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MK SPECTRAL TYPES FOR OB$^+$ STARS IN THE SOUTHERN MILKY WAY[1]

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ABSTRACT

MK spectral types are presented for 291 stars selected from the Case-Hamburg Luminous Star survey.

Subject headings: stars: early-type — stars: fundamental parameters

1. INTRODUCTION

MK spectral types are given in Table 2 (below) for 291 stars classified as OB$^+$ in the Case-Hamburg Luminous Star survey. This survey is complete to 12th magnitude and covers the entire Milky Way between Galactic latitudes $\pm 10°$. Most of the stars are from the Southern survey (Stephenson & Sanduleak 1971), but a few are from the Northern survey (Stock, Nassau, & Stephenson 1960; Nassau & Stephenson 1963; Nassau, Stephenson, & MacConnell 1965). The observations reported here are part of a program to obtain classification spectrograms of all OB$^+$ stars in the Case-Hamburg survey that did not have published spectral types. The instrumental set-up used to take these spectrograms is no longer in service, and it would seem appropriate to publish at this time all of the existing observations. Nearly all nonemission OB$^+$ stars brighter than $B = 12.0$ that were observable from Cerro Tololo Inter-American Observatory and which did not have published MK spectral types at the time of observation are included in Table 2 below; some fainter stars, and a few emission-line stars are also included.

2. OBSERVATIONS

Classification spectrograms were obtained with the 1 meter image-tube spectrograph at CTIO during 1978–1979, using grating No. 35 in second order (this grating has 600 lines mm^{-1} and a first-order blaze wavelength of 7500 Å). A BG38 filter was used to block the overlapping first order spectrum. The spectra were recorded on IIIa-J photographic plates baked in nitrogen. The dispersion of the spectrograms is 62.5 Å mm^{-1} with a resolution of 2 Å. The spectra are well widened, to 1.0 mm in most cases, to increase the signal-to-noise. Spectra of some standards were widened even more than this, and several spectra with different exposure times were taken of each of the standards. Typically for the standards, which are bright, neutral density filters of 0.5 up to 7.5 magnitudes were used to increase the exposure time.

3. SPECTRAL CLASSIFICATION

The standards are listed in Table 1, with references. The types listed by Morgan & Keenan (1973) (table footnote b) were used as primary standards. The MK system does not have standards earlier than O4 or luminosity classes for spectral classes earlier than O9. For these stars, standards listed by Walborn (1973) were used as primary standards; all of Walborn's classification criteria for these spectral types were visible at our lower resolution. Standards taken from Garrison, Hiltner, & Schild (1977), Johnson & Morgan (1953) and Walborn (1971, 1972) and spectral types from Hiltner, Garrison, & Schild (1969) were used for interpolation between the primary standards.

The following spectral atlases were used to identify the lines, and to help determine which lines or line ratios could be used as temperature or luminosity criteria: "Revised MK Spectral Atlas for Stars Earlier than the Sun" (Morgan, Abt, & Tapscott 1978) which covers the region from 3470 to 4690 Å and "An Atlas of Representative Stellar Spectra" (Yamashita, Nariai, & Norimoto 1978) which covers the wavelength range from 3780 to 4920 Å. Our spectra, which have approximately the same resolution, range from about 3750 Å to a little beyond Hβ (4861 Å).

3.1. *The O3–O8 Stars*

For the stars of spectral classes O3 to O8, the temperature and luminosity criteria are nearly independent. Therefore all the stars that were determined to be earlier than O9 in a preliminary classification were first arranged in a sequence of decreasing temperature (independent of the luminosity) using mainly the relative strengths of the He I λ4471 and He II λ4542 lines. The He I λ3820/He II λ3923 ratio was also used in determining the spectral class. The He II λ4200/He I + He II λ4026 ratio was not found to be useful as a primary criterion.

The stars of each temperature class were then arranged in a sequence of decreasing luminosity using the criteria established by Walborn (1971) for spectral classes O4 to O8: the strengths of the N III λλ4634–4642 emission and the He II λ4686 emission/absorption. The absorption strengths of Si IV λ4089 and N III λ4097 in O7 and O8 spectra and C III λλ4068–4070 in the O8 spectra were also used as luminosity indicators. These lines were particularly useful when the spectra were not exposed well enough in the 4600 Å region to rely entirely on the 4686 and 4634–4642 Å lines. For the O3 stars the following lines (Walborn 1982) were used: He II λ4686, N V λ4604 and λ4620 absorption and N IV λ4058 emission.

3.2. *O9 and Later Classes*

For the stars of these classes the luminosity and temperature criteria are no longer independent and spectral classification is

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TABLE 1

STANDARD STARS

Ia	Ib	II/III	IV/V	Ia	Ib	II/III	IV/V
HD 93129A O3 If* [a]			HDE 303308 O3 V((f))[a]		ζ Per B1 Ib[b]	o Per B1 III[b]	ω Sco B1 V[b]
HD 190429A O4 If+ [a]			HD 46223 O4 V((f)),[a] O4[b]		HD 109867 B0.7 Ib[e]	σ Sco B1 III[f]	
		HD 150136 O5 III[c]	HD 46150 O5,[b] O5 V((f))[a]	χ^2 Ori B2 Ia[b]	HR 6743 B2 Ib[g]	γ Ori B2 III[b,f]	22 Sco B2 V[b]
	HD 69464 O6.5 Ib(f)[a]				3 Gem B2.5 Ib[d,f]		
29 CMa O7 Ia[c]		ξ Per O7.5 III(n)((f)),[a] O7 III[c]	15 Mon O7,[b] O7 V((f))[a]	o^2 CMa B3 Ia[b]		HR 4074 B3 III[g]	
		HD 93222 O7 III((f))[a]		η CMa B5 Ia[b]	67 Oph B5 Ib[d]	τ Ori B5 III[c]	κ Hya B5 V[c]
HD 151804 O8 Iaf[a]		λ Ori O8 III((f))[a]					19 Tau B6 IV[b]
HD 148546 O9 Ia[c]	τ CMa O9 Ib[b]	ι Ori O9 III[b]	10 Lac O9 V[b]			η Tau B7 III[b]	
			HR 2806 O9 V,[d] O9 IV[e]	β Ori B8 Ia[b]		27 Tau B8 III[b]	18 Tau B8 V[b]
		HD 189957 O9.5 III[a]	σ Ori O9.5 V[b]				α Del B9 IV[b]
ϵ Ori B0 Ia[b]		HD 48434 B0 III[d,f]	υ Ori B0 V[b]				α Lyr A0 V[b]
		HD 108639 B0.2 III[e]	τ Sco B0 V[b]	α Cyg A2 Ia[b]			
κ Ori B0.5 Ia[b]	HR 3090 B0.5 Ib[g]	ϵ Per B0.5 III[b]	HD 36960 B0.5 V[f]			o Sco A5 II[b]	
		κ Aql B0.5 III[c,d]				θ^2 Tau A7 III[b]	

[a] Walborn 1973.
[b] Morgan & Keenan 1973.
[c] Garrison et al. 1977.
[d] Johnson & Morgan 1953.
[e] Walborn 1972.
[f] Walborn 1971.
[g] Hiltner et al. 1969.

an iterative process: the spectrum of each star was compared with the standards, and assigned the spectral type of the standard it most closely resembled. Then, assuming the luminosity class to be correct, the spectrum was compared with standards of different temperature classes, revising the temperature class if necessary. Now taking that temperature class to be correct, the spectrum was compared with standards of different luminosity classes and the process was repeated. For most stars, one or at most two iterations were needed to get accurate spectral types.

To check the consistency of the classification, the stars of each luminosity class were arranged in a temperature sequence such that the temperature criteria varied smoothly over the sequence. The O8 stars were also included in the sequence. The main temperature criteria are the ratio of He I λ4471/He II λ4542 for O9 and Si III λ4553/Si IV 4089 in B0 and later types in which He II is no longer present. The absolute strength of O III λλ3755–3760 is also useful, but it has to be used with care since it is also sensitive to luminosity. The same is true of the ratio Si IV λ4116/He I λ4121, which is just resolved on these plates. The ratio of O II λ4642/C III + O II λλ4647–4651 was useful in separating B0, B0.5, and B1. As a final check on the consistency of the classification, the stars of each temperature class were then arranged in a luminosity sequence. During these consistency checks, it was found necessary to revise the spectral types of a few stars.

The luminosity classification was much more difficult than the temperature classification and this was particularly true of the O9 stars. The lines of Si, C, N, and O are all sensitive to temperature. The strength of Si IV λ4089, which increases with luminosity in O8 and classes later than O9, did not show this behavior in the O9 standards, possibly because it has a sharp maximum at this temperature class. τ CMa (O9 Ib std) has weaker Si 4089 than ι Ori (O9 III std) while the He II 4686 and C III lines are consistent with the luminosity classification. (The He II 4542 is weaker in τ CMa, so it may be cooler than the O9 III standard). It must also be kept in mind that τ CMa has been classified O9 II by Walborn and that it was replaced by 19 Cep in the Morgan et al. atlas of 1978. Both τ CMa and ι Ori are known to be spectroscopic binaries, and some moder-

TABLE 2
SPECTRAL TYPES OF LSS STARS

Star (1)	Spectral Type (2)
LSII +12°3	O9 III
II +14°8	B1 Vne$_{2+}$
II +15°1	B3 IIIne$_1$
II +16°8	B1 III
II +17°10	B1 III
II +18°9*	sdO
II +20°13	O9.5 IV
II +20°14	A1 Ia:
II +22°7	F0 Ia?
II +33°5*	He Star
II +39°53	O7 V:
IV +2°13*	He Star
IV +10°9*	sdO
IV −1°2*	He Star
IV −4°15	O6 Ib(f)
IV −4°25	O9.5 Ia
IV −8°11	B2 Ib(n)
IV −8°28	O9.5 III
IV −12°1*	sdO
IV −12°110	B1 Vn
IV −13°15	O4 V
IV −14°109*	He Star
VI +2°11	B2 III
VI +6°12*	B2 Vnne$_{2+}$
VI −1°5	B8 Ia:
LSS 0039	B0 Ibe$_2$
0070	B3 III
0107	B1 III
0218*	B1 III
0271	B2 IIIne$_{2+}$
0424	O7 Iaf
0453	B0 III
0464	O9 III
0477	B0 Ib
0516	B0.5 III
0552	O7 III
0606	B0.5 V(n)e$_2$
0690	B1 III
0695	B0 II
0743	B1 II
0810	B9 Iab
0867	B0 V(n)e$_1$
0918*	B1 IIInne$_2$
1029	O7 IIInn
1046	B3 Ib
1096	B5 Iab
1106*	B0.5 Vn
1108	B5 Ia
1131	O7 V:n
1135	O6 III
1148	O7 IIIn
1160*	B1 III:n
1174	O9 V
1205	O6 Ib(f)(n)
1211	B0.5 Ib
1215	O6 V
1224	B3 III
1253	B0.5 Vnn
1280	O9 III
1288	B2 Ib
1332	O9.5 Ib
1397	B1 III:
1408	B0.5 V
1449	B2 III
1467	B0.5 III
1476	B2 III
LSS 1484	B1 III
1502	O7 IIIn
1520*	B1 Ia
1542	O7 V
1565*	B0.5 Ia
1595*	O9 Ia
1614	O9.5 Ib
1678	O9 III
1683*	B1 Vn
1704	B5 Ib
1706	O7 III
1740	B2.5 Ib
1778	B1 Vn
1780A	B0 Ia
1800	O6 V
1807*	B0 V(n)
1808	B1 Ia
1809*	O7 V
1814*	O6 V
1819	O4 V
1821	O9 V
1847	O4 V
1853	B1 Ib
1854*	B1 V
1857	O9 III
1860	O6 IIIn
1864*	B1 V
1867	B0.5 V
1869	O5 V
1870	O9 III
1871*	O9.5 Vnne$_2$
1872	O9 V
1874	O5 V
1878*	O9.5 V
1880	O6 V
1886	O4 V
1887	O7 V(n)
1892	O5 V
1907	O5 II(f)
1912	B1 V
1916*	VV Cephi
1922*	He Star
1938	O9 Ib
1953	B3 III
1972	O8 IIIn
1976	B0.5 Ia
1982	B1 Ib
1988	B0.5 Ib
2007	B0 Ib
2018*	sdO
2025	O9 III
2032	B3 Iab
2049	B0.5 Ib:
2085	B5 Ia
2089	O9 V
2115	B0.5 Ia
2241	B1 Ia
2315	B1 Ia
2316	B1 Ia
2318	B0.5 Ia
2343	O7 III
2352	O7 Ib(f)
2383*	B2 IIIne$_{2+}$
2394*	He Star
2402	B2 V
2436	B0 III
LSS 2451A	B2 III
2451B	B1 III
2481	White Dwarf
2513	B1 V
2526	B0.5 V
2626	O6 V
2645	B0.5 III
2694	B1 V
2695	O7 III
2699	B3 Vn
2702	O7 III
2723	B0.5 Vne$_1$
2751	B0.5 Ia
2778	B1 Ib
2800	B2 III
2804*	Dwarf Nova?
2824	B1 III
2826*	O7 III
2854	B1 III(n)
2863	B1 Ib
2895	B1 III
2915	O7 Ib(f)
2983	B0.5 III
3006	B2 Ib
3052	B1 Ia
3055*	B0 Vn
3058	B0 Ia+
3072	B2.5 Ia
3094*	B2 Ia
3135	O9 Ia
3139	B5 Ia
3140	O9.5 Ib
3153	O7 III
3159	B1 Ib
3171	B1 Ib
3178	B0 III
3181	O9 III(n)
3183	O9.5 III
3198	O5 IIIn
3201	O7 IIIn
3223	B0.5 Ia
3236	B8 Ia
3252	B2 III
3259	O9.5 V
3307	B0 Ia+
3332	O7 V:(n)
3367*	B1 Ia
3371*	VV Cephi
3378*	He Star
3390*	B0 Ia
3399	O9 Ia
3412*	B1 Ia
3426	B1 Ia
3444A	O7 III
3507	B0.5 Ia
3514	B2 V
3527	B0.5 Ia
3528	B0 Ia
3533	B0.5 Ia
3639	B1.5 Ia
3640	B3 III
3672	O8 II(f)
3711	O9.5 Ia:
3730*	B1 Ib:
3740	O9.5 III
3769	B0 Ia

TABLE 2—*Continued*

Star (1)	Spectral Type (2)	Star (1)	Spectral Type (2)	Star (1)	Spectral Type (2)
LSS 3780	B1 Ia+	LSS 4145	B0.5 V	LSS 4561	B1 Ib
3790	O9.5 Ia	4153	B0 III	4609	B0.5 V
3799	O8 III:n	4161	B0.5 Ib	4614	B1 Ia
3823	B0.5 III	4171	O6 Ib(f)	4625*	B0 Ia
3868	O6 III	4200	O5 III	4634	B9 Ia+e_{2+}
3873	O5 III	4207	O4 III(f)	4665	O9 IIIn
3874	O9.5 IV	4239	B5 Ia	4800	O7 III
3894	B5 Ia:	4240	B1 Ia	4822	B1 V
3906	O7 V	4255	B8 Ia	4867	O9 V
3915*	O7 II	4293*	B2 Ib	4872	B2 III
3958*	B0.5 III	4300*	He Star	4880	O5 V
3963	B3 Ia	4304	O9.5 III	4896	B0 V(n)
3968*	B1.5 Iab	4306N	O9.5 Ib	4910	O7 II(f)
3972	B1 Ib	4306S*	O9 V	4923*	O9.5 IIInn
3976F	B3 V	4309	O9 III	4925	O9 IV
3976P	B1 III n?	4320	B0.5 Ia	4936	B2.5 Ibne$_1$
3978	B2 III	4342	O9 III	4939	B0.5 III
3988	B0 Ia	4348	B0 Ia	4955	B0.5 Ia
3997	B0 Ib	4351	B1 III	4957	B0 Ib
4009	B1 Ia	4376	O8 III	4967	B0.5 Ia
4011	B0.5 Ib (n?)	4379	B0.5 Ib(n)	4979	B1 Ia
4015	B1 II	4391	B1 II	4981	O9.5 V
4016	B1 Ib	4421	B1 III	5007*	B0.5 Ia(n)
4022	O9.5 III	4424	B2.5 IIIn	5019	O9 Ib
4032	B2 Ib	4425	B0 Ia:e_{2+}	5026	B1 Ia
4059	O5 V	4444	O8 III	5046	O7 II
4103*	B0 IIIne$_1$	4482	B0.5 Ia	5048	B1 III
4106	B2 Ib	4511	O9 III	5083	O7 IIn
4121	B3 Iane$_{2+}$	4537	B0.5 Ib	5095	O9.5 III
4129	B2.5 Ia	4542	B0.5 Ia	5099	B0.5 Ib
4142	O3 III	4551	O9 Ib	5128	B0.5 Ia

NOTES.—LSII+18°9: Drilling 1987. LSII+20°14: A0 Ia? LSII+33°5: Drilling & Hill 1986. LSIV+2°13: Drilling & Hill 1986. LSIV+10°9: Drilling and Hill 1986. LSIV−1°2: Drilling & Hill 1986. LSIV−12°1: Drilling 1987. LSIV−14°109: Drilling & Hill 1986. LSVI+6°12: H-poor? 0218: Sharp lines, O lines weak. 0918: H-poor? 1106: C III λ4651 strong. 1160: B1 III+ B0 V binary? 1520: O II strong? 1565: Si III λ4553 strong but not the other lines in multiplet. 1595: N III λ4097 strong. 1683: Hγ core looks filled in; no emission in Hβ. 1807: Nebular emission lines of [O III], and in Hβ core. 1809: Nebular emission lines of [O II], [O III], and in Hβ, Hγ cores. 1814: Nebular emission lines of [O III]. 1854: Nebular emission lines of [O II], [O III], and in Hβ, Hγ cores. 1864: Nebular emission lines of [O II], [O III], and in Hβ, Hγ cores. 1871: Nebular emission lines of [O III], and in Hβ, Hγ cores. 1878: Nebular emission lines of [O II], [O III], and in Hβ core. 1916: Drilling 1979. 1922: Drilling & Hill 1986. 2018: Drilling 1987. 2383: H-poor? 2394: Drilling & Hill 1986. 2804: Balmer lines have strong emission cores and broad, weak absorption wings. He I λ4471 and λ4713 in emission. Emission line at ≈5016 Å. Very faint emission in O II λ4415? 2826: Strong N III 4097? 3055: With strong C III λ4647 and O II λ4642. 3094: B2Ia+? 3367: O II strong. 3371: Drilling 1979. 3378: Drilling & Hill 1986. 3390: Strong N III? 3412: C III strong. 3730: Binary? 3915: Strong N III λ4097. 3958: Strong C III. 3968: C III strong?? 4103: Very strong N lines, N III λλ4511–4515 present, and C lines absent. 4293: C III strong? 4300: Drilling & Hill 1986. 4306S: N III strong; C weak?? 4625: Very strong N lines, with C lines very weak. 4923: Strong IS 4430. 5007: ADS 11310. A second spectrum taken the following night, shows emission lines, and was classified as B2Iane$_{2+}$; Hβ is in emission; Hγ has strong emission core; Hδ absent; higher Balmer lines very weak.

ate spectral variability may also cause these discrepancies. However, there are similar problems with this line in the O9 III, IV, and V standards. Si IV λ4089 has about the same strength in the O9 III, O9 IV, and O9 V standards but the He II λ4686 and C III λλ4068–4070 are consistent with the luminosity classification, as are He I 4144 and O III λλ3755–3760. Of the other luminosity criteria, He II 4686/He I λ4713 and Si IV λ4116/He I λ4121, the first can be difficult because λ4686 is very weak except at class V. Si IV λ4116 and He I λ4121 are just resolved on our plates and can only be used to differentiate class I from classes III and V. All this makes it necessary to depend on C III λλ4068–4070 in some cases but this can be complicated by, for instance, abundance effects. The lines of He I λλ4388, 4144 and O III λλ3755–3760 are also useful, but again, are weak and temperature-sensitive.

4. RESULTS

The spectral types are presented in Table 2. The f-parameter is given for the early-type stars, indicating N III emission; however, weak N III emission designated by ((f)) (Walborn 1971) cannot be seen on our image-tube spectra. The star's LS catalog number is given in column (1) and the spectral type in column (2); an asterisk (*) next to the star number indicates that it is commented on in the notes. A colon next to the spectral type indicates that it is somewhat uncertain; n indicates line broadening, (n) that they are broadened slightly, nn that they are very broad. Stars with emission in the Balmer lines have been given emission types on the system of Lesh (1968).

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Note added in proof.—LSS 4634 ($b = -6.3$ degrees) coincides in position with *IRAS* Point Source 18023−3409, which has been listed as a possible new planetary nebula by A. Preite-Martinez (A&AS, 76, 317 [1988]). It may therefore be similar to the low-mass post–asymptotic giant branch B supergiant discussed by S. Parthasarthy (ApJ, 414, L109 [1993]).