# THE $U$, $B$, $V$, $R$, AND $I$ EXTINCTIONS IN FOUR AREAS OF THE SOUTHERN COALSACK

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**Abstract.** From star counts the extinctions in five spectral bands were determined for four areas of the Southern Coalsack. The wavelength dependence of the extinction values follows the Whitford curve. Minimum masses for six globules are given.

## 1. Introduction

In 1971, Dr B. J. Bok decided to undertake a multicolor program of star counts for the region of the Southern Coalsack. He accumulated about thirty $U$, $B$, $V$, and $R$ photographic plates of the region, most of them obtained with the 24–36 in. Curtis-Schmidt telescope at Cerro Tololo Inter-American Observatory. Dr E. W. Miller, during an observing run in Chile in 1972, supplemented the observational material with three infrared plates and photoelectric photometry for two sequences in the same region. At Dr Bok's suggestion, this material has been analyzed in order to study the extinction in the Coalsack in five spectral bands.

The early work of Unsöld (1929) and Lindsay (1941) indicated that the average photographic extinction in the Coalsack is approximately one magnitude. Based on observations of stars behind the Coalsack, Houck (1956) found that $A_V$ can amount to 3.4 mag. From star counts in circular areas of 10′ in diameter, Mattila (1970) computed values of $A_B$ as large as 2.4 mag. Rodgers (1959) determined the photographic extinction and approximate distances for seven areas of about one sq deg each. His values of the extinction cover the range 0.7 to 2.4 mag. and his average distance, the best available to date, places the Coalsack at 175 pc from the Sun. The total infrared extinction in the line-of-sight of the Coalsack was studied by Westerlund (1960a, b). In areas of one to two sq deg, Westerlund derived values of $A_I$ between 1.1 and 3.2 mag.

TABLE I

Coordinates and sizes of the four areas 1975

| Area | R.A. | DEC. | Size (sq min arc) |
|---|---|---|---|
| I | $12^h57^m.6$ | $-61°28'$ | 1495 |
| II | 12 59.7 | −62 47 | 1225 |
| III-a | 12 33.0 | −63 42 | 300 |
| IV | 12 29.5 | −65 30 | 809 |

*Greenberg and Van de Hulst (eds.), Interstellar Dust and Related Topics*, 43–51.

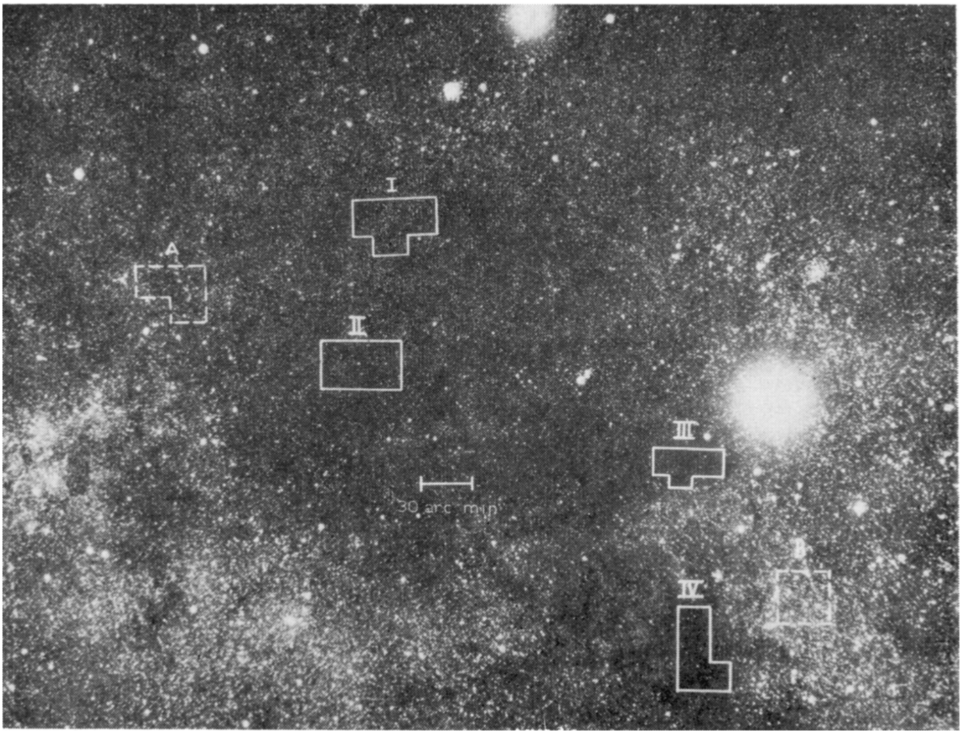


Plate A. *The Southern Coalsack.* A high contrast reproduction of the Franklin-Adams chart. The brightest star is $\alpha$ Crucis, at the top is $\beta$ Crucis. North is at the top, East is to the left.

For the present study four areas of heavy obscuration have been selected. In general, these four areas show a homogeneous star density on the blue plates; however, inside two of them, a few small dark nebulae are clearly delineated on the red plates. The coordinates of the centers of the four areas and their apparent sizes are given in Table I. In order to determine the extinction by the method of the Wolf diagrams (Bok, 1937), two comparison areas – labeled *A* and *B* – were selected outside of the observable limits of the Coalsack. All six areas are shown in outline on Plate A.

## 2. Observational Material

The ultraviolet, blue, and visual plates were taken with the standard combination of emulsions and filters, which reproduce approximately the spectral bands of Johnson's (1964) system of magnitudes. The red plates were taken with O98-02 emulsion and an RG-2 filter which define a spectral band between H$\alpha$ and 7000 Å. For the infrared plates the standard *I-N* emulsion and a Wratten 89-B filter were used.

Two new photoelectric sequences established near the Coalsack were used in the derivation of magnitudes from the photographic material. Finding charts and UBV photoelectric magnitudes for these sequences, and for other sequences in the Southern

Milky Way, are being published by Bok *et al.* (1972). The $R$ and $I$ magnitudes for the stars in both sequences were derived from transformations of the UBV photoelectric data. For the $R$ magnitudes the relation $R = V - 0.5 \times (B - V)$ was used. Bok and Hine (1969) have shown that this transformation gives accurate $R$ magnitudes when the interpolation between UBV photoelectric data is done on O98-02 plates with RG-2 filter. For the $I$ magnitudes the diagram relating the colors $(V-R)$ and $(V-I)$ published by Mendoza (1967) was used.

The star counts in the different magnitude intervals were made with the aid of a Cuffey iris photometer. All plates selected for counting and analysis contain at least one of the four areas and one sequence. The images of the sequence stars were first measured with the iris photometer. The iris readings were then plotted against the magnitudes of the sequence. From this plot, the iris readings corresponding to successive whole magnitudes were then obtained. Next, the image of each star was measured and recorded in its proper interval of magnitude. The same procedure was repeated for the four areas in each of the five spectral bands. The final result of the counts are values of $A(m)$, the number of stars per square degree within magnitudes $(m-\frac{1}{2})$ and $(m+\frac{1}{2})$.

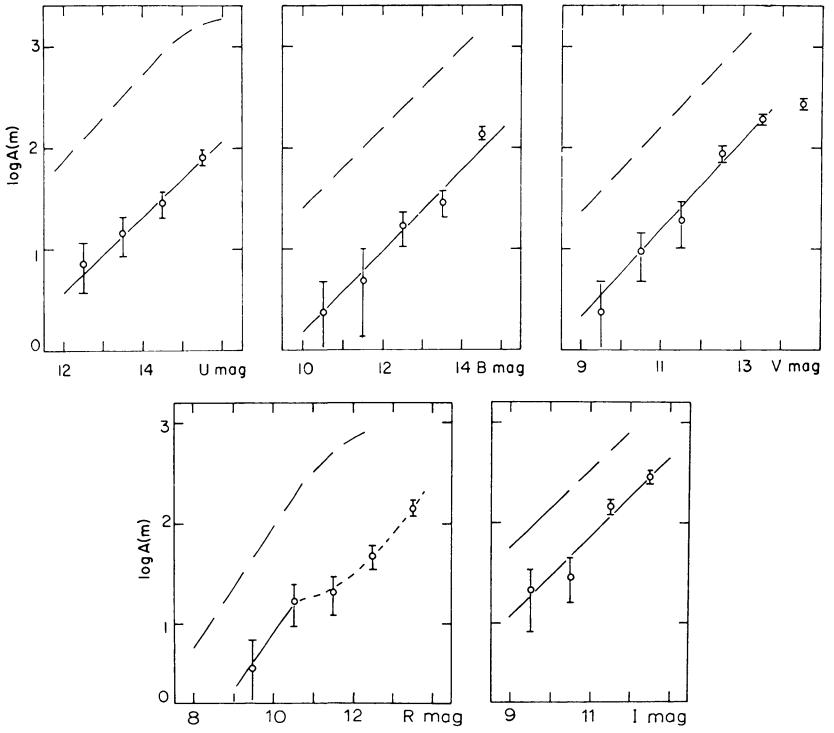


Fig. 1. *The Wolf Diagrams for Area I.* The abscissae are the magnitudes in the UBVRI-system, the ordinates the logarithms of the numbers of stars per square degree. The apparent size of the area is 1495′ × 1495′.

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## 3. Extinction Determinations

The study of the counts for the comparison areas shows that area *B* is richer in stars than area *A*. Obviously both areas are not free from general extinction and probably they are still affected – to a small degree – by the Coalsack itself. Nevertheless, areas *A* and *B* represent a fair sample of the distribution of stars at the galactic latitude and longitude of the Coalsack. Accordingly, as a satisfactory set of reference counts for the Wolf diagrams, the mean of the counts in both areas has been used. In Figures 1, 2, 3, and 4 the Wolf diagrams for the different spectral bands are shown. For each diagram the dashed line represents the mean of the counts in comparison areas *A* and *B*. The error bars of the open dots correspond to the statistical errors of the counts. Because of the small distance from the Sun to the Coalsack, there are essentially no foreground stars in the counts for small regions and, hence, the difference in magnitudes between the continuous and dashed lines is equal to the extinction. A dotted line is used to indicate that the counts seem to show extinction produced by more than one cloud. The values of the derived extinctions have been collected in Table II. Area IV is not covered very well by any of the red plates and for this reason no value of $A_R$ is listed.

Small isolated dark clouds are found in areas III and IV. No counts were made

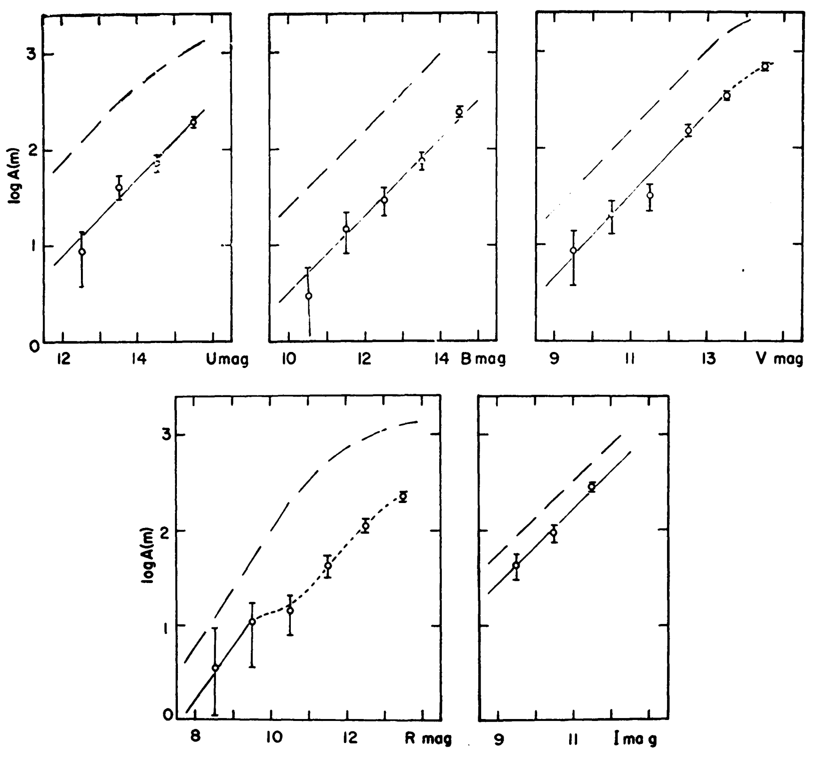


Fig. 2. *The Wolf Diagrams for Area II.* The apparent size is 1225′×1225′.

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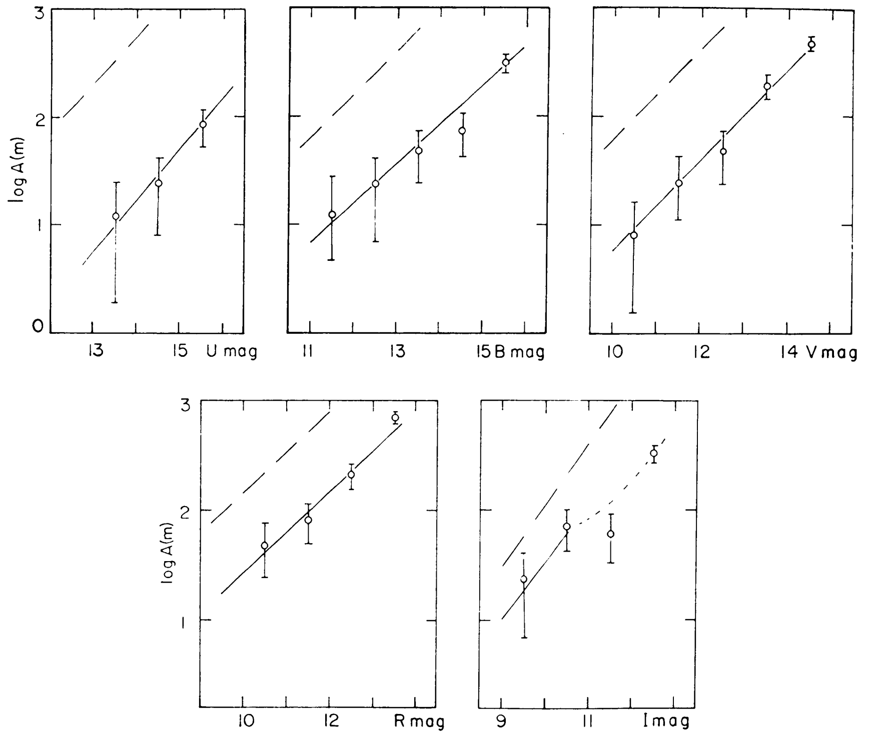


Fig. 3. *The Wolf Diagrams for Area III-a.* The counts refer to the homogeneous smaller area of the original area III. The apparent size is 300′ × 300′. In cases for which the continuous line diverges from the dashed one, the extinction for the faintest apparent magnitude is accepted and listed in Table II.

inside the small areas covered by these clouds since there are no stars – or very few stars – shining through them. Area III contains three very dark clouds and a fairly homogeneous smaller area. Westerlund (1960a) has pointed out that these clouds seem to form the most obscured parts of the Coalsack (see Figure 6 of his paper). Considering the total area III – approx. 777′ × 777′ – the computed values of an average extinction would be meaningless because the small clouds contribute a large percentage of the area but nothing to the number of stars. Therefore, only the counts for the

TABLE II

Values of the derived extinctions in four areas of the southern coalsack

| | Areas | | | | Errors |
|---|---|---|---|---|---|
| | I | II | III-a | IV | |
| $A_U$ | $3\overset{m}{.}6$ | $2\overset{m}{.}6$ | $3\overset{m}{.}4$ | $2\overset{m}{.}8$ | $\pm 0\overset{m}{.}4$ |
| $A_B$ | 3.0 | 2.2 | 2.8 | 2.4 | ±0.3 |
| $A_V$ | 2.2 | 1.6 | 2.3 | 1.8 | ±0.2 |
| $A_R$ | 1.7 | 0.9 | 1.9 | — | ±0.1 |
| $A_I$ | 1.4 | 0.7 | 1.2 | 0.7 | ±0.1 |

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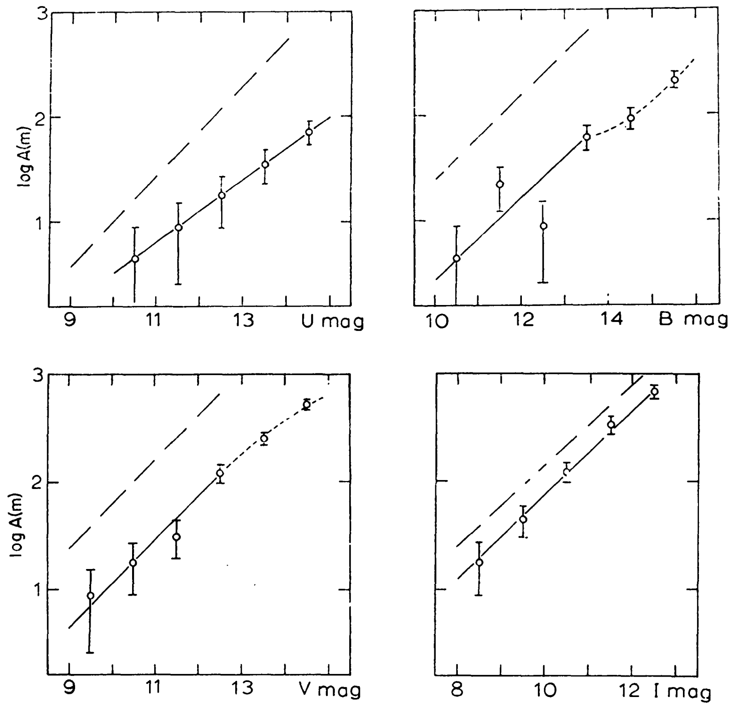


Fig. 4. *The Wolf Diagrams for Area IV.* The apparent size is 809′ × 809′. No counts were made on the red plates. As in Figure 3, the maximum value of the extinction is accepted and listed in Table II.

smaller homogeneous area were used to compute the listed extinction. This smaller area has been named III-a. Inside area IV – covering a total of 920′ × 920′ – two small dark clouds are easily delineated. To the faintest magnitudes of the sequences no stars are counted inside these clouds either. Again the areas of the dark clouds were subtracted, leaving area IV with 809′ × 809′, and the extinctions derived for the new area are given in Table II. The errors for the extinction values in the five spectral bands have been estimated from the differences between the reference star counts of the comparison areas *A* and *B*.

The values presented in Table II can be combined to derive an extinction curve. The results are presented in Figure 5, where the values of the extinctions are normalized to $E(B-V) = 1.0$. The continuous curve is Whitford's (1958) extinction-curve applicable to the interstellar medium excluding the region of the Orion Nebula and NGC 6530. To avoid confusion no error bars have been attached to the points in Figure 5. Within the accuracy of these results, the Coalsack seems to follow closely the average properties of extinction known for the obscuring component of the interstellar medium.

## 4. Masses of the Globules

The observed properties of the small dark clouds found in areas III and IV are consistent with the definition of blobules given by Bok *et al.* (1971). From inspection of the red plates it is possible to see that quite a few globules are contained in the Southern Coalsack.

In order to estimate lower limits for the masses of the globules it may be assumed that their minimum extinctions are at least equal to the extinctions of the adjacent areas. The computations were made using the relation derived by Lynds (1968) between the mass and the extinction of a dark nebula (see Equation (24) of her paper). The distance to the Coalsack is taken to be 175 pc, obtained by Rodgers (1960).

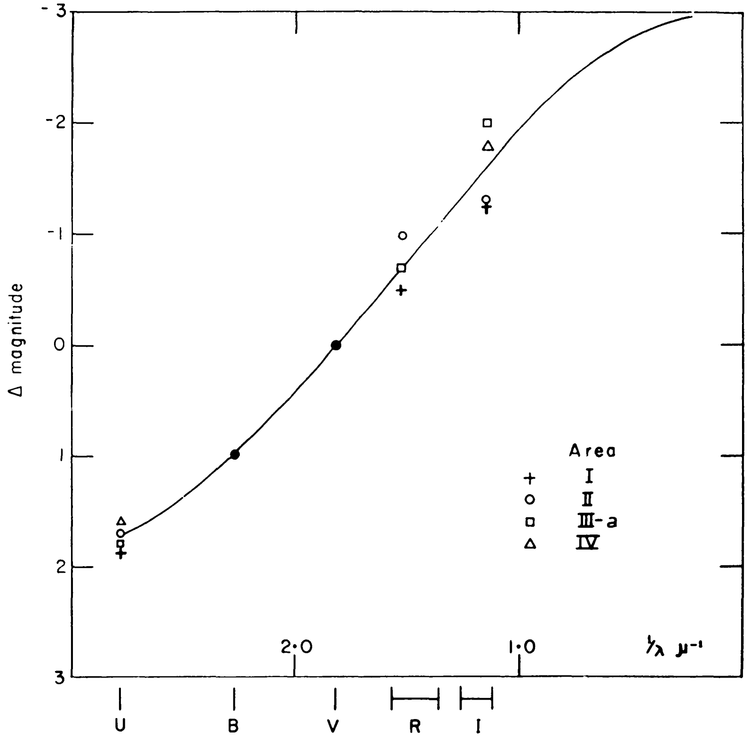


Fig. 5. *The Extinction Curve for the Southern Coalsack.* The derived extinctions are plotted together with-Whitford's (1958) extinction curve. The UBVRI extinction values are normalized to $E(B-V) = 1.0$.

For the dust grains forming the globules it is assumed that the efficiency factor for the cross-section of extinction in the visual is $10^{-1}$, the mean density is 3 gm cm$^{-3}$, and the radius is $10^{-6}$ cm. The computed minimum masses for six representative globules in the Coalsack are given in Table III. Approximate coordinates of the centers and actual sizes are included in the tabulation. These masses correspond to the minimum contributions from the dust grains only. If the ratio of gas to dust in the Coalsack is similar to the general galactic ratio, the total minimum masses would be 100 times larger (Spitzer, 1968) than the values given in Table II.

TABLE III

Computed minimum masses for the globules of areas III and IV

| 1975 (R.A.) | (DEC.) | Angular area (sq. min of arc) | Radius ($10^3$ AU) | Visual extinction (minimum value) | $M/M_{\odot}$ (min. values) |
|---|---|---|---|---|---|
| $12^h32^m0$ | −63°33′ | 48 | 50×20 | $2^m_.5$ | 0.035 |
| 12 30.5 | −63 38 | 42 | 38 | 2.5 | 0.031 |
| 12 28.5 | −63 43 | 19 | 26 | 2.5 | 0.014 |
| 12 30.5 | −65 10 | 84 | 70×20 | 2.0 | 0.049 |
| 12 27.4 | −65 33 | 27 | 31 | 2.0 | 0.016 |
| 12 27.3 | −65 44 | 27 | 31 | 2.0 | 0.016 |

*Notes:*

(1) For irregular clouds two dimensions are given in column 3.

(2) The actual extinctions may be considerably greater than those listed in column 4.

(3) The listed masses in column 5 are only the minimum *dust* masses, calculated on the basis of the extinctions in column 4; the actual masses, considering gas and dust, are probably 100 times larger than the listed values.

## 5. Conclusions

On the basis of the available observational material and within the accuracy of the results derived from this study the following conclusions can be drawn:

(a) The Southern Coalsack is a conglomerate of small and large clouds. It is *not* a sheet of variable extinction, *nor* a nearspherical unit cloud.

(b) The average extinction for the denser regions is approximately three magnitudes in $U$, two magnitudes in $V$, and one magnitude in $I$.

(c) The dependence of the extinction with respect to wavelength in the Southern Coalsack seems to be similar to the average dependence observed in the galactic interstellar medium.

(d) Six globule-like clouds of the Southern Coalsack have average minimum masses of three solar masses (gas and dust included) and radii of about $3 \times 10^4$ AU.

## Acknowledgements

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**Note added in proof.** The discovery of a small dense cloud of formaldehyde in the Southern Coalsack has recently been reported by M. W. Sinclair and J. W. Brooks (*Astrophys. Letters* **11**, 207, 1972). The position of the cloud coincides with the coordinates of the second globule listed in Table III of this report. The diameter of the formaldehyde cloud has been estimated to be close to 0.3 pc. The diameter of the globule, measured on red plates, is approximately 0.37 pc. Further radio astronomical molecular studies of the Southern Coalsack are obviously of great interest.

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