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CATALOGUE OF COORDINATES AND B-MAGNITUDES IN -20º – +2º ZONE BASED ON THE ULUGH BEG ASTRONOMICAL INSTITUTE PART OF THE FON PROJECT

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ABSTRACT. Catalogue of 13.4 million stars down to 17.5^m was obtained in 2017 by using plates from the Kitab Observatory of Ulugh Beg Astronomical Institute (UBAI) of the Uzbek Academy of Sciences. Kitab's part of Photographic Sky Survey (Russian abbreviation is FON, in next contexts) project include more than 2600 photographic plates, exposed on the Double Astrograph of Zeiss (DAZ, D/F = 40/300, 69"/mm) from 1981 to 1996. Digitization of these plates was made by using Epson Expression 10000XL scanner with the 1200 dpi resolution. Catalogue includes objects from the 1963 plates in declination zone between -20° and +2° for middle epoch 1984.97. The equatorial coordinates of objects were determined in the Tycho-2 reference system and the B-magnitudes in the system of the photoelectric standards. Five participants from Uzbekistan, Germany and Ukraine have taken part in the processing of the digitized images. The average internal accuracy of the catalogue for one observation are 0.23" and 0.15^m for the equatorial coordinates and B-magnitudes respectively. For the stars brighter than 14^m the errors are 0.09" and 0.05^m respectively. The analysis of the catalogue and its comparison with the several astrometric catalogues was done.

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

1. Introduction

Kitab observatory is the branch of UBAI and exists since 1930. This observatory was organized on the initiative of prof. M.F. Subbotin (1893-1968), appointed in 1922 by the director of the Tashkent Astronomical Observatory (formerly name of UBAI). This is only in the Central Asia and unique place of five world latitudinal stations where is located on the same geographical parallel. It is located on the +39°08' parallel.

In 1975, a double astrograph of Zeiss was installed to conduct observations in the Kitab and from 1980 to early 2000, several thousand observational data were obtained. Most of these data were obtained under the FON project.

Photographic Sky Survey (abbreviation in Russian is FON) project was initiated by the Main Astronomical Observatory of the National Academy of Sciences of Ukraine (MAO NANU, Kyiv, Ukraine) (Kolchinskii, 1977) and observations were made at six observatories such as Goloseevo, Zvenigorod, Dushanbe, Abastumani, Zelenchuk and Kitab. These observatories were equipped with 40 cm Double Astrograph of Zeiss (DAZ) and wide field astrographs with the same aperture, but focal length were 200 and 300 cm. The observations of the sky zone from -20° to +28° according to their declinations on the same astrograph (DAZ, D/F = 40/300) in Kitab, were made with a shift of the centers of photographic fields on two degrees by declination and four degrees by right ascension (Fig. 1). The photographing of each field was conducted with two exposures (long: from 22 to 28 minutes and short: from 40 to 75 seconds) on the same photographic plate with the shift on both coordinates. The duration of the long exposure was chosen in such a way to obtain images of stars down to 16-17 magnitude. During 1981-1996 more than 2600 astronegatives were taken under the project. The main part of these plates consists of the southern sky (more than 1900 plates with full overlapping) and selected fields in the northern sky. The Kitab observatory had successfully completed its task under the FON project.

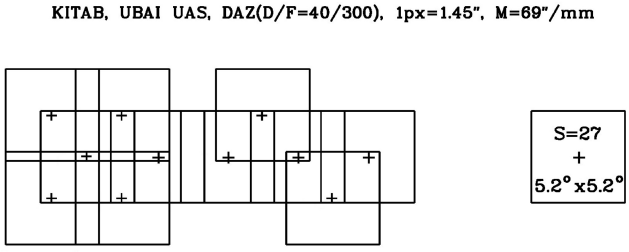

Figure 1: The overlapping scheme of photographic plates obtained in Kitab.

2. Processes of digitization and compiling the catalogue of the southern part of FON project in Tashkent

In 2014-2015 all astronegatives in Kitab were transferred to the UBAI in Tashkent (Uzbekistan) and digitization and systematization of these plates was started. In 2016, all plates of the project were scanned using flatbed scanner Epson Expression 10000XL. Totally 1963 astro negatives (cover sky by declination from -20° to +2°) were processed for compiling the catalogue. As before mentioned, for the digitizing of astronegatives a commercial scanner Epson Expression 10000XL was used. The spatial resolution is 1200 dpi (Protsyuk, 2014c, Protsyuk, 2014d) and size of the scanned images was up to 30x30 cm or 13000x13000 pixels (1px=1.45″). For obtaining useful information from digitized astronegatives following steps have been done and for processing the scanned images common method which was developed and has been applied in practice in the MAO NASU (Andruk, 2012, Andruk, 2015b) was used:

1. Image conversion from *tiff* to *fit* using the GIMP package after scanning astronegatives.
2. The processing of the scans using the LINUX/MIDAS/ROMAFOT package to obtain the rectangular coordinates *X*, *Y* and instrumental magnitudes of registered objects.
3. The separating of the registered objects into two exposures for each digitized plate (Andruk, 2012).
4. The creating of the files with the reference stars for each digitized plate using the Tycho-2 catalogue (Protsyuk, 2014b).
5. The creation of an additional file for the determination of 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 α, δ of the Tycho-2 catalogue.
8. Conversion of the instrumental photometric values of objects to the system of photoelectric B_{pe} stellar magnitudes of the Johnson's system (Andruk, 2017).

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 (Relke, 2015).

The equatorial coordinates and the photometric B-magnitudes of registered objects were obtained for all scans using specially developed software in the LINUX/MIDAS/ROMAFOT (Andruk, 2010), which was described in (Yatsenko, 2011, Muminov, 2012, Protsyuk, 2014a). This software has already been successfully applied for the processing of the scanned images of Kyiv's part of the FON project to create a new photographic catalogue down to 16-17 stellar magnitude (Andruk, 2016a, Andruk, 2016b).

2.1. Astrometric and photometric reduction

At the stage of diagnosing the systematic errors of the scanner $\Delta\alpha$ and $\Delta\delta$ and at the stages of reduction of the rectangular coordinates *X, Y* of the objects to the system of equatorial coordinates α, δ of the Tycho-2 catalogue, the tangential coordinates ξ, η and *B*-magnitudes were calculated using the method of least squares by formulas of the form (1) and (2), respectively:

$$\begin{cases} \xi_i = a_1 + a_2 X_i f_i + a_3 Y_i f_i + a_4 R_i m_i + a_5 f_i + \sum b_{lm} X_i^l Y_i^m \\ \eta_i = c_1 + c_2 X_i f_i + c_3 Y_i f_i + c_4 R_i m_i + c_5 f_i + \sum d_{lm} X_i^l Y_i^m \end{cases} \quad (1)$$

$$(l = 0 \div 6,\ m = 0 \div 6,\ l + m = n,\ n = 1 \div 6)$$

$$B_i = e_1 + e_2 X_i + e_3 Y_i + e_4 R_i + e_5 R_i^2 + \sum f_n m_i^n \quad (2)$$

$$(\mathrm{n} = 1, 2, \ldots 5)$$

where $i = 1, 2, \ldots N$ is the number of stars in the Tycho-2 catalogue on the plate; X_i, Y_i and R_i are the coordinates and distance of the image of the stars relative to the center of the plate; m_i is the instrumental photometric magnitudes of the stars; f_i is FWHM of the stars; the coefficients a_2, a_3, a_4 and c_2, c_3, c_4 are responsible to the coefficients of a_5, c_5 which are taken into account the influence of the light curve (calculated separately); the coefficients of the full sixth-degree polynomial (27 terms) b_{lm} and d_{lm} in the generalized case describe the aberrations of the telescope optics, weighed down by systematic scanner errors; the coefficients e_2, e_3, e_4, e_5 are responsible for the photometric equation (photometric error) of the field, and the coefficients f_1, f_2, f_3, f_4, f_5 correspond to the functional description of the type of characteristic curves themselves. The equation (2) is chosen as optimal, minimizing the photometric reduction errors in the B_{pe} photoelectric standards system.

2.2. Compiling the catalogue and its accuracy

The catalogue of Kitab consists near 13.4 million stars and galaxies up to 17.5^{m} for the middle epoch 1984.97. The equatorial coordinates were taken in the system of Tycho-2 and the photographic magnitudes in the system of Johnson. For compiling the catalogue 1963 astronegatives of Kitab observatory were processed. The quantities of the processed plates by zones are shown in Table 1. The linear size of the plates is around 30x30 cm or 13000x13000 px. The field of view of the telescope or sky area on the plates is roughly 5.5°x5.5°.

Table 1: Number of processed plates in zones

Zone	N	Zone	N
0	*179*	**-10**	*180*
-2	*174*	**-12**	*182*
-4	*234*	**-14**	*201*
-6	*228*	**-16**	*177*
-8	*240*	**-18**	*168*

In the second step of processing of 1963 plates, around 130.98 million objects were registered. After the procedures of mutual identifications, the average number of measurements of the stars and galaxies is l=4.4, and near

1.25 millon stars and galaxies (9.38% of the total number) are also added to the catalogue which were measured once.

The number of stars by magnitudes is given on Fig. 2.

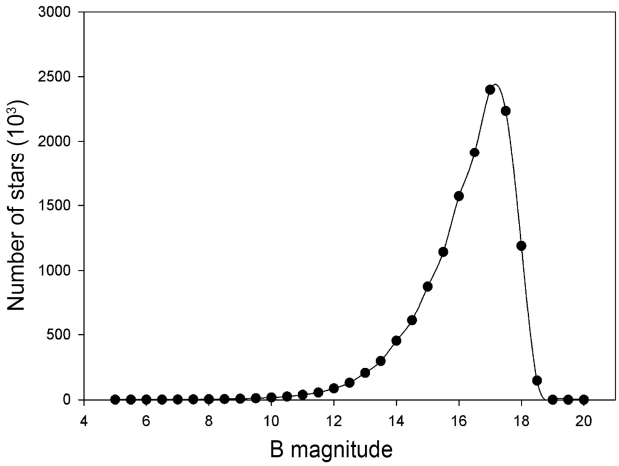

Figure 2: Number of stars by B-magnitudes.

The criteria of the identification and selection of candidates of the stars and galaxies in the overlapping zones is given below:

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 ± 2^m (because of the accounting of variable stars).

If the candidate was identified at least on two plates it was according to the criteria, otherwise it was estimated as object of the catalogue.

In the Table 2 the distribution of internal errors of defined equatorial coordinates σ_α, σ_δ, photometric magnitudes σ_{Bph}, *FWHM*, intensity at the center of object and number of stars and galaxies on the intervals of stellar magnitudes of the catalogue are given. The average errors are provided at the top of the table 2 and their corresponding values are equal: σ_α=0.225"; σ_δ=0.234"; σ_{Bph}=0.154^m. Calculated errors of equatorial coordinates by declinations are shown on Fig. 3. The errors of equatorial coordinates and magnitudes as the function of B-magnitude are shown on Fig. 4.

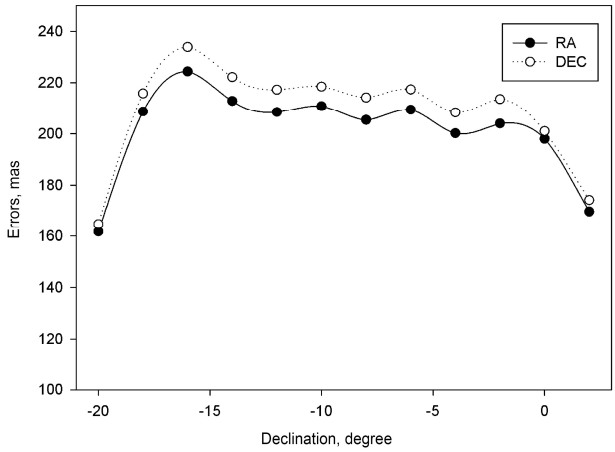

Figure 3: Estimated errors by declinations of the stars.

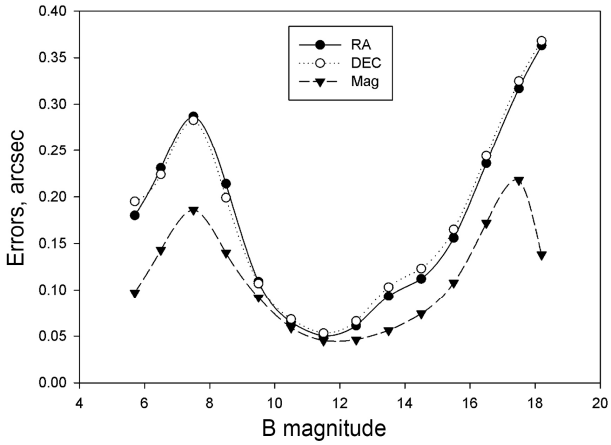

Figure 4: The errors of RA, DEC and magnitudes according to B-magnitudes.

Table 2. The internal errors of the defined equatorial coordinates and stellar magnitudes of the catalogue.

	B_{ph}	σ_α	σ_δ	σ_{Bph}	*FWHM*	*Intencity*	*k*
1	*5.72*	*0.180*	*0.195*	*0.097*	*83.4*	*113.7*	*226*
2	*6.57*	*0.231*	*0.224*	*0.143*	*79.2*	*109.2*	*1276*
3	*7.58*	*0.287*	*0.283*	*0.186*	*69.4*	*105.6*	*3828*
4	*8.56*	*0.214*	*0.199*	*0.140*	*54.1*	*100.4*	*9250*
5	*9.56*	*0.109*	*0.107*	*0.092*	*34.6*	*100.2*	*20863*
6	*10.56*	*0.065*	*0.068*	*0.059*	*21.4*	*95.3*	*48313*
7	*11.56*	*0.050*	*0.053*	*0.045*	*13.7*	*87.2*	*110290*
8	*12.57*	*0.061*	*0.066*	*0.046*	*9.7*	*74.0*	*259387*
9	*13.56*	*0.093*	*0.103*	*0.056*	*7.7*	*57.8*	*591427*
10	*14.55*	*0.112*	*0.123*	*0.074*	*6.8*	*40.1*	*1197019*
11	*15.54*	*0.156*	*0.165*	*0.108*	*6.3*	*23.9*	*2208206*
12	*16.53*	*0.236*	*0.244*	*0.172*	*5.9*	*13.1*	*3562269*
13	*17.55*	*0.317*	*0.325*	*0.218*	*5.6*	*7.8*	*3726545*
14	*18.15*	*0.363*	*0.368*	*0.138*	*5.3*	*5.6*	*416800*
Avg.	***16.17***	***0.225***	***0.234***	***0.154***	***6.4***	***20.6***	***12155699***

3. Conclusion

In 1981-1996 in frame of the FON project more than 2600 photographic plates with 30x30 cm in size corresponding to 5.5°x5.5° field of view were obtained in Kitab observatory and this archive is stored at the Astronomical Institute of the Uzbek Academy of Sciences in Tashkent, Uzbekistan. The archive includes between -20 and +28° of the sky by declination. As result of digitization and processing of 1963 plates of the Kitab's archive the catalogue of near 13.4 million equatorial coordinates and B-magnitudes of stars and galaxies down to 17.5^m was compiled for the middle epoch 1984.97 (Pakuliak L.K., 2016, Yuldoshev, 2017).

The coordinates were defined in the system of Tycho-2 and photographic B magnitudes in the Johnson's system. The internal accuracy of the catalogue is $\sigma_{\alpha\delta}$=0.23" and σ_B=0.15^m for all objects on the catalogue, $\sigma_{\alpha\delta}$=0.085" and σ_B =0.054^m for the objects in 5^m-14^m. The convergence of the coordinates with reference system of Tycho-2 and magnitudes with the photoelectric B magnitudes is $\sigma_{\alpha\delta}$=0.042" (for 356 665 objects) and σ_B=0.16^m (for 6 719 objects) respectively. The errors related to the UCAC4 catalogue are $\sigma_{\alpha\delta}$=0.26" (identified 9 892 697 or 73.75% objects).

In addition, it is planning to digitize and process of 1600 plates of FON project in Tajikistan. This archive covers from 0° to +90° of the sky (Mullo-Abdolov, 2017).

Interim results on the progress of compiling the catalogue of Kitab's part of FON program were reported at the Gamov-2015 (Andruk, 2015a), Gamov-2016 (Yuldoshev, 2016a), and other conferences (Muminov, 2013; Muminov, 2016; Yuldoshev, 2016b).

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References

Andruk V.M. et al: 2010, *Kinem. Phys. Cel. Bodies*, **26, N3**, 146.

Andruk V.N., Ivanov G.A., Yatsenko A.I. et al.: 2012, *Bull. T. Shevchenko Nat. Univ. Kyiv., Astron*. **N48**, 11 (in Ukraine)

Andruk V.N., Relke H., Protsyuk Yu.I. et al.; 2015, *Odessa Astron. Publ.*, **28,** 188.

Andruk V.N., Pakuliak L.K., Golovnya V.V. et al.: 2015, preprint, *arxiv.org/abs/1512.05535*.

Andruk V.N., Golovnia V.V., Ivanov G.A. et al.: 2016, *Kinem. Phys. Cel. Bodies*, **32, N1**, 38.

Andruk V.N., Pakuliak L.K., Golovnia V.V. et al.: 2016, *Kinem. Phys. Cel. Bodies*, **32, N5**, 260.

Andruk V.N., Pakuliak L.K., Golovnia V.V. et al.: 2017, *Science and Innovation*, **13a, N1**, 17.

Kolchinskii I.G., Onegina A.B.: 1977, *Astrometry and Astrophysics*, **N33**, 11 (in Ukraine).

Mullo-Abdolov A., Kokhirova G., Relke H. et al.: 2017, *Odessa Astron. Publ.,* 30, this issue

Muminov M.M., Kahharov B.B., Yuldoshev K.H. et al.: 2013, *Izvestija GAO. Pulkovo*, **220**, 517.

Muminov M.M., Ehgamberdiev Sh.A., Latipov A.A. et al.: 2016, *Izvestija GAO. Pulkovo*, **223**, 339.

Pakuliak L.K., Andruk V.M., Golovnia V.V. et al.: 2016, *Odessa Astron. Publ*. **29, N1**, 132

Protsyuk Yu.I., Martynov M.V., Mazhaev A.E. et al.: 2014, *Kinem. Phys. Cel. Bodies*, **30**, **N6**, 296.

Protsyuk Yu.I., Andruk V.N., Kazantseva L.V. 2014 *Odessa Astron. Publ.,* **27**, **N1**, 59-60.

Protsyuk Yu.I., Andruk V.N., Kazantseva L.V. et al.: 2014, *Odessa Astron. Publ*., **27**, **N1**, P..61.

Protsyuk Yu.I., Kovylianska O.E., Protsyuk S.V. et al.: 2014, *Odessa Astron. Publ*., **27**, **N1**, 63.

Relke E., Protsyuk Yu.I., Andruk V.N. et al. 2015, *Odessa Astron. Publ*., **28, N2**, 211.

Yatsenko A.I., Andruk V.N., Golovnya V.V. et al.: 2011, *Kinem. Phys. Cel. Bodies*, **27**, **N5**, 249.

Yuldoshev Q.X., Muminov M.M., Ehgamberdiev Sh.A. et al.: 2016, *Odessa Astron. Publ*., **29,** 160.

Yuldoshev Q., Usmanov O., Ehgamberdiev E. et al.: 2016, *Bull. T. Shevchenko Nat. Univ. Kyiv., Astron.* **N54**, 28 (in Ukraine)

Yuldoshev Q.X., Ehgamberdiev Sh.A., Muminov M.M. et al.: 2017, *Kinem. Phys. Cel. Bodies*, **33**, **N5**, 250.