AN IMPROVED OPTICAL REFERENCE FRAME FOR LONG-TERM EARTH ROTATION STUDIES

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ABSTRACT. The Earth orientation parameters, based on optical astrometry observations of latitude/universal time variations and the Hipparcos Catalogue, covering the interval 1899.7-1992.0, were determined in past years at the Astronomical Institute in Prague, in close cooperation with the Czech Technical University in Prague. During the solution we discovered that not all Hipparcos stars are suitable for such a long-term study; many of them proved to have large errors in proper motions, mostly due to their multiplicity and shortness of the Hipparcos mission. Eventually, we had to improve about 20% of the proper motions from the same observations that we used to estimate the Earth orientation parameters.

New catalogues have appeared recently that are based on the combination of the Hipparcos Catalogue with past ground-based observations: FK6, TYCHO 2, and most recently ARIHIP, being a selection of the Combination Catalogues FK6, GC+HIP, TYC2+HIP and HIP. We made the inventory of all stars observed in Earth orientation programs at 33 observatories during the 20th century, and found 4480 different stars. Out of these we construct the Earth Orientation Catalogue (EOC) that is basically given in the International Celestial Reference System (ICRS). Whenever possible, we take over the positions, proper motions, parallaxes and radial velocities from the following catalogues, in the order of their importance: ARIHIP (3023 stars), TYCHO 2 (1271 stars), and Hipparcos (140 stars); 46 stars were identified in none of them. However, not all of these stars are astrometrically excellent in the sense of the classification introduced by Wielen et al.; only 1982 belong to categories 1-3. The positions and proper motions of the remaining 2498 stars will therefore be thoroughly checked and, if necessary, improved on the basis of the latitude/universal time observations.

1. INTRODUCTION

During the past years, three different solutions of Earth orientation in the Hipparcos reference frame were derived, in close cooperation of the Astronomical Institute and Czech Technical University in Prague, all of them covering the interval 1899.7–1992.0:

1. Solution OA97 (Vondrák et al. 1998), based on observations made with 45 different instruments (48 series) located at 31 observatories. 4.32 million individual observations of latitude/universal time variations were used, and 11% of Hipparcos star proper motions and/or positions were corrected from the series of Earth orientation observations.

2. Solution OA99 (Vondrák et al. 2000), based on observations with 47 instruments (merged into 39 series, with the steps caused by different coordinates of the instruments located at the same observatory removed) at 33 observatories. 4.45 million observations were used, and 20% of Hipparcos star proper motions/positions were corrected. We increased the percentage of the corrections, by changing the statistical criteria, because we found that more stars are probably double than we originally expected.

3. Solution OA00, based on 47 different instruments (merged into 41 series, with slightly different steps in data removed) at 33 observatories. 4.44 million observations were used, 20% of the Hipparcos stars corrected.

The above mentioned corrections of Hipparcos proper motions/positions were applied because we had problems with double and multiple stars, whose motions are not linear.

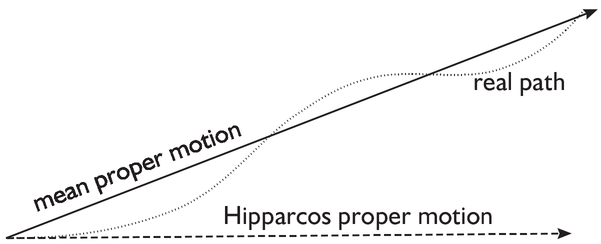

Figure 1: Real path of one of the components of a double star, mean and Hipparcos proper motion

The Hipparcos mission was shorter than 4 years, and therefore the Hipparcos proper motion reflect the instantaneous motion of one of the components of the star that is not suitable for extrapolation of the position to the epochs distant from the mean epoch of Hipparcos Catalogue (see Fig. 1). It was also sometimes not quite clear which of the components was observed in Earth orientation programmes – it might be different from the one for which the position and/or proper motion in the Hipparcos entry is given. These corrections were therefore computed and applied when found statistically significant, either to proper motions, or to positions or to both, for each instrument separately. The corrections were derived from the deviations of individual observations of the same star from 5-day average latitude/universal time values. Statistical criteria such as sufficient number of observations, length of the interval covered by the observations and the ratio of biases and/or drifts to the uncertainty in their estimations have been used.

These problems led us to the idea of creating a unique star catalogue consisting of all stars observed during the twentieth century in Earth orientation programmes. The catalogue is meant to be eventually used for future reanalysis of Earth Orientation Parameters from old optical observations. In order to do that we decided to utilize the catalogues that came out of the combination of observations both from space and ground. Quite naturally, the intensive astrometric observations of latitude/universal time made during the most of the last century at many observatories that we collected must not be abandoned in this work.

2. RECENT STAR CATALOGUES

New star catalogues, given in the Hipparcos reference frame, appeared recently. They are based on combination of space mission Hipparcos (Hipparcos and Tycho Catalogues) with older ground-based catalogues. Therefore, mainly the proper motions are improved since much longer time span covered by observations is used. They are as follows:

- **FK6** (Wielen et al. 1999, 2000) containing 878 basic and 3272 additional fundamental stars, these parts are denoted here as **F61** and **F63**, respectively. The catalogue was created from the combination of Hipparcos and FK5 catalogues;
- **TYCHO-2** (Høg et al. 2000) containing 2.5 million stars, here denoted as **TYC2**. Combination of Tycho with 144 ground-based catalogues was used to derive this catalogue;
- **GC+HIP** (Wielen et al. 2001a) containing 20 thousand stars, here denoted as **GCH**. It comes from the combination of Hipparcos with Boss' General Catalogue;
- **TYC2+HIP** (Wielen et al. 2001b) containing 90 thousand stars, here denoted as **T2H**. This is the combination of Hipparcos with proper motions from TYCHO-2;
- **ARIHIP** (Wielen et al, 2001c) containing 91 thousand stars. It is the selection of 'best' stars from above mentioned **FK6, GCH, T2H, HIP** catalogues.

Wielen et al. (1999) introduced the classification of the stars according to their 'astrometrical excellence' into three categories by assigning the number of asterisks to each star, and utilized it in their above mentioned catalogues. It goes from *** (highest rank) to * (lowest rank); no asterisk means that the star is probably a component of double or multiple system, and therefore not astrometrically excellent. In the following we use these catalogues, in combination with astrometric observations of latitude/universal time, to derive the new Earth Orientation Catalogue.

3. EARTH ORIENTATION CATALOGUE

First of all, we made an inspection of all optical data of Earth orientation programs available, and found 4480 different stars observed during 1899.7–1992.0 at 33 observatories. The distribution of these stars on the sky and the histogram of their magnitude distribution are displayed in Fig. 2. Its asymmetric character (due to the concentration of the observatories on northern hemisphere) is evident. These stars were then identified in the catalogues described in Section 2, and their catalogue entries (i.e., magnitudes, positions, proper motions, parallaxes and radial velocities) were taken over to the new Earth Orientation Catalogue (EOC), in the following order of importance:

1. **ARIHIP**, from which we took over the majority, i.e. 3023 stars;
2. **TYC2**, from which we took over 1271 stars;
3. **HIP**, from which we took over only 140 stars;
4. **XXX**, or 'local' catalogues (i.e., those used by the observatories and often improved from their own observations), from which we took over the remaining 46 stars that could be identified in none of the preceding catalogues.

This procedure, during which we searched for only the stars that had not been identified in the preceding step, assures that the most accurate positions/proper motions available in the most recent catalogues are used in the new catalogue.

The numbers of the stars in EOC are constructed in the following way:

- Hipparcos number is used if the star is contained in HIP and is either single or its component A was observed.

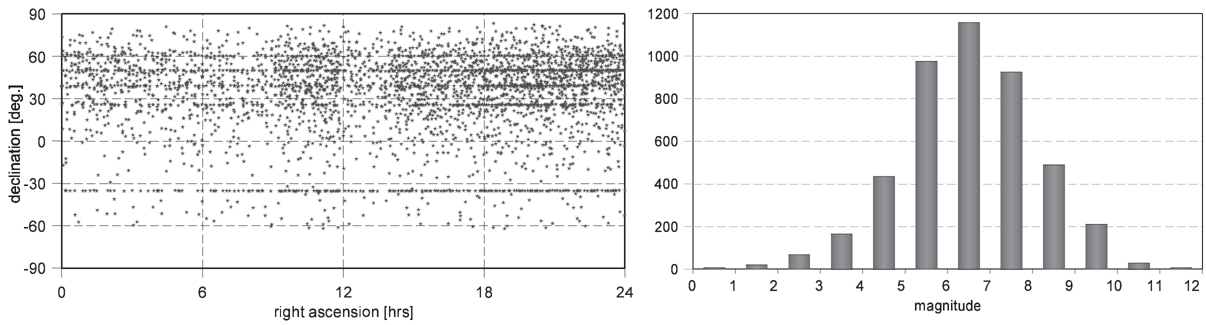

Figure 2: Distribution of EOC stars on the sky (left), and their magnitude distribution (right).

- Numbers 200001, 200002, ... for the stars that are not contained in Hipparcos Catalogue; there are only 107 such stars (61 being taken over from TYC2 and 46 from local catalogues).
- HIP number + 300000 for the stars that are contained in HIP but either photocenter or other component than A is observed. Number of these stars is not exactly known at the moment, it will gradually increase as the positions of 'astrometrically not excellent' stars are checked against the observations (see below).

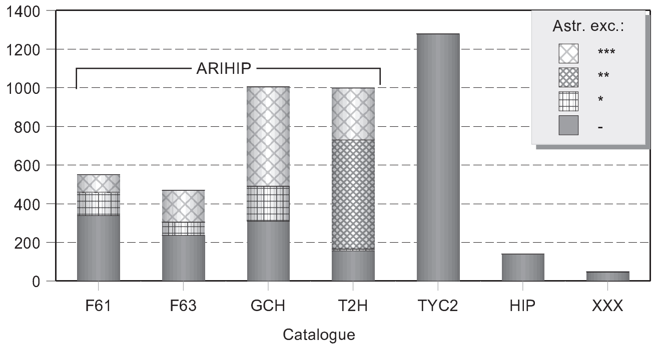

Figure 3: Catalogue of origin and 'astrometrical excellency'.

The origin of EOC entries is shown in Fig. 3, where a more detailed statistics is given – the entries taken over from ARIHIP are further subdivided into the four original subcatalogues of ARIHIP (F61, F63, GCH, and T2H). The statistics of the astrometric excellence classification is also depicted, in different textures (see legend). Out of the total number of 4480 stars, only 1982 are classified as 'astrometrically excellent', with one of the categories *, **, ***. Obviously, the majority of EOC stars that are not 'astrometrically excellent' require a thorough check of their positions and proper motions, and probably an improvement of many of them. To achieve this, two possible methods are presently under consideration:

- Simpler method, similar to the one that we used in our previous work: each observation of the star in question is used to determine its position with respect to 'astrometrically excellent' stars at each night, for each instrument separately. Then the observations of the same star at different epochs from all observatories are put together, Hipparcos position with a proper weight is added (only if the component observed is identical with the entry in Hipparcos Catalogue), and if the difference is statistically significant the position/proper motion is determined by linear regression.
- More complicated method, consisting in the application of a modified chain method (Vondrák 1980) that is used to determine positions and proper motions of all stars observed

by each instrument, alternatively in combination with properly weighted Hipparcos positions (Ron & Vondrák, this volume). These 'local' catalogues are then tied to the ICRS via 'astrometrically excellent' stars, and the catalogue entry for the same star combined from all individual instruments.

The following three examples demonstrate some typical cases that we can meet when checking the 'non-excellent' stars. All of them are based on the observations with PZT's at Richmond, Florida. The first above mentioned method was used, and the corrections of positions and proper motions with respect to original catalogues, referred to J2000.0, are shown.

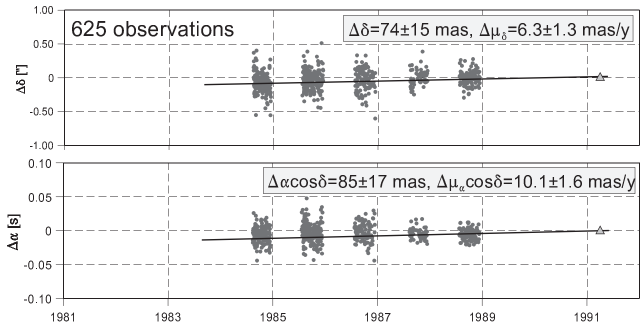

Figure 4: Richmond PZT observations of the star EOC716.

The first example (Fig. 4) shows the case of the star EOC716, whose entry comes from T2H catalogue (mag=6.2, $\alpha = 0^h 08^m 52.13633^s$, $\delta = 25°27'46.7454''$), that can be constrained to Hipparcos position. It is most probably a single star, whose proper motion nevertheless require a correction. PZT observations (small circles) are combined with the position in the Hipparcos Catalogue at the epoch J1991.25 (triangles). In linear regression (full line), all individual PZT observations are given weights equal to 1, while the Hipparcos position is assigned the weight of 1000, reflecting its superior accuracy. This practically assures the constraint to the position in the Hipparcos Catalogue at its mean epoch. The corrections of proper motion evidently exceed their formal uncertainties.

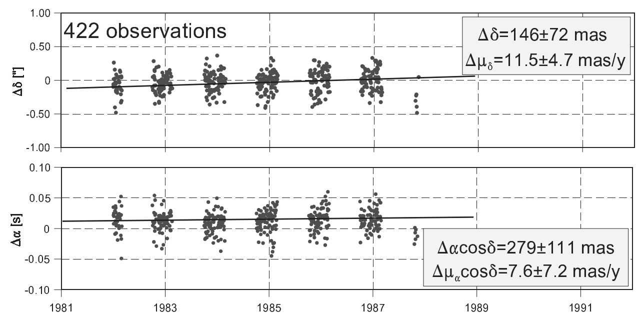

Figure 5: Richmond PZT observations of the star EOC326947.

The second example, depicted in Fig. 5, shows the case when not only proper motion but also position of the star requires a correction. Double star HIP26947 (angular distance of the components is 2.67″, according to Hipparcos), whose entry comes from TYC2 catalogue and refers to component A (mag=8.6, $\alpha = 5^h 43^m 03.18405^s$, $\delta = 25°21'47.6756''$), was probably seen as a single star on PZT photographic plate, and its photocenter was measured. The full black regression line fitted to individual observations obviously does not intersect the baseline at the epoch 1991.25. The star number becomes EOC326947 if these corrections, witnessing that the observed object is different from component A, are confirmed by observations made at other observatories.

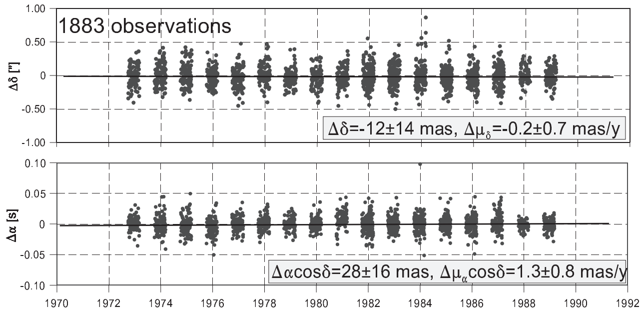

Figure 6: Richmond PZT observations of the star EOC200028.

The third example is shown in Fig. 6. It demonstrates the case of the star whose entry, that was taken over from the TYC2 catalogue, does not require a correction. The star is not contained in the Hipparcos Catalogue, and therefore it was given a new number EOC200028. Neither the position nor the proper motion of the star (mag=8.0, $\alpha = 6^h05^m05.59794^s$, $\delta = 25°48'03.3309''$), as given in TYC2 catalogue, evidently require a correction, as can be seen from the full black regression line fitted to individual observations; the corrections found are quite comparable with their formal uncertainties and are therefore statistically insignificant.

4. CONCLUSIONS

The new Earth Orientation Catalogue is being constructed that will hopefully be more accurate than the Hipparcos catalogue, in a long-term sense. To this end, the combination of ground-based optical observations in Earth orientation programmes with space observations (Hipparcos, Tycho) will be used to improve proper motions of some of the stars that are not 'astrometrically excellent' in Wielen's sense. The EOC, when finished, is planned to be used in a newly prepared solution of Earth Orientation Parameters from optical astrometry in the interval 1899.7–1992.0.

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