3400 – 7500 Å Energy Distribution and *JHKLM* Photometry of Solar-Type Stars

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Abstract

Energy distribution data in the range 3400 – 7500 Å obtained by means of the scanner installed at the 60-cm Zeiss reflector, and *JHKLM* photometry provided at the 1.25 m reflector of the Sternberg Institute Crimean Station for 8 stars of spectral types G1.5-G3 of V and IV luminosity classes, are presented. The accuracy of the spectrophotometric data is 1.5% in the range 4000 – 6000 Å. and about 2% in the ranges 3400 – 4000 and 6000 – 7500 Å. The accuracy of the *JHKLM* photometry is 2% in the bands J, H, K and L and 5% in the M band. Comparison of energy distribution in the spectra of stars with three reliable sets of spectrophotometric data of the Sun shows that the temperature of BS 88, BS 7504 and BS 4030 is lower than of the Sun, and the temperature of HD 213575 is near to the solar one.

Comparison of the stellar *JHKLM* photometry with synthetic solar photometry in these IR bands was done. In the case of the equality of J magnitudes of the Sun and BS 7504, the differences of fluxes in K and L bands are maximal (9 – 13%), while in the H and M bands they are only 1 – 2%.

JHKLM photometry of different authors is presented. The differences between the measurements of various authors are more in many cases than the accuracy declared.

Comparison of color indices $J - H$, $J - K$, $J - L$, $J - M$ of the solar type stars and of the Sun doesn't permit us to consider these stars as full solar analogs.

1 Introduction

Comparison of solar spectral energy distribution and photometric characteristics of the Sun with the corresponding data for solar type stars may be very useful when we answer the question of whether the Sun is the typical representative of the spectral type G2 V. The Sun is well known to be the standard of this subtype in the MK - classification based on the spectral lines intensities.

The Sun is often used as a standard in the investigations of different parameters of stars such as luminosity, mass, metallicity and so on. It is very important also to know photometric parameters of the Sun, i.e. color indices in different photometric systems. The position of the Sun on the two - color diagrams and comparison with solar type stars positions will make use for the decision of the problem if the Sun is "quite normal" or "slightly peculiar" star.

2 Spectral energy distribution in the range 3400 - 7500 Å

In the paper by Glushneva (1994), synthetic $W - B$ and $B - V$ color indices of the $WBVR$ photometric system, developed at the Tien' Shan' High Altitude Station of the Sternberg Institute, were computed for 22 G0 - G8 stars having homogeneous MK spectral classification (Garcia, 1989). The color indices of the Sun in the same system were obtained from most reliable series of spectrophotometric measurements. Comparison of observed color indices of solar type stars and synthetic color indices of the Sun showed that $(W - B)_\odot$ corresponds to the mean value of this color index for stars of the spectral type G1.5. This conclusion is also confirmed by direct comparison of energy distributions of stars and the Sun in the range from 3200 to 5500 Å However, $(B - V)_\odot$ corresponds to the mean value of this color index for G3 - G5 stars. This last conclusion was obtained also in our earlier publication (Glushneva et al., 1986).

As a continuation of these investigations, 8 stars of spectral subtypes G1.5 - G3 were included to the observational spectrophotometric program.

Observations were done by means of the spectrophotometer installed at the 60-cm Zeiss-2 reflector of the Sternberg Institute Crimean Station. Spectral resolution is about 50 Å. The grating with discrete scanning and photomultiplier working in the regime of photon counting were used. The tests of the amplifier demonstrated its high stability. The deviation from linearity did not exceed 0.5% at counting speed of $3*10^5$ counts/sec.

In the process of observations, the spectral width of the entrance slit was 50 Å and an inlet diaphragm of 27".5 was used. The counting time was 1 s for standard stars and 10 s for program stars at each spectral interval. Registration of spectra was done according to the scheme: standard star, program star, background, again program star, and standard star. The stars of the observational program were compared with standard stars by means of the method of equal altitudes. Differential extinction was taken into account with spectral extinction coefficients obtained on each observational night. Spectra of two standard stars, with the differences in airmass not less than 0.5, were registered several times on the night.

The energy distribution in the spectra of program stars was calculated using the nearest to the time of program star registration standard star spectrum. The background and spectral extinction coefficients of the night of observations were taken into account.

Mean energy distribution data were obtained for each star on the basis of measurements on 2-5 nights, i.e., 4-5 individual scans were used because on each night the spectrum of program star was scanned twice. Because of the inconvenience of operating with energy distribution data in instrumental wavelength system the mean energy distribution was recalculated for 50 Å steps beginning from 3425 Å.

Eight bright stars spread across the sky more or less uniformly were used as standards : β Ari, γ Ori, β Tau, α Leo, η UMa, α Lyr, α Aql, α Peg. These stars served as standards for the spectrophotometric catalog of the Sternberg Astronomical Institute. Spectral energy distribution data of standard stars with 100 Å steps are presented in the paper by Glushneva et al. (1992). All the data are reduced to the scale of the Vega energy distribution based on the data obtained by D. S. Hayes (1985).

Table 1 contains HD and BS numbers of investigated stars, their spectral types, V magnitudes and color indices $W-B, B-V$ and $V-R$ from the $WBVR$ catalog (Kornilov et al., 1991). The spectral type of BS 7504 (16Cyg B) was taken according to classification by Garcia (1989). The last three lines of Table 1 include the same color indices calculated for the Sun and for the mean G2 V star.

For calculation of the synthetic color indices of the Sun energy distribution was used according to the data of the monograph by Makarova et al. (1991). This monograph contains different characteristics of the Sun including energy distribution for the center of solar disk and the mean all over the disk obtained by means of calculating of average values of the best observations chosen on the basis of spectral analysis. The spectral resolution is 50 Å in the range $3000-5000$ Å and 100 Å from 5000 to 7000 Å. In the range $7000-9000$ Å, data are presented with 200 Å steps. These energy distribution data were also published in the Solar Physics (Makarova et al., 1994).

Response curves of the $WBVR$ photometric system were taken from the catalog by Kornilov et al. Synthetic color indices obtained were published in the paper by Kharitonov, Glushneva & Knyazeva (1994).

$W-B$ indices for the mean G2 V star are strongly dependent on the set of stars of this spectral subtype used for obtaining of average $W-B$. So, Kharitonov & Knyazeva (1997, in preparation) used G2 V stars from the Catalog of Bright stars with spectrophotometric data available. However for some of these stars spectral types are different in various sources.

Mean square roots characterizing scattering of color indices of stars are presented in parentheses.

In the last line of Table 1 mean $W-B$ and $B-V$ indices are presented for G2 V stars according to homogeneous spectral classification by Garcia (Glushneva, 1994).

The scatter of $W-B$ for the stars of Table 1 is maximal (about 0.20 mag) for the $B-V$ and $V-R$ indices, which are about 0.12 mag and 0.08 mag.

The eighth column of Table 1 includes synthetic color indices $(B-V)$ calculated on the basis of observed energy distribution data. Response curves were taken from the catalog by Kornilov et al. The comparison of observed and synthetic $B-V$ indices shows that they are in a very good agreement : the mean difference $(B-V)_{syn}-(B-V)_{obs}$ is only $0.^{m}006$. Two stars (BS 1729 and BS 5072) were observed earlier and are the members of the catalog of the Sternberg Astronomical Institute (Voloshina et al., 1982) and Astrophysical Institute (Alma-Ata, Kazakhstan; Kharitonov et al., 1988). $(B-V)_{syn}$ for these stars, marked by the asterisk in Table 1, is the mean for $(B-V)_{syn}$ obtained on the basis of spectrophotometric data of Moscow and Alma-Ata catalogs (Glushneva, 1994).

Table 1. Color indices of solar type stars in the $WBVR$ photometric system.

HD	BS	SP	V	$W-B$	$B-V$	$V-R$	$(B-V)_{syn}$	
10307	483	G1.5 V	4.965	-0.049	0.623	0.499	0.629	
186408	7503	G1.5 V	5.986	-0.004	0.659	0.521	0.659	
89010	4030	G1.5 IV-V	5.968	0.036	0.668	0.529	0.683	
34411	1729	G1.5 IV-V	4.705	-0.033	0.622	0.499	0.618*	
146233	6060	G2 Va	5.499	-0.028	0.650	0.524	0.643	
1835	88	G2 V	6.402	0.034	0.660	0.537	0.670	
213575		G2 V	6.951	0.004	0.677	0.538	0.663	
117176	5072	G2.5 Va	4.973	0.075	0.727	0.574	0.714*	
217014	8729	G2.5 IVa	5.459	0.055	0.676	0.517		
186427	7504	G3 V	6.244	0.008	0.671	0.531	0.674	
193664	7783	G3 V	5.932	-0.128	0.601	0.497	0.634	
SUN		G2 V		-0.056	0.674	0.505		KGK[a]
Stars		G2 V		-0.045	0.640	0.523		KK[b]
		(mean)		(0.054)	(0.037)	(0.032)		
				0.001	0.660			G[c]

[a] KGK - Kharitonov, Glushneva, & Knyazeva (1994)
[b] KK - Kharitonov & Knyazeva (in preparation)
[c] G - Glushneva (1994)

Table 2, from the paper by Glushneva (1994), contains observed color indices $W-B$ and $B-V$ for G - stars. The spectral classification by Garcia was used.

Table 2: Mean observed color indices $W-B$ and $B-V$ for different subtypes of G stars

SP	$W-B$	$B-V$	n
G0	-0.101	0.605	8
G1	-0.124	0.612	2
G1.5	-0.126	0.641	2
G2	0.001	0.660	2
G2.5	0.028	0.674	2
G3	0.042	0.674	2
G4	0.067	0.726	2
G5	0.023	0.674	1
G8	0.064	0.748	3
Sun	-0.055	0.674	(Makarova et al.)
	-0.071	0.650	(Lockwood et al.)
	-0.076	0.662	(Burlov-Vassil'ev et al.)

$$C_{W-B} = -1.366 \quad C_{B-V} = 0.620$$

The last three lines of this table present synthetic color indices $W-B$ and $B-V$ of the Sun according to energy distribution data from the monograph by Makarova et al. and from the papers by Lockwood et al. (1992) and Burlov - Vassil'ev et al. (1994).

The energy distribution of the Sun was obtained by Lockwood et al. on the basis of observations at Lowell observatory by means of the comparison with the energy distribution of Vega, obtained by the same authors using models of blackbodies with melting points of platinum and copper. The spectral resolution is 4 Å.

The observations by Burlov - Vassil'ev et al. were produced at the mountain Terskol (3100 m above sea level) located at the North Caucasus. Their equipment was investigated carefully and special attention was paid to the atmospheric extinction determination and its stability control. Absolute calibration was made by means of two ribbon lamps. The comparisons were produced with the State primary etalon (Moscow) and the standard of World Radiation Center in Davos. These comparisons showed that the error of absolute calibration does not exceed 2% in the range 3000 – 7000 Å

Energy distribution data are presented with 50 Å step in the range 3325 – 6675 Å (Burlov - Vassil'ev et al. 1994) and in the range 6500 – 10700 Å (Burlov - Vassil'ev et al. 1996).

Comparison of the mean energy distribution data over the entire solar disk normalized to 5575 Å according to three sets described above shows that in the ultraviolet region these data of different authors are in satisfactory agreement but in the red, the data by Lockwood et al. are higher. Probably it may be connected with the difference of spectral resolution, because these data were transformed to the resolution of 50 Å to make all three sets comparable.

Comparison of $W - B$ indices of G2 V stars and the Sun from the Table 2 demonstrates that $W - B$ of the Sun according the data of all the authors corresponds to the earlier than G2 spectral subtype (between G1 and G1.5).

The mean ratios of the monochromatic fluxes from the Sun to the fluxes from solar type stars in the range 3500 – 7500 Å are presented in Table 3.

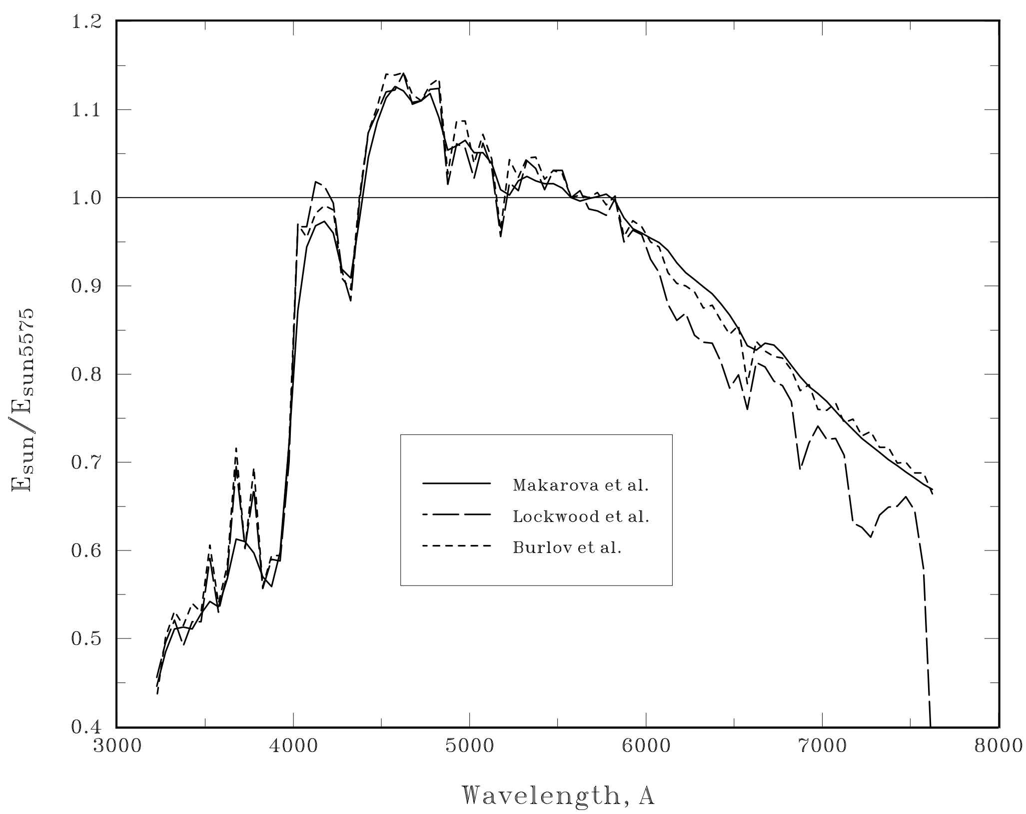

Figure 1: The energy distribution of the Sun normalized to 5575 Å.

Table 3. Mean ratio of the monochromatic fluxes from the solar type stars to the fluxes from the Sun in the range 3500 - 7500 Å

λλ	HD 213575	BS 88	BS 483	BS 4030	BS 6060	BS 7503	BS 7504	BS 7783
Using the energy distribution in the spectrum of the Sun according to Makarova et al.								
3425-3575	0.997	0.919	1.044	0.930	1.009	0.927	0.924	1.022
3625-3975	0.996	0.965	1.099	0.968	0.985	0.987	0.951	1.057
4025-4475	1.010	1.005	1.039	1.009	1.032	1.009	0.991	1.020
4525-4975	0.991	1.001	1.012	0.984	1.017	0.997	0.995	0.998
5025-5475	1.002	1.004	1.004	1.004	1.008	0.999	0.997	0.993
5525-5975	0.988	1.007	0.991	0.986	0.985	0.994	0.997	0.972
6025-6475	0.981	1.003	0.951	1.008	0.965	0.970	0.976	0.955
6525-6975	1.011	1.041	0.957	1.061	0.980	0.992	1.001	0.975
7025-7525	1.003	1.023	0.974	1.082	0.968	0.978	0.993	0.993
Mean	0.998	0.996	1.008	1.004	0.994	0.984	0.981	0.998
Using the energy distribution of the Sun according to Lockwood et al.								
3425-3575	0.979	0.903	1.026	0.919	0.991	0.910	0.908	1.005
3625-3975	0.970	0.940	1.071	0.940	0.959	0.962	0.926	1.030
4025-4475	0.981	0.977	1.009	0.980	1.004	0.980	0.963	0.992
4525-4975	0.991	1.000	1.011	0.983	1.017	0.996	0.995	0.997
5025-5475	1.003	1.006	1.005	1.005	1.010	1.000	0.998	0.994
5525-5975	0.997	1.016	1.000	0.995	0.994	1.003	1.006	0.980
6025-6475	1.047	1.069	1.014	1.075	1.029	1.035	1.041	1.018
6525-6975	1.077	1.109	1.019	1.130	1.043	1.056	1.066	1.039
7025-7525	1.095	1.117	1.064	1.182	1.057	1.068	1.085	1.084
Mean	1.016	1.015	1.024	1.023	1.012	1.001	0.999	1.015
Using the energy distribution of the Sun according to Burlov-Vassil'ev et al.								
3425-3575	0.953	0.879	1.000	0.904	0.965	0.886	0.885	0.979
3625-3975	0.955	0.926	1.055	0.926	0.945	0.948	0.912	1.015
4025-4475	0.987	0.983	1.015	0.986	1.010	0.986	0.969	0.998
4525-4975	0.979	0.988	0.999	0.971	1.004	0.984	0.982	0.985
5025-5475	0.994	0.997	0.997	0.996	1.001	0.991	0.989	0.986
5525-5975	0.988	1.007	0.991	0.986	0.985	0.993	0.997	0.972
6025-6475	0.999	1.021	0.968	1.027	0.982	0.988	0.994	0.972
6525-6975	1.023	1.054	0.968	1.073	0.991	1.003	1.013	0.987
7025-7525	0.994	1.015	0.966	1.072	0.960	0.970	0.985	0.984
Mean	0.986	0.986	0.995	0.993	0.983	0.972	0.970	0.986

Since energy distributions of the Sun and stars were normalized to the fluxes at 5575 Å, maximal differences of these data are in the ultraviolet and near infrared ranges.

For BS 88, BS 4030, BS 7503 and BS 7504 monochromatic fluxes in the range 3400 – 4000 Å are less than solar ones for the solar data by all three groups of authors. It indicates lower temperature of these stars relative to the solar one.

Taking into account the accuracy of solar and stellar energy distribution in the ultraviolet ($\sim$ 2% in each case) the differences of the mean ratio relative to 1.00 as large as 3% or more may be considered to be significant.

The energy distributions of HD 213575, BS 483, BS 6060 and BS 7783 are nearer to the solar one than in the case of stars mentioned above.

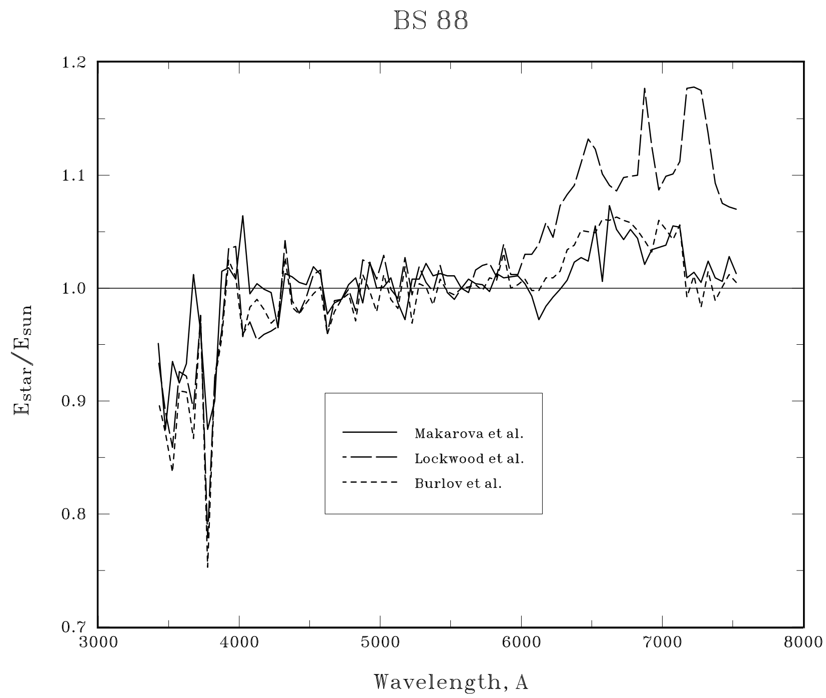

Figure 2: The ratio of the monochromatic fluxes from BS 88 to the fluxes from the Sun in the range 3400 - 7000 Å.

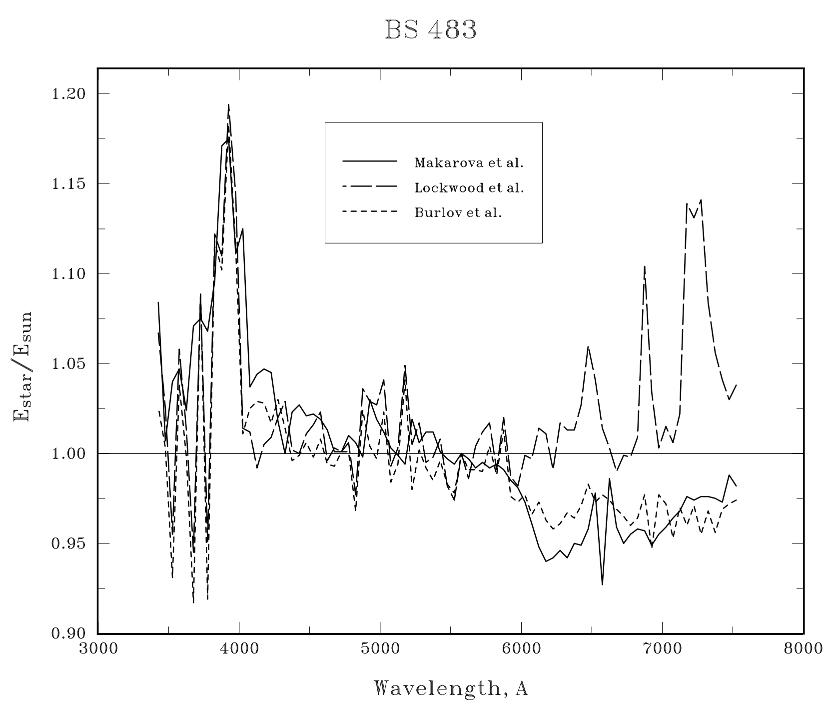

Figure 3: The ratio of the monochromatic fluxes from BS 483 to the fluxes from the Sun in the range 3400 - 7000 Å.

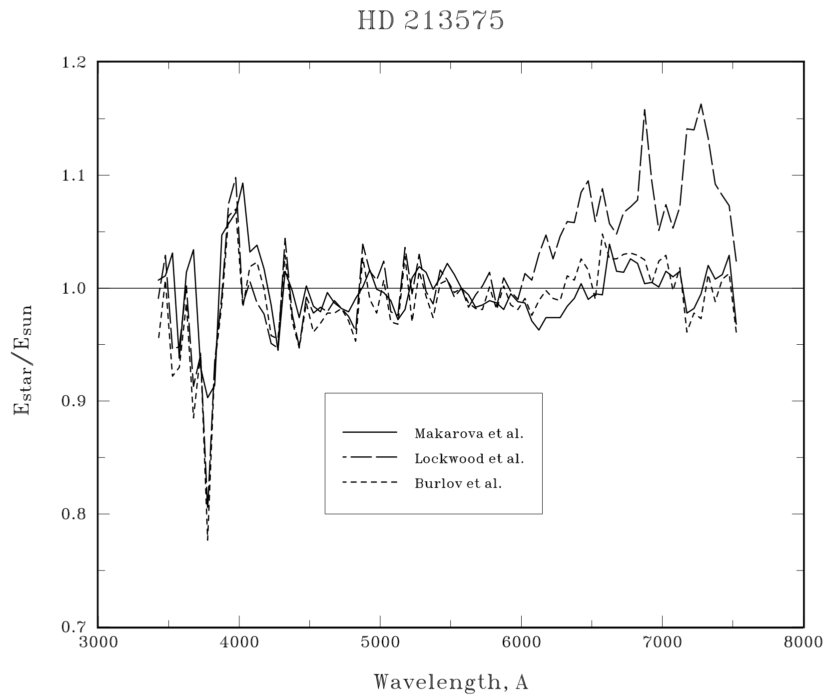

Figure 4: The ratio of the monochromatic fluxes from BS 2135 to the fluxes from the Sun in the range 3400 - 7000 Å.

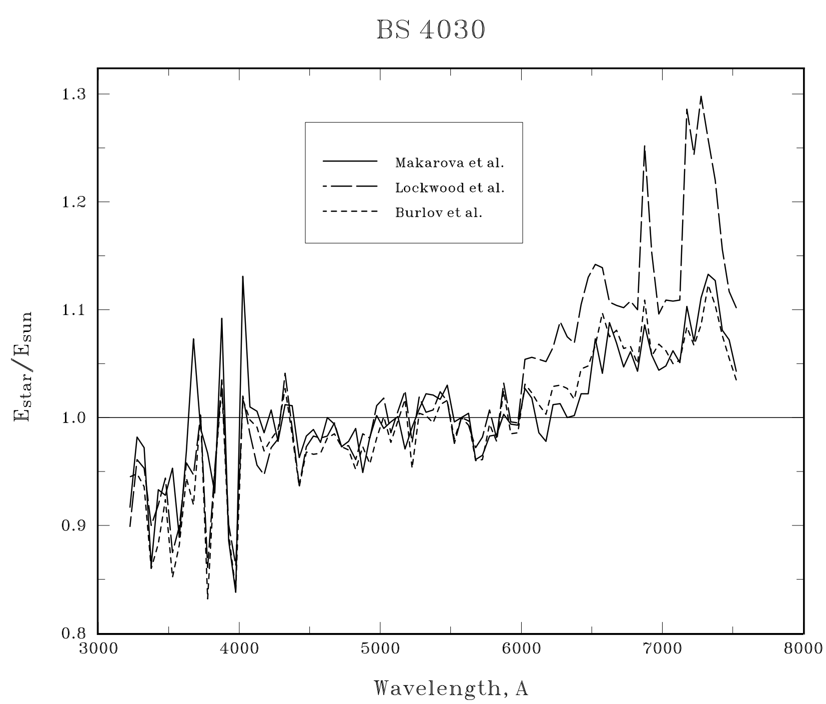

Figure 5: The ratio of the monochromatic fluxes from BS 4030 to the fluxes from the Sun in the range 3400 - 7000 Å.

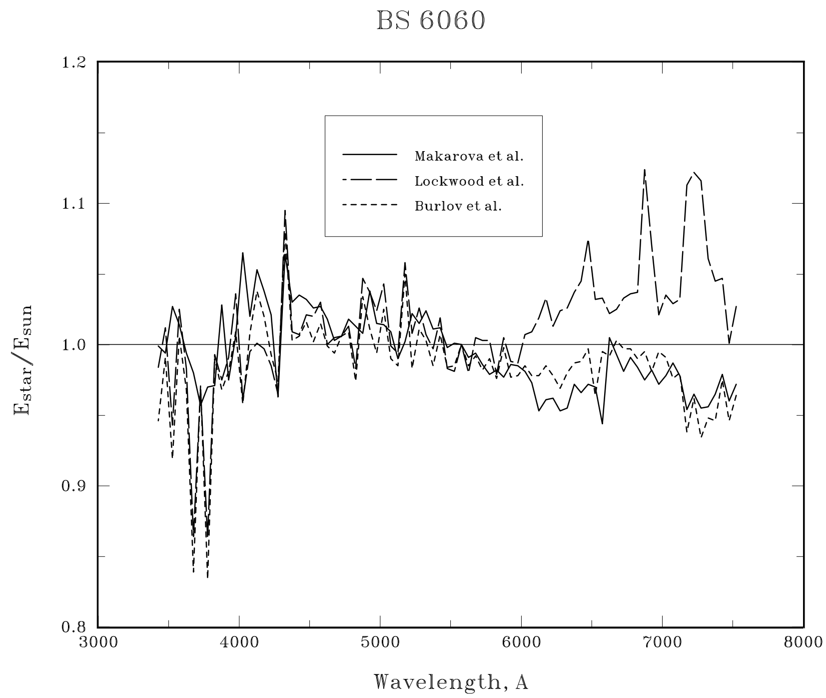

Figure 6: The ratio of the monochromatic fluxes from BS 6060 to the fluxes from the Sun in the range 3400 - 7000 Å.

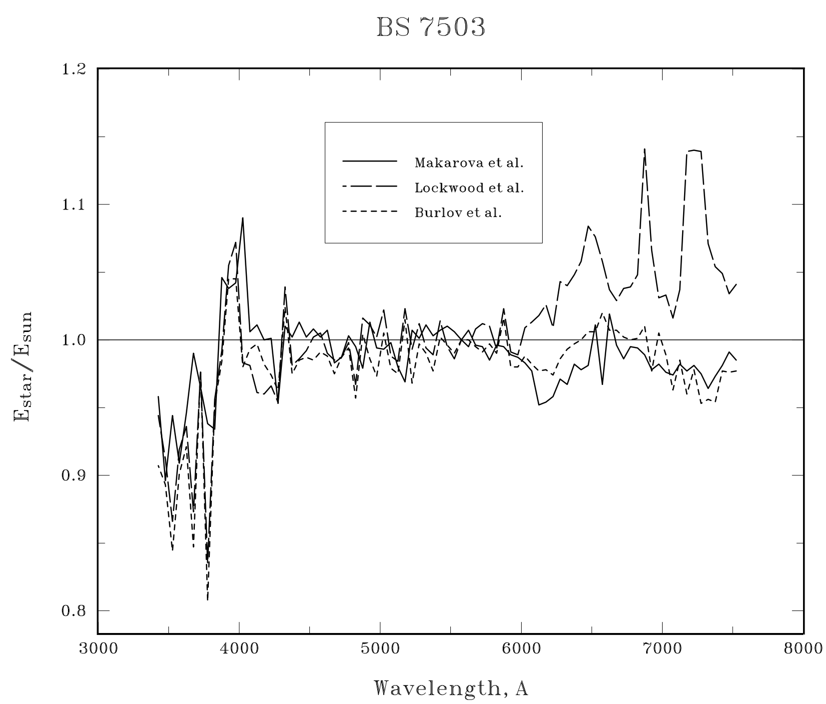

Figure 7: The ratio of the monochromatic fluxes from BS 7503 to the fluxes from the Sun in the range 3400 - 7000 Å.

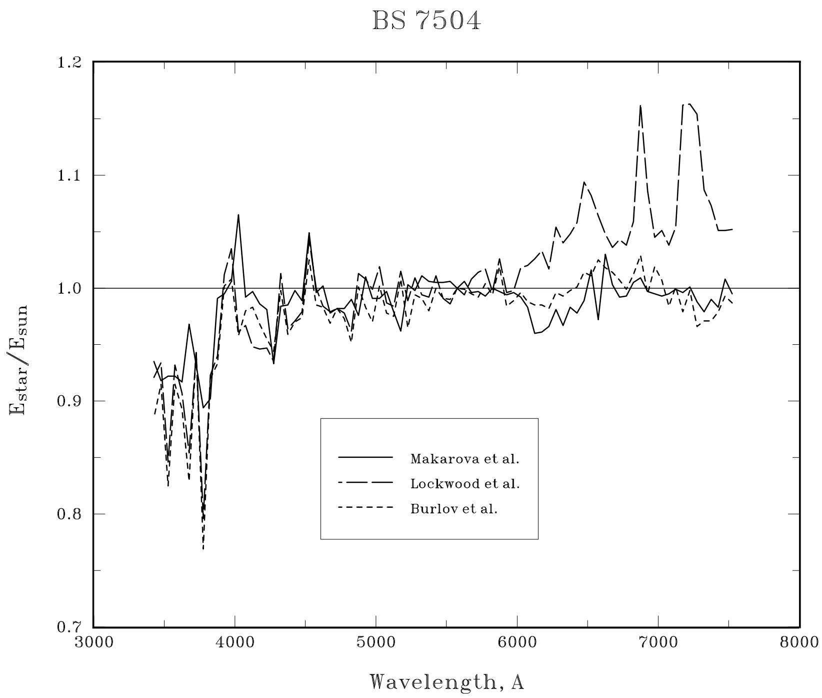

Figure 8: The ratio of the monochromatic fluxes from BS 7504 to the fluxes from the Sun in the range 3400 - 7000 Å.

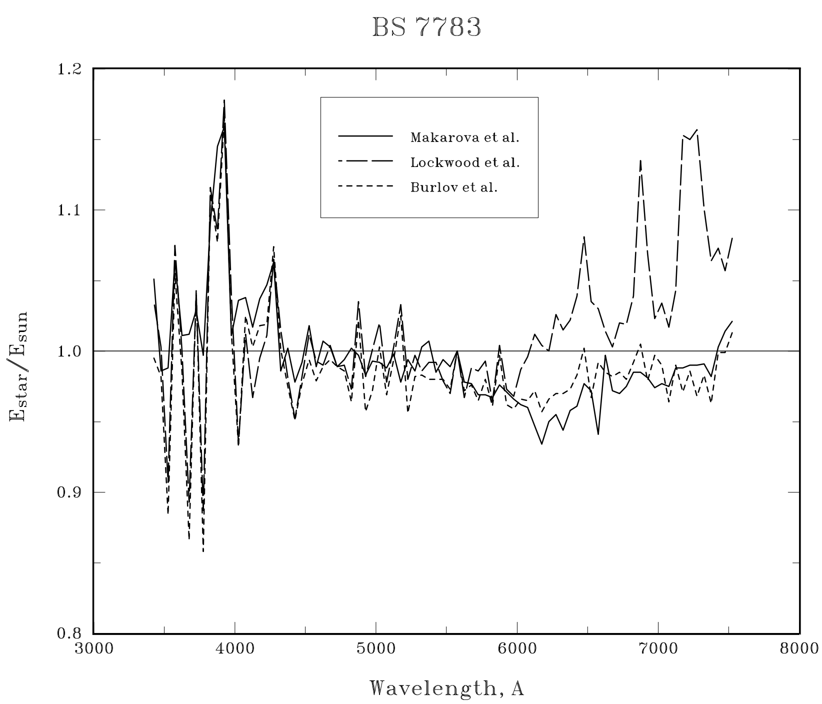

Figure 9: The ratio of the monochromatic fluxes from BS 7783 to the fluxes from the Sun in the range 3400 - 7000 Å.

3 $JHKLM$ photometry of solar type stars

Photometric observations of stars in the infrared were produced at the 125-cm reflector of the Sternberg Institute Crimean Station by mean of $JHKLM$ photometer (Nadzhip et al., 1986). Each star of the program was observed during 2 - 3 nights. Atmospheric extinction was not taken into account in this spectral range because the observations were planned specially to reduce difference of airmass to a minimum. As a rule this difference was of an order of some thousandth of airmass and rarely reached 0.05.

BS 334, BS 458, BS 4031, BS 6075, BS 7328, BS 7957 and BS 8499 were used as standard stars. These stars were chosen from the catalog by Johnson et al. (1966). As H, M, and for many stars L magnitudes are absent in this catalog, missing magnitudes were calculated using formulae presented in the paper by Koorneeff (1983). The accuracy of observations is $0.^m02$ in J, H and K bands, $0.^m03$ in L band and $0.^m05$ in M band.

Table 4 contains infrared color indices $V-J$, $V-H$, $V-K$, $V-L$ and $V-M$ obtained on the basis of different authors' observations. We include in this table not only the stars of our observational program but also some stars which are considered to be the best solar analogs (BS 2290, stars in Hyades) or have energy distribution in the range $3400-7500$ Å near enough to the solar one (BS 1729, BS 5072; Glushneva, 1994).

Table 4. Color indices of solar type stars in the $JHKLM$ system.

HD	BS	SP	V	$V-J$	$V-H$	$V-K$	$V-L$	$V-M$	Author
10307	483	G1.5 V	4.96	1.06	1.38	1.42	1.52	1.44	GS
				1.08		1.39	1.54		J
186408	7503	G1.5 V	5.96	1.04		1.43	1.58		J
				1.13	1.45	1.48	1.55	1.46	C
				1.07	1.39	1.49	1.57	1.43	GS
89010	4030	G1.5 IV-V	5.97	1.17	1.48	1.54	1.53	1.46	GS
				1.12	1.46	1.53			B
				1.16	1.51	1.57	1.65	1.55	E
34411	1729	G1.5 IV-V	4.71	1.07		1.42			J
				1.09	1.38	1.43	1.56		JMM
				1.13		1.46	1.47		S
146233	6060	G2 Va	5.50	1.11	1.45	1.50	1.48	1.39	GS
1835	88	G2 V	6.39	1.07	1.39	1.45	1.51	1.39	B
				1.07	1.39	1.46	1.52	1.47	E
				1.10	1.48	1.55	1.51	1.51	GS
				1.12	1.44	1.51			A
213575		G2V	6.95	1.21	1.57	1.63	1.66		GS
186427	7504	G3 V	6.20	1.09	1.43	1.51	1.59	1.45	GS
				1.16		1.55	1.78		J
				1.12	1.43	1.50	1.56	1.51	C
				1.14		1.53	1.61		W
				1.15	1.47	1.54	1.56	1.57	A'H
44594	2290	G3V	6.61	1.06	1.39	1.45	1.46	1.44	C
				1.06	1.39	1.45	1.50	1.48	W,E
117176	5072	G2.5 Va	4.9	1.28		1.73	1.77		S
217014	8729	G2.5 IVa	5.50	1.13		1.51	1.72		J
				1.14	1.47	1.54	1.54	1.48	C
193664	7783	G3 V	5.93	0.99	1.32	1.40	1.47	1.29	GS
28099	vB 64	G6 V	8.12	1.13	1.44	1.47	1.52	1.515	C
				1.14	1.44	1.49			C
				1.13	1.44	1.47	1.56	1.55	W,E
29461	vB 106	G5 V	7.96	1.12	1.41	1.47			C
30246	vB 142	G5 V	8.34	1.18	1.47	1.53			C

J - Johnson et al., C - Campins et al., GS - Glushneva, Shenavrin,
W - Wamsteker, B - Bouchet et al., A'H - A'Hearn et al., S - Selby et al.,
E - Engels et al., AC - Allen, Cragg, JMM - Johnson, Macartur, Mitchell.

In spite of the accuracy of observations declared by most of the authors, which is $0^m.02 - 0^m.03$ in J, H, K, L bands in some cases observations of the different authors are in worse agreement.

As for color indices of the Sun in the infrared, many former determination are based not on the direct observations of the Sun, but are obtained as a result of the comparison with the stars – solar analogs. The energy distribution of these stars in the infrared range was considered to be similar to solar energy distribution (Johnson 1965; Campins et al. 1985; Wamsteker 1981; A'Hearn et al. 1984). Kharitonov & Knyazeva (1996) calculated synthetic $V-J$, $V-H$,$V-K$, $V-L$ and $V-M$ indices using energy distribution of the Sun from the monograph by Makarova et al. Response curves were taken from the paper by Bessell and Brett (1988).

Color indices of the Sun in the $JHKLM$ system obtained by different authors are presented in Table 5. The differences between minimal and maximal values of color index $V-J$ are $0.^m08$, $V-H$ - $0.^m12$, $V-K$ - $0.^m07$, $V-L$ - $0.^m11$, and $V-M$ - $0.^m14$.

Table 5. Color indices of the Sun in the $JHKLM$ system according to the data of different authors.

	$V-J$	$V-H$	$V-K$	$V-L$	$V-M$
Johnson	1.06		1.41	1.53	1.40
Campins et al	1.116	1.426	1.486	1.520	1.467
Wamsteker	1.109	1.439	1.483	1.557	1.540
A'Hearn et al	1.03	1.35	1.42	1.445	
Kharitonov, Knyazeva (synthetic CI)	1.11	1.47	1.43	1.46	1.46

Table 6 contains ratios of the normalized fluxes from the Sun to the fluxes from solar type stars in the infrared bands according to the data of different authors. These values were obtained from color indices by means of equating of J magnitudes of stars and the Sun. The flux of the Sun is more than the flux of solar type stars in H band while in K, L, M the flux of the Sun is less. For 16 Cyg B, BS 2290, vB 64, vB 106 and vB 142 it was noted by Kharitonov & Knyazeva (1996).

Table 7 presents color indices $J-H$, $J-K$, $J-L$ and $J-M$ of the Sun and solar type stars. Color indices for the stars of our observational program are given in the upper part of the table. It is interesting to note that $J-K$, $J-L$ and $J-M$ of 16 Cyg A (BS 7503) and 16 Cyg B are equal, and the difference between their $J-H$ indices is only $0.^m02$. For stars considered to be the best solar analogs color indices observed by different authors are presented.

The lower part of the Table 7 includes synthetic color indices of the Sun calculated by Kharitonov & Knyazeva and solar color indices obtained by different authors by means of the comparison with solar type stars. It is fully natural that these color indices obtained for the Sun are in the agreement with observed color indices of solar type stars. But synthetic color indices calculated on the basis of solar energy distribution differ from the observed color indices of solar type stars.

Discrepancies between these stellar and solar color indices may be due to the differences of response curves used in the process of integrating and realized in observations. Therefore, direct determinations of color indices of the Sun in the $JHKLM$ photometric system are very necessary and urgent.

Table 6. Ratios of the normalized fluxes from the Sun to the fluxes from solar type stars in the infrared bands according to the data of different authors

Stars		J	H	K	L	M	Author
BS 7504	G3 V	1.000		0.938	0.780		J
		1.000	1.047	0.946	0.920	0.964	C
		1.000		0.938	0.895		W
		1.000	1.037	0.938	0.946	0.938	A'H
		1.000	1.018	0.912	0.871	0.991	GS
BS 2290	G3 V	1.000	1.028	0.939	0.955	0.973	C
		1.000	1.127	1.028	1.009	1.028	W
vB 64	G6 V	1.000	1.047	0.982	0.964	0.968	C
		1.000	1.047	0.982	0.929	0.938	W
vB 106	G5 V	1.000	1.067	0.973			C
vB 142	G1.5 V	1.000	1.067	0.973			C
BS 483	G1.5 V	1.000	1.037	0.964	0.903	0.973	GS
		1.000		1.010	0.903		J
BS 7503	G2 IV-V	1.000		0.938	0.839		J
		1.000	1.037	0.973	0.938	1.018	C
		1.000	1.037	0.912	0.871	0.991	GS
BS 1729	G2 IV-V	1.000		0.973			J
		1.000		0.991	1.009		S(n)
BS 6060	G2 Va	1.000	1.018	0.938	0.982	1.066	GS
BS 4030	G2 IV	1.000	1.047	0.955	0.991	1.057	GS
		1.000	1.018	0.920			B
BS 88	G2 V	1.000	1.038	0.946	0.921	1.029	B
		1.000	1.038	0.937	0.913	0.956	E
		1.000	0.982	0.887	0.946	0.946	GS
		1.000	1.038	0.937			A
HD 213575	G2 V	1.000	1.000	0.911	0.913		GS
BS 7783	G3 V	1.000	1.028	0.919	0.888	1.048	GS

4 Conclusion

For 8 stars of spectral types G1.5-G3 (BS 483, BS 7503, BS 4030, BS 6060, BS 88, HD 213575, BS 7504, and BS 7783) energy distributions in the range 3400 – 7500 Å and $JHKLM$ photometry were produced.

The energy distribution data were compared with solar energy distribution using three sets of the most reliable data. The comparison showed that energy distribution in the spectra of BS 483, BS 6060, BS 7783 and HD 213575 are the nearest to the solar energy distribution in the range 3400 – 7500 Å. Synthetic color $B-V$ indices calculated on the basis of obtained energy distribution data are in very good agreement with observed $B-V$ indices of $WBVR$ photometric system realized at Tien'-Shan' Highmountain Station. The mean difference of the synthetic and observed $B-V$ indices is only $0.^m006$.

Comparison of the observed infrared indices of stars $V-J, V-H, V-K, V-L, andV-M$ with corresponding solar indices shows that scattering in the color indices of stars around the Sun, according to the data obtained by different authors, exceeds the accuracy of infrared measurements declared by various authors.

The $J-H, J-K, J-L$ and $J-M$ indices of the observed stars are nearer to the solar ones obtained by means of the comparison with solar type stars than to the synthetic solar indices.

Discrepancies between observed infrared stellar color indices and synthetic solar ones may be due to the differences of response curves used in the process of integrating and realized in observations.

So direct determinations of color indices of the Sun in the $JHKLM$ photometric system are important.

It is interesting to note that according to our observations, $J-K, J-L, J-M$ of 16 Cyg A and 16 Cyg B are equal and the difference between their $J-H$ is $0.^m02$.

Table 7. Color indices $J-H$, $J-K$, $J-L$, $J-M$ of the Sun and solar type stars

BS	$J-H$	$J-K$	$J-L$	$J-M$	
483	0.32	0.36	0.46	0.38	
4030	0.31	0.37	0.36	0.29	
6060	0.34	0.39	0.37	0.28	
7503	0.32	0.42	0.50	0.36	
7504	0.34	0.42	0.50	0.36	
88	0.38	0.45	0.41	0.41	
HD213575	0.36	0.42	0.45		
7783	0.33	0.41	0.48	0.30	
2290	0.33	0.39	0.40	0.38	
	0.33	0.39	0.44	0.42	
vB 64	0.31	0.34	0.39	0.385	
	0.31	0.34	0.43	0.42	
vB 106	0.29	0.35			
vB 142	0.29	0.35			
Sun synth	0.36	0.33	0.35	0.35	
		0.35	0.47	0.34	J
	0.33	0.374	0.448	0.431	W
	0.32	0.39	0.415	0.455	A'H
	0.31	0.37	0.404	0.37	C

References

A'Hearn, M.F., Dwek, E., & Tokunaga, A.T. 1984, ApJ., 282, 803

Allen, D.A., & Cragg, T.A. 1983, MNRAS, 203, 777

Bessel, M.S., & Brett, J.M. 1988, PASP, 100, 1134

Bouchet, P., Manfroid, J., & Schmider F.X. 1991, A&AS, 91, 409

Burlov-Vassil'ev, K.A., Gurtovenko, E.A., & Matveev, Yu.B. 1994, Kinematika i fizika nebesnykh tel, V.10. N.3. P.3

Burlov-Vassil'ev, K.A., Vassil'eva, I.E., & Matveev, Yu.B. 1996, Kinematika i fizika nebesnykh tel, V.12. N.3. P.75

Campins H., Rieke G.H., & Lebofsky M.J. 1985, AJ, 90, 896

Engels D., Sherwood W.A., Wamsteker W., & Schuitz G.V. 1981, A&AS, 45, 5

Garcia, B. 1989, Bull. Inform. Centre de Donnees stellaires., 36, 27

Glushneva, I.N. 1994, Astron. Zhurn., 71, 652.

Glushneva, I.N., Makarova E.A., & Kharitonov, A.V. 1986, Highlights of astronomy, ed J.-P. Swings, 1986., 7, 853

Glushneva, I.N., Kharitonov, A.V., Knyazeva, L.N., & Shenavrin, V.I. 1992, A&AS, 92, 1

Hayes, D.S. 1985, in Calibration of Fundamental Stellar Quantities, ed. D. S. Hayes, L. E. Pasinetti, & A. G. D. Philip, (Dordrecht: Reidel) p. 225

Johnson, H.L. 1965, Comm. Lunar. and Planet. Lab., 3, 73

Johnson, H.L., Mitchell, R.I., Iriarte, B., & Wis'niewski, W.Z. 1966, Comm. of the Lunar and Planet. Lab., 63, 99

Johnson, H.L., Macartur, J.W., & Mitchell, R.I. 1968, ApJ, 152, 465

Kharitonov, A.V., Tereshchenko, V.M. & Knyazeva, L.N. 1988, Spectrofotometricheskij Katalog Zvezd, (Alma-Ata: Nauka)

Kharitonov, A.V., Glushneva, I.N., & Knyazeva, L.N. 1994, Astron. Zhrun., 71, 657

Kharitonov, A.V., Knyazeva, L.N. 1996, Izvestiya VUZov Radiofizika, V.39. N.10. P.1234

Kornneef, J. 1983, A&AS, 51, 489

Kornilov, V.G., et al. 1991, Trudy Gos. Astron. Inst. P.K. Shternberga, V.63. 399 pp.

Lockwood, G.W., Tüg, H., & White, N.M. 1992, ApJ, 390, 668

Makarova, E.A., Kharitonov, A.V., & Kazachevskaya, T.V. Solar Flux, 1991, (Moscow: Nauka) 362 pp.

Makarova, E.A., Kharitonov, A.V., & Kazachevskaya, T.V. 1994, Solar Phys., 152, 195

Nadzhip, A.E., Shenavrin, V.I., & Tikhonov, V.G. 1986, Trudy Gos. Astron. Inst. P.K. Shternberga, 58, 119

Selby, M.J., Hepburn, I.,Blackwell, D.E., Booth, A.J., Haddock, D.J., Arribas, S., Leggett, S.K., & Mountain, C.M. 1988, A&A, 74, 127

Voloshina, I.B., Glushneva, I.N., Doroshenko, V.T., Kolotilov, E.A.,

Mossakovskaya, L.V., Ovchinnikov, S.L. & Fetisova, T.S. 1982, Spectrophotometry of Bright Stars, ed. I.N. Glushneva (Moscow: Nauka) 255 pp.

Wamsteker, W. 1981, A&A, 97, 329.

Discussion following Irina Glushneva's talk

White: One comment about the Markarova monograph, which is not familiar to many of us. I have copies, and there's a wealth of information in it, about the instruments used as well as extensive tabulations of the data. We've tried unsuccessfully for two years to get the funds together to have it translated into English, but it's an extremely useful volume.

Hall: I was wondering about the Hayes 1985 Vega calibration, because there was recently a paper published in A&A by Megessier, analyzing all the different Vega calibrations. He settled on the Hayes & Latham 1975 and the Tüg, White, & Lockwood 1977 calibrations as the best. Wasn't the 1985 "calibration" just an average of lots of others?

Garrison: That calibration came from one of the Dudley Observatory workshops, and I seem to remember there were lots of objections to it, but I can't remember what they were.

Hall: I think Megessier's objection was that Hayes 1985 was an average of calibrations from different sources, so for example, you weren't really sure what the internal errors were. So it might affect the spectrophotometric calibration a bit if you used a more uniform source like Hayes & Latham, which a lot of people use. Have you looked at how that might affect your choice of the best solar analogs?

Glushneva: Hayes analyzed all the calibrations and made a weighted mean, with maximum weight on his own, of course [laughter].

Hall: Ah, and there's the big objection, it was this average and you weren't sure which calibration it was.

Glushneva: My opinion is that it is more correct to use some absolute calibration of Vega flux and the weighted mean, as it was done in the case of the Hayes 1985 Vega calibration, than to choose one "best" calibration because of possible systematic errors present in any spectrophotometric calibration. For four calibrations used by Hayes for weighted mean in the visual range the systematic agreement is of the order of the internal error. The mean standard deviation is only 1.5% at 5000 Å. It is a very good result. However, in the UV and red, the agreement is worse. In producing the weighted mean. Hayes gave weight (2) to Hayes and Latham 1975 (HL) calibration, and to the rest weight (1). The weighted mean lies between approximately HL and Tug. et al. 1977 calibrations in the visual range, but in the UV, the Tüg et al. calibration is higher than HL one, which is nearer to the weighted one.

Garrison: One comment, I noticed in your table you had the Hyades vB 64 listed as G6 V. That was a misidentification of a star by Hiltner, who took the spectra. Morgan classified that star correctly; vB64 is really G2 V.

Glushneva: The spectral type of vB 64 G6V was taken from the paper by Campins et al. (1985) with infrared color indices. The corresponding line of Table 4 has index C, showing the author of publication. But the photometric catalog by Blanco et al. (Publ. of the US Naval Observatory, Washington, 1970) gives spectral type G0 for this star. So there are significant differences in spectral type between various publications for this star.

Garrison: The *real* vB 64 is very close to G2 V. Hiltner misidentified a star he *thought* was vB64, and Morgan classified that star correctly as G6 V. So Morgan never really classified vB64. This is important, because Hardorp made quite a case out of vB64, all based on Morgan's correct classification of the wrong star. In fact, Hardorp made it his strongest case, because he mistakenly took Morgan's classification as confirmation of his "cooler Sun."