Secondary Spectrophotometric Standards: Results and Future Observational Programme

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Abstract

Three sets of spectrophotometric standards are presented : eight bright B and A stars of $0^m.0$ – $2^m.65$, fourteen B – A stars of 3^m–4^m from the catalogue of 238 secondary spectrophotometric standards and 24 A0-G0 stars of 7^m–8^m. For all of these stars UBV photometry was produced and brightness variations exceeding $0^m.01$were not found.

Spectrophotometric standards are used widely for a comparison with the variable and pecular stars when information on spectral energy distribution is necessary. Two main properties of spectrophotometric standards must be taken into account: the reliability of energy distribution data and the absence of brightness variations at least within the limits of the accuracy of measurements. As stars with reliable energy distribution they may be used for comparison with model atmospheres, for obtaining mean energy distribution for stars of different spectral types and creation of the new observational techniques.

Secondary spectrophotometric standards are produced as the result of comparison with stars provided with reliable energy distribution data, *i.e.* primary standards, compared with black body model or lamps calibrated in absolute monochromatic fluxes. In the process of creating two large spectrophotometric catalogues containing data on the energy distribution in the spectra of the more than 2000 stars, eight stars of the spectral types B and A and brightness interval $0^m.03$–$2^m.65$ were chosen as standards: α Lyr, γ Ori, α Aql, β Tau, α Leo, η UMa, α Peg, β Ari. Each star of both catalogues (Voloshina, Glushneva *et al.* 1982; Kharitonov *et al.* 1988) was compared with one or several standard stars by means of the method of equal altitudes taking into account differential extinction.

At first spectral energy distribution was obtained for each standard star as the mean for all the data of different authors published up to that time. The energy distribution of Vega, the main spectrophotometric standard, was obtained also on the base of spectral calibration. In 1976, the energy distribution were changed as a result of the new comparison of standard stars to Vega which were done independently at the Fessenkov Institute and Sternberg Institute. Newly published data were used also (Kharitonov and Glushneva, 1978).

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Table 1. Mean square errors of the energy distribution data for standard stars (%)

λ	σ
3200–3300	2.1
3300–3700	1.2
3700–4000	1.5
4000–5000	1.0
5000–6000	1.0
6000–7000	1.0
7000–7600	1.3

The next step for more exact data for the system of standards was a reduction to the new scale of the Vega energy distribution based on data obtained by D.S.Hayes (1985). This reduction was done for all the stars of both catalogues. Energy distribution data of eight standard stars in the range 3200-7700 A may be taken from Kharitonov *et al.* (1988) or Glushneva *et al.* (1992). For all standard stars, including α Lyr, UBV-photometry was produced during three observational seasons at Mount Maydanak near Kitab (Uzbekistan, about 3000m above sea level). Observations did not show short time variations (during several hours or days) exceeding the errors of measurements ($\sigma = 0\overset{m}{.}005$). Spectrophotometric standard α Aql is suspected of long time variability with the variations of the brightness about $0\overset{m}{.}02$ (Sparauskas, private communication).

The set of 238 stars was proposed as secondary spectrophotometric standards in the range 3200-7600 A (Glushneva *et al.* 1992). These stars are common to the catalogues of the Sternberg Institute and Fessenkov Institute and the differences between spectral energy distribution data of the two catalogues do not exceed 5%, while the mean inner accuracy of both catalogues data in this range are about 3.5%. For 99 stars the energy distribution data in the near infrared (6000-10800A) obtained at the Sternberg Institute are also presented. Table 2 demonstrates the consistency Δ of the data obtained at the Sternberg and Fessenkov Institutes.

Table 2. Mean values of Δ as a function of S_p and λ

Number of stars	76	68	25	19	47
Spectral type	O-B	A	F	G	K-M
3200–3700	0.012	-0.004	-0.019	0.016	0.020
3700–4000	0.004	-0.003	-0.003	0.010	0.001
4000–5000	0.013	0.006	0.004	0.015	-0.008
5000–6000	0.013	0.009	0.013	0.019	-0.005
6000–7000	0.001	-0.004	0.004	0.020	-0.010

$\Delta = 2(E_A - E_M)/(E_A + E_M)$, where E_A and E_M are monochromatic fluxes of stars in the Alma-Ata and Moscow catalogues.

Good agreement of the results obtained fully independently may be considered as indirect evidence that these 238 stars are not variable within the limits of a few percent. However, many of them are variables or suspected variables, i.e. the members of GCVS or NSV. At the same time many suspected variables are in fact of constant brightness within the limits ≈1%. In any case photoelectric observations of the brightness variations are very important. Fourteen B and A stars of 3^m–4^m which are not members of GCVS or NSV and the 67–70 Name-Lists were chosen. The Bright Star Catalogue numbers of these stars are: BS 269, 580, 1165, 1520, 2540, 3690, 5107, 5867, 6396, 7236, 7710, 8335, 8597, 8634. For all these stars we have energy distribution data in the near infrared, obtained at the Sternberg Astronomical Institute Crimean Station. These data were combined with the mean of the results of the Sternberg and Fessenkov catalogues in the range 6300-7600 A common for all the measurements. In this range the differences between these sets of observations (Sternberg visual, Fessenkov visual and Sternberg near-infrared) also do not exceed 5%, and in many cases the differences between $1/2\ (E_A + E_M)$ (mean of Alma-Ata and Moscow data) and Sternberg near-infrared data are even less (for example, for BS 8634 mean $\mid \Delta \mid= 0.01$). Such good agreement makes it possible to obtain the mean of data presented in the Table 3 and 5 of the paper by Glushneva *et al.* (1992) in the range 6300-7600 A.

Energy distribution data in the range 3200-10800 A for 14 stars are presented in the paper, submitted to a Joint Meeting of Commissions 9 and 25 at the 21-st General Assembly of the IAU, Buenos Aires, Argentina *Automated Telescopes for Photometry and Imaging* (Glushneva, 1992, in press). These data are based on the Vega energy distribution obtained by D.S. Hayes (1985). Mean value of differences between averaged Alma-Ata and Moscow data in the range 6300-7600A and Moscow infrared data in this range for 14 stars is $\mid \Delta \mid= 0.034$. All these stars were observed photometrically at the Sternberg Institute Tyan'-Shan' expedition and brightness variations exceeding 0.01 were not found for the W, B, V, R bands (Kornilov *et al.*, 1991). Now the main task is a creation of a set of fainter standards, connected with the eight bright ones. For this aim a new programme of spectrophotometric standards observations for the space project 'Lomonosov', planned at the Sternberg Institute was begun. In the addition to the great amount of astrometric measurements, this project (Nesterov *et al.* 1990) will include photometric and spectrophotometric observations of stars of 10^m–12^m. For these stars it is necessary to have spectrophotometric standards and now observations of 7^m–8^m stars located at the zone +40 deg relative to the ecliptic are produced at the Sternberg Institute Crimean Station.

Eighty A0–G0 stars spread across the sky more or less uniformly were chosen. These stars were not mentioned as variables or suspected variables, however U, B, V photometric measurements were started as a test of possible variability. As a first step in the spectrophotometric investigations of these stars energy distribution data for 24 stars were obtained in the range 3400-7500A (Biryukov *et al.* 1992, in press). Eight bright stars were used as standards. To decrease their flux only one half of the main mirror aperture remained opened and for the brightest standards the Cassegrain mirror was stopped down also. A Czerny-Turner grating spectrophotometer with discrete scanning was used. A photomultiplier with photon counting electronics was used as a detector. Table 3 contains the data on the internal accuracy for the energy distribution of the 24 stars investigated.

Table 3. Mean square errors of 24 A0–G0 stars of 7^m–8^m (%)

λ	σ
3400–3700	2.2
3700–4000	1.6
4000–5000	1.1
5000–6000	0.9
6000–7000	1.0
7000–7550	1.6

The future programme of spectrophotometry of standard stars includes continuation of observations of about 60 7^m–8^m stars with parallel U, B, V photometry which on completion willbe followed by the programme for stars of 9^m–10^m.

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Discussion

A.T. Young: *Have you compared your results with the Gunn-Stigler atlas? There must be many stars in common.*

Glushneva: Yes, we did it for separate stars. But in general the comparison of two catalogues as a whole is not a simple task. At first it is necessary to discover and exclude systematic errors which may be connected with the standards also. In the process of the creation of the Moscow and Alma–Ata catalogues common stars were compared several times and systematic errors $\sim$ 2–4% for the Moscow catalogue and up to 10% for several stars of Alma–Ata catalogue were found and excluded. I presented the result of comparison of the corrected data.

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