

## Subsection Virtual observatories and intensive data

# COMPARISON OF ZERO ZONE CATALOGUES OF THE FON PROGRAM BASED ON THE KYIV AND KITAB OBSERVATIONS

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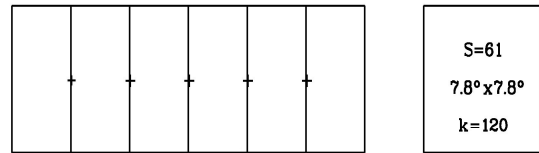
**ABSTRACT.** The two new catalogues for the zero zone of the FON project were created after the processing of two different collections of digitized photographic plates. The photographic plates were received at the DAZ and DWA telescopes of the Kitab observatory of the Republic of Uzbekistan (KO UAS) and of the Main astronomical observatory in Kyiv (MAO NASU) in the number of 90 and 120 plates, respectively. The digitization of these photographic plates in the frame of the Ukrainian Virtual Observatory project was performed by means of the Epson Expression 10000XL scanner with the scanning resolution of 1200 dpi. The coordinates of stars and galaxies for the both catalogues are determined in the system of the Tycho2 catalogue. The stellar magnitudes of all objects are done in B-magnitudes of the photoelectric standard system. The difference between the calculated and the reference positions is equal  $\sigma_{\alpha\delta} = \pm 0.06\text{--}0.07''$ . The internal accuracy of the both catalogues for all objects is  $\sigma_{\alpha\delta} = \pm 0.20''$ ,  $\sigma_B = \pm 0.18^m$  and  $\sigma_{\alpha\delta} = \pm 0.27''$ ,  $\sigma_B = \pm 0.17^m$ , respectively. We present the comparison of these both catalogues with each other and with the Tycho2, UCAC4 as well as PPMX catalogues and discuss the results.

**Keywords:** photometric – methods: data analysis – catalogs, virtual observatory tools – astrometry - techniques

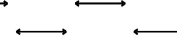
### 1. Introduction

On the basis of the processing of different sets of observational data of the FON project (Kislyuk et al., 2000, Yatsenko et al., 2011) for the zero zone were created two star catalogues of the positions and stellar magnitudes. This work was done by the using of the resources of the Ukrainian Virtual Observatory UkrVO (Vavilova et al., 2012, Vavilova et al., 2012). The sets of observational data consist of the photographic plates exposed with the Double Wide Angle Astrograph (DWA, 40/200, 103"/cm, Golosevo, h=186m) and the Zeiss Double Astrograph (DAZ, 40/300, 76"/cm, Kitab, h=657m). The catalogues were created on the basis of photographic plates digitized

KIEV, MAO NASU, DWA(D/F=40/200), 103"/mm, 1px=2.17", 13000x13000



$\Delta\alpha = 16\text{min}$



KITAB, UBAI UAS, DAZ(D/F=40/300), 67"/mm, 1px=1.45", 13000x13000

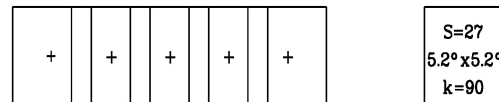


Figure 1: Scheme and the relative size of the overlapping zones for the MAO NASU and KO UAS.

by the using of the Epson Expression 10000XL scanner (Andruk et al., 2010, Golovnya et al., 2010, Protsyuk et al., 2014, Protsyuk et al., 2014, Protsyuk et al., 2014). The reduction procedure was done with the software that was previously used in the series of works (Andruk et al., 2014, Muminov et al., 2014, Yizhakevych et al., 2014, Protsyuk et al., 2014, Kazantseva et al., 2015) and is described in detail in the following publications (Muminov et al., 2015, Andruk et al., 2015, Andruk et al., 2016). The photographic plates were scanned with a spatial resolution of 1200 dpi, the size of each plate is 30 x 30 cm (13000 x 13000 pixels). The working areas (see Figure 1) are 7.8° x 7.8° (1 px = 2.17 ") and 5.2° x 5.2° (1 px = 1.45") for the DWA and DAZ telescopes respectively. The versions of both catalogues were obtained by the processing of single scans without the rotation of the plates on the 90°. This approach allows to save resources for the storing and processing information more than twice times without the loss of accuracy of the results. The software concept and the steps of the processing of digitized photographic plates

for the zero zone will be then applied for all photographic plates of the FON project exposed as in Kyiv (sky area from 0 to 90 degrees) and as well as in Kitab (sky area from 0 to -20 degrees) respectively.

**2. The processing of the digitized photographic plates and creating of the catalogues**

The processing of these two digitized sets of photographic plates exposed with the DWA (120 plates) and DAZ (90 plates) telescopes was performed on the base of the common method which was developed and has been applied in practice in the MAO NASU. The steps of the processing of the scanned photographic plates are:

1. Conversion of the tiff-format files to the fit-format files using the GIMP package.
2. The processing of the scans using the MIDAS/ROMAFOT package to obtain the rectangular coordinates X, Y and instrumental magnitudes of registered objects.
3. The dividing of the registered objects into two exposures for each digitized plate.
4. The creating of the files with the reference stars for each digitized plate using the Tycho2 catalogue.
5. The creating of the files for the relationship between the rectangular and equatorial coordinate systems of reference stars.
6. Correction of the rectangular coordinates of registered objects for systematic errors.
7. Reduction of the rectangular coordinates X, Y of registered objects in the system of equatorial coordinates  $\alpha$ ,  $\delta$  of the Tycho2 catalogue.
8. Conversion of the instrumental photometric values of objects to the system of photoelectric  $B_{pe}$  stellar magnitudes of the Johnson's system.

For the calibration of the characteristic curves of the photographic plates, the recording photometric field errors and the conversion of the instrumental photometric values to the system of photoelectric  $B_{pe}$  stellar magnitudes of the Johnson system were used data from the catalogues (Kornilov et al., 1991, Mermilliod, 1991, Andruk et al., 1995, 1996, Relke, et al., 2015). For the plotting of the characteristic curves of photographic plates was used the photometric information of both exposures.

The process of the creating of the CAT1 and CAT2 catalogues for the two sets of observations at the DWA and DAZ telescopes was as follows. In the overlapping zones of the photographic plates the identification and selection of candidates in stars and galaxies was carried out according to the following criteria:

- 1) the difference between equatorial coordinates should not be greater than the size of the one pixel
- 2) the difference between stellar magnitudes should not exceed  $\pm 2$  mag (because of the accounting of variable stars).

If the found candidate meets the selection criteria at least on two plates, it was included in the list of the objects for the catalogues. For the non-overlapping areas of the plates of DAZ telescope the candidates in stars and galaxies were implemented by the direct identification with the objects from the UCAC4 catalogue (Zacharias et al., 2013). The CAT1 and CAT2 catalogues contain

1320108 and 1795840 stars and galaxies up to  $B_{ph} \leq 16.5^m$  (the photographic magnitudes of the Johnson system) for the epoch of 1990.35 and 1983.29 respectively. The CAT1 and CAT2 catalogues cover the zones of width up to  $8^\circ$  (from  $-4^\circ$  to  $+4^\circ$ ) and of width up to  $5.2^\circ$  (from  $-2.6^\circ$  to  $+2.6^\circ$ ), respectively. As the result of the comparing CAT1 and CAT2 catalogues was received a third MCAT catalogue, which contains the averaged data for the 669480 stars and galaxies.

**3. Internal errors of the catalogues**

The distribution of internal errors of defined equatorial coordinates  $\sigma_\alpha$ ,  $\sigma_\delta$  and photometric magnitudes  $\sigma_{B_{ph}}$  of stars and galaxies on the intervals of stellar magnitudes of the three catalogues are given in the table 1. The average errors are provided at the top of the table 1 and their corresponding values for three catalogues are equal:

$$\sigma_\alpha = \pm 0.279", \pm 0.208", \pm 0.105"; \sigma_\delta = \pm 0.273", \pm 0.201", \pm 0.157"; \sigma_{B_{ph}} = \pm 0.168^m, \pm 0.176^m, \pm 0.140^m.$$

Table 1. The errors of the defined equatorial coordinates and stellar magnitudes for the three catalogues

$B_{ph}$ mag	$\sigma_\alpha, \sigma_\delta$ arcsec		$\sigma_{B_{ph}}$ mag
CAT1			
6.6	$\pm 0.286$	$\pm 0.249$	$\pm 0.204$
7.6	0.218	0.178	0.155
8.6	0.138	0.119	0.116
9.6	0.086	0.082	0.081
10.6	0.066	0.066	0.061
11.6	0.062	0.064	0.068
12.6	0.106	0.108	0.094
13.6	0.190	0.192	0.119
14.6	0.285	0.278	0.162
15.3	0.355	0.346	0.212
16.3	0.395	0.396	0.262
17.1	0.455	0.416	0.156
CAT2			
6.6	$\pm 0.203$	$\pm 0.356$	$\pm 0.296$
7.6	0.264	0.224	0.264
8.6	0.148	0.143	0.231
9.6	0.097	0.094	0.175
10.6	0.064	0.064	0.134
11.6	0.057	0.059	0.086
12.6	0.106	0.107	0.093
13.6	0.162	0.159	0.116
14.6	0.179	0.177	0.144
15.5	0.218	0.215	0.201
16.2	0.263	0.253	0.193
17.1	0.258	0.289	0.278
MCAT			
6.7	$\pm 0.173$	$\pm 0.203$	$\pm 0.333$
7.6	0.139	0.142	0.209
8.6	0.093	0.095	0.160
9.6	0.070	0.061	0.110
10.6	0.056	0.046	0.077
11.6	0.050	0.045	0.067
12.6	0.062	0.078	0.087
13.6	0.090	0.133	0.103
14.6	0.111	0.167	0.148
15.3	0.123	0.191	0.170
16.2	0.132	0.207	0.182
17.1	0.132	0.187	0.491

#### 4. Actual accuracy (external errors) of the catalogues

The results of the comparison of the three catalogues with the reference Tycho2 catalogue are presented in the second part of the table 2 as well as on the figure 2.

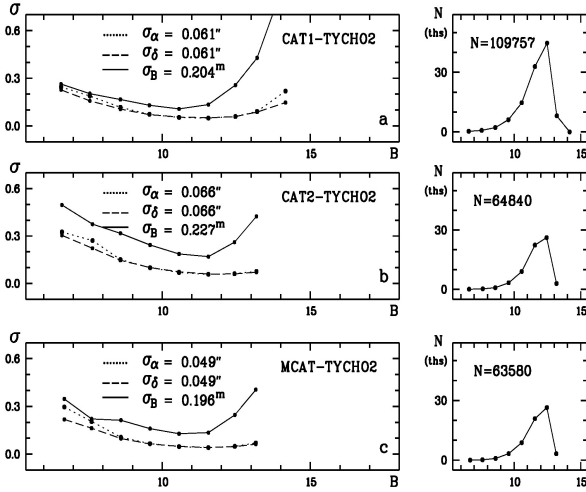


Figure 2: The trend of the errors of astrometric reduction with the B-magnitude for the three catalogues relative to the reference Tycho-2 catalogue.

We point out that the errors of astrometric reduction for the reference stars of the Tycho2 catalogue do not exceed the value of  $\sigma_{\alpha\delta} = \pm 0.07''$ . The comparison of the calculated equatorial coordinates of the created catalogues was also made with the equatorial coordinates of the UCAC4 (Zacharias et al., 2013) and PPMX (Roeser et al., 2008) catalogues. The results of the comparison are given in the third and fourth parts of the table 2 as well as on the figures 3 and 4.

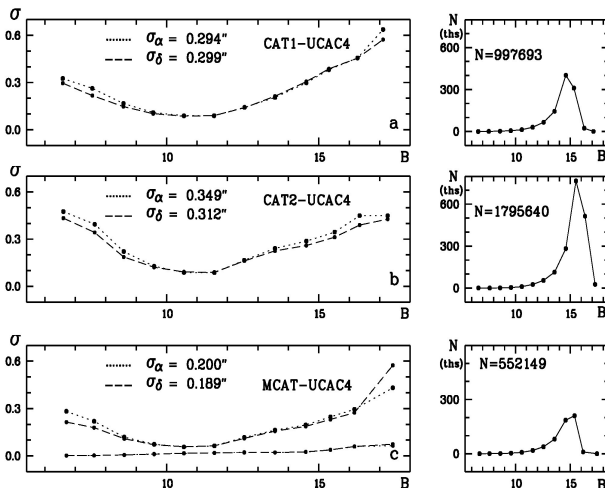


Figure 3: The trend of the errors of differences in equatorial coordinates with the B-magnitude for the three catalogues relative to the UCAC4 catalogue.

The astrometric errors of the created catalogues relative to the UCAC4 catalogue are:  $\sigma_\alpha = \pm 0.294''$ ,  $\pm 0.349''$ ,  $\pm 0.200''$ ;  $\sigma_\delta = \pm 0.299''$ ,  $\pm 0.312''$ ,  $\pm 0.189''$ . The error values relative to the PPMX catalogue are:  $\sigma_\alpha = \pm 0.260''$ ,  $\pm 0.274''$ ,  $\pm 0.186''$ ;  $\sigma_\delta = \pm 0.273''$ ,  $\pm 0.261''$ ,  $\pm 0.188''$ .

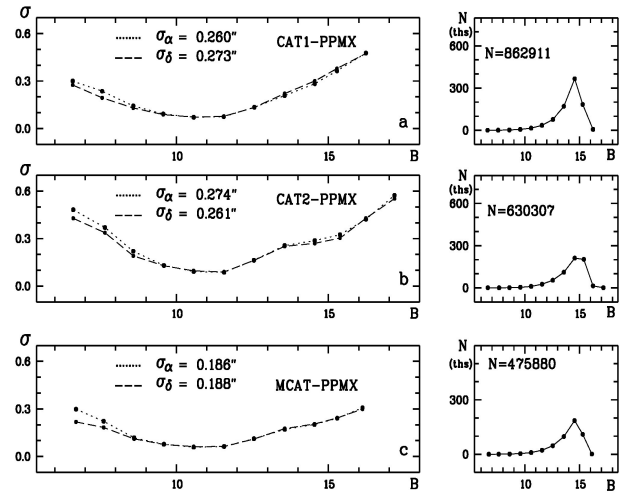


Figure 4: The trend of the errors of differences in equatorial coordinates with the B-magnitude for the three catalogues relative to the PPMX catalogue.

The photometric errors for the new three catalogues are presented on the figure 5.

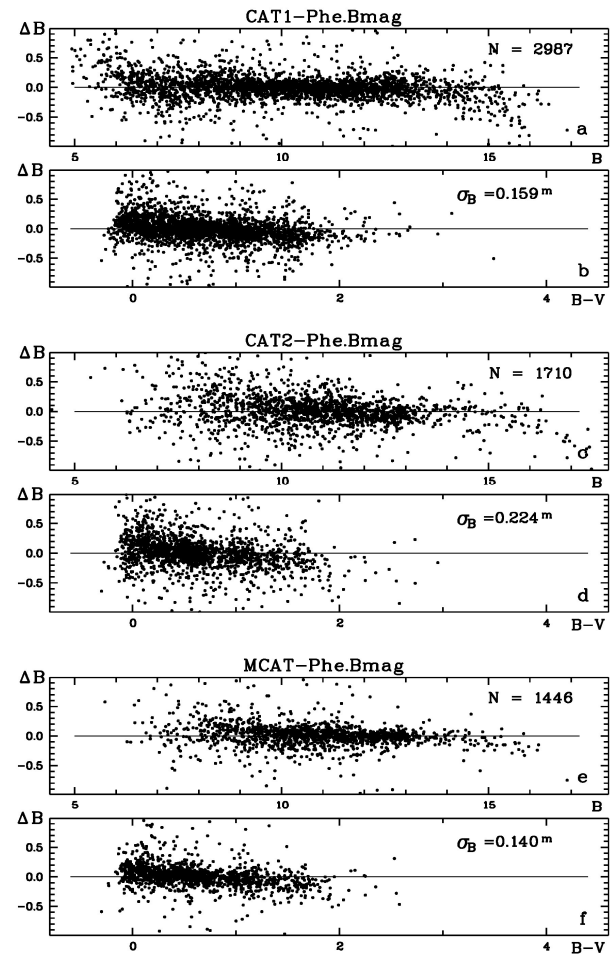


Figure 5: The trend of the errors of differences in magnitudes with the B-magnitude for the three catalogues relative to the photo electrical B-magnitudes.

The photometric errors were determined by the comparing of the stellar magnitudes of our three catalogues

with the photoelectric values of reference photometric catalogues. The calculated results are presented at the bottom of the table 2. For the three catalogues the error values are as follows:  $\sigma_{\text{Bph}} = \pm 0.159^{\text{m}}, \pm 0.224^{\text{m}}, \pm 0.140^{\text{m}}$ .

Table 2. The external errors of the three catalogues

	CAT1	CAT2	MCAT
N	320108	1795840	669480
$\sigma_{\alpha}$	0.279"	0.208"	0.105"
$\sigma_{\delta}$	0.273"	0.201"	0.157"
$\sigma_{\text{Bph}}$	0.168 <sup>m</sup>	0.176 <sup>m</sup>	0.140 <sup>m</sup>
TYCHO2			
	109757	64810	63580
	0.061"	0.066"	0.049"
	0.061"	0.066"	0.049"
	0.204 <sup>m</sup>	0.227 <sup>m</sup>	0.196 <sup>m</sup>
UCAC4			
	997693	1795840	552149
	0.294"	0.349"	0.200"
	0.299"	0.312"	0.189"
PPMX			
	862911	630307	475880
	0.260"	0.274"	0.186"
	0.273"	0.261"	0.188"
Pe.Bmag			
	2987	1710	1448
	0.159 <sup>m</sup>	0.224 <sup>m</sup>	0.140 <sup>m</sup>

### 5. Some remarks

The "Photographic Survey of the Northern Sky" (FON project) was proposed by the Main astronomical observatory Academy of Sciences of Ukraine, Kyiv (MAO NASU) (Kolchinsky et al., 1977; Kolchinsky et al., 1979). The idea of this project was due by the situation in the field of photographic astrometry in the early seventies of the twenties century. Some observatories of the former Soviet Union (Goloseevo, Zvenigorod, Dushanbe, Abastumani and Kitab) equipped with identical astrographs produced by the "Carl Zeiss Jena" (DDR) took part in this project. The observatories finished the observations at the end of the 90s of the XX century and have in their archives thousands of the photographic plates waiting for the reduction. The archive of the Kitab observatory (zone from  $-20^{\circ}$  to  $+30^{\circ}$ ) contains about 2600 photographic plates. Now the staff members of the Kitab observatory have organized the digitalization of the photographic plates of the "FON" project.

### 6. Conclusion

The created star catalogues of the positions and stellar magnitudes (Bph) of the zero zone of the Kyiv and Kitab parts of the FON project will be posted on the web pages of the MAO NASU and the Astronomical Institute of the Uzbek Academy of Sciences. The catalogues contain the equatorial coordinates of stars ( $\alpha, \delta$ ) on the equinox 2000.0 as well as the stellar magnitudes (Bph). We provide the errors definitions of these values and number of determinations as well as an additional information in the form of the average values for the diameters of star images  $f$  (FWHM) and the values of the maximal intensity in the center of object images ( $cInt$ ).

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