ISSN 2409-9066. Sci. innov. 2017, 13(1): 15—23 doi: https://doi.org/10.15407/scine13.01.015

Andruk[1], V.M., Pakuliak[1], L.K., Golovnia[1], V.V., Shatokhina[1], S.V., Yizhakevych[1], O.M., Protsyuk[2], Yu.I., Eglitis[3], I., Eglite[3], M., Kazantseva[4], L.V., Relke[5], H., Yuldoshev[6], Q.X., and Muminov[7], M.M.

[1] Main Astronomical Observatory, the NAS of Ukraine, 27, Akademika Zabolotnoho St., Kyiv, 03680, Ukraine, tel. +380 44 5264768
[2] Research Institute «Mykolaiv Astronomical Observatory», 1, Observatorna St., Mykolaiv, 54030, Ukraine, tel. +380 512 477014
[3] Baldones Observatory, Institute of Astronomy, University of Latvia, Baldone, Latvija, LV-2125, tel. +371 679 328 63
[4] Astronomical Observatory of Kyiv Shevchenko National University, 3, Observatorna St., Kyiv, 04053, Ukraine, tel. +380 44 4862691
[5] Walter-Hohmann-Observatory, 159, Wallneyer St., Essen, 45133, Germany, tel. +49 201 493941
[6] Ulugh Beg Astronomical Institute of the Uzbek Academy of Sciences, 33, Astronomicheskaya St., Tashkent, Uzbekistan, fax: +998 712 344867, tel. +998 712 358102
[7] Andijan State University, 129, Universitetskaja St., Andijan, 170100, Uzbekistan, fax: +998 742 238 830

STAR PHOTOMETRY ON DIGITIZED ASTRONEGATIVES

This paper discusses the issues of characteristic curve restoration for astronegatives exposed in the wide range of expositions in U, B Johnson color bands using different telescopes. Photographic plates are digitized by Epson commercial scanners. Digitized images are processed in MIDAS/ROMAFOT software. The accuracy of characteristic curve restoration using photoelectric data is within the range 0,1—0,2^m.

Keywords: U and B stellar magnitudes, astronegatives, and image processing.

In 2004, the MAO of the NAS of Ukraine developed basic software in LINUX/MIDAS/ROMAFOT environment in order to obtain the rectangular coordinates and photometric characteristics of the objects recorded in the digitized astronegatives [1, 2]. In parallel, a program to determine the equatorial coordinates and photometric values of stars, galaxies, and satellites of the major planets, asteroids and other objects was developed in FORTRAN and launched successfully [3, 4, 5, 6]. As of today, processing of large volumes of records and images has been successfully implemented with catalogues of locations and magnitudes of objects obtained in various observational programs:

- Photographic sky survey (PSS) program (2260 plates of the Kyiv part of the program have been processed and a catalog of positions and *B*-values of 19.5 million stars and galaxies has been created) [7, 8];
- The first epoch of observations for obtaining stellar proper motions in the vicinity of open clusters (290 records captured in Mykolaiv Astronomical Observatory have been processed; a catalog of positions and *B*-values of 2.7 million stars has been created) [9]
- Saturn's satellites (1385 positions from 250 astronegatives processed) [10];
- Other objects [11];
- Observations of Uranus and Neptune (1575 positions obtained at different observatories) [12];
- Pluto (59 positions) [13] and others [14].

In 2015, 2200 plates of the Kitab part of PSS program (from 0 to –20°) [15, 16], as well as 750 plates exposed in the U-band on 1.2 m Schmidt telescope [17] started to be scanned and processed. The star magnitudes of objects recorded in the astronegatives have been reduced in Ty-

cho2 system or in the system of *U*, *B* photoelectric measurements of stars [18, 19, 20, 21].

STAGES OF ASTRONEGATIVE PROCESSING

The process of extracting useful information from the digitized plates with images of star fields consists of the following stages:

1) digitization of astronegatives by commercial scanners such as *Epson* and *Microtek* (scan mode 1200 dpi) [22, 23];

2) conversion of files from 16-bit tiff to 8-bit fits format using GIMP package;

3) calculation of rectangular coordinates *X*, *Y* and instrumental photometric magnitude values

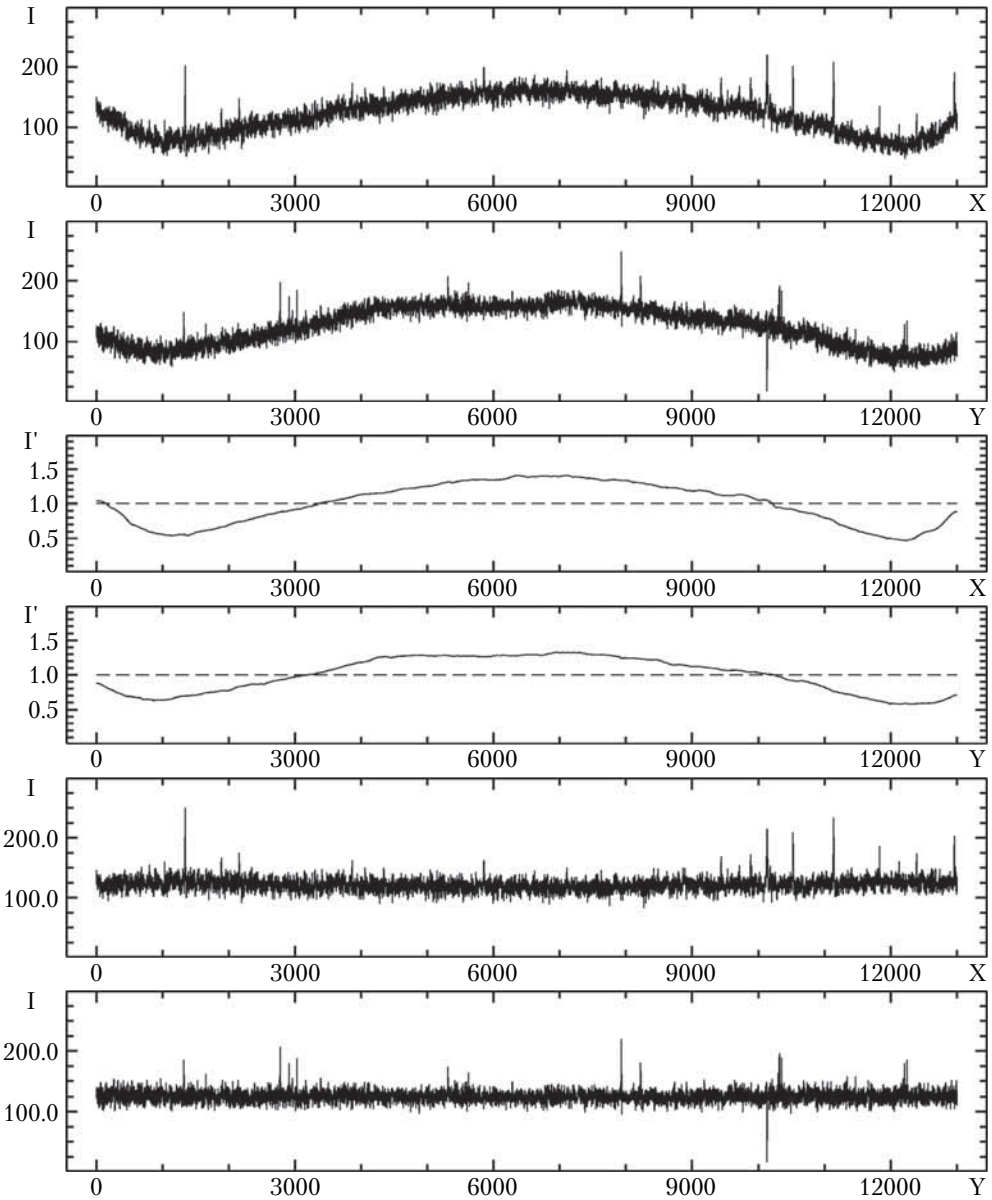

Fig. 1. Photometric matching of digitized astronegative. Central photometric profiles in *X*, *Y* for the plate number 219 of Kyiv PSS program

m, *f* for all objects recorded in astronegatives in MIDAS/ROMAFOT;

4) separation of recorded objects (if necessary) on exposure [24];

5) creation of auxiliary data file for identification of rectangular and equatorial coordinates of reference stars [25];

6) astrometric reduction for all objects to the equatorial α, δ coordinate system of Tycho2 catalog by the epoch of plate exposure;

7) photometric reduction of instrumental magnitude values *m* to U_{pe}, B_{pe} photoelectric system.

Before computing the data on recorded objects in ROMAFOT, photometric matching of the digitized picture of the star field is done in MIDAS. Fig. 1 shows an example of central photometric profiles in *X*, *Y* for the plate number 219 of Kyiv PSS program: the top two panels bear the profiles for the primary scan; the central panel shows a normalized profile of flat field envelopes; the bottom panels feature the resulting profiles after the correction of primary scan of flat field envelop; for digitized records the flat field is smoothed 3D image of the distribution of blackening density of the plate after removing the exposed objects from it.

The fixation of objects is illustrated in more detail in Fig. 2 for a part of plate numbered 15652 exposed in the U-band on 1.2-meter Schmidt telescope in Baldone (Latvia). The panels show: *a* – a 3D projection of the scanned area; *b* – built tops of the re-exposed stars; *c* – the sum of the two previous projections; *d* – flat field for this area (the stars are removed); *e* – diaphragms for the objects; *f* – the final view before processing in ROMAFOT.

TWO-EXPOSURE PHOTOMETRY OF STARS

Fig. 3 features H and D curves *1* and *2* for the long (20 min) and short (20 s) exposures of astronegative 1 of Kyiv PSS program (telescope Dou-

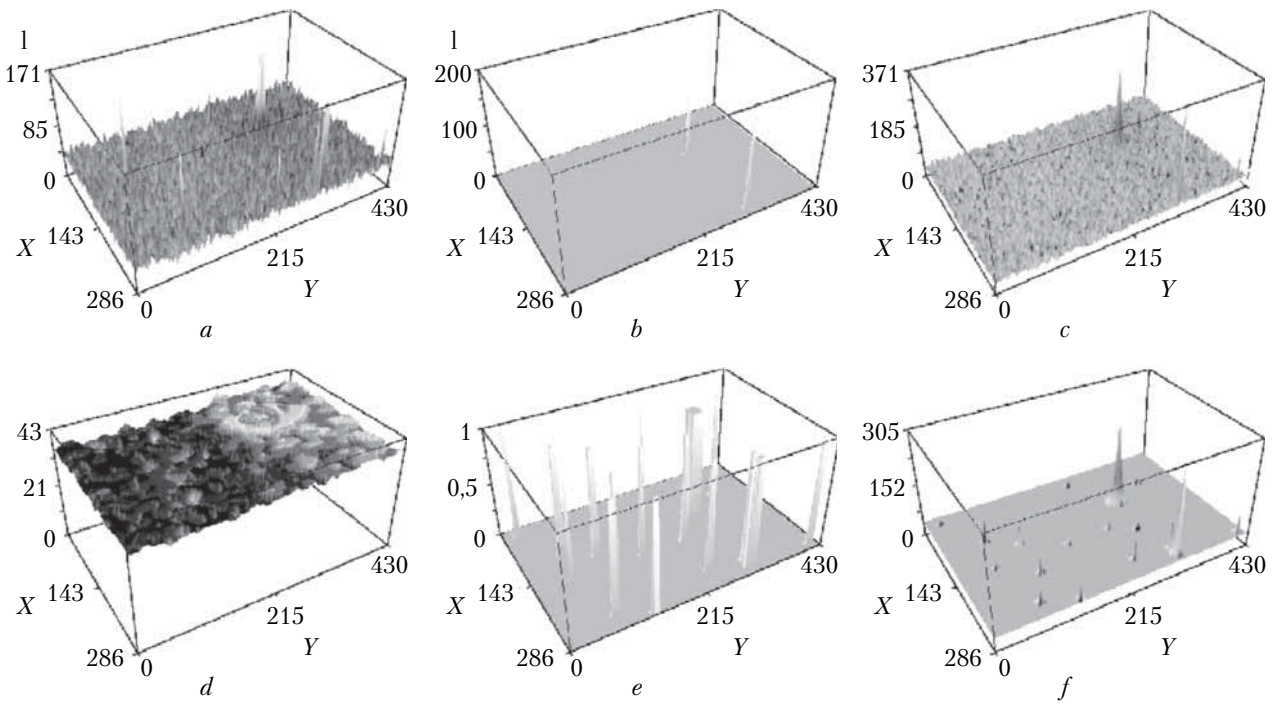

Fig. 2. Processing in MIDAS/ROMAFOT of a part of plate numbered 15652 exposed in the U-band on 1.2-meter Schmidt telescope in Baldone (Latvia)

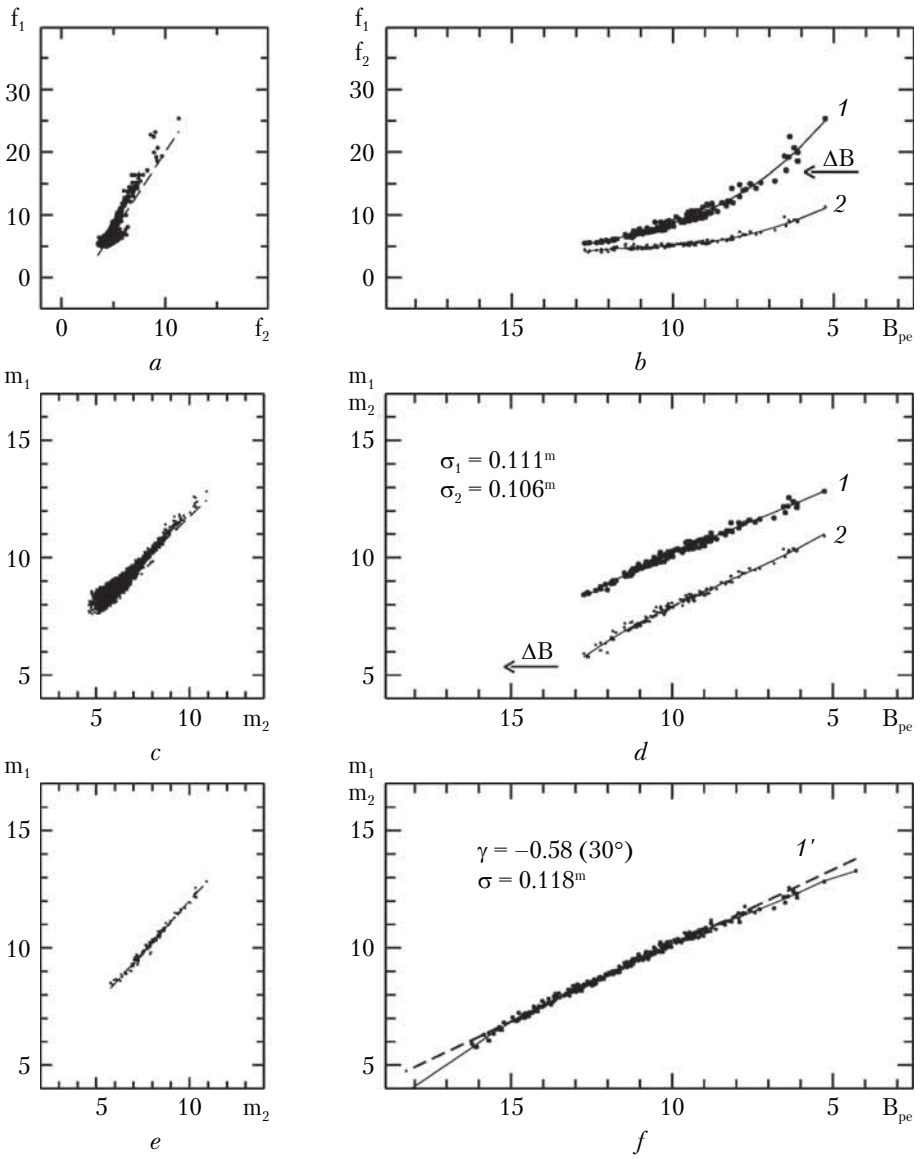

Fig. 3. H and D curves *1* and *2* for the two exposures of astronegative 1 of Kyiv PSS program (telescope DWA, Kyiv)

ble Wide Angle Astrograph, DWA, Kyiv). The panel *a* shows the correlation of diameters of star images f_1 for the long exposure with respect to that of the short one f_2; panel *b*: the correlation of diameters of star images of the two exposures f_1, f_2 and photoelectric magnitude values B_{pe}; panel *c*: correlation of instrumental values m_1 and m_2 of the two exposures; panel *d*: H and D curves of astronegative for the two exposures; panel *f*: combined H and D curve. Errors (differences between the calculated and the photoelectric *B*-values) of H and D curve for distance from the plate center *R*, color index $B-V$ and photoelectric values B_{pe} are negligible and estimated as 0.1^m. The combined H and D curve 1' is obtained through shifting by ΔB the *B*-magnitudes for the short exposure 2 as extension of curve *1* for the long exposure towards the faint and extremely faint stars

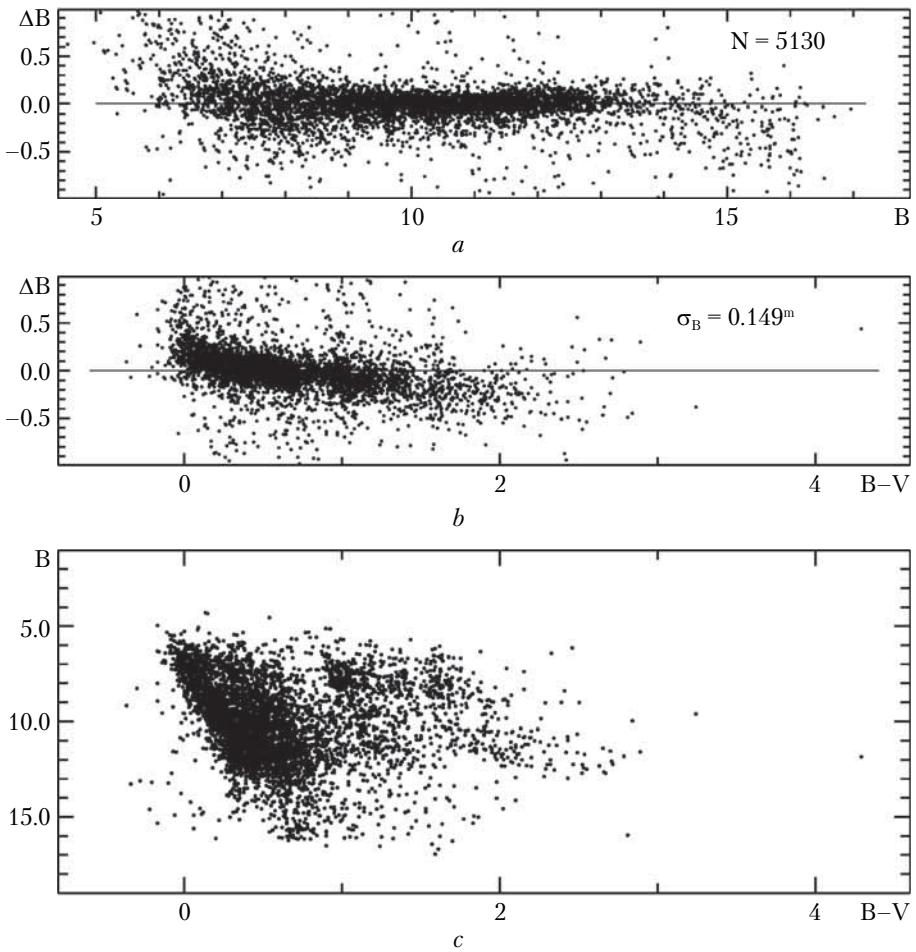

Fig. 4. Photometric errors of the catalogue of near-pole area of Kyiv PSS program. The top panels *a* and *b* feature differences ΔB between the catalogue B_{ph}-magnitudes and photoelectric B_{pe}-magnitudes with respect to photoelectric B_{pe} and $(B-V)_{pe}$ magnitudes for N_{pe} = 5130 stars

>13^m. Practically, curve *1'* is used for determining photographic star and galaxy magnitude values B_{ph} recorded on all 2260 astronegatives of Kyiv PSS program. As result of PSS program implementation, a catalogue of 19 451 751 stars and galaxies up to $B \le 16.5^m$ for an epoch of 1988.1 has been created. The coordinates of stars and galaxies are obtained in the system of Tycho-2 catalogue; the *B*-magnitudes are received in the system of photoelectric standards [18, 19, 20, 21]. The internal accuracy of the catalogue for all objects is $\sigma_{\alpha\delta} = \pm 0.23''$ and $\sigma_B = \pm 0.14^m$ (for the stars within $B = 7^m - 14^m$ the errors are $\sigma_{\alpha\delta} = \pm 0.10''$ and $\sigma B = \pm 0.07^m$) for the equatorial coordinates and *B*-magnitudes, respectively. Convergence between the calculated and reference positions is $\sigma_{\alpha\delta} = \pm 0.06''$; convergence with photoelectric B_{pe}-magnitudes within $B = 5^m - 17^m$ is $\sigma_B = \pm 0.15^m$. Fig. 4 shows photometric errors of the catalogue of near-pole area of Kyiv PSS program. The top panels a and b feature differences ΔB between the catalogue B_{ph}-magnitudes and photoelectric B_{pe}-magnitudes with respect to photoelectric B_{pe}- and $(B-V)_{pe}$-magnitudes for N_{pe} = 5130 stars. The impact of color matching (panel *b*), which is typical for DWA-type refractors.

SINGLE-EXPOSURE STAR PHOTOMETRY

Fig. 5 features a H and D curve of astronegative no. 1335 and errors (1.2-m Schmidt telescope, Baldone, work field is about 20 sq. degrees). The errors $\sigma = \pm 0.17^m$ for $k = 195$ stars are given as difference between the calculated U-magnitudes and their photoelectric values U_{pe} with respect to rectangular coordinates X and Y, distance from the plate center R, color index $B-V$, and photoelectric values U_{pe}. To control reliability of H and D curves for the single-exposure astronegatives the errors of differences of computed coordinates (panels *a*, *b*) and U-magnitudes (panels *c, d, e*) identified on the two astronegatives

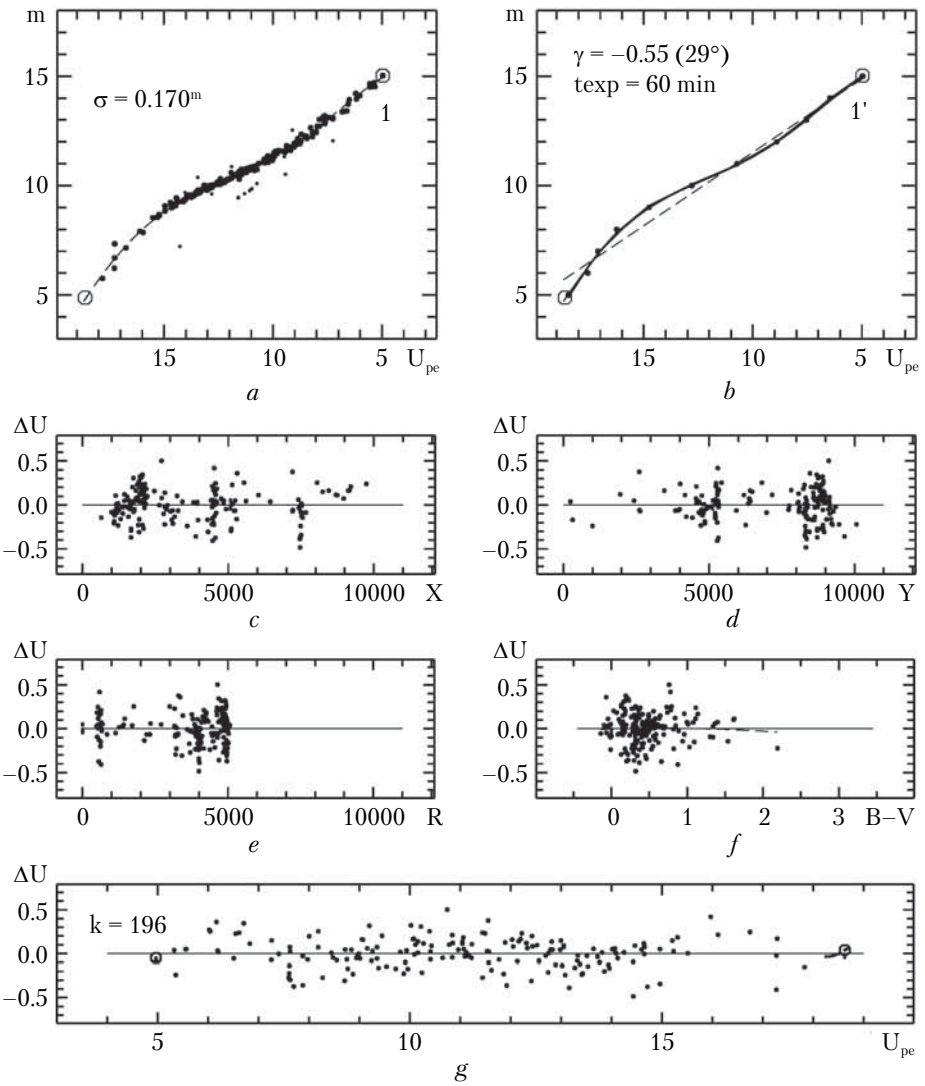

Fig. 5. H and D curve of astronegative no. 1335 and errors (1.2-m Schmidt telescope, Baldone, work field is about 20 sq. degrees). The errors $\sigma = \pm 0{,}17^m$ for $k = 195$ stars are given as difference between the calculated U-magnitudes and their photoelectric values U_{pe} with respect to rectangular coordinates X and Y, distance from the plate center R, color index $B-V$, and photoelectric values U_{pe}

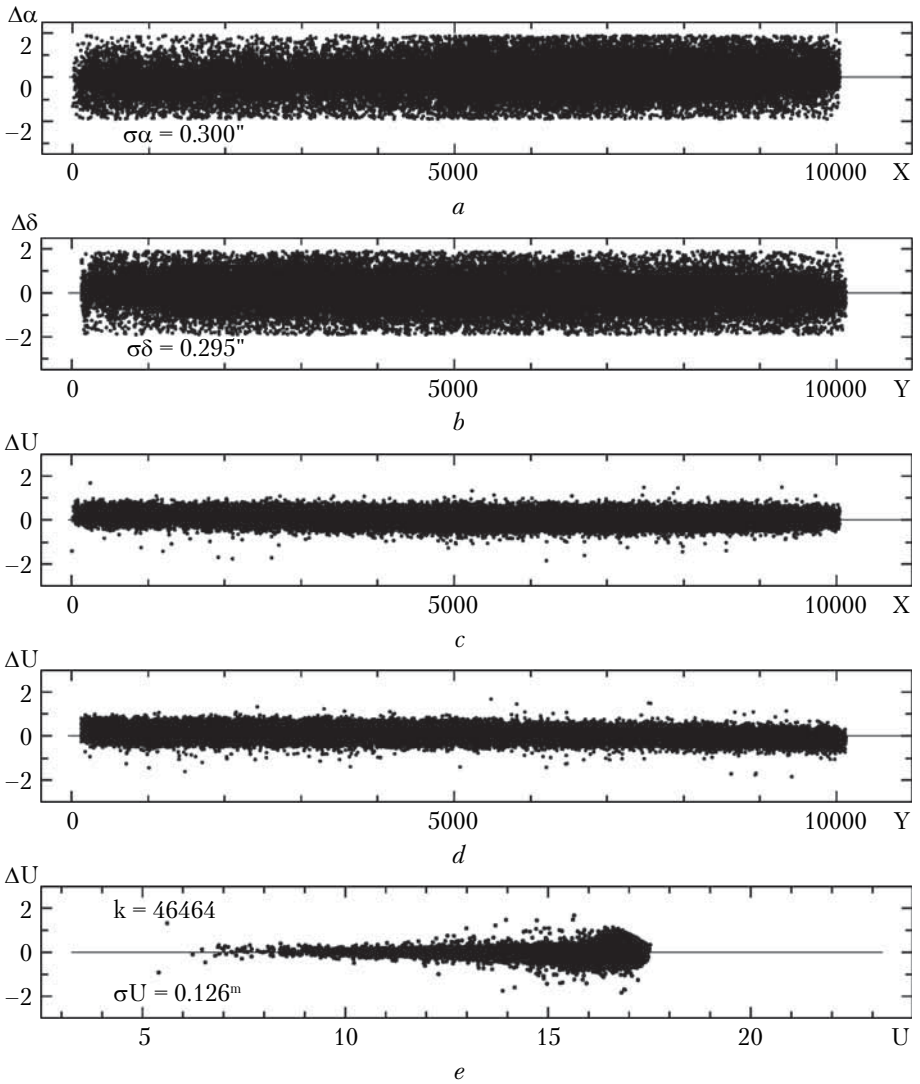

Fig. 6. Errors of differences of computed coordinates (panels *a, b*) and U-magnitudes (panels *c, d, e*) identified on the two astronegatives (no. 1355 and no. 1335) (1.2-m Schmidt telescope, Baldone). The differences are given with respect to rectangular coordinates *X* and *Y* and *U*-magnitudes

(no. 1355 and no. 1335) (1.2-m Schmidt telescope, Baldone) are given in Fig. 6. The astronegatives are taken with 60 min exposure. Average error of *U*-magnitude differences calculated for the two astronegatives is $\sigma_U = \pm 0.13^m$.

CONCLUSIONS

For the astronegatives with two exposures a method for building H and D curves has been implemented using software, with results obtained in the form of catalogs of positions and *B*-magnitudes of stars and galaxies. In the absence of photometric standards for the extremely faint stars, for the single-exposure astronegatives an empirical or analytical correlation between the measured and the reference magnitudes is sought in order to correctly build H and D curves.

REFERENCES

1. Andruk V.M., Vidmachenko A.P., Ivashchenko Yu.M. Processing of CCD frames of images of star fields without the frame of a flat field using new software in program shell of MIDAS/ROMAFOT. *Kinematics and Physics of Celectial Bodies*. Suppl. 2005. No. 5. P. 544—550.
2. Andruk V.N., Ivanov G.A., Pogoreltsev M.T., Yatsenko A.I. On application of a skanner for determination of coordinates and photometric characteristics of stars from FON program plates. *Kinematika Fiz. Nebesnykh Tel*. 2005. **21**, No. 5. P. 396—400 [in Russian].
3. Andruk V., Pakuliak L. A trial Microtek Skan Maker application for star photometry. *Journal of Phisical Studies*. 2007. **11**. No. 3. P. 329—333.
4. Golovnya V., Andruk V., Yatsenko A. Astrometry of the plates of the DWA digitized with the Microtek ScanMaker 9800XL TMA scanner. *Journal of Physical Studies*. 2010. **14**. No. 2. P. 2902-1—2902-8.
5. Andruk V.M., Butenko G.Z., Yatsenko A.I. Photometry of plates digitized using MICROTEK SCANMAKER 9800XL TMA scanner. *Kinematics and Physics of Celectial Bodies*. 2010. **26.** No. 3. P. 146—150.
6. Andruk V.M., Pakuliak L.K., Golovnya V.V., Ivanov G.O., Yizhakevych O.M., Protsyuk Yu.I., Shatokhina S.V. *Catalogue of star positions and B-magnidudes in 60-th declination zone based on UkrVO Joint Digital Archive*. 2015, Available at: https://arxiv.org/abs/1512.05535.
7. Andruk V.M., Golovnia V.V., Ivanov G.A., Yizhakevich E.M., Pakuliak L.K., Protsyuk Yu.I., Shatokhina S.V. Catalog of positions and B-magnitudes of stars in the circumpolar region of the Northen Sky Survey (FON) project. *Kinematics and Physics of Celectial Bodies*. 2016. **32.** No. 1. P. 38—47.
8. Andruk V.M., Pakuliak L.K., Golovnia V.V., Ivanov G.O., Yatsenko A.I., Shatokhina S.V., Yizhakevych O.M. Catalog of equatorial coordinates and B-magnitudes of stars of the FON project. *Kinematics and Physics of Celectial Bodies*. 2016. **32.** No. 5. P. 260—263.
9. Protsyuk Yu.I., Martynov M.V., Mazhaev A.E., Kovylianska O.E., Protsyuk S.V., and Andruk V.N. Compiling Catalogs of Stellar Coordinates and Proper Motions via Coprocessing of Archival Photographic and Modern CCD Observations. *Kinematics and Physics of Celestial Bodies*, 2014, Vol. 30, No. 6, pp. 296—303.
10. Yizhakevych O.M., Andruk V.M., Pakuliak L.K. Catalog of astronomical positions of Saturn's moons obtained by photographic observations at the MAO NASU 1961—1991. *Odessa Astronomical Publications*. 2015, **28**, No. 2, P. 213—216.
11. Vavilova I., Golovnya V., Andruk V., Pakuliak L., Yizhakevych O., Shatokhina S., Protsyuk Yu., Kazantseva L., Lukianchuk V. The scientific use of the UkrVO joint digital archive: GRBs fields, Pluto, and satellites of outer lanets. *Odessa Astronomical Publications*. 2014, **27,** No. 1, P. 65—66.
12. Protsyuk Yu., Yizhakevych O., Kovylianska O., Protsyuk S., Andruk V., Kashuba S., Kazantseva L. Uranus and Neptune from UkrVO digital archive: strukture, quality analysis. *Odessa Astronomical Publications*. 2015, **28**, No. 2, P. 204—206.
13. Kazantseva L.V., Shatokhina S.V., Protsyuk Yu.I., Kovylianska O.E., Andruk V.M. Processing results of digitized photographic observations of Pluto from the collections of the Ukrainian Virtual Observatory. *Kinematics and Physics of Celestial Bodies*, 2015, Vol. 31, No. 1, pp. 37—54.
14. Protsyuk Yu., Andruk V., Mazhaev A., Kovylianska O., Protsyuk S., Golovnia V. Determination of proper motions of circumpolar stars by using images from UkrVO plate archives. *Odessa Astronomical Publications*. 2015, **28**, No. 2, P. 302—303.
15. Andruk V.M., Relke H., Protsyuk Yu.I., Muminov M.M., Ehgamberdiev Sh.A., Yuldoshev Q.X., Golovnia V.V. Comparision of zero zone catalogues of the FON program based on the Kyiv and Kitab observations. *Odessa Astronomical Publications*. 2015, **28**, No. 2, P. 188—191.
16. Muminov M.M., Ehgamberdiev Sh.A., Latypov A.A., Kahharov B.B., Yuldoshev Q.X., Andruk V.N., Golovnia V.V. Catalog of equatorial coordinates and B magnitudes of stars in equatorial zone of the northern Sky Survey project based on the digitized plates of the Kitab observatory. *Izv. Gl. Astron. Obs. Pulkove*. 2016, No. 223, P. 339—344 [in Russian].
17. Alksnis A., Balklavs A., Eglitis A., Paupers O. Baldone Schmidt telescope plate archive and catalogue. *Baltic Astronomy*. 1998, **7,** P. 653—668.
18. Kornilov V.G., Volkov I.M., Zakharov A.I., Kozyreva V.S., Kornilova L.N., Krutyakov A.N., Krylov A.N., Kusakin A.V., Leontiev A.V., Mironov A.V., Moshkaliov V.G., Pogrosheva T.M., Sementsov V.N., Khaliulin Kh.F. 1991, in Kornilov V.G. (ed.): *Catalogue of WBVR magnitudes of bright stars in the northern sky*, Trudy Gosudarstvennogo astronomicheskogo insituta im. Sternberga, 63, Moskow University [in Russian].
19. Mermilliod J.C. *VizieR Online Data Catalog: Homogeneous Means in the UBV System* (Mermilliod 1991). URL: http://adsabs.harvard.edu/cgi-bin/nph-data_query?bibcode=2006yCat.2168....0M&link_type=DATA&db_key=AST&high=.
20. Andruk V.M., Kharchenko N.V., Schilbach E., Scholz R.-D. Photometric survey near the main Galactic Meridian. 1. Photoelectric stellar magnitudes and colours in the UBVR system. *Astronomische Nachrichten*. 1995. **316,** No. 4. P. 225—248.
21. Relke E., Protsyuk Yu., Andruk V. The compiled catalogue of photoelectric UBVR stellar magnitudes in the Tycho2 system. *Odessa Astron. Publ*., 2015, **28**, No. 2, P. 211—212.

22. Protsyuk Yu.I., Andruk V.N., Muminov M.M., Yuldoshev Q.X., Ehgamberdiev Sh.A., Eglitis I., Eglite M., Kovylianska O.E., Golovnia V.V., Kazantseva L.V., Kashuba S.G. Method for evaluating the astrometric and photometric charakteristics of commercial scanners in their application for the scientific purpose. *Odessa Astron. Publ.* 2014, **27**, No 1, P. 61—62.
23. Protsyuk Yu.I., Kovylianska O.E., Protsyuk S.V., Andruk V.M. Results of processing of astronegatives with commercial scanner. *Odessa Astron. Publ.* 2014, **27**, No. 1, P. 63—64.
24. Andruk V., Ivanov G., Yatsenko A., Golovnia V., Yizhakevych O., Pakuliak L., Shatokhina S. Astrometry of DWA plates digitalized by two kinds of scanners. Separation of images of the stars from two exposures. *Visnyk Kyiv. Nats. Univ. T. Shevchenko.* Ser. Astron. 2012. No. 48. P. 11—13 [in Ukrainian].
25. Protsyuk Yu.I., Andruk V.N., Kazantseva L.V. Software for processing of digitized astronegatives from archives and Databases of Virtual Observatory. *Odessa Astron. Publ.* 2014. **27**, No. 1, P. 59—60.

Received 17.10.16

В.М. Андрук [1], Л.К. Пакуляк [1], В.В. Головня [1], С.В. Шатохіна [1], О.М. Їжакевич [1], Ю.І. Процюк [2], І. Еглітіс [3], М. Егліте [3], Л.В. Казанцева [4], О. Рельке [5], К.Х. Йулдошев [6], М.М. Мумінов [7]

[1] Головна астрономічна обсерваторія НАН України, вул. Академіка Заболотного, 27, Київ, 03680, Україна, тел. +380 44 5 264 768
[2] Науково-дослідний інститут «Миколаївська астрономічна обсерваторія», вул. Обсерваторна, 1, Миколаїв, 54030, Україна, тел. +380 512 477 014
[3] Обсерваторія Балдоне Інституту астрономії Латвійського університету, Балдоне, Латвія, LV-2125, тел. +371 679 328 63
[4] Астрономічна обсерваторія Київського національного університету ім. Т. Шевченко, вул. Обсерваторна, 3, Київ, 04053, Україна, тел. +380 44 486 26 91
[5] Вальтер Хоманн обсерваторія, вул. Валнейер, 159, Ессен, 45133, Німеччина, тел. +49 201 493 941
[6] Астрономічний інститут АН Республіки Узбекистан, Ташкент, Узбекистан, факс: +998 712 344 867, тел. +998 712 358 102
[7] Андижанський державний університет Республіки Узбекистан, Андижан, Узбекистан, факс: +998 742 238 830

ПРО ФОТОМЕТРІЮ ЗІР З ОЦИФРОВАНИХ АСТРОНЕГАТИВІВ

Обговорюються питання побудови характеристичних кривих для астронегативів, експонованих у широкому діапазоні експозицій в *U*-, *B*-смугах системи Джонсона на різних телескопах. Фотоплатівки із зображеннями зоряних полів оцифровані за допомогою сканерів фірми Epson; fits-файли оброблені в програмному середовищі MIDAS/ROMAFOT. Точність побудови характеристичних кривих з використанням фотоелектричних вимірів зір знаходиться в межах $0,1—0,2^{m}$.

Ключові слова: *U* та *B* зоряні величини зір, обробка оцифрованих астронегативів.

В.Н. Андрук [1], Л.К. Пакуляк [1], В.В. Головня [1], С.В. Шатохина [1], Е.М. Ижакевич [1], Ю.И. Процюк [2], И. Еглитис [3], М. Еглите [3], Л.В. Казанцева [4], Е. Рельке [5], К.Х. Йулдошев [6], М.М. Муминов [7]

[1] Главная астрономическая обсерватория НАН Украины, ул. Академика Заболотного, 27, Киев, 03680, Украина, тел. +380 44 526 4768
[2] Научно-исследовательский институт «Николаевская астрономическая обсерватория», ул. Обсерваторная, 1, Николаев, 54030, Украина, тел. +380 512 477 014
[3] Обсерватория Балдоне Института астрономии Латвийского университета, Балдоне, Латвия, LV-2125, тел. +371 679 328 63
[4] Астрономическая обсерватория Киевского национального университета им. Т. Шевченко, ул. Обсерваторная, 3, Киев, 04053, Украина, тел. +380 44 486 2691
[5] Вальтер Хоманн обсерватория, ул. Валнейер, 159, Эссен, 45133, Германия, тел. +49 201 493 941
[6] Астрономический институт АН Республики Узбекистан, Ташкент, Узбекистан, факс: +998 712 344 867, тел. +998 712 358 102
[7] Андижанский государственный университет Республики Узбекистан, Андижан, Узбекистан, факс: +998 742 238 830

О ФОТОМЕТРИИ ЗВЕЗД С ОЦИФРОВАННЫХ АСТРОНЕГАТИВОВ

Обсуждаются вопросы построения характеристических кривых для астронегативов, экспонированных в широком диапазоне экспозиций в *U*-, *B*-полосах системы Джонсона на различных телескопах. Фотопластинки с изображениями звездных полей оцифрованы при помощи сканеров фирмы Epson; fits-файлы обработаны в программной среде MIDAS/ROMAFOT. Точность построения характеристических кривых с применением фотоэлектрических измерений звезд заключена в пределах $0.1—0.2^{m}$.

Ключевые слова: *U* и *B* звездные величины звезд, обработка оцифрованных астронегативов.