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PHOTOELECTRIC COLORS OF B STARS IN FIVE REGIONS OF THE SOUTHERN MILKY WAY

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The Linnell-King photoelectric photometer on the 60-inch Rockefeller Reflector of the Boyden Station has been used for the measurement of color indices for 125 O to B5 stars in five key sections of the southern Milky Way. Particulars about these regions are shown in Table I. The first field, S.A. 193, was chosen because previously it had been shown by the Gaposchkins[1] and by Bok and Wright[2] to be quite free from overlying obscuration. The second field, that of GL Carinae, was placed on the program because it has an abundance of B stars in a small area of the sky. It was obviously necessary to place on the program the marked O−B star concentrations near η Carinae. The fourth field was included to check whether or not the apparent edge of the B star concentration of Carina was real or caused by increasing overlying near-by obscuration. The Sagittarius-Scorpius field was selected to cover the section near the galactic center and its surroundings which is richest in early B-type stars, in order to provide an estimate of the space reddening for various directions and distances for this section of the Milky Way.

TABLE I. CENTERS FOR PHOTOELECTRIC COLORS

Field	Gal. Long. l	Gal. Lat. b	Total Area (Square Degrees)	No. of B stars
S.A. 193	261°	+1°	2.5	15
GL Carinae	258	0	1.3	27
η Carinae	255	0	4	21
Vela	252	0	6	16
Sagittarius-Scorpius	328	−3	20	46
				125

The spectra for the stars in the Carina section were taken from the Henry Draper Catalogue and the Henry Draper Extension Charts;[3] we used all stars with spectral types B5 and earlier, omitting stars simply classified as B. For the Sagittarius-Scorpius field spectra from two sources were available, those of the Henry Draper Catalogue and the Extension Charts and those of Wallenquist.[4] We have measured all stars with H.D. or H.D.E. spectra B0 to B5, as well as the stars simply marked B, which at the same time had spectral classifications of $B\tau$ or $B\tau-$ in Wallenquist's catalogue; we are thus quite certain that every star in Sagittarius-Scorpius for which the color has been measured is really a B star.

1. *The colors and the color system.* Each observation consists of two settings through a Corning 5551 blue filter and two settings through a Corning 3385 yellow filter. Sky readings were made after each star reading for the Sagittarius-Scorpius stars and after every two or three star readings for the stars in the Carina section. The reason for the difference in treatment lay in the unusually fluctuating character of the sky background in Sagittarius and Scorpius; we note further that the color of the sky background for the Sagittarius-Scorpius field is much redder than we have found for any other southern field. One standard star was selected for each field (two for Sagittarius-Scorpius) and this star was measured repeatedly during the night, once every 30 to 45 minutes. Fortunately none of the six standards was found to have a variable color index and in the reductions we have depended entirely upon differences between the observed color index of any star in the field and the standard star for the particular field. This procedure has the dual advantage of obviating the necessity for making corrections for differential extinction and for applying zeropoint corrections to our colors, which would otherwise be required because of

the fact that our silvered 60-inch mirror loses reflectivity in the blue more rapidly than in the yellow.

The probable error of a derived color index from one single observation is about ±0.008 mag. Since every star was observed at least three times, the probable error of a final relative color index should be close to ±0.005 mag., as far as internal agreement is concerned. The zeropoint of our color system is, however, not defined to that accuracy and we have therefore given all color indices only accurate to the nearest one-hundredth of a magnitude. Because of the repeated observations of our standard stars, relative magnitudes on the International Photographic System could be determined for all field stars. The probable error of a final magnitude of one of our field stars is of the order of ±0.02 mag.

Intercomparisons between the standard stars in our six fields were made on many nights and there is every reason to believe that all of our color indices are strictly on the same color system, including a common zeropoint. The problem is to relate this color system and its zeropoint firmly to a known system, viz., either the International System, or the Stebbins, Huffer and Whitford system. From the start we should keep in mind that we are here primarily concerned with colors of B stars affected to a different degree by space reddening, but all with very nearly identical intrinsic colors. We should further not overlook the fact that the International System is not properly defined for B stars, reddened or unreddened, because the North Polar Sequence lacks such stars.

In the past it has generally been the custom to use linear transformation formulae for passing from one color system to another. Recent work, notably that of Johnson,[5] has shown that this procedure is not valid for color indices <0.3 and when the blue magnitudes refer to a spectral interval in which considerable ultraviolet light ($\lambda < 3800$ A) is transmitted. This conclusion was confirmed quite recently by King[6] who showed that the color equation of his magnitudes and colors, measured with the same filter combination as ours, relative to the Cape photographic results gave a decidedly non-linear color equation. A similar effect is shown in Figure 3 of Oosterhoff's paper,[7] where it is to be noted that Oosterhoff has used the same color filters as used in our work. Our blue filter apparently transmits considerable amounts of ultraviolet light with wave lengths shorter than 3800 to 3900 A. The crowding of the Balmer lines near the series limit and some radiation from the continuum beyond the series limit produce the non-linearity in the color equation. The relatively large amount of radiation with $\lambda < 3800$ A is somewhat surprising in view of the fact that we have used a silvered mirror, but the evidence points clearly to excess ultraviolet light affecting our colors.

In our color analysis we should refer back to some established color system unless we wish to determine anew normal colors and the conversion factor from color excess to total absorption. In our case the Stebbins, Huffer and Whitford system[8] is obviously the most direct one to which to relate our color excesses. This is not only so because we are working in very much the same spectral range, but also because, for color systems with widely different ultraviolet characteristics, we may still expect almost linear relations between color excesses, as distinct from color indices, provided the zeropoints of the normal colors are properly adjusted.

To obtain a zeropoint for our blue and yellow magnitudes, we had originally reduced our magnitudes m_b and m_y, b referring to our blue magnitudes, y to our yellow magnitudes, to the magnitudes for a standard sequence for S.A. 68 published by Stebbins, Whitford and Johnson.[9] The relation between our color system and that of Stebbins, Whitford and Johnson was established unambiguously from observations of six stars, with color indices ranging between +0.3 and +1.5, in the standard sequence for S.A. 68. We found the following relations between our magnitudes m_b and m_y and our color index $C_{b-y} = m_b - m_y$ and the magnitudes and colors P, V and $P - V$ on the International Scale:

$$\begin{aligned} m_b &= P + 0.04\,(P - V), \\ m_y &= V + 0.20\,(P - V), \\ C_{b-y} &= 0.83\,(P - V). \end{aligned}$$

We note that these three relations are strictly applicable only to the color index interval +0.3 to +1.5 for which they were derived.

Star H.D.E. 306608 (B8) has been the basic standard for all of our color work and its magnitude and color have been derived on the system of S.A. 68, using first a star in Harvard Standard Region C4 and later one in S.A. 158 as intermediary standards. The magnitudes and colors of the five other "color standards" have in turn been related to the data for H.D.E. 306608 and the final list of derived colors and magnitudes is shown in Table II.

TABLE II. MAGNITUDES AND COLORS OF STANDARD REFERENCE STARS AS DERIVED FROM COMPARISONS WITH S.A. 68

Field	Star	Sp.	m_b	m_y	C_{b-y}
S.A. 193	H.D.E. 306608	B8	9.68	9.91	−0.23
GL Carinae	H.D.E. 306171	B5	9.54	9.71	− .17
η Carinae	H.D. 93190	B2	8.57	8.61	− .04
Vela	H.D. 90832	B3	9.19	9.21	− .02
Sagittarius-Scorpius	H.D. 161103	B0	8.55	8.50	+ .05
Sagittarius-Scorpius	H.D. 164019	B0	9.21	9.32	− .11

We have compared our color system directly with that of Stebbins, Huffer and Whitford.[8] Special measurements were made for six stars in and near Messier 8 and the Trifid nebula and we have also made an indirect comparison via Oosterhoff's color indices of southern O and B stars, reduced to the Stebbins, Huffer and Whitford system.

TABLE III. OBSERVATIONS FOR SIX STARS NEAR MESSIER 8 AND THE TRIFID NEBULA

H.D.	Sp.	C_s	E_1	C_{b-y}	(C_{b-y}) comp
164384	B5*	−0.14	+0.03	−0.35	−0.34
164833	B0*	− .14	+ .08	− .33	− .34
162978	B0	− .14	+ .08	− .32	− .34
163800	B0*	.00	+ .22	− .08	− .10
162717	B3	+ .17	+ .36	+ .15	+ .19
162718	$B0_{ne}$	+ .20	+ .42	+ .25	+ .24

* Listed as OB star by Nassau and Morgan.[10]

In Table III we give the measured color indices, C_{b-y}, and the corresponding Stebbins, Huffer and Whitford color indices, C_s, for six stars in the region near Messier 8 and the Trifid nebula. It will be noted that three of the stars are practically unreddened and that the others are quite reddened; the six stars have almost identical normal color indices. The relation between the color system C_s and ours is given by the formula:

$$C_{b-y} = -0.10 + 1.7 \times C_s.$$

This relation is again only valid for the stars for which it was derived, i.e. for B stars with negative intrinsic color indices whose colors are affected by different amounts of space reddening.

In Table IV we give similarly the comparison between our colors, C_{b-y}, and Oosterhoff's colors,[7] C_1, for twelve stars in common between the two lists. The first and second columns give the H.D. number and spectral type for each star, the third and fourth Oosterhoff's color, C_1, and his derived color excess E. The fifth column has our observed color index, C_{b-y}, and in the sixth column are reproduced the quantities C_1 (comp) $= -0.94 + 0.90 \times C_{b-y}$. According to Oosterhoff the relation between his colors, C_1, and the Stebbins, Huffer and Whitford colors, C_s, is:

$$C_s = 0.57 + 0.56 \times C_1.$$

Upon combination of these two relations, we find the relation:

$$C_{b-y} = -0.09 + 2.0 \times C_s.$$

We note that two stars in common between Tables II and IV are also in the list of Stebbins, Huffer and Whitford.[8] They are H.D. 161103 and 164019 for which the colors C_s and C_{b-y} are as follows:

H.D. 161103 Sp. $B0_{ne}$ $C_s = +0.04$ $C_{b-y} = +0.05$
H.D. 164019 Sp. B0 $C_s = -0.08$ $C_{b-y} = -0.11$

These stars seem, however, quite far south for observations from the northern hemisphere and the possibility of a zeropoint error in the northern observations is not unlikely. We have not used them in relating our color system to that of Stebbins, Huffer and Whitford, even though they suggest a smaller negative constant correction to our color system than do the results of Tables III and IV.

The combined evidence suggests the need for the application of a constant correction to our color system. We shall assume that the relation between our color system and that of Stebbins, Huffer and Whitford is given by the relation:

$$C_{b-y} = -0.10 + 1.8 \times C_s,$$

and, to ensure consistency between our color system for the B stars and the color system of Stebbins, Huffer and Whitford (which is also that used by Oosterhoff), we have applied a constant zeropoint correction of +0.10 mag. to all of our measured color indices. This correction is obviously in the nature of an upper limit.

For future work in B and A stars it seems preferable that we use a blue filter that transmits less ultraviolet light than Corning 5551. We note in passing that slit spectra obtained recently with the Stone spectrograph on the 60-inch reflector confirm that at the altitude of the Boyden Station considerable ultraviolet light is reflected by our silvered mirror. In a private communica-

TABLE IV. DATA FOR TWELVE STARS IN COMMON WITH OOSTERHOFF'S LIST

H.D.	Sp.	C_1	E	C_{b-y}	C_1 (comp)	ΔC_1	m_y	$m_{\text{Oost.}}$	Δm
93843	Oe5	−1.28	+0.08	−0.39	−1.29	+0.01	7.39	7.46	−0.07
100276	B0	−1.23	+.10	−.32	−1.23	.00	7.23	7.27	−.04
97166	B2	−1.19	+.10	−.27	−1.18	−.01	7.89	8.04	−.15
97381	B2	−1.17	+.11	−.24	−1.16	−.01	8.34	8.36	−.02
90273	B0*	−1.15	+.14	−.22	−1.14	−.01	9.13	9.14	−.01
100242	B2	−1.14	+.13	−.22	−1.14	.00	8.35	8.48	−.13
96670	B0	−1.11	+.16	−.21	−1.13	+.02	7.44	7.49	−.05
93403	B0	−1.08	+.18	−.14	−1.07	−.01	7.31	7.36	−.05
90615	B2	−1.05	+.18	−.10	−1.03	−.02	8.28	8.31	−.03
164019	B0	−1.04	+.20	−.11	−1.04	.00	9.32	9.35	−.03
96638	B2	−1.02	+.19	−.10	−1.03	+.01	8.63	8.67	−.04
161103	B0_{ne}	−0.89	+.29	+.05	−0.90	+.01	8.60	8.60	.00

* B3 in H.D.E.

tion Dr. Harold L. Johnson informs us that his analysis of our color indices and those of Oosterhoff suggests that Corning 5551 transmits considerably for wave lengths shorter than 3800 A.

We comment finally on the conversion factor 1.8, which seems well-established and by which we find that Stebbins, Huffer and Whitford color indices must be multiplied to reduce them to our color system. Since our transformation formula is based on the data of Tables III and IV, the factor 1.8 applies really to color excesses rather than to color indices. Now it can be readily shown that our choice of blue filter (which evidently affects our normal color indices) will have only a slight effect on the color excesses, provided the zeropoints are adjusted with care. We note further that all available evidence shows that our color-base is slightly narrower than that of the International System, with, for stars with color indices greater than +0.3,

$$C_{b-y} = 0.83\ (P - V),$$

suggested by our results for S.A. 68 and with a somewhat higher value for the constant (0.90) according to King's results.[6] From all this we conclude that the Stebbins, Huffer and Whitford color excesses should be multiplied by a factor of at least 2.0, possibly 2.2, if we wish to reduce them to the International System.

Stebbins, Huffer and Whitford have used the factor 1.5 to pass from their color indices to color indices on the International System. This value for the conversion factor was found principally by comparing normal colors of unreddened A and K stars. Our results indicate that the value 1.5 is decidedly too small for the conversion of color excesses of reddened B stars.

Oosterhoff has commented in a footnote (l.c., page 317) on the conversion of our color indices to the C_s system and to the International System and he concludes that our color base is much narrower than his; Table IV shows that the opposite is more likely to be true and refutes Oosterhoff's interpretation of our results.

In the reduction of our measured colors we have depended on the normal colors and mean absolute magnitudes of Table V. The normal colors are in essence based upon Johnson's measures for bright stars[11] and upon the data of Stebbins, Huffer and Whitford. The listed mean absolute magnitudes in the last column of Table V are of course only approximate. We should be able to improve in the near future considerably on the original H.D. classifications and then derive improved distances with the aid of the luminosity classifications.

TABLE V. ADOPTED NORMAL COLOR INDICES AND MEAN ABSOLUTE MAGNITUDES

Sp.	C_{b-y}	M_{ptg}
B0	−0.38	−4.4
B1	−.36	−4.0
B2	−.34	−3.4
B3	−.32	−2.6
B4	−.30	−2.3
B5	−.28	−1.9

In the computation of total absorption, we have used the factor 5 to pass from color excesses on the C_{b-y} scale to total photographic absorption. This is consistent with the factor 4 generally employed for transferring from excesses on the International System to total photographic absorptions. It is further consistent with the factor 9 used by Stebbins, Huffer and Whitford, if one admits that the excesses in the color system C_s should be multiplied by 2.2 (as suggested above) in order to derive excesses on the International System.

Independently, Oosterhoff has obtained apparent magnitudes for his stars in very much the same fashion that we used. We have compared his "photoelectric magnitude in the yellow spectral region" with our values of m_y; the differences Δm between our values and his are in the last

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column of Table IV. The average systematic difference amounts to −0.05 mag. and the average deviation of the individual differences from the mean is ±0.03 mag., which is consistent with Oosterhoff's and our own estimates of the accidental errors of the two sets of magnitudes.

2. *Space reddening for the section from S.A. 193 to the Vela field.* The four fields in Vela, Carina, Centaurus are so interconnected that there is considerable advantage to treating in one single section the color excesses of B stars for all four fields. We are purposely considering them in order of decreasing galactic longitude since we can then start off with the field for which conditions are the least complex. We shall in our analysis not only depend on our own southern color indices, but we shall also make use of Oosterhoff's published colors, which, it has been shown, are on a system related with precision to ours and which help us to bridge the gaps between our separate fields.

The section from S.A. 193 at $l = 261°$ to the field near GL Carinae at $l = 258°$ is rich and uniform with relatively few obvious patches of overlying obscuration. Considerable local obscuration, associated in part with some of the finest southern emission nebulosities, occurs directly south of the galactic circle at these longitudes, but there are only occasional small dark patches in the section under investigation. We have measured color excesses for 15 B stars in and around S.A. 193 and for 27 B stars in and near GL Carinae. In addition there were 14 stars in Oosterhoff's list, either inside our fields or in the smooth part of the Milky Way connecting our two fields; 6 of these 14 stars are common to our list and Oosterhoff's, with agreement between the derived total absorptions.

For S.A. 193 the absorption increases in a rather regular fashion with estimated distance from the sun. At a distance of 1000 parsecs the total photographic absorption amounts to 0.7 mag., at 1600 parsecs the absorption amounts to 0.85 mag. and at 2500 parsecs to 1.10 mag. These estimates are of course uncertain because of the possibility of errors in the estimated distances (corrected for absorption), which are based on the assumed mean absolute magnitudes of Table V. There is insufficient evidence to state anything definite about irregularities in the distribution in depth of the absorbing material and we can say only that the absorption is of the order of 0.5 to 0.7 m/kpc to a limiting distance of 2500 parsecs.

For the field near GL Carinae, the absorption is definitely greater than for the section of S.A. 193; Oosterhoff's data and ours both suggest that the total photographic absorption at 1300 parsecs amounts already to 1.3 mag. on the average, but that there is little increase beyond this distance. A most striking effect is that we have here less uniformity. We note, for example, the marked difference in space reddening for two stars of spectral type B5, H.D. 97557 and H.D.E. 306141, which are observed close together and both probably within 1000 parsecs of the sun; the first of these two stars is almost not reddened at all and the second is quite reddened. The two stars are seen projected against backgrounds of faint stars that give only a slight indication of difference in absorption for these two directions, and offhand one would hardly expect the observed marked difference in reddening. Luminosity classes would be most helpful for this part of the sky.

Directly to the north and west of the GL Carinae field lies a compact and interesting group of early B stars, none of them of spectral type B0 and all within a radius of half a degree from the center of the group ($\alpha = 11^h00^m$, $\delta = -59.°0$); they are found directly south of the beautiful near-by galactic cluster NGC 3532. This loose aggregation, which seems to qualify as one of the "Associations" as defined by Ambartsumian and his co-workers,[12] has an average distance modulus corrected for absorption equal to $\overline{m_0 - M} = 10.7$ and a corresponding total photographic absorption of 1.6 mag.; the distance of the group is then of the order of 1400 parsecs, which is at least three times as far away as NGC 3532. We note the presence in the group of an unreddened B3 star at an estimated distance of only 600 parsecs, which indicates that most of the interstellar absorption occurs probably at about 1000 parsecs from the sun.

The situation in and immediately surrounding the η Carinae nebula itself is quite complex. We have nine stars with known color excesses in the smooth region directly south of the brightest nebulosity and—judged by inspection of long exposure ADH plates—not affected by the associated dark nebulosity. Only one star has an indicated total photographic absorption of about two magnitudes, whereas the total photographic absorptions for the other stars are one magnitude or less. Since the range of distance modulus is small, we can use the average of the eight derived absorptions and distance moduli corrected for absorption and we find: $\overline{m_0 - M} = 11.2$, $d = 1700$ psc, total photographic absorption = 0.6 mag. This suggests the value $A_{pg} = 0.4$ mag./kpc or slightly less to a limiting distance of 2000 parsecs at $l = 255°$, $b = -1°$.

It has long been known that an extensive dark nebula is associated with the bright nebula near η Carinae, or at least is seen superposed over most of the bright nebula. Star counts made twenty years ago[13] indicated that the dark nebula is at a distance of the order of 800 to 1200 parsecs, while the distance of the emission nebula and the associated stars was estimated at 1100 parsecs.

We have colors for ten stars, five from Oosterhoff's list and five from our list, in the section of the bright η Carinae nebula. Our five stars, which are more toward the edge of the nebulosity than Oosterhoff's, give the average total absorption 0.7 mag. for $\overline{m_0 - M} = 11.2$, which is practically identical with the result for the region to the south, whereas Oosterhoff's colors for the five stars more deeply embedded in the nebulosity give 1.4 mag., with the distance not well determined since three of the five stars are emission O stars. The presence of several only slightly reddened stars, seen projected against sections of the bright nebula poor in faint stars, indicates that the dark nebula is probably at very nearly the same distance as the bright nebula, in other words that the two are intimately associated. The new evidence seems to suggest a somewhat greater distance for the bright and dark nebula than the value found in 1932; we adopt as the most likely value for the average distance of the η Carinae complex of O and B stars, of bright and of dark nebulosity, the value:

$$d = 1500 \text{ parsecs } (\pm 200 \text{ psc}).$$

Irregular reddening is observed for 11 stars to the north and east of the bright nebula. This space reddening seems to be caused by an irregular dark complex at a distance of not more than 1100 parsecs; the average observed total photographic absorption at this distance is close to 2.0 mag. Here we find the reddest observed star for our observed section of the Milky Way, H.D. 93795, B3, with an observed color excess on our scale of +0.83 mag., a total photographic absorption of 4.2 mag. and an estimated distance, corrected for absorption, of only 320 parsecs! This star requires careful further study.

About half-way between the η Carinae nebula and our Vela field is the galactic cluster NGC 3293 with associated strong emission nebulosity. Oosterhoff has measured color excesses for six stars close to this cluster and we derive from his colors the average total photographic absorption 1.4 mag. at a distance of 1400 parsecs. It would seem as though NGC 3293 and associated nebulosity are still a part of the star-nebulosity complex associated with the η Carinae nebula.

The Vela field at $l = 252°$, $b = 0°$ marks the edge of the pronounced Carina-Crux-Centaurus B star concentration. Here the observed space reddening differs rather markedly for the stars north and south of the galactic circle. The southern part, with eight stars fairly close together, has an average photographic absorption 1.1 mag. for $\overline{m_0 - M} = 10.7$, $d = 1400$ parsecs. This result is very much in line with what we have found for other fields in this section not affected by obvious overlying obscuration. But seven stars directly to the north of this group yield the total photographic absorption 2.7 mag. for $\overline{m_0 - M} = 10.0$, $d = 1000$ parsecs. Apparently a dense obscuring cloud overlies the northern part of the Vela field, but, surprisingly, the star counts to faint limits on ADH plates give only a slight indication of a deficiency in numbers for the northern as compared to the southern half. The absorption marks presumably an edge of the Vela dark nebula.

It is of interest to ask if the apparent edge to the B star concentration is real or caused by increasing overlying obscuration toward smaller galactic longitudes. It appears to be a real edge. The dropping off in numbers of the early B stars is much more abrupt than the gradual diminution in star numbers for the faint stars on ADH plates of the region and the comparable gradual decrease in the numbers of B8 to A2 stars.

Our conclusions regarding the amounts of interstellar obscuration are summarized in tabular form in Table VI. It is evident that in the relatively clear regions for the section of the Milky Way between $l = 250°$ and $l = 263°$ the average coefficient of interstellar photographic absorption varies from 0.4 to 1.0 mag./kpc to a limiting distance of 2500 parsecs, but that in certain parts of this section, notably at northern galactic latitudes for $l = 250°$ to $255°$, there is present considerable additional local obscuration at distances of 1000 parsecs or less.

We ask naturally what bearing these results have on the spiral structure of our galactic system. It has become increasingly more evident that the η Carinae section represents the direction for a major "spiral knot" of our galactic system. The evidence on this point will be summarized in a forthcoming paper by Hoffleit, in which special attention will be given to the emission nebulae associated with the plentiful O and B stars for this section of the Milky Way. We note, however, that the O and B stars with determined colors and color excesses are mostly at distances between 1300 and 1700 parsecs, thus suggesting an average distance of 1500 parsecs from our sun to the heart of the Carina "spiral-knot" of our galactic system.

It has been known for twenty years that the section of the Milky Way between $l = 252^\circ$ and 262° is one of the most transparent ones. While the absorption in the parts free from overlying obscuration is not excessive, our new results do indicate higher average values than earlier work.

The first determination of color indices for the η Carinae region was made by one of us in 1932.[13] The photographic color indices published at that time compare well with the new photo-electric colors. But in the earlier analysis the normal color indices for unreddened stars of spectral types B0–B5 were not taken sufficiently negative, with as a consequence underestimated values of the derived total absorptions.

Studies by the Gaposchkins[1] and by Bok and Wright[2] had given indications of high transparency for the direction of S.A. 193; Bok and Wright found indications for essential freedom from interstellar absorption to distances of 1600 parsecs, with a total indicated absorption of 2 mag. at 3000–4000 parsecs. Our new colors confirm the earlier conclusion of great relative transparency for this part of the sky, but they indicate definitely that there is some absorption, probably amounting to a total of 0.85 mag. at 1600 parsecs.

TABLE VI. SUMMARY OF ABSORPTION RESULTS (CARINA–CRUX–CENTARUS)

l	b	Observed Total Ptg. Abs. at Distance	Center
261°	+1°	0.7 mag. at 1000 psc	S.A. 193.
		0.85 mag. at 1600 psc	
		1.1 mag. at 2500 psc	
258	0	1.3 mag. at 1300 psc	GL Carinae field.
257	+1	1.6 mag. at 1400 psc	South of N. G. C. 3532.
255	−1	0.6 mag. at 1700 psc	South of η Carinae nebula.
255	0	0.7 mag. at 1700 psc	η Carinae nebula.
255	+1	2.0 mag. at 1100 psc	Northeast of η Carinae nebula.
254	0	1.4 mag. at 1400 psc	N. G. C. 3293.
252	−1	1.1 mag. at 1400 psc	Southern half of Vela field.
252	+1	2.7 mag. at 1000 psc	Northern half of Vela field.

"Field II" of Bok and Wright (at $l = 249^\circ$, $b = +1^\circ$) is three degrees west of our Vela field. Because of the sharp dropping off in numbers of early B stars, the Bok-Wright field did not have many measured colors for stars beyond 1000 parsecs. The originally derived total absorption of 0.5 mag. at 1000 parsecs seems definitely too small. We note that "Field II" is even closer to the Vela dark nebula[14] than our Vela field.

We have already compared our derived distance of 1500 parsecs for the η Carinae nebula with the original estimate of 1100 parsecs.[13] In 1944, Father Heyden[15] revised the original estimate downward to 600 parsecs. This revision must now be rejected, largely because it was based on a very few associated stars and on assumed absolute magnitudes that appear to have been too faint. We should stress, however, the preliminary nature of all distance determinations for the η Carinae region. Here, more than for any other section of the Milky Way, we urgently need luminosity classifications for the O and early B stars.

3. Near-by obscuration overlying the galactic center. For the section of the Milky Way between $\alpha = 17^h 30^m$ and $18^h 00^m$, $\delta = -27^\circ$ to -31° (centered at $l = 329^\circ$, $b = -3^\circ$), we have little to add to our summary in the "Report of Progress" presented to the American Philosophical Society (in press). We reproduce here for the

TABLE VII. SUMMARY OF ABSORPTION RESULTS (SAGITTARIUS–SCORPIUS)

l	b	Observed Total Ptg. Abs. at Distance	Center
329°	−4°	1.6 mag. at 1500 psc	Large Sagittarius Cloud.
		1.8 mag. at 2300 psc	
329	−2	2.0 mag. at 1600 psc	West of Large Sgr. Cloud.
327	−2	>3 mag. within a few hundred psc of ⊙; one star with 6.8 mag. at 200 psc	Outlying parts of Ophiuchus dark nebulosity.
329	−1	2 to 4 mag. relatively close to ⊙	Outlying parts of Ophiuchus dark nebulosity.
327	−4	2.0 mag. at 1500 psc	Region of irregular obscuration; dense obscuration at dist. >800 psc from ⊙.
329	−7	<0.5 mag. at 1000 psc	Intermediate lat., where Cepheids, globular clusters appear in abundance.

TABLE VIII. CATALOGUE OF OBSERVED COLOR INDICES AND APPARENT MAGNITUDES OF 124 SOUTHERN O AND B STARS.

H.D. or H.D.E.	Sp.	C_{b-y}	E	5E	Pg_p	m_o-M
S.A. 193						
99416	B3	-0.15	+0.17	+0.85	8.66	10.4
100025	B3	-0.19	+0.13	+0.65	9.50	11.4
100242	B2	-0.12	+0.22	+1.10	8.14	10.4
100276	B0	-0.22	+0.16	+0.80	6.92	10.5
100335	B5	-0.20	+0.08	+0.40	7.55	9.0
100381	B5	-0.21	+0.07	+0.35	8.46	10.0
306485	B3	-0.13	+0.19	+0.95	9.64	11.3
306490	B5	-0.11	+0.17	+0.85	10.86	11.9
306493	B2	-0.13	+0.21	+1.05	10.42	12.8
306495	B5	-0.15	+0.13	+0.65	9.88	11.1
306523	B5	-0.13	+0.15	+0.75	10.22	11.4
306593	B5	-0.12	+0.16	+0.80	9.75	10.8
306688	B5	+0.05	+0.33	+1.65	10.58	10.8
306723	B5	-0.06	+0.22	+1.10	10.67	11.5
306832	B5	-0.15	+0.13	+0.65	9.74	11.0
GL Carinae Field						
96446	B3p	-0.34	-0.02	-0.10	6.25	9.0
96622	B5	-0.08	+0.20	+1.00	8.78	9.7
96638	B2	0.00	+0.34	+1.70	8.53	10.2
96670	B0	-0.11	+0.27	+1.35	7.24	10.3
96810	B5	+0.04	+0.32	+1.60	8.67	9.0
97151	B2e	-0.31	+0.03	+0.15	7.32	10.6
97166	B2	-0.17	+0.17	+0.85	7.63	10.2
97222	B3	-0.05	+0.27	+1.35	8.70	10.0
97253	Oe	-0.10	+0.29	+1.45	6.94	10.5
97381	B2	-0.14	+0.20	+1.00	8.11	10.5
97557	B5	-0.20	+0.08	+0.40	6.95	8.4
305954	B5	-0.02	+0.26	+1.30	10.86	11.5
305957	B5	+0.05	+0.33	+1.65	11.06	11.3
306041	B5	-0.16	+0.12	+0.60	9.48	10.8
306050	B5	-0.08	+0.20	+1.00	9.52	10.4
306056	B5	-0.14	+0.14	+0.70	9.91	11.1
306058	B3	0.00	+0.32	+1.60	9.94	10.9
306059	B5	-0.14	+0.14	+0.70	9.28	10.5
306068	B5	-0.04	+0.24	+1.20	10.71	11.4
306141	B5	+0.24	+0.52	+2.60	10.11	9.4
306152	B2	+0.02	+0.36	+1.80	10.08	11.7
306153	B5	-0.01	+0.27	+1.35	10.21	10.8
306157	B2	+0.24	+0.58	+2.90	10.55	11.0
306162	B5	+0.08	+0.36	+1.80	10.71	10.8
306165	B3	-0.12	+0.20	+1.00	9.69	11.3
306168	B3	-0.04	+0.28	+1.40	10.20*	11.4
306171	B5	-0.07	+0.21	+1.05	9.54	10.4
η Carinae Field						
93190	B2	+0.06	+0.40	+2.00	8.57	10.0
93321	B5	-0.21	+0.07	+0.35	9.40	11.0
93342	B0	+0.34	+0.72	+3.60	9.38	10.2
93403	B0	-0.04	+0.34	+1.70	7.17	9.9
93723	B5	-0.15	+0.13	+0.65	8.31	9.6
93795	B3	+0.51	+0.83	+4.15	9.02	7.5
93843	Oe5	-0.29	+0.10	+0.50	7.01	11.5
303202	B3	-0.10	+0.22	+1.10	9.62	11.1
303225	B5	-0.19	+0.09	+0.45	9.68	11.1
303299	B5	-0.01	+0.27	+1.35	9.29	9.8
303300	B3	+0.07	+0.39	+1.95	9.86	10.5
303304	Oe5	+0.14	+0.53	+2.65	9.81	12.2
303413	B5	-0.02	+0.26	+1.30	9.65	10.3
305443	B5	-0.11	+0.17	+0.85	10.44	11.5
305452	B3	-0.16	+0.16	+0.80	9.25	11.0
305469	B3	-0.33	-0.01	-0.05	9.08	11.7
305479	B5	-0.08	+0.20	+1.00	10.72	11.6
305556	B5	-0.16	+0.12	+0.60	8.58	9.9
305560	B3	+0.08	+0.40	+2.00	9.84	10.4
305602	B5	+0.11	+0.39	+1.95	10.12	10.1
305619	B0	+0.18	+0.56	+2.80	9.67	11.3
Vela Field						
90187	B3	-0.04	+0.28	+1.40	8.84	10.0
90273	B3	-0.12	+0.20	+1.00	8.92	10.5
90578	B3	-0.14	+0.18	+0.90	9.13	10.8
90615	B2	0.00	+0.34	+1.70	8.18	9.9
90801	B5	0.00	+0.28	+1.40	9.43	9.9
90831	B0	+0.12	+0.50	+2.50	9.48	11.4
90832	B3	+0.08	+0.40	+2.00	9.19	9.8
300683	B5	-0.19	+0.09	+0.45	9.51	11.0
300739	B5	+0.08	+0.36	+1.80	10.48	10.6
300774	B3	+0.37	+0.69	+3.45	10.03	9.2
300777	B5	+0.11	+0.39	+1.95	9.31	9.3
300813	B0	+0.23	+0.61	+3.05	9.79	11.1
300814	B3	+0.17	+0.49	+2.45	9.47	9.6
302771	B3	-0.09	+0.23	+1.15	9.94	11.4
302772	B5	-0.19	+0.09	+0.45	10.41	11.9
302839	B5	-0.07	+0.21	+1.05	9.60	10.5
Sagittarius Field						
161103	B0	+0.15	+0.53	+2.65	8.54	10.3
161291	B0	+0.47	+0.85	+4.25	9.35	9.5
161756	B3	-0.05	+0.27	+1.35	6.15	7.4
162742	B3	+0.10	+0.42	+2.10	8.47	9.0
163065	B3	+0.11	+0.43	+2.15	8.68	9.1
163247	A2	+0.25			9.72	
163300	A3	+0.18			9.28	
163453	B0	+0.33	+0.71	+3.55	9.60	10.4
163454	Oe5	+0.01	+0.40	+2.00	8.19	11.2
163613	B5	+0.10	+0.38	+1.90	8.58	8.6
163685	B5	-0.23	+0.05	+0.25	5.67	7.3
163984	B3	-0.12	+0.20	+1.00	8.16	9.8
164019	B0	-0.01	+0.37	+1.85	9.21	11.8
164032	B2	-0.11	+0.23	+1.15	7.23	9.5
164106	B3	-0.02	+0.30	+1.50	8.92	10.0
164606	B5	-0.18	+0.10	+0.50	8.88	10.3
165207	B5	-0.32	-0.04	-0.20	7.87	10.0
316197	B5	+0.24	+0.52	+2.60	9.80	9.1
316204	B5	+0.07	+0.35	+1.75	9.29	9.4
316274	B	+0.48	+0.80	+4.00	10.92	9.5
316311	B	+0.63	+0.95	+4.75	10.92	8.8
316325	B	+0.37	+0.69	+3.45	10.82	10.0
316326	B2	+0.35	+0.69	+3.45	10.42	10.4
316332	B	+1.04	+1.36	+6.80	10.58	6.4
316341	B3	+0.16	+0.48	+2.40	9.81	10.0
316384	B2	+0.14	+0.48	+2.40	10.46	11.5
316392	B3	+0.10	+0.42	+2.10	10.34	10.8
316393	B5	+0.16	+0.44	+2.20	10.83	10.5
316406	B2	+0.03	+0.37	+1.85	10.54	12.1
316415	B3	+0.43	+0.75	+3.75	10.40	9.2
316419	B3	+0.11	+0.43	+2.15	10.28	10.7
316421	B3	+0.26	+0.58	+2.90	10.56	10.3
316436	B5	+0.27	+0.55	+2.75	10.45	9.6
316465	B3	+0.15	+0.47	+2.35	10.26	10.5
316525	B0	+0.06	+0.44	+2.20	10.39	12.6
316568	B3	+0.09	+0.41	+2.05	9.67	10.2
316569	B3	+0.07	+0.39	+1.95	9.38	10.0
316587	B3	+0.07	+0.39	+1.95	10.59	11.2
316589	B5	+0.06	+0.34	+1.70	10.63	10.8
316705	B5	+0.31	+0.59	+2.95	11.26	10.2
316729	B3	+0.07	+0.39	+1.95	9.96	10.6
316730	B3	+0.03	+0.35	+1.75	9.64	10.5
316764	B5	+0.13	+0.41	+2.05	10.06	9.9
316779	B5	+0.10	+0.38	+1.90	10.94	10.9
316859	B3	+0.21	+0.53	+2.65	10.59	10.5
317009	B3	-0.08	+0.24	+1.20	9.80	11.2
318479	B5	+0.06	+0.34	+1.70	10.07	10.3
318699	B5	+0.15	+0.43	+2.15	10.23	10.0

* Increased by 0.75 mag. to allow for binary nature.

sake of completeness the original conclusions for the Sagittarius center together with some additional comments.

1. Seven stars on our list are seen projected against the Large Sagittarius Cloud ($\alpha = 17^h 53^m$, $\delta = -29°$; $l = 329°$, $b = -4°$) and its immediate surroundings and in the directions free from obvious near-by overlying obscuration. The observed reddening for these stars indicates a total photographic absorption of 1.6 mag. at 1500 parsecs and 1.85 mag. at 2300 parsecs, with one star at 300 parsecs having only 0.25 mag. total photographic absorption. If we accept Baade's estimate of 2.6 mag. for the total absorption between our sun and the galactic center,[16] then we note that we account for more than half of this total over the first 1500 parsecs. In other words most of the absorption between our sun and the galactic center occurs within the first 2000 parsecs from our sun.

2. In the clearest star-rich portion ($\alpha = 17^h 46^m$, $\delta = -28\overset{\circ}{.}5$) directly west of the Large Sagittarius Cloud, we find six stars all with very similar reddening, but with an apparent range of $\overline{m_0 - M}$ between 9.0 and 12.6. The total photographic absorption amounts to 2.0 mag. at 1600 parsecs, but it is probable that this absorption is caused mostly by obscuring matter well within 800 parsecs of our sun; it is presumably associated with the extensive obscuration of the Ophiuchus dark nebula. The reddest stars of our survey are found directly south of these six stars, near $\alpha = 17^h 42^m$, $\delta = -29\overset{\circ}{.}5$, and to the north near $\alpha = 17^h 40^m$, $\delta = -27\overset{\circ}{.}5$. These stars are observed through outlying parts of the dense and near-by obscuring clouds of the Ophiuchus complex. In the southern group, we find five stars with estimated total photographic absorptions in excess of 3 mag., the reddest of which, H.D.E. 316332, has an observed color excess on our scale of +1.36 mag., with a corresponding estimated total photographic absorption of 6.8 mag. at a corrected distance of only 200 parsecs. In the northern group are two stars with total photographic absorptions estimated to be in excess of 4 mag., both with $\overline{m_0 - M} = 9.5$. We note that these stars, while in relatively star-poor fields, are really at galactic latitude zero and at the longitude of the galactic center.

3. To the southwest of the Large Sagittarius Cloud, near $\alpha = 17^h 48^m$, $\delta = -30°$, we find very irregular obscuration. Since stars that are not highly reddened are seen here projected against dense obscuration, we conclude that the responsible dark clouds are at least at 800 parsecs distance from our sun. We find here only one single estimated total photographic absorption in excess of 2.5 mag. (2.8 mag. at $\overline{m_0 - M} = 9.6$) and the remainder (11 stars) are all between 1.7 mag. and 2.4 mag. The average absorption of 2.0 mag. holds for a corrected mean distance of 1500 parsecs.

4. Eastward from the Large Sagittarius Cloud (toward S. Gal. Lat. in excess of 5°), the absorption is variable and thins out rapidly as we move away from the galactic circle. The appearance in abundance of faint Cepheid variable stars at latitudes $-5°$ to $-10°$ is in accordance with the observations that suggest relative transparency.[17]

The general picture for this part of the sky is one of fairly heavy and variable obscuration relatively near the sun. Extensions from the Ophiuchus complex overlie the western half of our section, but there is evidence for considerable additional dark nebulosity to distances of 1500 parsecs. It seems as though most of the dark nebulosity between our sun and the galactic center is accounted for by these dark nebulae within 1500 parsecs of our sun.

A second feature is worth noting. Our list contains nine B0 to B2 stars and one Oe5 star, but none of these are associated with emission nebulosity. This is in marked contrast to the Carina-Crux-Centaurus section, for which ADH plates with comparable exposure time show abundant Hα emission nebulosity. In other words the available evidence does not support the presence of a section of a spiral arm within 2500 parsecs of the sun and seen passing between our sun and the galactic center. Dr. W. W. Morgan has, however, drawn our attention to the fact that H.D. 159176 at $l = 323°$, $b = -1°$ has an associated HII emission region according to observations of Sharpless and Osterbrock.[18]

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GLOBULAR CLUSTERS. I. PHOTOELECTRIC AND SPECTROSCOPIC OBSERVATIONS IN M3 AND M92

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ABSTRACT

Photoelectric observations of 62 stars and spectroscopic observations of 13 stars in the globular clusters M3 and M92 show that the Hertzsprung-Russell diagrams for these clusters differ from one another intrinsically somewhat in the manner that H–R diagrams for open clusters do, suggesting that differences in composition and evolution are involved. The red giants, particularly in M92, were also found to differ spectroscopically from any other known objects and to have color classes far exceeding their spectral types.

In a previous paper,[1] color-magnitude diagrams for the globular clusters M3 and M92 were discussed and compared. Color indices and photovisual magnitudes were determined by a combination of photoelectric and photographic measures, the former providing a standard sequence and the latter being used for interpolation. These diagrams extended from the top of the red giant branch at absolute photovisual magnitude -3 down to a segment of the main sequence at $+4$ and showed how the giant and sub-giant sequences join the main sequence in globular clusters. The horizontal branch around zero absolute magnitude contains a distinct gap completely devoid of nonvariable stars within which the cluster-type variables fall.

When the color-magnitude diagrams for M3 and M92 were superposed with color axes matched, the variable-star gaps coincided but the giant and sub-giant sequences appeared to be systematically redder in M3 than in M92. Since this color difference was readily evident in the photoelectric sequences themselves, it clearly had nothing to do with the photographic interpolation procedure; it implied either an unaccountable photoelectric error or a highly significant intrinsic difference between the clusters. A differential stretch of this sort in the color scale could not be ascribed to absorption reddening or other outside effects.

Limited photoelectric sequences set up last year in connection with the work just reviewed [1] were extended this spring to permit a direct photoelectric intercomparison of the giant and horizontal branches of the two clusters. Photoelectric measures in and near M3 and M92 now include 62 stars, of which 50 are thought to be cluster members. All data are summarized in Tables I and II.

The photoelectric observations were made at the Newtonian focus of the 100-inch telescope and at the prime focus of the 200-inch telescope using the Ross $F/4.65$ field corrector. An Emitron 5060 eleven-stage end-on photomultiplier [2] was used in conjunction with a d.c. feed-back amplifier[3] and deflections were recorded on a Brown strip-chart recording potentiometer. The blue filter was Schott BG-12 (1 mm thick) plus GG-13 (2 mm) and the yellow filter was GG-11 (2 mm). Deflections were transformed by the customary reduction procedure to international P and V magnitudes using standard stars in Selected Areas 57 and 61 for reference.[4,5]

If color-magnitude diagrams are plotted for