Both types of polarization investigation are still in the preliminary stages, but promise to contribute significantly to our understanding of galactic emission and magnetic fields.

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Discussion

Westfold: I think some of us would like to be assured by the observers that they are not taking linear polarization for granted. By doing so they are putting their faith in the synchrotron process of emission together with an isotropic distribution of electron velocities. It is desirable that, at least in selected areas, a number of measurements sufficient to determine all the Stokes parameters should be taken. If it were found that linear polarization was not always present it would indicate the need for an alternative hypothesis, or at least the relaxation of the assumption of isotropy. Again, if the polarization of the spurious spill-over contribution were not linear, this might offer a means of separating the spurious component from the main cosmic contribution in which we are interested.

Gardner: We have attempted to detect circular polarization in an extended region in Centaurus A which is approximately 50% linearly polarized, and also in Jupiter, 25% linearly polarized. In each case, we obtained less than 4% circular polarization.

Westerhout: The Dwingeloo observers are indeed aware of the fact that one should try elliptical polarization as well. They have not got that far yet.

The spurious signal comes from the ground only, and is a function of altitude, irrespective of what its origin is. Therefore it can be easily subtracted.

The scatter Dr. Gardner finds in his intensities is exactly of the same kind as we had in Dwingeloo during our first measurements. Improvements in feed and receiver made them disappear. During the daytime, considerable scatter remains owing to solar radiation in the side-lobes.

Lequeux: In connection with Dr. Westfold's remarks, I should like to say that Le Roux has shown that the polarization of synchrotron radiation of a single electron is not linear but elliptical with an ellipticity of the order of $\frac{1}{7}$, the amount of which depends on the isotropy of the velocities of the relativistic electrons and of their energy spectrum. This could perhaps be observed in radio sources.

36. AN OUTLINE OF THE SPIRAL STRUCTURE OF THE SOUTHERN MILKY WAY

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Introduction

It has become clear in recent years that the spiral features of our Galaxy — like those of all galaxies — are of recent origin and are presumably short-lived phenomena. To trace them optically, we need to confine ourselves to concentrations in the interstellar gas and to stars and star groupings recently formed from these. We are hence limited primarily to OB associations and star clusters in which the earliest spectral types for the stars are not later than B2, preferably O5 to B1. It is most important that radial velocities be measured for a fair sampling of these stars, especially so for directions in which the radial velocity effects due to galactic rotation vary appreciably with distance. Radial velocities of the stars in question and those found from interstellar absorption lines are not only useful as indicators of distance, but they are very much needed for the identification of star groups and their associated HI clouds, found by 21-cm techniques. They assist also in the study of HII regions, which can now be located by either radio or optical methods.

Since obscuring matter is apparently concentrated into spiral arms (favouring the inner parts of the arms), dark nebulae can assist materially in delineating spiral features. We know the distances from the Sun for many dark nebulae and hence can plot their positions on the galactic plane. The polarization effects produced optically can furthermore be used to decide whether we are looking along a spiral arm or across one.

We should note specifically that clusters without stars of spectral type earlier than B3 — or single stars of type B3 and later — will give us little or no information about the spiral structure of our Galaxy, since most of these objects have existed long enough to have wandered 500 pc or more from their places of origin. The tracing of the "fossil spiral features", shown by the B3 to A2 stars and other objects of comparable age, is an interesting special problem that does not concern us here.

Radio-astronomical techniques yield much useful information on spiral structure; the interpretation of 21-cm profiles depends, however, on the velocity model of our Galaxy. Data on the radio continuum point to directions of great intensity, either discrete sources or directions for which we view tangentially along a spiral arm. But, the radio astronomer has to turn to the optical astronomer for identification of the sources of continuum radiation and he comes to his optical colleagues also to request a number of anchor points within 5000 pc of the Sun and, if possible, at greater distances. The optical astronomer provides from stellar and interstellar radial velocities the basis for a kinematic model of our Galaxy, which is needed for the interpretation of 21-cm profiles.

The Stromlo optical work has to date been concerned with probes to help find the distances to certain associations and nebulous centres that appear to be marked concentrations in spiral features of our Galaxy.

Because of the absence, until quite recently, of suitable spectrographic equipment, we have not yet been able to contribute to the kinematical model of our Galaxy. In the future we shall use the Stromlo nebular spectrograph and the cameras of short and intermediate focus of the coudé spectrograph for radial velocity work on OB stars, gaseous nebulae, and interstellar absorption lines.

The southern Milky Way may be divided rather naturally into separate sectors each with its own peculiar appearance and its own dominating characteristics. We shall report here on the work for sectors in which considerable material has been accumulating. In doing so we shall stress Stromlo work and only mention related work done elsewhere if the results appear to be especially relevant.

$220° < l^{II} < 228°$

The known optical features all lie at distances from the Sun between 500 and 1500 pc. The I Canis Majoris association, at an estimated distance of 950 pc, fits into this general picture. The most clearly defined 21-cm features are also assigned distances within this same range. This is a section of the sky for which we should in the future concentrate on optical radial velocity work for stars in the range $m_V = 9$ to 12 — for the dependence of galactic rotational velocities upon distance from the Sun is quite marked. At a distance of 1500 pc from the Sun, we find $V_R \sim +20$ km/sec and at 3000 pc we have $V_R \sim +30$ km/sec, the precise figures depending upon the model of galactic rotation that is assumed.

$228° < l^{II} < 247°$

The association I Puppis ($l^{II} = 245°$) falls within this sector. It has been made the subject of special studies at Mount Stromlo Observatory. The Tonantzintla lists (Münch 1954) show here large numbers of OB stars, with a marked concentration near $l^{II} = 245°$, $b^{II} = -1°$. A special list was prepared of 10 OB stars between $\alpha = 7^h50^m$ and 7^h57^m, $\delta = -27°40'$ and $-28°16'$ (1960). B. J. and P. F. Bok have obtained *UBV* colours and magnitudes for these stars, principally using the 26-inch reflector at Mount Bingar. J. A. Graham has measured Hβ indices for these same stars with the Strömgren photometer attached to the 30-inch or 50-inch reflectors at Mount Stromlo, and B. J. Bok, H. Gollnow, and M. Mowat have measured radial velocities for a few of the stars, as a test program for the nebular spectrograph on the 74-inch reflector. Two of the stars appeared to be emission-line objects, not suitable for Hβ photometry, and another was found to be an A-type foreground star. The remaining seven stars are at a mean distance, according to Hβ photometry, of 5400 pc from the Sun (standard deviation $\pm$ 800 pc), with the overlying obscuration amounting to $A_V = 1^m.5$, which is quite a small absorption for such a large distance.

The stellar radial velocity data provide excellent support for the surprisingly large assigned distance for the I Puppis association. With the Stromlo nebular spectrograph, we have obtained radial velocity plates for five stars in the I Puppis association. Preliminary measurements of the 10 available plates by Miss Mowat yield radial velocities of respectively +75 (3), +81 (1), +85 (3), +59 (1), and +76 (2) km/sec, the numbers in brackets showing the number of plates available for each star. The average value, uncorrected for solar motion, is +77 km/sec, and after correction to the local standard of rest, the average is +59 km/sec. The corresponding distance is 4300 pc, the precise value depending upon the model for the rotational velocities in the Galaxy that is used.

An HI profile available from the Parkes radio telescope (F. J. Kerr) is shown in Figure 1. It shows that there is much neutral hydrogen in the region of I Puppis and in the precise velocity range defined by the OB stars, +50 to +100 km/sec. All told, there is for $l^{II} = 245°$, $b^{II} = -1°$, little doubt of the presence of a spiral feature at a distance of the order of 4000 to 5000 pc from the Sun. We note that the assigned distance agrees well with that of 4200 pc for I Puppis given by Markarian and listed by Schmidt (1958).

There are also several nearby features. The most striking is probably the galactic cluster NGC 2362, with the brilliant central star, τ Canis Majoris, which is at a distance of 1600 pc from the Sun. In this sector, there are many 21-cm features within

2000 pc of the Sun, and there seems to be a spur extending from 3000 to 4000 pc from the Sun.

R. J. Davis (1959) has studied this sector in great detail. He finds evidence for HI associated with NGC 2362 and with the association II Puppis, both within 2000 pc of the Sun, but urges the use of larger antennae for the proper study of the HI associated with the associations and with I Puppis. His HI profiles for the I Puppis regions agree with the Parkes profile in showing that there is much HI in the velocity range +50 to +100 km/sec, that is, at estimated distances between 3500 and 6000 pc from the Sun.

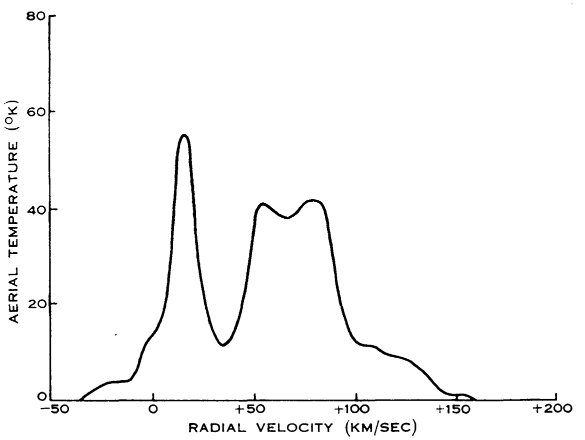

Fig. 1.—H-line profile from Parkes telescope. $l^{II} = 245^{\circ}\!.0$; $b^{II} = 0^{\circ}\!.0$.

The picture of the spiral structure that is obtained for this sector agrees with that shown in Figure 1 of an earlier paper (Bok 1959), where the "Vela spur" is shown in the range $210° < l^{I} < 220°$, to which corresponds $243° < l^{II} < 253°$. Apparently, this spur would be better named the "Vela-Puppis spur".

$247° < l^{II} < 275°$

The nearby Gum nebula ($d \sim 175$ pc) dominates this field. There are associated strong features at 1400 Mc/s in the radio continuum (Mathewson, Healey, and Rome 1962) and the 21-cm profiles show the presence of neutral atomic hydrogen relatively near the Sun. We note that the cluster IC 2391, at a distance of about 160 pc, falls within the section. The optically observed HII regions are, with one exception, at distances no larger than 600 pc, the distant one ($l^{II} = 254°$) being at about 1200 pc. Mills (1959) has a "spiral edge" at $l^{II} = 265°$ (3·5 m), but I know of no optical evidence to support the hypothesis that we are observing here along the edge of a spiral arm. The "extended maximum" observed by Mills may well mark the inner edge of the Vela–Puppis spur. This whole section is obviously in need of much further study by optical and radio methods. Colours and magnitudes for early-type stars have recently been obtained for the section by A. G. Velghe at Boyden Observatory, but the analysis is not yet complete. In addition to optical work on colours, magnitudes, and Hβ indices for early-type stars, we must stress the need for optical polarization work and for radial velocity measurements. At these longitudes, the radial velocity effects caused by the rotation of the Galaxy vary nicely with distance from the Sun and one can hence hope to obtain firm distance estimates for the more remote features.

$275° < l^{II} < 297°$

This sector lies between the obscured edge (in Vela) of the Carina–Crux–Centaurus concentration and the Southern Coalsack. Optically, the region is dominated by the η Carinae nebula and there are many other striking clusters and emission nebulae in this range of longitude, notably the distant OB clusters NGC 3293 (Feast 1958, 2600 pc) and NGC 3766 (Sher 1962, 1900 pc), and the distant clusters and OB groupings associated with the η Carinae nebula and IC 2944. There are also several nearby clusters, mostly of stars with spectral classes later than B2, notably NGC 3532 (Koelbloed 1959, 430 pc) and IC 2602 (Whiteoak 1961, 155 pc). The features in the radio continuum at 1440 Mc/s (Mathewson, Healey, and Rome 1962) are largely of thermal origin and most of these are readily identified with conspicuous emission regions, the η Carinae nebula, NGC 3103, NGC 3603, IC 2872, and IC 2944.

The earlier estimate for the distance to the η Carinae nebula and associated OB groupings (Bok and van Wijk 1952, 1500 pc) seems to have been too small. More recent values by Hoffleit (1956), Graham (unpublished), and Faulkner (1963) suggest an average distance to the "spiral knot" of the order of 2500 pc. The presence of at least one dozen OB stars with distances (according to Hoffleit and Graham) in excess of 3000 pc seems established. Colour and magnitude studies for a field centred upon GL Carinae yield one OB grouping for which the Hβ indices (Graham) suggest an average distance of 3500 pc. It is the region immediately surrounding the OB cluster NGC 3572. Several OB stars in this part of the sky are probably as distant as 5000 pc. There is great variety in the absorption characteristics of this section — with one of the clearest patches centred upon Selected Area 193, where B. J. and P. F. Bok and J. M. Basinski find (unpublished) $A_V = 1^{m}\!.2$ at 3500 pc.

The *absence* of O to B2 stars within 1000 pc of the Sun is most striking. For the range $\alpha = 10^h$ to 12^h, $\delta = -55°$ to $-65°$, only three of the eight stars with known distances and brighter than $m_V = 7 \cdot 0$ are possibly within 1000 pc of the Sun. One of these, θ Carinae, is associated with the cluster IC 2602, which represents, for this section, the only apparently young grouping close to the Sun. According to Whiteoak (1961), its distance is 155 pc and its probable age is of the order of 10^7 years. This paucity of OB stars within 1000 pc of the Sun is in marked contrast to their high density per unit volume at 1500 to 3000 pc from the Sun.

We note, furthermore, that the density per unit volume is very high for the B8 to A0 stars within 1000 pc of the Sun. According to Figure 7 of an article by Bok (1956), the numbers of B8 to A0 stars per 1000 pc^3 increase for a section of the Milky Way centred upon Selected Area 193, from $0 \cdot 08$ near the Sun to $0 \cdot 32$ at 1000 pc from the Sun. I know of no higher concentration of B8 to A0 stars than the one at 1000 pc from the Sun in Carina–Crux–Centaurus. Apparently the great concentrations of B8 to A0 stars are not necessarily regions of high concentration of O to B2 stars. This particular concentration of B8 to A0 stars is probably our best nearby sample of a "fossil spiral feature". There is apparently little or no associated interstellar gas and cosmic dust.

Optically, there is every indication that, in this sector of the Milky Way, we are looking tangentially along a spiral feature that is well traced for distances between 1000 and 4000 pc from the Sun and that contains a magnificent "spiral knot" at about 2500 pc from the Sun.

The 21-cm picture is here far from simple. The profiles are difficult to interpret because of the poor distance resolution in radial velocity according to distance from the Sun. The results of Kerr (1962) suggest that we are looking along a spiral arm at least for $280° < l^{II} < 295°$, but the whole 21-cm situation needs to be clarified.

$297° < l^{II} < 325°$

According to Kerr's results, we are looking in this sector mostly in depth along the Sagittarius spiral arm, notably so for the interval $310° < l^{II} < 317°$, with HI concentrations shown for the entire range 500 to 6000 pc from the Sun. The result is based upon Kerr's model of velocity distribution *with* expansion. On the basis of the Leiden model of distribution of circular velocity (Oort, Kerr, and Westerhout 1958), we have a thin cigar-shaped feature pointing away from the Sun for $310° < l^{II} < 315°$ to a distance of about 2500 pc, which is then followed by a void. Neither result appears to be in agreement with the optical picture. The I Crucis association and its associated nebulosity (Rodgers, Campbell, and Whiteoak 1960), at a distance of approximately 2000 pc from the Sun, are at one edge of the sector (near $l^{II} = 297°$). Optically, the region is characterized principally by small and obviously rather distant HII regions, strung like beads of small pearls upon the galactic equator. Considerable effort has been made at Mount Stromlo Observatory to obtain distances for the OB stars in this sector of the Milky Way, especially the central section $310° < l^{II} < 317°$. Unpublished colour studies by B. J. and P. F. Bok and R. van der Borght for OB stars found by A. W. Rodgers and J. B. Whiteoak, together with Hβ work by J. A. Graham, show that the majority of the OB stars are at an average distance of 1800 pc from the Sun, with an overlying absorption of $1\overset{m}{.}5$ to $2\overset{m}{.}0$. There are in this section close to 20 HII regions, mostly faint and of small angular size, all presumably at about 2000 pc from the Sun (Rodgers, Campbell, and Whiteoak 1960). Graham has suggested that there may also be OB stars at distances greater than 2000 pc from the Sun, but this remains to be seen. There is, however, no evidence for the presence of Extreme Population I objects closer than 1500 pc from the Sun. The optical results give every indication that in this section we are looking *across* a spiral feature, a conclusion that is strengthened by the beautiful alignment of optical polarization vectors in this section found by Smith (1956). I recently took a series of Uppsala Schmidt plates using different emulsions and colour filters for the purpose of studying the general aspect of the sector. The only marked evidence of nebulosity is near $l^{II} = 314°$ (half-way between α and β Centauri). It is No. 85 in the Catalogue by Rodgers, Campbell, and Whiteoak (1960) and has associated dark nebulosity. Radial velocity measurements for the critical group of OB stars are very much desired and will be undertaken at Mount Stromlo Observatory, hopefully this year. We note that G. Lyngå of Lund Observatory is engaged upon an extensive study of galactic clusters in this sector.

$325° < l^{II} < 355°$

In contrast to the sector that we have just described and analysed, we find here abundant Hα emission, indicative of the presence of large HII regions and many O and early B stars. For the interval of galactic longitude $325° < l^{II} < 345°$, the resolution in radial velocity with respect to distance is a good one and hence we can assign fairly reliable distances to the HI concentrations found by 21-cm techniques.

Three spiral features affect the appearance of this sector of the Milky Way. The principal one is the Sagittarius arm, which is marked clearly by a string of HII regions and related OB stars and associations. Its edge seems to be near $l^{II} = 325°$, where we find an OB concentration and associated nebulosity. According to J. A. Graham, and B. J. and P. F. Bok, there are two concentrations of early-type stars near $l^{II} = 327°$, one mostly of later B stars near $b^{II} = +2°$ and at a distance of 870 ± 170 pc, the other of early B stars near $b^{II} = -2°$ and at 2400 ± 200 pc. The small dispersion in distance moduli suggests that the latter group is a unit association. This grouping was noted by J. B. Whiteoak in his doctoral thesis and G. Lyngå has classed it as an association on the basis of his unpublished survey from objective prism plates made with the Uppsala Schmidt telescope. He comments on the supergiant character of several of the OB stars. Lyngå is studying a number of galactic clusters at these longitudes.

NGC 6231 (I Scorpio — distance 1900 pc) at $l^{II} = 343°$ is another concentration in the Sagittarius arm. Surprisingly it is not a strong feature in the radio HII picture (Mathewson, Healey, and Rome 1962). NGC 6193 ($l^{II} = 336°$), at a distance of about 1300 pc, is still another concentration, and its presence is indicated in the HII radio contours. The cluster NGC 6067, near $l^{II} = 330°$, fits nicely into this picture. A recent distance determination by Thackeray, Wesselink, and Harding (1962) places it at a distance of 2100 pc.

In addition, there are certain features at the inner boundary of the Carina–Cygnus arm, notably the II Scorpio association, at an average distance of only 175 pc from the Sun, and the Ophiuchus dark nebula complex. According to the basic spiral diagram assumed here for the purpose of discussion (Bok 1959), the II Scorpio association — along with the Southern Coalsack — mark the inner section of the Carina–Cygnus arm, from which protrude the Vela–Puppis spur and the Orion spur.

We have no new material for the third spiral feature, the Norma–Scutum arm of Thackeray (1956). However, Graham points out that two of Thackeray's stars, HD 142468 and 142565, are in our section near $l^{II} = 327°$. The first of these has been included in our colour-magnitude Hβ survey and has a photometric distance of 2400 pc. Furthermore, the radial velocities of these two stars, -40 and -25 km/sec, seem to place them at distances comparable to that of NGC 6067, which, at 2100 pc, has a mean radial velocity of -43 km/sec (Thackeray, Wesselink, and Harding 1962).

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Discussion

Becker: I am very much impressed by the powerful way you attack the problem of galactic structure in the southern hemisphere by combining all possible methods. I have just one question. I have the feeling that the Cygnus–Carina arm shows a rather strong curvature, the centre of which is at a distance of only 6 or 7 kpc instead of 9 kpc.

Bok: At the moment we are merely trying to plot as much information as possible, and do not feel tied down to any one model, and we are not at present looking at very detailed shapes. We would like to provide anchor points for the radio astronomers.

I was rather disturbed by the run of the original Morgan arms. The tilt of the arms seemed rather great and a circular shape may be more reasonable for both optical and radio data.

Lindblad: I wish to express my great admiration for the magnificent survey of the Southern Milky Way. I am especially interested in certain details, spurs, and interconnecting links, and wish to emphasize the great complication of a spiral arm. It is also of great interest how stars of somewhat later types are connected with the basic structure of OB stars and interstellar gas.

Bok: A stars are particularly abundant in Carina. One objection to the Cygnus–Carina arm is the gap of 1000 pc in Carina. There are many A stars but no OB out to 1000 pc. From 1500 pc to 3500 pc there is a considerable concentration of OB stars.

Lindblad: What distance do you get for the Norma cloud? We had 1500 pc.

Bok: From his work with Hβ indices Mr. Graham gets 2400 pc.

Westerlund: A recent paper by M. S. Roberts (*A.J.* **67**: 79–85 (1962)) suggests that the Wolf–Rayet stars define a 4-kpc–long portion of a spiral arm from Cygnus through the solar neighbourhood towards Carina.

Courtès: At longitude 330° the radial velocity of the HII region obtained by optical interferometry confirms the two spiral arms described by Professor Bok. But we need more information about the existing stars in order to see if the selection of velocities in two spiral arms is in good agreement with the photometric distance separation of the stars.

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Blaauw: With reference to the rich A-type population at 800–1000 pc which Professor Bok pointed out: if we photographed the Galaxy from a distance in the blue, would this concentration contribute so much to the light that one would see it in the spiral features, leading to a different picture of the system than that of the OB stars?

Bok: This is quite possible, but *UBV* photometry would make it possible to distinguish between concentrations of A stars and OB stars.

Blaauw: This may well affect our interpretation of other galaxies.

Graham: I would like to emphasize the great amount of work that needs to be done on the faint OB stars in the Vela–Puppis region. Professor Bok has already pointed out the great distances to which we see in this direction because of the comparatively low absorption. Some hundreds of OB stars in these fields have been picked up by the Tonantzintla workers, and we at Stromlo have observed no more than a dozen of these. I feel that more extensive studies in these regions would be very useful.

37. RADIAL VELOCITIES AS A GUIDE TO SPIRAL STRUCTURE

A. D. Thackeray
Radcliffe Observatory

Four main methods of delineating spiral structure in the Galaxy have been developed in the past 10 years.

(1) Morgan and associates used spectroscopic distances of clusters and associations, particularly those in HII regions, and showed that the further set was strung along what is now known as the Perseus arm.

(2) The Leiden and Sydney workers extended the survey to very great distances through the 21-cm observations. Here of course the distance scale depends intimately on a velocity model for the Galaxy.

(3) Münch's (1957) studies of double and multiple interstellar lines gave strong support to the existence of the Perseus arm, with CaII and NaI concentrated in the arm.

(4) Courtès' interferometric velocities of diffuse nebulae is an optical analogue of the 21-cm approach, with a bias towards the nearer nebulae on account of the absorption at optical wavelengths.

Münch's approach has advantages in the inner portion of the Galaxy since the light-path is limited by a distant star whose distance may be determined, while the 21-cm observations are unlimited in depth, and distance determination can easily be subject to serious ambiguity.

The Radcliffe coudé spectrograph, operating at 6·8 and 15·6 Å/mm, has been used for investigating structure in the H and K lines of distant OB stars. Thackeray (1956) already reported (before the first publication of the Sydney 21-cm results) a few spectacular cases of doubling (particularly in Norma) discovered with the Cassegrain spectrograph operating at 19 Å/mm at K. These results have been expanded and refined with the coudé spectrograph, but progress is necessarily slow on account of the difficulty of detecting strategic stars.

Figure 1 shows eight cases of double CaII between $l^{II} = 328°$ and 27°. The low-velocity components correspond of course to gas close to the Sun. The high-velocity components (usually somewhat weaker) lie along the dashed line which

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