Publ. Astron. Obs. Belgrade No. 90 (2010), 29 - 32 *Contributed Paper*

A BETTER REFERENCE FRAME BY USING IMPROVED PROPER MOTIONS OF SINGLE AND DOUBLE STARS

G. DAMLJANOVIĆ[1] and N. PEJOVIĆ[2]

[1]*Astronomical Observatory, Volgina 7, 11060 Belgrade 38, Serbia*
E–mail: gdamljanovic@aob.bg.ac.rs

[2]*Astronomy Department, Faculty of Mathematics,*
Studentski trg 16, 11000 Belgrade, Serbia
E–mail: nada@matf.bg.ac.rs

Abstract. We used the satellite Hipparcos observations and the ground-based observations (made during the last century of latitude variations), as our input data. The ground-based data were obtained with 26 instruments of observatories located all over the world, and the observed stars were included in the programs used for the Earth's rotation study. Now, with these ground-based observations we can improve the Hipparcos proper motions. So, the ground-based data of mentioned stars were used here, if these stars are contained in the Hipparcos Catalogue. The goal of our investigations was to improve the proper motions in declination of stars (which were observed ground-based and from the Hipparcos Catalogue), and thus to improve the reference frame, because the Hipparcos Catalogue is the optical counterpart of the International Celestial Reference Frame (ICRF). There is a large number of ground-based observations per year of each of the mentioned stars. Also, the observed time intervals of these stars are usually much longer than the Hipparcos ones (the satellite mission lasted less than four years). So, it is possible to correct the Hipparcos proper motions. Our basic method (the linear fit for single stars) is adapted (the sinusoidal fit for double and multiple stars) and some results are presented here.

1. INTRODUCTION

The products of the Hipparcos satellite mission (ESA 1997) were the Hipparcos (HIgh Precision PARallax COllecting Satellite) and Tycho catalogues. They were linked to the ICRF and appeared in 1997 (after the XXIII GA of IAU in Kyoto), and since 1997 the Hipparcos Catalogue is considered the primary optical counterpart of ICRF. Also, one of decisions of the IAU GA in Kyoto was to adopt the ICRF as the realization of the ICRS (the International Celestial Reference System) from the beginning of 1998. After that, it was actual to check and correct the positions and proper motions of Hipparcos Catalogue stars using ground-based observations of these stars. On the other hand, in 1995 Commission 19 (Earth Rotation) of IAU established the Working Group on Earth Rotation in the Hipparcos Reference Frame (WG ERHRF), with Dr. Vondrák as the Head, to collect the optical observations of latitude and universal time variations. These observations were made from 1899.7 to 1992.0; they were in line with the Earth orientation programmes and were used to derive the Earth Orientation

Parameters (EOP). During a few years, the WG ERHRF collected about 4.4 million observations. The data were from 33 observatories all over the world; there were about 50 instruments (Vondrák et al. 1998).

The Hipparcos Catalogue contains 118218 stars brighter than magnitude 12, and the epoch of the catalogue is 1991.25; the positions are with an accuracy of the order of 1 marcsec at 1991.25 and the proper motions in $\mu_\alpha \cos\delta$ and μ_δ are with a standard error of about 1 marcsec/yr. Some star catalogues appeared after the Hipparcos one: the ARIHIP one, the Earth Orientation Catalogue (EOC-2), etc. The EOC-2 is with more accurate star positions and proper motions than the Hipparcos ones. Also, we did our investigations to improve the Hipparcos proper motions in declination. It is $\mu_\delta = \frac{\delta_1 - \delta_2}{t_1 - t_2}$ (Eichhorn 1974), where δ_1 and δ_2 are two positions (in the same system) of the same star for the epochs t_1 and t_2, respectively. The error of μ_δ is $\epsilon_{\mu_\delta} = \frac{\sqrt{\epsilon_1^2 + \epsilon_2^2}}{t_2 - t_1}$, where ϵ_1 and ϵ_2 are standard errors of δ_1 and δ_2, respectively. So, ϵ_{μ_δ} is proportional to $\frac{1}{t}$, and with a sufficiently long interval of observations we can get a very good accuracy ϵ_{μ_δ} (better than the Hipparcos one).

2. DATA

Shortly after appearing of the Hipparcos Catalogue, it was evident that there were some problems concerning the Hipparcos data. The accuracy of the data concerning single stars is better than that for double/multiple ones. There is a different accuracy of the data on different parts of the celestial sphere. The error of apparent position has attained about 19 mas until now; the influence of proper motions is linear in time from the moment 1991.25, and the value 19 mas is one order of magnitude larger than the average position error in the Hipparcos Catalogue. These reasons are enough to start with improving the Hipparcos proper motions. So, it is of importance to combine the satellite data (as the Hipparcos ones) with the ground-based ones.

The polar motion coordinates (x_i, y_i) for our calculations are from Vondrák's file EOPOA00.dat; the $MJD = JD - 2400000.5$ is Modified Julian Date. We used the latitude variations φ_i (Vondrák et al. 1998) which Dr. Vondrák sent us via private communication. The φ_i were obtained during the last century (1899.7 – 1992.0) and primarily used to derive the EOP. The several types of classical astrometric instruments were operating. They are the visual and floating zenith-telescopes (ZT and FZT), the visual zenith tube (VZT) and the photographic zenith tube (PZT). Also, we used the Hipparcos data. There are 2347 common ground-based/Hipparcos stars. The goal was to improve the Hipparcos proper motions in declination μ_δ of stars observed with these instruments. We used the data of 26 classical instruments (14 ZT, 1 FZT, 1 VZT and 10 PZT ones) located at 19 observatories. They are 6 PZT stations: Mizusawa-MZP/MZQ, Mount Stromlo-MS, Ondřejov-OJP, Punta Indio-PIP, Richmond-RCP/RCQ, Washington-WA/W/WGQ. Than 7 ZT stations of the International Latitude Service (ILS): Carloforte-CA, Cincinnati-CI, Gaithersburg-GT, Kitab-KZ, Mizusawa-MZZ, Tschardjui-TS, Ukiah-UK. The independent stations 1 FZT (Mizusawa-MZL), 1 VZT (Tuorla-Turku-TT) and 6 ZT: Belgrade-BLZ (Damljanović 1997), Blagoveschtschensk-BK, Irkutsk-IRZ, Poltava-POL, Pulkovo-PU/PUZ, Warsaw-VJZ. More about it are in (Vondrák et al. 1998) and in (Damljanović 2007).

3. METHOD AND CONCLUSIONS

In the beginning, the values of φ_i were used to study the terrestrial rotation (Vondrák et al. 1998, Ron and Vondrák 2001, Vondrák and Ron 2003). These ground-based observations (tens of years) lasted much longer than the Hipparcos ones (shorter than 4 years). The annual number of ground-based observations for every star is on the average several hundred. So, our value of ϵ_{μ_δ} can be less than the Hipparcos one though the Hipparcos accuracy of the star coordinates is by two orders of magnitude better than the one of the star coordinates following from the φ_i observations.

First, we removed the polar motion components $\Delta\varphi_i$, the systematic (local, instrumental) changes se_i with time, and get the residuals r_i' (Damljanović 2005, Damljanović and Pejović 2005). The $\Delta\varphi_i$ were calculated by using the Kostinski formula (Kulikov 1962) $\Delta\varphi_i = x_i \cos\lambda_W + y_i \sin\lambda_W$, where λ_W is the longitude (the west direction) of the observatory. The r_i' are with systematic catalogue effects which are of our interest here. For each star, the r_i'' are the averaged values of r_i' over subperiods of about 1 year (Damljanović et al. 2006, Damljanović and Pejović 2006). Then, we can use the LSM with the linear fit $r_i'' = a + b(t_i - 1991.25)$, and get the corrections b to the proper motions in declination for treated Hipparcos stars. The values t_i are the times (in years) corresponding to r_i''. The value a is the correction $\Delta\delta$ and b is the correction $\Delta\mu_\delta$; both are referred to the epoch 1991.25. The points r_i'' and the Hipparcos one (1991.25, 0.″0) are with the suitable weights (Damljanović et al. 2006). This procedure is valid for PZT (Damljanović and Pejović 2008, McCarthy 1970) and VZT observations, but for ZT and FZT ones there are some additional steps in order to obtain the values of a and b by using the observations of star pairs (Damljanović and Pejović 2006, Damljanović 2007, Damljanović 2008). For the case of a single star, we process star by star by using the LSM, and the input values r_i'' and (1991.25, 0.″0). We add our corrections b to the corresponding Hipparcos proper motions in declination. So, we obtain the values μ_δ and their standard errors; the results (as the catalogue of 2347 stars) are contained in PhD thesis (Damljanović 2007) and few published papers (Damljanović and Pejović 2006, Damljanović and Pejović 2008).

In the case of double or multiple stars, we get the model (for star by star procedure), as the second step of our calculations,

$$r_i''' = b' t_i' + A \sin(2\pi t_i'/P) + B \cos(2\pi t_i'/P), \tag{1}$$

where: the residuals $r_i''' = r_i'' - a$, the time $t_i' = t_i - 1991.25$, b' is the unknown correction to the Hipparcos proper motions in declination (close to the suitable values b), the amplitude $am = (A^2 + B^2)^{1/2}$ of periodic part. The periodic part is $am \cos(2\pi t_i'/P - F)$ with the period P and phase F (from the moment 1991.25). We have got three unknowns to calculate: b', A and B. The value P (in years) is from the interval $(2; 4m')$ with step $k = 1$ year, where m' is the number of the observed years. For each star we have got $(4m' - 3)$ different solutions of the unknowns b', A and B. We use the solution when the calculated curve is the best fit for the set of the input points (r_i''' and (1991.25, 0.″0)) and value P. That fit is for the case $\sigma_0 = min.$, where σ_0 is the root-mean-square error of differences between the calculated points and suitable input ones. Like that, we can determine the values P and F.

For the single stars with a sufficient number of observations, the newly obtained values of proper motions in declination (Damljanović 2007) are substantially more precise than those of the Hipparcos ones. Our results were compared with ARIHIP and EOC-2 data, and we found a good agreement (Damljanović et al. 2006, Damljanović 2007). For example, the value $b \pm \varepsilon_b$ for star H15334 is -0.44 ± 0.15 mas/yr, and it is $\mu_\delta = -17.13 \pm 0.15$ mas/yr. From EOC-2, it is $\mu_\delta = -17.29 \pm 0.12$ mas/yr, and from Hipparcos $\mu_\delta = -16.69 \pm 0.69$ mas/yr.

Conclusions: after removing all known effects (as the polar motion one and some local and instrumental errors) from the instantaneous latitude, the residuals are then used for our first step to calculate the corrections of the Hipparcos proper motions in declination by using the LSM with the linear fit. This step was good enough for the single stars results. The newly obtained values of proper motions in declination are substantially more precise than those of the Hipparcos Catalogue. It is because the time interval covered by the latitude observations (tens of years) is much longer than the Hipparcos one (less than four years), and because of the great number of ground-based observations made during this interval. The calculated results were compared with the ARIHIP and EOC-2 ones (Vondrák 2004) and we found a good agreement. For double and multiple stars, we developed the second step of our calculations using LSM with the sinusoidal curve. So, the Hipparcos proper motions can be improved by using together the Hipparcos data and the ground-based ones.

Acknowledgments

GD performed his work as a part of the Project No 146004 "Dynamics of celestial bodies, systems and populations" supported by the Ministry of Science and Technological Development of R. Serbia.

References

Damljanović, G.: 1997, The analysis of the variation of Belgrade latitude for the period 1949-1985, MSc Thesis, University of Belgrade.

Damljanović, G.: 2005, *Serb. Astron. J.*, **170**, 127.

Damljanović, G.: 2007, Improvement of accuracy of proper motions of Hipparcos Catalogue stars using optical latitude observations, PhD Thesis, University of Belgrade.

Damljanović, G.: 2008, *Planetary and Space Science*, **56**, 1896.

Damljanović, G., Pejović, N.: 2005, in the Proc. of the IAU Coll. Dynamics of Populations of Planetary Systems, Cambridge University Press, Cambridge, **197**, 471.

Damljanović, G., Pejović, N.: 2006, *Serb. Astron. J.*, **173**, 95.

Damljanović, G., Pejović, N.: 2008, *Serb. Astron. J.*, **177**, 109.

Damljanović, G., Pejović, N., Jovanović, B.: 2006, *Serb. Astron. J.*, **172**, 41.

Eichhorn, H.: 1974, Astronomy of star positions, Frederick Ungar Publ. Co. New York.

ESA: 1997, The Hipparcos and Tycho Catalogues, ESA SP-1200.

Kulikov, A. K.: 1962, Izmenyaemost' sirot i dolgot, Moskva.

McCarthy, D.D. : 1970, Reduction method and star positions for Washington and Richmond Photographic Zenith Tube, Master's Thesis, University of Virginia.

Ron, C., Vondrák, J.: 2001, in the Proc. of the Journées 2000 Systèmes de Référence Spatio-Temporels, ed. N.Capitaine, Observatoire de Paris, 201.

Vondrák, J.: 2004, *Serb. Astron. J.*, **168**, 1.

Vondrák, J., Pešek, I., Ron, C., Čepek, A.: 1998, Earth orientation parameters 1899.7-1992.0 in the ICRS based on the HIPPARCOS reference frame, Publ. of Astron. Inst. of the Academy of Sciences of the Czech R., **87**.

Vondrák, J., Ron, C.: 2003, in the Proc. of the Journées 2002 Systèmes de Référence Spatio-Temporels, eds. N.Capitaine and M.Stavinschi, Astr. Inst. of the Romanian Academy and Observatoire de Paris, 49.