attributable to a small spiral arm, with a radial velocity of −50 km/sec. It is seen as an absorption feature at the position of the centre source, indicating that it is lying in front of this source. If the source was situated at a distance of only 3 kpc from the sun, the small spiral arm would be lying in a region where thus far only small deviations from circular velocity have been observed. On the other hand, in the neighbourhood of the galactic centre, 21-cm line measurements show deviations from circular motion as large as 200 km/sec. They conclude that the source is situated in the central region and is probably to be identified with the nucleus of our Galaxy.

As regards the expansion observed in the nuclear region, Paranago [11] in a study of the K-effect has shown that some sub-systems of the Galaxy may be expanding while others are contracting. An alternative view was put forward by Lindblad. He suggested that perhaps there are some similarities between the galactic system and the barred spirals, where we have a very small nucleus from which threads of dark matter extend and where we very often find a small spiral in the centre of the system.

It is obvious that in the direction of the galactic centre optical measurements, particularly in the far infra-red, are urgently needed for comparison with the radio data.

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## (E) THE GALACTIC DISK

According to the general evolutionary ideas outlined in section (A), p. 13 above, we should find in the disk both old objects, formed immediately after the contraction of the primeval cloud into the disk, and recently formed stars. The study of the interarm population of our Galaxy is a difficult problem due to the interstellar absorption. Information from nearby galaxies, especially from M 31, is in some ways more readily obtainable.

In the disk of M 31 we find stars of absolute magnitude about $-3$ photo-visual, which are similar to the brightest stars observed in globular clusters. Observations with the 200-inch telescope have shown that the number of these stars of population II decreases rapidly from the nucleus to the adjacent regions, and then slower towards the limit to which the system can be traced by optical means.

One of the most puzzling things concerning the disk of our Galaxy has been that in our neighbourhood stars of the sort found in the disk of M 31 could not be identified in any great amount. If the disk of the Galaxy contains population II we should expect to find in our vicinity many stars of the sub-giant type, for instance. Eggen's recent colour-magnitude diagram [1] for the stars in our neighbourhood shows a main sequence and a branching-off at about absolute magnitude 3·5. Both stars of the M 67 type and of the globular cluster variety occur around this branching point, but the further run of the branch indicates that we are dealing mainly with stars of the M 67 type. Nevertheless, as there is good reason to believe that the Galaxy is an Sb spiral like M 31, it is to be expected that an important component of the disk of our Galaxy should be objects of pure population II. At the conference, the following evidence in this direction was given by Baade.

(1) *Novae and planetary nebulae*

A general picture of the distribution of the disk population of the Galaxy would be obtained by means of objects of very high luminosity, like novae and planetary nebulae. The distribution of novae has been studied by Kukarkin [2] and by McLaughlin [3] who, using rough corrections for absorption, derived essentially the same picture. The novae are found to fill a disk-like volume. Only one nova, VY Aqr, situated at a distance of about 5 kpc from the galactic plane, appears to be associated with the halo. In M 31 the novae follow the general intensity distribution of the disk, showing no relation whatsoever to the spiral arms.

The same galactic distribution is shown by the planetary nebulae. They have somewhat lower luminosity than the novae, but in H$\alpha$ light and objective-prism surveys they can be easily found even if apparently very faint. From the recent surveys by Minkowski [4] and by Haro [5] a rather complete picture of the distribution, including the galactic nuclear region, has been obtained. Haro remarked that several planetary nebulae of apparent magnitude 16 and fainter have been found in the polar caps; the distribution of the planetary nebulae may therefore be somewhat different from the novae in that a larger proportion are halo members. However, most of them belong to the disk.



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## (2) *Globular clusters*

When allowance is made for the absorption, the space distribution of the observed globular clusters appears to indicate an excess of objects at low galactic latitudes. A large number of these clusters must be completely hidden behind obscuration. Several investigators have tried to estimate the number of these; the figures vary from some 50 to nearly 100. We thus arrive at the conclusion that there is a disk-component of the globular cluster population.

Morgan [6] has shown that the integrated spectral classes of the globular clusters of the halo strongly depend upon the criterion used for the classification. He used a dispersion of 150 Å/mm and three criteria, the ratio of H$\gamma$ to the G band, the intensity of the hydrogen lines, and finally the intensity of the Fe I lines. According to the hydrogen intensities the halo clusters have spectral classes between F6 and F8, while slightly earlier spectral classes are obtained from the ratio of H$\gamma$ to G. The spectral classes, inferred from the iron lines, however, are 0·8 classes earlier. The globular clusters of the halo have weak metal lines compared with the strength of the hydrogen lines. From the luminosity function of the stars in globular clusters, as established by Sandage, we know that the integrated spectra refer to the stars of the three brightest magnitudes.

Morgan also studied a group of clusters to which Mayall had called attention, with considerably later spectral class. No discrepancy exists between the spectral classes inferred from the intensities of the hydrogen lines on the one hand and the metal lines on the other, and the clusters were found to be in the interval G2–G5. Morgan pointed out that their integrated spectra are similar to that of the nuclear region of M 31. The interesting point is that these late-type globular clusters have very small $z$-components in the Galaxy. The ten clusters of types G2–G5 in Mayall's list have a mean $z$-component of only 1·4 kpc. Thus it seems that we have here a spectroscopic method to pick out globular clusters of the galactic disk.

Very little is known about these disk clusters because many are situated in southern declinations and projected against star clouds. A study of two of them is being made by Sandage and collaborators (NGC 6356 and 6712). Cuffey is investigating the colour-magnitude diagram of NGC 6838 on plates taken at the Mt Wilson 100-inch. According to Mrs Hogg [7] only three of Mayall's G-type clusters have been searched for variable stars. In NGC 6838 four variables are listed, but apparently none of the stars is of the RR Lyrae type, in NGC 6356 five variables are listed and in NGC 6712 twelve. According to Oosterhoff[8] one of the variables of NGC 6712, with the period of 105 days and amplitude about 1 magnitude, is similar to variables of this kind in other globular clusters. The search for variable stars in the G-type clusters should be pushed vigorously.

Of course not all globular clusters at low latitudes are to be regarded as disk members. Due to their motions across the galactic plane some of the halo clusters will be found within the disk at present. Such a case is NGC 6522, the centre of Baade's variable star field in Sagittarius. It has a distance of only 600 pc from the galactic plane, but, according to the spectral class, it is a halo cluster.

Baade advocated a search for new low-latitude clusters by means of the Palomar Sky Survey. These new clusters as well as previously known objects are then to be investigated by photo-electric and spectroscopic means. From this we may get a clearer picture of the distribution of the disk component of the globular clusters. One of the most difficult data to obtain in this study will be the intrinsic colours.

Thackeray mentioned in this connexion that within a year or so a rather large material on southern globular clusters will appear from the work of Kinman at Pretoria. Spectra and radial velocities, both for the integrated clusters and for individual stars, will become available.

### (3) *RR Lyrae variables*

The first indication that some RR Lyrae stars belong to the galactic disk was found by Soviet astronomers[9]. This induced Struve[10] to rediscuss Joy's radial velocities of the brightest RR Lyrae stars. He found that the solar motion referred to the variables with periods shorter than 0·4 day was considerably smaller than that referred to variables with longer periods. The stars forming Joy's material are situated within 1500 pc from the sun. According to Baade, a plot of the number of variables at various distances from the galactic plane shows that even this material is very deficient due to absorption effects close to the galactic plane. At $z=250$ pc the deficiency factor is about 5, and at $z=0$ about 8. A set of radial velocities which is free of these deficiencies would undoubtedly show even stronger the admixture of low velocity stars among RR Lyrae variables with periods below 0·4 day. It is not clear yet how we can separate the disk members from the rest of the RR Lyrae stars. Perhaps *a*-type variables with periods below 0·4 day are to be sought for disk members, as is suggested by Oosterhoff's work[11].

By means of the RR Lyrae stars it may thus be possible to arrive at an estimate of the relative strength of the disk population II in our neighbour-



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hood and the almost equally old population of the M 67 type. The problem is very difficult, as it includes the determination of colour excesses for the calculation of distances and *z*-values.

### (4) *Long-period variables*

Long-period variables occur in different components of the Galaxy, which complicates studies based on these objects. On the other hand the long-period variables offer several advantages. The probability of their discovery from a comparison of plates of different epochs is so high that in the whole sky practically all stars of this type brighter than photographic magnitudes 11 or 12 are known. In numerous fields investigated at Harvard, Sonneberg, Leiden and Moscow all variables brighter than $15^m$ are known, and in addition we know at least all variables brighter than $18^m$ in a few smaller fields investigated by means of large telescopes. The periods and limits of light variation are easily determined even from small plate material provided a sufficient time interval is covered.

Some morphologic peculiarities of the long-period variables, in the first place the length of the periods and the form of the light curves, are definitely connected with the the kinematic characteristics. The majority of stars with periods between 160 and 220 days have symmetrical light curves and a large velocity dispersion and certainly belong to the halo. On the contrary, most stars with periods longer than 400 days have asymmetrical light curves and belong to the disk. Unfortunately, the separation of the population components by means of light curves is not quite definite, and it would be very valuable to have some spectroscopic criteria in addition. The spectroscopic differences seem to be very small, however. Keenan has recently made extensive studies at Mt Wilson to search for correlations between spectral peculiarities and light-curve characteristics, but the preliminary results show only the general spectrum-period dependence.

Kukarkin mentioned that his conclusions [12] of 1954 on the non-random distribution of the long-period variables in the polar caps are not substantiated, because certain selection effects had been neglected. He stressed, however, that the stars of this type show a tendency to group in the galactic star clouds. The periods of stars situated close to each other in space are usually also nearly equal.

Besides the difficulty of assigning specific variables as members of the halo, disk, etc. there are some other obstacles for using the long-period variables as an effective tool for galactic research. Most important is perhaps that only 400 of the 3500 known objects have been investigated



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adequately. Two years ago Soviet astronomers therefore started regular observations of these stars brighter than $12^m$ at maximum. Ashbrook at Harvard, Whitney in Oklahoma, Weber in Paris, and astronomers in Sonneberg, Stalinabad, Odessa, and Moscow are studying stars neglected up to now. Some results have already been obtained, the properties for more than 200 stars have been corrected, and certainly the characteristics of all long-period variables brighter than $12^m$ at maximum will be known within three or four years. It seems desirable to ask the amateur organizations to extend their programmes on these stars.

Another difficulty is our poor knowledge concerning the long-period variables in other galaxies. Baade stated that in M 31 the search for these variables on ordinary blue plates has led to only very few stars, but in the continuation of this work on photovisual plates the stars suddenly appear in large numbers. He hoped that especially from investigations of some of the E galaxies of the local group, for instance NGC 185, which has been studied ever since the 200-inch telescope came into operation, a rather complete picture of the distribution of long-period variables will be obtained. So far, Baade has intercompared five pairs of long-exposed photovisual plates of NGC 185 and found more than 500 red variables. From a preliminary study it is evident that there are several types among these. Predominant are periods around 200 days, but there are also a few about 340 days. Others, which are variable by about a magnitude or a magnitude and a half, have periods of about 100 days and are quite regular; they seem to be of the same type as those found in globular clusters. It was very difficult to accumulate this material, because only nights with the best seeing can be used. Baade has, however, collected about 100 plates since the study began, and he believes this material will provide answers to some of the questions concerning the long-period variables.

In the Magellanic Clouds we may have to go to about magnitude 17·5 on blue plates to find the long-period variables with periods around 200 days, and to magnitude 20 to find those around 400 days. This has not been done yet. Thackeray mentioned, however, that one long-period variable with a maximum around 17·5 has been found in the cluster NGC 121, which is situated in the Small Cloud.

Thackeray also called attention to the three long-period variables in 47 Tucanae. They have periods around 200 days and according to Feast their spectra are very similar to those of ordinary long-period variables. Parenago in this connexion raised the question if we are certain that there are no more than three long-period variables in 47 Tucanae, and if not more variables of this type could be found in this and other globular clusters. Thackeray said that there are some irregular variables present in 47 Tucanae, in addition to the three regular variables, but he doubted that there are more than these three regular ones present. The irregulars have M type spectra and at Pretoria several other stars in 47 Tucanae of spectral class M are known, which appear not to be variables. Baade expressed his great interest in Parenago's question and pointed out that Mrs Hogg's catalogue [7] contains several more clusters with which long-period variables seem to be associated. In all cases, however, the clusters are found projected against large Milky Way clouds and the variables are rather distant from the centres of the clusters. Baade stressed that the three long-period variables in 47 Tucanae seem to be a unique case.

Vyssotsky reported on recent work at the McCormick Observatory for determining the proper motions of long-period variables. These have been completed for 347 of the brighter variables, all but sixty-three of which are situated north of the equator. The proper motions are being reduced to the McCormick system, which is only slightly different from the FK 3 system. The radial velocities for 290 of these stars are known from the work of Merrill [13] and as stated by Thackeray, the radial velocities for some of the southern stars are being determined at Pretoria. An attempt will be then made to derive secular parallaxes for groups of stars, and hence absolute magnitudes and the space-motion distribution. Some difficulties will probably be met with in this connexion due to the non-uniformity of the observations, especially with regard to the apparent magnitudes, and the groups therefore have to be made rather large. A similar study was made several years ago by Ikaunieks [14].

### (5) *Infra-red spectral surveys*

The infra-red spectral surveys carried out at the Warner and Swasey Observatory and reported by Nassau cover a belt 12° wide along the galactic equator from about longitude 200° through 0° to about 340°. Much of the observations and the discussions have already been published [15]. The disk-like distribution of the M stars, and the fact that these stars are greatly concentrated in the direction of the galactic nucleus, have been shown. All the BD stars of class M2 and later in the belt have now been classified, and lists have been published for M5 and later. Using the same plates some 700 new carbon stars and about seventy new S stars have been found. Lists giving approximate magnitudes for these stars have also been published. The carbon stars seem to be more concentrated to the galactic plane than the M stars, while the S stars show still greater concentration. In addition, all the red variables in the zone, as listed in the



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*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.