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Preliminary report

PHOTOGRAPHIC ZENITH TUBES OBSERVATIONS TO IMPROVE HIPPARCOS PROPER MOTION IN DECLINATION OF SOME STARS

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SUMMARY: A procedure of calculation and results of an attempt to improve proper motions in declination for some HIPPARCOS stars are presented. A long series of optical observations of these stars observed with Photographic Zenith Tubes (PZT) are used. The HIPPARCOS ESA mission (ESA 1997) was nearly 4 years long, but each of the different Earth rotation programmes (PZTs included) covers a few decades in the interval 1899.7 – 1992.0 (Vondrák et al. 1998). The HIPPARCOS mission period of a few years only is not enough to determine the precise proper motions for some stars, with the standard error of proper motions of about 1 mas/year, but ground-based data covering a few decades with positional errors one or two orders higher than HIPPARCOS ones are nevertheless useful for checking or improving some HIPPARCOS proper motions (mostly of double and multiple stars). Here, the observations of two PZTs (with different longitudes and the same latitude) are used to improve some HIPPARCOS proper motions in declination; the method is explained and some results are presented.

Key words. Astrometry – Reference systems

1. INTRODUCTION

The HIPPARCOS Catalogue is an optical reference frame and contains 118218 stars (brighter than magnitude 12) with lot of high precision data: positions (the accuracy is about 1 *mas* at 1991.25 – epoch of the catalogue), proper motions (the standard error of $\mu_\alpha \cos\delta$ and μ_δ is nearly 1 *mas/year*), parallaxes, photometry, etc. The International Celestial Reference Frame (ICRF), with 608 compact radio sources, materializes the International Celestial Reference System (ICRS). The accuracy of positions of radio sources is between 0.3 *mas* – 0.5 *mas* (Ma et al. 1998). 59 new sources were added (IERS Annual Report 1999) in the ICRF-Ext. 1. Unfortunately, the HIPPARCOS mission had a duration shorter than 4 years, not enough to obtain a satisfactory accuracy of proper motions for some stars.

On the other hand, there are ground-based observations for about 4500 HIPPARCOS stars from different Earth rotation programmes which were used for latitude and universal time UT0 investigations (Vondrák 2004). These stars were observed at 33 observatories (about 4400000 astrometric observations have been collected) in the period 1899.7 – 1992.0. We can use these observations to improve the proper motions for some HIPPARCOS stars (in the first place, of double and multiple ones). Better HIPPARCOS proper motions (the long-term part) of stars means more stable reference frame in time. Also, detected problems of the HIPPARCOS mission will give a useful information for other satellite missions in the future. Recently there were several projects using the combination of some ground-based data with the ESA mission ones, whose results appear in the new catalogues: FK6(I), FK6(III), ACT, TYCHO-2, GC+HIP, TYC2+HIP, ARIHIP and EOC. The most recent one, EOC (the Earth Orientation Catalogue), was made by Vondrák and Ron (2003), and it is based on different Earth rotation programmes. Here, part of the observational data of the same Earth rotation programmes are used (PZT latitude ones) to get improved Hipparcos proper motions in declination for some stars.

The latitude observations of two PZTs were used, Mount Stromlo – MS, Australia, and Punta Indio – PIP, Argentina (Vondrák 2002, private communication). The observational programme of MS contains 184 stars, the PIP one 165 stars, and there are 157 stars in common. The observed intervals overlap enough: 1957.8-1985.7 for MS, 1971.6-1984.5 for PIP. These two coincidences, a significant number of common stars and a good piece of common interval of observations, are welcome for checking the procedure of calculation (described below) and the results concerning the same star observed at two observatories with different longitudes ($\lambda_W = 211.^o0$ for MS, $\lambda_W = 57.^o3$ for PIP) and the same latitude $\varphi = -35.^o3$.

2. DATA AND CALCULATIONS

2.1. Data

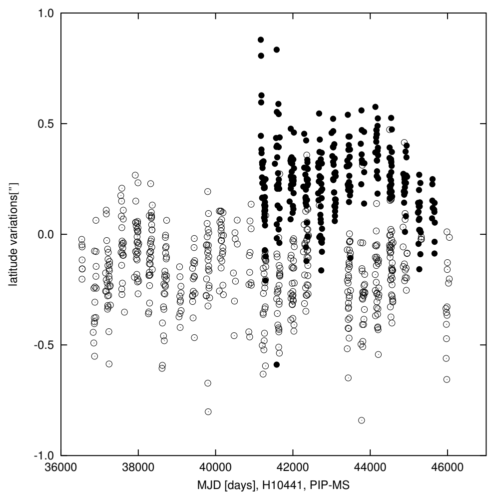

Fig. 1. *MS (white circles) and PIP (black circles) latitude variations φ_i with time (MJD) for HIPPARCOS star H10441.*

The main features of the PZT latitude variations φ_i (around the corresponding mean latitudes) used here have been already described by Vondrák et al. (1998), Damljanović and Pejović (2005) and Damljanović and Vondrák (2005). The calculation of the apparent places of stars was made by using the IAU models for precession from 1976 and nutation from 1980, the MERIT Standards (Melbourne et al. 1983) and the HIPPARCOS data. Until 1998, the proper motions of about 20% of PIP and MS stars were corrected (Vondrák et al. 1998) with respect to the HIPPARCOS Catalogue. The tectonic plate motions were removed by means of the model NUVEL – 1 (Argus and Gordon 1991), also the mean latitudes and the corrections of conventional longitudes. The data were corrected for the instrumental constants (micrometer screw, plate scale, etc.) and for refraction.

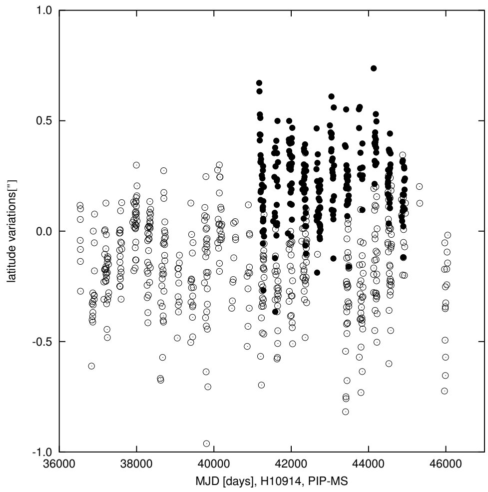

Fig. 2. *The same as in Fig. 1, but for H10914.*

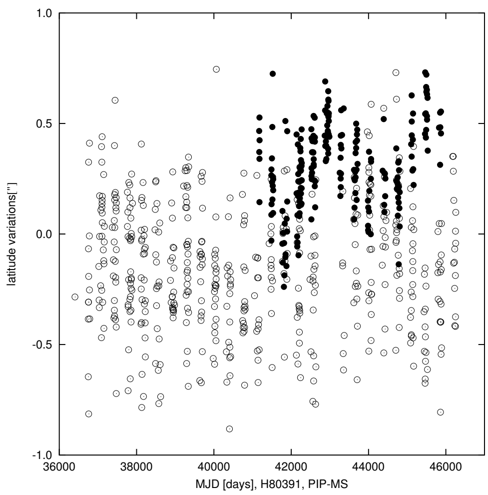

Fig. 3. *The same as in Fig. 1, but for H80391.*

The mean latitudes and tectonic plate motions were subtracted from the MS and PIP latitude data:

$-35^o19^{'}17.^{''}450 + 0.^{''}182/cy * (t - t_1)$, for MS (interval 36141 – 46306 MJD),

$-35^o20^{'}40.^{''}566 + 0.^{''}036/cy * (t - t_1)$, for PIP (interval 41165 – 45883 MJD), $t - t_1$ is from 32000 MJD (in centuries),

and here we used the latitude variations φ_i (in *arcsec*) with time MJD (in *days*) as the input data.

As an example, these φ_i data for the three stars, H10441, H10914 and H80391, are presented in the Figs. 1, 2 and 3, respectively. The observations were obtained with two different PZTs, MS (white circles) and PIP (black ones). From these three figures, one can see a large scatter of points, also a systematic shift of the data coming from two instruments (presented in the Figs. 4 and 5) and polar motion variations.

The φ_i data were made available to the author by Vondrák (2002, private communication). The polar motion changes $\Delta\varphi_i$, the systematic effects (local, instrumental, etc.), and so far unknown corrections of proper motions in declination (which are of our interest) are still present in φ_i.

2.2. Procedure of calculation

The observations were made with two instruments and at different places, very far from each other, and their systematic changes with time (local, instrumental, etc.) are mutually independent. Also, the polar motion effect $\Delta\varphi_i$ is present in the available φ_i data. For all our stars we therefore determined and removed this polar motion and systematic changes.

The systematic changes (local, instrumental, etc.) for each instrument were detected and removed by using observations of all stars. Then, we have computed the residuals for each star (without systematic and latitude variations) to be able to investigate the corrections of the proper motions in declination. For each common star we can calculate its corrections (one correction is from MS data and the other from PIP ones) and compare them. The method is valid if these corrections are mutually consistent.

2.2.1. Polar motion effect

The polar motion effect $\Delta\varphi_i$ is dominant and has the variations of few tenths of an *arcsec*, much larger than the effect of the proper motion correction. Thus, it is first necessary to calculate the polar motion component and to remove it from the values φ_i. We did it by using the polar motion coordinates x_i and y_i from the file EOPOA00.dat (Vondrák 2000, private communication) and the Kostinski formula (Kulikov 1962)

$$\Delta\varphi_i = x_i \cos\lambda_{in} + y_i \sin\lambda_{in}, \quad (1)$$

where $\Delta\varphi_i$ is calculated polar motion effect for the moment i, λ_{in} is the longitude of MS ($\lambda_W = 211.^o0$) or PIP ($\lambda_W = 57.^o3$).

The residuals r_i (for the moment i) for any star are:

$$r_i = -(\varphi_i - \Delta\varphi_i). \quad (2)$$

We put the sign *minus* in front of the parentheses because the calculated values of b (see below) for some star can thus be added to the HIPPARCOS proper motion in declination.

Next, the outlier values r_i were rejected in accordance with $2.7 * \sigma$ statistical criterion so that the next step of the calculation contains more homogeneous values r_i. After that, it was possible to calculate the average values r_n of r_i. We have got about one r_n value per year. Hence, for each star there is nearly the same number of points r_n as the number of years of the observational period. The values r_n are presented in the Figs. 6, 7 and 8 for stars H10441, H10914 and H80391, respectively; the systematic shifts are clearly seen.

Within an observational year, there are from only a few to few hundred observations of the same star (observed with MS or PIP), presented in Figs. 1-3. In Figs. 6-8, the polar motion changes with time are removed, but not the systematic ones.

2.2.2. Local and instrumental systematic variations

After removing the polar motion changes with time from the values φ_i, the systematic changes (local, instrumental, etc.) with time are still present in the values for r_n, as seen from Figs. 4. (for MS) and 5 (for PIP). For each star, every r_n is the averaged value of r_i values over the subperiod of about 1 year. In Fig. 4, the dots are the values r_n for stars observed with MS, and in Fig. 5 for stars observed with PIP; the black circles are the averaged values of r_n for all stars over 0.2 years, and the straight line is the linear trend calculated by using the Least Squares Method (LSM). The subperiod of 0.2 years is optimal to get averaged values, and we found it after several experiments with several other values; the task was to find the value as small as possible, but not to lose the necessary information about the systematic effects.

It was necessary to remove detected systematic changes from r_i and to get the values r'_i. In this paper, the linear approximation of the systematic changes with time is not used. It is presented in Figs. 4 and 5 for the sake of illustration. The linear approximation of the systematic changes was, however, used in some other papers (Damljanović and Pejović 2005, Damljanović and Vondrák 2005).

From Fig. 4 and especially from Fig. 5 it is clear that the curve of the systematic changes with time is more complicated than a linear approximation. Also, this complicated curve can affect our results significantly. Therefore, in this paper, to get the values r'_i, the averaged (black circles in Fig. 4 and Fig. 5) values over subperiods of 0.2 years are used as better approximation of the real systematic changes.

Finally, the values of r'_n are calculated by using the values r'_i in the same way as the values r_n were calculated from r_i, but in this case the systematic changes (local and instrumental) were removed from the r'_n values. The values r'_n for the stars H10441, H10914 and H80391 are presented in Figs. 9-11, respectively. A significant difference between the trends in Figs. 1-3 and those in Figs. 9-11 is clearly seen.

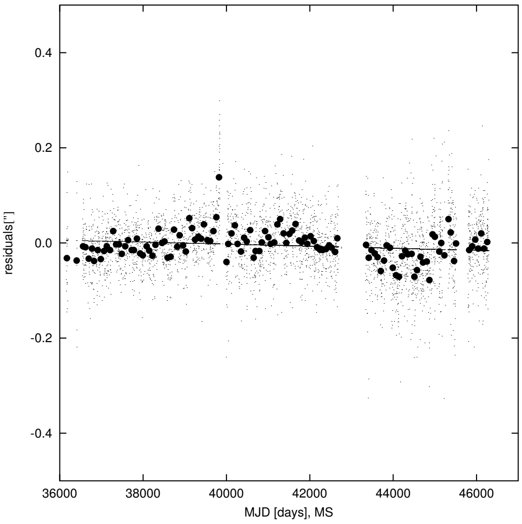

Fig. 4. *MS systematic changes: the dots r_n are the averaged values of r_i, one in about 1 year for every observed star, calculated linear trend – straight line, and averaged values of r_i ones per 0.2 years for all stars – black circles, with time (MJD).*

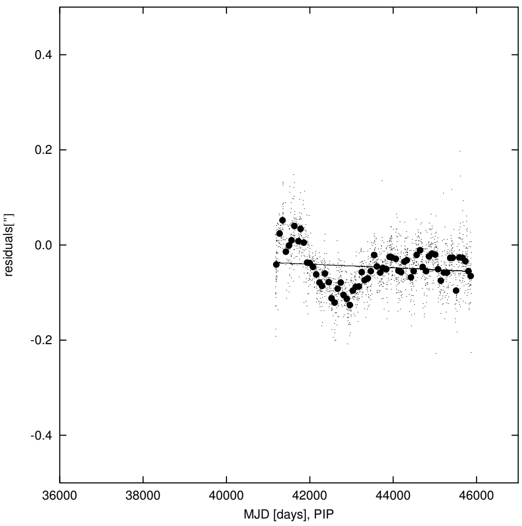

Fig. 5. *The same as in Fig. 4, but for PIP observations.*

2.3. Results

Comparing Figs. 1 and 9, 2 and 10, 3 and 11, the significant improvement is evident; from systematically shifted black – white points (first three figures) until agreement between them (last three figures).

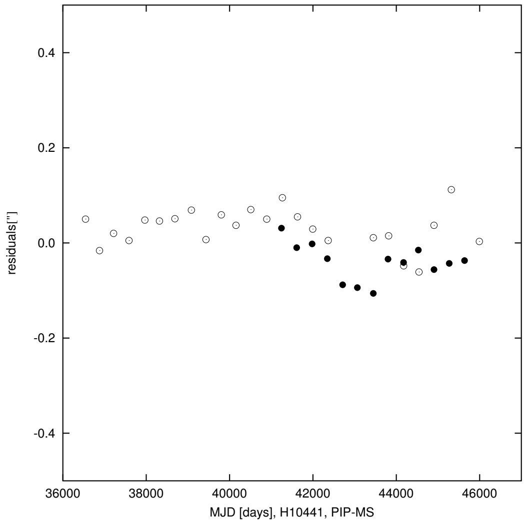

Fig. 6. *MS (white circles) and PIP (black circles) averaged residuals r_n changes with time (MJD) of HIPPARCOS star H10441.*

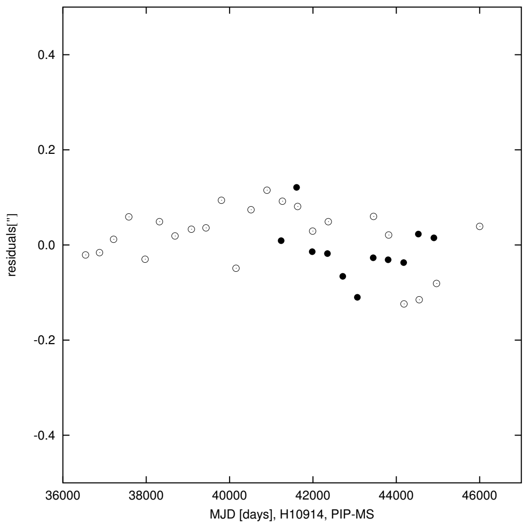

Fig. 7. *The same as in Fig. 6, but for the star H10914.*

The correction of proper motion in declination for each of the studied stars is equal to b, if the LSM is applied to the numerical values of white points for MS or black points for PIP (Figs. 9, 10 and 11), i. e. to the values r'_n for each star. The straight line fits for each star and instrument are presented in Figs. 9, 10 and 11, and in spite of different observation intervals covered with the two instruments the lines are nearly parallel to each other (see Figs. 9, 10 and 11 for H10441, H10914, H80391, respectively). The lines are nearly parallel because the b values for the two instruments are close to each other; consequently, the applied method yields similar results for two different instruments.

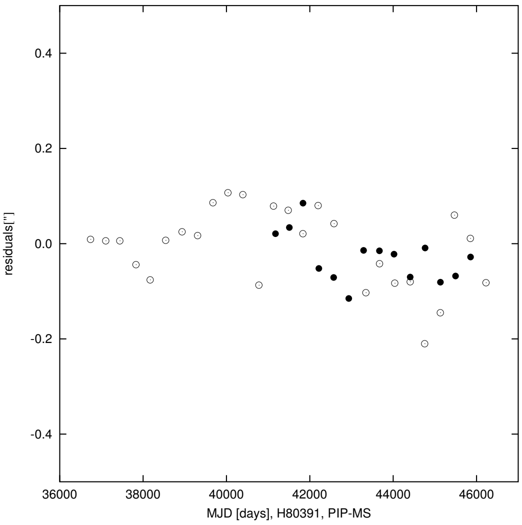

Fig. 8. *The same as in Fig. 6, but for the star H80391.*

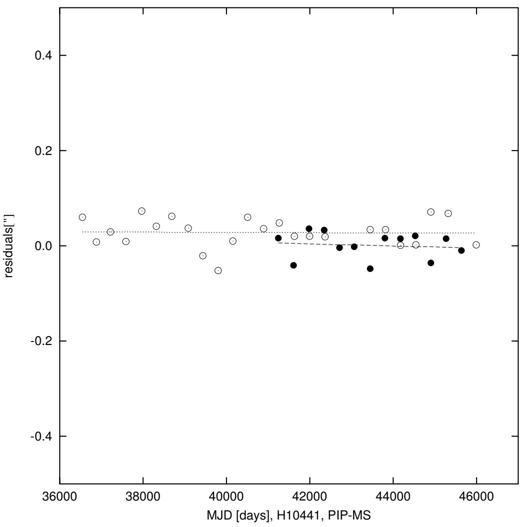

Fig. 9. *MS (white circles) and PIP (black circles) averaged residuals r'_n changes with time (MJD) for HIPPARCOS star H10441, and its linear trends.*

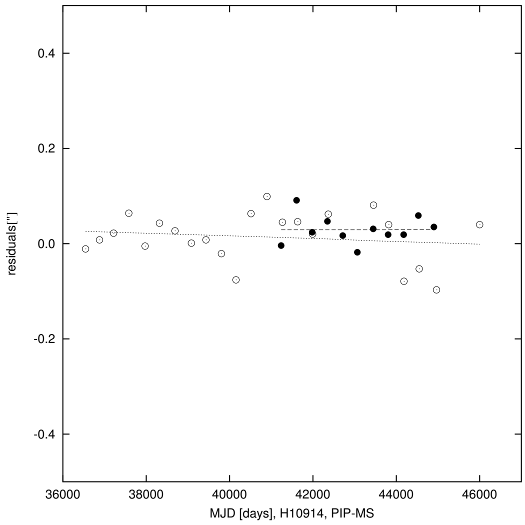

Fig. 10. *The same as in Fig. 9, but for the star H10914.*

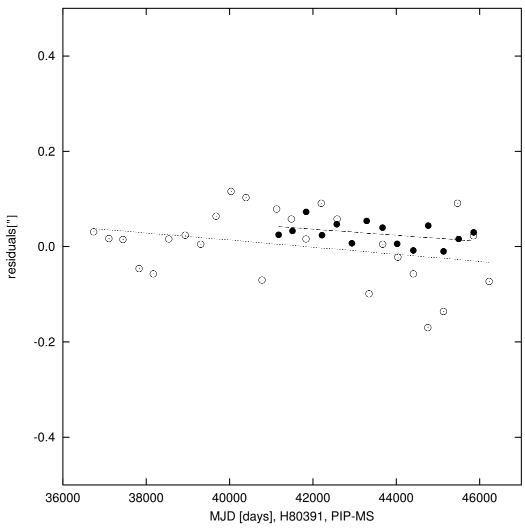

Fig. 11. *The same as in Fig. 9, but for the star H80391.*

The values b are calculated by using the LSM and according to the model

$$r'_n = a + b * (t_n - 1991.25), \quad (3)$$

with the results:
$b_{\rm MS} = -0.''0001/\text{year} \pm 0.''0008/\text{year}$ for the star H10441,
$b_{\rm PIP} = -0.''0008/\text{year} \pm 0.''0020/\text{year}$, H10441,
$b_{\rm MS} = -0.''0011/\text{year} \pm 0.''0014/\text{year}$, H10914
$b_{\rm PIP} = +0.''0001/\text{year} \pm 0.''0028/\text{year}$, H10914,
$b_{\rm MS} = -0.''0027/\text{year} \pm 0.''0018/\text{year}$, H80391,
$b_{\rm PIP} = -0.''0023/\text{year} \pm 0.''0014/\text{year}$, H80391.

For star H80391, the calculated values of b for both data sets (MS and PIP) are mutually consistent and the error is always less than the corresponding value of b. Thus, it is acceptable as the real correction of the HIPPARCOS proper motion in declination. This is not the case for the other two stars (H10441 and H10914, the values of b are very small and less than its own errors). In the cases of H10441 and H10914, it can be concluded that the corrections are nearly to zero.

3. CONCLUSIONS

As it was explained in the procedure of calculation and demonstrated with the results concerning three HIPPARCOS stars (H10441, H10914 and H80391), it is possible (for cases such as H80391 for example) to get the relevant corrections of proper motions in declination for some HIPPARCOS stars which were subject of ground-based PZT observations for a few decades (MS and PIP, here) or to confirm the HIPPARCOS data as it was done for H10441 and H10914. In any case, the database of ground-based observations with long history, as the Earth rotation programmes (with PZTs and other instruments data), is useful for the purpose of improving even modern satellite data, and can give us a better reference frame.

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ПРЕЦИЗНИЈА СОПСТВЕНА КРЕТАЊА У ДЕКЛИНАЦИЈАМА ХИПАРКОС ЗВЕЗДА ПОСМАТРАНИХ ФОТОГРАФСКИМ ЗЕНИТНИМ ТУБАМА

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Претходно саопштење

У раду је описан начин рачунања и представљени су добијени резултати побољшаних сопствених кретања у деклинацији Хипаркос звезда које су више деценија посматране фотографским зенитним тубама. Хипаркос мисија Европске астрономске агенције (ЕСА 1997) је трајала нешто краће од 4 године што се показује као ограничавајући фактор за прокламовану тачност сопствених кретања (углавном двојних и вишеструких) звезда. Током периода 1899.7-1992.0 рађени су посматрачки програми звезда посматраних у оквиру програма истраживања Земљине ротације који сада могу да се искористе за проверу и побољшање сопствених кретања Хипаркос каталога и референтног система.