PUB. ASTRON. SOC. PACIFIC, Volume 86, August 1974

FAINT OB STARS BEHIND THE COALSACK

JUAN C. MUZZIO, HUGO G. MARRACO, AND ALEJANDRO FEINSTEIN*
Observatorio Astronómico, Universidad Nacional de La Plata, Argentina

Received 3 April 1974

An investigation of OB stars in the Coalsack region is done by means of *UBV* photographic photometry. The study includes previously known OB stars within a 1° radius circle centered at $\ell = 302\overset{\circ}{.}4$, $b = -0\overset{\circ}{.}2$, and newly discovered faint OB stars in five small areas (80 square arc minutes each) within the same circle. Total visual absorption values and minimum distance moduli are derived for all the stars, and the absorption vs. distance modulus diagram is presented. A possible distant OB association is noted in the region sur rounding the compact cluster Hogg 15.

Key words: interstellar matter — reddening — OB stars — spiral structure

I. Introduction

The section of the Milky Way near the southern Coalsack (roughly $301° < \ell < 305°$, $-3° < b < 2°$) is a critical region for the understanding of the spiral structure of our galaxy. According to the H I diagram of Kerr (e.g., Kerr 1970, see also Kerr and Kerr 1970) the interarm region between the Carina arm and the Sagittarius arm is seen in this region. However, Courtès and his co-workers (e.g., Courtès et al. 1970) indicate that optical H II regions show a Sagittarius-Carina arm and a Norma-Centaurus arm. The line of sight in the direction of the Coalsack cuts through the former at about 2 kpc from the sun. Courtès et al. (1970) draw the Norma-Centaurus arm for $\ell \geqq 305°$, if it follows at $\ell < 305°$ its distance behind the Coalsack should be about 4 kpc from the sun.

The absorption of light by the Coalsack itself poses a difficult problem to the optical study of the objects behind it. According to Rodgers (1960) the mass of dust is at about 174 pc from the sun and produces a total photographic absorption which ranges between $0\overset{m}{.}7$ to $2\overset{m}{.}4$ for different regions. Total blue (*B*) absorptions in the range $2\overset{m}{.}2$ to $3\overset{m}{.}0$ were also found by Tapia (1972) in other regions of the Coalsack with a different method.

Marraco (1974) compiled a catalog of the known OB stars in this region from published searches. All of them were based on objective-prism surveys, and the catalog is probably complete down to, at least, photographic apparent magnitude 12. To reach very distant OB stars through heavy overlying absorption requires a fainter magnitude limit and the method used by Miller (1972) has proved to be very useful. Thus, we decided to do a *UBV* photographic study of known OB stars in a rather large area of the Coalsack region and to supplement it with a search for fainter OB stars in five small areas within the same region. Further studies of these stars with photoelectric photometry and spectroscopic techniques will help to unravel the spiral structure in the region.

II. Observations

Two sets of *UBV* plates taken with the Curtis-Schmidt telescope at Cerro Tololo Inter-American Observatory (CTIO) were used for the study. The plates are centered at $\alpha_{1950} = 12^h44\overset{m}{.}1$, $\delta_{1950} = -62°48'$; a third available plate set, with a slightly different plate center, was found to be of poorer quality and was used for checking purposes only.

The plates are calibrated with two photoelectric sequences obtained by one of us (A.F.) with the 36-inch telescope of the CTIO in April 1970. The first sequence is essentially the sequence of Rodgers (1960) to which two more stars are added. Our values are given in Table I. The first column in the table gives the star numbers in Rodgers' sequence; the second

*Visiting Astronomer, Cerro Tololo Inter-American Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

TABLE I

NEW PHOTOELECTRIC *UBV* RESULTS FOR RODGERS' (1960) SEQUENCE

Number	HD	V	$B-V$	$U-B$	n	Notes
1	111464	6.63	1^m41	1^m61	3	
2	111174	8.14	0.38	0.36	5	
3	111024	9.03	0.22	−0.17	3	
4	111124	9.40	0.70	−0.38	5	(1)
5	111557	9.67	0.54	0.16	2	
6	111125	9.84	0.16	−0.39	2	
7	111091	10.45	0.30	0.24	4	
8		10.55	1.05	0.01	3	(2)
9	312050	11.01	0.28	0.14	4	
10		11.26	1.74	0.82	2	
11	311888	11.83	0.47	0.33	3	
12		12.41	1.60	1.63	4	
13		12.53	0.36	0.23	2	
14		12.64	0.55	0.23	5	
15		12.49	1.20	1.00	2	(3)
16		12.96	0.89	0.36	1	
17		13.12	0.55	0.39	3	
18		13.49	0.93	0.64:	1	
19		14.26	0.97	0.83:	1	
—	312890	10.90	1.08	0.99	4	(4)
—	312891	10.81	1^m51	1^m23	3	(4)

Notes to Table I
(1) LS 2768 OB⁺h (Stephenson and Sanduleak 1971).
(2) LS 2778 OB⁺ (Stephenson and Sanduleak 1971).
(3) Possible variable.
(4) Star added to the original sequence of Rodgers (1960).

column gives the HD numbers. The *UBV* data are given in the third through fifth columns; the number of independent observations is given in the sixth column. Numbers referring to notes to the table are given in the last column. The second sequence is obtained from the cluster NGC 4609 (Feinstein and Marraco 1971). Both sequences lie within 40′ from the plate center and they are about 40′ from each other. In all, about 40 stars were used to calibrate the plates in the magnitude ranges $9^m03 < V < 14^m62$, $9^m25 < B < 16^m09$, $9^m08 < U < 16^m06$.

The systematic differences between our photoelectric values and those of Rodgers (1960), in the sense of Rodgers minus Feinstein, are $\langle \Delta V \rangle = -0^m019 \pm 0^m062$, $\langle \Delta(B-V) \rangle = -0^m025 \pm 0^m092$, $\langle \Delta(U-B) \rangle = -0^m119 \pm 0^m121$ from 18 stars in common (star 15 was not included because it is probably variable). The systematic differences between our photoelectric values and those of Bok, Bok, and Miller (1972), in the sense Bok et al. minus Feinstein, are $\langle \Delta V \rangle = -0^m020 \pm 0^m034$, $\langle \Delta(B-V) \rangle = 0^m000 \pm 0^m017$, $\langle \Delta(U-B) \rangle = -0^m055 \pm 0^m043$, from six stars in common.

The *UBV* photographic reduction procedures were explained earlier (Muzzio, Marraco, and Feinstein 1974) and they are only briefly summarized here. The photographic images of the sequence and program stars are measured with the Askania iris photometer of the La Plata Observatory. The iris vs. magnitude curves are derived from the standard sequence by best fitting polynomials including linear color equations. The observed magnitudes and colors of the program stars are then obtained from the corresponding iris readings, the best fitting polynomials and the color equations.

From the mean square errors derived from the best-fitting polynomials, we estimate the following mean square errors for the values obtained from the mean of two plate sets: $\sigma_V = \pm 0^m052$, $\sigma_{B-V} = \pm 0^m069$, $\sigma_{U-B} = \pm 0^m072$.

Systematic differences among different parts of the plates were investigated through the residuals of the two sequences and also through the differences between the results of the two plates available for each color. We find that the systematic differences are negligible within 1° of the plate center and that they rise steeply outside that region.

III. The Program

To avoid systematic errors in the results, the investigation was limited to a circle of 1° radius centered at the plate center given above. Stars with blended images or outside the magnitude range of our sequences were excluded from the investigation. All previously known OB stars (Marraco 1974) which met the requirements were included in our program and were measured in both plate sets.

The search for faint OB stars was conducted in the five regions shown on Plate I. Each region has an area of 80 square arc minutes (s.a.m.) and the five regions are within 1° from the plate center. All the stars within the five areas were measured on both plate sets. A few stars brighter than $V = 13^m$ were chosen at random near the selected areas and measured as well. The observed colors of the stars were then used to select the stars which appear to be of spectral type B3 or earlier.

IV. Results and Analysis

Since we have no information on the luminosity classification of the OB stars we assumed that all the program stars are of luminosity class V and we adopted the corresponding unreddened colors and absoluted magnitudes given by Schmidt-Kaler (1965) for main-sequence stars. The reddening curve was taken as

$$E_{U-B}/E_{B-V} = 0.72 + 0.05\, E_{B-V} \quad ,$$

and the ratio of total to selective absorption was assumed to be

$$R = A_V/E_{B-V} = 3.0 \quad .$$

As a consequence of the first assumption our derived true distance moduli should be regarded as minimum values, since many of our program stars may lie above the main sequence. Our derived color excesses are also affected by the first assumption, but only slightly.

Table II presents the results for the previously known OB stars. The first column gives the star number of Stephenson and Sanduleak (1971) (LS) or Lyngå (1968) (Ly); the second through fourth columns give the *UBV* photographic values; the fifth column gives the spectral type assigned from the color indices of the star (stars which fall above the O5 V reddening line were reduced as O5 V stars and are indicated as O+); the sixth column gives the total visual absorption, A_V; and the seventh column gives the true distance modulus, $V_0 - M_V$.

The results of the faint-OB-stars search are presented in Table III with the same format as Table II, except for the first column where the stars are identified by their numbers on Plate I. The first number is the region number and the second one the number of the corresponding star within that region.

Finally, Table IV presents the results for stars within the 1° radius circle centered at $\ell = 302.^\circ4$, $b = -0.^\circ2$ and with photoelectric *UBV* photometry whose colors indicate that they are OB stars. They include stars 4 (LS 2768) and 8 (LS 2778) of Table I and stars 25, 32, H1, H2 (Ly 152), and H4 observed by Feinstein and Marraco (1971) in the neighborhood of NGC 4609. Star H16 of Feinstein and Marraco (1971) was not included because its published $(U-B)$ color index was found to be in error; the actual $(U-B)$ value is -0^m06 and it is not therefore an OB star. Star H3 (LS 2745) was not included either because it is a Wolf-Rayet star according to Roberts (1962) and Stephenson and Sanduleak (1971). The format of Table IV is the same as Tables II and III except for the last column which includes notes to the table.

V. Discussion

Figure 1 presents the minimum distance modulus $(V_0 - M_V)$ vs. total visual absorption (A_V) diagram for the stars in Tables II, III, and IV. Previously known OB stars with photographic *UBV* data are shown as circles; the OB stars found in our photographic search are

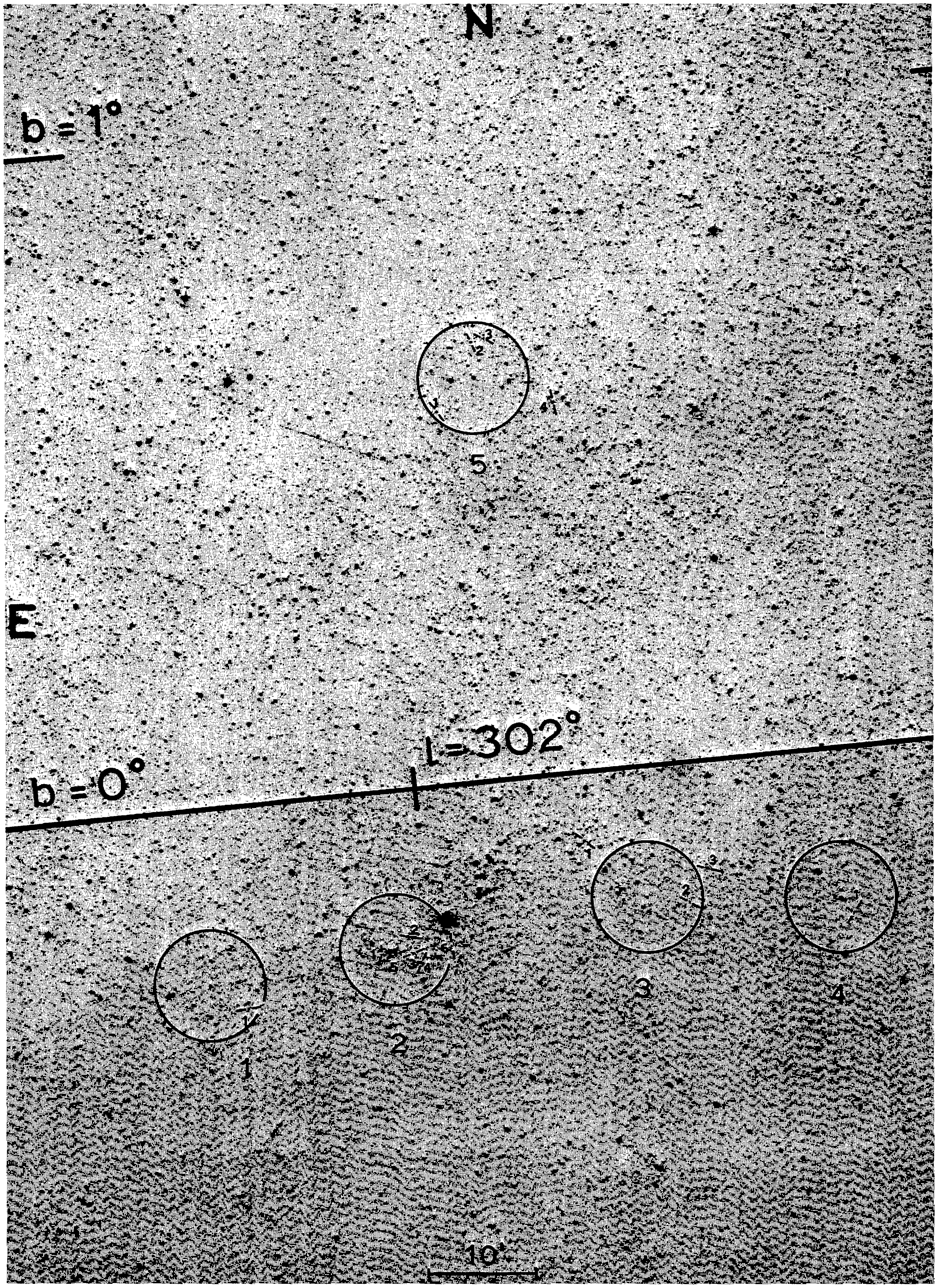

PLATE I

The OB Stars found in our search. The circles show the five areas where the search is complete.

TABLE II

RESULTS FOR PREVIOUSLY KNOWN OB STARS

Number	V	$B-V$	$U-B$	(Sp)	A_V	V_0-M_V
Ly 163	11.32	$1^{m}19$	$-0^{m}19$	O+	$4^{m}6$	$12^{m}4$
Ly 164	11.43	0 .73	−0 .38	O+	3 .2	13 .8
Ly 171	11.35	0 .82:	−0 .15	B0.5	3 .3	11 .9
Ly 176	10.80	1 .30:	0 .06	O+	4 .9	11 .5
Ly 177	11.47	0 .59	−0 .26	B1	2 .6	12 .5
LS 2739	12.29	1 .14	−0 .03	O+	4 .4	13 .4
LS 2754	10.66	0 .61	−0 .29	B1	2 .7	11 .6
LS 2759	11.11	0 .93	−0 .09	B0	3 .7	11 .6
LS 2770	11.14	0 .59	−0 .39	B0	2 .7	12 .7
LS 2782	10.43	1 .20	−0 .50	O+	4 .6	11 .4
LS 2822	10.39	$1^{m}00$	$-0^{m}28$	O+	$4^{m}0$	$12^{m}0$

TABLE III

RESULTS FOR NEW OB STARS FOUND IN OUR SEARCH

Number	V	$B-V$	$U-B$	(Sp)	A_V	V_0-M_V
1-1	13.52	$1^{m}59$	$0^{m}30$:	O+	$5^{m}8$	$13^{m}3$
2-1	14.34	1 .14	0 .09	B0.5	4 .3	14 .0
2-2	13.56	1 .12	0 .09	B0.5	4 .2	13 .2
2-3	13.86	1 .29	0 .11	O5	4 .9	14 .6
2-4	13.19	1 .03	0 .11	B1.5	3 .9	12 .3
2-5	14.46	1 .04	0 .26:	B3	3 .8	12 .4
2-6	14.28	1 .05	0 .23	B3	3 .8	12 .2
3-1	13.50	0 .88	0 .12	B3	3 .3	11 .9
3-2	14.57	1 .13	0 .10	B0.5	4 .3	14 .2
3-3	12.72	1 .11	0 .08	B0.5	4 .2	12 .4
4-1	14.24	1 .03	0 .18:	B2	3 .9	12 .9
5-1	13.71	1 .04	0 .14	B2	3 .9	12 .3
5-2	13.62	1 .22:	0 .30	B2	4 .4	11 .7
5-3	13.99	1 .33	0 .13	O+	5 .0	14 .6
5-4	12.27	$0^{m}75$	$-0^{m}19$	B0.5	$3^{m}1$	$13^{m}0$

shown as triangles; and the stars with photoelectric values are shown as squares. Filled symbols are used for stars with assigned spectral types between B3 and O5, and open symbols for stars classified as O+. A cross shows the position of the cluster NGC 4609 (Feinstein and Marraco 1971) in the diagram. The lines labeled B3 V and O5 V show the limits of completeness of the survey: no B3 V stars above the line labeled B3 V and no O5 V stars above the line O5 V can have apparent magnitudes brighter than the faint limits of the sequence.

Any discussion based on Figure 1 should be done bearing in mind the fact that our $V_0 - M_V$ values are only minimum values. It seems probable, however, that the absorption increases steeply from about $A_V = 1^{m}0$ at $V_0 - M_V = 10^{m}6$ to about $A_V = 3^{m}5$ at $V_0 - M_V = 12^{m}0$. The trend seems to be gentler beyond that distance but may be only an apparent feature due to the incompleteness of our data above the B3 V line.

The diagram shows no evidence of groupings of OB stars near $V_0 - M_V = 11^{m}7$ and $13^{m}3$ as should be the case if the two OB associations proposed by Houck (1956) were present.

On the other hand, it is interesting to note the existence of a possible distance OB associa-

TABLE IV

RESULTS FOR OB STARS WITH PHOTOELECTRIC VALUES

Number	V	$B-V$	$U-B$	(Sp)	A_V	V_0-M_V	Notes
R 4	9.40	$0^{m}70$	$-0^{m}38$	O5	$3^{m}1$	$11^{m}9$	(1)
R 8	10.55	1.05	0.01	B0	4.0	10.7	(2)
FM 25	11.66	1.19	0.02	O5	4.6	12.7	
FM 32	11.23	1.35	0.16	O5	5.1	11.8	
FM H1	11.49	1.13	−0.15	O+	4.4	12.7	(3)
FM H2	12.19	0.87	−0.12	B0.5	3.5	12.6	(4)
FM H4	12.26	$1^{m}05$	$-0^{m}04$	O8	$4^{m}1$	$13^{m}2$	

Notes to Table IV

Stars designated with R are from Table I and stars designated with FM are from Feinstein and Marraco (1971).

(1) LS 2768 OB+h (Stephenson and Sanduleak 1971).

(2) LS 2778 OB+ (Stephenson and Sanduleak 1971).

(3) Suspected as OB+ by Lyngå (1968).

(4) Ly 152 OB+ (Lyngå 1968).

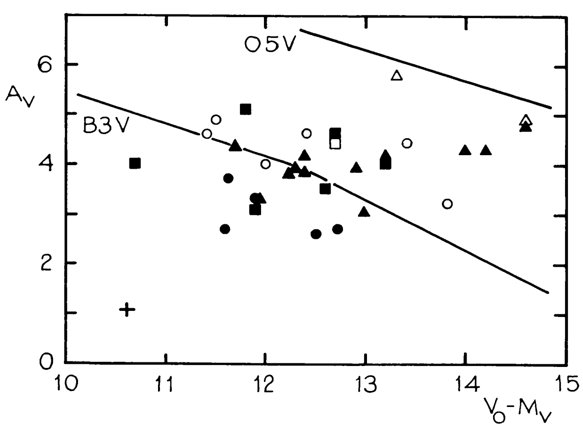

FIG. 1 — The total visual absorption (A_V) vs. minimum distance modulus ($V_0 - M_V$) diagram for stars of spectral type B3 or earlier. The cluster NGC 4609 (Feinstein and Marraco 1971) is shown as a cross. See text for explanation of the other symbols.

tion in region 2 which surrounds the compact cluster Hogg 15. Within that region lie the stars H1, H2, H3, H4, and 32 of Feinstein and Marraco (1971) and their star 25 is also nearby. The first and second stars are classified as (OB$^+$) and OB$^+$ by Lyngå (1968) and the third one as WN5 by Roberts (1962) and as WNh by Stephenson and Sanduleak (1971). Another star in the zone is classified as OB$^+$ by Lyngå (1968) but blended images prevented us from measuring it. Besides, six new OB stars were found by us in region 2, which make a total of twelve early-type stars on an area of 80 s.a.m. The results for the stars that appear to form the association give total visual absorption values in the range $3^{m}5$–$5^{m}1$ and minimum distance moduli between $11^{m}8$ and $14^{m}6$. The results should be considered with caution, since the members of the group may be intrinsically brighter than our conservative estimates and therefore farther away. Anyway, the existence of such an OB association is at variance with the results of Westerlund (1960) and Kerr and Kerr (1970) that suggest the presence of an interarm region behind this part of the Coalsack. The OB association would be slightly outside the Sagittarius arm in the model of Kerr (1970); it might fit into the Norma-Centaurus arm of the model of Courtès et al. (1970) if its members are only slightly evolved from the main sequence.

UBV and Hβ photoelectric photometry and image-tube spectroscopy of the faint OB stars found in this search will be invaluable and are urgently needed, especially for the possible OB association in region 2 since it is probably very distant and an excellent spiral tracer.

Use of the facilities at the Cerro Tololo Inter-American Observatory is especially acknowledged. This work was partially supported by a contract of A. Feinstein with the Consejo Nacional de Investigaciones Científicas y Técnicas de la República Argentina. The authors are grateful to Dr. E. W. Miller for helpful discussion about the manuscript.

REFERENCES

Bok, B. J., Bok, P. F., and Miller, E. W. 1972, *A.J.* **77**, 733.

Courtès, G., Georgelin, J. P., Georgelin, J. M., and Monnet, G. 1970, *I.A.U. Symposium No. 38*, W. Becker and G. Contopoulos, eds. (Dordrecht, Holland: D. Reidel Publishing Co.), p. 209.

Feinstein, A., and Marraco, H. G. 1971, *Pub. A.S.P.* **83**, 218.

Houck, T. E. 1956, Dissertation, The University of Wisconsin.

Kerr, F. J. 1970, *I.A.U. Symposium No. 38*, W. Becker and G. Contopoulos, eds. (Dordrecht, Holland: D. Reidel Publishing Co.), p. 95.

Kerr, F. J., and Kerr, M. 1970, *Ap. Letters* **6**, 175.

Lyngå, G. 1968, *Arkiv f. Astr.* **5**, 181.

Marraco, H. G. 1974, "*A Finding List of OB Stars in the Coalsack Zone*", University of La Plata Observatory.

Miller, E. W. 1972, *A.J.* **77**, 216.

Muzzio, J. C., Marraco, H. G., and Feinstein, A. 1974, *Bol. Asoc. Arg. Astron. No.* **18** (in press).

Muzzio, J. C., and McCarthy, C. C. 1973, *A.J.* **78**, 924.

Roberts, M. S. 1962, *A.J.* **67**, 79.

Rodgers, A. W. 1960, *M.N.R.A.S.* **120**, 163.

Schmidt-Kaler, Th. 1965, *Landolt-Bornstein, New Series* VI/1, 297.

Stephenson, C. B., and Sanduleak, N. 1971, "Luminous Stars in the Southern Milky Way", *Pub. Warner and Swasey Observatory*, Vol. 1, No. 1.

Tapia, S. 1972, "*The U, B, V, R, and I Extinctions in Four Areas of Southern Coalsack*", Steward Observatory.

Westerlund, B. 1960, *Arkiv f. Astr.* **2**, 429.