (1984) as a function of $M_V(Hip)$. The filled symbols in the lowest panel present the M_V values obtained using the Balona & Shobbrook's (1984) reference line, while the crosses are corrected for the evolution away from the reference line. The β/c_0 diagram for the stars used is shown in the top panel. The solid lines are ZAMS and the average line for LC V according to Crawford (1978).

3. stars at ecliptic latitude > 47.5 deg and σ_π/π between 10% and 20%,
4. stars at ecliptic latitude < 47.5 deg and σ_π/π between 10% and 20%.

In Fig. 2 and Fig. 3 the differences between the values of M_V from the Hipparcos parallaxes and from the photometry as a function of $M_V(Hip)$ and as a function of *v sin(i)* for each subsample are presented. In these figures we have used different symbols to indicate the different luminosity classes: open circles - LC III, crosses - LC V and asterisks - LC IV and IV-V. In general, samples 1, 2 and 3 give same results and show a good agreement between the photometric and trigonometric values of M_V for LC IV and V. For these luminosity classes there is no dependence of the Balona & Shobbrook M_V determination on the *v sin(i)* either. The stars of LC III, however, show a tendency to be slightly fainter according to the photometric estimation, but still within the errors of the calibration.

The uncertainty in the trigonometric M_V values depends on the relative error of the parallax. When the relative error is smaller than 10%, the uncertainty in the M_V determination should not be larger than ±0.2 mag. For the photometric $M_V(c_0, H\beta)$ values we expect an uncertainty of the same order. In this case the values of the difference $M_V(Hip) - M_V(B\&Sh)$ should be found within a ±0.5 mag band, as it is for the samples 1 and 2. This is the case with the sample 3 as well, with a few exceptions. When the relative error increases to 20%, the uncertainty in the M_V determination can be as large as ±0.5 mag and the differences should be distributed in a ±0.7 mag band, as can be clearly seen from the 4th subsample.

Sample 1 represents the best trigonometric measurements. For this sample the agreement between the photometric $H\beta$ luminosities and trigonometric measurements is good and the rotation has apparently not influenced the photometric M_V determination. A closer inspection of sample 3 shows that the reason for the large differences for some stars is probably due to the photometric calibration. Involving the stars at ecliptic latitude < 47.5 deg and σ_π/π between 10% and 20% (sample 4) in the analysis, we know that less accurate parallaxes are included but apparently a systematic difference that cannot be seen in the other three subsamples. This systematic difference can probably be explained with the asymmetry in the error calculated from the parallaxes M_V values, or could be due to the Lutz-Kelker bias (Lutz & Kelker 1973) which becomes more significant with increasing relative errors in the trigonometric parallaxes. Since the parallaxes' accuracies depend on the number of observations of a star and on the ecliptic latitude respectively, different samples could lead to different conclusion.

3. Conclusions

Our conclusions are confined to subsample 1. Subsample 1 contains the stars with the smallest formal and (at the same time) relative errors in the parallax measurements, brighter than 5.5 mag in general. For stars B0.5-B9, LC IV and V, there is a good match between the M_V values, calculated from the Balona &

Shobbrook (1984) calibration and the M_V obtained via the Hipparcos parallaxes. The photometric $H\beta$ luminosities do not depend on the rotational velocity for the whole range from 0 to 300 km/s. This result is in agreement with those of Crawford (1978).

For LC III the difference between the photometric and trigonometric M_V values could be as large as 0.5 mag in average. The M_V determined from the Balona & Shobbrook (1984) calibration are less negative in comparison to that calculated from the parallaxes. In that way the photometric calibration consequently gives an estimate of a slightly smaller distance than the Hipparcos parallax.

It is of interest to test some of the other upper part MS luminosity calibrations, existing in the literature. The calibration of Balona & Shobbrook (1984) is the only one that includes detailed evolutionary corrections, but there is a number of other ZAMS calibrations. A more recent review of the present situation regarding the empirical and semi-empirical calibrations is made by Sch$\ddot{o}$nberner & Harmanec (1995), who present a new empirical brightness calibration of the early type ZAMS Pop. I stars. To test roughly the present situation, we have restricted our subsample 1 only to the LC V stars. The β/c_0 diagram for these stars, together with the ZAMS line and the average line for LC V, as given by Crawford (1978) is shown in Fig. 4. Below this diagram, the results from the application of the Sch$\ddot{o}$nberner & Harmanec's (1995) new $M_V((b-y)_0)$ reference line, Philip & Egret (1980) $M_V((b-y)_0)$ reference line, Crawford (1978) $M_V(\beta)$ reference line and Balona & Shobbrook (1984) $M_V(c_0,\beta)$ calibration are given. The first three calibrations are only regarding the ZAMS and are not meant to describe stars within the main-sequence band. For the aim of comparison, we have used the Balona & Shobbrook's (1984) formula (2), which does not include terms for correcting the evolution and represents only their reference line. The result is plotted with filled symbols in the bottom panel of Fig. 4. In the same plot the results from Balona & Shobbrook final formula, (3), which includes evolutionary correction terms, are given with crosses as well.

According to these plots, the Sch$\ddot{o}$nberner & Harmanec (1995) new reference line gives magnitudes systematically fainter for $M_V < -0.5$ mag. The reference lines of Crawford (1978) and Philip & Egret (1980) present a good agreement with the Hipparcos parallaxes.

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