Astron. Astrophys. 360, 391–398 (2000)

ASTRONOMY AND ASTROPHYSICS

The Hipparcos, Tycho, TRC, and ACT catalogues

A whole sky comparison of the proper motions

R. Hoogerwerf[1] **and A. Blaauw**[1,2]

[1] Sterrewacht Leiden, Postbus 9513, 2300 RA Leiden, The Netherlands
[2] Kapteyn Instituut, Postbus 800, 9700 AV Groningen, The Netherlands

Received 3 November 1999 / Accepted 14 April 2000

Abstract. We present a whole sky comparison of the proper motions contained in the Hipparcos Catalogue, the Tycho Catalogue, the Tycho Reference Catalogue (TRC), and the Astrographic Catalogue plus Tycho Reference Catalogue (ACT). The catalogues are compared in the 20 declination zones defined by the original Carte du Ciel project. We find that (1) the proper-motion errors in the ACT Catalogue are underestimated in all zones, sometimes by as much as 30%. (2) There are systematic differences, as large as 1.2 mas yr^{-1}, between the proper motions in the TRC and ACT depending on the zone. We confirm the known underestimation of the proper-motion error (by as much as 40%) of the faint stars ($B_T > 10$ mag) in the Tycho Catalogue.

Key words: catalogs – astrometry – reference systems

1. Introduction

Accurate and reliable astrometric data are of crucial importance in many fields of Galactic astronomy. Any study which covers an area on the sky larger than a few tens of square degrees (the typical size of a photographic plate), or which needs absolute proper motions, might suffer from unknown systematic effects in data sets which are not absolute and coherent over the entire sky. These studies include, for example, investigations of the stellar kinematics and dynamics in the Solar neighbourhood (see, e.g., Dehnen & Binney 1998), the search for extended moving groups (see, e.g., Chereul et al. 1998 and de Zeeuw et al. 1999), and the search for Galactic halo streamers (Helmi et al. 1999). For such studies the reliability of the conclusions depend sensitively on the quality of the astrometric data.

In this paper we discuss a comparison of the proper motions in four all-sky astrometric catalogues: the Hipparcos Catalogue (HIP) (ESA 1997), the Tycho Catalogue (TYC) (ESA 1997), the Tycho Reference Catalogue (TRC) (Kuzmin et al. 1999), and the Astrographic Catalogue plus Tycho Reference Catalogue (ACT) (Urban et al. 1998). This study was triggered by the discrepancies in proper motions between these astrometric catalogues found by Hoogerwerf (2000) in a study of astrometric membership determination of moving groups using the TRC and ACT catalogues.

Send offprint requests to: R. Hoogerwerf
Correspondence to: hoogerw@strw.leidenuniv.nl

2. Catalogues

2.1. Hipparcos and Tycho

The HIP and TYC catalogues are the culmination of the Hipparcos astrometry satellite project. Hipparcos had a mission lifetime of ~four years and ended its observations in 1993. The HIP Catalogue contains high-precision astrometry (~1 mas in position and parallax and ~1 mas yr^{-1} in proper motion) for $118\,218$ stars. The catalogue is complete to $V \sim 7.3$ mag and has a magnitude limit of $V = 12.4$ mag. In contrast, the accuracy of the TYC Catalogue is only ~25 mas(yr^{-1}) for position, parallax, and proper motion. However, it consists of $1\,058\,332$ stars, is complete to $V_T \sim 10.5$ mag, and has a magnitude limit of $V_T = 11.5$ mag. The V_T band is one of the two broad-band photometric filters of the Tycho experiment, and is similar to the Johnson V filter. A comprehensive description of the satellite and the construction of the catalogues can be found in ESA (1997).

2.2. TRC and ACT

The "Tycho Reference Catalogue" (TRC) and the "Astrographic Catalogue plus Tycho Reference Catalogue" (ACT) both combine the positional information in the Astrographic Catalogue (Epoch ~1910) with that in the Tycho Catalogue (Epoch 1991.25) to obtain proper motions. The Astrographic Catalogue is the result of the Carte du Ciel project, started at the end of the 19$^{\rm th}$ century, with the goal of constructing an all-sky astrometric catalogue complete to photographic magnitude $m_{\rm pg} = 11$ mag (see, e.g., Eichhorn 1974, Débarbat et al. 1988, and Urban & Corbin 1998). Twenty different observatories participated in this enormous project, each covering its own strip in declination. The TRC Catalogue was constructed by a European consortium (Kuzmin et al. 1999) and the ACT Catalogue by the U.S. Naval Observatory (Urban et al. 1998). Each consortium constructed its own machine-readable version of the Astrographic Catalogue from the 254 printed volumes of raw data. They then used standard photographic-plate reduction techniques to produce a version of the Astrographic Catalogue on the International Celestial Reference System (ICRS) (i.e., the Hipparcos reference system, see also ESA 1997). The mean epoch of the Astrographic Catalogue is ∼1910. The positions in the Astrographic Catalogue were combined with the Tycho positions of epoch 1991.25 to obtain proper motions. The AC position for a star situated in an overlap region between two adjacent zones is the average of the positions in both zones. The exact details of this entire procedure differ between the two consortia.

The TRC and ACT list proper motions with an accuracy of ∼3 mas yr^{-1} for $990\,182$ and $988\,758$, respectively. Note that *proper motions* in Right Ascension listed in the ACT Catalogue are **not** multiplied by $\cos\delta$ (where δ is the declination) while the *proper-motion errors* in Right Ascension **are** multiplied by $\cos\delta$ (Urban 1999).

2.3. Tycho 2

A new version of the Tycho Catalogue, the Tycho 2 Catalogue, was released in February 2000. Through a careful re-analysis of the raw Tycho data it was possible to more than double the number of stars in the Catalogue to 2.5 million stars (Høg et al. 2000a, 2000b). The proper motions on the Tycho 2 Catalogue have been constructed in a similar manner as for the TRC and ACT catalogues. The main difference between the TRC/ACT and Tycho 2 is that besides the Astrographic Catalogue, 143 other transit and astrographic catalogues have been used to obtain the proper motions (see Høg et al. 2000b). The average accuracy of the proper motions is ∼2.5 mas yr^{-1}.

Although the TRC and ACT have now been superseded, we feel that a comparison of these catalogues with the Hipparcos Catalogue is warranted. Both the TRC and ACT have been used extensively and an assessment of the quality of these catalogues will help interpreting the results of these studies. We do not discuss the Tycho 2 catalogue in this paper.

3. Comparison

3.1. Method

We compare the proper motions in the different catalogues by examining the normalized proper-motion difference in Right Ascension (RA) and Declination (Dec) for each pair of catalogues. We define the normalized proper motion difference as

$$\Delta_{x,y} = \frac{\mu_x - \mu_y}{\sqrt{\sigma^2_{\mu_x} + \sigma^2_{\mu_y}}}, \tag{1}$$

where μ_x and μ_y are the proper motions in either RA or Dec in catalogues x and y, respectively, and σ_{μ_x} and σ_{μ_y} their respective errors. We now introduce $F_x(\mu_x)$ which gives the probability of observing the proper motion μ_x when the real proper motion is $\hat{\mu}_x$ and the real proper-motion error is $\hat{\sigma}_{\mu_x}$. We define $F_x(\mu_x)$ to be a Gaussian with a mean $\hat{\mu}_x$ and a standard deviation $\hat{\sigma}_{\mu_x}$. Similarly we define $F_y(\mu_y)$ to be a Gaussian with a mean $\hat{\mu}_y$ and a standard deviation $\hat{\sigma}_{\mu_y}$. Under the assumption that μ_x and μ_y are independent realizations of the same proper motion we find that the mean of $\Delta_{x,y}$ is

$$\bar{\Delta}_{x,y} = E(\Delta_{x,y}) = \frac{\hat{\mu}_x - \hat{\mu}_y}{\sqrt{\sigma^2_{\mu_x} + \sigma^2_{\mu_y}}} = 0, \tag{2}$$

because $\hat{\mu}_x = \hat{\mu}_y$ (the real proper motion of the same star). For the standard deviation of $\Delta_{x,y}$ we find

$$\sigma^2_{\Delta_{x,y}} = E([\Delta_{x,y} - E(\Delta_{x,y})]^2) = \frac{\hat{\sigma}^2_{\mu_x} + \hat{\sigma}^2_{\mu_y}}{\sigma^2_{\mu_x} + \sigma^2_{\mu_y}}, \tag{3}$$

which should equal unity when the quoted errors σ_{μ_x} and σ_{μ_y} in the catalogues reflect the real errors $\hat{\sigma}_{\mu_x}$ and $\hat{\sigma}_{\mu_y}$, respectively. However, when the proper-motion errors in catalogue y are over- or underestimated by a factor q, i.e., $\sigma_{\mu_y} = q\hat{\sigma}_{\mu_y}$ (assuming that $\sigma_{\mu_x} = \hat{\sigma}_{\mu_x}$), $\sigma_{\Delta_{x,y}}$ is not equal to unity and q can be expressed as,

$$q = \frac{\sigma_{\mu_y}}{\sqrt{\sigma^2_{\Delta_{x,y}}(\sigma^2_{\mu_x} + \sigma^2_{\mu_y}) - \sigma^2_{\mu_x}}}. \tag{4}$$

The normalized proper-motion difference distribution $\Delta_{x,y}$ should in principle be a normal distribution with zero mean and unit variance. Any deviations from this distribution are indicative of systematic errors in the catalogues or systematic differences between catalogues. To obtain the mean and standard deviation of the observed $\Delta_{x,y}$ distribution we determine the best fitting Gaussian using a maximum likelihood scheme. Stars deviating more than five times the width (from the 16$^{\rm th}$ to the 84$^{\rm th}$ percentile) of the $\Delta_{x,y}$ were rejected before the fit.

For each pair of catalogues we calculate $\Delta_{x,y}$ for all stars in common between the two catalogues ($\Delta^{\rm all}_{x,y}$), and for all stars in common between the two catalogues which are also contained in the HIP Catalogue ($\Delta^{\rm hip}_{x,y}$). To construct $\Delta_{x,y}$ we use the formal errors of the individual stars as quoted in the Catalogues. The comparison is done for each Astrographic Catalogue Declination zone to detect any zonal dependence of the results. Furthermore, to investigate if any magnitude effect is present in $\Delta_{x,y}$, we also divide the sample into four magnitude intervals: (1) all magnitudes, (2) bright stars ($B_T < 8$ mag), (3) intermediate stars ($8 \leq B_T < 10$ mag), and (4) faint stars ($B_T \leq 10$). B_T is one of the broad-band filters of the Tycho experiment, and is similar to the Johnson B filter.

3.2. Results

Figs. 1 and 2 show the mean and standard deviation of $\Delta_{x,y}$ resulting from the Gaussian fits. We first discuss the zone-independent results and then report on some peculiar zones.

3.2.1. Underestimation of ACT proper-motion errors

The third panel of Fig. 2 shows that the standard deviation of $\Delta^{\rm hip}_{\rm HIP,ACT}$ is larger than unity for all zones but one. Using $\sigma_x = 1.0$ mas yr^{-1} (HIP proper-motion error) and $\sigma_y = 3.0$ mas yr^{-1} (ACT proper-motion error) as the typical errors in Eq. (4), and

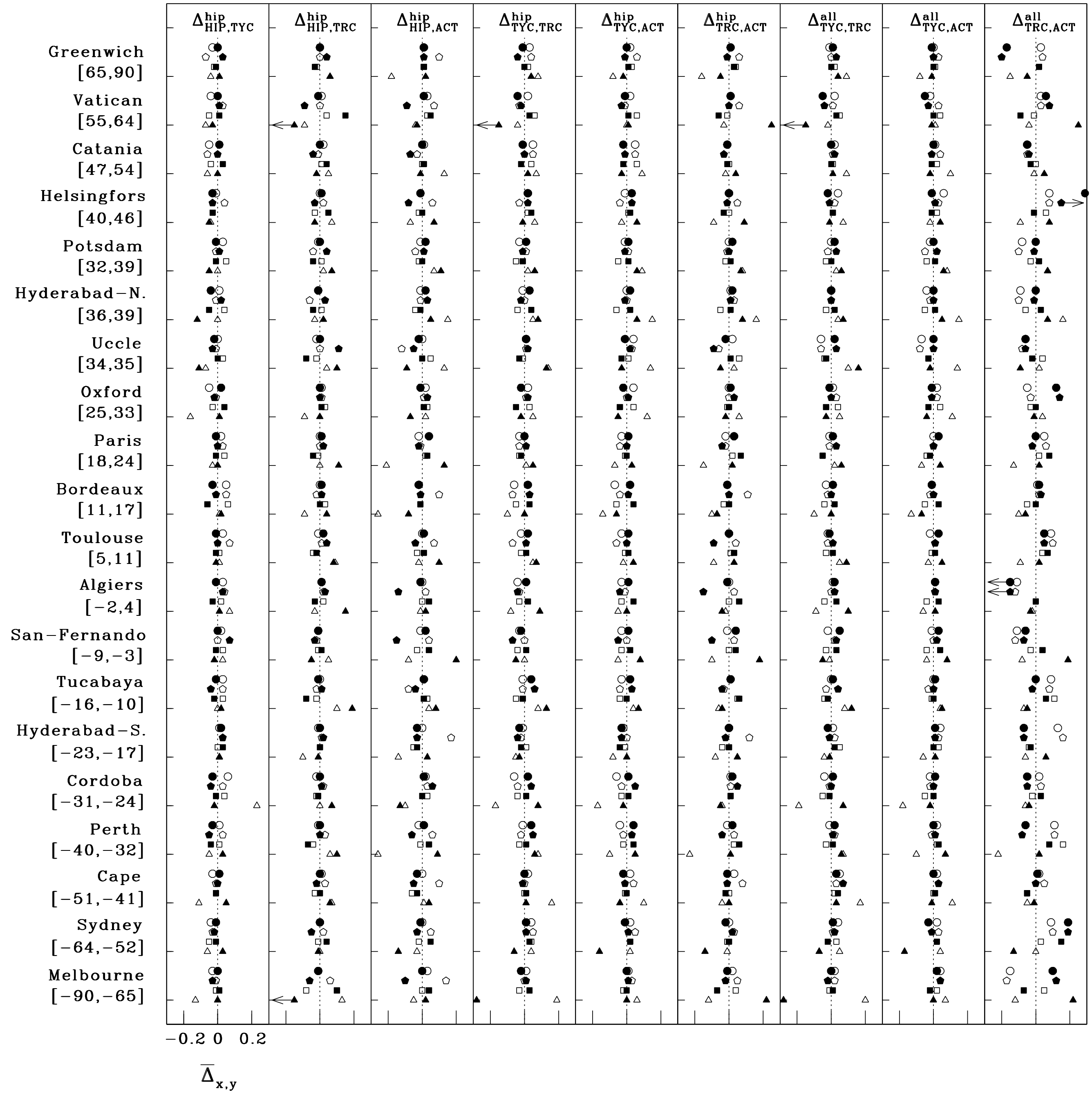

Fig. 1. Mean of the normalized proper-motion difference distribution, $\bar{\Delta}_{x,y}$, resulting from the Gaussian fit (see Sect. 3.1). The zones, denoted by observatory and declination, run from bottom (south pole) to top (north pole). The Potsdam Observatory stopped its work soon after the First World War, and its zone was later reobserved at Oxford, Hyderabad, and Uccle. The catalogues compared are indicated at the top of each panel. The open and filled symbols denote $\bar{\Delta}_{x,y}$ in RA and Dec, respectively. Bright stars are denoted as triangles ($B_T \leq 8$ mag), intermediate stars as squares ($8 \leq B_T \leq 10$ mag),faint stars as pentagons ($B_T \leq 10$ mag), and the complete sample as circles. The symbols with arrows indicate values of $\bar{\Delta}_{x,y}$ which lie outside the plotted range. The dotted line indicates the expected mean of zero.

assuming the HIP data are correct, the average standard deviation of 1.4 indicates an underestimate of the ACT proper-motion errors, or a fraction of them, by ∼30%. The standard deviation of $\Delta^{\rm hip}_{\rm HIP,ACT}$ is closest to unity around the equator and increases towards the equatorial poles. The large standard deviation of $\Delta^{\rm hip}_{\rm HIP,ACT}$ is partly due to the shape of the normalized proper-motion difference, which is clearly non-Gaussian (see Fig. 3). The wings of the $\Delta^{\rm hip}_{\rm HIP,ACT}$ distributions are much broader than for a Gaussian distribution. Therefore, we expect that only a fraction of the ACT proper motions or proper-motion errors are incorrect. However, we can not identify which stars have unreliable data. The standard deviation of $\Delta^{\rm hip}_{\rm HIP,ACT}$ shows no magnitude dependencies indicating that this effect is inherent to the construction of the ACT. The shape of the $\Delta^{\rm hip}_{\rm HIP,ACT}$ distribution can, of course, also be due to overestimated proper-motion errors of the stars around the mode of the distribution.

Since the binaries have been treated differently in the ACT than in TRC construction we investigate wether the large standard deviations might be caused by binary contamination. We remove all HIP and TYC entries with the slightest indication of duplicity[1] from the sample and redo the comparison. We find only marginal differences. The large standard deviations are thus not due to contamination by binaries.

The standard deviations of the $\Delta^{\rm hip}_{\rm HIP,TRC}$ distribution are mostly consistent with unity, except for declinations between -60° and -20°. Nine of the 20 zones of the $\Delta^{\rm hip}_{\rm HIP,TRC}$ distribution have standard deviations larger than unity while for the $\Delta^{\rm hip}_{\rm HIP,ACT}$ distribution this is the case for 19 of the 20 zones.

3.2.2. Faint Tycho stars

The $\Delta^{\rm all}_{\rm TYC,TRC}$ and $\Delta^{\rm all}_{\rm TYC,ACT}$ standard deviations show a very dramatic trend with magnitude (see Fig. 2). This trend is similar for all zones. Fig. 2 shows that the samples of faint stars, and therefore also the complete samples, have standard deviations on the order of 1.6 whereas the bright and intermediate samples have standard deviations close to unity. The typical errors in the Tycho Catalogue are an order of magnitude larger than those in the TRC and ACT, and therefore dominate the normalized proper-motion difference distribution. This means that the faint stars in the TYC Catalogue have underestimated proper-motion errors up to 40% (Eq. (4)). We do not see these large standard deviations in the faint sample of the $\Delta^{\rm hip}_{\rm TYC,TRC}$ and $\Delta^{\rm hip}_{\rm TYC,ACT}$ distributions. The standard errors of the proper motions given in the Tycho catalogue are known to be underestimates for the faint stars (see ESA 1997: Vol. 1 p. xv and p. 142 and Vol. 4 Sect. 18.5).

3.2.3. Systematic differences between TRC and ACT

The mean values of the $\Delta^{\rm all}_{\rm TRC,ACT}$ distribution show a large scatter around zero (see Fig. 1). For 13 of the 20 zones the mean of $\Delta^{\rm all}_{\rm TRC,ACT}$ in either RA or Dec differs by more than 0.1 from zero (see also Fig. 3 for an example). Assuming typical errors of 3 mas yr^{-1} for both the TRC and ACT, this amounts to more than 0.4 mas yr^{-1} systematic difference in proper motion between the two catalogues. Some zones show mean values of $\Delta^{\rm all}_{\rm TRC,ACT}$ as large as 0.3 (i.e., 1.2 mas yr^{-1} difference). Furthermore, for almost half of the zones the difference between the means of $\Delta^{\rm all}_{\rm TRC,ACT}$ in RA and Dec differ by more than 0.1 from each other. So not only are the means inconsistent with zero, they are also inconsistent for the two components of the proper motion. The majority of these differences are consistent with the systematic errors quoted in the TRC (less than 1.0 mas yr^{-1}) (see Høg et al. 1998), and we expect that those in the ACT to be of a similar magnitude. There appears to be no systematic trend of the $\Delta^{\rm all}_{\rm TRC,ACT}$ mean with Astrographic Catalogue zone.

3.2.4. TRC and ACT correlated

The standard deviations for $\Delta^{\rm hip}_{\rm TRC,ACT}$ and $\Delta^{\rm all}_{\rm TRC,ACT}$ are systematically smaller than unity, with only a few exceptions. This is indicative of a correlation between the proper motions in the catalogues. This comes as no surprise as both catalogues originate from the same material, the Astrographic Catalogue and the Tycho Catalogue, and have been constructed in a similar manner. $\Delta^{\rm hip}_{\rm TRC,ACT}$ and $\Delta^{\rm all}_{\rm TRC,ACT}$ are independent of magnitude except for the Cape zone (see Sect. 3.2.5).

3.2.5. Peculiar zones

Only two of the 20 zones show some peculiarities. These are the Cape and Vatican zones. The Cape zone is peculiar in that the standard deviations of its $\Delta^{\rm all}_{\rm TRC,ACT}$ distributions show a magnitude dependence which is not present in any of the other zones. The trend with magnitude is similar to that found for the $\Delta^{\rm all}_{\rm TYC,TRC}$ and $\Delta^{\rm all}_{\rm TYC,ACT}$ distributions. The normalized proper-motion difference distributions for other catalogue pairs in the Cape zone do not show any peculiarities.

The Vatican zone is special in the sense that it has large $\Delta^{\rm hip}_{\rm HIP,TRC}$ standard deviations. While most of the zones have $\Delta^{\rm hip}_{\rm HIP,TRC}$ standard deviations close to unity, the standard deviation of the Vatican zone is as large as 1.5. The Vatican zone also has one of the largest $\Delta^{\rm hip}_{\rm HIP,ACT}$ standard deviations. The other catalogue comparisons for the Vatican zone do not show any deviating characteristics. We do not know what caused these peculiarities in these two zones. The median epochs are 1903 for the Cape zone and 1909 or the Vatican zone. The peculiarities can thus not be due to a small epoch difference for these two zones.

4. An independent comparison

One of the consequences of the differences in the construction of the TRC and the ACT catalogues is that Hipparcos stars are more like reference stars in the TRC and field stars in the ACT. This is mainly due to the moment at which the respective catalogues are put onto the Hipparcos reference system. In the construction of the ACT catalogue the ACRS[2] was used as the reference catalogue for the plate reductions, and only after the whole catalogue was completed was it transformed from the FK5 to the Hipparcos reference frame. Furthermore, this transformation was done in a zonal sense, i.e., not for each individual plate. In the TRC construction the ACRS was also used as the reference catalogue for the plate reductions. However, before

[1] We checked the following fields for indications of duplicity H2, H10, H36, H43, H48, H55, H56, H57, H58, H59, H60, H61, and H62 in the Hipparcos Catalogue and fields T2, T10, T36, T40, T42, T49, and T51 in the Tycho Catalogue

[2] ACRS: Astrographic Catalogue Reference Stars (Corbin & Urban 1991)

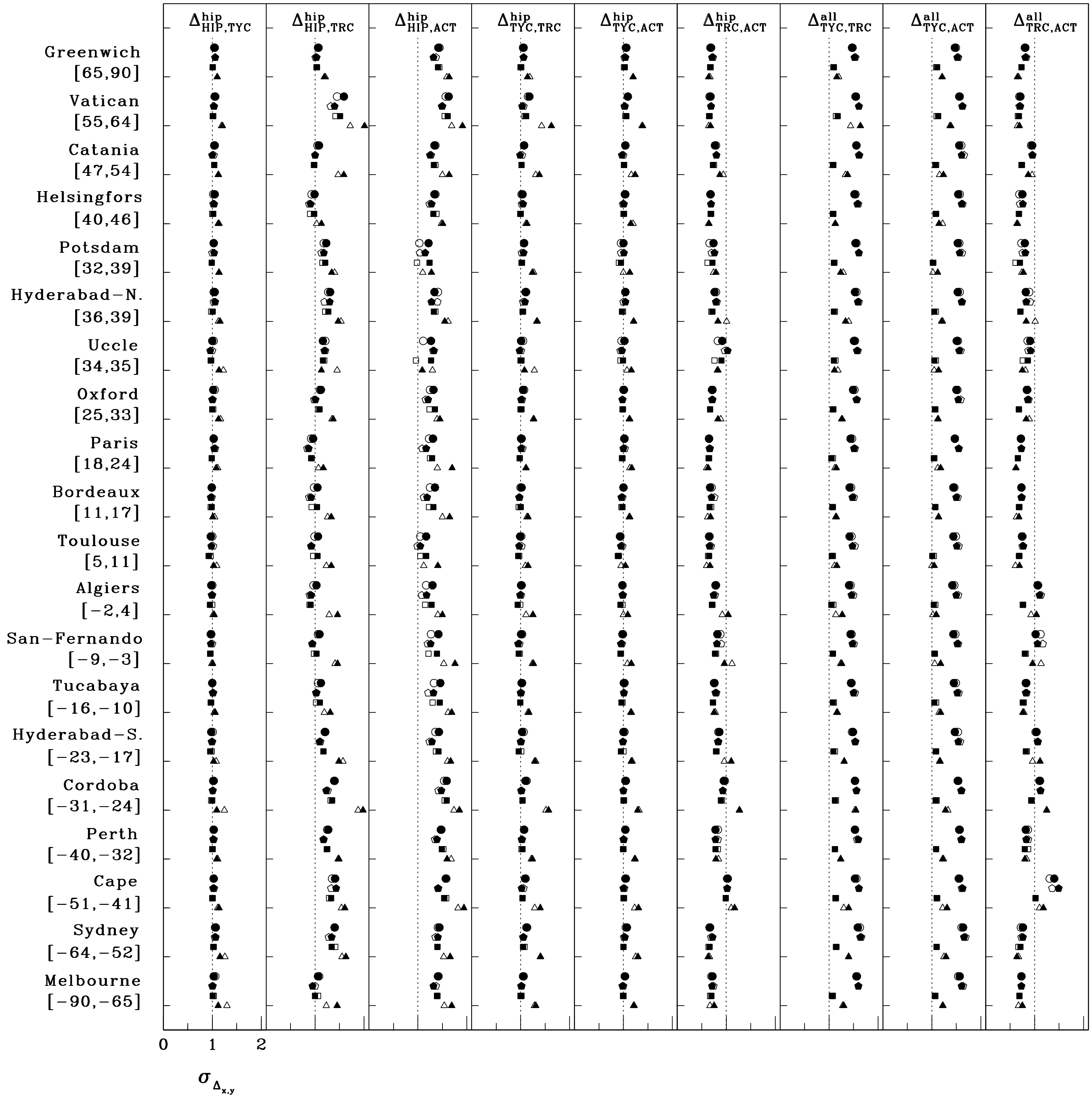

Fig. 2. Standard deviation of the normalized proper-motion difference distribution, $\sigma_{\Delta_{x,y}}$. Labels and symbols identical to Fig. 1. The dotted line indicates the expected standard deviation of one. The dramatic trend of the $\Delta^{\rm all}_{\rm TYC,TRC}$ and $\Delta^{\rm all}_{\rm TYC,ACT}$ standard deviations versus magnitude indicates that the faint TYC stars have underestimated proper-motion errors.

starting the reduction process the ARCS was first transformed to the Hipparcos reference frame.

To make an evaluation of the ACT and TRC independent of the Hipparcos Catalogue we compared both catalogues with stars from the Southern Proper Motion Program[3] (SPM) (Girard et al. 1998; Platais et al. 1998). This catalogue is the only one available at this moment with sufficient accuracy ($\sim$2.5 mas yr^{-1}) and number of stars ($\sim$10 000 HIP stars and $\sim$40 000 TYC stars are contained in the SPM). We calculated the normalized proper-motion differences $\Delta^{\rm hip}_{\rm TRC,SPM}$, $\Delta^{\rm hip}_{\rm ACT,SPM}$, $\Delta^{\rm all}_{\rm TRC,SPM}$, and $\Delta^{\rm all}_{\rm ACT,SPM}$ for several magnitude intervals. The results are summarized in Table 1.

The table shows that the $\Delta^{\rm hip}_{\rm TRC,SPM}$ and $\Delta^{\rm hip}_{\rm ACT,SPM}$ yield similar results: $\sigma_\Delta \sim 1.2$. Despite the similar standard deviations we still notice that the $\Delta^{\rm hip}_{\rm ACT,SPM}$ distribution is not properly fitted by a single Gaussian (see Fig. 4). The fact that the

[3] we used the SPM version 2.0

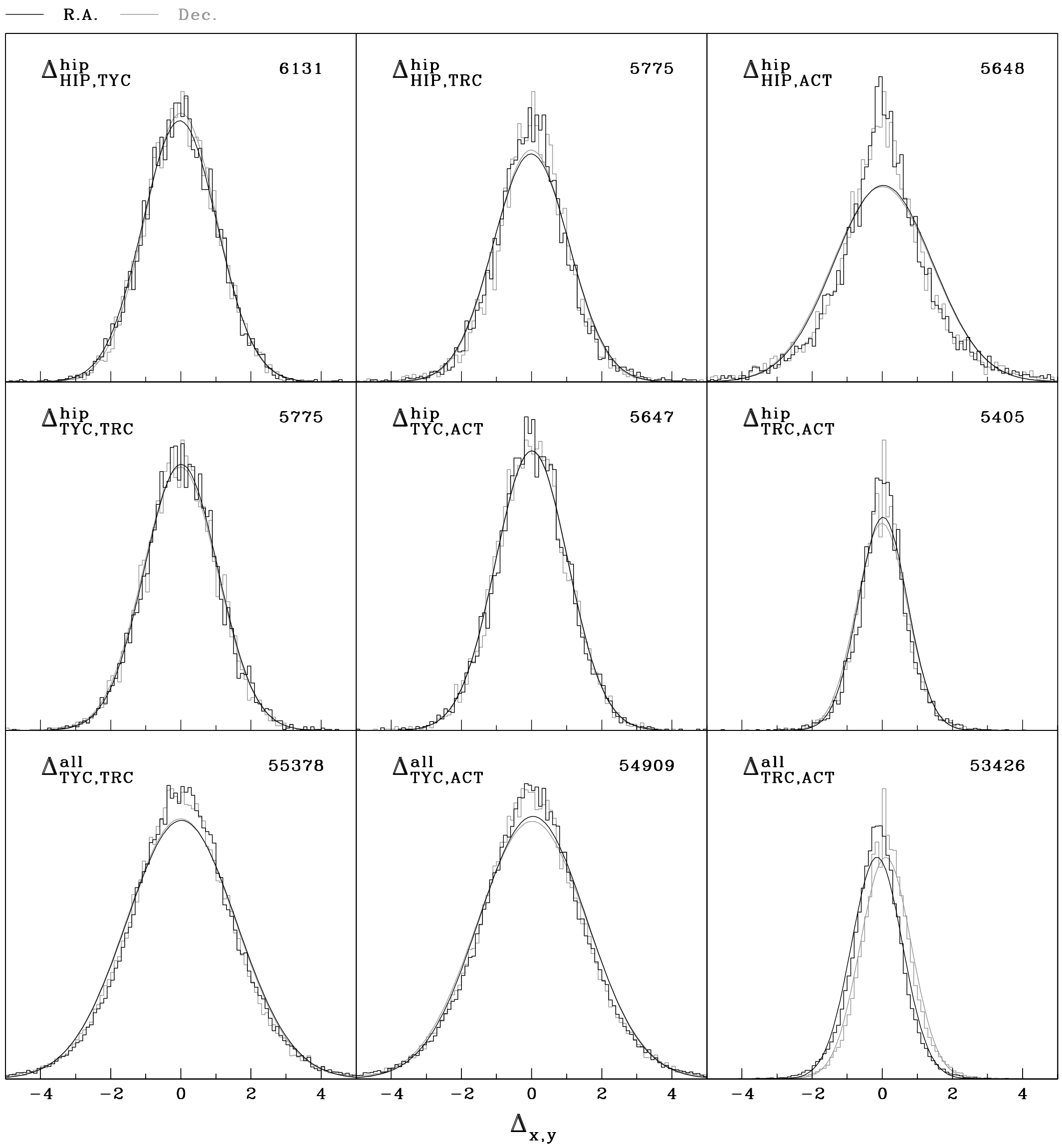

Fig. 3. This figure shows a typical example of the normalized proper-motion difference distributions, $\Delta_{x,y}$ (the Melbourne zone, $-90^\circ \leq \delta \leq -65^\circ$). The labels in the panels indicate the catalogues compared and the number of stars used in the comparison. The black and grey lines indicate $\Delta_{x,y}$ for RA and Dec, respectively. The smooth lines denote the Gaussian fits to $\Delta_{x,y}$.

standard deviations of the $\Delta^{\rm hip}_{\rm ACT,SPM}$ distribution are smaller is mostly due to the typical errors in the SPM which are $\sim$2.5 mas yr^{-1} instead of $\sim$1 mas yr^{-1} for the HIP. The larger errors dilute the characteristics we clearly see in the $\Delta^{\rm hip}_{\rm HIP,ACT}$ distribution.

Based on this comparison of the TRC and the ACT with an independent catalogue (the SPM) we confirm the conclusion we reached earlier: a fraction of the ACT stars has underestimated errors.

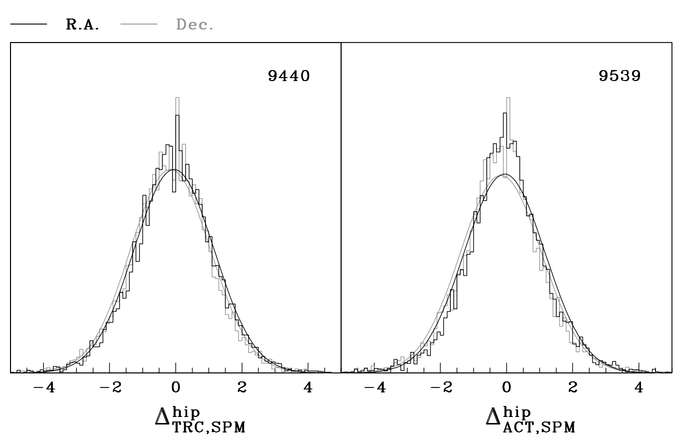

Fig. 4. Idem as Fig. 3 but for $\Delta^{\rm hip}_{\rm TRC,SPM}$ and $\Delta^{\rm hip}_{\rm ACT,SPM}$

5. Conclusions

We compared the proper motions in four astrometric catalogues: the Hipparcos Catalogue (HIP), the Tycho Catalogue (TYC), the Tycho Reference Catalogue (TRC), and the Astrographic

Table 1. Standard deviations in right ascension and declination for the $\Delta_{\rm TRC,SPM}$ and $\Delta_{\rm ACT,SPM}$ distributions for four different magnitude intervals.

$\Delta_{\rm x,y}$	$\sigma_{\Delta_{x,y},\alpha*}$	$\sigma_{\mathbf{\Delta_{x,y}},\delta}$
	$-2 < B_T < 15$	
$\Delta^{\rm hip}_{\rm TRC,SPM}$	1.21 ± 0.01	1.21 ± 0.01
$\Delta^{\rm hip}_{\rm ACT,SPM}$	1.22 ± 0.01	1.23 ± 0.01
$\Delta^{\rm all}_{\rm TRC,SPM}$	1.41 ± 0.01	1.40 ± 0.01
$\Delta^{\rm all}_{\rm ACT,SPM}$	1.27 ± 0.01	1.27 ± 0.01
	$-2 < B_T < 8$	
$\Delta^{\rm hip}_{\rm TRC,SPM}$	1.35 ± 0.03	1.47 ± 0.03
$\Delta^{\rm hip}_{\rm ACT,SPM}$	1.25 ± 0.03	1.30 ± 0.03
$\Delta^{\rm all}_{\rm TRC,SPM}$	1.36 ± 0.03	1.47 ± 0.03
$\Delta^{\rm all}_{\rm ACT,SPM}$	1.24 ± 0.02	1.31 ± 0.03
	$8 < B_T < 10$	
$\Delta^{\rm hip}_{\rm TRC,SPM}$	1.20 ± 0.01	1.20 ± 0.01
$\Delta^{\rm hip}_{\rm ACT,SPM}$	1.24 ± 0.01	1.26 ± 0.01
$\Delta^{\rm all}_{\rm TRC,SPM}$	1.26 ± 0.01	1.24 ± 0.01
$\Delta^{\rm all}_{\rm ACT,SPM}$	1.26 ± 0.01	1.23 ± 0.01
	$10 < B_T < 15$	
$\Delta^{\rm hip}_{\rm TRC,SPM}$	1.19 ± 0.02	1.16 ± 0.02
$\Delta^{\rm hip}_{\rm ACT,SPM}$	1.17 ± 0.01	1.16 ± 0.01
$\Delta^{\rm all}_{\rm TRC,SPM}$	1.46 ± 0.01	1.43 ± 0.01
$\Delta^{\rm all}_{\rm ACT,SPM}$	1.30 ± 0.01	1.28 ± 0.01

plus Tycho Catalogue Reference Catalogue (ACT). The first two resulted from the Hipparcos satellite mission while the last two were constructed using the almost-century old Astrographic Catalogue and the Tycho Catalogue. The HIP, TRC, and ACT give highly accurate (1, 3, and 3 mas yr^{-1} accuracy, respectively) proper motions, while the proper-motion errors in the TYC Catalogue are an order of magnitude larger. Note that ACT proper motions in Right Ascension do not include the $\cos\delta$ term. The aim of our comparison is to assess the quality of the proper motions and to detect any systematic difference between the catalogues. We created normalized proper-motion difference distributions for each possible pair of catalogues (Eq. (1)), for each of the 20 declination zones of the Astrographic Catalogue. These distributions should in principle be normal distributions with zero mean and unit variance.

For most pairs of catalogues the normalized proper-motion distribution does not show any dependence on zone. Only two zones show peculiarities. The Cape zone shows $\Delta^{\rm all}_{\rm TRC,ACT}$ standard deviations that are (a) larger than unity and (b) magnitude dependent, whereas all other zones have standard deviations smaller than, or close to, unity. The Vatican zone shows peculiar standard deviations in its $\Delta^{\rm hip}_{\rm HIP,TRC}$ distributions. Its value of 1.5 is much larger than the value of 1.2 for the other zones.

We also find four zone-independent effects:

(1) A fraction of the ACT proper-motion errors is most likely underestimated by about 30%. This conclusion is based on the standard deviation of $\Delta^{\rm hip}_{\rm HIP,ACT}$ which is systematically larger than unity (∼1.4), and on the non-Gaussian shape of the $\Delta^{\rm hip}_{\rm HIP,ACT}$ distribution. A independent comparison of the AT and the SPM catalogue confirms this result.

(2) The proper-motion errors of the faint Tycho stars are underestimated by almost 40%. The standard deviations of $\Delta^{\rm all}_{\rm TYC,TRC}$ and $\Delta^{\rm all}_{\rm TYC,ACT}$ for the faint stars ($B_T \leq 10$ mag) are dramatically different from those of the bright ($B_T < 8.0$ mag) and intermediate stars ($8.0 \leq B_T < 10.0$ mag). The latter two regimes have standard deviations close to unity while the faint stars have standard deviations as large as 1.6. The standard errors given in the Tycho catalogue are formal errors. They are known to be underestimated for the faint stars, as stated by the authors of the Tycho Catalogue in ESA (1997: Vol. 1 p. xv and p. 142 and Vol. 4 Sect. 18.5).

(3) There are systematic differences between the proper motions in the TRC and the ACT. This conclusion is based on the distribution of the means of the $\Delta^{\rm all}_{\rm TRC,ACT}$ distributions of all zones. The proper motions in the TRC and ACT sometimes show systematic differences of more than 1 mas yr^{-1}. These differences change from zone to zone and do not show any systematic behaviour. Our analysis cannot reveal the source of this discrepancy.

(4) As expected, the normalized proper-motion difference distributions $\Delta^{\rm hip}_{\rm TRC,ACT}$ and $\Delta^{\rm all}_{\rm TRC,ACT}$ show that the TRC and ACT catalogues are correlated (standard deviations smaller than unity). This correlation is expected because both catalogues have been constructed in a similar fashion from the same material.

The Hipparcos, TRC, and ACT catalogs will remain the most complete and accurate astrometric catalogues for at least the next decade. In 10 to 20 years the results of several astrometric space missions, e.g., SIM (see, e.g., Shao 1998), FAME (see, e.g., Horner et al. 1999), and GAIA (see, e.g., Gilmore et al. 1998), will become available. These satellites will provide micro-arcsecond astrometry for over a billion stars.

Acknowledgements. We thank Erik Høg and Sean Urban for reading the draft version of this paper and their comments and suggestions. We also thank the referee, Dr. T. Corbin, for his careful reading detailed comments. This research is supported by the Netherlands Foundation for Research in Astronomy (NFRA) with financial aid from the Netherlands Organization for Scientific Research (NWO).

References

Chereul E., Crézé M., Bienaymé O., 1998, A&A 340, 384

Corbin T.E., Urban S.E., 1991, Astrographic Catalogue Reference Stars, U.S. Naval Observatory, Washington (Doc. No. NSSDC/WDC-A-R&S 91-10)

Débarbat S., Eddy J.A., Eichhorn H.K., Upgren A.R., 1988, Mapping the Sky: Past Heritage and Future Directions, IAU Symp. 133

Dehnen W., Binney J.J., 1998, MNRAS, 298, 387

Eichhorn H.K., 1974, Astronomy of Star Positions, Frederick Ungar, New York

ESA, The Hipparcos and Tycho Catalogues, 1997, ESA SP–1200

Gilmore G.F., Perryman M.A.C., Lindgren L., et al., 1998, in: Reasenberg R.D. (ed.), Astronomical Interferometry, SPIE Proc. 3350, p. 541

Girard T.M., Platais I., Kozhurina-Platais V., van Altena W.F., López C.E., 1998, AJ 115, 855
Helmi A., White S.D.K., de Zeeuw P.T., Zhao H.S., 1999, Nat 402, 53
Høg E., Kuzmin A., Bastian U., Fabricius C., Kuimov K., Lindegren L., Makarov V.V., Röser S., 1998, A&A, 335, L65
Høg E., Fabricius C., Makarov V.V., et al., 2000a, A&A 355, L27
Høg E., Fabricius C., Makarov V.V., et al., 2000b, A&A, 357, 367
Hoogerwerf R., 2000, MNRAS 313, 43
Horner S.D., Germain M.E., Greene T.P., et al., 1999, in: Szabados L., Kurtz D., The Impact of Large-Scale Surveys on Pulsating Star Research, ASP Conf. Series, in press
Kuzmin A., Høg E., Bastian U., et al., 1999, A&AS 136, 491
Platais I., Girard T.M., Kozhurina-Platais V., et al., 1998, AJ 116, 2556
Shao M., 1998, in: Reasenberg R.D. (ed.), Astronomical Interferometry, SPIE Proc. 3350, p. 536
Urban S.E., 1999, private communication
Urban S.E., Corbin T.E., 1998, Sky & Telescope, Vol. 95, No. 6, p. 40
Urban S.E., Corbin T.E., Wycoff G.L., 1998, AJ 115, 2161
de Zeeuw P.T., Hoogerwerf R., de Bruijne J.H.J., Brown A.G.A., Blaauw A., 1999, AJ 117, 354