Astrometry of the h and χ Persei clusters based on the processing of digitized photographic plates

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Abstract. The work was carried out to ascertain the possibility of using the scanner Epson Expression 10000XL of Astronomical Institute Academy of Sciences of Uzbekistan for any astrometric and photometric works. Photographic plates were obtained with the normal astrograph of Astronomical Institute (D/F = 330mm/3467mm, M = 59.56 "/mm). The digitizing of photographic plates with linear dimensions 16 x 16 cm was made with a spatial resolution of 1200 dpi (1px = 1.25"). For this study the images of the first (1935.0) and second (1976.9) epochs were used in the sky area of 4 sq. degrees with the χ and h Persei open clusters. Positions and B-magnitudes of the stars were obtained in the system of the TYCHO2 reference catalogue. The errors of differences in the positions and proper motions for the 655 reference stars used for the astrometric reduction are $\sigma_{\alpha\delta}$ = ± 0.0.074" and $\sigma_{\mu\alpha\delta}$ = ± 0.0018"/year respectively. The internal photometric errors σ_m are $\pm 0.065^m$. The comparison of the determined B-magnitudes with the B-magnitudes of the TYCHO2 gave the error values of $\sigma_B = \pm 0.208^m$. The comparison of 8123 common stars down to B $\leq 17.5^m$ with UCAC4 gave the error values of $\sigma_{\alpha\delta} = \pm 0.28$", $\sigma_{\mu\alpha\delta}$ = ±0.0075"/year and $\sigma_m = \pm 0.139^m$ for positions, proper motions and stellar magnitudes respectively.

Key words: catalogs, image processing, surveys, open clusters and associations

Introduction

The glass archive of the Astronomical Institute of the Academy of Sciences of Uzbekistan (AI ASU) contains about 10 thousand photographic plates. For the period 1895 - 1976 the photographic plates were obtained with the normal astrograph and the rest ones beginning from year 1976 and until 1985 on the double Zeiss astrograph of the Kitab observatory. Up to 1963 about 3000 images were received in the frameworks of the different observing programs. The following programs were completed: the observations of galaxies (1100 plates); minor (1100 plates) and major planets (60 plates);

150-200 plates contain the images of planetary nebulae and star clusters, near 200 plates have the images of comets and variable stars and 150 plates were obtained with different targets such as the solar eclipse, the transit of Mercury across the Sun's disk, photometric images for the testing of the astrograph. The observations of the second epoch for the selected targets included open and globular clusters and areas of peculiar stars. Up to 1980 the systematic observations of the major planets and their satellites were carried out (Jupiter, Saturn, and Uranus).

Starting from 1976 the observations of the targets with long exposures became impossible due to a significant light pollution increase from the Tashkent city. The last observations with the normal astrograph were carried out in late 1976 and it was χ and h Persei clusters. All further AI ASU activities were continued in the Kitab observatory, where the double Zeiss astrograph (D/F = 400mm/3000mm) was installed in 1975.

The main scientific program was the photographic survey of the northern sky, so-called "FON project" (Andruk et al. (2015b), Andruk et al. (2015c), Andruk et al.(2016)), namely the observations of the equatorial area from -20 up to +20 degrees. For this project over 2500 photographic plates of the size 30 x 30 cm were obtained. Additionally, the images of the close open clusters (50 areas) and areas with young star formation regions (50 areas) were received. All these plates are the valuable store of astronomical information because some of them contain a lot of previously unexplored open clusters. At the initiative of the AI ASU astronomer V. S. Shevchenko, the double Zeiss astrograph was used for obtaining the images of fields with variable stars as well as the star formation regions in the Milky Way. The archive of the double Zeiss astrograph contains more than 6000 photographic plates.

1. The digitizing and processing of the observed material

Getting started with the digitizing and processing of observed material in order to obtain the equatorial coordinates α and δ, proper motions μ_α and μ_δ and B-magnitude of stars, the authors decided to start the study on the samples of the photographic plates obtained in the areas with the χ and h Persei clusters. The clusters on this photographic material were previously studied in Muminov (1996), Muminov (1982). Scans prior testing results are presented in Muminov et al.(2012). The experience of the digitized photographic plate processing to obtain the positions and star magnitudes is presented in the following publications: Andruk et al.(2005), Andruk,Pakuliak (2007), Andruk et al.(2010), Golovnya et al.(2010), Kazantseva et al.(2015), Protsuyk et al.(2014), Yatsenko et al. (2011), Vavilova et al.(2012), Vavilova et al. (2016). We used the method of astronegative processing presented in Andruk et al.(2015a), Andruk et al. (2015b), Andruk et al. (2015c).

2. The processing of the digitized images

The photographic plates of the first and second epochs with corresponding numbers of 76 (1935.0) and 4209 (1976.9) from the glass archive of the AI

ASU were digitized using the scanner Epson Expression 1000XL. The plates were obtained with the normal astrograph (D/F = 330mm/3467mm, M = 59.56 "/mm). The digitizing of plates with dimensions of 16 x 16 cm was carried out with a spatial resolution of 1200 dpi (1px = 1.25"). The rectangular coordinates X and Y, instrumental photometric values m (mag) and f (FWHM) were acquired using the software package MIDAS/ROMAFOT for the LINUX operation system (MIDAS,1994). The reduction to the equatorial coordinate system α, δ, and stellar B-magnitudes was implemented in the system of the TYCHO2 reference catalogue.

The results of the reduction without the correction for the systematic errors of the scanner are presented in Fig.1. mdtX, mdtY are the coefficients of the brightness equation which is significant for right ascension and negligible for declination except stars fainter than 11^m.

The differences between the calculated coordinates and magnitudes of the reference stars and their TYCHO2 catalogue values $\Delta\alpha$ (panels a, b, c), $\Delta\delta$ (d, e, f) are shown relative to the rectangular coordinates X, Y and the B-values of the reference catalogue.

The panels on the left and right represent the first and the second epochs correspondingly. On the bottom, you can see the characteristic curves of both plates (g). Hereinafter, m are the instrumental photometric values and B are the B-values of the TYCHO2 reference catalogue.

The trends of the random (residual) errors after the correction of the measured and calculated equatorial coordinates for the instrumental errors of the scanner, the brightness equation as well as for the telescope optical aberrations are shown on the similar panels in Fig.2.

The above said corrections were applied to the coordinates only because the instrumental errors of the scanner do not affect the photometric data, and the telescope aberration effects are completely accounted by the photometric reduction model. On the e-panels, there are the averaged systematic errors of the scanner relative to Y-coordinates (solid lines).

Fig.3 shows the distribution of stars from the TYCHO2 across the fields of the plates and the density of reference stars per square degree (k/S). The dimensions of the area S for the plates of the first and the second epochs are 4.76 and 4.29 square degrees, and the numbers of reference stars k are 881 and 800 correspondingly.

3. The comparison of the TYCHO-2 and UCAC-4 in the area of clusters

To study the accuracy of the modern TYCHO2 and UCAC4 (Zacharias N. et al., 2013) in the region of χ and h Persei clusters the internal catalogue errors of the calculated equatorial coordinates σ_α and σ_δ, proper motions $\sigma_{\mu\alpha}$ and $\sigma_{\mu\delta}$ as well as photometric errors σ_m were arranged by the intervals of stellar magnitudes in the fields about 3 x 3 degrees at the centre of the clusters ($\alpha \approx 2^h20.7^m$, $\delta \approx 57°08'$). The results are presented graphically in Fig.4 and Fig.5 for TYCHO2 and UCAC4 respectively.

So, 1680 stars of the TYCHO2 catalogue have the following average errors: $\sigma_\alpha = \pm 0.060"$, $\sigma_\delta = \pm 0.067"$, $\sigma_{\mu\alpha} = \pm 0.0031"$/year, $\sigma_{\mu\delta} = \pm 0.0032"$/year, $\sigma_B = \pm 0.137^m$.

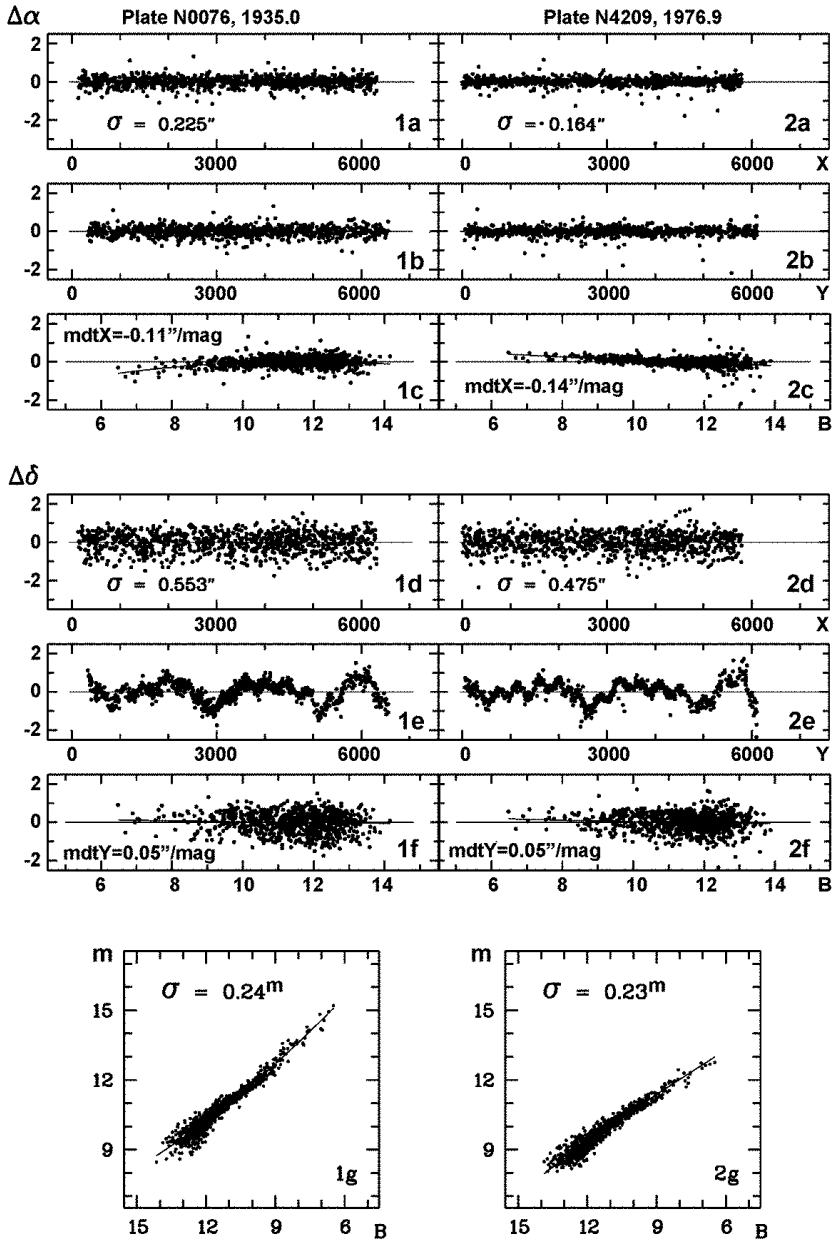

Fig. 1. Trends of the residual errors in coordinates **before** their correction for the instrumental errors of the scanner and for the telescope optical aberrations for the first (1935.01.05) and the second (1976.11.26) epochs and the calibrating curves of both plates.

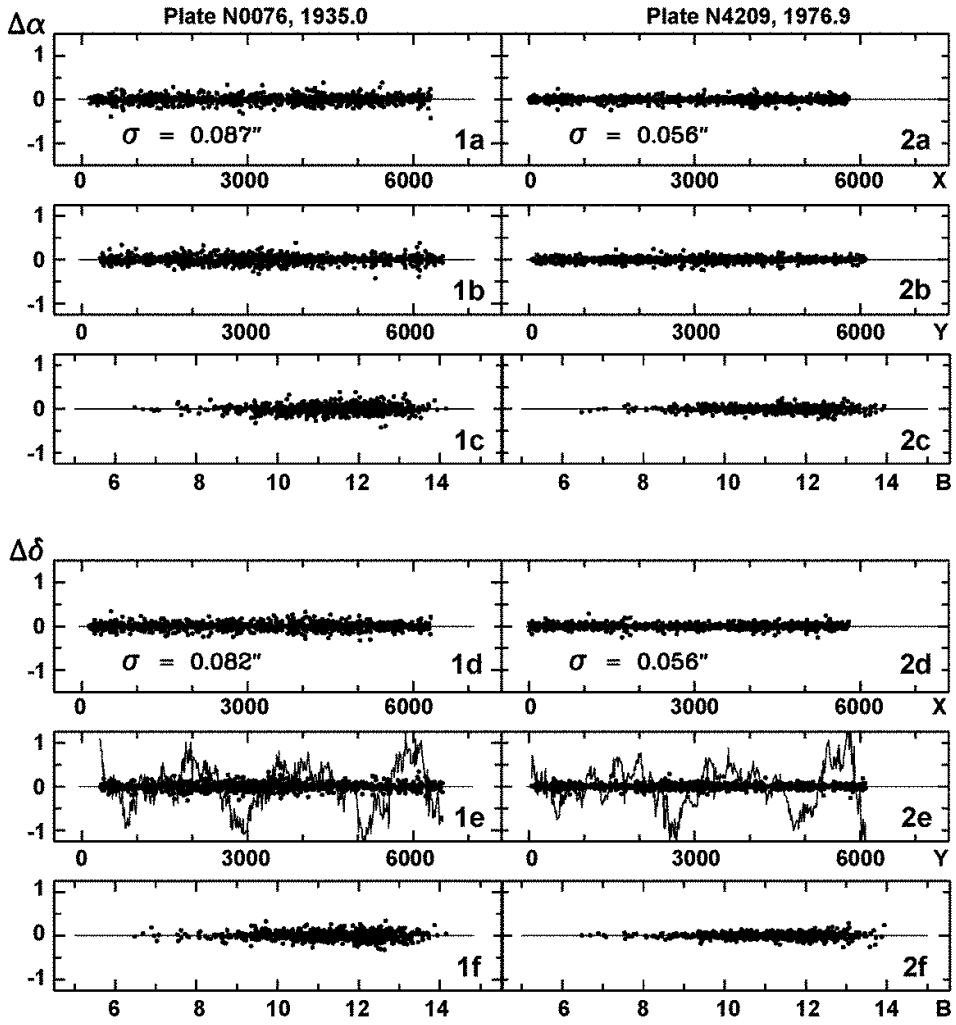

Fig. 2. Trends of the residual errors in coordinates **after** the correction for the instrumental errors of the scanner and for the telescope optical aberrations for the first (1935.01.05) and the second (1976.11.26) epochs.

Respectively, 41 726 stars of the UCAC4 catalogue are characterized by the following errors: $\sigma_\alpha = \pm 0.053$", $\sigma_\delta = \pm 0.051$", $\sigma_{\mu\alpha} = \pm 0.0051$"/year, $\sigma_{\mu\delta} = \pm 0.0049$"/year, $\sigma_{fu} = \pm 0.157^m$. Hereinafter, fu is the UCAC magnitudes, obtained in a single band-pass 579-642 nm, thus fu magnitudes are between Johnson V and R. B_U is B values from UCAC (Zacharias N. et al., 2013).

For this region, a comparison of positions and proper motions between

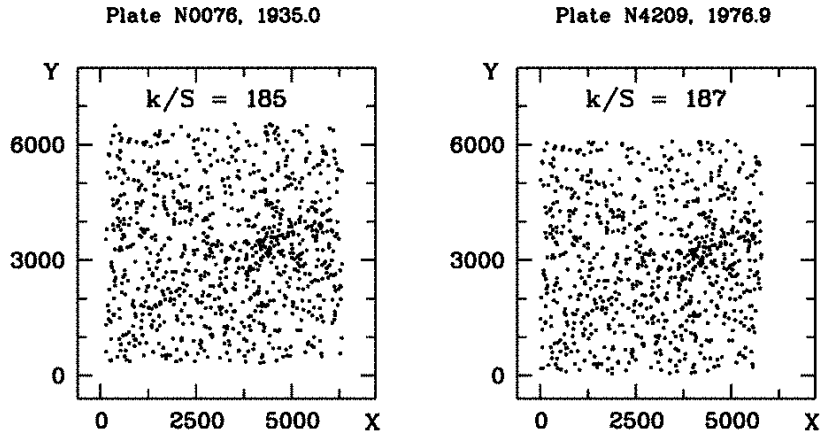

Fig. 3. The distribution of reference stars across the plate field.

these two catalogues was also made. The results as a distribution of differences with magnitudes are represented in Fig.6. For 1496 cross identified stars the errors of differences in positions are $\sigma_\alpha = \pm 0.072$" and $\sigma_\delta = \pm 0.068$" (panels a and b), the errors of differences in proper motions are equal to $\sigma_{\mu\alpha} = \pm 0.0027$"/year and $\sigma_{\mu\delta} = \pm 0.0031$"/year (panels c and d).

On the bottom of Fig.6, the color-magnitude diagrams for the corresponding values of the TYCHO2 stars are shown on the left e-panel: (B-V)-B. The UCAC4 stars are on the right f-panel: (B_U-fu)-B_U. The diagrams show the differences between photometric systems of two catalogues, which can be used as the reference in further works. In particular, they confirm the incorrectnesses in the UCAC4 star magnitude system, which is undesirable in the works related to the study of the star clusters. The all above-mentioned values of the errors serve as criteria when assessing similar parameters of the produced catalogue of objects in the area with the clusters(CAT).

4. Creation of CAT and its comparison with UCAC4

The star catalogue of the positions and proper motions was obtained as follows. For both plates, the equatorial coordinates of stars were obtained for the observing epochs t_1 and t_2 in the system of TYCHO2 for the equinox 2000.0 together with the absolute proper motions $\mu_{\alpha i}$ and $\mu_{\delta i}$. The epoch difference is $\Delta t = 41.9$ years. Positions of the second epoch were then reduced to the epoch and equinox 2000.0 using derived proper motions.

The estimation of the accuracy of the resulted catalogue was made by the comparing with TYCHO2 and UCAC4 catalogues. The results of the comparison with TYCHO2 are given in the Tab.1 and in Fig.7.

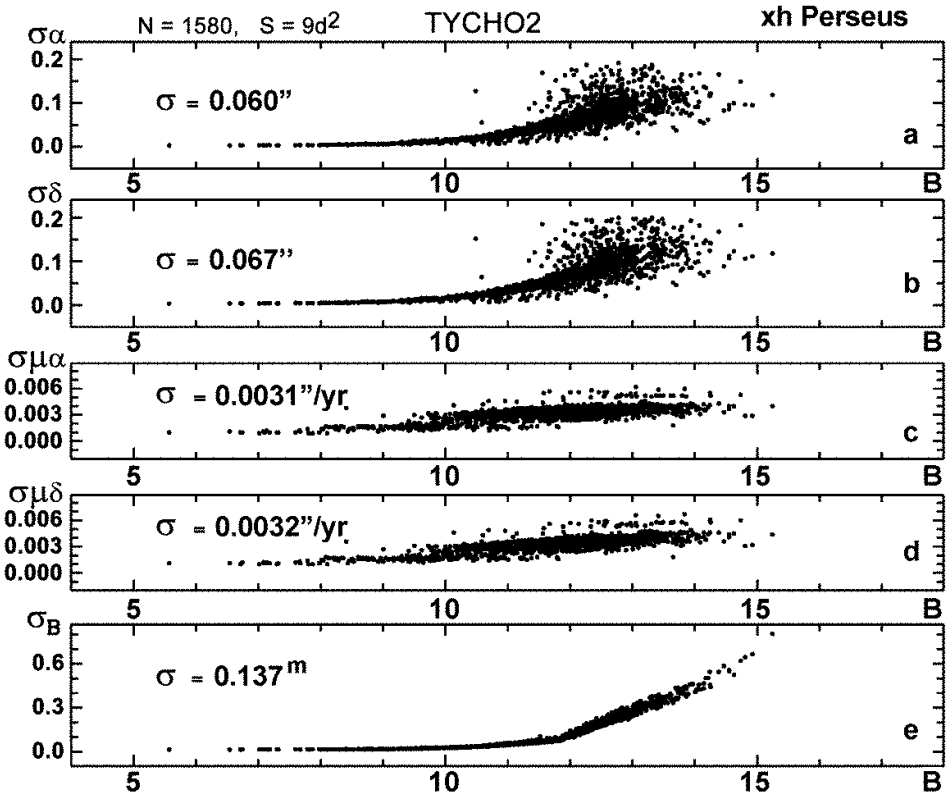

Fig. 4. Trends of the internal errors of the TYCHO2 along the TYCHO2 B-axis for positions σ_α, σ_δ, proper motions $\sigma_{\mu\alpha}$ and $\sigma_{\mu\delta}$ and magnitudes σ_B in 3 x 3 degrees area around χ and h Persei clusters.

Tab.1 contains the data for 655 common stars. Columns 3 and 4 present the errors of the differences of coordinates $\sigma_{\Delta\alpha}$ and $\sigma_{\Delta\delta}$, columns 5 and 6 - the same errors of proper motions $\sigma_{\Delta\mu\alpha}$ and $\sigma_{\Delta\mu\delta}$, columns 7 and 8 contain photometric errors on internal convergence σ_m and the resulted ones σ_B in TYCHO2 B-system. Average values of the diameters of the star images f (FWHM), the intensities in the center of the star images cIn and the number of stars in the corresponding interval k are given in columns 9, 10 and 11.

The errors of differences of coordinates and proper motions for the calculated and reference stars are $\sigma_{\alpha\delta} = \pm\ 0.074$" and $\sigma_{\mu\alpha\delta} = \pm\ 0.0018$"/year respectively. The photometric errors are $\sigma_m = \pm\ 0.065^m$ and $\sigma_B = \pm\ 0.208^m$ on the internal accuracy and from the comparison with TYCHO2 B-values respectively.

The similar data from the comparison of CAT with the UCAC4 is presented in Tab.2 and demonstrated graphically in Fig.8. The description of

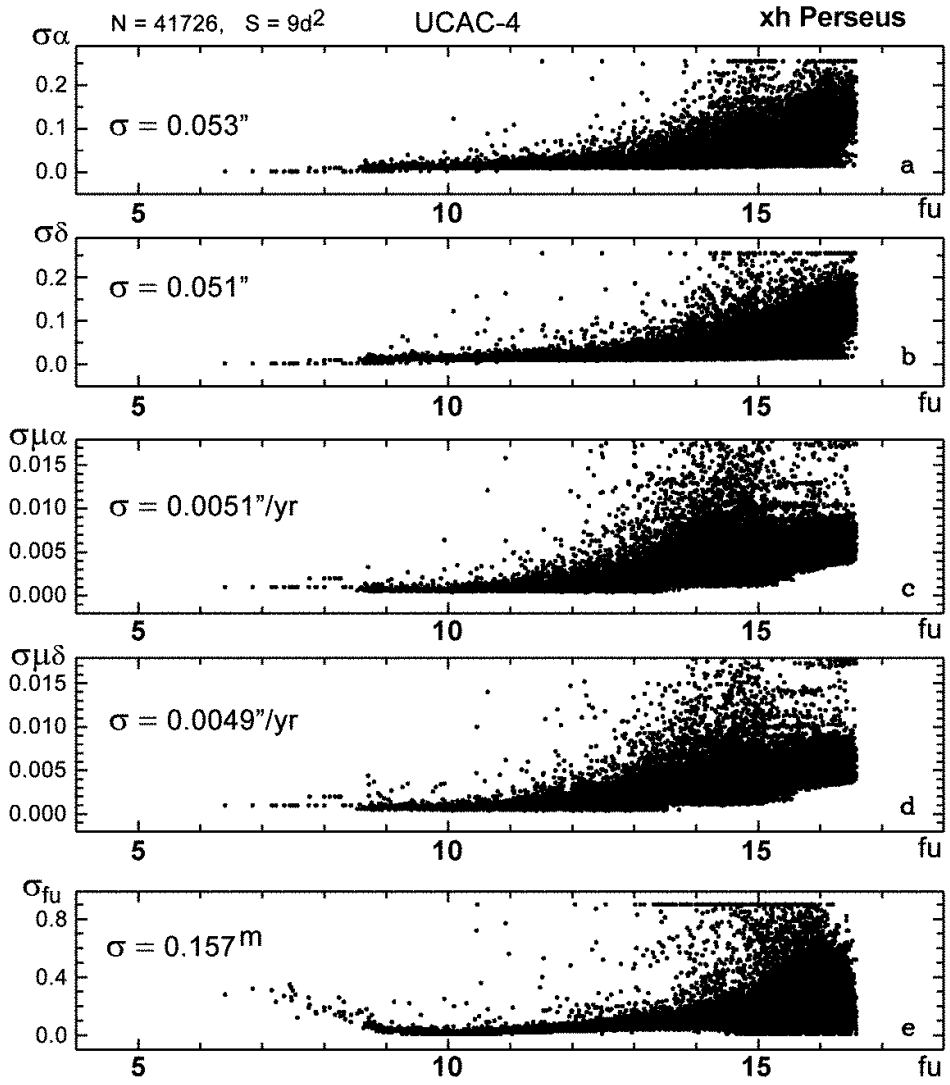

Fig. 5. The trends of the internal errors of the UCAC4 catalogue along the magnitude axis for positions σ_α, σ_δ, proper motions $\sigma_{\mu\alpha}$ and $\sigma_{\mu\delta}$ and magnitudes σ_{fu} in 3 x 3 degrees area around χ and h Persei clusters.

the columns is the same as in Tab.1, except the σ_B column, which was not obtained because of above-mentioned incorrectnesses of UCAC4 photometric data and their elimination from the CAT accuracy evaluation.

The comparison of 8123 common stars down to B $\leq$ 17. 5^m with the UCAC4 data gave the errors $\sigma_{\alpha\delta} = \pm$ 0.28”, $\sigma_{\mu\alpha\delta} = \pm$ 0.0075 ”/year and

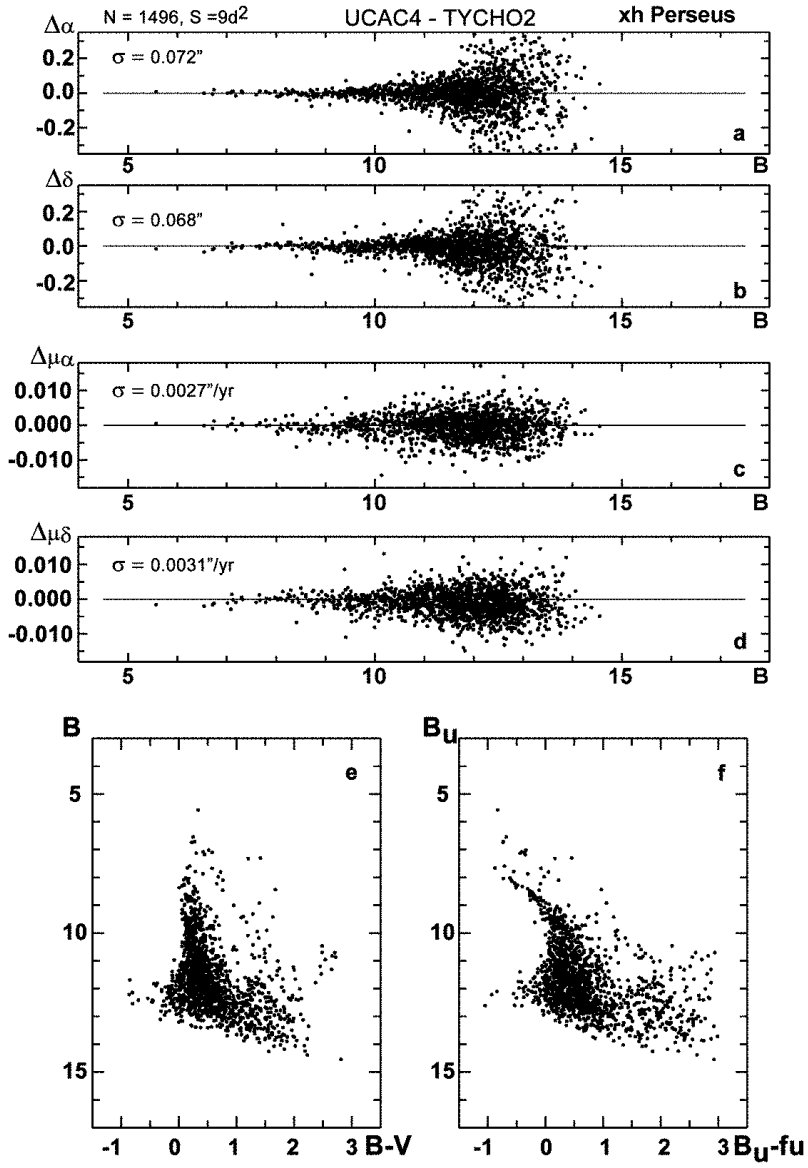

Fig. 6. The errors of differences in positions Δ_α, Δ_δ and proper motions $\Delta_{\mu\alpha}$, $\Delta_{\mu\delta}$ for the TYCHO2 and UCAC4. The panels e and f show the two color diagrams built from the common stars sample for the TYCHO2 (left) and UCAC4 (right) catalogues. V is V-value from TYCHO2

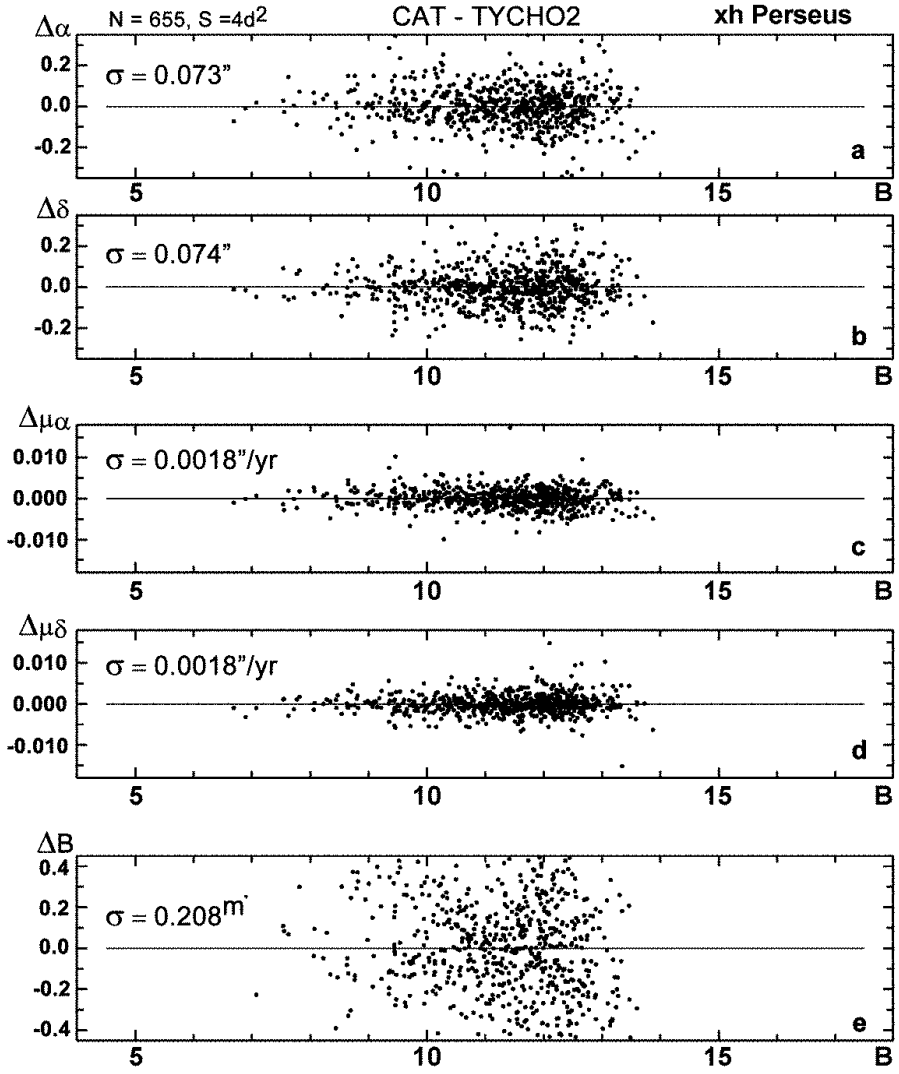

Fig. 7. The astrometric differences of the equatorial coordinates Δ_α, Δ_δ, proper motions $\Delta_{\mu\alpha}$, $\Delta_{\mu\delta}$ and photometric differences Δ_B between the CAT and TYCHO2 catalogues.

$\sigma_m = \pm\ 0.139^m$. Fig.9 displays the distributions of the proper motions μ_α, μ_δ within the picture plane of the square region 2 x 2 degrees (χ and h Persey clusters, $\alpha \approx 2^h 20.7^m$, $\delta \approx 57°08'$). The left and right panels show 655 common stars of TYCHO2 and CAT respectively.

Table 1. The accuracy of CAT in relation to the TYCHO2

	B mag	$\sigma\Delta_\alpha$ mas	$\sigma\Delta_\delta$ mas	$\sigma\Delta_{\mu\alpha}$ mas/y	$\sigma\Delta_{\mu\delta}$ mas/y	σ_m mag	σ_B mag	FWHM px	cIn	k
1	6.79	40.8	14.0	0.5	2.1	0.414	0.222	44.72	161.30	2
2	7.58	54.6	63.5	1.6	1.5	0.306	0.28	34.24	157.9	7
3	8.58	70.3	50.7	1.9	1.3	0.170	0.212	24.58	154.51	23
4	9.57	72.	60.6	1.9	1.7	0.053	0.205	16.71	147.55	69
5	10.55	71.9	64.3	1.8	1.6	0.073	0.140	12.32	138.11	121
7	11.54	69.4	70.2	1.8	1.7	0.051	0.181	9.18	124.28	210
8	12.40	76.4	86.6	1.8	1.9	0.053	0.252	7.23	108.16	190
9	13.29	87.4	119.3	2.1	2.5	0.073	0.360	6.20	91.93	33
	11.33	72.9	74.4	1.8	1.8	0.065	0.208	10.76	124.51	655

Table 2. The accuracy of CAT in relation to the UCAC4

	B mag	$\sigma\Delta_\alpha$ mas	$\sigma\Delta_\delta$ mas	$\sigma\Delta_{\mu\alpha}$ mas/y	$\sigma\Delta_{\mu\delta}$ mas/y	σ_m mag	FWHM px	cIn	k
1	6.86	61.2	23.4	2.2	0.2	0.449	47.09	159.96	2
2	7.53	45.6	55.8	1.6	2.4	0.351	36.96	159.52	4
3	8.42	64.4	52.9	1.9	1.9	0.188	26.34	155.45	19
4	9.60	90.1	95.7	3.1	3.8	0.067	16.96	147.76	79
5	10.60	106.2	106.7	3.0	3.5	0.087	12.10	136.90	162
6	11.55	149.0	148.8	4.5	3.9	0.055	9.06	122.04	308
7	12.56	195.9	203.1	4.5	5.1	0.057	6.86	103.14	565
8	13.55	247.7	259.0	6.0	6.2	0.059	5.53	76.21	1088
9	14.53	255.6	273.1	6.0	6.6	0.078	4.99	45.48	1705
10	15.50	290.7	316.9	7.7	8.3	0.163	4.79	23.80	2249
11	16.46	310.5	368.5	10.4	10.8	0.260	4.59	12.54	1721
12	17.14	321.9	417.6	10.5	11.4	0.186	4.36	8.28	221
	14.75	264.3	292.2	7.2	7.7	0.139	5.53	45.68	8123

Conclusion

The study of scanners and software packages for the estimation of the positional accuracy on the images of the first (1935.0) and second (1976.9) epochs in the sky region with χ and h Persei clusters (the size of the region is 4 square degrees) gave the following results: $\sigma_{\alpha\delta} = \pm$ 0.085 " and $\pm$ 0.056" for the first and the second epochs respectively.

The errors of differences of coordinates and proper motions for 655 calculated and reference stars common in TYCHO2 and our catalogue are $\sigma\Delta_{\alpha\delta} = \pm$ 0.074" and $\sigma\Delta_{\mu\alpha\delta} = \pm$ 0.0018"/year respectively.

The photometric errors are $\sigma_m = \pm\ 0.065^m$ and $\sigma_B = \pm\ 0.208^m$ for the accuracy on internal convergence and by the comparison with the B-magnitudes of the TYCHO2 catalogue.

The comparison of 8123 common stars down to B $\leq 17.5^m$ with the stars of the UCAC4 gave the errors $\sigma_{\alpha\delta} = \pm$ 0.28", $\sigma_{\mu\alpha\delta} = \pm$ 0.0075"/year and $\sigma_m = \pm\ 0.139^m$ for the equatorial coordinates, proper motions and magnitudes respectively.

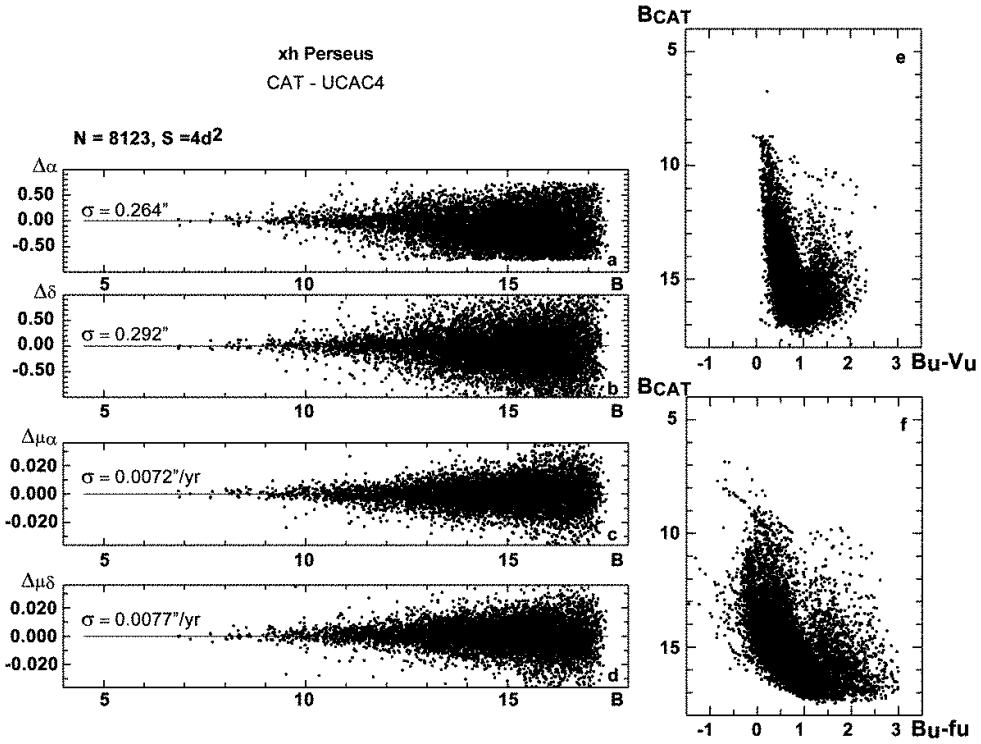

Fig. 8. The astrometric differences UCAC4-CAT of positions Δ_α, Δ_δ, proper motions $\Delta_{\mu\alpha}$, $\Delta_{\mu\delta}$ and two color diagrams for the UCAC4 stars. Here N is the number of reference stars, S is the area in the square degrees, B is the B-values from the TYCHO2, B_{CAT} - obtained magnitudes in B-scale of the TYCHO2, B_U, V_U, fu - stellar magnitudes of the UCAC4.

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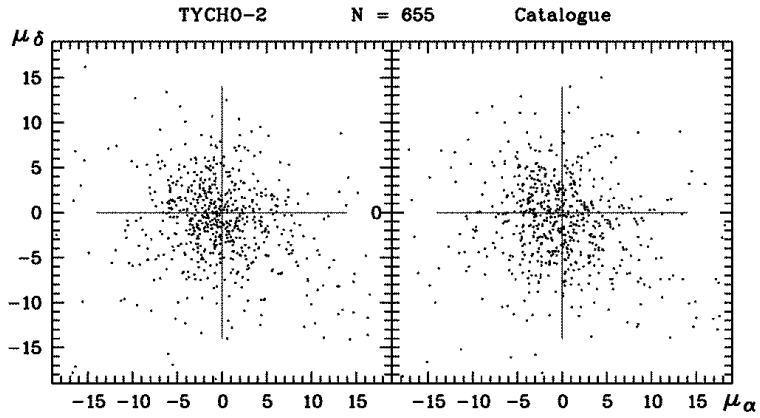

Fig. 9. The distribution of proper motions in a picture plane.

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