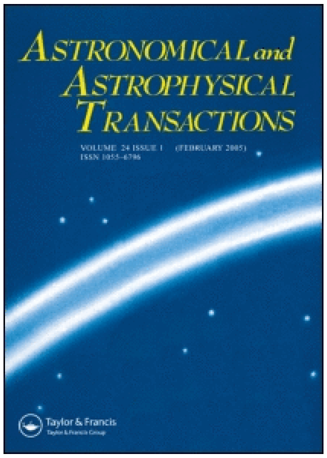

Astronomical & Astrophysical Transactions
The Journal of the Eurasian Astronomical Society
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453505

Solar type stars: Spectral energy distribution and **JHKLM** photometry

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Online Publication Date: 01 February 2000
To cite this Article: Glushneva, I. N., Borisov, G. V., Shenavrin, V. I. and Roshchina, I. A. (2000) 'Solar type stars: Spectral energy distribution and **JHKLM** photometry', Astronomical & Astrophysical Transactions, 18:4, 631 - 644
To link to this article: DOI: 10.1080/10556790008208167
URL: http://dx.doi.org/10.1080/10556790008208167

Astronomical and Astrophysical Transactions, 2000, Vol. 18, pp. 631–644
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SOLAR TYPE STARS: SPECTRAL ENERGY DISTRIBUTION AND *JHKLM* PHOTOMETRY

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(Received April 22, 1998)

Energy distribution data in the range 3400–7500Å 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 eight stars of spectral types G1.5–G3 of V and IV luminosity classes are presented. The accuracy of the spectrophotometric data is about 2% in the range 3400–4000Å, 1% in the range 4000–6000Å and about 1.5–2% in the range 6000–7500Å. The accuracy of *JHKLM* photometry is 2% in the bands J, H, K and L and 5% in the M band. A comparison of the energy distribution in the spectra of stars with three reliable sets of spectrophotometric data of the Sun is presented. The differences between stellar and solar energy distribution data are at a minimum for BS 6060 and HD 213575. Comparison of stellar *JHKLM* photometry with synthetic solar photometry in these IR bands was done. The colour indices $J-H$, $J-K$, $J-L$, and $J-M$ of the Sun and solar-type stars were analysed.

KEY WORDS Solar analogues, energy distribution, IR photometry

1 INTRODUCTION

The Sun is well known to be the standard of the G2 V 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 the photometric parameters of the Sun, i.e. colour indices in different photometric systems.

To find a solar "twin" it is necessary that the colour indices of a star in different photometric systems should be similar to the solar indices to within the limits of accuracy of the observations.

Comparison of the solar spectral energy distribution and the 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 a typical representative of the spectral type G2 V.

The position of the Sun on the two – colour diagrams and comparison with solar-type star positions will make use for the answer to the question of whether the Sun is a "quite normal" or a "slightly peculiar" star.

2 SPECTRAL ENERGY DISTRIBUTION IN THE RANGE 3400–7500Å

In the paper by Glushneva (1994) synthetic $W-B$ and $B-V$ colour 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 a homogeneous MK spectral classification (Garcia, 1989). The colour indices of the Sun in the same system were obtained from the most reliable series of spectrophotometric measurements. Comparison of observed colour indices of solar-type stars and synthetic colour indices of the Sun showed that $(W-B)_{\odot}$ corresponds to the mean value of this colour index for stars of spectral type G1.5. This conclusion is also confirmed by direct comparison of the energy distributions of stars and the Sun in the range from 3200 to 5500Å. However, $(B-V)_{\odot}$ corresponds to the mean value of this colour 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 eight stars of spectral subtypes G1.5–G3 were included in the observational spectrophotometric programme. Observations were done by means of the spectrophotometer installed at the 60-cm Zeiss-2 reflector of the Sternberg Institute Crimean Station. The spectral resolution is about 50Å.

A grating with discrete scanning and a photomultiplier working in the regime of photon counting were used. Tests of the amplifier demonstrated its high stability. The deviation from linearity did not exceed 0.5% at a counting speed of 3×10^5 counts/sec.

In the process of observations the spectral width of the entrance slit was 50Å and an inlet diaphragm of $27''\!.5$ was used. Registration of spectra was done according to the scheme: standard star, programme star, background, programme star again and standard star. The stars of the observational programme were compared with standard stars by means of the method of equal altitudes. Differential extinction was taken into account with the spectral extinction coefficient obtained on each observational night. For this, the spectra of two standard stars with differences in airmass not less than 0.5 were registered several times during the night.

The observational data were put into a computer and the continuum in the wavelengths of the hydrogen absorption lines in the spectra of standard stars was constructed in the graphic regime. The energy distributions in the spectra of the programme stars were calculated using the energy distribution in the spectra of standard stars and the spectral extinction coefficient of the observational night.

The mean energy distribution data were obtained for each star on the basis of measurements on 2–5 nights, i.e. 4–10 individual scans were used because on each night the spectrum of the programme star was scanned twice.

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	
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	
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

Note. KGK – Kharitonov, Glushneva, Knyazeva (1994).

Because of the inconvenience of operating with energy distribution data in an instrumental wavelength system, the mean energy distribution was recalculated in 50Å steps beginning from 3425Å.

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 catalogue of the Sternberg Astronomical Institute. (Voloshina *et al.*, 1982) Spectral energy distribution data of standard stars with 100 Å steps are presented in the paper by Glushneva *et al.* (1992).

Energy distribution data in the spectra of standard stars were obtained by means of the comparison with α Lyr, the main spectrophotometric standard. The calibration of α Lyr published by Hayes (1985) was used.

Table 1 contains HD and BS numbers of the investigated stars, their spectral types, V magnitudes and colour indices $W-B$, $B-V$ and $V-R$ from the WBVR catalogue (Kornilov *et al.*, 1991).

The spectral type of BS 7504 (16 Cyg B) was taken according to the classification by Garcia (1989).

The last line of Table 1 includes the same colour indices calculated for the Sun (Kharitonov *et al.*, 1994).

For the calculation of the synthetic colour indices of the Sun, an 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 centre of the solar disk and the mean over all of the disk obtained by means of calculating the average values of the best observations chosen on the basis of the spectral analysis.

The spectral resolution is 50Å in the range 3000–5000Å and 100Å from 5000 to 7000Å. In the range 7000–9000Å data are presented with 200Å steps. These energy distribution data were also published in Solar Physics (Makarova *et al.*, 1994). The response curves of the $WBVR$ photometric system were taken from the catalogue by Kornilov *et al.* (1991). Synthetic colour indices obtained for the Sun were published in the paper by Kharitonov, Glushneva and Knyazeva (1994).

Table 2. Energy distribution in the spectra of program stars in erg/cm^2 s cm$\times 10^{-5}$

λ	*BS 88*	*BS 483*	*BS 6060*	*BS 7503*	*BS 7504*	*BS 7783*	*HD 213575*
3425	49.8	214.7	122.1	76.4	57.2	86.4	30.9
3525	52.0	218.9	133.3	79.9	59.9	86.2	33.6
3575	50.3	217.5	130.0	76.0	59.2	91.7	30.2
3625	54.3	225.7	135.1	83.9	62.4	92.4	34.6
3675	63.6	254.7	143.7	94.7	71.1	99.8	38.1
3725	60.2	254.5	139.8	91.9	68.1	101.0	34.1
3775	53.5	247.2	138.5	87.4	63.9	95.7	32.4
3825	52.6	242.3	132.4	83.1	61.6	100.0	31.3
3875	58.2	253.9	137.6	91.3	66.4	103.0	35.2
3925	62.4	272.6	139.5	96.9	71.3	111.5	38.0
3975	74.4	310.6	173.5	117.2	86.8	117.2	46.2
4025	95.1	380.5	222.4	148.4	111.3	145.4	57.3
4075	96.2	379.7	230.4	148.1	112.1	157.6	58.5
4125	99.6	391.9	243.8	152.8	115.6	158.4	60.4
4175	99.6	395.1	241.8	151.9	114.9	162.3	59.5
4225	98.0	389.0	234.4	149.9	112.8	161.7	56.8
4275	90.9	363.2	211.9	136.7	102.8	157.2	52.2
4325	94.3	352.4	231.4	143.2	107.1	144.2	55.4
4375	101.0	387.2	240.6	152.6	115.1	157.3	58.5
4425	107.7	416.7	258.9	165.3	125.0	164.5	61.2
4475	111.6	430.2	268.1	169.9	128.7	173.4	65.4
4525	116.2	441.2	273.3	175.2	139.9	182.3	65.8
4575	116.8	445.1	276.7	176.1	134.4	179.3	66.3
4625	112.2	440.5	273.0	176.2	134.5	181.7	67.1
4675	112.1	430.2	265.8	170.0	129.7	178.7	65.7
4725	112.7	431.1	267.3	171.0	130.6	176.7	65.5
4775	115.0	438.0	272.3	175.0	131.5	178.9	65.8
4825	112.9	426.0	264.5	169.6	129.5	176.0	65.0
4875	106.6	407.9	254.3	161.0	123.2	169.0	63.4
4925	111.1	423.3	263.2	167.4	128.1	167.5	64.7
4975	109.1	420.6	258.6	165.2	126.4	170.0	63.9
5025	107.8	412.6	255.0	163.0	124.8	167.7	62.9
5075	108.7	409.0	253.9	163.7	125.6	167.1	62.5
5125	105.1	402.5	246.1	158.9	121.9	166.9	60.7
5175	100.6	389.2	242.0	152.7	116.3	158.9	59.5
5225	103.6	396.3	245.2	157.6	120.5	160.3	60.8
5275	105.3	397.7	247.5	159.2	121.8	161.7	62.4
5325	107.3	402.2	251.0	161.6	124.1	165.3	62.4
5375	105.6	399.8	246.6	159.5	122.8	165.0	61.2
5425	105.5	394.6	246.1	159.8	122.3	161.1	61.6
5475	105.3	393.0	242.7	160.2	122.4	162.5	62.4
5525	104.7	389.7	242.2	158.7	121.8	160.9	61.5
5575	102.5	387.9	239.3	156.1	119.8	160.9	60.1
5625	102.9	385.3	236.3	156.5	120.0	156.8	59.5
5675	102.8	384.3	237.5	155.3	119.2	157.0	59.0
5725	102.9	386.4	236.3	155.6	119.6	156.2	59.3
5775	102.6	386.5	235.1	154.4	119.4	156.5	59.7
5825	103.4	384.2	234.0	154.8	119.3	155.0	59.1
5875	101.1	375.6	228.4	151.7	116.7	153.4	57.6
5925	99.9	368.8	227.8	149.0	114.9	150.8	57.7
5975	99.4	365.0	226.2	147.9	114.5	149.2	57.0
6025	98.2	360.3	224.0	146.5	113.4	147.7	56.6

Table 2. Continued

λ	*BS 88*	*BS 483*	*BS 6060*	*BS 7503*	*BS 7504*	*BS 7783*	*HD 213575*
6075	96.6	353.9	220.9	144.7	111.8	146.6	55.4
6125	93.6	345.6	214.2	139.6	108.0	143.1	54.4
6175	93.4	337.6	212.9	137.9	106.6	139.1	54.2
6225	93.1	334.3	210.7	136.9	105.9	139.9	53.6
6275	92.9	333.0	207.0	137.5	106.6	139.4	53.1
6325	92.8	328.5	205.4	135.7	104.2	136.6	53.2
6375	93.4	328.3	207.2	136.6	104.9	137.4	53.1
6425	92.7	324.2	203.6	134.4	103.2	136.1	53.1
6475	91.0	322.3	201.7	132.7	102.7	136.3	51.6
6525	92.0	322.8	197.4	134.3	103.6	133.1	50.9
6575	85.8	299.2	188.0	125.6	96.9	126.0	49.7
6625	90.9	316.0	198.7	131.5	102.0	132.6	51.6
6675	90.0	310.4	198.3	129.8	100.3	130.5	50.9
6725	89.1	307.0	195.7	128.3	99.0	130.0	50.8
6775	88.7	304.7	195.1	127.7	97.9	129.0	50.7
6825	86.7	301.1	190.8	125.8	97.6	128.5	49.8
6875	83.4	296.0	185.9	123.1	96.3	126.3	48.1
6925	83.3	289.4	184.8	120.1	93.9	124.1	47.5
6975	82.6	288.2	181.0	119.3	92.8	122.0	46.8
7025	81.8	286.0	179.9	117.1	91.5	120.8	46.9
7075	82.0	283.6	179.0	115.3	90.4	118.9	46.0
7125	80.7	280.6	174.9	114.6	89.4	118.8	45.6
7175	76.2	278.9	168.2	112.3	87.9	117.1	43.3
7225	75.6	274.7	168.0	111.4	87.2	115.8	42.9
7275	74.1	272.3	164.3	109.4	85.1	114.5	43.0
7325	74.6	269.3	162.6	107.0	83.4	113.4	43.6
7375	72.7	265.9	162.3	106.8	83.4	111.1	42.6
7425	71.7	262.6	162.9	106.5	81.9	112.3	42.3
7475	72.6	263.9	158.3	106.6	83.2	112.4	42.6
7525	70.8	259.9	158.6	104.9	81.3	112.1	39.7

The scattering of $W - B$ for the stars of Table 1 are maximal (about 0.17 mag) concerning the $B - V$ and $V - R$ indices which are about 0.08 mag and 0.04 mag.

The eighth column of Table 1 includes synthetic colour indices $(B - V)_{syn}$ calculated on the basis of the observed energy distribution data. The response curves were taken from the catalogue by Kornilov *et al.* (1991). The comparison of observed and synthetic $B - V$ indices shows that they are in a very good agreement: the mean difference $(B - V)_{\rm syn} - (B - V)_{\rm obs}$ is only $0\overset{m}{.}006$.

Energy distribution data in the spectra of the programme stars in the range 3400–7500Å with 50Å steps are presented in Table 2. Monochromatic fluxes are expressed in erg/cm^2 s cm. The accuracy of the spectrophotometric data is about 2% in the ultraviolet (3400–4000Å), 1% in the range 4000–6000Å and 1.5–2% in the near infrared (6000–7600Å).

For comparison of the solar energy distribution and energy distribution data of solar-type stars, three sets of solar data were used: Makarova *et al.* (1991), Lockwood *et al.* (1992) and Burlov–Vassil'ev *et al.* (1994, 1996).

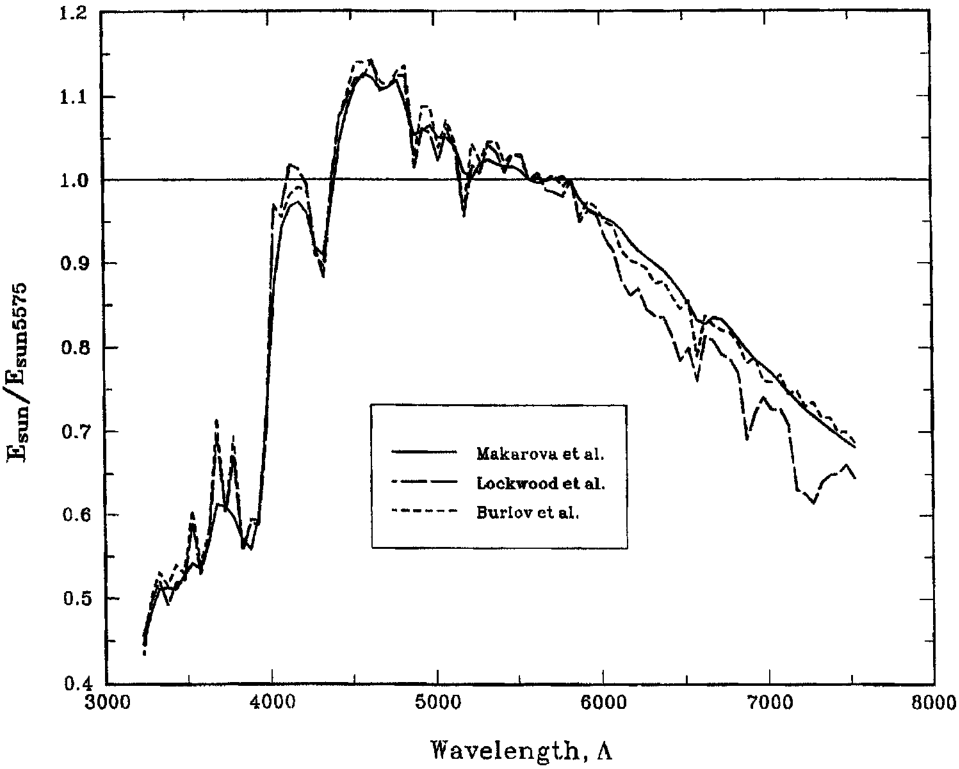

Figure 1 Energy distribution of the Sun normalized at 5575Å.

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

The observations by Burlov–Vassil'ev *et al.* were produced at Terskol mountain (3100 m about sea level) located in the northern Caucasus. Their equipment was investigated carefully and special attention was paid to the determination of atmospheric extinction 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 the World Radiation Center in Davos. These comparisons showed that the error of the absolute calibration does not exceed 2% in the range 3000–7000Å.

Energy distribution data are presented with 50 Å steps in the range 3325–6675Å (Burlov–Vassil'ev *et al.*, 1994) and in the range 6500–10 700Å (Burlov–Vassil'ev *et al.*, 1996).

Figure 1 demonstrates the mean energy distribution data over all of the solar disk normalized to 5575Å according to the three sets described above.

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

λλ	*HD 213575*	*BS 88*	*BS 483*	*BS 4030*	*BS 6060*	*BS 7503*	*BS 7504*	*BS 7783*
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
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
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

Comparison of these data shows that in the ultraviolet region the data of different authors are in satisfactory agreement but the red data by Lockwood *et al.* are higher. This is probably connected with the difference of spectral resolution, because these data were transformed to the resolution of 50 Å to make all three sets comparable.

The mean ratio of the monochromatic fluxes from the Sun to the fluxes from solar-type stars in the range 3500–7500Å are presented in Table 3 and for two stars: BS 6060 and BS 7504 in Figures 2a and 2b.

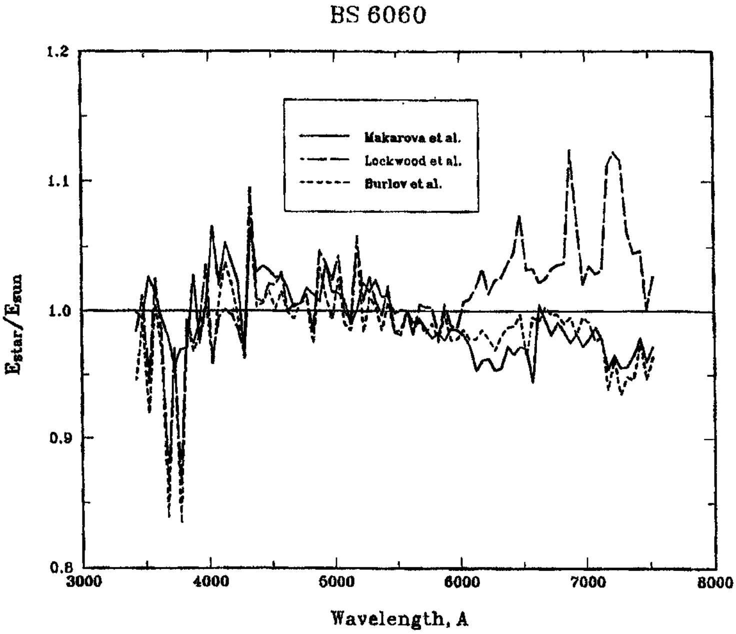

Figure 2a The ratio of the monochromatic fluxes from the star BS 6060 to the fluxes from the Sun in the range 3400–7500Å.

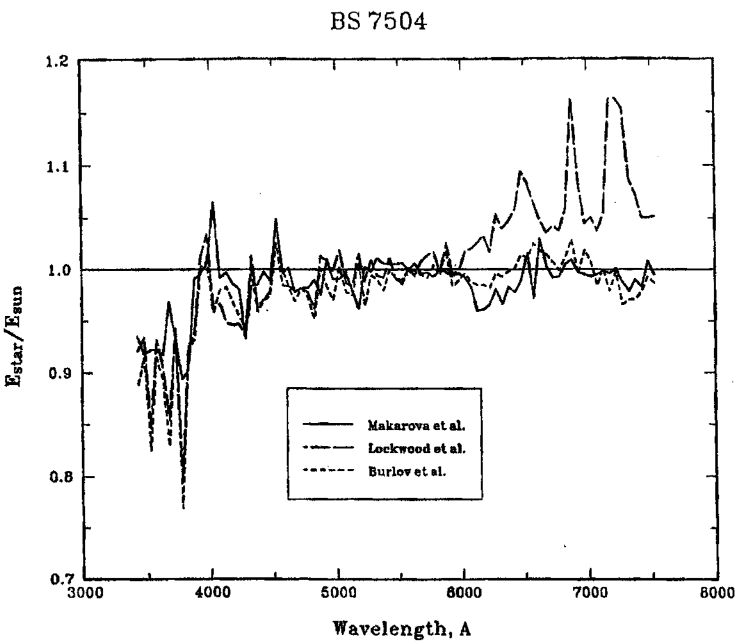

Figure 2b The ratio of the monochromatic fluxes from the star BS 7504 to the fluxes from the Sun in the range 3400–7500Å.

The energy distribution data for BS 4030 was taken from the spectrophotometric catalogue by Kharitonov *et al.* (1988).

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

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

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

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

It is interesting to note that Porto de Mello (1997) concluded on the basis of the detailed analysis of the optical spectrum and evolutionary state of BS 6060 that this star surpasses all previously claimed solar twins in likeness to the Sun.

3 *JHKLM* PHOTOMETRY OF SOLAR-TYPE STARS

Photometric observations of stars in the infrared range were produced at the 125-cm reflector of the Sternberg Institute Crimean Station by means of the *JHKLM* photometer (Nadzhip *et al.*, 1986). Each star of the programme 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 differences of airmass to a minimum. As a rule this difference was of the order of some thousandths of the 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 catalogue by Johnson *et al.* (1966). As H, M and for many stars L magnitudes are absent in this catalogue missing magnitudes were calculated using formulae presented in the paper by Koornneef (1983).

The accuracy of the observations is $0\overset{m}{.}02$ in the J, H and K bands, $0\overset{m}{.}03$ in the L band and $0\overset{m}{.}05$ in the M band. Table 4 contains infrared magnitudes of programme and standard stars. The upper part of Table 4 includes also the accuracy of the measurements.

Table 5 contains colour indices $V-J$, $V-H$, $V-K$, $V-L$ and $V-M$ obtained on the basis of different authors' observations.

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

As for colour indices of the Sun in the infrared many former determinations are based not on direct observations of the Sun but are obtained as a result of the

Table 4.

Infrared magnitudes of solar-type stars

Program stars	*J*		*H*		*K*		*L*		*M*	
BS 88	5.29	0.03	4.91	0.04	4.84	0.03	4.88	0.04	4.88	0.10
BS 483	3.90	0.02	3.58	0.02	3.54	0.02	3.44	0.02	3.52	0.05
BS 4030	4.80	0.02	4.49	0.02	4.43	0.02	4.44	0.02	4.51	0.05
BS 6060	4.39	0.02	4.05	0.02	4.00	0.02	4.02	0.02	4.11	0.05
BS 7503	4.89	0.01	4.57	0.02	4.47	0.01	4.39	0.02	4.53	0.05
BS 7504	5.11	0.01	4.77	0.02	4.69	0.01	4.61	0.02	4.75	0.05
BS 7783	4.94	0.03	4.61	0.02	4.53	0.02	4.46	0.02	4.64	0.05
HD 213575	5.74	0.02	5.38	0.02	5.32	0.02	5.29	0.03		

Infrared magnitudes of standard stars

Program stars	*Standard stars*	*V*	*J*	*H*	*K*	*L*	*M*
BS 88	BS334	3.45	1.58	0.98	0.83	0.77	0.89
BS 483	BS458	4.10	3.17	2.91	2.85	2.79	2.85
BS 4030	BS4031	3.44	2.81	2.66	2.62	2.59	2.63
BS 6060	BS6075	3.23	1.60	1.11	0.99	0.96	1.05
BS 7503	BS7328	3.76	2.25	1.79	1.67	1.58	1.70
BS 7504	BS7328	3.76	2.25	1.79	1.67	1.58	1.70
BS 7783	BS7957	3.43	1.90	1.40	1.28	1.19	1.31
HD 213575	BS8499	4.15	2.58	2.12	2.01	1.95	2.05

comparison with stars – solar analogues. The energy distribution of these stars in the infrared range was considered to be similar to the solar energy distribution. (Johnson, 1965; Campins *et al.*, 1985; Wamsteker, 1981; A'Hearn *et al.*, 1984). Kharitonov and Knyazeva (1996) calculated synthetic $V-J$, $V-H$, $V-K$, $V-L$ and $V-M$ indices using the energy distribution of the Sun from the monograph by Makarova *et al.* The response curves were taken from the paper by Bessell and Brett (1988).

Colour indices of the Sun in the *JHKLM* system obtained by different authors are presented in Table 6. The differences between the minimal and maximal values of the colour index $V-J$ are $0\overset{m}{.}10$, $V-H$ are $0\overset{m}{.}12$, $V-K$ are $0\overset{m}{.}09$, $V-L$ are $0\overset{m}{.}09$ and $V-M$ are $0\overset{m}{.}14$.

The last two lines of Table 6 contain colour indices of the solar reference spectrum (Colina *et al.*, 1996) obtained for Wamsteker (1981) and Campins *et al.* (1985) photometric systems.

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

Colour indices for the stars of our observational programme 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 (BS 7504) are equal, and the difference between their $J-H$ indices is only $0\overset{m}{.}02$.

Table 5. Colour 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
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		G2 V	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
193664	7783	G3 V	5.93	0.99	1.32	1.40	1.47	1.29	GS

Note. J=Johnson *et al.*, C=Campins *et al.* (1985); GS=Glushneva, Shenavrin; W=Wamsteker (1981); B=Bouchet *et al.* (1991); A'H=A'Hearn *et al.* (1984); E=Engels *et al.* (1981); AC=Allen and Cragg (1983).

Table 6. Colour 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
Colina *et al.*	1.11	1.45	1.47		
	1.16	1.44	1.50		

The lower part of Table 7 includes synthetic colour indices of the Sun calculated by Kharitonov and Knyazeva and solar colour indices obtained by different authors by means of the comparison with solar-type stars. It is entirely natural that these colour indices obtained for the Sun are in agreement with the observed colour indices of solar-type stars. But the synthetic colour indices calculated by

Table 7. Colour 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	
HD 213575	0.36	0.42	0.45		
7783	0.33	0.41	0.48	0.30	
Sun synth	0.36	0.33	0.35	0.35	
	0.34	0.36			CBC
		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

Note. Here CBC means the paper by Colina *et al.* (1996).

Kharitonov and Knyazeva (1996) and Colina *et al.* (1996) on the basis of the solar energy distribution differ from the observed colour 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. So direct determinations of colour indices of the Sun in the $JHKLM$ photometric system are very necessary and urgent.

4 CONCLUSION

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

Energy distribution data were compared with the solar energy distribution using three sets of the most reliable data. The comparison showed that the 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 3400–7500Å. Synthetic colour $B-V$ indices calculated on the basis of the obtained energy distribution data are in a very good agreement with the observed $B-V$ indices of the $WBVR$ photometric system used at the Tien'-Shan' High Mountain Station. The mean difference of the synthetic and observed $B-V$ indices is only $0\overset{m}{.}006$.

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

$J-H$, $J-K$, $J-L$ and $J-M$ 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 the observed infrared stellar colour indices and the 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 colour indices of the Sun in the $JHKLM$ photometric system are important.

It is interesting to note that according to our observations the $J-K$, $J-L$, $J-M$ of 16 Cyg A and 16 Cyg B are equal and the difference between their $J-H$ is $0\overset{m}{.}02$.

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