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The Tycho Reference Catalogue ⋆

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Abstract. The Tycho Reference Catalogue (TRC) contains high-quality positions and proper motions for 990 182 stars of the Tycho Catalogue. The proper motions were derived from Tycho positions and Astrographic Catalogue positions reduced to the Hipparcos system. The median accuracy of the TRC position components is 40 mas at J1991.25. The median precision of the proper motion is about 2.5 mas/yr . Systematic errors are less than about 1.0 mas(/yr). The quality of the proper motions in TRC is assessed by comparison with the Hipparcos and Tycho Catalogues. Comparison with the recent ACT Catalogue which is based on an independent reduction of the same observations as used for the TRC is reported.

Key words: astrometry – reference catalogues – proper motions – Astrographic Catalogue – Tycho Catalogue

1. Introduction

The Tycho Reference Catalogue (TRC) is presented, containing high-quality positions and proper motions for 990 182 stars of the Tycho Catalogue. It is suited as a source of astrometric reference stars and of proper motions for galactic kinematic studies. The catalogue is made available from the CDS.

The proper motions were derived from Tycho positions and Astrographic Catalogue (AC) positions reduced to the Hipparcos system. This undertaking was envisaged when the Tycho project was proposed (Høg et al. 1982) and was elaborated later on (Röser & Høg 1993). The resulting TRC Catalogue contains between 4 and 117 stars per square degree, depending on galactic latitude.

A new reduction of all Tycho observations is progressing which will result in a Tycho2 Catalogue (Høg 1997) with about 2.5 million stars, including proper motions derived from the AC positions. In parallel, a second version of TRC, the TRC2, is in preparation for which a more accurate (block-adjustment) reduction of the AC will be applied (Kuimov 1997; Kuzmin et al. 1997b).

The progress in terms of size and quality of astrometric reference catalogues during the recent years is illustrated in Table 1. The catalogues are listed in their sequence of publication, including those expected in the near future.

Table 1. Astrometric reference catalogues. Date of publication, number of stars, and median precision at the Hipparcos epoch of 1991.25 are given. Systematic errors are about 150 mas and 2.5 mas/yr for the PPM and ACRS, but less than 1 mas and 1 mas/yr for the catalogues based on Hipparcos.

Name	Date	N stars	$\sigma_{\rm pos}$ mas	$\sigma_{\rm pm}$ mas/yr
SAO	1966	260 000	1 000	10
ACRS	1991	320 000	200	5
PPM	1991	469 000	200	4
HIP	June 1997	120 000	0.8	0.9
TYC	June 1997	1 060 000	40	40
ACT	Sep. 1997	989 000	40	∼2.5
TRC	April 1998	990 000	40	∼2.5
Tycho2	1999	2 500 000	100	∼2.5
TRC2	2000	2 500 000	100	∼2.5

The SAO, ACRS and PPM catalogues are based on meridian and photographic observations. The PPM (Röser & Bastian 1991, Bastian et al. 1993) included, for the first time, the century-old Astrographic Catalogue observations. This catalogue actually comprises about two dozen catalogues of positions at mean epoch B1905.0, containing 8.6 million photographic observations of about 4.5 million stars brighter than $B = 12.5$. The observations were only available in printed volumes until the Sternberg Astronomical Institute (Nesterov et al. 1990, Kuzmin et al. 1997a) and, in parallel, the US Naval Observatory in 1987–1994 produced their machine readable versions. Independent reductions of the data sets onto the ICRS/Hipparcos system were recently performed (Kuzmin et al. 1998, Urban et al. 1998a).

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⋆ Based on observations made with the ESA Hipparcos astrometry satellite, and on work by the Tycho Consortium in collaboration with the INCA, FAST and NDAC Consortia.

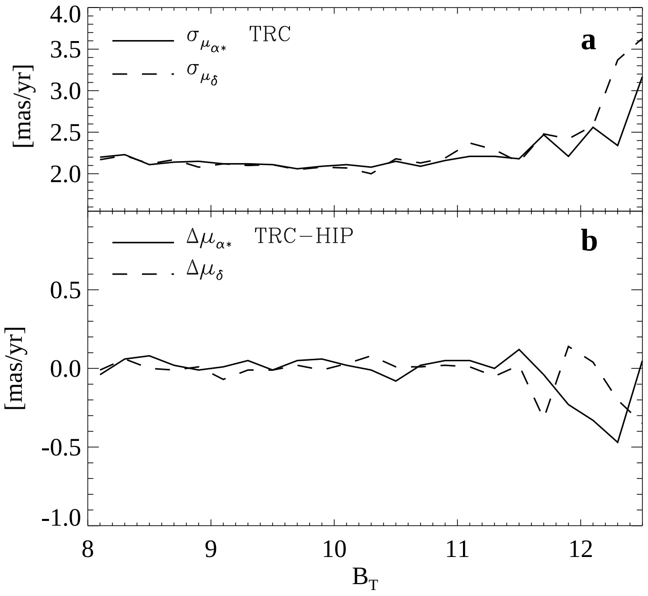

Fig. 1. Precision and systematic differences of TRC proper motions relative to HIP for 93 078 common stars as functions of the Tycho blue magnitude, B_T. **a** Precision; **b** Systematic differences. Abbreviation: $\mu_{\alpha*} = \mu_\alpha \cos\delta$.

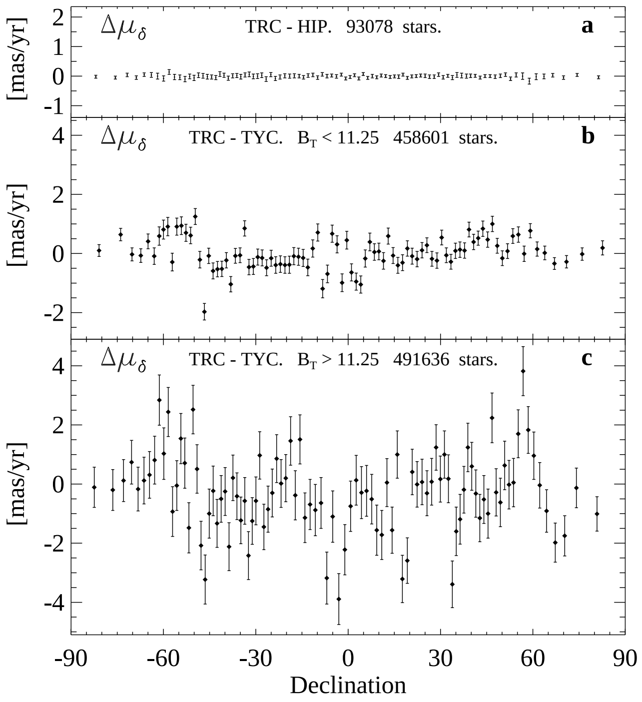

Fig. 2. Systematic differences of the proper motion μ_δ in TRC, as function of declination. **a** TRC–HIP for 93 078 mostly bright stars; **b** TRC–TYC for the 458 601 stars with $B_T < 11.25$ mag; **c** TRC–TYC for the remaining fainter 491 636 stars.

The Astrographic Catalog Reference Stars, ACRS (Corbin & Urban 1991) was prepared especially for the planned re-reduction of the AC and therefore did not include that data set, as PPM did. The ACRS was also exploited in the construction of the TRC (see Sect. 2.1), because HIP does not provide a sufficient density of stars.

The Hipparcos and Tycho Catalogues, HIP and TYC, (ESA 1997) provide a much more accurate coordinate system of positions and proper motions. They were immediately exploited to improve the positional coordinate system of the AC and in combination with the Tycho positions to produce the proper motions contained in the 'Astrographic Catalog and Tycho' (ACT) catalogue (Urban et al. 1998b) and TRC.

The comparison in Sect. 3 of the proper motions in TRC with those in ACT and with the proper motions in the Hipparcos and Tycho Catalogues assesses its quality as far as presently possible. A truly external comparison is not possible, but the comparison with the TYC proper motions is of particular interest because these did not contribute to the construction of TRC. The comparison with ACT illustrates, only too well, the occasional ambiguities in identifying TYC stars in the AC, which in spite of all efforts have lead to errors in either ACT or TRC.

Positions published in TRC are given for the epoch J2000.0. They were derived by applying proper motion for the short time interval between J2000.0 and the respective weighted mean epoch. The mean epochs are typically about 1987, quite close to the Tycho epoch, J1991.25, because the Tycho position was assigned a much higher weight in the adjustment than the AC positions. TRC positions calculated for the TYC epoch will not quite coincide with the TYC positions. The difference is generally below 2 mas, but larger differences, supposedly improvements of TYC, of about $\sigma_{\rm TYC}$, may occur when a star has two or more widely separated AC epochs. The median external standard error of positions in TRC at J1991.25 is the same as for TYC, i.e., about 40 mas.

2. The Tycho Reference Catalogue

2.1. Construction of the catalogue

The construction of the TRC shall here be described only briefly, the details to be given elsewhere (Kuzmin et al. 1998).

In order to ensure a safe identification of stars between the AC and TYC, stars with uncertain magnitudes and positions in TYC were rejected as well as stars with large significant proper motions, leaving a subset of 1 018 531 stars for the further processing.

The 22 652 Astrographic Catalogue plates were reduced onto the Hipparcos system with the method of zone-specific a-posteriori corrections (Kuzmin et al. 1997b) by means of the ACRS and HIP. A preliminary investigation of ACRS (Kuzmin et al. 1997b) using HIP revealed

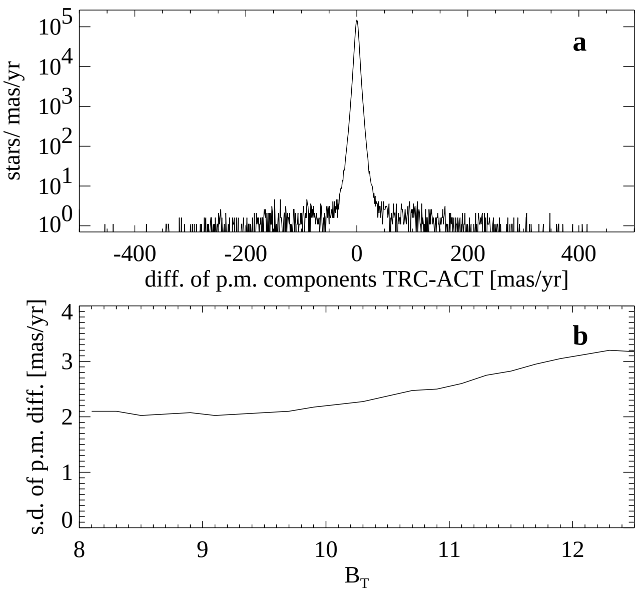

Fig. 3. Comparison between TRC and ACT proper motions. **a** distribution of differences (note logarithmic scale!); **b** standard deviation of the differences.

significant systematic errors, which had to be corrected before it could be used in the plate reductions. The residuals after a first reduction with a linear plate model were analyzed for significant plate-scale systematic terms. In a second step these terms were also solved for, again using the ACRS, and averaged for each zone. In the third step all the systematic effects were applied as known corrections, and reduction with the linear reduction model was performed again, but now using Hipparcos as the reference catalogue. 46 AC plates for which Hipparcos did not provide the necessary minimum number of reference stars were reduced onto the corrected ACRS.

Preliminary proper motion residuals, TRC-HIP, were analyzed in each zone for magnitude equation and the three step reduction was repeated if necessary. Finally, the resulting proper motions were again compared with the proper motions in the Hipparcos Catalogue and a residual magnitude equation, now as a function of declination rather than just zone, of up to about 0.5 mas/yr/mag, were found by a robust method. This correction was applied to obtain the final TRC.

Colour-dependent terms were also investigated, but were found to be negligible compared with the magnitude equation.

In summary, the ACRS was brought to the Hipparcos system and used together with HIP to bring AC as close as possible to HIP. In contrast, the AC reduction for the ACT relied strongly on the original ACRS and only made the transition to HIP as a last correction.

The matching of the resulting positions for each plate with stars in TYC did not use any proper motion, but assumed an upper limit of 180 mas/yr to define the size of the search window. Cases of doubt were resolved, if possible, by means of the magnitudes given in the two catalogues. Thus, no kinematic bias was introduced, as could happen e.g. if the closest candidate had been chosen. The price to pay is that high proper motion stars are excluded from TRC, but they will often be HIP stars and already have good proper motions. This strategy is very different from the one used for the ACT, which used TYC proper motions and relied on astrometry rather than photometry.

The proper motions were constructed from one TYC position and typically 2–3 AC positions using a weighted least squares fit. Unexpectedly poor fits led to the rejection of 13 152 stars the most likely reason being erroneous identification at one of the AC epochs.

Due to the specifics of the TRC proper motion derivation, based on two close AC epochs and TYC, internal proper motion error estimates provided by the least-squares adjustment account mostly for the random error of proper motions. Based on a comparison with Hipparcos, 1.6 mas/yr was added quadratically to account for residual systematic errors and thus derive an estimate of the external errors.

2.2. Content of the catalogue

The TRC content is precisely described in connection with its distribution through the CDS. Briefly, the catalogue contains for each star: the TYC identifier, position and proper motion referred to the International Celestial Reference System, ICRS, (Feissel & Mignard 1998) along with the respective standard errors. Furthermore, the TYC magnitudes (B_T, V_T) and various flags are given.

3. Verification and quality assessment

The positions of TRC are practically identical to the TYC positions at epoch 1991.25 as already discussed in Sect. 1. The TRC proper motions need, however, an assessment of their quality with respect to random and systematic errors. Presently only three catalogues are suited for this purpose: HIP, TYC and ACT none of which being strictly external to TRC. Based on the quality of the Astrographic Catalogue and the epoch difference to TYC of some 85 years, one cannot hope for a better precision than about 2.5 mas/yr.

3.1. Comparison with the Hipparcos Catalogue

The Hipparcos Catalogue was the primary reference catalogue for TRC and a strong correlation between TRC and HIP proper motions must be expected. Fig. 1 shows the precision and systematic differences of TRC relative to HIP as function of the Tycho blue magnitude, B_T. Robust estimates have been used. The errors in Fig. 1a were obtained as one half the difference between the 84th and the 16th percentiles in the distribution function corrected for the contribution from HIP, and the systematic differences in Figs. 1b are obtained as median values. The precision of about 2.2 mas/yr which follows from Fig. 1 cannot be expected to represent a valid estimate for the non-Hipparcos stars.

3.2. Comparison with the Tycho Catalogue

The Tycho proper motions were not used in the construction of TRC and constitute the best source for estimating the systematic errors of the TRC proper motions. Such a comparison will be dominated by the rather low precision of the TYC proper motions of about 40 mas/yr, but this is partly compensated by their large number and very small systematic errors with respect to HIP (cf. Fig. 18.3 of Vol. 4 of ESA 1997). Figure 2 shows the systematic differences, TRC–TYC, of μ_δ as a function of declination for stars common to TRC and ACT. Each point represents the trimmed mean value for 5000 stars. The figure confirms that systematic errors, as function of declination or magnitude, are generally below 1 mas/yr, at least for $B_T < 11$. A minor part of the small trends as function of declination common for Figs. 2b and 2c (of the order 0.5 mas/yr) may be due to errors in the Tycho proper motion system, but AC is probably the main contributor. The corresponding diagrams (not shown) for $\mu_{\alpha *}$ look similar. We conclude that the systematic errors of TRC proper motions are less than about 1.0 mas/yr. For the faintest stars, however, we cannot rule out larger systematic errors, up to 2.5 mas/yr. This is indicated by the differences between Figs. 2b and 2c because a magnitude effect is more likely in AC than in TYC.

3.3. Comparison with the ACT catalogue

The TRC and the ACT catalogues have the same aim and are based on the very same observational material, but different strategies were adopted for the reduction of the AC material, the cross identification between TYC and AC and also the initial selection of TYC stars. A comparison between ACT and TRC is of interest because it can tell about errors introduced by the adopted plate models and also errors in the cross identifications.

Although TRC and ACT both contain about 990 000 stars, they have only 950 290 stars in common. The ACT contains 38 468 stars not in TRC and TRC contains 39 892 stars not in ACT. These latter are flagged in TRC.

The distribution of differences between TRC and ACT proper motion components is shown in Fig. 3a and the standard deviation in Fig. 3b. The standard deviation, of about 2.65 mas/yr, exceeds the internal standard errors of either catalogue and demonstrates, without the least mercy, the immense importance of the reduction model used. More than 19 000 stars (2 per cent) differ more than 10 mas/yr in either $\mu_{\alpha *}$ or μ_δ (flagged in TRC) and a few differ even by more than 400 mas/yr. This clearly demonstrates the difficulties involved in spanning up to 100 years in a cross identification, which could have been ameliorated by including observations from more epochs.

4. Conclusions

We have presented a new large reference catalogue, the Tycho Reference Catalogue, providing an accurate, dense and stable realization of the ICRS/Hipparcos system. External errors in proper motions are below 2.5 mas/yr and internal errors are of the same size. A sequel, the TRC2, of 2.5 million stars is in progress and a first version, Tycho2, will appear in 1999.

Acknowledgements

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