spiral structure and star spiral structure when the distance scale of the gas is kinematic and the distance scale of the stars is photometric. When such inhomogeneous distance scales are employed, discrepancies in the derived space distribution of the stars and gas may be expected even if, in reality, they were in perfect agreement.

Discussion

Burke: Our observations of M31 showed that agreement of bright star arms with hydrogen maxima was close for only about half of the cases. Therefore, all discussion of distance scale apart, if one tries to force agreement between hydrogen arms and bright star arms there is 50% chance that one is trying to make a coincidence where no coincidence exists.

Weaver: I quite agree, and I am not suggesting that allowing for differences in the distance scales is a universal panacea. We do not and probably should not expect to find agreement in all cases between stars and gas. My point is that if we use inconsistent distance scales we shall never find agreement between stars and gas even in those cases in which it exists.

Courtès: In finding a relation between the two distance scales I use one common point, that is the HII regions. When you obtain the same velocity for the 21-cm line, the Hα line, and the K line, it is obvious, or at least very likely, that the exciting star responsible for the HII region emitting Hα belongs to the same gas spiral arm.

Weaver: Do you find good agreement between the radial velocity of the star and of the HII region?

Courtès: This agreement is mainly between the different components of the interstellar matter — HI, HII, and K or Na lines — but often the radial velocity of the star is also in good agreement with these velocities. This is especially true for the Perseus arm.

Parijsky: I have two remarks on Dr. Thackeray's and Dr. Weaver's papers.

1. A new possibility for distance scale measurements arises when we compare the brightness of HII regions in Hα or Hβ with that in the radio continuum. The main difficulty is to ascertain the distribution of dust along the line of sight (cf. *Izvestia Glavnoi Astron. Obs. Pulkovo, U.S.S.R.* **21**: 54–61 (1961)).

2. There is some difficulty when we try to apply the 21-cm absorption method to the very bright nebulae, owing to high absorption at the centres of the nebulae. In such cases the method gives the wrong result.

Bolton: 21-cm absorption measurements on emission nebulae possibly form the best meeting point between the two methods of determining distance scales in the nearby regions of the Galaxy. Radio telescopes of the size of the 210-foot can possibly detect absorption features in 100 emission nebulae.

Tifft: Regarding the correlation between optical and radio structure, one should not neglect to consider the distribution of dark absorbing material with distance. Since dust and gas can be expected to occur together we can expect a reasonable correlation. From three-colour photometry of stars — both OB stars and *general* field stars — we can determine individual absorptions and map the absorption field in depth to some degree of accuracy.

39. AN INFRARED SURVEY OF THE SOUTHERN MILKY WAY

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Introduction

The determination by optical means of the galactic structure at great distances from the Sun is becoming more and more important. Most optical investigations, using ordinary techniques — objective-prism survey in the blue spectral region $+UBV$ photometry — do not reach very far out owing to the heavy obscura-

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tion in most directions in the galactic plane. Only a few very luminous OB stars and some rare supergiants have been identified in some selected regions at distances exceeding 4 kpc.

Important conclusions about the structure of our Galaxy may be drawn from studies of the red giant and supergiant stars. These objects are best studied by infrared techniques. The following advantages are immediately evident:

1. The interstellar absorption in infrared is one-half the visual absorption.
2. All the S stars and carbon stars and practically all M stars are giants. Therefore, they can be identified with ease to great distances.
3. The number of M stars per square degree is generally large in the galactic plane. Frequently, 20 to 40 M2–M4 stars are found brighter than $I=12^{\rm m}$, thus presenting a rich material for statistical analysis.

In this paper a progress report is presented from an infrared survey of a belt 10° wide along the galactic equator from $l^{\rm II}=230°$ through the centre direction to $l^{\rm II}=10°$. The plate material has been gathered with the Uppsala Schmidt telescope at Mount Stromlo equipped with an objective prism giving the dispersion of 2100 Å/mm at the atmospheric A-band. Exposures of 30 min on hypersensitized Eastman Kodak I-N plates give a limiting magnitude of about $I=12\overset{\rm m}{.}5$. The classification of the red stars follows the Case infrared system introduced by Nassau and van Albada (1949).

Previously, surveys of the Southern Milky Way (or parts of it) have been carried out by V. Blanco and L. Münch (1955) and by E. v. P. Smith and H. J. Smith (1956). The limiting infrared magnitudes of these surveys are about $I=10^{\rm m}$–$10\overset{\rm m}{.}5$ and they are thus comparable to those carried out by Nassau, Blanco, and others (Nassau 1958) of the Northern Milky Way. The results from these surveys of the apparently-bright red stars indicate that carbon stars and S stars may be found in spiral arms. Generally, a good correlation has been found between the number of M stars and the brightness of the Milky Way.

The M Stars

A good indicator of the galactic structure in a region is given by the ratio of the number of early M stars (M2–M4) to the number of intermediate M stars (M5–M6·5) to the number of late M stars (M7–M10), provided the survey reaches *the same distance for all three groups*. In spiral arms the ratio is greater than 7 : 2 : 1; in interarm regions the ratio may be as low as 2 : 1 : 1 (Westerlund 1960*a*,*b*). Neckel (1958) suggests that in the centre direction the ratio is less than 1 : 1 for M2–M4 to M5–M10 stars.

In order to obtain an idea about the distribution of M stars in the Southern Milky Way we have gathered in Figure 1 some results from star counts and measurements in eight regions. The counts were made in Puppis, Centaurus, Norma, and Scorpius in areas of 2 square degrees centred at $b^{\rm II}=+3$, 0, and $-3°$. For the histograms in the upper two rows the apparently most transparent of the three latitude zones was used at each longitude. In the remaining four regions, Carina (Westerlund, unpublished), Crux (Westerlund 1960*b*), centre direction (Nassau and Blanco 1958), and Scutum (Albers 1962), photometric results were available and the choice of field more limited.

The boxed-in numbers above the histograms in the upper row in Figure 1 give the total numbers of stars per square degree in each field to the plate limit. We notice that the numbers increase towards the centre direction, and also, that the total number of late M stars increases faster than the number of early M stars.

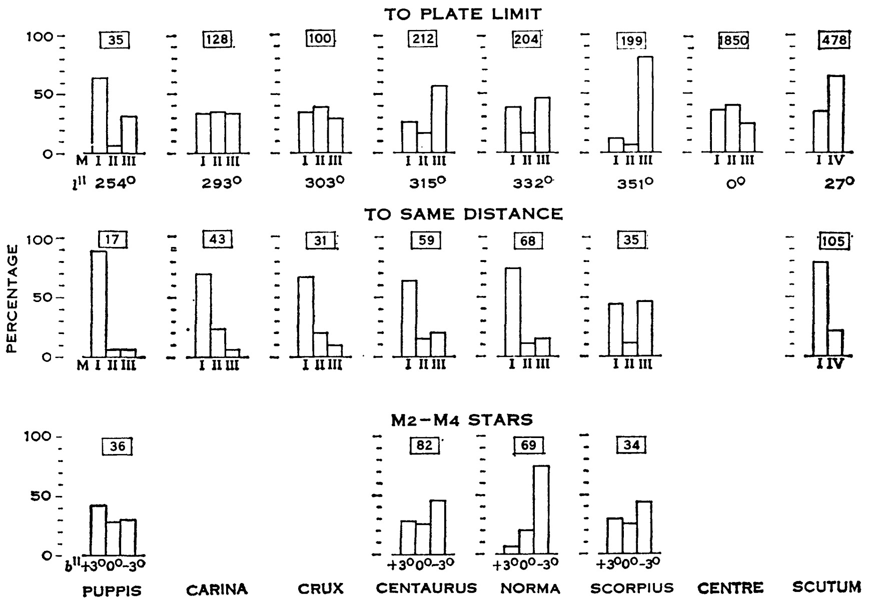

Fig. 1.—Histograms showing the distribution of M stars in eight regions of the Southern Milky Way. The results for the centre direction are from Nassau and Blanco (1958) and for the Scutum Cloud from Albers (1962). [I, 2–4; II, 5–6·5; III, 7–10; IV, 5–10.]

The second row in Figure 1 shows the histograms after the application of corrections to limit the counts of the number of stars in each group to the same distance. This distance has been chosen so that the material in each group is definitely complete. Limiting apparent infrared magnitudes are then: for M2–M4, $11^{m}.25$, and for M5–M6·5 and M7–M10, $10^{m}.25$, and the corresponding correcting factors: for M2–M4, 0·67; M5–M6·5, 0·25; and M7–M10, 0·1.

The histograms in this row show in all regions, except in Scorpius, the dominating population of early M stars to be expected in spiral arms. If we assume an average absorption of $A_I = 1^m$ and an absolute infrared magnitude of $M_I = -3^m$ for the early M stars, we find that the survey reaches about 4 kpc from the Sun. The Sagittarius arm is probably only 2·5 kpc from the Sun. It is, therefore, possible that we see a part of the same spiral arm in Scorpius as in Scutum. The number of late M stars may, however, increase much faster behind this arm than the number of early M stars, resulting in the observed distribution.

The bottom row of histograms in Figure 1 shows the distribution of early M stars at the four longitudes where counts were made. The extreme clustering of early M stars at $b^{II} = -3°$ in Norma should be noted. The number of late M stars is approximately the same at all three latitudes at this longitude. Therefore, the clustering of the M2–M4 stars is definitely real and not a result of heavy obscuration.

The Carbon Stars

It should be noted that the carbon stars (and the S stars) found in the infrared objective-prism surveys most likely form a more homogeneous group than those identified by other means. The CN (LaO) bands have to be fairly strong before a carbon star (S star) is identified in the infrared. It is particularly important that the early carbon stars are not included as they tend to make the class more heterogeneous.

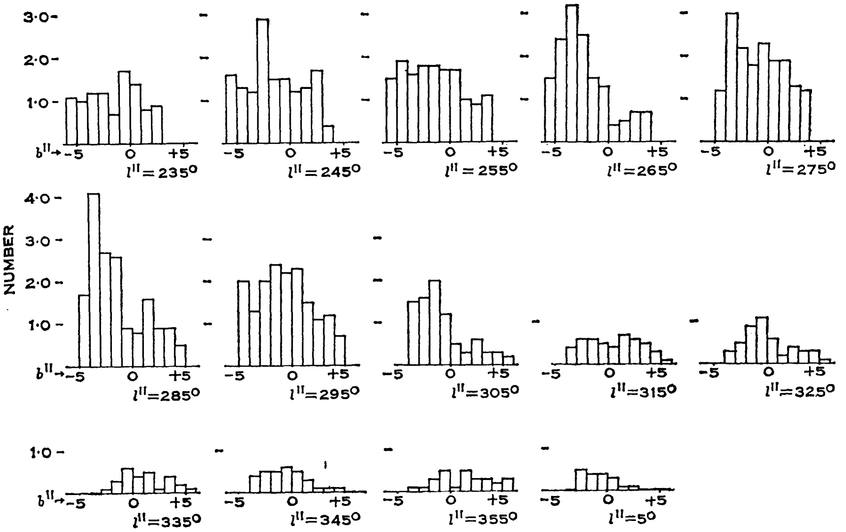

Fig. 2.—The distribution of carbon stars in the Southern Milky Way.

The distribution of the 1326 carbon stars identified in the present survey is shown in Figure 2 for 10-degree strips in galactic longitude and for 1-degree zones in latitude. The concentration of carbon stars to the Carina region is most striking. So is the fact that most of the carbon stars are found south of the galactic equator. We may also note the sudden drop in the number of stars at $l^{II} = 310°$. From $l^{II} = 335°$ through the centre direction the number remains very low.

The concentration of carbon stars in the Carina direction has previously been accepted as indicating that these stars belong to the spiral arm population. Earlier surveys have dealt with apparently bright stars with distances corresponding to those of the OB associations. In the present survey we can safely assume that, in the Carina direction, we have carbon stars scattered along at least 7 kpc of a spiral arm. (The infrared absolute magnitude of carbon stars is $M_I \sim -4^m$.) On the other hand, in the direction of the galactic centre, we may assume that we reach the Sagittarius arm at about 2·5 kpc from the Sun, and that this arm is about 1 kpc thick. Assuming the number of carbon stars per unit volume inside the spiral arms to be approximately the same everywhere, we find that we ought to have about 10–15 times as many stars in the Carina direction as in the Sagittarius direction. This is approximately the case in this survey. The lack of carbon stars in the centre direction depends then only upon the fact that we cross one spiral arm perpendicularly and do not reach another (containing carbon stars).

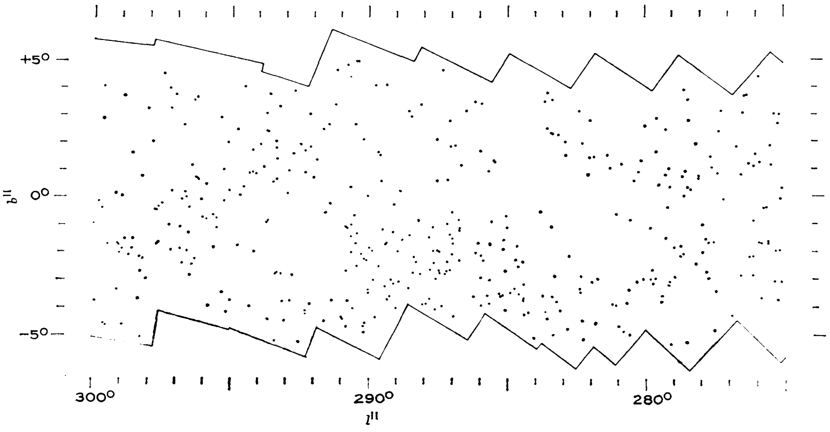

Fig. 3.—The detailed distribution of carbon stars in Carina.

In Figure 3 the detailed distribution of the carbon stars in Carina is shown. We note:

(*a*) The concentration of the stars to the southern latitudes.

(*b*) The complete lack of stars in two regions. The elongated region to the right corresponds to the dark nebula No. 384 in Khavtasi's Atlas of Galactic Dark Nebulae (1960), which is denoted as having low obscuration. The circular region at l^{II}=292–3°, b^{II}= −2° is No. 417 in the same Atlas and has moderate absorption. Blanco and Nassau (1957) have suggested that carbon stars appear to avoid regions with very heavy obscuration and that they may be found in semi-obscured regions. The present survey indicates that the carbon stars are evenly distributed in the spiral arms. The effects of the dark nebulae on the observed distribution of carbon stars appears to be the normal one; heavy obscuration prevents the distant stars from being seen.

(*c*) We note in Figure 3 also a great number of close pairs of stars. The existence of pairs of carbon stars with a separation of less than 0°.2 has been noted previously by Nassau (1958) and others. In the present survey we have found 137 pairs of this type. We have divided this material in zones of 10×1° and computed for each zone the number of pairs to be expected from a random distribution of the stars of the average density observed in that zone. The result is given in Table 1 in a summarized form. It is evident that the maximum number of pairs exists in the Carina region even when the higher density of carbon stars there is considered. It appears extremely important to investigate this further with regard to the magnitude differences between the components, and with regard to spiral structure.

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The S Stars

The distribution of the 87 S stars identified is shown in Figure 4. This material is probably not as complete as for the carbon stars owing to the difficulty of separating S stars from very reddened early M stars. However, as both these groups of objects appear in the same regions of the Milky Way, the possibly omitted objects do not affect the overall distribution.

TABLE 1

THE DISTRIBUTION OF PAIRS OF CARBON STARS WITH A DISTANCE OF LESS THAN $0\overset{\circ}{.}2$ BETWEEN THE COMPONENTS

l^{II}	b^{II}	Number of Pairs	
		Observed	Expected
230–260°	−6 to +4°	26	9
260–300°	−5 to +5°	101	20
300– 10°	−4 to +6°	10	3
Total number		137	32

The character of the S stars as spiral-arm tracers is confirmed in this survey by their overall agreement with the OB associations (rectangles and squares in Fig. 4). It appears desirable to determine distances for these stars before any far-reaching conclusions are drawn.

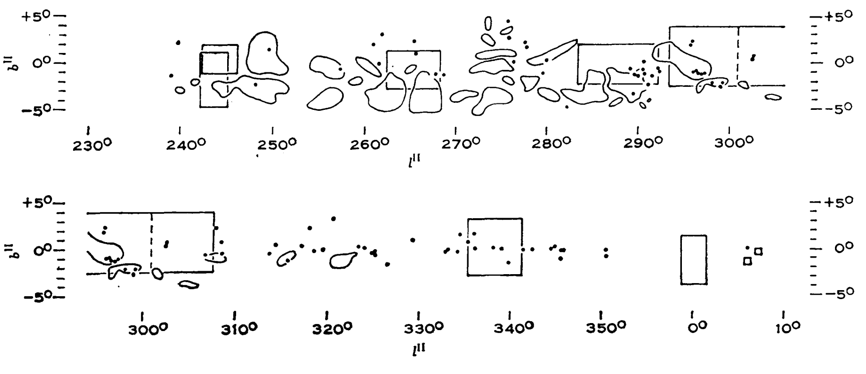

Fig. 4.—The distribution of S stars (dots) in the Southern Milky Way. Rectangles and squares denote OB associations. The other marked areas have three or more carbon stars per square degree.

In Figure 4, the positions of the concentrations of carbon stars are also shown. The marked regions contain a minimum of three carbon stars per square degree. It is quite evident that the carbon stars avoid the OB associations and the S stars.

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It appears important to note in this connection the distribution of the Wolf–Rayet stars in the Milky Way (Roberts 1962) and to compare it with the distribution of the red stars and the OB associations. The Wolf–Rayet stars concentrate south of the galactic equator (as do the carbon stars). They are fairly numerous in the Sagittarius arm (as are OB stars, S stars, and early M stars). They avoid completely the Orion spur and the anticentre direction. The two regions of highest density are the Carina and Cygnus regions.

Comparison between Infrared–Red and UBV Photometry

In a detailed study of some areas in the region of the Southern Coalsack (Westerlund 1960*a*,*b*), it was found that the conclusions about the interstellar absorption and the distances of the dark nebulae and the clusters in the region as drawn from the infrared–red photometry were in good agreement with the results by Houck (1955) and Rodgers (1960).

A detailed study of the red stars in a region centred on SA 193 has recently been finished (Westerlund, unpublished data). The average redenning over 2 square degrees centred on SA 193 is $A_I = 1^m\!.2$, corresponding to $A_V = 2^m\!.4$. However, from the centre of SA 193 towards the cluster NGC 3766 there is a zone with considerably lower absorption. In fact, a few carbon stars at very great distances found in this zone appear completely unreddened. This result is in fair agreement with results by Bok (unpublished) and Sher (1962).

Conclusions

The following conclusions may be drawn from the present data:

1. The early M stars show clusterings with preference for spiral arm regions.
2. The late M stars are evenly distributed in arm and interarm regions. Their density increases appreciably as the galactic centre is approached.
3. The carbon stars (identified by the infrared CN bands) are spiral arm objects. Their more even distribution per unit volume as compared with OB stars makes them extremely useful for tracing distant spiral arms. They appear to avoid the OB associations.
4. The carbon stars appear fairly frequently in pairs.
5. The S stars (identified by the infrared LaO bands) are spiral arm objects. Their surface distribution agrees well with the distribution of OB associations.
6. Most carbon stars and Wolf–Rayet stars are found south of the galactic equator between $l^{II} = 260°$ and $l^{II} = 300°$. OB and S stars scatter along the equator.
7. Results from detailed studies of galactic regions using infrared techniques are in good agreement with results from investigations using ordinary techniques. Because of the lower absorption in the infrared–red spectral region, this favours very much the use of infrared techniques.

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References

Albers, H. (1962).—*A.J.* **67**: 24–36.

Blanco, V. M., and Münch, L. (1955).—Tonantzintla y Tacubaya, Bol. No. 12: 17–29.

Blanco, V. M., and Nassau, J. J. (1957).—*Ap. J.* **125**: 408–13.

Houck, T. E. (1955).—Ph.D. Dissertation, University of Wisconsin.

Khavtasi, J. Sh. (1960).—"Atlas of Galactic Dark Nebulae." (Akad. Nauk GSSR: Tbilisi.)

Nassau, J. J. (1958).—"Stellar Populations." (Ed. D. J. K. O'Connell.) pp. 183–94. (North Holland Publishing Co.: Amsterdam.)

Nassau, J. J., and van Albada, G. B. (1949).—*Ap. J.* **109**: 391–413.

Nassau, J. J., and Blanco, V. M. (1958).—*Ap. J.* **128**: 46–56.

Neckel, H. (1958).—*Ap. J.* **128**: 510–32.

Roberts, M. S. (1962).—*A.J.* **67**: 79-85.

Rodgers, A. W. (1960).—*M.N.* **120**: 163–72.

Sher, D. (1962).—*Observatory* **82**: 63–6.

Smith, E. v. P., and Smith, H. J. (1956).—*A.J.* **61**: 273–6.

Westerlund, B. (1960*a*).—*Arkiv f. Astr.* **2**: 429–50 =Uppsala Medd. No. 130.

Westerlund, B. (1960*b*).—*Arkiv f. Astr.* **2**: 451–65 =Uppsala Medd. No. 131.

Discussion

Aller: The absolute magnitudes, -4 and -5 for C stars and -4 for S stars, refer to their *infrared absolute* magnitudes, do they not? What are their absolute magnitudes on the V colour system?

Westerlund: Yes, that is so. For one C star in the LMC about -3 has been observed for M_V. Galactic M stars are about -2. I have not yet observed the S stars.

Thackeray: Has Dr. Westerlund tried comparing the relative statistics of early M stars (concentrated in the spiral arms) and OB stars? Such a comparison between the outer and inner arms would be of special interest. I have in mind the number of red stars found in M11 and NGC 6067 in the inner part of the Galaxy. But perhaps this is only a consequence of the richness of these clusters.

Westerlund: Do these clusters contain M stars?

Thackeray: I believe M11 contains a few, but none have yet been found in NGC 6067. There are possibly different evolutionary effects in different parts of the Galaxy.

Westerlund: So far I have detailed observations of only one region in Carina and one in Crux where the early M stars are mostly between 2·5 and 4 kpc. If the C stars do define spiral arms, they have definite advantages over OB stars in that they are more evenly distributed and are easier to find.

Lindblad: The results for the M stars seem to be in good agreement with the results of stellar motions, the late M stars having a wider velocity dispersion. The relation between carbon and Wolf–Rayet stars is very interesting. It would be of great interest to have a similar analysis for the northern sky in order to see how the conditions may depend on distance from the centre.

Feast: At mean light the visual absolute magnitude of S stars is about $-0\overset{m}{.}5$. Is it possible to estimate the fraction of your C and S stars which are variable?

Westerlund: No, not yet. I have followed some variables in Carina and Crux.

Perek: What would be the average absorption coefficient in the direction of the galactic centre from your material?

Westerlund: The average infrared absorption at distances less than 2 kpc from the Sun is about 1^m. If there are any spiral arms inside Sagittarius, there are no C stars apparent. Either the C stars are cut out by absorption or none are present. The latter seems more likely.

Buscombe: Can the Sun's position 60 pc from the galactic plane partially explain the excess of carbon stars, Wolf–Rayets, HII radio sources, and early OB clusters seen south of the plane?

Westerlund: No, I do not think so.