REALIZATION OF VILNIUS *UPXYZVS* PHOTOMETRIC SYSTEM FOR ALTAU42 CCD CAMERA AT THE MAO NAS OF UKRAINE

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The description of two-inch glass filters of the Vilnius *UPXYZVS* photometric system, which are made at the Main Astronomical Observatory of NAS of Ukraine for AltaU42 CCD camera with format of 2048×2048 pixels, is presented in the paper. Reaction curves of instrumental system are shown. Estimations of minimal star's magnitudes for each filter's band in comparison with the visual V one are obtained. New software for automation of CCD frames processing is developed in program shell of LINUX/MIDAS/ROMAFOT. It is planned to carry out observations with the purpose to create the catalogue of primary *UPXYZVS* CCD standards in selected field of the sky for some radio-sources, globular and open clusters, *etc.* Numerical estimations of astrometric and photometric accuracy are obtained.

INTRODUCTION

For the purpose to expand an opportunity of astrophysical researches of celestial objects using the AltaU42 CCD camera the set of glass filters of the Vilnius photometric system *UPXYZVS* has been made in 2004. Photometric investigation with the Vilnius system filters allows us to characterize physical properties of astronomical objects more unequivocally. Seven-colour Vilnius system *UPXYZVS* enables us to carry out multivariant spectral classification of stars at presence of interstellar reddening in all interval of their temperatures [9]. The first stage of CCD-variant of *UPXYZVS* system realization will be the observations of the elected primary photoelectric standards of the Vilnius system for northern sky [3] with camera AltaU42. The next stage is creation of CCD-variant of the new photometric *UPXYZVS* standards in some areas of the sky (globular and open clusters, infra-red and radio sources, *etc.*) for the purpose of carrying out of stars-statistical researches of the Galaxy. It is planned to add such photometric researches in the Vilnius system by the measurements in Johnson's *UBVRI* system. As a result of such observational program the catalogue of stars (and other objects) for two photometric systems and astroclimate researches in the points of observation (extinction, influence of lunar-solar inflow on a transparency of an atmosphere, brightness of a luminescence of the night sky, trembling of an atmosphere) will be obtained. We have an experience of carrying out of such works [2, 4, 6]. Processing of CCD images is carried out in the MIDAS/ROMAFOT software [5, 7]. In LINUX/MIDAS/ROMAFOT environment the program (as a MIDAS procedures) of cyclic processing of finite quantity of CCD-frame's files in a FITS-format was created. The ROMAFOT software was used for determination of photometric and astrometric characteristics (star magnitude, rectangular coordinates X, Y, *etc.*) for all objects of star's fields registered on CCD frames.

Quantum efficiency of CCD-camera (matrix 2048×2048 pixels) has shown in Table 1 and in Fig. 1 (a solid line). On the same figure an atmospheric spectral transparency (equivalent thickness for ozone and water layers are 3 and 10 mm) and mirror's reflection are shown by the dashed line and by the points, respectively [1, 9].

THE CHARACTERISTIC OF THE MAO NAS OF UKRAINE *UPXYZVS* GLASS FILTERS

In March 2004 the Astroprylad Cooperative Society has made for MAO NAS of Ukraine three sets of seven glass filters of *UPXYZVS* systems. Its diameter is two inches and physical thickness is 15.5 mm; quartz or "K8" glass is added for identical filter's optical thickness. Filters of "Golosiiv" variant of the Vilnius photometric system (with AltaU42 CCD camera) are making according to the original recommendations [8, 9] with

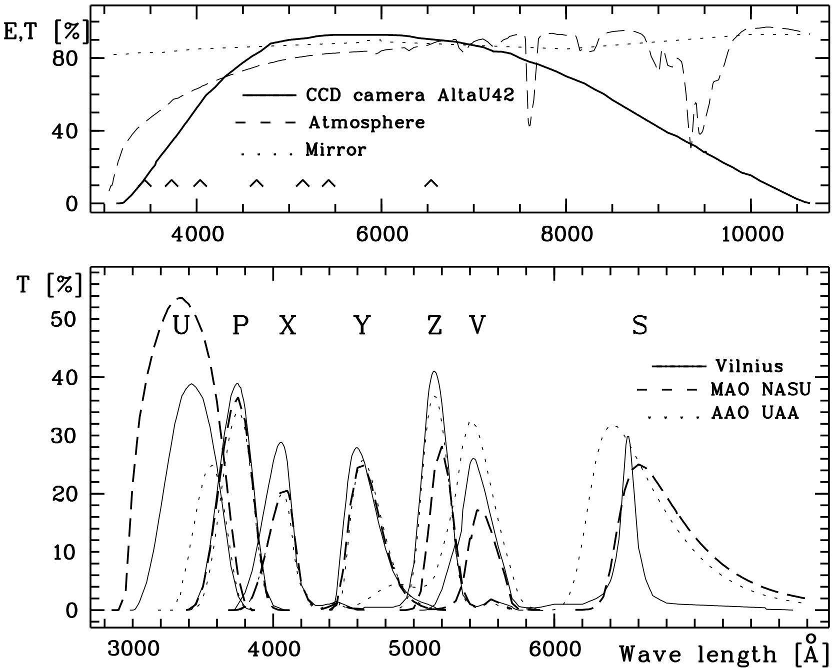

Figure 1. Spectral quantum efficiency of CCD-camera, atmospheric transparency (equivalent thickness for ozone and water layers are 3 and 10 mm, respectively) and mirror's reflection; transparency curve φ (in %) for filters of different variant of *UPXYZVS* Vilnius system

the exception of filter *S*, which is not interference in our case. In Table 2 there is the information on filter's components. In Table 3 the transparency curve for filters of "Golosiiv" variant of *UPXYZVS* system and optical properties of filters (wavelength λ_m in a maximum of transparency, half-width $\Delta\lambda$ reaction curves, its transparency for λ_m) are given. These data are shown in Fig. 1 too (dashed line). In this figure transparency curves of a standard variant of glass filters of the Vilnius system (solid line) and transparency curves for the filters made in 2002 (points) by the Astroprylad Cooperative Society for the Andrushivka Astronomical Observatory of the Ukrainian Astronomical Association (AAO UAA) are shown. These data we used for an estimation of the limiting magnitude of registered stars and photometric errors of the Vilnius system's filters.

"Golosiiv's" variant of glass filters was certificated by the Ukrainian State Research-and-Production Center of Standardization, Metrology, and Certifications (Kyiv).

Table 1. Quantum efficiency of AltaU42 CCD camera as a function of length waves λ (nanometer) is in accordance with advertising sheet of the manufacturer

λ	%	λ	%	λ	%	λ	%	λ	%
360	25.5	490	89.0	620	92.5	750	80.0	880	48.0
370	32.0	500	90.0	630	92.0	760	78.0	890	45.0
380	38.5	510	90.5	640	91.0	770	76.5	900	42.0
390	45.5	520	91.0	650	90.5	780	74.5	910	39.0
400	52.5	530	92.0	660	90.0	790	72.5	920	37.0
410	59.5	540	92.5	670	89.5	800	70.0	930	34.0
420	64.0	550	92.8	680	89.0	810	68.0	940	31.5
430	69.5	560	92.8	690	88.0	820	66.0	950	28.0
440	73.5	570	92.8	700	87.0	830	63.0	960	26.5
450	77.5	580	92.8	710	86.0	840	60.5	970	22.5
460	81.0	590	92.8	720	84.0	850	57.0	980	20.0
470	84.0	600	92.8	730	83.5	860	54.0	990	17.0
480	88.0	610	92.7	740	82.5	870	51.0	999	16.0

Table 2. Compound's components and optical properties of glass filters of *UPXYZVS* system of MAO NAS of Ukraine

Filters	Components	λ_m	$\Delta\lambda$	Transparency (%)
U	UFS2(9.8)+quartz(4.7)	335	62.5	53.7
P	SZS22(1.8)+UFS6(2.7)+quartz(10.4)	375	29.0	36.6
X	ZhS4(3.3)+ZS7(6.3)+SZS21(1.9)+FS6(2.1)+quartz(1.8)	410	26.0	20.5
Y	ZhS12(7.1)+SZS21(2.7)+SS15(2.1)+K8(2.7)	465	27.5	24.9
Z	ZhS17(1.9)+ZS7(3.1)+SZS22(9.4)	520	18.5	28.1
V	OS11(5.1)+SZS22(4.9)+PS7(2.1)+K8(2.4)	545	23.5	17.2
S	KS15(1.8)+SZS23(1.9)+K8(11.0)	660	67.5	25.0

Table 3. The data of transparency curves for filters of "Golosiiv" *UPXYZVS* system

λ, nm	φ_U	φ_P	λ, nm	φ_X	φ_Y	λ, nm	φ_Z	φ_V	λ, nm	φ_S
290	0.1		375	0.1		460			625	0.2
295	3.1		380	0.6		465			630	0.6
300	21.7		385	2.2		470			635	2.3
305	33.2		390	5.4		475			640	7.1
310	40.0		395	10.3		480		0.1	645	14.3
315	45.1		400	15.7		485		0.3	650	20.5
320	48.8		405	20.1		490		0.4	655	24.1
325	51.7		410	20.5		495	0.1	0.3	660	25.1
330	53.4		415	13.0		500	0.3	0.3	665	24.4
335	53.7		420	4.5		505	3.2	0.2	670	23.1
340	52.5	0.1	425	1.8		510	12.9	0.1	675	21.3
345	50.5	1.0	430	0.4		515	24.5	0.1	680	19.4
350	47.5	4.0	425	0.2		520	28.1	0.3	685	17.6
355	42.8	10.3	440	0.6	0.1	525	22.4	0.6	690	15.8
360	35.8	18.8	445	1.2	0.9	530	12.0	1.6	695	14.1
365	25.9	27.9	450	0.7	7.2	535	3.6	4.8	700	12.6
370	15.2	34.4	455	0.3	18.2	540	1.0	12.3	705	11.2
375	5.9	36.6	460	0.3	24.5	545	0.5	17.2	710	10.0
380	1.1	32.5	465	0.1	24.9	550	0.9	16.9	715	8.8
385	0.1	22.6	470		21.5	555	1.9	13.6	720	7.8
390		10.9	475		16.4	560	1.3	9.7	725	6.9
395		3.0	480		11.4	565	0.6	5.9	730	6.1
400		0.4	485		7.2	570	0.2	1.2	740	4.8
405			490		4.3	575	0.1	0.1	760	3.0
410			495		2.5	580			780	2.0
415			500		1.5	585			800	1.4
420			510		0.3	590			830	0.5

TRANSPARENCY CURVES FOR "GOLOSIIV" VARIANT OF *UPXYZVS* SYSTEM

The main role at formation of reaction curves of "telescope + CCD" photometric system is due to optical filters. The "Golosiiv's" system resulting curve is shown in Fig. 2 by dashed line and standard Vilnius system – by solid line. In the top part of Fig. 2 the half-width of "Golosiiv's" (thin line) and standard's reaction of the Vilnius photometric system are shown.

COMPARISON OF PHOTOMETRIC SYSTEMS. LIMITING STAR'S MAGNITUDES

The 2002 spring-and-summer observations of various sky areas (which have *UBVR* photoelectric standards) using the CCD "FPZS S1C-017" (without filters) at the AAO UAA Zeiss-600 telescope has allowed us to establish that the limiting star magnitude is $M_{\rm ex} = 21^m$ at about 10 min exposure time. The knowledge of this value allows us to estimate $M_{\rm ex}$ for observations with the "Golosiiv's" filters. A difference of limiting star magnitude Δm_i in integral light and in any of *UPXYZVS* filters of "Golosiiv's" system may be calculated as

$$\Delta m_i = 2.5 \log \left(\int e(\lambda) g(\lambda) c(\lambda) d\lambda \bigg/ \int e(\lambda) g(\lambda) c(\lambda) \varphi_i(\lambda) d\lambda \right), \tag{1}$$

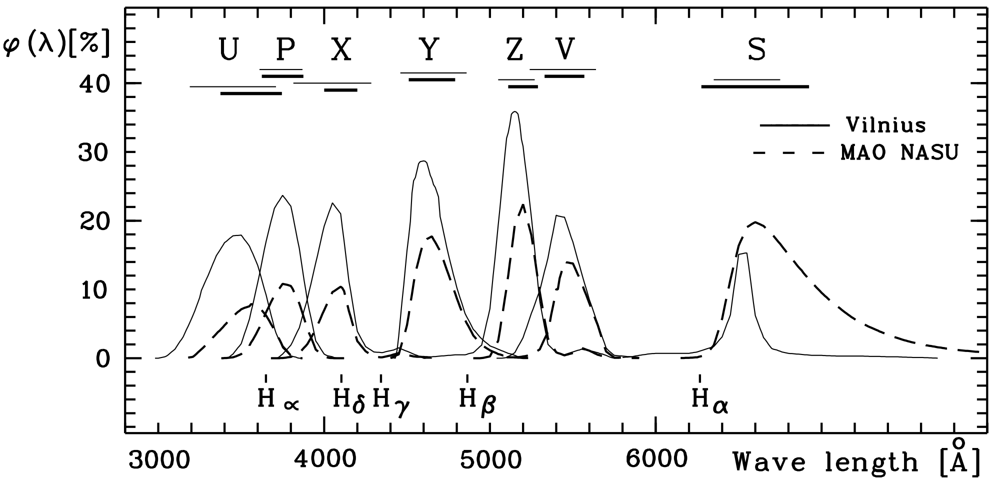

Figure 2. Results reaction transparency curves of the "Golosiiv's" and standard's Vilnius photometric system

where $e(\lambda)$, $g(\lambda)$, $c(\lambda)$, $\varphi_i(\lambda)$ are the transparency of an average atmosphere (layers of ozone and water are 3 and 10 mm), spectral mirror's reflection and spectral "matrix AltaU42+filter" sensitivity curves, respectively, for every λ. An average wavelength λ_{0i} and amount of registered energy E_i for every *i-th* filter are expressed as

$$\lambda_{0i} = \int \varphi_i(\lambda)\lambda d\lambda \Big/ \int \varphi_i(\lambda) d\lambda \, , \tag{2}$$

$$E_i = \int e(\lambda)g(\lambda)c(\lambda)\varphi_i(\lambda)d\lambda \Big/ \int e(\lambda)g(\lambda)c(\lambda)d\lambda \, . \tag{3}$$

The results of calculations are given in Table 4. Average wavelengths and half-width of reaction curves for "Golosiiv" and standard photometric system are λ_{0G}, λ_{0S} and $\Delta\lambda_G$, $\Delta\lambda_S$, respectively; their difference is $\lambda_{0G} - \lambda_{0S}$, amount of registered energy for "Golosiiv's" filters is E_i. There are also limiting star magnitude $\lim_G$ (for 10 min exposure time) for "Golosiiv", standard photometric system $\lim_S$, and their difference $\lim_G - \lim_S$. Clearly, from Table 4 that at an 10 min exposure (the Zeiss-600 telescope and AltaU42 matrix) using "Golosiiv" (or standard) filters in Kyiv conditions of observation, a star with $V = 15.90^m$ (or $V = 16.48^m$) will be accessible to registration.

AN ESTIMATION OF PHOTOMETRIC ACCURACY OF CCD OBSERVATIONS IN THE VILNIUS SYSTEM

An estimation of CCD photometry accuracy with the Vilnius system on example of processing of IC 4665 sky area observations obtained in May 2003 at the Andrushivka Astronomical Observatory was make at the $7.5' \times 7.5'$ field size. There are six photoelectric stars standards of the Vilnius system. The CCD-frames obtained with

Table 4. Comparison between "Golosiiv" and standard variants of transparency curves *UPXYZVS* systems

Filter	λ_{0G} nm	$\Delta\lambda_G$ nm	λ_{0S} nm	$\Delta\lambda_S$ nm	$\lambda_{0G} - \lambda_{0S}$ nm	E %	$\lim_G$ mag	$\lim_S$ mag	$\lim_G - \lim_S$ mag
U	356	37.0	345	40/52	11	0.40	15.00	14.56	0.43
P	375	25.0	374	26/26	1	0.51	15.26	15.35	−0.09
X	410	20.0	405	22/47	5	0.48	15.21	15.60	−0.39
Y	465	28.0	466	26/40	−1	1.21	16.21	16.34	−0.13
Z	520	18.0	516	21/25	4	1.15	16.15	16.72	−0.56
V	545	24.0	544	26/48	1	0.91	15.90	16.48	−0.58
S	660	65.0	655	20/32	5	3.54	17.27	16.22	1.15

an 60 s exposure have been processed in the MIDAS/ROMAFOT software. Comparison of star magnitudes differences ΔU, ΔP, ΔY, ΔZ, ΔV, ΔS for two successive CCD frames is shown on the left of Fig. 3. A root-mean-square error for one measurement of star brighter than 13^m is $\pm 0.02^m \div 0.03^m$. Comparison of stars magnitudes from our CCD observational results with photo-electric standards of the Vilnius system is shown on the right of Fig. 3. The error on external convergence ranges from $\pm 0.03^m$ to $\pm 0.07^m$.

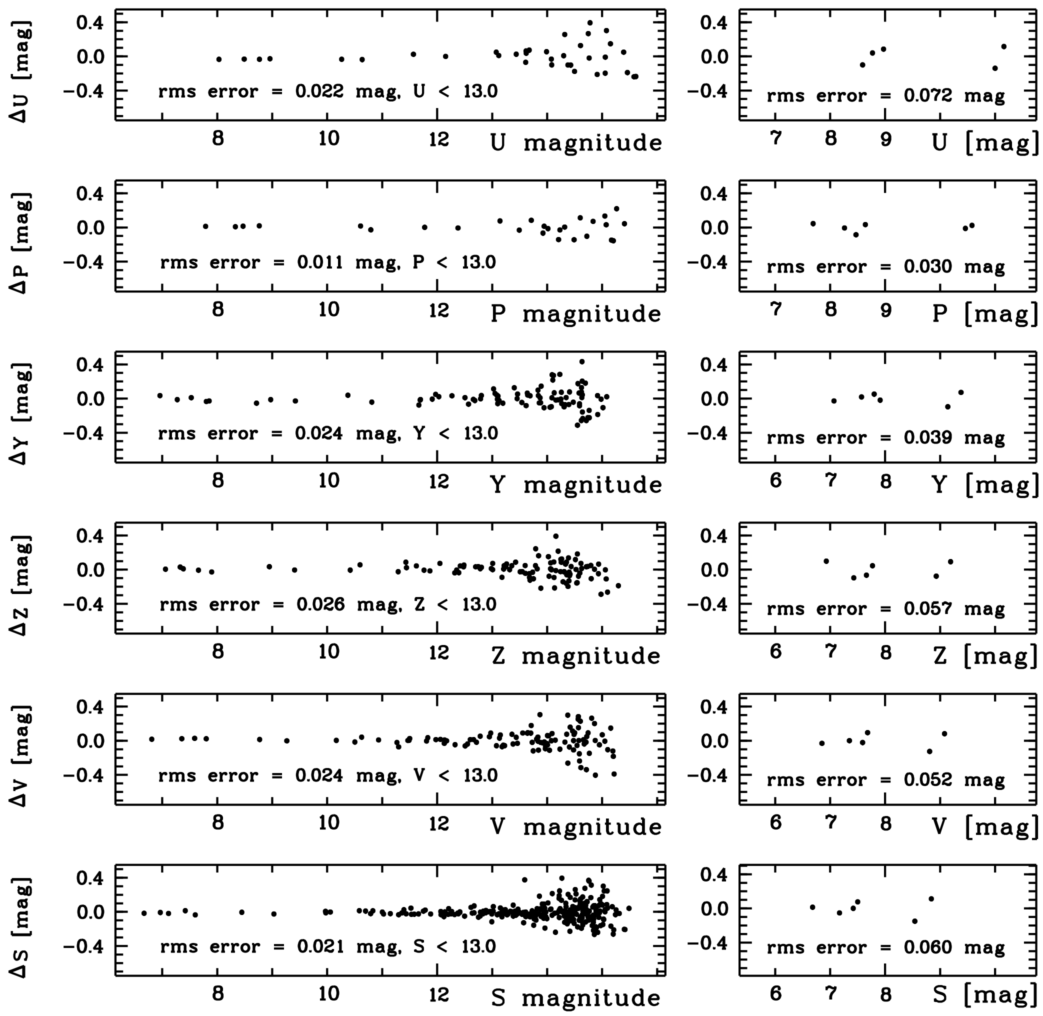

Figure 3. On the left: star magnitudes differences for two successive CCD frames; on the right: root-mean-square errors

CONCLUSIONS

"Golosiiv" glass *UPXYZVS* filters of the Vilnius system are made and have passed metrological certification. The research of transparency curves of "Golosiiv" photometric system is carried out and comparison with standard one is made. The estimation of the limiting star magnitude $M_{\rm ex}$ in each filter with AltaU42 CCD camera for the MAO NAS of Ukraine conditions is obtained. An accuracy estimation of CCD photometry with the Vilnius system was making on example of processing of the observations obtained in May 2003 at the Andrushivka Astronomical Observatory. The accuracy estimation of a star magnitude determination is made. The list of the observational programs to create the primary CCD standards in *UPXYZVS* filters of the Vilnius system is formed.

All experts having any interest in cooperative work on determination of stars magnitudes in Vilnius photometric system by the CCD method are invited.

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