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SPECTROPHOTOMETRIC STANDARDS 8^M- 10^M. 1. EQUIPMENT, METHODS AND FIRST RESULTS

Abstract. Justification of the task of creation a network the spectrophotometric of standards 8^m-10^m is given. Standards of this brightness are necessary for calibration of spectral observations using large telescopes. Selection of stars – candidates in spectrophotometric standards and primary standards was made. As candidates in the standards selected stars of spectral classes A and B which are located in the equatorial zone with declination ±3˚. The used equipment - a new CCD spectrograph is briefly described. Dispersing element of a spectrograph is the concave toroidal grating which simultaneously serves as collimator and as camera. The spectrograph operates in the slitless mode. As the receiver of radiation the CCD camera ATIC-490EX was used. The new spectrograph allows to investigate an energy distribution in the spectra of much dimer stars than in case of observations with spectrometers. Observations on the telescopes AZT-8 and Zeiss-600 at Kavenskoe plato carry out. The differential method of observations was used. Processing of CCD-spectrograms and numerical reductions detail is described. The energy distribution in spectral region 340 – 660nm is investigated, spectral resolution of the obtained data be 5 nm, the relative standard deviation - from 3 to 6%. The absolute energy distribution in spectra of two candidates for standards is presented.

Key words: stars, **s**pectrophotometric standards, CCD-spectrograph, method of observations.

Introduction. Study of energy distribution in the spectra of stars is the traditional subject of the Fesenkov Astrophysical Institute. The created in the institute spectrophotometric catalogue of stars [1] continues to be the most voluminous in the world. The spectral energy distribution is used to determine the physical parameters of stars and interstellar medium. In addition, stars with a known distribution of energy are used for standardization of spectrophotometric observations of diverse celestial objects and for calibration of equipment. Usually as the spectrophotometric standards serve stars of the early classes. In their spectra be available the extend ranges that is free from strong spectral lines. Spectrophotometric data is present in two forms: "unbroken" and "porous". In "unbroken" form data about spectral outside atmosphere illumination are presented continuously through a certain interval. This interval equals to interval of the averaging of intensities. Thus illumination was presented in histogram form. In "porous" form data are given for selected wavelengths. At present, unbroken energy distribution (integral spectrum) for more than 1500 stars studied. Almost all of them are brighter 6^m [1-6]. In the literature and in the database SIMBAD, there are several tens stars-standards 7^m - 8^m [7-10] and only a few - weaker.

The standards should be as much as possible, since from their numbers is influenced performance observation and accuracy of data. Obviously, observations at large telescopes require weaker standards. Therefore, adding to the available weak standards of even a few stars makes sense and task of creating weak spectrophotometric standards is relevant. It can be said that their creation is an "eternal" task, since over time weaker standards, more accurate, with higher spectral resolution and in a wider range of the spectrum are required. We decided to expand the list of standards toward weaker ones compared to thouse available in catalogues of stars and create network spectrophotometric standards 8^m-10^m. The present work is the first of a planned series of publications devoted to its creation.

The equipment. Energy distribution in the spectra of stars in the above papers [1-10] was obtained using singlechannel spectrometers, in which photomultipliers served as the radiation. For the study of energy distribution in the spectra of stars 8m-10m we specially made spectrograph [11], in which the radiation receiver is a CCD camera. We emphasize that we have not encountered special studies of the energy distribution in the spectra of stars with the help of CCD spectrographs.

Apparently, the lack of such studies is due not so much to the loss of their relevance as to the methodological difficulties that arise in their implementation.

It is worth noting that the accuracy of recording the radiation fluxes of a CCD camera is lower compared to photomultipliers. Nevertheless, the binding of spectral observations of a variety of celestial objects obtained with CCD spectrographs to standard stars in certain sections of the spectrum is quite often performed (see, for example, [12-13]). In our spectrograph for absolute measurements (SAM) a dispersive element is a toroidal diffraction grating. The constant of grating - 150 strokes/mm, the size of the shaded part of the grating - 20 * 20mm, the focal length - approximately 242mm. The dispersion of spectrograph is 25nm/mm, field size - 20 mm. Spectrograph runs essentially in a slitless mode. Entrance slit has a width of about 1 mm, which is clearly larger than the image of star in telescope with a focal length less than 20m. A wide slit and diaphragm is required for absolute measurements - so that there is no vignetting of the beam. Since the spectral resolution of the data is only 5 nm, the gapless version is quite acceptable. The main advantage of the grating used is that it provides a flat spectrum in the range from 300 to 800 nm. This property allows us to use the CCD-matrix as a radiation receiver. As the radiation receiver is a CCD camera ATIK-490EX. The main parameters of the matrix of this camera are the following: the number of pixels is 3380 * 2704, the size of pixels is 3.69 * 3.69 microns, the length of the matrix is 12.5 mm. The camera cooling is 25K below the air temperature, the spectral sensitivity range is from 320 to 860mk, the reading noise is 5 e. A detailed description of the spectrograph is given in [11]. Notice, that the SAM was originally designed to operate with 1 Zeiss-1000 telescope (1: 10 aperture light) located in the high-altitude TSAO. In connection with the installation of optical reducers on these telescopes, observations were made on the telescopes AZT-8 and Zeiss-600, located on the Kamenskoye Plateau. On the plateau, the transparency of the atmosphere is worse and, accordingly, the accuracy of the obtained data turned out to be lower than expected. One of the drawbacks of SAM is that the size of the matrix of the camera used does not allow us to simultaneously cover all the available area of the spectrum. When replacing the CCD camera with a larger one, the SAM will be eliminated.

Table 1 - List and characteristics of stars - candidates in weak spectrophotometric standards.

Hip (Tyc)	HD (BD)	α 2000	δ 2000	V	B-V	Sp
1241	1112	$00^h 15^m 27.3^s$	-03° 39' 15"	9.105^m	-0.066^m	B9V
9152	12021	01 57 56.1	-02 05 58	8.843	-0.071	A0
13917	18571	02 59 16.8	01 14 40	8.632	+0.038	A0V
18243	24520	03 54 07.0	02 11 02	8.626	+0.118	B9
20778	28190	04 27 03.5	04 16 51	9.021	+0.125	B9V
24053	289997	05 10 07.8	-00 16 58	9.964	+0.077	B8V
29258	42334	06 10 08.7	00 42 36	9.327	+0.025	B8III
32634	50087	06 51 40.6	00 19 36	9.084	+0.047	B9III
38123	63367	07 48 44.4	01 56 21	8.990	+0.060	B9V
Tyc210-680	BD+01 2119	08 32 43.6	00 53 49	10.13	-0.07	A0
48704	86027	09 55 59.6	02 47 55	8.356	-0.029	A0V
55011	97917	11 15 48.3	-02 17 58	8.880	-0.145	B9
Tyc281-353	BD+01 2668	12 13 25.3	01 09 22	10.29	-0.09	B5?
66872	BD+02 2711	13 42 19.0	01 30 18	10.263	-0.11	B5
Tyc317-603	BD+02 2790	14 14 25.9	01 47 58	10.11	0.03	A0
74972	136161	15 19 14.7	-02 10 02	8.891	0.330	A3V
82133	151355	16 46 47.0	02 12 34	8.826	-0.092	B4/5V
87417	162628	17 51 52.6	02 53 59	8.258	0.192	B9.5V
92559	174648	18 51 41.0	-01 45 35	8.827	0.118	B9.5V
Tyc479-625	185296	19 38 21.0	01 30 14	9.741	0.210	B9II
101541	BD-03 4950	20 34 43.6	-02 41 44	10.010	+0.141	A0
Tyc 531-232	BD+01 4436	21 10 11.5	02 14 20	9.99	+0.03	A0
112149	215112	22 42 58.0	-02 40 57	8.240	-0.041	B9V
Tyc 581-756	BD+02 4661	23 23 38.20	02 55 57	10.05	0.38	F2

The selection of candidate stars in standards and primary standards. As weak spectrophotometric standards, we selected 24 stars of the early spectral classes of 8^m-10^m , located uniformly along the equator (δ = ±3˚). This choice is due to two factors: the spectra of these stars have extended spectral regions that are free of strong lines and can be used as standards for observations in both hemispheres of the Earth. Naturally, the basic requirement for any standards must be met - they must be unchanged. The list of candidate stars in the standards is presented in Table 1.

The brightest candidate for standards is the star HD 151355 (V = 8.25^m), the weakest one is BD + 02 2711 (V = 10.37^m). The absolute majority of the stars in the list meet the requirements. Only one star is located outside the dedicated band and only one star has the spectral class F2. As with the creation of all the catalogs [1-10], observations are performed by a differential method. Stars - candidate in spectrophotometric standards were attached to stars for which the spectral distribution of energy was known in advance (they can be called secondary standards). As the last, 9 A0V stars of 7-8 values from the catalog [1], which are also located in the equatorial region, were taken. Their list and main characteristics are given in Table 2. The absolute distribution for them in the regions occupied by the Balmer lines was preliminarily graphically interpolated. In view of the limited volume of the article, we do not present interpolated data here.

Table 2 - List of the secondary spectrophotometric of standards and their characteristic

№п/п	HD	α_{2000}	δ_{2000}	π(mas)	V	B-V	Sp
1	009716	01^h 35.1^m	-02° 20'	5.29	7.43^m	0.16^m	A0V
2	023009	03 41.6	-00 10	6.20	8.64	0.21	A0V
3	036117	05 29.5	-00 03	6.09	7.99	0.10	A0
4	075620	08 51.1	00 28	4.01	7.97	0.11	A0V
5	100237	11 32.0	-01 47	3.31	7.34	-0.01	A0V
6	121513	13 55.8	01 31	3.25	8.00	0.11	A0V
7	147470	16 22.9	00 30	7.19	7.67	0.10	A0V
8	185198	19 37.9	01 30	1.60	7.32	0.19	B9.5V
9	216261	22 51.6	-01 49	4.02	8.16	0.16	A0V

Methods of observation and processing. Observations were performed by the method equal heights, which makes it possible to use in the reductions for absorption in the atmosphere the average value of the spectral transparency coefficient for the place of observation. Its values were taken from [11], in which they are given for the summer and winter seasons. The difference of air mass ΔM between the standard records and the candidate for the standards did not exceed 0.10 on the average. Each star was observed from 4 to 7 times. For various reasons (instrumental and atmospheric), some of the spectra records were discarded. The duration of exposures ranged from 100 to 500 seconds. The temperature of the camera and the binning for program and standard stars should be the same. Recording modes of their spectra differ only in exposure.

Stars, for which the absolute energy distribution is obtained by binding to secondary standards, can be called tertiary standards. Briefly describe the procedure for processing frames and the data obtained from them. In detail, it is set out in the instructions that we compiled. The result of observations with SAM are "raw" frames of spectra of stars in the "FIT" format, which must be "brought to the number". An example of one of the received frames is shown in Figure 1. Frames are processed in the "MaxIm DL-6" package in the standard way.

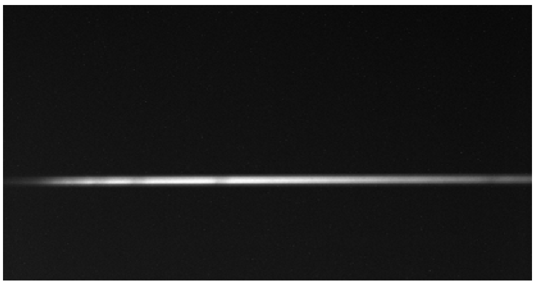

Figure 1 - The spectrogram of HD1112 (9.10^m; B9V)

The first stage of the processing of the captured frames begins with their clearing from the "hot" pixels generated by the matrix defects and cosmic rays. The second stage is the so-called calibration. This is a standard procedure, allowing for the use of additional frames (a flat field, biass and dark) to take into account all the hardware distortions. In our case, a plane field was not recorded because of the uniformity of the matrix used. The third step is subtraction of the background and conversion of frames into a numeric array in the Excel package. As a result, in the computer memory we have a set of numerical values of the charges (impulses) accumulated on the matrix, which are proportional to the fluxes from the stars at the corresponding wavelengths. The Excel program allows you to present it as a graph - a registrogram. The fourth stage is the identification on the register of wavelengths. It is carried out manually, "by eye". The cursor is directed to the center of depression in the spectrum caused by this or that line. For stars of early spectral classes, the Balmer lines of Hα, Hβ and Hγ serve as reference points, for stars of class G - lines H and K. A very important step is the division into 50-angstrom intervals. Dispersion of the spectrograph is practically linear. In our spectrograph 50A corresponds to 25.5 pixels. Due to small spectral shifts at different positions of the spectrograph, the start of the first 50-A interval must be determinate for each frame. A table of numbers of pixel was prepared in advance, corresponding to the beginning and end of the 50-angstrom intervals (template). The monitor marker was exposed to the center of the Hβ line. The number of pixel of center of the line was fixed and the table (template) was shifted to the ultraviolet or red part of the spectrum. The accuracy of the identification is 1-2 pixels (2-5A). For secondary standards, one more operation is required - it is necessary to perform interpolation of the continuous spectrum in the plots of the spectrum occupied by the Balmer lines. Interpolation is carried out after breaking the registrogram into 50-angstrem intervals. Interpolated table values, their values were monitored graphically, "by eye", which requires a certain skill. Because of the shortness of the intervals such an interpolation is carried out quite confidently. Naturally, the manual interpolation method takes considerable time, but in our case this is the best option. An example of a registrogram is shown in Fig. 2.

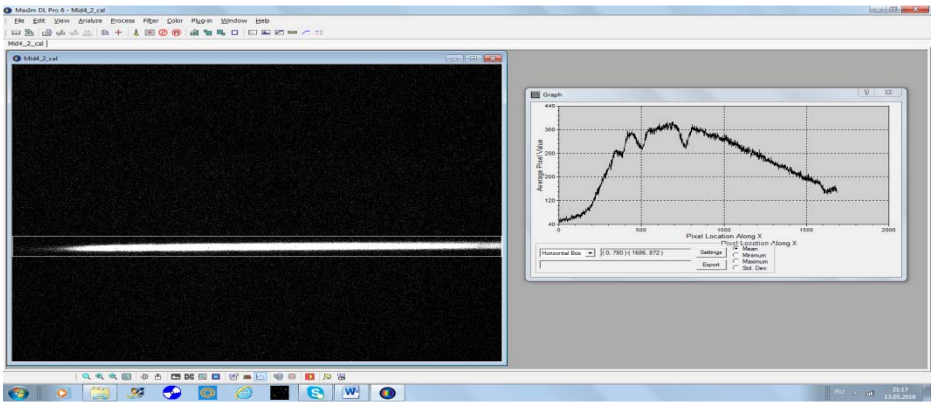

Figure 2 - The registrogram of HD24520 (8.63^m; B9)

Numerical reduction. The counts within the 50-angstrom intervals are summed and normalized, that is, the registrogram is converted into a histogram. All calculations and numerical reductions are performed in the Excel package. Reductions for the difference in exposure of the star and the standard and for the different absorption of radiation from them in the Earth's atmosphere are made according to the classical formula of differential spectrophotometry:

$$E^*(\lambda)=E_{st}(\lambda)\times[I^*(\lambda)/I_{st}(\lambda)]\times[\Delta t_{st}/\Delta t^*]\times p_{av}(\lambda)^{-\Delta M}, \quad (1)$$

where $E^*(\lambda)$ and $E_{st}(\lambda)$ are the outside atmospheric values of the spectral densities of the energy illuminations produced by the star and the standard;

$I^*(\lambda)$ and $I_{st}(\lambda)$ are averaged over the 5nm range for the star and the standard (when referenced to two standard entries, the average of the two observations); Δt_{st} and Δt^* - duration of exposures in seconds per standard and star; $p_{av}(\lambda)$ is the average value of the transparency coefficient for the observation site;
$\Delta M = M_{st} - M^*$ - the difference of air masses between the standard and the star.

For secondary standards we took values of monochromatic illumination and corresponding measurements not for the integral spectrum, but for quasi-continuous. For the studied stars, integral readings are taken within the intervals with the same pixel numbers (wavelengths of the centers of 50A intervals).

Table 3 - Распределение энергии в спектрах E(λ) для HD1112 и HD 12021 (единицы - 10^{-7}wt/m^2m)

λ, A	1112	12021	λ, A	1112	12021	λ, A	1112	12021
3425	80.5	178	4525	141.6	206	5625	80.1	108
3475	81.8	176	4575	137.0	200	5675	78.7	103
3525	84.9	178	4625	135.0	196	5725	75.2	101
3575	80.5	165	4675	130.6	189	5775	73.5	97
3625	79.9	169	4725	125.4	181	5825	72.0	96
3675	81.8	166	4775	121.9	172	5875	72.4	94
3725	92.8	173	4825	118.0	160	5925	68.8	91
3775	106.1	192	4875	111.3	154	5975	67.4	89
3825	131.0	226	4925	108.8	155	6025	66.4	88
3875	159.6	265	4975	109.3	154	6075	64.7	83
3925	168.1	272	5025	107.0	149	6125	63.2	82
3975	186.1	299	5075	105.2	145	6175	60.4	81
4025	191.3	309	5125	102.2	141	6225	57.5	76
4075	186.8	292	5175	99.7	137	6275	57.8	74
4125	178.6	274	5225	96.3	133	6325	56.2	72
4175	174.2	270	5275	93.6	127	6375	54.8	71
4225	171.6	263	5325	91.0	124	6425	54.5	68
4275	169.2	249	5375	88.4	121	6475	54.4	66
4325	158.8	229	5425	87.7	117	6525	50.5	63
4375	150.0	224	5475	86.9	115	6575	48.0	60
4425	146.4	220	5525	83.5	111	6625	47.0	63
4475	145.0	213	5575	80.5	111	6675	47.5	63

Here we present the results for two stars - the candidates for the standards: HD1112 and HD12021.The outside atmospheric energy distribution in the spectra of these stellar spectrophotometric standards are given in Table 3. The accuracy of the obtained data, characterized by a relative mean-square error, is from 3 to 6%. For stars 9^m-10^m this accuracy of absolute measurements can be considered quite satisfactory.

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СПЕКТРОФОТОМЕТРЛІК СТАНДАРТТАР 8^m-10^m. 1. АППАРАТУРА, ӘДІСТЕМЕ ЖӘНЕ АЛҒАШҚЫ НӘТИЖЕЛЕР

Аннотация. 8^m-10^m спектрофотометрлік стандарттардың жүйесін құру міндеттерінің негіздемесі келтірілді. Осы жарқылдың стандарты ірі телескоптарда спектрлік бақылаулардың калибровкасы үшін қажетті. Спектрофотометрлік стандарттардың және алғашқы стандарттардың жұлдыз-кандидаттардың таңдамалары жасалды. Стандарттардың кандидаттары ретінде ±3˚бейімделумен экваторлық аймақта орналасқан А және В спектрлік топтарының жұлдыздары таңдалды. Пайдаланылатын аппаратураның қысқаша сипаттамасы – жаңа ЗБА-спектрограф. Бір уақытта коллиматор және камера болып қызмет атқаратын ойық тороидты тор спектрографтың ыдыратқыш элементі болып табылады. Спектрограф саңылаусыз режимде жұмыс істейді. Сәулелену қабылдағыш ретінде ЗБП-камера ATIC - 490EX пайдаланылады. Жаңа спектрограф энергияның таралуын зерттеуге мүмкіндік береді. Ертеректегі спектрометрмен жұлдыздар спектрлерінде біраз әлсіз. Бақылаулар АЗТ-8 және Цейсс-600 телескоптарында орындалды. Бақылаудың дифференциалдық әдісі пайдаланылды. Спектрограммалармен ЗБА-кадрлар өңдеу процесстері нақтылап суреттелген. Энергияның таралуы 340 - 660нм спектрлік аймақтарда зерттеледі, алынған мәліметтердің спектрлік рұқсаты 5нм құрайды, салыстырмалы с.к.о. - от 3 ден 6% дейін. Стандарттардың екі кандидаттарының спектрлерінде энергияның нақты таралуы ұсынылды.

Түйін сөздер: жұлдыздар, спектрофотометрлік стандарттар, ЗБА-спектрограф, бақылау әдістері.

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СПЕКТРОФОТОМЕТРИЧЕСКИЕ СТАНДАРТЫ 8^m-10^m. 1. АППАРАТУРА, МЕТОДИКА И ПЕРВЫЕ РЕЗУЛЬТАТЫ

Аннотация. Приведено обоснование задачи создания сети спектрофотометрических стандартов 8^m-10^m. Стандарты данного блеска необходимы для калибровки спектральных наблюдений на крупных телескопах. Сделана выборка звезд-кандидатов в спектрофотометрические стандарты и первичных стандартов. В качестве кандидатов в стандарты выбраны звезды спектральных классов А и В, которые расположены в экваториальной области со склонением ±3˚. Кратко описана используемая аппаратура - новый ПЗС-спектрограф. Диспергирующим элементом спектрографа является вогнутая тороидальная решетка, которая одновременно служит коллиматором и камерой. Спектрограф работает в бесщелевом режиме. В качестве приемника излучения используется ПЗС-камера ATIC-490EX. Новый спектрограф позволяет исследовать распределение энергии в спектрах намного более тусклых звезд, чем со спектрометрами. Наблюдения выполнены на телескопах АЗТ-8 и Цейсс-600. Использовался дифференциальный метод наблюдений. Подробно описаны метод обработки ПЗС-спектрограмм и численные редукции. Распределение энергии исследуется в спектральной области 340 - 660нм, спектральное разрешение полученных данных составляет 5нм, относительная с.к.о. - от 3 до 6%. Представлено абсолютное распределение энергии в спектрах двух кандидатов в стандарты.

Ключевые слова: звезды, спектрофотометрические стандарты, ПЗС-спектрограф, методы наблюдений

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МАЗМҰНЫ

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