DISTANCES FOR SOUTHERN EARLY-TYPE STARS, ESPECIALLY IN CARINA AND OTHER H II REGIONS

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ABSTRACT

Spectral and luminosity classes, as well as apparent magnitudes and colors, have been obtained for some hundred and fifty southern stars, mainly in the η Carinae region, with some thirty in other southern H II regions and about twenty in the general direction of the galactic center. The distribution of these stars in the galactic plane is discussed. The distribution of color excesses with respect to observed bright and dark nebulosities confirms the over-all association of gas and dust in the Milky Way. Color excesses are highest in areas where H II emission is strong. K-line intensities tend to be strong in areas of H II emission but relatively weak in other regions.

I. INTRODUCTION

Continuing our investigations of the structure of the Milky Way in the general vicinity of Carina, Dr. Bart J. Bok and I, two years ago, initiated a program for determining accurate spectral classes, magnitudes, and colors of approximately one hundred early-type stars (Bok 1952; Bok and van Wijk 1952; Hoffleit 1953; Bok 1955; Hoffleit 1955). The observational part of the program, which has been carried out at the Boyden Station of Harvard Observatory, also included a number of early-type stars near the direction of the galactic center and, for comparison of our material with the Yerkes system, a selected group of stars in Orion. In addition, Campbell M. Wade made out a similar list of stars that appear to be the exciting agents of H II regions catalogued by Bok, Bester, and Wade (1953, 1955) in a survey of the Milky Way between galactic longitudes 260° and 355°.

The distribution of the selected B-type stars in Carina (11 per cent of the total known) is compared in Figure 1 with the distribution of all the known O6–B5 stars in the area in which previous investigations on the apparent association of B stars and nebulosity had been carried out (Hoffleit 1953). In selecting the stars for the present study, I attempted to get a representative distribution of stars both in and out of conspicuous nebulosity and, in so far as could be judged from earlier material, of a wide range in luminosity class. Only a few of the selected stars are conspicuously grouped; five are members of the cluster NGC 3293.

Slit spectra with a dispersion of approximately 100 A/mm were taken at the 60-inch Rockefeller reflector, mainly by M. J. Bester, T. E. Houck, Henry J. Smith, and Mrs. Elske von P. Smith. Photoelectric photometer records for the determination of blue and yellow magnitudes and colors were likewise obtained at the 60-inch, primarily by Mrs. Smith and Mr. Houck. All reductions and analyses of this material were carried out at Harvard, chiefly by myself, although Mr. Wade and Miss M. Rimbach took part in some of the photoelectric reductions.

Combining the new material with the earlier data published by Bok and van Wijk (1952) and by Oosterhoff (1951), we now have either revised spectral classes on the Yerkes system (Morgan, Keenan, and Kellman 1943) or magnitudes and colors on the Bok–van Wijk system (1952) for 156 southern stars listed in Table 2. Distances could be estimated for 123 of these.

II. THE ORION STARS

Before embarking on the reductions of the southern stars, we felt it advisable to test our systems of spectral classification, magnitude, and color against the Yerkes Observatory systems, in order that distance determinations should ultimately be reasonably consistent. From the list published by Sharpless (1952) on the Orion aggregate of early-type stars, I selected sixteen stars representing all luminosity classes among spectral classes O9–B9, in order to check the accuracy of my spectral and luminosity classifications.

For these stars the average difference in the assignment of spectral class amounts to ± 0.03 spectral division. In the assignment of the luminosity classes there was exact agreement in all but three cases. Two of the stars for which the Harvard spectra are of only moderate quality, I assigned to classes B2 IV: and B1 IV, whereas the Yerkes classes are B2 III and B2 V, respectively. In the third case I called a Yerkes B2 III star B2 V. While the latter discrepancy corresponds to an absolute-magnitude difference of 1.5, it represents but little difference in the appearance of the spectrum as such.

Photoelectric measurements on twenty-one Orion stars, all of luminosity class V, were carried out on the same system as that of Bok and van Wijk. All were observed

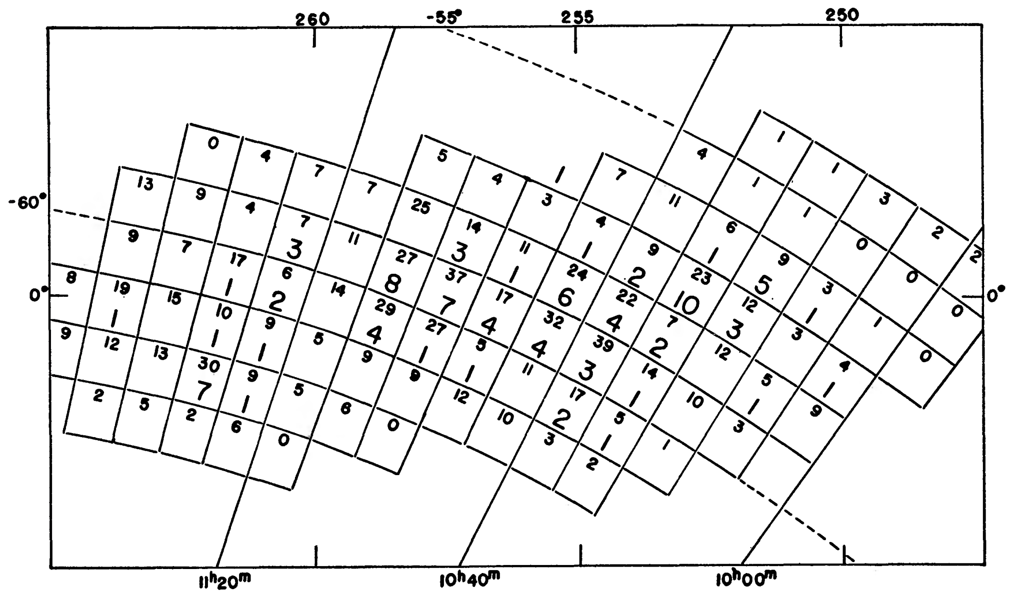

FIG 1.—The distribution of B stars in Carina Areas marked are 8^m R A. by 1° Decl. *Small numbers:* the total numbers of *HD* and *HDE* stars of classes O6–B5 in each small area. *Large numbers:* the numbers for which more accurate new data are presented in Table 2.

against HD 35912 as standard. Sharpless' determinations of the spectral class, yellow magnitude, color, and color excess (based on filters having effective wave-length transmission at 5540 and 4420 A) are repeated in the first five columns of Table 1. The Harvard magnitudes and colors relative to HD 35912 are given in the sixth and seventh columns. Corning 5551 and 3385 filters were used; the blue filter transmits considerable light at wave lengths shorter than 3900 A. There is excellent agreement in the yellow magnitudes. The probable error of a single difference from Sharpless' determinations amounts to ± 0.04 mag. Repeat measurements on different nights yielded a probable error for the Harvard values of ± 0.012 mag. and of ± 0.008 mag. for the colors.

The colors, determined on the Bok–van Wijk system, are on a somewhat more open scale than those determined by Sharpless. For establishing the zero point of this correlation, however, only indirect comparisons are possible; but they indicate a linear relationship between the two systems for all colors between -0.20 and $+1.60$ of the Sharpless scale and between -0.36 and $+1.52$ on the Bok–van Wijk scale (Fig. 2).

Sharpless has shown (1952) that his colors, $B - V$, are on the same system as Johnson's (1953) for stars with color indices greater than about −0.1. In this range, Johnson and Morgan have eight stars in common with Oosterhoff (1951). The conversion from Oosterhoff's to the Bok–van Wijk colors is

$$C_{b-y} = 1.14 + 1.11 C_1 ,$$

where C_1 refers to the Oosterhoff colors and C_{b-y} to the Bok–van Wijk colors in Table VIII (not Table IV) of their paper (1952). The open circles in Figure 2 represent the Oosterhoff colors thus reduced to the Bok–van Wijk system. These all represent stars of spectral classes A0 and later. The dots in the figure represent the Orion stars listed in Table 1. For these stars the colors had been measured relative to HD 35912, whose color

TABLE 1

INTERCOMPARISON OF SHARPLESS' AND HARVARD SYSTEMS OF MAGNITUDE, COLOR, AND COLOR EXCESS

HD	Sharpless Data*				Harvard Results				
	Sp.	m_y	$B-V$	E_y	m_y	ΔC	C_{b-y}	Normal Color	E
35912.	B2	6 35	−0 18	+0 05	6 35	0	−0 34	−0 34	0 00
34179†	B8 V	8 02	− 03	+ 07	8 03	+0 24	− 10	− 22	+ 12
34317	A0 V	6 41	− 02	− 02	6 43	+ 28	− 06	− 18:	+ 12
34511†	B5 V	7 39	− 10	+ 06	7 39	+ 06	− 28	− 28	00
34959.	B5p	6 50	− 11	+ 05	6 61	+ 14	− 20		.
35203†	B6 V	7 97	− 09	+ 06	8 06	+ 12	− 22	− 26	+ 04
35298†	B9 V	7 88	− 14	− 07	7 89	+ 12	− 22	− 20	− 02
35407	B5 V	6 31	− 16	00	6 27	+ 07	− 27	− 28	+ 01
35501	B8 V	7 42	− 06	+ 04	7 42	+ 18	− 16	− 22	+ 06
35588	B3 V	6 15	− 18	+ 02	6 09	+ 04	− 30	− 32	+ 02
35673	B9 V	6 50	00	+ 07	6 50	+ 24	− 10	− 20	+ 10
35730.	B5p	7 20	− 15	+ 01	7 18	+ 04	− 30		.
35834†	B8 V	7 67	− 05	+ 05	7 72	+ 20	− 14	− 22	+ 08
35881	B8 V	7 77	− 09	+ 01	7 77	+ 12	− 22	− 22	00
35910.	B6 V	7 58	− 10	+ 05	7 55	+ 11	− 23	− 26	+ 03
36012†		7 24	− 10	.	7 36	+ 05	− 29		.
36013†	B1 5 V	6 88	− 13	+ 12	6 87	+ 08	− 26	− 35	+ 09
36133.	B2 V	6 94	− 09	+ 14	7 08	+ 03	− 31	− 34	+ 03
36392†	B3 V	7 56	− 14	+ 06	7 52	+ 06	− 28	− 32	+ 04
36429	B5 V	7 56	− 13	+ 03	7 52	+ 08	− 26	− 28	+ 02
36627	B6 V	7 56	− 11	+ 04	7 56	+ 10	− 24	− 26	+ 02
36741 .	B2 V	6 58	−0 20	+0 03	6 55	−0 02	−0 36	−0 34	−0 02

* *Ap J*, **116,** 251, 1952
† Half-weight

on the Bok–van Wijk system was not known. A plot of the $B - V$ of Sharpless against ΔC_{b-y} = Color of star *minus* color of HD 35912 was simply adjusted to give the best agreement with the open circles at $B - V = 0$. This then implies a color index of −0.34 for the comparison star HD 35912 on the Bok–van Wijk system.

Normal color indices (ninth col., Table 1) have been adopted in accordance with the scale determined by Bok and van Wijk (1952) as given in the accompanying tabulation.

Spectral class	B0	B1	B2	B3	B4	B5
Normal color	−0 38	−0 36	−0 34	−0 32	−0 30	−0 28

The color excesses given in the tenth column correspond to these values. The systematic difference between these and the Sharpless blue-yellow colors (fifth col.) is negligible, while the probable error of a single difference amounts to ± 0.04 mag., corresponding to an uncertainty of 10 per cent in the distance.

These results indicate that our subsequent determinations for the southern stars should be effectively on the same scale as the Yerkes distance determinations for the northern stars. Unfortunately, however, the Orion stars studied here provide but a small range in color excess in comparison with the absorptions found in the Carina region.

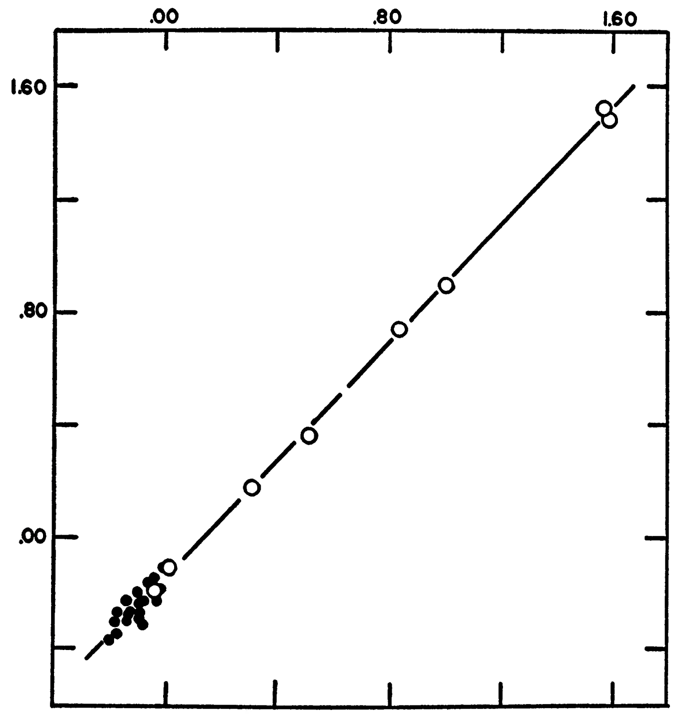

FIG. 2.—Relation between the Harvard system of colors (*ordinates*) and Sharpless' system (1952). *Open circles:* Oosterhoff colors reduced to the Bok–van Wijk (Harvard) system; *dots:* observed relative colors adjusted in ordinate to give best fit at Sharpless' color 0 00.

III. THE CATALOGUE OF SOUTHERN STARS

Table 2 is a catalogue of all the southern stars (other than the Wolf-Rayet types) for which either new spectra or new photoelectric measurements have been obtained. The spectra, reclassified on the Morgan-Keenan-Kellman system (1943), show satisfactory agreement with accurate classifications for some of the same stars obtained elsewhere (Morgan, Whitford, and Code 1953; Bidelman 1954; Hiltner 1954; Morgan, Code, and Whitford 1955).

Bok–van Wijk and Oosterhoff yellow magnitudes and colors, all reduced to the Bok–van Wijk system, are included for numerous stars. Oosterhoff's magnitudes have been corrected by -0.15 mag. to reduce them to the m_y of the Bok–van Wijk system. Similarly, recent determinations by Morgan, Code, and Whitford (1955) for twenty-three of the stars are included, their magnitudes having been reduced by 0.1. The relation between their colors and those in Table 2 is shown in Figure 3. Most of the magnitudes (m_y) and colors (C_{b-y}) in Table 2 are based on two measurements each, whence the average probable errors are found to be ± 0.014 in magnitude and ± 0.010 in color.

Three stars listed by Bok and van Wijk, namely, HD 93403, 90615, and 97222, were selected as comparison stars relative to which the magnitudes and colors of neighboring stars were measured. The following stars from Oosterhoff's list were also used as comparison stars: HD 90706, 91943, 101205, 136003, 145664, 149729, 153426, 156134, and 159176. Of these, Oosterhoff has noted two as double: HD 101205 (I 422, 7.7–7.7) and HD 159176 (h 4962, 5.7–10.5, in the galactic cluster NGC 6383). The latter was used for only one star, HD 158186, for which two estimates are in satisfactory accord; the faint component of the double comparison star is too faint to have introduced any appreciable error. HD 101205, however, appears to have varied. It was used as a standard of comparison for six stars, each observed on three nights. Their apparent synchronous

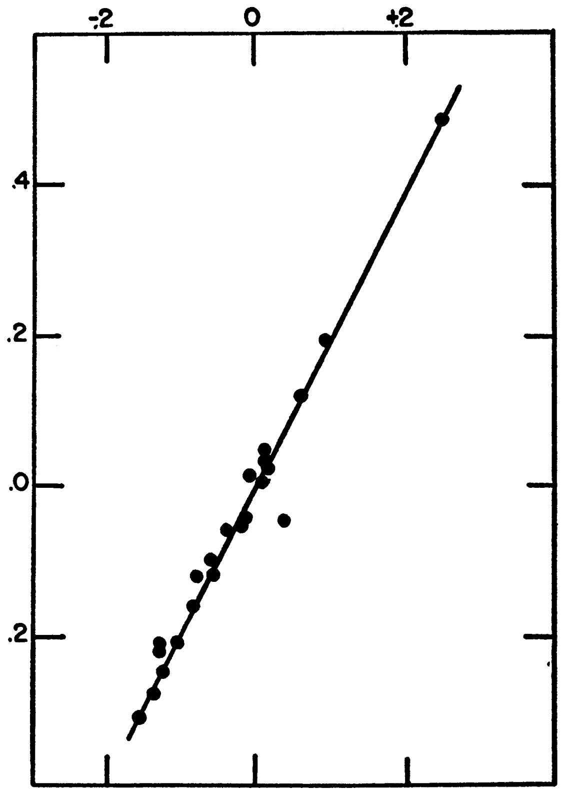

FIG. 3.—Relation between the Harvard colors (*ordinates*) and those of Morgan, Code, and Whitford (1955).

variations indicate that HD 101205 varies by 0.15 or 0.20 mag. I have attempted to allow for this apparent variation, in the deduced magnitudes of HD 101008, 101084, 101131, 101190, 101191, and 101332. Unfortunately, none of these had been measured relative to any other comparison stars; hence the results for them must be of somewhat lower weight than those for the majority of the stars in Table 2.

Three other stars—HD 97484, 152667, and 152723—also appeared to vary by 0.1–0.3 mag. HD 97484 is the eclipsing binary, EM Carinae, for which S. Gaposchkin (1946) found a period of 3.41 days and a photographic amplitude of 0.20 mag. The one spectrum plate obtained at the 60-inch shows double hydrogen lines and a single strong K line. I believe this is the first observation of the star as a spectroscopic binary.

HD 152667 and 152723 were measured relative to HD 153426. Either they or the standard comparison star may therefore vary. All three are too bright (6 or 7 mag.) for

TABLE 2

STARS IN CARINA, SOUTHERN H II REGIONS, AND SCORPIO-SAGITTARIUS

HD	Sp *	m_y	C_{b-y}	Source†	Normal Color	M_{Vis}	E	d	Long	Neb ‡	K:4026
88661	B0ne	5 51	−0 40	O, H	−0 38	−3 9:	−0 02	800	251	.	.
89201	B1 I	7 84	+ 43	H	− 36	−6 5	+ 79	1200	251	2 blue	−3
90187	B1nne	8 88	− 04	B	− 36	−3 2:	+ 32	1300	252	Near 12	+2
90273	O7	9 02	− 13	B, O	− 44:	−5 7:	+ 31	4300:	252	11 Hα	0:
90578	B1 5 III	9 27	− 14	B	− 35	−4 2	+ 21	3000	252	11 Hα	−4
90615	B0 II	8 17	− 02	B, O, Std	− 38	−5 2	+ 36	2000	253	Dark between 11 and 13 Hα	−4
90706	B4 I	7 04	+ 23	O, Std	− 30	−6 0	+ 53	1200	252	Outskirt 11	−1
90801	B2 V	9 43	00	B	− 34	−2 6	+ 34	1200	253	Thin	−5
90831	B2 III	9 36	+ 12	B	− 34	−4 1	+ 46	1700	253	13 red	−3
90832	B1 III	9 11	+ 08	B	− 36	−4 3	+ 44	1700	253	Between 11 and 13 Hα	−4:
91421	WN 5	8 89	− 13	H	..	. .	..	....	...	20 Hα	−2:
91572	O7	8 16	− 22	O, H	− 44:	−5 7:	+ 22	3550:	253	24 Hα	0
91597	(B3)	9 87	− 21	H	..	. .	..	....	255	17 Hα	.
91824	O7	7 82	− 29	O	− 44:	−5 7:	+ 15	3600	253	26 Hα	−1
91850	B1 IV:	9 15	− 03	O	− 36	−3 8:	+ 33	1800	253	26 Hα	−4
91943	B0 5 I	6 64	− 21	O, Std, M	− 37	−6 5	+ 16	2900	253	26 Hα	−4
91969	B0 I*a*	6.05	− 25	M	− 38	−6 7	+ 13	3200	253	26 Hα	−3
91983	B1 III	8 52	− 17	H	− 36	−4 3	+ 19	2300	253	26 Hα	−3
92007	B0 II	7 78	− 12	H	− 38	−5 2	+ 26	2200	253	26 Hα	−2
92044	B0 5 II	8 22	− 09	H	− 37	−5 1	+ 28	2400	253	26 Hα	−2
92061	(B5)	8 90	− 18	H	..	. .	..	....	253	29 blue	.
92206	O7	7 68	− 10	H	− 44:	−5 7:	+ 34	2200	254	31 Hα	+1:
92207	A0 I*a*	. ..	..	..	..	. .	..	....	254	31 Hα	.
92383	B0 V	9 34	− 13	H	− 38	−3 9	+ 25	2500	253	30 Hα	−6
92505	B3 IV:	6 88	− 30	H	− 32	−2 8:	+ 02	900	255	22 Hα	−5
92554	O9 5 II:	8 60	+ 05	O	− 39:	−5 3:	+ 44	2200	255	22 Hα	+4
93030	B0 V	. ..	..	. .	− 38	−3 9			256	Outskirts η	−9
93190	B2e	8 51	− 04	B, M	..	. .	..	....	255	η Hα	−3
93206	B0 I	6 32	− 12	O, M	− 38	−6 5	+ 26	2000	255	η Hα	−1:
93321	B5 V	9 61	− 21	B	− 28	−1 3	+ 07	1300	255	η Lane Hα	−8
93342	B0 III:	9 04	+ 34	B	− 38	−4 5	+ 72	1000	255	η Hα	+1
93403	O6	7 21	− 05	B, O, Std, M	− 46:	−6 0	+ 41	1700	255	η Hα	+4
93723	B3 IV	8 46	− 15	B	− 32	−2 8	+ 17	1200	255	η Lane Hα	−5
93795	A0 I*a*	8 51	+ 51	B	− 18	−7 0	+ 69	2600	255	η Hα	.
93843	O6	7.30	− 29	B, O	− 46:	−6 0	+ 17	3100	255	η Hα	+3
93890	(B)	9 14	+ 49	H					256	36 Hα	
94201	(B5)	9 34	− 15	H	..	. .	..	....	256	36 Hα	.
94369	B1 I	7 34	+ 03	O	− 36	−6 5	+ 39	2400	256	Outskirts η	−2:
94493	B0 5 I	7 19	− 24	O	− 37	−6 5	+ 13	4100	257	Thin Hα	−4
94900	(B5)	9 18	− 03	H	..	. .	..	....	257	40 Hα	.
94909	B0 I	7 28	+ 20	O, M	− 38	−6 0	+ 58	1200	256	Outskirts η	+3
94935	(B5)	8 59	− 04	H					257	40 Hα:	
94988	(B3)	9 26	− 11	H					257	40 Hα:	
95095	(B3)	9 55	+ 07	H	..	. .	..	....	257	40 Hα:	.
95461	B0 I	8 88	+ 12	O, M	− 38	−6 5	+ 50	3800	257	47 Hα	+4
95731	B0 II	9 00	− 06	O, M	− 38	−5 2	+ 32	3300	257	47 Hα	+1
96042	O9 5 Ve	8 32	− 11	H	− 39	−4 5	+ 28:	1900	257	47 Hα	+3:
96139	(Oe)	8 69	+ 11	H	..	. .	..	....	257	Thin?	.
96248	B1 I	6 51	− 05	O, M	− 36	−6 5	+ 31	1950	258	Thin	−3
96446	B2 V	6 59	− 34	B	− 34	−2 6	00	700	258	Thin	−9
96587	A2 V	9 68	+ 06	H	− 09	+1 2	+ 15	350	258	49 Hα	.
96622	O9 5 IV	8 86	− 08	B	− 39	−4 4	+ 31	2200	258	Thin dark	+2
96638	O8	8 52	00	B, O	− 42	−5 3	+ 42	2200	258	Thin dark	−3
96670	O8	7 34	− 10	B, O, M	− 42	−5 3	+ 32	1600	258	Thin	+1:
96810	B4 II:	8 63	+ 04	B	− 30	−4 5	+ 34	1950	258	Thin dark?	−3
97151	B1e	7 63	− 31	B	− 36:	−3 2	+ 05	1300	258	51 Hα	.
97166	O8	7 84	− 17	B, O	− 42	−5 3	+ 25	2400	258	Edge 51 Hα	0:
97222	B0 II:	8 75	− 05	B, Std	− 38	−5 2	+ 33	2900	258	51 Hα	−5:
97253	O6	7 04	− 10	B	− 46	−6 0	+ 36	1800	259	Thin	+1:
97381	B1 III	8 23	− 14	B, O	− 36	−4:3	+ 22	1950	259	Thin	−2
97434	O8:	8 07	− 10	O, H	− 42	−5 3	+ 32	2250	259	Thin	−2:
97484	O5:	{8 38 {8 53	+ 09 + 06	H ..	− 48: ..	−6 0: . .	+ 57 } + 54: }	2000	259	55 Hα	+4
97499	B2 5 V	9 15	− 17	H	− 33	−2 3	+ 16	1350	259	56 red?	−2
97557	B3 III	7 15	− 20	B	− 32	−3 7	+ 12	1100	258	Thin+dark	−4
97629	(B5)	9 53	− 13	H	..	. .	..	....	259	55 Hα	.
99416	B0 5 V	8 81	− 15	B	− 37	−3 5	+ 22	2500	260	Rel. clear	−1
99897	O7	8 33	− 12	H	− 44	−5 7	+ 32	3100	261	63 Hα	+2
99953	B1 I	6 43	+ 03	O, M	− 35	−6 0	+ 38	1300	262	Weak Hα	−3
100242	B0 IV:	8 30	− 12	B, O	− 38	−4 2:	+ 26	1700	261	Rel clear	0:
100276	B0 5 II	7 13	− 21	B, O, M	− 36	−5 1	+ 15	2000	261	Rel clear	−1
100335	B6 III:	7 75	− 20	B	− 26	−3 1	+ 06	1300	261	Rel clear	−3
100381	B2 V	8 67	− 21	B	− 34	−2 6	+ 13	1300	261	Rel clear	−4
100943	B5 I§	7 05	− 12	O, M	− 28	−6 0	+ 16	2800	261	Rel. clear	.
101008	O9 V	9 14	− 27‖	H	− 40	−4 7	+ 13	4350	262	68 Hα	−2
101084	B1 V	9 23	− 14‖	H	− 36	−3 2	+ 22	1900	262	68 Hα	−3
101131	O8	7 07	− 24‖	H	− 42	−5 3	+ 18	2000	262	68 Hα	+3
101190	O7	7 21	− 18‖	H	− 44	−5 7	+ 26	2100	262	68 Hα	0
101191	O8	8 45	−0 17‖	H	−0 42	−5 3	+0 25	3200	262	68 Hα	−3

TABLE 2—*Continued*

HD	Sp *	m_y	C_{b-y}	Source†	Normal Color	M_{Vis}	E	d	Long	Neb ‡	K:4026
101205	O8	6 40	−0 22	O, Std	−0 42	−5 3	+0 20	1400	262	68 Hα	+1
101332	B0 5 II	7 54	− 15‖	H	− 37	−5 2	+ 22	2100	262	68 Hα	−4
101545	O9 5 I*b*	6 26	− 24	O	− 39	−6 0	+ 15	2000	263	Thin Hα outskirts 63	−3
102997	B4 I*a*	6 47	+ 04	O, M	− 29	−7 0	+ 33	2300	264	Rel clear	+5
106068	B9 I	5 82	+ 05	O, M	− 20	−6 5	+ 25	1620	266		Stellar
106343	B2 I*a*#	6 14	− 17	O	− 34	−7 0	+ 17	2900	267		.
106362	B1 I	7 30	− 27	O	− 36	−6 5	+ 09	4700	267		−4
112272	B0 5 I*a*	7 44	+ 49	O, M	− 37	−6 5	+ 86	850	271		−6
112364	B1 I	7 31	− 06	O	− 36	−6 5	+ 30	2900	271		−4
115842	B0 5 I	5 96	+ 01	O, M	− 37	−6 5	+ 38	1300	275		−4
117111	B2 Ve	7 51	− 16	O, M	− 34	−2 6	+ 18	700	275	:	−6
117460	B2 III	7 08	− 20	O	− 34	−4 1	+ 14	1250	275		−4
117707	B0 5 I	9 45	+ 27	O	− 37	−6 5	+ 64	3600	275		+3
117797	O6	9 20	+ 18	O	− 46:	−6 0	+ 64	2500	275		+3
135240	O8 5	. ..	..	..	− 41	−5 2	..	....	287	.. ..	−4
135591	O9 I	5 32	− 36	H	− 40	−6 2	+ 04	1800	287	H II 2880*2*	−6
136003	(B1)	6 68	− 08	O, Std					290	.. ....	
137603	(Oe)	10 04	+ 94	H	..	. .	..	....	288	H II 2880*2*	.
144695	O9 V	9 80	+ 29	H	− 40	−5 0	+ 69	1900	299	H II	+1
144900	O9 III	9 71	+ 45	H	− 40	−4 7	+ 85	1100	300	H II 30000	−3
144918	(B0)	10 02	+ 49	H	..	. .	. ..	...	300	H II 30000	.
144969	B0 5 I(*a*)	8 40	+ 66	H	− 37	−6 5	+1 03	900	300	H II 30000	−3
144970	(B0)	9 89	+ 49	H					300	H II 30000	
145664	(B2)	8 32	+ 08	O, Std	..	. .	..	...	299	H II 2990*2*	.
145846	B2 Ve	8 88	+ 10	O	− 34	−2 6:	+ 44	700	299	H II 2990*2*	−2
146919	B0 5 I*a*	8 60	+ 30	O	− 36	−6 8	+ 66	2600	299	H II 2990*2*	+1
147331	O9.5 I*a*	8 74	00	O	− 39	−6 8	+ 38	5300	300	H II 2990*2*	+4
149729	(B2)	8 96	− 24	O, Std	..	. .			301	.. ...	.
150135	O6				− 46:	−6 0			304	H II 3040*2*	0
150136	O7:	. ..	..	..	− 44:	−5 7	..	....	304	H II 3040*2*	−2
150197	B0 I	9 47	+ 14	H	− 38	−6 5	+ 52	4700	305	H II 3040*2*	+3
150958	O6	. ..	..	..	− 46:	−6 0	...	....	306	H II 3040*2*	+4
151300	O6	9 24	+ 21	H	− 46:	−6 0	+ 67	2400	306	H II 3040*2*	+2
151932	(OC)	6 44	+ 01	H					310	H II 31100	
152408	(Oep)	5 72	− 10	H	..	. .	..	....	311	H II 31100	.
152667	O9 5 I	6 14	+ 02	H	− 39	−6 5	+ 40	1300	312	H II 31100	+1:
152723	O6.5	7 03	− 11	H	− 45	−6 0	+ 34	1900	312	H II 31100	+3
153426	(B2)	7 38	− 14	O					314	H II 31500	.
153919	(Od)	6 48	− 03	H	..	. .	..	....	315	H II 31500	+1:
156134	B0 I	8 16	+ 37	O, Std	− 38	−6 5	+ 75	1500	319	H II 31800	−3
156154	O7	8 20	+ 33	O	− 44	−5 7	+ 77	1000	319	H II 31800	+1
158186	B0 V	6 92	− 23	H	− 38	−3 9	+ 15	1000	323	H II 32300	−5
158926	B2 V	. ..	..	. . .	− 34	−2 6	..	....	319	Clear?	−7
159176	O7**	5 61	− 21	O, Std, M	− 44	−5 7	+ 23	1100	323	H II 3230*1*	.
161291	B0 5 I*b*	8 88	+ 47	B	− 37	−6 0	+ 84	1400	329	Dark	−4
161756	B3 V(*e*?)	6 20	− 05	B	− 32	−2 0:	+ 27	230	330	Dark	−6
163453	B0 5?pe V††	9 27	+ 33	B	− 28	−5 7:	+ 61	2400:	329	Dark?	.
163613	B1 I–II	8 48	+ 10	B	− 36	−6 0	+ 46	2750	330	Dark?	−4
163685	B3 IV	5 90	− 23	B	− 32	−2 8	+ 09	450	330	Rel clear (irregular)	−7
163984	B3 IV	8 28	− 12	B	− 32	−2 8	+ 20	1050	329	Rel clear (irregular)	−6
164019	B0 II:	9 21	− 02	B, O	− 38	−5 2	+ 36	3300	330	Rel clear	0:
164106	B5 III	8 94	− 02	B	− 28	−1 3	+ 26	620	330	Rel clear	−1
164402	B0 II	5 73:	− 28	O, M	− 38	−5 2	+ 10	1200	335	H II 3340*2*	−5
164637	B0 II	6 57:	− 31	O, M	− 38	−5 2	+ 07	1900	335	H II 3340*2*	−7
165207	B2 IV	8 19	− 32	B	− 34	−3 3:	+ 02	1900	329	Dark	−8
167264	B0 I	5 25	− 22	O, M	− 38	−6 5	+ 16	1550	338	Dark	−4
172910	B3 5 V	4 71	− 38	O	− 31	−1 8	− 07	200	327	Clear	−8
175191	B4 V	. ..	..	.	− 30	−1 6	..	...	338	Clear?	−9
175362	B7 5 V	5 22	− 36	O	− 23	−0 7	− 13	120:	327	Clear?	−6
180885	B6 V	5 45	− 32	O	− 26	−1 1	− 06	180	330	.. ..	−9
300777	B2:	9 20	+ 11	B	− 34	−2 6:				Near neb 13 red	−2
300814	B3 III	9 30	+ 17	B	− 32	−3 7	+ 49	1300	252	Rel clear	−6
302686	B3 V	{ 9 96	− 22	H	− 32	−2 0	+ 10	1950 }	252	6 blue	−3
		{ 8 89	− 16	..	..	. .	+ 16	1050 }			
303004	B1 III	10 02	+ 45	H	− 36	−4 3	+ 81	1100	252	25 blue	−3
303056	B5 V:	9 63	− 17	H	− 28	−1 3	+ 45	550	252	27 blue	.
303202	B2 V:	9 72	− 10	B	− 34	−2 6	+ 24	1700	255	η Hα	−3
303299	B0 V*e*	9 30	− 01	B	− 38	−3 9	+ 37	1900	254	η Hα	−1:
305298	(B)	10 80	− 02	H	..	. .	..	....	253	21 Hα	.
305452	B2 III	9 41	− 16	B	− 34	−4 1	+ 18	3300	255	η Hα	−5
305556	B0 II	8 74	− 16	B	− 38	−5 2	+ 22	3700	255	η Hα	−1:
305560	O9 5 I:	8 76	+ 08	B	− 39	−6 5:	+ 47	3800	255	η Lane Hα	+2
305619	O9 5 I*a*	9 49	+ 18	B	− 39	−6 5:	+ 57	4300	255	η Hα	+2
306041	B1 5 III	9 64	− 16	B	− 35	−4 2	+ 17	4000	257	Near 51, Hα	−5
306059	B3 5 V	9 42	− 14	B	− 31	−1 8	+ 17	1200	258	Thin	−3
306141	B1 V	9 87	+ 24	B	− 36	−3 2	+ 60	1000	258	Thin+dark	−4
316197	B3 V	9 56	+ 24	B	− 32	−2 0	+ 58	540	328		−6
316341	B4 V	9 65	+ 16	B	− 30	−1 6	+ 46	620	327	.. ....	−6
319699	O7	9 81	+0 50	H	−0 44	−5 7	+ 94	1400	317	H II 31800 b	.

* Spectra in parentheses are taken from the *Henry Draper Catalogue*

† Source for magnitudes and colors in third and fourth columns are as follows: "B," Bok and van Wijk (1952); "O," Oosterhoff (1951); "M," Morgan, Code, and Whitford (1955); "H," Hoffleit new results "Std" signifies a standard of comparison taken from the Bok–van Wijk or Oosterhoff lists

§ Estimates of spectral class from objective-prism plates, dispersion at Hγ 45 A/mm

** Spectral class from Morgan, Code, and Whitford (1955)

Spectral class from Bidelman (1954).

‖ HD 101205, possibly variable, used as comparison star.

†† Spectral class from Hiltner (1954).

‡ Numbers refer to the number of the nebulosity in *Harvard Ann*, Vol **119**, No 2, 1953, for Carina, and to the Bok, Bester, and Wade Catalogue of H II regions, *Harvard Reprint*, No. 416, 1955

reliable estimates on the Harvard patrol plates. Four photoelectric measurements each of HD 152667 and 153426 were obtained. In each case one of the four estimates is appreciably fainter than the other three. If these stars are also binaries, the available spectra give no confirmation.

Another possible variable is HD302686. Two measurements indicate its magnitude as 9.7, while a third gives 8.7, the latter value relative to each of two comparison stars. This star is at the center of a small blue nebula, No. 6 in the list of nebulosities in Carina (Hoffleit 1953). On an objective-prism plate taken with the ADH telescope, Hβ is suspected to be in emission, although no emission is seen on the adequately exposed B3 V-

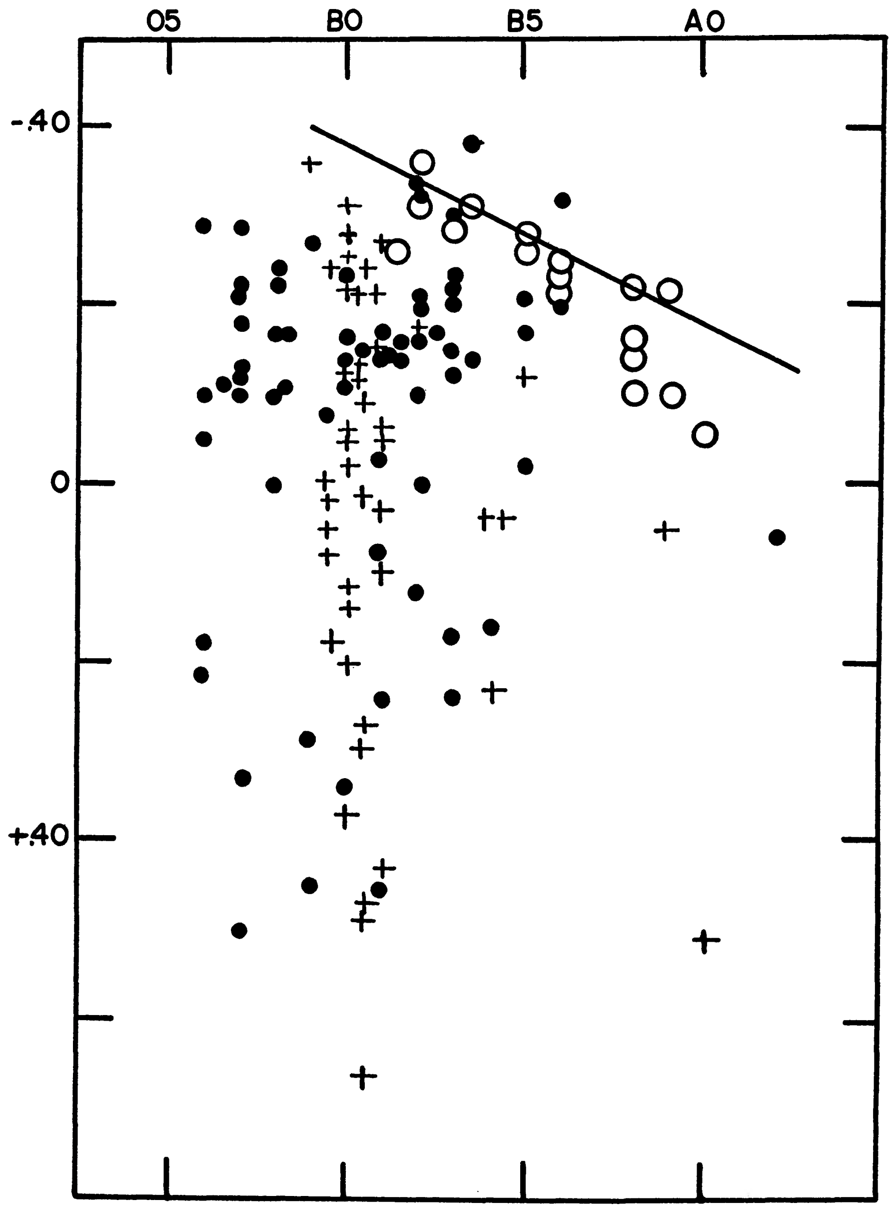

FIG 4.—Color indices as a function of spectral class. *Open circles:* stars in Orion, all of luminosity class V; *crosses:* stars of luminosity classes I and II; *dots:* all others in Table 2 except stars with emission lines.

type spectrum obtained with the 60-inch. Examination of about a hundred and fifty patrol plates (AM series, 1.5-inch Cooke lens) suggests a possible variation of about 0.4 mag., in contrast to the 1 mag. indicated photoelectrically. It is not impossible, however, that the discordant observation may represent a misidentification at the telescope.

In Figure 4 the observed color indices listed in Table 2 are plotted against the spectral classes. Unlike those of the selected Orion stars of Table 1 (*open circles* in Fig. 4), the colors show a large dispersion, indicating that many of the stars are highly reddened. The minimum limiting values in such a diagram, however, should represent the normal color indices unaffected by absorption, provided that not all the stars are in regions of obscuration. The slant line in the figure represents the adopted normal colors of Bok and van Wijk. They vary linearly from -0.38 at B0 to -0.28 at B5. The few points lying above this line could represent uncertainties in either color or spectral class. Systematic errors as great as 0.04 mag. in the normal colors are unlikely in view of the previous comparisons with Sharpless' results in Orion.

The color excesses for stars in different longitude intervals have been examined for possible correlations with bright nebulosity. The material was sorted into three groups: Hα emission, reflection nebulosity, and no apparent nebulosity in the line of sight of the stars. The figure shows no clear differentiation in color excess between the three groups nor any pronounced dependence of color excess on longitude for the stars as a whole.

Distances in parsecs have been estimated from the relation

$$5 \log d = m_y - M + 5 - 5E .$$

The factor 5 used to convert from color excess to total absorption was found by Bok and van Wijk to be consistent with the factor 4 generally employed for deriving total photographic absorptions from excesses on the International System. The probable errors of the apparent magnitudes and color excesses could account for errors of not more than 10 or 15 per cent in the distances. The uncertainties arising from errors in M are less readily evaluated. For the present, the absolute magnitudes corresponding to the spectral and luminosity classes must be taken from the Yerkes calibrations (Keenan and Morgan 1951; Struve 1953). Relatively little material has been available on accurate parallaxes and luminosities of high-luminosity early-type stars. Hence considerable uncertainty must exist in the assignment of discrete values of mean absolute magnitudes to the individual stars in Table 2, especially those of luminosity classes I and II, of whose absolute-magnitude dispersion we have little knowledge. An uncertainty in M, conservatively estimated at only $\frac{1}{2}$ mag., would introduce an uncertainty of nearly 30 per cent in the distances of the individual stars. The tabulated values of the distances of the supergiants are subject to errors of this order, which may be either random or systematic.

The distances listed in the ninth column of Table 2 are plotted in Figure 5 in a polar diagram as a function of galactic longitude. The larger symbols represent the O types and B0–B2 stars of luminosity classes I and II. The others are less likely to define spiral structure. It is to be stressed that no attempt has been made to attain uniform percentage distribution in the numbers of stars in various longitude intervals. The heavy concentration of points between longitudes 250° and 262° is accentuated by the concentration of the observational program in this area. The general character of Figure 5 would not be altered if we were to restrict it to the stars that are specifically involved in Hα nebulosity (indicated in the eleventh col.).

The relative intensities of the interstellar K line, listed in the final column of Table 2, are discussed in a later section.

IV. ON THE SPIRAL STRUCTURE IN CARINA

The B-type stars in Carina appear to be most numerous at about 1.2 and 2 kpc (Fig. 5). Whether or not the deficiencies of points in this direction at 1.5 and 2.7 kpc are real must be tested with data from neighboring fields, which are still lacking. The two straight lines in the upper right corner of Figure 5 represent schematically the two spiral arms in the Northern Hemisphere first mapped by Morgan, Sharpless, and Osterbrock (1952). The other three straight lines in the figure have been drawn through the concentrations of B stars in Carina and approximately parallel to the northern arms. The right-hand segment of the first line between the sun and the galactic center represents the third spiral arm indicated by Morgan and his co-workers (1953). The new observations presented here might be looked upon as indicating the extension of this arm toward Carina. But, in view of the suspected uncertainty in the adopted absolute magnitudes and the

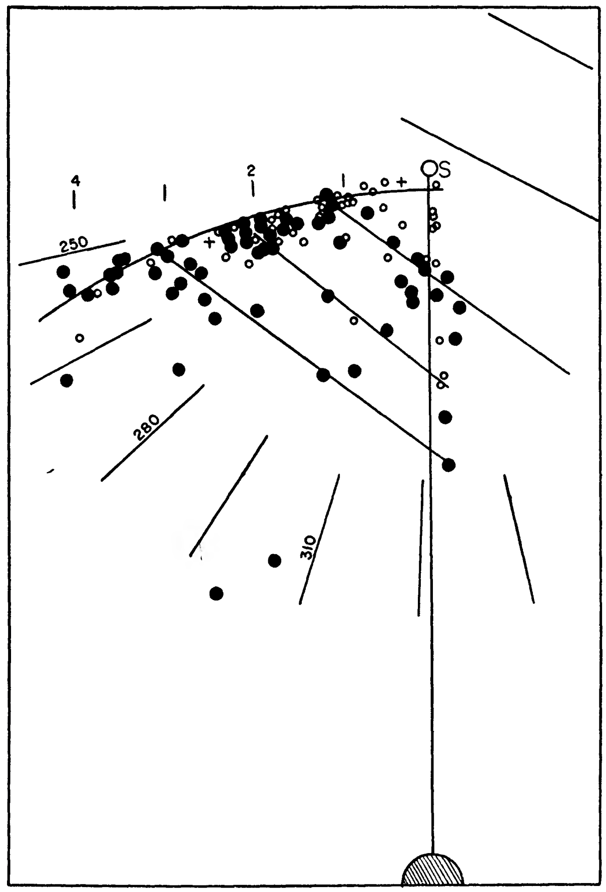

FIG. 5.—The distribution in the galactic plane of the stars in Table 2. *Solid circles:* stars of spectral classes O6–O8 and O9–B2 stars of luminosity classes I and II. *Open circles:* later spectral or lower luminosity classes; *crosses:* two A-type supergiants. Galactic center (indicated at lower edge of graph) at 8 kpc from the sun in longitude 327°. *Curved line:* arc of a circle 7 7 kpc from the galactic center; intervals of 1 kpc indicated. *Upper three diagonal lines:* spiral arms determined by Morgan *et al* , the others drawn parallel thereto and through the concentrations in Carina (longitudes 250°–265°).

fragmentary nature of the material for the greater longitudes, it is still unwise to present conclusions on the structure of the spiral arms in this quadrant as definitive. In the general direction of η Carinae, however, the evidence seems fairly conclusive that the stars are spread out over a wide range in distance. Figure 5 by itself is not sufficient to decide conclusively between the two old divergent hypotheses, whether the spiral arm through the η Carinae nebula is directed across or essentially along the line of sight.

The indicated dispersion in the distances might conceivably be diminished if we could group into means data for stars definitely belonging to the same cluster or other spatial association in which all the stars may be considered as effectively at the same distance. Examination of direct photographs of the Carina region indicates three such possible physical groups (Table 3), each including four or five of the stars in Table 2.

NGC 3293 is a tight cluster, and there is little doubt that the five stars listed are, in fact, members. Their individual indicated distances range from 2.2 to 3.2 kpc, with a mean of 2.6 ± 0.2 kpc. This corresponds to a probable error of about 0.3 kpc for a single star. The other two groups are more loosely structured. The four stars in the cluster associated with the nebula IC 2944 have more poorly determined individual distances (1.4–3.2; mean 2.1 ± 0.5) because their common photometric comparison star proved to be variable. The third group, at a mean distance of 1.7 ± 0.3 kpc, is more widely scattered in the sky and is unnamed. None of these groups includes stars at the largest distances shown in Figure 5. The two loose groups include dwarfs; but only one of the dwarfs appears exceptionally nearby for group membership (HD 96446).

In the H II regions between longitudes 260° and 355°, Mr. Wade selected two or more stars as the possible exciting agents in each of six nebulae. In four of these cases the dis-

TABLE 3

CLUSTERING AMONG THE CARINA STARS

Close Cluster NGC 3293				Loose Associations							
				IC 2944				Unnamed			
HD	m_y	Sp	kpc	HD	m_y	Sp.	kpc	HD	m_y	Sp.	kpc
91943	6 64	B0 5 I	2 9	101084	9 23	B1 V	2 0	96248	6 51	B1 I	2 0
91969	6 05	B0 I*a*	3 2	101131	7 07	O8	1 9	96446	6 59	B2 V	0 7
91983	8 52	B1 III	2 3	101191	8 45	O8	3 2	96662	8 86	O9 5 IV	2 2
92007.	7 78	B0 II	2 4	101205	6 40	O8	1 4	96638	8 52	O8	2 2
92044?	8 22	B0 5 II	2 4					96670	7 34	O8	1 6

tances derived for two stars in the same nebula differed by 0.2–0.7 kpc. In region H II *29902*, three stars yield the discordant results 0.7, 2.6, and 5.3 kpc. The first is presumably a foreground dwarf star. The color excesses of the other two differ appreciably, being +0.66 and +0.38, respectively. In H II 30402, the two determinations, 2.4 and 4.7 kpc, differ by a factor of 2.

The stars within the bounds of the strong η Carinae nebula itself have indicated distances ranging from 1.3 to 4.3 kpc. If the spiral arm in this direction were indeed more or less tangential to the line of sight, this spread would not be surprising. On the other hand, averaging data might only conceal any existing evidence for this.

The curved line passing near the sun in Figure 5 is an arc of a circle concentric with the galactic nucleus, 8 kpc from the sun in longitude 327°. If we ignore the gaps at 1.5 and 2.7 kpc in the distributions of the B stars in Carina and note that the numbers of B stars in the *Henry Draper Catalogue* are known to fall off toward smaller galactic longitudes, Figure 5 could be interpreted as exhibiting a spiral arm which is about 7.7 kpc from the galactic center. This would agree with Elske von P. Smith's interpretation (1955) of her polarization measurements in the southern Milky Way. She considers the line-of-sight distribution of material in Carina beyond about 2 kpc as the extension of Morgan's spiral arm in Sagittarius. Her conclusions are based on the apparent alignment of the interstellar dust particles. In general, observations made perpendicular to a spiral arm indicate high polarization and systematic orientation of position angles for the direction of polarization. In a direction along a spiral arm, on the other hand, the polarization is generally low and the angles heterogeneous. The structure of the nebulosities in Carina, however, indicates that it is a highly turbulent region. And in a highly turbulent region the nonalignment of the dust particles might not necessarily indicate that we are looking along a spiral arm rather than across it. In any case, observations at longitudes less than 250° are necessary to resolve the patterns portrayed in Figure 5.

V. COLOR EXCESSES IN THE SUPERGIANTS AND DWARFS

Having noted that color excesses of B-type supergiants average somewhat higher than those for dwarfs, I previously suggested (Hoffleit 1953, 1955) that the relatively young supergiants might still be surrounded by a residual shell of the primordial globule out of which they are believed to have originated. The present observations are used to test this hypothesis; but observational selection effects still vitiate its confirmation.

In Figure 6 the color excesses in Table 2 are plotted as a function of the indicated distance, the different symbols representing various luminosity groups. Beyond 2 kpc, all

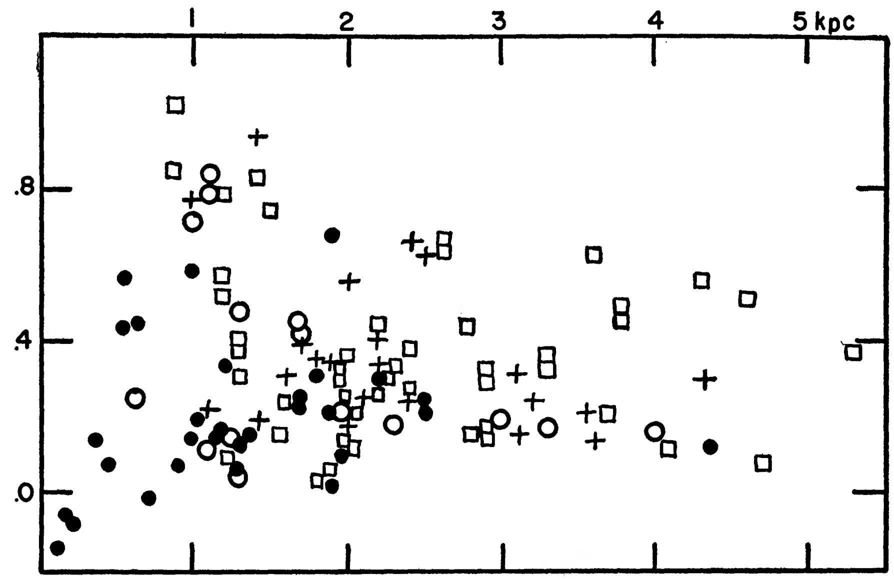

FIG 6.—Color excess as a function of distance from the sun. *Crosses:* classes O6–O8; *squares:* O9 and B stars of luminosity classes I and II; *open circles:* luminosity class III; *dots:* luminosity classes IV–V.

the stars show excesses of 0.1 mag. or greater, indicating that nearly all the stars beyond this limit in the fields represented are obscured by $\frac{1}{2}$ mag. or more. Among all the luminosity groups the dispersion in color excess is high. The largest excesses, on the whole, appear to correspond to the relatively nearby stars. That this should be wholly the effect of uncertainties in the corrections for total absorption or in the absolute magnitudes of the supergiants seems improbable. Stars more highly reddened than about $E = 0.6$ at great distances would, in general, be fainter than the apparent magnitude limit of the present survey.

With the exception of one low-weight O9 V star, no dwarfs are represented at distances beyond 2.5 kpc. An intercomparison of the characteristics of supergiants and dwarfs should therefore be limited to stars within this approximate distance. For these, the color excesses tend to average slightly larger for the supergiants than for the dwarfs (Table 4, upper half), although the dispersions in all the groups are large. An average difference of 0.2 mag. between the high (I and II) and the low (IV and V) luminosity groups, if real, could not be attributed to the normal intrinsic difference in color index between supergiants and dwarfs, especially as a few dwarfs are found to be highly reddened, while many supergiants are not. Hence these results again suggest that within 2 kpc heavy absorption occurs in relatively discrete clouds.

The selection of stars in the upper half of Table 4, however, favors the discovery of high color excesses among the supergiants relative to the dwarfs. To 9.5 mag. and 2.5 kpc, dwarfs with an absolute magnitude of −3 have a limiting observable color excess of 0.7 mag. Supergiants with an absolute magnitude of −6 and a color excess not over 0.7 mag. at 2.5 kpc would, however, be 6.5 mag. or brighter. Limiting our comparisons of mean color excesses, then, to stars with apparent magnitude limits of 6.55 for supergiants and 9.55 for dwarfs, we find the values in the second half of Table 4. While the supergiants still show a greater average color excess than the dwarfs, the differences are not adequately greater than their probable errors. Data on much fainter dwarf stars are desirable. Among the stars nearer than 2.5 kpc in Table 2, ten have color excesses greater than 0.7 mag., all of luminosity classes I–III.

TABLE 4

AVERAGE COLOR EXCESSES

Class	All Stars to 2.5 kpc			Carina Stars 1–2 kpc		
	m_y Average	No	Average $E\pm$p e.	No	Average $E\pm$p e	Distance (kpc)
B I–II	6 9	27	+0 39±0 03	9	+0 49±0 05	1 3
B III .	8 7	12	39± 02	8	42± 06	1 4
B IV–V	8 2	28	0 21±0 03	11	0 24±0 03	1 4
High−low			+0 18±0 04		+0 25±0 06	.
	Brighter than					
B I–II	6 55	10	+0 24±0 03	5	+0 27±0 03	1 8
B IV–V	9 55	18	0 15± 03	8	0 22±0 02	1 5
High−low			+0 09±0 04		+0 05±0 03	

All the stars with high color excess within 2 kpc, represented here, are apparently situated within areas of either Hα or dark nebulosity. The reddened nearby dwarfs are all apparently imbedded in dark material. The one very reddened dwarf at 1.9 kpc is an O9 star in an H II region. At least one of the high-luminosity stars is surrounded by a small blue reflection nebula. Are most of these examples of reddening to be attributed to normal statistical sampling of stars accidentally observed behind very dense independent obscuring patches, or is the obscuring material specifically associated with the individual stars? If the reddened stars and the discrete obscuring clouds were aligned purely by chance, the average color excess should not be higher for the supergiants than for the dwarfs at the same average distance, unless supergiants simply show a stronger preference for the dusty regions than do the dwarfs.

Supergiants are considered younger than dwarfs of the same spectral class. If high-luminosity stars do originate from dark globules, the supergiants might be more likely than the dwarfs to be surrounded by local dust shells—the remnants of the primordial globules. If the high reddening does represent such residual dust shells, they would presumably be short-lived, and not many supergiants would still reveal them to any appreciable extent. The material available on stars at any one given distance is small, however, and the analysis of the spottiness of the obscuring material is still too sketchy for us to ascertain how much of the reddening is due to irregular dust clouds between us and the star and how much might safely be attributed to material directly associated with the star itself.

VI. INTERRELATIONS BETWEEN GAS AND DUST

The color excesses discussed in the previous paragraphs have disclosed the presence of dust relative to selected O- and B-type stars, while an intercomparison of direct photo-

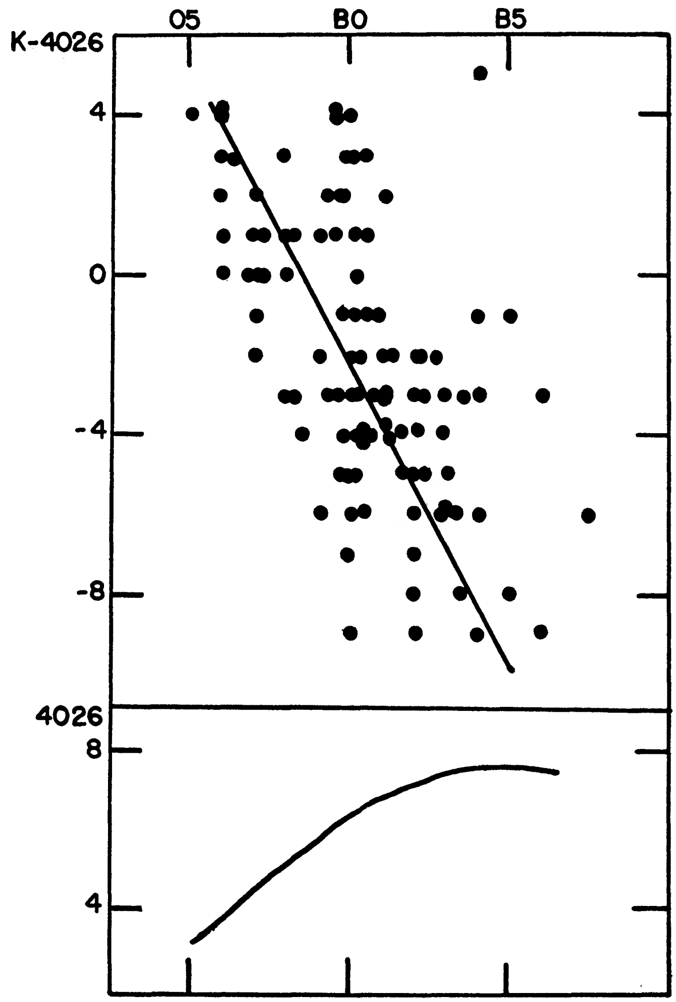

FIG. 7.—Estimates of the variation of K:4026 (arbitrary scale) with spectral class. *Lower curve:* average variation of the comparison line, 4026.

graphs in red and blue light has revealed (Hoffleit 1953) the distribution of hydrogen gas in the regions studied. In addition, the spectra obtained with the 60-inch may give some indication of the presence of interstellar ionized calcium between us and the selected B-type stars. This is of interest for a study of the interrelations between interstellar gas and dust.

The spectra from which the two-dimensional spectral classifications in the second column of Table 2 were determined have been used for estimating the intensity of the interstellar K line relative to He II 4026 as a comparison line. The values of the intensity ratio K:4026, given in the final column of Table 2 and in Figure 7 as a function of spectral class, are on an arbitrary scale, 10 representing a strong and 1 a barely perceptible line. Likewise, the unidentified interstellar band at 4430 was examined; but it was adequately exposed for simple eye-estimates on only sixteen plates. These few indicated no correlations with color excess, K-line intensity, or distance.

From spectral classes O6–B5 the stellar K line, though increasing in intensity, is negligibly weak or invisible. The helium line, 4026, reaches maximum intensity at B2. However, it varies by only about three units on the adopted intensity scale. Its estimated variation on this scale is shown in the lower half of Figure 7. In Figure 8 the K-line intensities, now corrected for the average variation of 4026, are plotted against distance. In the Carina region there is only little evident correlation. In the H II regions and in Sagittarius the more distant stars do show appreciably stronger interstellar K lines.

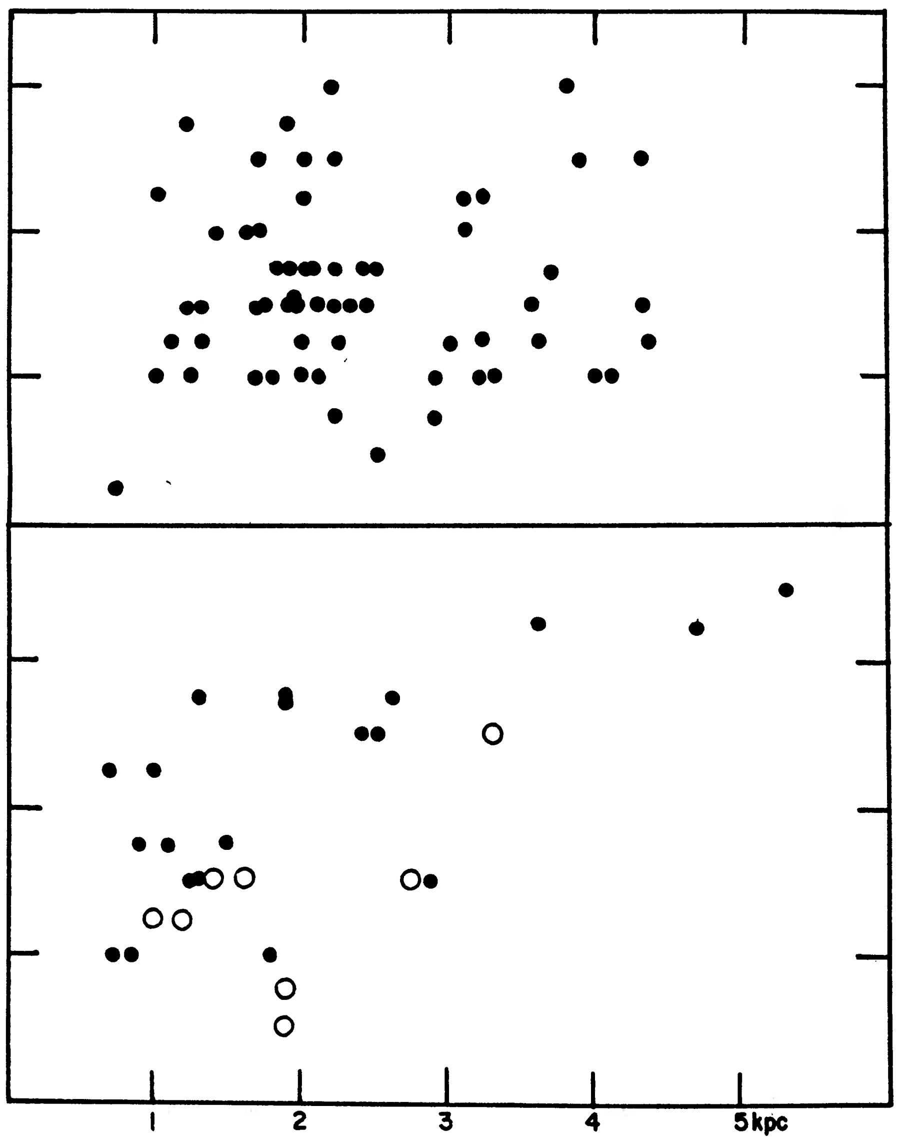

FIG 8.—Variation of K line with distance from the sun. *Upper diagram:* the Carina region; *lower diagram:* dots for H II regions; open circles for Scorpio-Sagittarius.

In Table 5, I have separated most of the material of Table 2 into three longitude groups: the Carina region, embracing the stars from longitudes 250° to 265°; the H II regions between 285° and 325° (practically all the stars on our program in this interval had been chosen because of their apparent involvement in H II regions); and the Sagittarius stars between 325° and 340°. These three groups represent a wide variety in the appearance of the general star field. The Carina region has about as complicated an assortment of gaseous and dark nebulosity as it is possible to find. The Sagittarius fields represented have little emission nebulosity but a wide range in the transparency of the interstellar dust clouds. In each of the three groups the stars are subdivided by distance, the divisions in each group corresponding more or less to the natural groupings noted in Figure 5. Table 5 shows the variation with distance of color excess and the interstellar K line in each of these groups.

TABLE 5

VARIATION OF COLOR EXCESS AND K-LINE INTENSITY WITH DISTANCE

Region	*d* (kpc)	No.	*E*	K Line
	1 5	21	0 35	3 8
Carina (250°–265°)	1 5–3	40	30	4 4
	3	16	27	4 8
	1 5	6	61	4 0
H II (285°–325°)	1 5–2	4	46	4 2
	2–4	2	66	6 5
	4	2	45	9 5
	0.7	8	19	0 9
Sgr (325°–340°) . .	1–2	6	.23	0 7
	2	2	0 41	4 0

Only in the Sagittarius region does there seem to be any semblance of correlation between distance and color excess, and there the average value of the absorption is smaller than in the other groups, which are rich in emission. In the H II regions the color excesses are found to range from 0.04 to 1.03 mag., but they average higher than in either of the other two groups. The K line, on the other hand, does show some increase in intensity with distance in all three groups, although the relation is not the same in all three.

In Table 6 I have re-sorted the material in the three longitude groups according to the prevailing character of the nebulosity in the area immediately surrounding each star. In Carina the emission areas show a relatively low general absorption in comparison with the obviously dark areas. On the other hand, the stronger K-line intensity in the Hα areas suggests that more ionized calcium atoms are present in the Hα clouds than in the dark obscuring clouds in Carina. In the Sagittarius regions there is a marked dependence of color excess on the apparent prevalence of dust clouds but no corresponding correlation with K-line intensity; in fact, there is a strong deficiency of interstellar calcium except for the two most distant objects.

Summarizing the results from these two tables, we find that Hα emission tends to occur in or near regions of high color excess, confirming the over-all association of gas and dust in the Milky Way. On the other hand, the specific spots where Hα appears strongest in Carina do not generally coincide with the spots having the highest color excess. In Sagittarius, where we have no emission nebulae represented, the average color excess is smaller than in the H II regions. Here the dependence of color excess on apparent obscuration is clearly marked. The interstellar calcium gas seems to be statistically well correlated with the presence of interstellar hydrogen, being relatively weak or absent where no hydrogen emission is observed.

VII. THE SMALL ROUND NEBULAE

In previous publications (Hoffleit 1953; Bok 1955) I have discussed several small bright nebulae whose central stars—if, indeed, they are the activating source of the nebular light—are of too late a type to permit the classification of the nebulae as planetaries. Improved spectral classes and color excesses are now available for two of the red and three of the blue small nebulae (Table 7). The central star of blue nebula

TABLE 6

COLOR EXCESS AND K-LINE INTENSITY AS FUNCTIONS OF APPARENT NEBULOSITY

Region	Character	No.	*E*	K Line
Carina	Conspicuous Hα	36	+0 28	4 7
	Relatively clear	7	+ 24	5 1
	Blue reflection nebulosity	3	+ 57	3 3
	Dark nebulosity	2	+ 48	2 0
H II Regions		14	+ 55	5 2
Sagittarius	Clear	2	− 03:	0 0
	Intermediate absorption	4	+ 23	3 2
	Conspicuous dark	5	+0 35	1 2

TABLE 7

CENTRAL STARS OF SMALL ROUND NEBULAE

Neb. No *	HD	Sp	*E*	K Line	*d* (pc)
Red:					
30	92383	B0 V	0 25	0	2500
49	96587	A2 V	15	Stellar	350
Blue:					
6	302686	B3 V	13:	+4	1950:
25	303004	B1 III	81	+3	1100
27	303056	B5 V:	0 45	. ..	550

* Harvard Ann , **119**, 53

No. 6 appears to be variable, and its spectrum may have emission lines. Hence the color excess recorded for it may not have the same meaning as for the others. For the two red nebulae, the color excesses of the central stars are considerably smaller than for the other two blue nebulae, in accordance with the differences noted between H II and dusty regions in the Carina field as a whole. The three values of the interstellar K-line intensity do not happen to confirm the indications from the field stars, but they are too few in number to be conclusive.

VIII. COMPARISONS WITH EARLIER HARVARD ESTIMATES OF DISTANCE

The Bok–van Wijk paper (1952) dealt separately with four discrete fields in what I have designated as the Carina region, namely, SA 193, the GL Carinae, η Carinae, and

Vela fields. The distance moduli that Bok and van Wijk determined in these fields depended upon the spectral classes of the *Henry Draper Catalogue* and mean absolute magnitudes corresponding to luminosity class about III–IV. It is of interest to see to what extent the present revisions in spectral class have altered the distances.

For the stars we have in common, the average distances in both systems are given in Table 8, as well as the distributions among the various luminosity groups and the number of stars reclassified O6–O8. Of the latter, Miss Cannon had classified only two as Oe5, the others as B types. About 54 per cent of the stars in Table 2 have been reclassified earlier than by Miss Cannon, 27 per cent later. This would increase somewhat the inferred average distances. The major contribution to the large increases noted in Table 8,

TABLE 8

COMPARISON WITH BOK AND VAN WIJK DETERMINATIONS OF DISTANCE

FIELD	DISTANCES		No.	O6–O8	I–II	III	IV–V
	B-vW	New					
SA 193 . . .	1060	1760	5	0	1	1	3
GL Car ..	1030	1870	14	4	2	3	5
η Car.. . .	1250	2470	12	2	4	2	4
Vela	1190	2170	7	1	1	3	2
Sgr .	950	1390	11	0	3	1	7
All	.. ..	..	49	7	11	10	21

however, comes from the appreciable percentage of high-luminosity stars. Among all the B stars in Table 2, between longitudes 250° and 265°, the following numbers and percentages apply:

Luminosity class .	I–II	III	IV–V
Number . .	26	12	21
Percentage .	44	20	36

In the H II regions two-thirds of the B stars are supergiants, but in the Sagittarius fields only one-third. Among the northern blue giant stars classified by Morgan, Code, and Whitford (1955), the corresponding relative numbers and percentages are similar:

Luminosity class.	I–II	III	IV–V
Number ..	381	177	410
Percentage ..	39	18	43

In SA 193 Bok and van Wijk had found that the absorption increased steadily with their estimated distances. The present limited results (seven stars) do not clearly support this contention, as indicated in the accompanying table.

HD .	99953	100335	100381	100242	100276	99416	99897
Distance .	1300	1300	1300	1700	2000	2500	3100
Color excess ..	0 38	0.06	0 13	0 26	0 15	0 22	0 32

Perhaps the most spectacular single difference between the Bok–van Wijk and the present results is for HD 93795. On the basis of Miss Cannon's estimate of B3 on a small-dispersion spectrum (400 A/mm), they derived a color excess of +0.83 mag. and a distance of 320 parsecs. Three spectra obtained with the 60-inch indicate a spectral class of A0 I*a*, showing sharp lines, a strong K line, and 4481 stronger than 4471. This revision decreases the apparent absorption and puts the star eight times farther away, at 2600 parsecs.

The distances I had estimated (Hoffleit 1953) depended on average values of the total absorption taken from the Bok–van Wijk paper and representing a wide area in the neighborhood of each star. Moreover, the absolute magnitudes I adopted for the *HD* spectra corresponded to main-sequence luminosities. Hence it should be expected that the estimates of distance for individual stars will depart strikingly from the present results. The average difference for all stars common to my earlier measurements (1953) and Table 2 is 900 parsecs, the new values being some 60 per cent larger than the old.

IX. SUMMARY

1. The distributions of selected early-type stars in Carina, southern H II regions between Carina and Sagittarius, and regions near the galactic center are shown in Figure 5. The data are still insufficient to define the orientation of the spiral arms in Carina with certainty. Possible concentrations at 1.2 and 2 kpc are indicated. The diagram emphasizes the need for extensive observations at longitudes less than 250°.

2. Intercomparisons between the new and previous Harvard estimates of the distances of the Carina nebulosities illustrate the danger of assuming mean absolute magnitudes when luminosity classes are not available. Even when they are, the absolute magnitudes still tend to be the greatest source of uncertainty in the distances, especially for stars of luminosity class I.

3. The newly determined distances average 0.5–1 kpc larger than previous estimates, primarily because of the high percentage of stars found to be supergiants. In Carina, 44 per cent of the B-type stars studied belong to luminosity classes I and II; in the H II regions, 67 per cent; and in the Scorpio-Sagittarius fields 33 per cent.

4. The hypothesis has been offered that some high-luminosity stars may still be surrounded by a residual of the primordial dust cloud out of which they originated. A test of this hypothesis on the basis of relative color excesses of supergiant and dwarf stars is vitiated by observational selection effects; data on fainter dwarf stars are needed.

5. Intercomparisons between color excess, intensity of the interstellar K line, and distance reveal significant differences between the complex Carina region, the H II regions, and the Sagittarius fields.

6. The average values of both color excess and interstellar K-line intensity are greater in extended areas where there is diffuse Hα emission than where such emission is absent, indicating an over-all association of gas and dust in the spiral arms. However, where both absorption and emission nebulosities are intermingled, as in Carina, the absorption is stronger in the dark than in the emission patches. Thus in the H II regions the average color excess is +0.55 mag.; in Carina the average varies from +0.24 in relatively clear spots to +0.28 where Hα is conspicuous, to +0.48 in the dark areas. In Sagittarius, where none of the stars considered here is in the line of sight of an emission nebulosity, the color excess is negligible in clear spots and averages +0.35 where the obscuration is most obvious.

7. In Sagittarius both the color excess and the intensity of the K line are found to increase with distance. In Carina and the H II regions no correlation between distance and color excess is indicated. All three types of regions show some correlation between distance and the K-line intensity, but the relation is not the same in all three.

8. In general, interstellar ionized calcium is strong where clouds of hydrogen emission are strongest and weak where hydrogen emission is absent. In regions of dark nebulosity the K line is of intermediate intensity.

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