General Catalogue of Variable Stars down to photographic magnitude 15, have been classified.

The current investigations deal with four fields in the Milky Way, namely, regions at longitude 33°, 41°, 55°, and 354° (the Scutum cloud). These are being studied by Westerlund, Velghe, McCarthy, and Albers, respectively. The studies include classifications of all stars between spectral types M2 and M10 down to 13th magnitude infra-red, and determinations of the mean interstellar absorption in each region.

In addition to this, two regions at higher latitudes are being studied, one at $l = 43°$ and extending up to $b = 22°$, the other at the longitude of the galactic centre and extending up to $b = 40°$. Some details concerning the work on the latter region have been given in a previous section of this report (p. 29).

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(F) SPIRAL STRUCTURE

Investigations of the structural form of the Galaxy are being actively carried on at a number of observatories. The portion of the Galaxy surveyed has been markedly increased since the time of the first Symposium for Co-ordination of Galactic Research. Many new results have been obtained, particularly in the southern hemisphere; additional observing programs are in the planning stage. New observational techniques for some problems have been found and are under investigation.

(1) *The 21-cm radiation of neutral hydrogen*

General survey of spiral structure as indicated by neutral hydrogen

In principle, the large-scale distribution of neutral hydrogen throughout the entire Galaxy can be observed in the 21-cm radiation of the neutral hydrogen atom. In practice, certain regions (sectors in the direction of the galactic center and anti-center) must be excluded because in them galactic rotation effects become very small or zero. Much useful information will be found in I.A.U. Symposium No. 4, *Radio Astronomy* [1].

In surveying the present status of 21-cm results on spiral structure, Westerhout first dealt at length with practical limitations on the accuracy attainable in the description of the hydrogen distribution. Antennas used for 21-cm spiral structure surveys generally have had small angular resolution. The Dutch 7.5-meter reflector, with which most of the surveys of the Milky Way have been made, had an elliptical antenna pattern of essentially gaussian form with half-widths of $2\overset{\circ}{.}78$ and $1\overset{\circ}{.}85$. A large volume of space was included in each pointing of the antenna; many hydrogen clouds were observed simultaneously. The 21-cm radiation received is spread in frequency by the differential galactic rotation of the clouds and by the random motion of the clouds. The observed line profile from a concentration of hydrogen clouds in a spiral arm generally has a broad hump with indications of small-scale internal structure.

To estimate the space density of hydrogen from such a profile, one must first statistically correct [2] the profile for random cloud velocities. Radio observations suggest a gaussian distribution of random velocities; optical observations [3] indicate an exponential distribution of velocities. The radio results may arise from an exponential distribution of velocities of the clouds plus a gaussian distribution originating in temperature broadening and turbulence in individual clouds. Little information on variation of the cloud velocity distribution in different parts of the Galaxy exists. For correction of the 21-cm line profiles it has been assumed that the velocity distribution is approximately gaussian with a dispersion of 15 km/sec at $R = 2$ kpc; the dispersion of random velocities is assumed to decrease to 6 km/sec for $R > 8$ kpc. Small changes in numerical parameters and in the reduction procedure produce large changes in the ratio of the space density of hydrogen in and between the arms. Inter-arm densities are particularly uncertain; they are especially sensitive to the corrections for random velocities.

Estimation of hydrogen density also requires that the gas temperature be known. In three galactic longitudes at distances within two or three kpc from the sun, large optical depths are reached; a harmonic mean temperature of 125° K has been found in these areas [4]. Lack of any additional information on gas temperature has necessitated adoption of the hypothesis that gas temperature is constant throughout space and of the value stated. This assumption must be regarded as a crude one. The temperature might well increase toward the galactic center; it might be higher in the arm than in the inter-arm region, or in the vicinity of groups of hot stars.

The rotation law of the Galaxy as a function of distance, R, from the galactic center must be known if a distance is to be assigned to a hydrogen

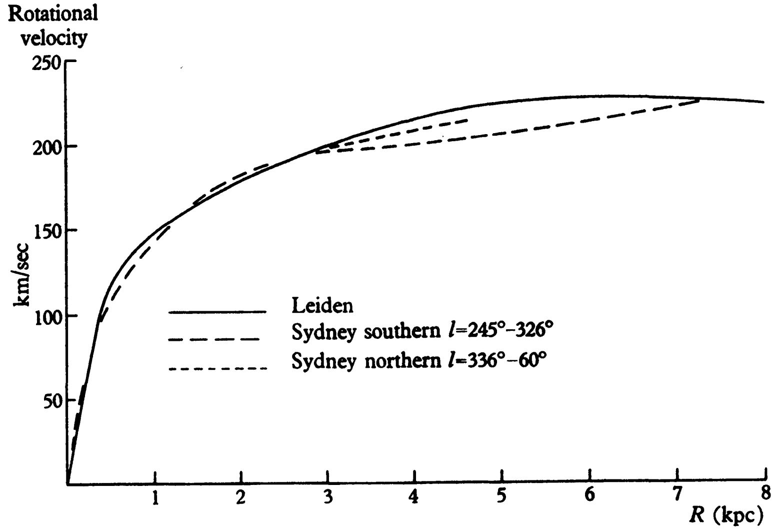

Fig. 1. Comparison of Sydney and Leiden galactic rotation curves.

cloud observed in a specified direction and moving with a measured radial velocity. In the inner portion of the Galaxy the rotation curve can, with some accuracy, be established from the 21-cm observations themselves. The agreement of the rotation curve derived from observation in the ranges $l = 245°$ to $326°$ at Sydney [5] and $l = 336°$ to $60°$ at Leiden [6] is only fair. The distance scale is known only with the same accuracy as the distance to the galactic center. Fig. 1 shows the agreement of the northern and southern observations. On the basis of a rotation curve drawn through the Leiden observations (fig. 1), and utilizing optical data of various kinds, Schmidt [7] derived the mass distribution in the Galaxy. From this mass model the rotation curve for the outer part of the Galaxy was derived; circular motion was assumed throughout. Large uncertainties in the numerical values of the parameters A, B, R_0, V_0, and the mass in model

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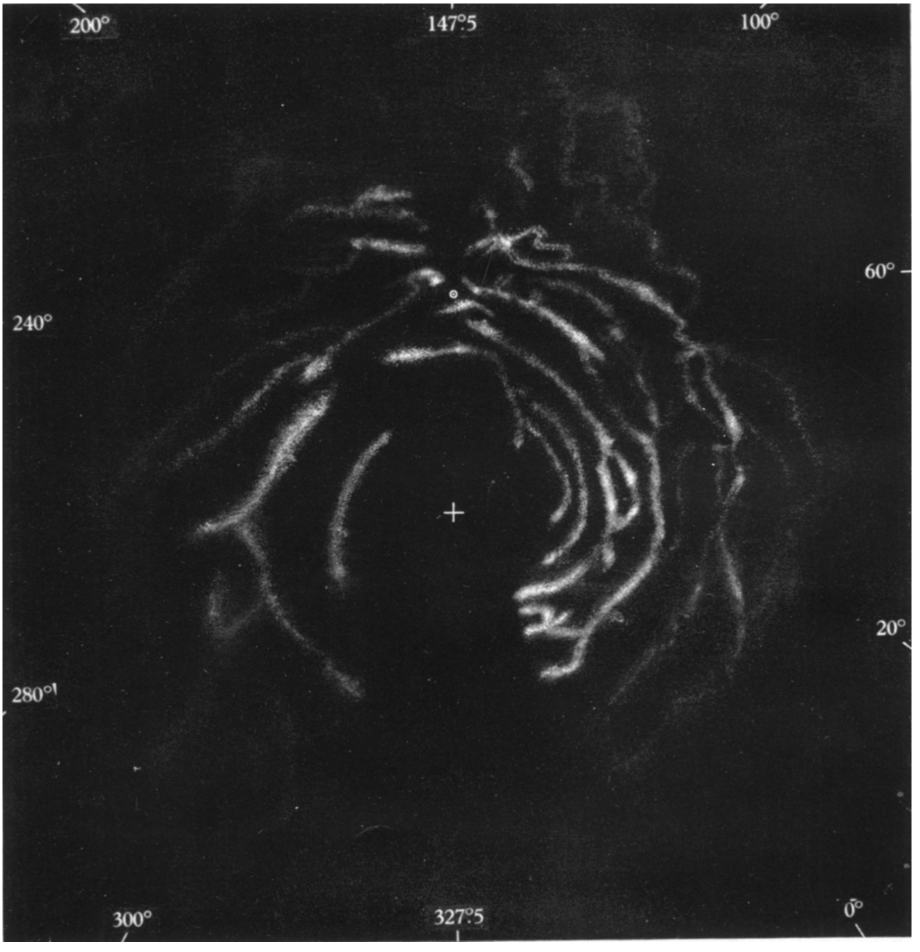

Fig. 2. Spiral structure of the Galaxy as shown by Leiden observations and by Sydney observations.

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produce large uncertainties in the distances derived for the hydrogen clouds.

The reduction of the 21-cm observations is thus subject to numerous uncertainties; details of the derived hydrogen distribution are unreliable. However, the broad features of the picture of spiral structure resulting from these observations are well established. Results obtained from overlapping observations at Leiden [8] and Sydney [9] show very satisfactory agreement. Fig. 2 illustrates the picture of spiral structure derived from the combined Leiden and Sydney observations.

Lindblad [10] spoke about the hypothesis of circular orbits utilized in the interpretation of the 21-cm observations. He drew attention to what he termed 'dispersion orbits' in the Galaxy. These are defined as the orbits that a cloud of free particles—the members of a stellar association, for example—pursue as the group is disrupted by differential galactic rotation. He expressed the belief that a close relation must exist between such orbits and spiral arms. If κ represents the frequency of oscillation along the radius vector in a galactic orbit that differs little from a circle, Lindblad asserts that at those R values for which $n = \frac{d\kappa}{d\omega} = 1$ or 2 the dispersion orbits are closed. For other values of n the orbits are more complicated figures and are not closed. At those R values where closed dispersion orbits occur, permanent, slightly elongated rings of material are to be expected. These concentrations of matter Lindblad identifies with spiral arms. From the galactic rotation curve derived at Leiden, Lindblad has found $n = 2$ at $R = 4{\cdot}3$, $4{\cdot}7$, $5{\cdot}3$, $6{\cdot}5$ and $8{\cdot}3$ kpc, and $n = 1$ at $10{\cdot}5$ and 13 kpc. These values are closely similar to those at which the Leiden observers find concentrations of hydrogen.

The most probable shape of a dispersion orbit is circular, though in nature, deviations may be expected. Fig. 3*a* shows a group of hypothetical dispersion orbits suggested by the picture of spiral structure in the Galaxy. The true arms of the Galaxy are represented by the concentration of material in these orbits. Motion in these orbits is not purely circular; there is a radial component as well. The precise motion in the orbit is known from the properties of the galactic model adopted for the calculation. Fig. 3*b* displays the form of the spiral arms that would be deducted if radial velocities of matter in the arms (Fig. 3*a*) were observed from the sun and if distances were derived for that matter under the assumption of circular motion. Great distortion of the true picture (Fig. 3*a*) results from such treatment. Lindblad drew attention to the fact that the structure pictured in Fig. 3*b* bears some resemblance to the picture of spiral arms derived from the 21-cm observations (fig. 2). The conclusion to be drawn is clear; the possibility of an alternative interpretation of the arm pattern on the basis of non-circular motion should not be overlooked.

Considerable discussion revolved around the question of how to test empirically the commonly accepted hypotheses of circular motion.

Lindblad suggested a simple test might be made by looking for velocity deviations in the center and anti-center regions, where, on the hypothesis of circular motion, the velocity should be zero. Westerhout reported that in the anti-center regions, local velocity deviations up to 30 km/sec are found in the hydrogen clouds. In the direction of the galactic center a concentra-

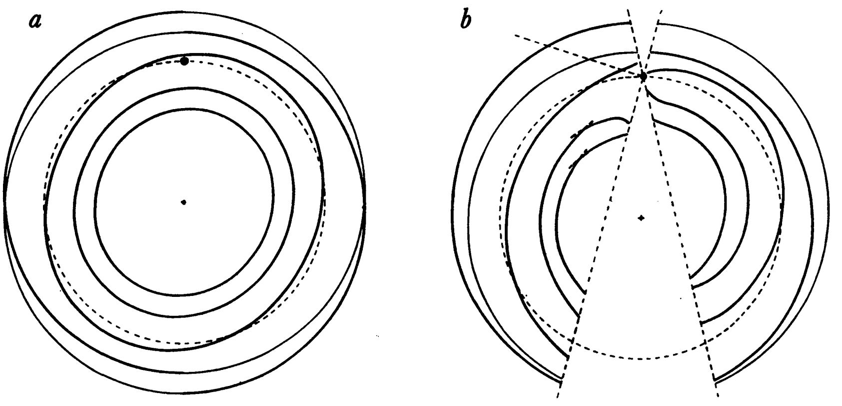

Fig. 3*a*. Dispersion orbits.
Fig. 3*b*. 'Apparent' structure for the same orbits shown in Fig. 3*a* deduced from radial velocities relative to the circular motion at the sun when these are interpreted as due to circular motion.

tion of hydrogen approximately 2° wide and more than 15° long is observed to be moving radially away from the galactic center. Further work on the question of velocity deviations is highly desirable.

An indirect approach to the question of circular motion might be made by testing the similarity of (*a*) the form of spiral structure derived by using radial velocities and the circular orbit hypotheses to determine distances, and (*b*) the form of spiral structure derived by some other completely independent method.

The hydrogen layer appears to be of rather constant thickness. Kerr proposed that the forms of the hydrogen spiral arms be based on distances derived from high resolution measurements of their angular thickness. Oort was not optimistic about the successful application of the method. Efforts at Leiden to separate nearby and distant spiral arms on the basis of this principle were not entirely satisfactory. Westerhout pointed out that in the outer parts of the Galaxy the thickness of the hydrogen layer appeared less constant than in the inner parts of the Galaxy. Here it would appear well to point out, however, that present estimates of the thickness of the hydrogen layer depend upon the velocity model and involve the assumption of circular motion.

According to Oort a satisfactory test for non-circular motion could be made by study of the galactic clusters. Photometric distances of the clusters could be found. Radial velocities could be measured and departures from a motion field circular about the galactic centre could be determined. A rather large number of clusters would be needed. The calibration of the absolute magnitudes and intrinsic colours to be used in the photometric distance scale is an important part of this approach to the problem.

Other galactic parameters, R_0 and V_0, also appear in the calculation of distances from galactic rotation effects. Weaver [11] stated that the values of V_0 presently derived by different methods are inconsistent. Investigation of the cause of the inconsistency is needed. The product $V_0 = R_0 \omega_0$ with $R_0 = 8{\cdot}2$ kpc and $\omega_0 = 26{\cdot}4$ gives 216 km/sec. The estimate of V_0 derived from the solar motion determined by Humason and Wahlquist from the local group of extra-galactic nebulae is 260 km/sec. The value includes the component of peculiar motion of the Galaxy in the direction of rotation; however, it indicated $V_0 > 200$ km/sec. Fricke used the high-velocity stars to calibrate the Bottlinger diagram. He found $V_0 = 276$ km/sec. Mayall used radial velocities of 50 globular clusters to derive $V_0 = 200$ km/sec. This fundamental determination underestimates V_0 by the galactic rotation of the system of globular clusters. Schmidt estimates that the average rotational velocity of the globular cluster system is 80 km/sec. The product $R_0 \omega_0$ appears to underestimate V_0. Arguments can be given to show that ω_0 cannot be far wrong; it is likely that $R_0 = 8{\cdot}2$ kpc is an underestimate. Even if motion is circular in the Galaxy, errors in the distance scale caused by an error in R_0 will seriously distort the picture of spiral structure. A better determination of the numerical value of R_0 is greatly needed.

Oort remarked that little weight can be attached to an estimate of V_0 derived from members of the local group of nebulae. The peculiar motion of the Galaxy is so large that it vitiates the result.

Tests of the circularity of galactic motions, the determination of spiral arms by methods independent of galactic rotation, and the galactic distance scale remain problems of high priority in galactic studies. Much work needs to be done on the random velocity distribution of interstellar material, and on the problem of variation of the temperature of neutral hydrogen throughout the Galaxy.

The z-distribution of neutral hydrogen

Kerr, Hindman, and Carpenter [12] have utilized observations of the 21-cm radiation of neutral hydrogen to investigate the z-distribution of the hydrogen. They found the gas layer to be thin, with an approximately constant thickness of 200–250 pc between half-density points. In the inner portion of the Galaxy the surface formed by all maximum density points is very flat. Deviations from an average plane (the 'principal plane' of the Galaxy) are of the order ± 35 pc. In the outer parts of the Galaxy, the surface formed by the points of maximum density is systematically distorted [13]. The effect is large scale, with little relation to the spiral pattern. Maximum distortion occurs in the direction toward and away from the Large Magellanic Cloud. The effect suggests a gravitational tide, but is much too large for a simple gravitational explanation of this nature if the mass of the Cloud is of the order of magnitude generally assumed. The effect may involve forces other than gravitation; it may be an after-effect of some earlier event in the history of the Galaxy. No decisions on such questions now seem possible.

It is of interest to note that the mass of M 32, estimated under the assumption that it gravitationally produces the distortion in M 31, is also unexpectedly large [14]. Other systems provide evidence that there are large interactions between galaxies. NGC 4565, an edge-on spiral, shows edge distortion similar to that observed in the Galaxy.

Oort expressed the opinion that the deviations in the z-direction observed in the outer portion of the Galaxy represent the remnant of some original structural feature of the Galaxy. The idea that they are caused by the Magellanic Clouds is not attractive. Blaauw questioned whether the strong departures from a plane in the outer parts of the Galaxy might not be in those regions where the period of oscillation in z is equal to the rotation period. In the inner region of the Galaxy the two periods may differ. The suggestion is an interesting one. However, the equality of period pictured might be the case only at rather large R values. Kerr remarked that the symmetry stretches over a rather long range in R and therefore the explanation involving the Magellanic Clouds appeared rather plausible to the Sydney group.

The galactic pole determined from observations of neutral hydrogen

The highly flattened hydrogen sub-system in the inner portion of the Galaxy provides the data for an accurate determination of the galactic pole. Two determinations have been made from the 21-cm observations.

At Leiden [15] a solution has been made on the basis of observations of the whole region inside the sun's circle on the northern side of the galactic center. The Sydney solution is derived from observations of the 'tangential points' on both sides of the galactic center. The sources of uncertainty differ in the two solutions shown in Table 4, but the derived values are in satisfactory agreement. Results very similar to those in Table 4 have been derived from the Cepheid variable stars [16] and from recent high resolution surveys of the radio continuum.

Table 4. *Position of the galactic pole derived from 21-cm observations*

	Galactic longitude	Galactic latitude	Sun's distance from galactic plane (in pc)
Leiden	332° ± 8° (p.e.)	88°.63 ± 0°.07 (p.e.)	+23 ± 10 (p.e.)
Sydney (preliminary)	349° ± 5°	88°.34 ± 0°.25	0 ± 32

The 21-cm radiation appears to fix the position of the galactic pole with high precision. However, the hydrogen represents a small percentage of the mass of the Galaxy. Blaauw called attention to the desirability of deriving the position of the pole from a very different kind of population—a disk population, but one that is not young, and that is likely to be symmetrically distributed. Objects found in the Warner and Swasey Observatory infra-red surveys [17] might be suitable for this purpose. It was agreed that a study of the distribution of such objects would provide a valuable check on the position of the pole derived from hydrogen. But it will be difficult to establish the pole with adequate accuracy, one- or two-tenths of a degree, from study of such a population.

Parenago pointed out that a powerful condition could be imposed on any solution for the pole if the direction of the galactic center could be fixed from radio or infra-red observations. However, it would be difficult, it was agreed, to fix the direction to the galactic center with high precision.

(2) *Continuous radio radiation*

Oort reviewed the present observational status of the continuous radio radiation as related to structure in the plane of the Galaxy. Three types of such radiation can be distinguished [18].

1. Thermal radiation arising from H II regions.
2. Non-thermal radiation originating in localized radio sources.
3. Non-thermal radiation probably originating in a continuous medium; source unknown, but possibly high energy electrons in interstellar magnetic fields.

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A survey of the thermal component of the continuous radiation provides knowledge of the distribution of ionized hydrogen throughout the Galaxy. However, when observations are made, both the thermal and non-thermal components of radiation are received. Separation of the two components is difficult though, in principle, possible. The thermal component of the radiation varies as ν^{-2}; the non-thermal component varies approximately as $\nu^{-2.6}$. In the non-thermal case the numerical value of the exponent is not accurately known. It varies somewhat with ν. It has been evaluated from studies of discrete sources and from studies of continuous radiation at high galactic latitudes.

It has been found empirically that, at least in the galactic plane, the thermal and non-thermal components of the radiation are of comparable

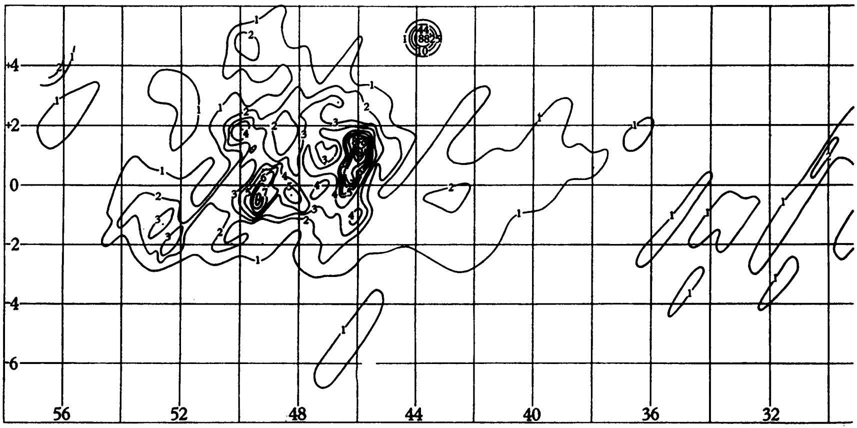

Fig. 4. Intensity-distribution of 22-cm radiation in the Cygnus region.

intensity at a wave-length of 20 cm. Observations at wave-lengths of 20 cm or less should thus show the galactic distribution of ionized hydrogen. Westerhout has utilized the 25-meter radio-telescope at Dwingeloo to complete a 22-cm survey in the latitude range $+6°$ to $-8°$ extending from longitude 320° through 0° to 56°. The half-width of the antenna pattern is of the order one-half degree. An example of the distribution found is shown in the map of the Cygnus region shown in Fig. 4.

A large part of the 22-cm radiation can be explained as thermal radiation from known H II regions. However, optical data are not sufficiently complete to permit a thorough comparison of optical and radio data.

Radio surveys at still shorter wave-lengths are required. At these shorter wave-lengths resolution becomes higher; the relative strength of the thermal component becomes greater. Individual H II regions should be identi-

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fiable over a large part of the Galaxy. The thickness of the ionized hydrogen layer in the Galaxy should be well determined.

At present the most complete radio survey of continuous radiation is that at a wave-length of 50 cm made by Piddington and Trent [19] in Sydney. A large part of the radiation at 50 cm is non-thermal in origin. This is clearly indicated by the fact that, in a direction inclined at a slight angle to the galactic plane, the optical data (which provide a measure of the strength of the thermal component) indicate much less radiation than is actually observed by Piddington and Trent.

Basically, the results of the 50-cm survey resemble those of the 22-cm survey. The picture of spiral structure is well reproduced in both surveys. Since only approximately one-third of the observed 50-cm radiation is thermal in origin, we must conclude that we are here observing non-thermal radiation connected with the spiral arms. Kerr indicated that the spiral-structure pattern is shown in the $3\frac{1}{2}$-meter survey made in Sydney by Mills. This observation strongly supports the hypothesis of non-thermal radiation in the arms.

The non-thermal radiation in the arms could be produced by cosmic-ray electrons moving in interstellar fields. It is probable that such fields are stronger in the arms than outside the arms. As surveys at longer wave-lengths become available, it will be of particular interest to compare in detail the distribution of thermal and non-thermal radiation in the vicinity of the arms, to determine whether the layer in which the non-thermal emission originates may be thicker than the layer from which the thermal radiation comes.

In longer wave-lengths the galactic halo shows strongly. Recent observations [20] indicate that neutral hydrogen clouds of quite high velocity exist in the halo. These clouds are probably far from the galactic plane.

In regard to the third component of continuous radio radiation, the galactic radio sources, little can be said. A number of galactic sources have been identified, but no systematic survey has yet been made. A complete survey of such sources that will yield information on the general physical characteristics and the galactic distribution of such sources remains an important future problem.

Westerhout gave additional information on the occurrence of neutral hydrogen in the halo. Secondary maxima in the 21-cm profiles interpreted as these clouds indicate very low antenna temperatures, of the order of one to one and one-half degrees. They indicate predominantly negative velocities of approximately 40 km/sec, with a maximum velocity of 200 km/sec. The reality of such clouds in the halo needs careful checking.

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Considerable discussion centred on the question of whether the 22-cm survey, say, should be used as a guide in the search for the largest associations and H II regions, or whether such a search should be made completely independently. Oort expressed the view that a survey at 10 cm would be preferable for a guide in such an optical survey. Several radio installations will be capable of making such a survey in the future. Westerhout and Blaauw felt that the 22-cm survey could serve some useful purpose as a guide in an optical search. Westerhout and Kerr indicated that at 22-cm wave-length the galactic ridge does not show over the longitude range approximately 60° through the anti-centre to 260°. A 10-cm survey would probably be even more confined to the region of the galactic center.

(3) *OB star surveys*

Morgan discussed two main topics: (*a*) the importance of continued and expanded observations of O associations; (*b*) means of discovering such associations over great distances.

Morgan pointed out that O associations contain very bright super-giants, objects five to ten magnitudes brighter than exist in clusters such as the Pleiades and Hyades. The statement was illustrated by an H-R diagram [21] of the I Sco association, which has NGC 6231 as its nucleus. It contains many super-giants earlier than B0. Such stellar groups are of great interest from an evolutionary point of view; they also provide a means of delineating spiral structure to very much greater distances than is possible through observance of ordinary galactic clusters. Evolutionary differences between associations will complicate the calibration of the absolute magnitudes of the association stars. However, Morgan believes calibration of the required accuracy can be achieved.

Morgan described several methods for finding O associations:

(*a*) O associations can be discovered in the course of H II surveys [22]. Not all H II regions have their origin in O associations. But those H II regions that are connected with O associations have a characteristic appearance: they almost always appear to have the form of an incomplete circle. The method of finding O associations by the form of their related H II regions fails when the general star field is extremely rich. Even if one employs an interference filter, it is difficult to delineate precisely the regions of emission. Here Courtès' Fabry-Perot method [23] in which interference fringes are superimposed over an unresolved stellar background might prove useful. Not all associations contain stars early enough to ionize the gas in their neighbourhood. These would not be discovered by the H II-region technique.

(*b*) Three-color photometry [24] in wave-length ranges corresponding roughly to U, B, V provides a means of separating super-giants from other stars. Preferably a Schmidt telescope should be used. The three images are taken on one plate; the exposures are of such duration that the different intensities in the ultra-violet of different stars are clearly brought out. The three-color method makes use of the fact that an early-type star, even if reddened, produces a stronger ultra-violet image than an intrinsically red star.

(*c*) An alternative method [25] based essentially on the same principle as the three-color procedure makes use of very small dispersion spectra of 10,000–30,000 Å/mm. Inspection of the energy distribution in these very short spectra permits early-type stars (whether reddened or unreddened) to be separated from intrinsically red stars.

Sandage called attention to the importance of the O associations in the extra-galactic distance-scale problem. Distances of extra-galactic nebulae are derived from the brightest stars in the nebulae. Possibly the most important method of determining the absolute magnitudes of such stars is through study of associations in our own Galaxy.

One aspect of associations displayed in extra-galactic systems so far has not been observed in the Galaxy: super-associations. By this term Baade, who introduced the topic, referred to such objects as the star cloud NGC 206 in the south-preceding arm of the Andromeda nebula. This object, of length about 800 pc, appears to have A stars for its brightest members. In IC 1613 an irregular member of the local group, all blue stars are concentrated in one section of the system. Search for (and subsequent study of) such super-associations in our own Galaxy would be valuable. Heckmann reported that the big Schmidt at Bergedorf was being used for a general spectral survey. The prism, of ultra-violet glass, produces a dispersion of 570 Å/mm at Hγ. The limiting magnitude of the survey is approximately 13·5. At present, only high luminosity stars are being noted. The complete catalog, which will contain co-ordinates and charts, will probably include more than 10,000 objects. From the work done so far, it appears that the O and B stars are not entirely crowded together in small groups; there are OB stars between the groups. Eventually, the program will be extended to fainter stars with the aid of a second prism producing approximately half the dispersion used for this first survey. This second prism will be used at both Bergedorf (with the big Schmidt) and at Bloemfontein (with the ADH Schmidt).

(4) *Cepheid variables and galactic structure*

The classical Cepheid variable stars provide an important source of information on the form and kinematic properties of the Galaxy. However, many of the numerical parameters describing basic physical properties of the Cepheids require improvement before the full usefulness of these stars can be realized. In particular, the zero-point of the period-luminosity relation and the intrinsic colors of the Cepheids are not known with sufficient accuracy. The intrinsic dispersion in the period-luminosity relation is unknown. Even more basically, the question of the uniqueness of the relation needs investigation.

Oosterhoff described the observations and results of the Leiden Southern Station photo-electric program on Cepheids carried on with the Rockefeller Astrograph in the period 1953–56 by Walraven, Muller and Oosterhoff. In all, 182 Cepheids were observed in two colors (yellow and blue). These were mainly southern stars; a few northern Cepheids were included for comparison purposes.

Observations were confined to maximum light except in a few instances in which ephemerides were badly in error. A few standard stars were observed to permit reduction of the instrumental photometric system to the Cape 1953 S system [26]. To assign absolute magnitudes, Oosterhoff employed the period-luminosity relation determined by Shapley [27], with zero-point corrected by $-1{\cdot}7$ magnitudes. This correction, derived from seventeen stars, was applied rather than the value $-1{\cdot}4$ or $-1{\cdot}5$ magnitudes found earlier since previous investigators [28] had made insufficient corrections for interstellar extinction. For intrinsic colors Oosterhoff assumed (*a*) that galactic and Magellanic Cloud Cepheids are identical in properties; (*b*) that, as found by Code [29] and by Feast [30], the spectral types of long-period Cepheids at maximum light range from F5 to early G. He adopted the relation $\text{C.I.}_{\max} = 0{\cdot}01 + 0{\cdot}10 \log P$. For the ratio of total photographic extinction to color excess Oosterhoff adopted the value 3·5, derived from a discussion of published values [31]. The Cepheids were observed at maximum; the period-luminosity relation refers to median magnitude. The observations were corrected to median magnitude by means of a statistical amplitude-period relation: $\text{amp}_{\text{pg}} = 0{\cdot}32 + 0{\cdot}91 \log P$.

Fig. 5 shows the galactic-plane projection of the spatial distribution of population I Cepheids as derived from the Leiden Southern Station observations and the fundamental data described above. Several stars considered to be population II Cepheids on the basis of *z*-height have been omitted. The average *z*-value of the population illustrated in

Fig. 5 is $-23{\cdot}9 \pm 5{\cdot}5$ (m.e.) pc; the z-dispersion of the same population is 65 pc.

Interstellar extinction was found to be very irregular over the sky. All stars together produce a negative correlation between extinction per kpc and distance. In the Carina region there is no correlation between extinction and distance; in the Sagittarius region the correlation is positive. In the directions in which extinction is small, one sees to great distances; where it is large in relatively nearby regions, one sees to small distances. This situation results in the negative correlation observed for all stars.

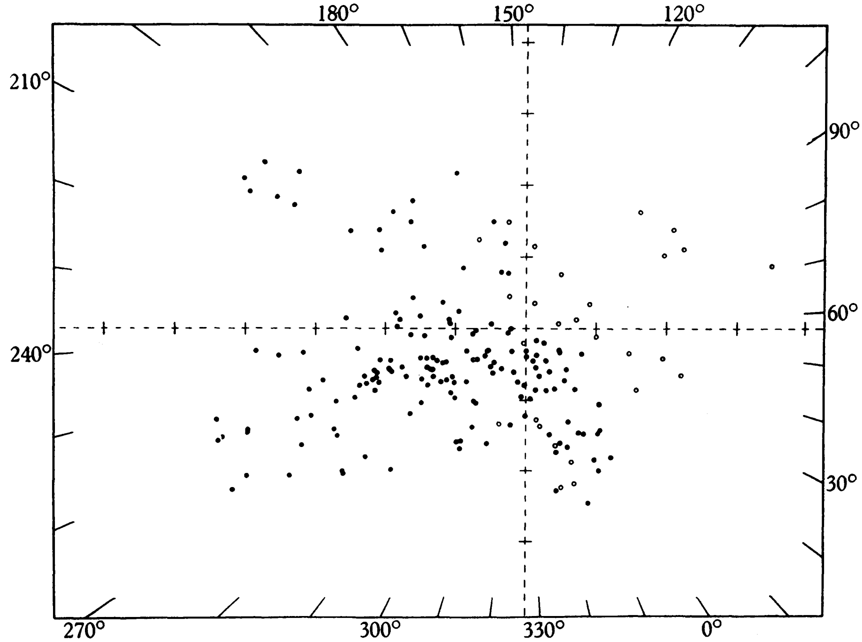

Fig. 5. Distribution of Cepheid variable stars in the galactic plane.

From fifty Cepheids for which radial velocities [32] were available, Oosterhoff found the value of the Oort A-parameter to be $17{\cdot}4 \pm 2{\cdot}1$ (m.e.) km/sec kpc.

In Fig. 5 the OB associations observed by Morgan, Whitford, and Code [33] are indicated by open circles; Cepheids by filled circles. The most distinct feature of the diagram, Oosterhoff said, is the concentration of Cepheids in Carina. This concentration indicates, he stated, that the line of sight falls in the Carina arm for a distance of three or four kpc. He identified this group of stars with the neutral hydrogen concentration shown in Fig. 2. Oosterhoff indicated that the Carina arm delineated by the

Cepheids can be followed to the neighborhood of the sun. Many of the Cepheids observed are in the direction of Sagittarius, but they do not belong to the Sagittarius arm. The Leiden Station observations did not extend beyond $l = 20°$, hence Oosterhoff could not trace the Carina arm farther. He suggested that the associations I Vul and I, II, III Cyg form a continuation of this arm. Oosterhoff assigned to the Sagittarius arm what he termed a second concentration of Cepheids lying in the longitude-range 200° to 10° and at a distance of 1·5–2 kpc. He called attention to the existence of seven OB associations involved with this more distant group of Cepheids. Only one association is found in the nearer Carina arm. A number of Cepheids are found in longitude 236°; the Sydney group finds no hydrogen concentration here. Oosterhoff suggested that these Cepheids may belong to the Orion arm.

The distance limit to which Cepheids are observed is very irregular with longitude. Many Cepheids must remain to be discovered.

The importance attributed to the Cepheids as galactic probes was indicated by the extent of the discussion that followed Oosterhoff's communication. Blaauw made the important point that the precision with which the population I Cepheids delineated spiral arms might depend upon the periods of the variables investigated. If period is an indicator of the evolutionary stage of the Cepheid (shorter periods being associated with older stars) one would expect the longer-period objects to define the arms more precisely than the short-period ones. Tests of this hypothesis should be made in the Galaxy and in members of the local group of galaxies. The investigation could be planned on a rather broad base. The distribution of periods in concentrations of Cepheids might be correlated with the type of environment in which the concentration is embedded. The characteristics of the environment here serve as indicators of probable evolutionary stage.

Morgan outlined a test for the relatedness of groups of Cepheids and OB stars presumably coincident in space: such groups should have the same average radial velocity. This direct test could be applied to many of the concentrations delineated by Oosterhoff. It should find frequent application in future investigations.

Discussion of photometric aspects of the Cepheid observations emphasized several points. It is imperative to investigate in detail the photometric system on which the observations are made. For a *general* program on Cepheids (or any other type of star) a standard photometric system, preferably U-B-V, should be adopted. Careful choice of filters or, for photographic work, filters and plates, enables one to reproduce very closely the response functions of the standard system. Transformations, if required at all, are then very small and the customarily employed linear transformation formulae are adequate for the purpose. Quantities well-established on the standard system, as, for example, the ratio of total photographic extinction to colour excess, can be used directly or with a very small transfer correction. Transformation uncertainties are not unnecessarily introduced in the final results.

Of special importance is the problem of the intrinsic colours of the Cepheids. Intrinsic colors must be known if an accurate zero-point of the period-luminosity relation is to be derived; they must be known if the period-luminosity relation is to be used in conjunction with observed magnitudes and colors in the determination of accurate distances of the Cepheids. In this latter connection, an error of one-tenth magnitude in an intrinsic colour introduces an error of approximately 12 % in the distance of the star. That the Cepheids are intrinsically bluer than was formerly believed has been established (*a*) from studies of Cepheids in the Magellanic Clouds [34], (*b*) from investigations of Cepheids in fields in which color excess as a function of distance modulus has been established by study of early-type stars or from a model of the reddening medium [35], (*c*) by observing polarization of the light of Cepheids previously supposed free from interstellar extinction effects [36], (*d*) by identifying the Cepheids, through spectral resemblances, with the non-variable stars of type Ib. No one of these methods of investigation permits derivation of intrinsic colors free from all objections. It is not certain that Magellanic Cloud Cepheids are identical with galactic Cepheids or that the Clouds are free from interstellar extinction, that mean color excesses, determined as functions of distance in a particular region of the sky, apply in the particular direction of the Cepheid, or that the color-excess function is not a step function rather than a uniform function as is customarily assumed; that the relation between extinction and polarization is any more than statistical; that the variable Cepheids do indeed resemble the non-variable Ib stars.

Kraft [37] and van den Bergh [38] have pointed the way to one solution to the problem of the intrinsic colors and absolute magnitudes of the classic Cepheid variables that may be free from these objections. The colors and absolute magnitudes may be found by investigation of Cepheids that appear to be probable members of galactic clusters. They have prepared lists of twelve clusters containing thirteen Cepheids with periods from 3 to 10 days. These stars should serve as fundamental checks on zero-point corrections and intrinsic colors established by other methods.

Considerable interest attaches to the size of the cosmic scatter in the period-luminosity relation. Knowledge of the dispersion about the period-

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luminosity relation is of importance in the evolutionary picture of Cepheids; it provides an estimate of the accuracy to be expected for a distance determination made through use of the relation. It is of interest to try to reduce the scatter about the relation by investigating light curves and other characteristics of the Cepheids and correlating those characteristics with departures from the present period-luminosity relation.

Kukarkin reviewed the present observational situation of Cepheids and spoke about problems requiring investigation. More than 600 Cepheids have been discovered in the Galaxy. Eggen [39] has photo-electrically observed thirty-two northern Cepheids in two colors; Oosterhoff has obtained two-color photo-electric results for 182 southern Cepheids at maximum light; Irwin [40] has two-color observations for 140 southern Cepheids; Mianes, at St Michel, is making two-color photo-electric observations of all Cepheids in the northern sky brighter than magnitude 13 at maximum. The spectrographic observations of Joy [41] and of Stibbs [42] have furnished radial velocities for approximately 200 Cepheids.

We know very little about very distant Cepheids in the Galaxy. It is important that large telescopes be employed to search for faint Cepheids in at least ten fields in transparent regions along the galactic equator. Very many Cepheids remain to be found. On the basis of the number of Cepheids in M 31, Baade estimates that there are 30,000 Cepheids in our own Galaxy. Rosino at Asiago is presently investigating three fields in Cygnus, Cassiopeia and Monoceros for faint variable stars. Additional investigations, especially in the southern hemisphere, are needed. The small z-dispersion of the classical Cepheids means that one could confine a search for these stars to a very narrow zone of galactic latitude not more than a few degrees wide. Population II Cepheids will be more difficult to find; information on these objects is needed also.

An accurate complete morphological study of Cepheids in the different components of the Galaxy would be of great value. Properties of Cepheids in the spherical component differ from those of Cepheids in the disk. The variety of differences appears to be large and, at present, poorly understood. Investigations of period changes deserve special attention. Such changes can be established with great accuracy; they appear to be of different character in Cepheids belonging to different galactic components. Parenago reported that from an investigation of forty or forty-five Cepheids he found period changes to be essentially discontinuous, and not proportional to time. Rate of change of period appears to be greater for long-period Cepheids, and is greater for Cepheids in the spherical component of the Galaxy than for Cepheids in the disk component. The changes observed are small. To detect them, one requires a long series of observations. Physically, the changes must correspond to variations in radius or absolute magnitude or both. Absolute magnitude changes of one- or two-thousandths of a magnitude might be expected; comparably small changes in radius might also be expected. Observatories with large plate collections of Cepheids could make a valuable contribution by studying period changes. Kukarkin has lists and maps of northern Cepheids. These are available to any observatory wishing to work on the Cepheid problem.

A general program of accurate observation of Cepheids now known and as they are newly discovered is work of the greatest importance for a more complete understanding of the Galaxy.

(5) *Spectrophotometric-photometric investigations*

Ramberg reported that he was engaged in spectrophotometric-photometric studies of several regions in and near the galactic plane in longitudes related to special directions in the Galaxy (in the direction of rotation, opposite to the direction of rotation, and so forth) in order to obtain information on large-scale galactic structure. The specific fields examined were chosen on the basis of homogeneity of a real star density and freedom from obscuration. He reported in detail on observations of 3063 stars in an area of 11 square degrees in Lacerta ($l=69°$, $b=-8°$). The observations were made with the 40-cm Stockholm astrograph; the limiting magnitude is 13·25. Photographic and photovisual magnitudes were derived on the International System. Unwidened spectra were traced on a microphotometer and classified in a rough two-dimensional system.

The discussion of galactic structure was based on diagrams of measured color index plotted as a function of apparent photographic magnitude for individual spectral types. For stars of spectral type F0 to F8 and dG0 to dK0 the color index as a function of apparent magnitude shows no trend up or down. Ramberg interprets this to mean that the region of observation is very clear to a distance of 900 pc, at which distance he estimates a total interstellar extinction of 0·16 magnitude photographic. For the limiting magnitude of the survey, the dwarf stars do not permit observations beyond 900 pc. Plots of color index as a function of apparent magnitude for the giant stars G0 to K6 show, at a certain apparent magnitude, a sharp increase in apparent color. The fact that all classes show the increase at essentially the same apparent magnitude is interpreted to mean that the stars all have similar absolute magnitudes. At the same point at which the sharp rise in color occurs, an increase in number of stars takes place. Ramberg interprets this to mean that at a distance of

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approximately 900 pc the cone of view enters a concentration of stars and dark material.

The A-type stars are of special interest. The sharp increase in color sets in at different apparent magnitudes for the A3, A2, A0 stars. The differences between these values and the value found for the G-K giants indicate differences in the absolute magnitudes of the various spectral types. For the A0 stars the sharp rise in color starts at $m_{pg} = 10{\cdot}00$, increases to a maximum at 11·80 and thereafter remains constant. This latter feature signifies that the line of sight finally passes through the obscuring cloud and reaches a second relatively clear region.

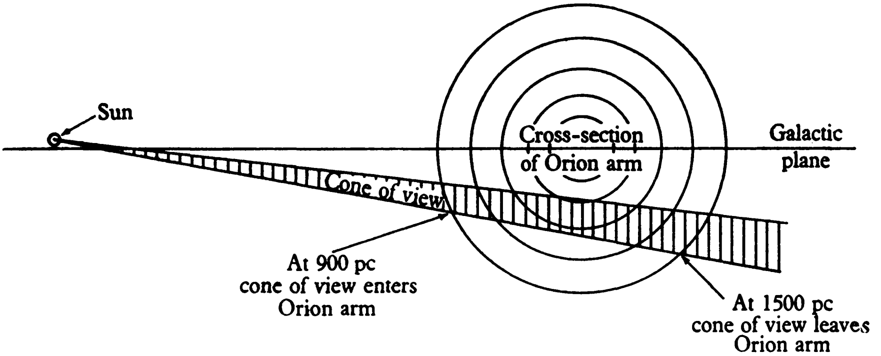

Fig. 6. Schematic diagram showing interpretation of the observed stellar distribution in Lacerta.

The physical interpretation of the observations given by Ramberg is shown schematically in Fig. 6.

The line of sight crosses the galactic plane and goes through the Orion arm. In the region of the arm Ramberg finds that the space density of A-stars increases by a factor of about two over what it is observed to be before entering the arm; the space density of the late-type giants increases by a larger factor. This would seem appropriate, since the giants are less concentrated to the galactic plane than the A-stars and the line of sight crosses the arm at an appreciable distance (about 170 pc) below the plane. There may be some indication of a neutral hydrogen concentration in the same general region as the region of increased star density observed by Ramberg.

A few faint B stars were observed in the Lacerta field. Ramberg finds these to be at a distance of approximately 5000 pc, probably in the Perseus arm.

(6) *Wilson's method of determining absolute magnitudes of late stars*

Wilson and Bappu [43] have made an extensive test of Wilson's [44] method of estimating absolute magnitudes of late-type stars (G through M) by measuring the widths of the Ca II emission lines. Coudé spectrograms of dispersion 10 Å/mm were employed. Whenever possible, both H and K emission lines were measured. The wave-lengths of the shortward component and of the longward component, determined with respect to metallic absorption lines in the stellar spectrum, provide data for determination of the line width W, expressed in km/sec. The line width W, when corrected for instrumental broadening by subtraction of 15 km/sec, $W-15=W_0$, serves as a measure of absolute magnitude.

Fig. 7*a* shows a plot of M_v as a function of log W_0 for 125 low-velocity stars not differentiated by spectral type. They have been divided into three groups on the basis of the intensity of the emission lines. Absolute magnitudes have been inferred from MK luminosity classes through the calibration by Keenan & Morgan. The dashed lines represent the spread corresponding to an error of $\pm 10\%$ in W_0.

Fig. 7*b* is identical with Fig. 7*a* except that spectral type is indicated rather than line strength.

Fig. 7*c* illustrates the relation between M_v (determined from trigonometric parallax) and log W_0. The line drawn is identical with those in Figs. 7*a* and 7*b*. The stars included in Fig. 7*c* are those for which the measured trigonometric parallaxes are at least four times the size of their probable errors.

The evidence strongly supports the hypothesis that the width of the Ca II emission is a function of only the absolute magnitude of the star. Temperature (spectral type) or strength of emission line do not appear to be involved in the relation, which is found to hold over a range of at least 15 magnitudes. Internal consistency of the measurements indicates that one good spectrogram should fix the absolute magnitude of any late-type star with suitable lines to within $\pm 0{\cdot}5$ magnitude. No satisfactory theory of the observed relation between log W and log L yet exists.

Wilson's method of deriving absolute magnitudes appears, at present, to provide, particularly among the very luminous stars, the highest resolution of any method known. It should make possible a much better picture of the galactic distribution of late-type stars than we have at present. It should find application in a great many fields of galactic research; it may be an aid in the calibration of the absolute magnitudes of other types of stars through its application in galactic clusters.

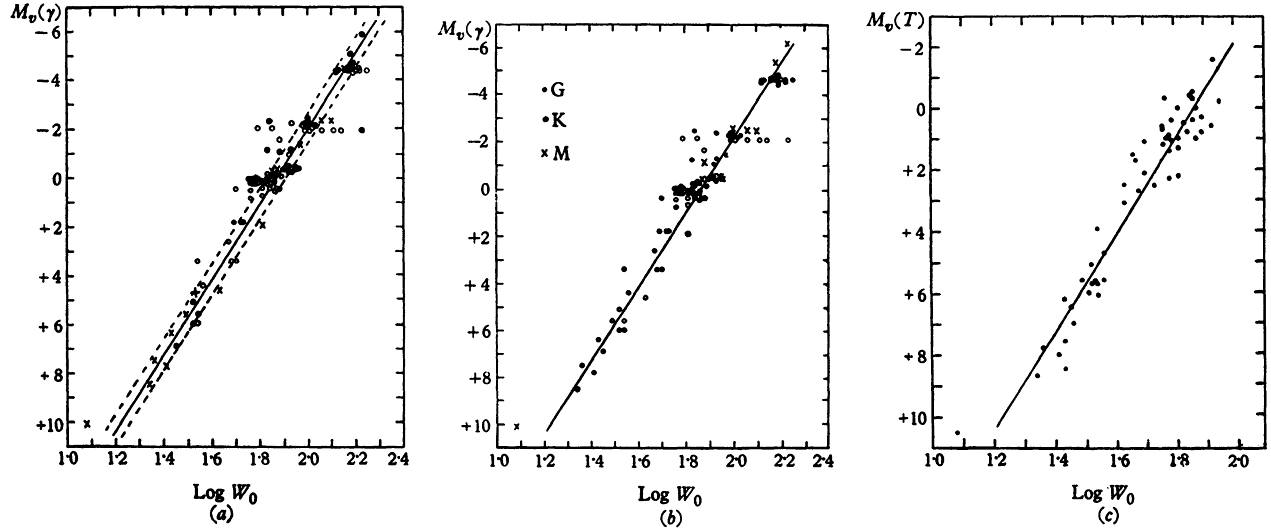

Fig. 7*a*. Logarithm of the corrected Ca II emission-line widths (W_0) plotted against Yerkes spectroscopic absolute magnitude. Stars divided into three intensity groups. Intensity increases in order 1, 2, ..., 5. The dashed lines indicate the spread corresponding to $\pm 10\%$ error in the measurement of the line width.

Fig. 7*b*. Same as Fig. 7*a* except that stars are grouped by spectral type G, K or M. Line intensities not indicated. Straight line identical with that shown in 7*a*.

Fig. 7*c*. Logarithm of corrected Ca II emission-line widths plotted against absolute magnitudes derived from trigonometric parallaxes. Straight line same as that in Figs. 7*a*, 7*b*.

Wilson plans to extend the study by employing smaller dispersion, 38 Å/mm, and to speed up the measurement process by use of photo-electric scanning technique. He proposes to concentrate, at first, on the study of super-giants, giants, and sub-giants.

(7) *Parenago's plan for co-operative observational work in certain areas*

Parenago discussed a plan for extensive co-operative work on five areas of the Milky Way in the manner proposed by Kapteyn in his Plan of Selected Areas [45]. Effectively, the plan proposed by Parenago [46] would constitute a revision of Kapteyn's Special Plan [45]. It would in no way affect the Kapteyn General Plan.

In the light of modern galactic research, regions of the Milky Way larger in area than those marked out by Kapteyn must be investigated. Each of these larger areas should hold some special interest; each should be chosen carefully on the basis of our best present knowledge of galactic structure. As knowledge increases, or as special needs arise, other areas for co-operative work may be added. In this sense Parenago's plan is a basic one, capable of expansion as needed.

The five areas selected by Parenago for co-operative study are listed in Table 5. Exact boundaries are given in Parenago's paper [46].

Table 5. *Areas in Parenago's Plan*

Area no.	Constellation	R.A. 1900	Decl. 1900	*l*	*b* centre	Area in square degrees	Expected no. of stars brighter than $m_{pg}=13{\cdot}0$
I	Aquila	$18^h\,32^m$ to $19^h\,44^m$	$-1°$ to $+18°$	12°	0°	240	22,000
II	Cygnus	20 38 to 20 56	+43 to +47	53	0	12	2,000
III	Taurus	4 00 to 5 04	+16·5 to +31·5	141	−13	130	4,000
IV	Taurus	5 22 to 6 02	+23·5 to +30·5	150	0	45	3,600
V	Orion	5 00 to 5 40	−10 to +5	178	−17	143	10,000
Totals						570	41,600

For all stars brighter than photographic magnitude 13 in these regions, Parenago stated it was desirable to obtain the following data:

1. Proper motions. First epoch photographs are available at those observatories that took part in the Carte du Ciel program. The observatories at San Fernando, Algiers, Toulouse, Bordeaux, Paris, Oxford, and Helsinki are involved. Valuable absolute proper motions of long-period Cepheids, clusters, and planetary nebulae are expected by Parenago since the transformation from relative to absolute would be made through a large number of stars in the area. Assistance in measurement and reduction of plates in this extensive program was offered by Parenago.

2. Apparent magnitudes in the photographic and photovisual wave-

length ranges. Later, if possible, apparent magnitudes in the ultra-violet and infra-red should be determined. Magnitudes to a fainter limit may be required in smaller areas within the large regions.

3. Spectral types, with estimates of luminosity classes or absolute magnitudes.

4. Polarization measurements.

5. Radial velocities determined by objective prism methods.

6. Studies of known variables, combined with a search for, and subsequent study of, new variables and emission-line stars.

The estimated number of stars to be observed in each region is given in Table 5.

The observational data, when complete, will permit many studies to be made, among them being the following:

1. Determination of the extinction law by various methods: (*a*) star counts, (*b*) color excesses, (*c*) polarization, (*d*) mean proper motions in different magnitude intervals, (*e*) three-color methods.

2. Determination of the space density from star counts according to apparent magnitude.

3. Investigation of components of proper motion perpendicular to the galactic plane. This investigation is possible since three of the five regions lie on the galactic equator. In these regions, the z-components of stars can be derived without radial velocities.

4. In the region in Cygnus a study of components perpendicular to the direction of galactic rotation can be made; in the fourth region, in Taurus, a study of components in the direction of rotation is possible. Radial velocities will not be necessary in either case.

5. In the second through fifth regions stellar associations can be investigated.

6. Nearby obscuring clouds occur in the first and third regions.

Much discussion followed Parenago's proposal. There was general agreement that the proposed plan was an interesting one, but reservations were expressed in regard to the possibilities of carrying it through to completion. Vyssotsky especially stressed the danger of serious systematic errors in proper motions derived from Carte du Ciel plates. Blaauw, Oort, and Malmquist mentioned the need for separation of different population components in kinematic studies. Such separation is not basic to the proposal as it was outlined; but to include it would increase the work significantly. At the Groningen Symposium on Co-ordination of Galactic Research it was emphasized, for example, that it is of greater value to have accurate spectrographic data for a small number of stars than just star counts, even if in two colors, for a large number of stars. Smaller areas than those proposed might be advisable. Lindblad and Schalén stressed the large amount of labor involved in the plan and called attention to work now in progress on at least some aspects of such area surveys in other parts of the sky. More than five areas are required if we are to gain a well-rounded picture of the Galaxy; if more numerous areas are investigated, each may have to be smaller than the five suggested.

Parenago agreed that the determination of proper motions would be difficult, but expressed the belief that only Carte du Ciel observatories could determine adequate proper motions since only they can have two epochs separated by sixty years. He stated that the proper motions should be determined with the help of AGK 2 or 3. He agreed fully that the separation of the stars into different population components was most important. Possibly the general study of the five areas should be restricted to stars earlier than A5. More areas may be required, but, in any case, so many observations are required that a co-operative plan of the nature suggested is called for.

(8) *Remarks on spectral surveys*

Kharadze called attention to the importance of the study of A-type stars. At the Abastumani Observatory 55,000 HD A-stars have been mapped; the galactic belt between $b = \pm 10°$ has been intensively investigated. Photometric distances were computed; the effects of interstellar extinction were removed by use of Parenago's model [47] of the reddening medium. About twenty clusterings of A-stars were found. Three of these coincide in direction with O associations; one coincides in direction with a T association. The average size found for an A-star group is $40 \times 40 \times 60$ pc, with the long dimension in the line of sight. This elongation is fictitious; it occurs because of uncertainties in the distances.

A stars and their importance in galactic structure problems were extensively discussed in the first Symposium on Co-ordination of Galactic Research. The need for studies of the space distribution and kinematic studies of these stars remains. Morgan and Thackeray noted that serious regional systematic errors in classification of A stars are present in the HD catalog. Care must be exercised in using the HD spectral types in large surveys.

Morgan mentioned the desirability of extending to fainter magnitudes the M-star survey [48] made by Nassau and his associates at the Warner and Swasey Observatory. M stars are among the main indicators of the disk population of the Galaxy. A catalog listing, possibly, the 2000 brightest members of this group and extending around the entire galactic belt would be exceedingly valuable. There is a possibility that the Stockholm

Observatory, using the equipment at the Boyden Station, will take an active part in a southern survey of these stars.

At the Leander McCormick Observatory spectral types are being determined for stars in the AGK 2 and AGK 3 catalogs. From the observations to date three facts have emerged: (*a*) the spectral types listed in *Yale Transactions*, vol. 24, are systematically late. Such an error can be the source of false statistics and spurious effects among the fainter stars. (*b*) Some stars show simultaneously weak hydrogen and H and K lines of Ca II. There is some tendency for these objects to appear in bunches. (These are probably metallic-line stars, though the explanation needs investigation.) (*c*) Certain other stars also appear to have a clumpy distribution—the F8 stars, for example; objects rare in the HD catalog.

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(G) LOCAL STRUCTURE AND STELLAR MOTIONS

The region within about a kiloparsec of the sun contains no globular clusters, and few associations, planetary nebulae, novae, or Cepheids; the interpretation of 21-cm observations is complicated by peculiar motions which are comparable with galactic rotation effects. Nevertheless, this is an extremely important region for the study of galactic structure. Not only are all distance calibrations ultimately based on objects near the sun, but only in this region do we have the resolution necessary to examine the detail of galactic structure and only here can we study the numerous fainter members of the various stellar populations. As elsewhere, the

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