33. COMMISSION DE LA STRUCTURE ET DE LA DYNAMIQUE DU SYSTEME GALACTIQUE

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1. INTRODUCTION

In the present Report, we shall limit ourselves to the presentation of results relating directly to the structure and dynamics of our Galaxy. An attempt will be made to include references to scientific papers available in Australia on 1 December 1963. Sections 1 to 6 have been written by Bok, Sections 7 and 8 by Perek. As an appendix to this report, the report of the Committee of Selected Areas, prepared by Dr T. Elvius, is added on page 548. Special reference is made to the Reports most immediately related to that of Commission 33, which are for Commissions 25, 27, 29, 30, 34, 37, 40 and 43.

In recent years much progress has been made in the study of Stellar Populations, notably in the relations between abundances of the elements and the kinematics of the stars. Reports for this borderline field, which now are scattered over Reports for several Commissions, may well have to be included in future Reports for Commission 33. The material is not included in the present Report.

The principal event to be recorded is IAU/URSI Symposium no. 20 on 'The Galaxy and the Magellanic Clouds', held in Australia between 17 and 29 March 1963. The volume with the papers and discussions is in press; for published summaries see (**1**), (**2**) and (**3**).

Since the Berkeley Assembly, one book has been published in our field, that of Idlis (**4**) and the Report of the Third Full Session of the Commission on Stellar Astronomy of the Astronomical Soviet of the Academy of Sciences of the U.S.S.R., held in October, 1960, in Tbilisi, has also been published (**5**). Agekian has a chapter on Stellar Systems in Volume II of Mikhailov's Textbook on Astrophysics and Astronomy (**6**). Several relevant summarizing articles have appeared in print. Reference is made to Volume III of the Compendium of Astronomy and Astrophysics (**7**), published in 1963, which, in its 22 chapters and two appendices, contains an excellent survey of the observational techniques for the study of our Galaxy. Members of Commission 33 will be much interested in the forthcoming Volume V in the same series on *Galactic Structure*, which covers fully the areas of our interests.

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One recent publication that has come to our attention is by Dr A. Elvius, who has distributed on a limited scale some lecture notes on Galactic Dynamics, prepared in connection with a course presented at Chalmers University in Gotenborg, Sweden.

Perek (**8**) has published a survey article on problems of the dynamics of our Galaxy. It contains a very helpful general discussion on problems relating to models for our own and other galaxies. We record here the publication of the Fourth Fundamental Catalogue (FK4) by the Astronomical Rechen-Institut, Heidelberg (**9**), which provides a new fundamental system of proper motions that should make possible more precise proper motion studies of our Galaxy than in the past. Members of Commission 33 will wish to express their indebtedness to Fricke and his associates.

Three international symposia were held during the period covered by the present Report, which covered material closely related to that of our Commission. The first was at Princeton in 1961 and dealt with Interstellar Matter in Galaxies (**10**). The second was held at La Plata (**11**). The third was held at Bosscha Observatory in Indonesia and it dealt with Standards for Stellar Photometry and Spectral Classification (**12**).

The publication of the Mount Stromlo Atlas of the Southern Milky Way came too late for inclusion in the 1961 Report and is recorded here (**13**).

Material relevant to the work of Commission 33 has appeared in the first volume of the series *Annual Review of Astronomy and Astrophysics* (**14**), notably in the chapters by M. S. Roberts (The Content of Galaxies: Stars and Gas) and D. G. Wentzel (Magnetic Fields and Spiral Structure). Volume II, with chapters by A. Blaauw (Stellar Associations), B. Y. Mills (Radio Radiation from the Galaxy) and D. R. Layzer (Formation of Stars and Galaxies) will be eagerly awaited.

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II. THE OVERALL STRUCTURE OF OUR GALAXY; THE GALACTIC NUCLEUS

During and after IAU/URSI Symposium no. 20, there was much discussion on the distance scale of our Galaxy and the related problems of the circular velocity of galactic rotation at the

Sun and the law of distribution of circular velocities (**1**). The hitherto generally accepted values of the constants are given side by side with the proposed new versions:

Past Values	*New Values*
R_0 = 8·2 kpc	R_0 = 10 kpc
θ_0 = 216 km sec^{-1}	θ_0 = 250 km sec^{-1}
A = 19·5 km sec^{-1} kpc^{-1}	A = 15 km sec^{-1} kpc^{-1}
B = − 6·9 km sec^{-1} kpc^{-1}	B = − 10 km sec^{-1} kpc^{-1}

No agreement was reached about changing the adopted value for the standard solar motion of 20 km sec^{-1} toward an apex at 18^{h} 00^{m}, +30°, and no changes are recommended. There is also, as yet, no general support for a general expansion velocity relative to the galactic centre of 7 km sec^{-1} as recommended by Kerr. Firm recommendations have, however, been made for the adoption in all reductions of a single law of circular velocity, θ_0 (R), versus R, the distance from the galactic centre, a matter that is especially important for the reduction of 21 cm data.

The increased value of R_0 and the lower value of the Oort constant A have received strong independent support. The problem was reviewed in the Joint Discussion on Stellar Motions and Stellar Dynamics held at Berkeley (**2**) and the general tenor of the discussion was clearly in favour of the suggested changes. Kraft and Schmidt's result for cepheid variables (**3**) and those of H. L. Johnson and Svolopoulos for galactic clusters (**4**) support the proposed changes and most recently Weaver and Takase (**5**) have recommended a value A = 14 km sec^{-1} kpc^{-1} and R_0 = 11 kpc. Brandt (**6, 7**) has presented additional arguments in favour of a larger value of R_0, but the general validity of his approach has been questioned by G. Burbidge (**8**). Petrie (**9**) still supports a large value, A = 18 km sec^{-1} kpc^{-1}, but he comments that his results agree with the smaller value if his distances based on absolute magnitudes from H-gamma measurements are all increased by 15%. Barkhatova (**10**) has determined A from galactic clusters and finds A = 20 km sec^{-1} kpc^{-1}. The K-term proves to be negative. Thackeray (**11**) speaks in favour of the new value of A.

Independent confirmation of the smaller value of A has come from several sides, notably as a result of studies by Sinzi (**12**) and by Howard and Kirk (**13**). The problem of the galactic distance scale and the related one of galactic rotation have been reviewed by Stibbs (**14**), who has concluded independently that Petrie's preferred higher value of A can be reconciled with a smaller value if the Petrie distance scale is adjusted.

The angular velocity of rotation for the system of globular clusters decreases with distance from the galactic centre by 10 or 11 km sec^{-1} kpc^{-1} for the regions near the Sun, according to Sharov and Pavlovskaya (**15**). The observed increase in velocity dispersion for globular clusters with increasing distance from the centre can be explained either by different places of origin for different clusters or by the infiltration of extra-galactic clusters, moving with close to parabolic velocities in the outer regions of the galaxy.

The larger value of R_0 is supported by Arp's analysis of the distribution of RR Lyrae variables (**16**), in which the mean value M_B = + 0·5 has been used. Fernie (**17**) has developed an approach depending upon the distribution of globular clusters relatively near the Sun, which leads to a value of 9·7 kpc for the distance from the Sun to the galactic centre.

In recent years much new information has accumulated for the nuclear regions of our Galaxy. We draw attention to the Report of Commissions 34 and 40 and also to the papers presented at IAU/URSI Symposium no. 20 for summaries of the new evidence of radio astronomical origin. We note that at the same Symposium G. Courtès presented results obtained optically by interference techniques which apparently refer to emission nebulae in the central regions of our Galaxy. An attempt by Moroz (**18**) to observe directly in the infra-red (1·0–2·5μ) the radio source Sgr A did not, however, yield a positive result.

Several astronomers have examined the probable stellar content of the galactic nucleus. Plaut reports good progress on the Palomar-Groningen variable star programme (**19**); the first published results for Fields 1 and 2 may be expected in 1964.

The astronomers associated with the Warner and Swasey Observatory have given much attention to the central region of our Galaxy. McCuskey and Melhorn (**20**) have completed a search for late M-type stars near the galactic centre and for an area surrounding Selected Area 158. The search plates were taken by Pik-Sin The at Bosscha Observatory. The number of late M stars per 10^6 pc^3 remains constant at 0·2 in a stratum 1 kpc thick south of the galactic plane. At approximately 6 kpc from the Sun, the concentration rises to five or six times the basic value. The line of sight appears to penetrate regions associated with the galactic nucleus even at 1500 pc from the galactic plane. Mavridis and Blanco are continuing the study of the distribution of M stars in the four Plaut areas. V magnitudes are being determined for all M stars found to the limit of the survey (13·5 infra-red). We note in passing that McCuskey and Blanco have under way a parallel study of the distribution of late M-type stars in the anti-centre region ($l^{II} = 188°$). Blanco (**21**) has published the results of an H-alpha survey of the regions surrounding the galactic centre. Since publication, 47 additional H-alpha objects have been found (Pik-Sin The) and many new definite or suspected planetary nebulae. McCuskey and Purbosiswojo (Bosscha) have in progress a study of the space distribution of stars, according to spectral-luminosity class and photographic magnitude for an area of 70 square degrees centred upon $l^{II} = 0°$, $b^{II} = 0°$, complete to $B = 11·5$ (3000 stars). They find a total B absorption of 3·6 mag. at 2 kpc from the Sun. The space density of the B0 – B5 stars and OB stars remains constant to 2·2 kpc from the Sun, that of the B8 – A0 stars drops to one half at 600 pc from the Sun. Perek (**22**) has made a preliminary determination of the distances of 345 planetary nebulae and finds that there are no major density fluctuations between the Sun and the galactic centre.

Considerable attention is being paid to the nuclear bulge. McCuskey and also Bok, Bok and Basinski are concentrating on the region of Selected Area 158, where McCuskey finds an absorption of less than 1 mag, over 8 kpc. Reference should be made to a general discussion of the problem of the stellar composition of the nuclear regions by van den Bergh (**23**) and especially of the useful paper by Wallerstein (**24**), whose results for a field at $b^{II} = +10°$ indicate no maximum of star density for the stars redder than $B - V = 1·5$ at the distance of the galactic centre, suggesting that the bulge does not extend to $z = 1800$ pc.

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III. CALIBRATION PROBLEMS: THE VICINITY OF THE SUN

A most significant contribution to the all-important problem of the calibration of criteria for absolute magnitude has been published by Blaauw (**1**). The chapter is in two parts, each subdivided into three sections. For stars of spectral class A to M, Blaauw shows how the Mount Wilson absolute magnitudes may be adapted to modern use and he provides (his Table 3, p. 401) also mean visual absolute magnitudes for each MK spectral-luminosity class. He discusses calibration procedure used in the work of Oke, of Hossack and Halliday, and of Wilson and Bappu. For O and B stars and for supergiants, Blaauw presents first a summary of fundamental data on absolute magnitudes using the main sequence fitting procedure, starting from the Hyades and leading to a zero-age main sequence of H. L. Johnson and others. He then gives special attention to the Scorpio-Centaurus Association, with results that confirm the Johnson values, and lists his recommended values in his Table 3 (page 401). There is a brief discussion of the work of Petrie and others and Blaauw notes especially the promise for the future of work on H-beta intensities.

A further comprehensive survey of luminosity criteria has been published by Voigt (**2**). The first part of this survey article describes the principal features of the MK system and of the classifications and luminosity systems developed at Paris and in Sweden. The systems employed by Strömgren and Gyldenkerne are described and also the basis for multi-colour photometry. We note here that colour studies in the far infra-red are becoming increasingly important for future work on galactic structure. The article has a listing of normal colour indices and it contains a tabulation of the absolute magnitudes recommended by Schmidt-Kaler. At the same meeting of the Astronomische Gesellschaft, Schmidt-Kaler (**3**) presented a new calibration of the MK system in which the conclusion is drawn that the most luminous supergiants in the range O to F8 have identical constant absolute magnitudes $M_{pg} = -8{\cdot}4$. We note that in the Large Magellanic Cloud, there are eight stars with values of $M_v < -9$; in other words, there exist supergiants with absolute magnitudes approximately one magnitude brighter than the value quoted by Schmidt-Kaler.

Much work is under way on the calibration and interpretation of multi-colour indices. Strömgren (**4**) has published a comprehensive summary of his work and that of his associates. We note here especially the work of Gyldenkerne, who has established three independent astrophysical parameters, which may give useful clues with regard to the ages and past evolution of the G and K giant stars. Gyldenkerne has completed H-beta photometry for stars classified as A0 in the Bright Star Catalogue, north of $-10°$, and four-colour measurements u, b, v, y are under way. Three-dimensional classification in the K, N, M system of Gyldenkerne (**5**) has been extended to G5 to K3 of selected stars.

Extensive work on multi-colour photometry is in progress at Kitt Peak Observatory (Crawford, Strömgren) and at Mount Stromlo Observatory (Graham, Gascoigne, Westerlund, Walraven). The Walravens are completing the analysis of their material gathered at the Leiden Southern Station. Crawford (**6**) has published U, B, V data and H-beta indices for 501 stars of spectral types B8 and B9 brighter than $V = 6{\cdot}5$, north of $-30°$, and Graham (**7**) has provided a considerable body of data for stars of the southern hemisphere.

Basic work on spectral-luminosity classification continues to have the attention of Swedish astronomers. Ljunggren and Oja have published two papers on the subject (**8**), (**9**). They have investigated by spectrophotometric techniques from objective prism spectra for 400 field stars and 45 Praesepe stars, and, from the analysis of this material and published data, they have arrived at improved values for the absolute magnitudes and intrinsic colours of stars classified on the Uppsala system. Larsson-Leander (**10**) has calibrated the Stockholm classification system and finds that the intrinsic colours for the Stockholm classes are the same as those for the MK classes of the same name, with the exception of main sequence stars later than dG 5.

Kraft and Preston have developed a new method for obtaining absolute magnitudes of G and K-type stars. In essence, it depends on the fact that the width of the Doppler core of H-alpha in absorption is linearly correlated with the width of the K_2 emission, hence there is a 'Wilson-Bappu' effect in reverse for H-alpha in G and K-type stars. The method is being applied by Kraft to stars found on objective prism plates photographed at Tonantzintla for a 60° sector of the Milky Way, Auriga to Puppis, and permits the identification of G and K supergiants, which is of interest for studies of spiral structure and galactic rotation.

Hoffleit reports that work is well under way on the revision of the Yale Catalogue of Bright Stars, a project that is of great importance for the work of members of Commission 33, and is especially relevant to the problems under discussion in the present section of the Report.

Jaschek and Jaschek have completed a search for southern Be stars in the range B0 to B5, $V < 6{\cdot}5$, and are in the process of analysing this material with special reference to the Scorpio-Centaurus stream (**11**).

The search for faint M giants has importance for problems of galactic research. Blanco (in association with Pascu) (**12**) has found that, for giant M stars, $B-V$ is practically independent of the subclass, changing only from 1·55 for M0 to M5 to 1·90 for M7. $V-I$, on the other hand, increases from 1·10 at M0 to 5·30 at M9. Classification of very faint M giants thus becomes possible.

The programme on the search for luminous stars in the northern Milky Way (a finding list of OB stars and supergiants to $m = 13$, with $-12° < b < +12°$) is being continued at the Warner and Swasey and Hamburg-Bergedorf Observatories (**13**); Volume II has been published (**14**) and Volumes III and IV are in press. This means that we shall soon have available the catalogue for the whole range $15° < l^{\rm II} < 145°$. Volume V (145° to 190°) is almost finished and the work on Volume VI (190° to 230°) is well under way. The H-alpha survey for Volume I is in press and Volume IVa, containing identification charts, has been published (**15**). Pesch (**16**) has studied spectroscopically and photometrically, mostly with the 36-inch and 82-inch McDonald reflectors, 50 B, A and F supergiants from Volumes I and II of the catalogues named above. He finds that the luminosity classes assigned in the Catalogues are systematically too bright. Luyten has continued his investigations of faint blue stars and finds that in high galactic latitude their numbers continue to increase at least as far as the twenty-first magnitude. From proper motions determined for more than 600 of these stars, some as faint as the twentieth magnitude, he finds that the percentage of genuine white dwarfs among them is vanishingly small for stars brighter than the thirteenth magnitude and increases steadily to about 25% at magnitude 17. While their luminosities seem to range all the way from those for normal main sequence stars to those of white dwarfs, there appears to be some possibility that a subdivision into three main groups can be made. If so, then the mean absolute magnitude of these groups are around + 3 to + 4, around + 8 (U Geminorum stars) and fainter than +11 (white dwarfs).

Other searches were continued for faint stars of large proper motion on plates taken with the Palomar 48-inch Schmidt telescope, mainly to find more stars of very low luminosity and more white dwarfs.

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IV. THE SPIRAL STRUCTURE OF THE GALAXY

Problems relating to the spiral structure of our Galaxy are fairly evenly distributed over the areas of activity assigned to Commissions 33, 34 and 40. It is obviously our task to limit ourselves here primarily to a Report on stellar distribution, leaving the gas, optically, to the Report for Commission 34 and radioastronomically to that for Commission 40. The only stars and star-groupings that are of interest for the study of the spiral structure of our Galaxy are the youngest stars, clusters and associations, OB stars of spectral class earlier than B2 and clusters and associations with one or more stars earlier than B2. Cepheid variables with periods of 10 days and greater have a marginal interest. Since young stars and clusters and associations have random velocities often as great as 10 km sec^{-1}, they will move from their places of origin by 100 pc in 10^7 years. Hence, stars or clusters with ages greater than 3×10^7 years are of little use for the tracing of spiral arms.

At IAU/URSI Symposium no. 20, several methods were discussed for the tracing of the spiral arms of our Galaxy.

1. The 21 cm line of H I yields the most extensive material, but for the interpretation of the observed profiles one needs a reliable velocity-distance law of circular motion and knowledge about a possible expansion (or contraction) velocity at various distances from the galactic centre (see Report for Commission 40).

2. The most direct approach is through the measurement of distances for individual young stars, clusters and associations—with due attention to the problems of space reddening and interstellar absorption.

3. Studies of optical radial velocities of OB stars and emission nebulae—especially when these are properly correlated with analyses based on 21 cm profiles for the same regions—can provide evidence, *if* one is prepared to accept the most likely form for the law relating distance from the galactic centre and circular velocity of rotation. The interferometric velocities for faint emission nebulae measured by Courtès (1) hold much promise for the future.

4. The study of single and multiple interstellar absorption lines can yield results of great value, since they refer only to the region between the Sun and the star in the spectrum of which they are observed and not beyond (see Report for Commission 34).

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5. Studies of surface distribution by optical and radio techniques can provide useful information. The optical data (Elsässer and Haug, for example) are affected by absorption difficulties, which do not influence studies in the radio continuum at wavelengths in the decimeter and centimeter range but which become controlling factors in the decameter and longer wavelength regions (see Reports for Commissions 34 and 40).

Survey articles on spiral structure have been published by Whiteoak (**2**) and by Schmidt (**3**) and there is a series of papers on the subject by Oort, Schmidt, Thackeray, Becker, Weaver and Bok in the volume (in press) reporting of the proceedings of IAU/URSI Symposium no. 20. Semi-popular articles on spiral structure have been written by Tassoul (**4**), Rossiger (**5**) and Bok (**6**); references should also be made to a survey article by Elsässer (**6a**). The distribution of galactic star clusters has been considered by W. Becker (**7**) and by Johnson, Hoag, Iriarte, Mitchell, Hallam and Sharpless (**8**); see also the forthcoming chapter by Sharpless. W. Becker and Fenkart (**9**) have studied the distribution of 55 H II regions; Kraft and Schmidt the distribution of the cepheid variables. Beer (**10**) has examined the distribution of southern B stars.

The time has not yet arrived when we can draw a definitive diagram for the spiral structure of our Galaxy. The 21 cm picture is not clear because of uncertainties in the law relating circular velocity with distance from the galactic centre and the related problem of a possible general galactic expansion or contraction—at least for the gas associated with spiral arms near the Sun (Kerr and others). There is fair agreement as to the places where spiral concentrations are found within 3 kpc from the Sun, but there is no agreement as yet as to what these observed concentrations imply for the overall spiral structure of our Galaxy. Roberts (**11**) has discussed the distribution of Wolf-Rayet stars over the sky and its bearing upon the spiral structure of the Galaxy. He finds evidence for strong concentrations of WR stars near $l^{II} = 75°$ (Cygnus), $l^{II} = 290°$ (Carina) and $l^{II} = 350°$ (Scorpius), and a remarkable void in the range $140° < l^{II} < 230°$. The presence of the Cygnus-Carina arm, the Sagittarius arm, the Vela spur and the Perseus region are clearly shown, but the Orion spur—with many OB stars—is not shown in WR stars.

Figure 7 in W. Becker's paper (**7**) and Figure 1 of the paper by W. Becker and Fenkart (**9**), together with the earlier diagram by Bok (**12**) show the situation from the optical point of view. The composite diagram shown by Whiteoak (**2**) relates the optical and radio data. Briefly summarized, one can represent the available *optical* data quite well by the Morgan-Osterbrock-Sharpless picture of three parallel sections of spiral arms, inclined by 55° to 60° to the radius vector from the galactic centre to the Sun. There are several gaps in the observed sections of the spiral arms, notably in the range $300° < l^{II} < 325°$, where there is only a thin string of small and distant H II regions. Bok and others, however, favour a basic optical pattern of more nearly circular spiral arms, a point of view that coincides more nearly with that of the Sydney and Parkes radio astronomers. We note here that the data from the 210-foot radio telescope at Parkes indicate that a typical spiral arm is patchy in form with the patches on the average 500 to 1000 pc in diameter. They point to the depth of the spiral features in Carina (near $l^{II} = 290°$), which seem severely bounded in longitude on either side, and in which young galactic clusters have been located in the whole range of distance from the Sun 1000 to 5000 pc. In a similar manner, the feature near $l^{II} = 327°$ appears to have considerable depth—as though it marks the edge of an inner spiral arm. The Orion—Puppis—Vela section would then mark a spur protruding from the more nearly circular spiral arms, a picture that apparently fits reasonably well with the radio-astronomical spiral array. To complicate the situation, Beer (**10**) finds that some of the southern B stars studied at Radcliffe Observatory fall between the radio spiral arms. Reference to some of these features will be made in the detailed summary of regional surveys to follow.

I. I. Pronik and V. I. Pronik (**13**) hold the view that there exist in our galaxy two massive and roughly annular zones of O – B0 stars, the outer one coinciding with the Orion Arm, the inner one with the Sagittarius Arm. Genkin (**14**) has investigated the spiral structure of the Galaxy from the contour of the 21 cm line, taking account of the K effect. For $K = -2$ km sec^{-1} kpc^{-1}, the arms turn out to be almost symmetrical logarithmic spirals with a characteristic angle of 72°. Analyses of spiral structure and related problems based on radio-astronomical data have also been made by Agekian and Klosovskaya (**15**) by Sorochenko (**16**) and by Lozinskaya and Kardashev (**17**), who find that the thickness of the H I disk increases continuously from the center outward. Schöneich and Nikolov (**18**) have found that 25 galactic clusters with diffuse two-colour diagrams tend to fall in the regions of the Perseus, Orion and Sagittarius Arms.

The data on cepheid variables summarized by Kraft and Schmidt (**19**) favour the presence of a Carina Arm, stretching from the Sun in a direction $l^{II} = 295°$ between 1000 and 5000 pc, but no further clear spiral pattern is distinguishable. There are two useful new lists of colours and magnitudes of cepheid variables, one by Irwin (**20**) for 145 southern cepheids, the other by Bahner, Hiltner and Kraft (**21**) for 45 northern cepheids.

Data on OB stars have been accumulating in the southern hemisphere through the efforts of the Radcliffe observers (**22**) and the H-gamma measurement of Beer (**10**). He has in press a list of 461 new OB star distances derived from H-gamma intensities, which are being used as a basis for further studies of spiral structure. Upgren shows (**23**) that measurements of H-gamma total intensities provide a good measure for separating OB +, OB and OB − stars ($M = -5{\cdot}9$, $-4{\cdot}6$ and $-2{\cdot}5$ respectively) to $m = 13$.

Considerable difficulties arise in the analysis of observational data on the surface brightness of the Milky Way. Elsässer reports that he and Th. Neckel are analysing the data gathered for the southern Milky Way by Elsässer and Haug and they find that the results depend critically on the model for the spatial distribution of absorbing material—which appears very highly concentrated in a local dust cloud with a diameter of the order of 500 pc. Kostyakova (**24**) reports spectrophotometric observations of seven southern Milky Way regions from a research vessel in the Indian Ocean; analysis and discussion will follow shortly.

The present section obviously is not the place to discuss problems of the interpretation of the spiral structure of our Galaxy. We must note, however, that the recent trend has been to lower the estimates of the magnetic field in our Galaxy. The situation is reviewed in two survey papers by McNally (**25**) and there was much discussion on the subject at IAU/URSI Symposium no. 20. The general conclusion appears to be that in the interstellar medium in our Galaxy the average field is not likely to exceed 5×10^{-6} gauss, and that the values quoted earlier—as high as a few times 10^{-5} gauss—are definitely too large. In view of the decreasing emphasis on the galactic magnetic field as controlling the spiral pattern of our Galaxy, it becomes all the more important to consider gravitational factors; the paper presented by Lindblad at IAU/URSI Symposium no. 20 surveys the gravitational approach.

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V. STELLAR DISTRIBUTION IN LOW GALACTIC LATITUDES

General Surveys

To supplement the surveys noted in other Sections of this Report and in Dr Elvius' Report on Selected Areas, we list here briefly a few General Surveys otherwise not fully reported.

1. The Uppsala Milky Way Survey (**1**) is continuing. The results for the range $40° < l^{I} < 60°$ have been published as Part II of the series (**2**). Ljunggren is now investigating the adjoining sector at lower longitudes ($10° < l^{I} < 40°$) and Oja that at higher longitudes ($80° < l^{I} < 100°$). The limiting magnitude (m_{4400}) is now 10·5.

2. The extensive three-colour photometry undertaken at Basel which includes stars to $m = 19$, and which uses as a basis mostly 48-inch Palomar-Schmidt plates in the *R*, *G*, *U* system, includes in addition to the nine Selected Areas, fields as follows: Small and Large Sagittarius Cloud, and fields in Scutum, Aquila, Cepheus, Cassiopeia, Taurus, Lacerta and the region of the Hyades. The progress of the work has been slowed down by the unavailability of suitable photo-electric standards.

3. Boulon reports that at the Observatoire de Haute-Provence, ten fields are being investigated in the range $55° < l^{II} < 192°$, and that in each field spectral-luminosity classes and colours are being determined together with objective prism radial velocities; approximately 1000 stars are included in the survey. One result is that the width of the Orion arm is found to be of the order of 550 pc.

4. Useful compilations of radial velocities, magnitudes and colours and spectral-luminosity data have recently been published for OB stars. The work for the northern hemisphere was performed by Mrs Rubin and associates (**3**), that for the southern hemisphere by Buscombe (**4**). Iwanowska reports that a 'Spectral Sky Atlas', consisting of objective prism plates photometrically calibrated, is in preparation at Toruń Observatory.

5. Infra-red surveys are more and more coming to the fore. Westerlund (**5**) has completed an infra-red survey for M, S and carbon stars for the range $230° < l^{II} < 10°$, including the galactic centre, complete to infra-red magnitude 10·5. He finds that the M2 – M4 stars tend to cluster along spiral arms, and that the later M stars are more evenly distributed. The distribution of 1326 carbon stars and 87 S stars shows these stars to be connected with spiral

arms; see also Westerlund's infra-red study of the Southern Coalsack (**6**). At Warner and Swasey Observatory, several major infra-red studies are under way. Blanco (**7**) has investigated several young associations, where he has found a marked absence of stars later that M2 — which result has an important bearing on evolutionary theory. Mavridis and Nassau are studying the distribution of M, S and carbon stars in seven fields centered on galactic clusters — an objective prism survey that is complete to infra-red $m = 13{\cdot}5$. Velghe and Nassau are engaged upon a search and study of C, S and WR stars in three areas centered at $l^{\mathrm{II}} = 77°$ and $0° < b^{\mathrm{II}} < +22°$ (Cygnus and Draco), covering about 74 square degrees of the sky. They are also studying the distribution of the M stars in six regions of different obscurations in these areas. All the M stars from M 2 to M 10 and up to infra-red $m = 13{\cdot}5$ have been classified; the determination of V and I magnitudes for these stars is in progress. H. M. Johnson reports on experiments performed with infra-red objective prism plates obtained at the Tonantzintla Observatory. He has developed high-contrast darkroom techniques of printing which permit extension of the known searches of Blanco (**7**) and Herbig and Kuhi (**8**) to fainter limits than previously reached.

6. Dr G Kuzmin reports as follows on current researches in the U.S.S.R.

The spectral surveys down to photographic magnitude 12·5 with the aid of the 16-inch astrograph and objective prism of the Crimean Astrophysical Observatory together with determinations of magnitudes and colour indices have been continued. The following eight Milky Way areas, 15 to 60 square degrees each and an $8° \times 7°$ area around the Orion nebula have been studied:

α 1950	δ 1950	
$18^{\mathrm{h}}\ 10^{\mathrm{m}}$	$-15°$	Pronik (**9**)
18 54	+ 5	Pronik (**10**)
20 04	+36	Numerova (**11**)
20 44	+45	Metik (**12**)
21 24	+58·5	Alksnis (**13**)
00 00	+66·5	Raznik (**13a**)
01 30	+61	Brodskaya (**14**)
02 30	+59	,,
05 32	−5·5	Kopylov, Straizis (**15**)

The distribution of stars of various spectral classes, as well as of obscuring clouds have been considered and some conclusions on the structure of the Galaxy in the solar neighbourhood have been made. For the first area the luminosity function has been found. For three areas the catalogue of spectra and photographic magnitudes of 5600 stars is published.

The spectral surveys down to photographic magnitude 12·5 have also continued at the Abastumani Astrophysical Observatory, using the 28-inch prismatic camera. Kharadze and Bartaya (**16**) have published the spectral classes and photographic magnitudes of 2400 stars in the following Milky Way fields:

α 1950	$18^{\mathrm{h}}15^{\mathrm{m}}$	$20^{\mathrm{h}}32^{\mathrm{m}}$	$1^{\mathrm{h}}32^{\mathrm{m}}$
δ 1950	$-12°$	$+38°$	$+61°$

each about 18 square degrees in size, and of 2310 stars in the following $4° \times 3°$ fields (**17**)

α 1950	$20^{\mathrm{h}}44^{\mathrm{m}}$	$20^{\mathrm{h}}28^{\mathrm{m}}$	$20^{\mathrm{h}}32^{\mathrm{m}}$	$21^{\mathrm{h}}10^{\mathrm{m}}$
δ 1950	$+41°$	$+44°$	$+46°{\cdot}5$	$+60°$

A number of S and C stars has been discovered by Dolidze (**18**) using spectral surveys in red. The spectra of 855 M stars in red and infra-red have been classified in an area $\alpha = 21^{\mathrm{h}}\ 04^{\mathrm{m}}$, $\delta = +38°$ of about 30 square degrees (**19**). The results for Cas IV, Cas VII and Vul I are being prepared for publication.

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In the limits of the Parenago plan, the spectra in four areas of Parenago's regions were classified at the Abastumani Observatory. A catalogue of photographic, photovisual and photored magnitudes down to photographic magnitude 13·5 of stars in Parenago's regions has been published by the Main Astronomical Observatory of the Ukrainian Academy of Sciences (**20**). An investigation of space distribution of stars in an area $\alpha = 18^h\ 50^m$, $\delta = +5°$, $6° \times 6°$, based on this catalogue, has been fulfiled by Voroshilov (**21**). Kolesnik (**22**) has studied the distribution of stars and dark clouds in the region of Selected Area 40 ($3° \times 3°$).

Dombrovsky (**23**) has analysed the structure of the Galaxy in Cygnus in connection with polarization observations. Area $\alpha = 19^h\ 12^m$, $\delta = +38°$, 40 square degrees in size has been studied.

Methods of studying dark clouds by means of star counts has been discussed by Uranova (**24**).

Regional Surveys

We shall not report here on the many important researches on galactic star clusters, which serve admirably as anchor points for studies of spiral structure. These are listed in the Report for Commission 37 and they are currently especially enriching our knowledge of the Southern Milky Way.

Before we begin the detailed summary, a few general comments are in order. W. Becker (**25**) has analysed the techniques of correcting colour-magnitude arrays for interstellar reddening and has recommended the use of a mean colour excess as the best means for deriving a corrected distance for the cluster. In a later paper, Becker (**26**) has commented at length on the proper application of three-colour techniques to the problems of stellar statistics. He discusses the methods for locating different varieties of stars in colour-magnitude arrays, the fixing of absolute magnitudes and the effects of interstellar reddening. Miss Seitter (**27**) has compared the effectiveness of the *R*, *G*, *U* and *U*, *B*, *V* systems and finds that the use of the latter is not advisable for regions of high reddening.

Zone $0° < l^{II} < 60°$ (Sgr, Scu, Aql, Sge, Vul). Albers (**28**) has used infra-red techniques to investigate the distribution of 1200 M stars in the Scutum Region. He concludes that the Scutum Cloud as such stands out from its surroundings principally because it is in a direction of low absorption. The *total* infra-red absorption for this direction may be no more than 1·0 mag. in the clear regions. There is a concentration of M stars for the direction of the Scutum Cloud at a distance of 2500 pc ($15° < l^{II} < 20°$), which may be part of the Sagittarius arm. There is also evidence for a concentration of late M stars associated with the galactic nucleus. Becker has applied his three-colour techniques to the Scutum Cloud (**26**) and he finds a density maximum for giant stars at a distance of about 1000 pc. He comments on the exceptionally large number of late-type giants for this section of the Milky Way. Roslund (**29**) has surveyed the distribution of O and B stars for the Milky Way in Scutum ($l^{II} = 25°$; $b^{II} = -1°$). He finds an average visual absorption of one magnitude in front of the Scutum Cloud, and some nearby regions of very great obscuration. The region beyond 1 kpc from the Sun is relatively clear. There is some indication of an excess space density for the OB stars at a distance of 1 kpc from the Sun, but the space densities drop at distances of the order of 1000 to 1500 pc, which suggests that the OB concentration is at a distance no more than 1500 pc from the Sun.

Kharadze reports that at the Abastumani Observatory, the two dimensional spectral classification and magnitude determinations to $m = 12$ has continued according to Parenago's Plan for two areas, one in Aquila ($l^{II} = 29°$). M stars have been classified to 18th magnitude. Most of the interstellar absorption within 9 kpc from the Sun occurs at distances between 150 and 500 pc from the Sun. OB stars appear to concentrate at discrete distances, presumably associated with spiral structure, one such feature being at 3800 to 5000 pc from the Sun. Two papers on the subject will appear shortly in Abastumani Observatory Bulletins nos. 30 and 31.

Iwaniszewski (**30**) has investigated one of three fields in Aquila-Sagitta ($l^{II} = 48°$) in the region of the Great Rift, with results agreeing closely with earlier ones by Weaver and by Calvert. Very strong absorption is present at distances less than 700 pc from the Sun. Similar results have been obtained by Lisicki (**31**).

Zone $60° < l^{II} < 120°$ (Cyg, Cep, Cas). Kharadze, Apriamashvili and Kotchlashvili have in press (Abastumani Obs. Bull. no. 31) a catalogue of 1000 stars for Parenago's Plan Area in Cygnus. Barbier (**32**) has published two papers on the stellar distribution in the region of P Cygni ($l^{II} \sim 75°$), where she finds two concentrations in depth, the first at distances in the range between 500 and 2200 pc, the second near 3000 pc, with a gap between them. This suggests two crossings by the line of sight of spiral arms. McCuskey, collaborating with Menges and Houk, has extended his work for LF 5 (**33**) with photometric studies for the known OB stars. Five OB clusters are at distances between 1800 and 2300 pc; these are presumably associated with the Perseus arm. The greatest density of B stars is at a distance of 1800 pc.

Zone $120° < l^{II} < 180°$ (Cas, Per, Aur, Gem). Brodskaya (**34**) has studied the space distribution of A0 stars in the Perseus—Cassiopeia section of the Milky Way. There appears to be a continuously decreasing space density for the A0 stars in these directions, which is indicative of the presence of an interarm region to 1000 pc from the Sun in this direction. Kalandadze is completing her work on the Parenago's Plan Areas in Taurus (4000 stars).

Zone $180° < l^{II} < 240°$ (Ori, Mon, CMa). There is little to report beyond the references already quoted.

Zone $240° < l^{II} < 300°$ (Pup, Vel, Car, Cru, Cen). Velghe has under way an extensive investigation of photo-electric colours and magnitudes for 196 OB stars in the region of the I Vela Association ($263° < l^{II} < 273°$; $-5° < b^{II} < +2°$). From data gathered at Boyden and Radcliffe Observatories, it appears that the so-called I Vel Association represents a spiral feature stretching from the Sun to a distance of 4 kiloparsecs in a direction not coincident with the Carina-Cygnus arm. The apparent absence of OB stars elsewhere in the area may be caused by heavy local obscuration at $l^{II} = 270°$.

Bok has described the work currently in progress at Mount Stromlo Observatory for the region of I Puppis ($l^{II} = 245°$), (**35**). There seems to be good evidence (*U*, *B*, *V*, H-beta, optical and 21 cm radial velocities) for a spiral feature at 5000 pc from the Sun. There are several nearby features in the Pup-Vel section, notably the Gum Nebula (175 pc) and several H II Regions within 2 kpc of the Sun. Westerlund reports a new association, Puppis III, at a distance of 1700 pc from the Sun (**36**); it contains 23 OB stars and the cepheid RS Puppis.

Much work is in progress for this sector $275° < l^{II} < 300°$, which is dominated by the η Carinae Nebula, at a probable distance of 2500 pc. (Faulkner (**37**), Graham). Recent work on this sector has been summarized by Bok (**35**) and reference to the relevant papers on OB stars and galactic clusters may be found there. We note that, in this sector, there are several features at distances greater than 3000 pc from the Sun, notably a cluster studied by Sher, NGC 3603, which may be at 5 kpc from the sun. The OB stars seem to occur at all distances between 1 and 5 kpc from the Sun. Basinski, Bok (B.J. and P.F.) report for Selected Area 193 a very high concentration of B8 – A0 stars at a distance of 1 kpc from the Sun (0·32 per 1000 pc^3, as against 0·08 near the Sun), whereas there are few OB stars within 1 kpc for this same direction. Lyngå and Graham report that they have in preparation a finding list of 460 faint OB stars in Carina. Westerlund has under way an infra-red survey for Selected Area 193 and surroundings The ratio of early M to late M stars is the characteristic one for spiral arm regions. He is also engaged upon multi-colour photometry in the Southern Coalsack.

Zone $300° < l^{II} < 0°$ (Cen, Cir, Nor, Sco, Sgr). Bok reports (**35**) that Mount Stromlo observers are paying special attention to the sector near alpha and beta Centaurii, $310° < l^{II} < 317°$, where the majority of OB stars is at an average distance of 1800 pc from the Sun.

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Lyngå is engaged upon an extensive study of OB stars and galactic clusters in the same sector. A very different sort of galactic structure is found in the rich sector $325° < l^{II} < 355°$. A probable edge of the Sagittarius Arm is at $l^{II} = 325°$, where B.J. and P.F. Bok and Graham (**38**) find a marked concentration of OB stars at $l^{II} = 328°$, distance 2500 ± 300 pc. Ramberg reports that his study for the same sector is approaching completion. He finds strong indications for the presence of a southern spiral arm stretching from 1000 to 1800 pc from the Sun. Recent work at other longitudes in this sector has been summarized by Bok (**35**). Pik-Sin The (**39**) has located a possible new OB Association in Scorpius (17^h 10^m, $-33°$) at a distance of 1400 pc from the Sun; it is being investigated by C. Röslund.

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VI. STELLAR DISTRIBUTION IN HIGH AND INTERMEDIATE GALACTIC LATITUDES

During the past triennium much work has been done on the stellar distribution in the North Galactic Polar Cap. Special attention has been paid to the distribution of late-type stars. Very useful results have been reported on the basis of analyses of objective prism plates obtained with the Schmidt telescope of the Warner and Swasey Observatory and the Hamburg-Schmidt telescope. Upgren (**1**) has studied the distribution of stars of spectral types G5 to K5 and later, distinguishing between luminosity classes III, IV and V; he was unable to distinguish stars of higher luminosity from class III, nor could he, at the dispersions employed in this work, distinguish weak-line from strong-line stars. All classifications were made from plates extending into the ultra-violet. His catalogue covers 396 square degrees; it contains 4027 stars and appears to be complete to photographic magnitude 12·75. Density functions perpendicular to the galactic plane have been calculated and also percentages of giants and dwarfs at various apparent magnitudes. The Upgren paper provides much basic material for a study of the variation with height above the galactic plane, z, of the force per unit mass perpendicular to the galactic plane, $K(z)$, and certain inconsistencies are noted. The curve for $K(z)$ as a function of z derived by Upgren differs completely from the customary curves (Oort, Hill, Schmidt). Upgren finds at $z = 1000$ pc a value of $K(z)$ equal to one third or less of the average value for 100 to 400 pc, whereas the more traditional curves generally show a value of $K(z)$ at 1000 pc equal to twice the average for the range 100 to 400 pc. The importance of related density and velocity studies cannot be over-stressed. Upgren has recently reported (**2**) the results of an objective prism survey for stars of spectral class F2 to G5 (1127 stars to $B = 12{\cdot}5$). He finds that the density gradient for the main sequence F stars is considerably greater than for the early G stars. Blanco reports that Sanduleak has made a survey of faint M stars for an area of 120 square degrees near the North Galactic Pole, complete to $V \sim 17$. They estimate that less than 5% of the average number of M stars found (10 per square degree) can be giant M stars. Preliminary analysis indicates a marked upward revision of the mass density per pc^3 near the Sun.

Extensive researches on stellar distribution in the North Galactic Polar Cap are under way at the Uppsala Observatory. A paper not previously recorded in the Reports of Commission 33 is that of Malmquist (**3**), which contains spectrophotometric data for 3000 stars to $B = 13{\cdot}5$ (79 square degrees). In a preliminary note (**4**), Malmquist reports that he finds the interstellar absorption for the direction of the North Galactic Pole to be greater than hitherto estimated, about double the value of 0·25 mag. (blue) generally quoted. The problem is under investigation by Ljunggren.

Work on the brighter stars has also advanced considerably. Westerlund (**5**) is publishing U, B, V magnitudes and colours for 110 stars of early spectral type within 15° of the North Galactic Pole and for 110 stars within 12° of the South Galactic Pole. Reddening and blanketing effects are noted. Slettebak, Bahner and Stock (**6**) have obtained slit spectra to $m = 12$ for 84 stars of spectral type F2 and earlier for the purpose of obtaining spectral types, radial velocities and estimates of axial rotation. U, B, V magnitudes and colours are also available for these stars. The majority of these stars are 'Older Population I', but there are ten with decided Population II characteristics; sixteen new metallic line stars have been found. Klemola (**7**) has made a study of the mean absolute magnitudes for 205 stars of spectral type B0 to A5, all except 12 in the North Galactic Polar Cap. most of them in the range $9 < V < 12$. Proper motions are known for all stars and the τ-components have been used for the estimation of mean absolute magnitudes. The basic radial velocity material for the A1 to A5 stars is from Slettebak, Bahner and Stock (**6**) and for the B0–A0 stars from Greenstein (**8**). Derived mean visual absolute magnitudes are +2·1 for B0 – B3, + 0·9 for B4 – B7, + 1·5 for B8 – A0 and + 3·6 for A1 – A5. Apparently the high latitude B stars are not unlike horizontal branch stars in globular clusters.

Luyten is pressing on with the search for faint blue stars in both Galactic Polar Caps. The latest reports are by himself (**9**) for the North Cap, a joint paper with Haro (**10**) for the South Cap and another by Luyten (**11**).

The Uppsala and Mount Stromlo studies for the South Galactic Cap are continuing. Basinski, Bok and Bok have colours and magnitudes ready for approximately 1000 stars in an area of 19 square degrees, but lack of Uppsala spectra has held up publication. Elvius reports that spectrophotometric data are being collected by Eriksson, which work includes blue and visual magnitudes for 3000 stars.

While data on stellar velocities are strictly reserved for the sections to follow, we should mention here briefly the special studies and analyses on radial velocities that bear directly on the problems of stellar distribution in high galactic latitudes. Odgers and Petrie report good progress with their work on F stars in the North Galactic Polar Cap. Radial velocities are now available for 202 stars of types A0 to F5, apparent magnitude 9·0 and brighter. Their analysis is being held up by difficulties with the assignment of absolute magnitudes to the stars in question and the expectation is that absolute magnitudes correct to within ± 0·3 mag. will be obtained. Wayman (**12**) has published radial velocities for 120 stars of types A0 to A4, $m < 9{\cdot}5$, for a region near the South Galactic Pole. The velocities perpendicular to the galactic plane, which refer to stars within 400 pc from the plane, can be represented by a Gaussian distribution with a dispersion $\sigma = \pm 9{\cdot}2$ km/sec. There is no suggestion of an increase in velocity dispersion with distance from the plane. Jones (**13**) has developed a simple dynamical theory for the density variations of objects perpendicular to the galactic plane. He has applied the theory to A0 stars and concludes that the average density of gravitating matter near the Sun amounts to 0·14 solar masses per pc^3, which agrees very well with Oort's value of 0·15 solar masses per pc^3 (**14**).

The work on stellar distributions in high galactic latitudes is of course intimately related to studies of stellar distribution at intermediate latitudes and, more broadly, to research on the galactic halo. McCuskey reports on work in progress by Philip, who has photometric and spectral data for a region of 33 square degrees at $l^{II} = 75°$, $b^{II} = -29°$; at this longitude 5 fields with latitudes $-29° < b^{II} < +32°$ are under investigation (D. A. MacRae and R. Fleischer collaborating). Upgren (**15**) has published a paper on the variation of the luminosity function with distance from the galactic plane. The useful range of absolute magnitudes is −2 to +5 and the survey reaches to distances of 500 pc from the plane. For distances between 100 and 200 pc from the plane, the young and old stars are equally represented, but at greater distances the stars of the oldest groups seem to prevail. The new results agree quite well with earlier work by Bok and MacRae (**16**). W. Becker reports that the work on three-colour photometry now under way at Basel should lead to important new data on the distribution of galactic halo stars of Population II, which are readily recognizable in the two-colour diagram. The paper by Tammann (**17**) for two fields in Cancer shows the power of the *R*, *G*, *U* approach. The studies by Kinman and Wirtanen (**18**) of faint RR Lyrae stars will, for high and intermediate galactic latitudes, give us much new information about the extent of the halo and its population characteristics. The mean distance of the faintest group of high-latitude RR Lyrae variables found by them is approximately 25 kpc, indicating the vast extent of the halo of our Galaxy.

Work on interstellar matter in the halo is reported to Commission 34. We note, however, that the work of Münch and Zirin (**19**) on interstellar absorption lines found in stars at intermediate and high galactic latitudes shows that gas clouds exist to a probable height of 1 kpc —far in excess of the average height suggested by the effective half-thickness of 120 pc often quoted for the gaseous layer in our Galaxy. Oort, Müller and Raimond (**19a**) have reported evidence for high-velocity (120 to 175 km/sec) clouds of H I in the galactic corona. We note here that Burbidge and Hoyle (**20**) have suggested that the galactic halo may be a highly transient phenomenon. Belton and Brandt (**21**) have discussed the interpretation of the rotation curve of our Galaxy obtained from 21 cm observations. They indicate that there must be an excess of unknown matter in the Galaxy, distributed like halo Population II objects, if the data from $K(z)$ are to be brought into line with 21 cm results. They suggest the presence of large numbers of intrinsically faint stars with high velocity dispersions perpendicular to the galactic plane.

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VII. STELLAR MOTIONS

Theory

Filin (**1**) found that random errors of the distances and radial velocities do not affect the reliability of the Camm function. A method for the determination of the vertex from proper motion was proposed by Rudnicki (**2**). Strömberg's formula for the asymmetric shift of the centroids was modified by Einasto (**3**). The new formula fits better the observations and leads to the rotational velocity of the Sun of 250 km sec^{-1}. Przybylski (**4**) has suggested a simple method of computing galactic components of stellar velocities by means of a Cracovian formula avoiding an intermediate computation of galactic co-ordinates. A table of nine direction cosines for the conversion of the observed velocity components into galactic components is being prepared by Perek.

Neutral Hydrogen

The outflow of neutral hydrogen from the galactic nucleus raises the question of whether it is replenished by some inward motions. Pariskij (**5**) found that only ionized gas can flow inwards. The velocity is about 10 km sec^{-1} and the radius of the area is 1 to 1·5 kpc.

A new reduction of the Leiden hydrogen observations was made by Agekian and Klosovskaya (**6**) using the Camm function and adjusting the whole profiles, not only the maximum values. The Leiden results were confirmed within 2·5 km sec^{-1} kpc^{-1} in the angular velocity.

General kinematics of the local gas system was investigated by Helfer (**7**). The contributions of the interstellar hydrogen to the radial velocities were developed into a double Fourier series. Various explanations of the deviations of these expressions from circular motions are offered. The observed deformations of the gas disk were explained by Lozinskaya and Kardashev (**8**) by the gas-dynamic interaction between the Galaxy and the intergalactic medium.

A possible large scale circulation of the neutral hydrogen in the Galaxy follows from the radio observations by McGee and Murray (**9**) and by McGee *et al* (**10, 11**). In the solar vicinity hydrogen is flowing outwards at a mean radial velocity of +6 km sec^{-1} near the direction of the galactic centre and anticentre. It is flowing inwards from above and below in high galactic latitudes at a mean velocity of −6 km sec^{-1}.

The increase of the neutral hydrogen densities at the positions of the OB associations and a better agreement of the motion of the neutral hydrogen with Weaver's galactic rotation curve than with Schmidt's was established by Kaftan-Kassim (**12**).

A good correlation of optical radial velocities from interstellar lines with the radio data was found by Howard and Wentzel (**13**). Thus large scale motions of neutral hydrogen and ionized calcium are identical. Field and Fletcher (**14**) obtained a strong correlation between the distribution of O and B stars, cepheids and neutral hydrogen independent of the assumed model of the Galaxy. Rubin *et al* (**15**) found a qualitative agreement between radial velocities of O to B5 stars within 3 kpc of the Sun and the 21 cm profiles. The distance of the Sun from the centre must be larger than 8·2 kpc. The mean circular velocity is about 15% above the radio model at 6 kpc from the centre. At 8 kpc both curves coincide. Beyond 8·5 kpc the stellar curve is flat and does not decrease as is expected for Keplerian orbits. The radial velocity component agrees well with the expansion observed for interstellar hydrogen.

Early-Type Stars

Mirzoyan (**16**) has discussed the motions of O to B 0·5 stars brighter than 10th magnitude. He derives a value of the constant A of 11 to 12 km sec^{-1} kpc^{-1}. A determination of A and B from proper motions of the O and B stars is in progress by Wayman. The K-term was investigated in detail by Missana *et al* (**17**) under the assumption that all O to B3 stars belong to associations. A catalogue of 280 B stars was compiled by Eggen (**18**). He found that all nearby B stars possibly form a large association of more than 1 kpc in the galactic plane and less than 100 pc in the z-direction. The velocity distribution shows a gradient of 40 km sec^{-1} kpc^{-1} in the radial direction away from the galactic centre. Karpowicz (**19**) and Moerdijk (**20**) found that at least one of a number of independent groups formed by the B stars takes part in the rotation of the local system. Blaauw (**21**) pointed out that the Scorpio-Centaurus, Orion and Perseus associations actually form the Gould belt. Important observational material, in particular for the Scorpio-Centaurus association, was accumulated by Buscombe and Morris (**22**), Morris (**23**), Petrie (**24**), Buscombe (**25**) and Buscombe and Morris Kennedy (**26**). Bonneau (**27**) has investigated residual radial velocities of O and B stars and of A0 to A2 super-giants. The velocity decreases in the anticentre region from + 4·5 km sec^{-1} at the Sun at the rate of 6·5 km sec^{-1} kpc^{-1}.

A value of the constant A of 17 km sec^{-1} kpc^{-1} has been derived from B and super-giant A stars by Boulon (**28**).

Thackeray (**29**) has compiled the third list of Radcliffe radial velocities of southern B stars and he has investigated the galactic structure in three southern regions of special interest. He has further found that the Norma direction is favourable to resolution of interstellar Ca II lines into two components which suggest the presence of two spiral arms. An analysis of B star radial velocities is in progress by Thackeray, Shuttleworth and Feast. A value of the constant A close to 15 km sec^{-1} kpc^{-1} is indicated. The curve of angular velocities and the variation of the K-term with spectral type have been studied.

Pilowski (**30**) has attempted to give a consistent explanation of the observed local velocity distribution and he has noted that stars which flow into the solar vicinity from spiral arms are characterized by their position in the velocity diagram. Their relative velocities and the distances of the spiral arms lead to the determination of the age of the groups (A stars and red giants).

A preliminary analysis of the radial velocity and absolute magnitude data on 570 B stars by Petrie (**31**) has yielded the following results on galactic motions and distribution up to 1·6 kpc from the Sun: The distribution does not indicate strongly any spiral structure and does not appear to be closely correlated with the denser hydrogen clouds as delineated by the 21 cm surveys. Oort's constant A is found to be $+17{\cdot}9 \pm 1{\cdot}2$ km sec^{-1} kpc^{-1}. This value depends on the H-beta distance scale. A negative K-term is found. The Ca II velocities yield roughly one half that given by stellar velocities and hence the Ca II is approximately uniformly distributed. A few local deviations from the circular model velocities are found suggesting motions of groups of stars. The random motions are not correlated with galactocentric distance but show some correlation with absolute magnitude.

Field Stars

An extended material of space velocities for 3483 stars with accurately determined proper motion and radial velocity was prepared by Eggen (**32**). Two further catalogues containing 6000 stars with less accurate data are in preparation.

Frequency curves of radial velocities of faint stars in Selected Area 19 were studied by Duflot (**33**). The B, A and F stars clustered around zero velocity. Only a few stars have large negative velocities; these are situated in the Perseus arm. The curve for G and K stars is irregular and has a maximum at -70 km sec^{-1}.

The analysis of McCormick proper motions by Emoto (**34**) shows a decrease of the rotational velocity with increasing distance from the galactic plane. The distances and radial velocities of several hundred stars have been determined by Boulon (**35**). The presence of the Orion spiral arm of about 550 pc thickness has been revealed in the solar vicinity. It appears that the value of the K-term is very sensitive to the distribution of the stars entering the solution on the celestial sphere.

The relation between ages and kinematics of G and K stars was investigated by Gyldenkerne. Young giant stars which evolved from A type stars show the vertex deviation of the A stars while those which evolved from the main sequence F and G stars do not show the deviation. The result of many years' work by Rootsmäe on the connection between the kinematical characteristics of various types of stars and their ages are summarized in his posthumous article (**35a**).

The distribution of tangential velocities received considerable attention. Einasto (**36**) found that groups with various velocity dispersions exhibit the same frequency curve of the logarithms of tangential velocities which is only shifted along the axis of abscissae. According to Shatsova (**37**) the distribution of the logarithms of the tangential velocities is normal. An extended material of tangential velocities of 1300 stars served to Lodén (**38**) for the determination of the solar motion and of the velocity ellipsoid.

The radial velocities have been used by Pavlovskaya (**38a**) to study the solar motion with respect to stars of different spectral types and luminosity classes. Pavlovskaya (**38b**) and

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Karimova (**38c**) have studied the velocity distribution in the transversal and radial directions to the galactic centre.

With the completion of the Fourth Fundamental Catalogue by Fricke and Kopff (**39**) a new fundamental system of proper motions, deviating noticeably from previous systems, is available. Fricke is at present investigating the effects of the differences between systems of proper motion on the determination of precessional corrections and of the constant *B*. The FK4 removes the deficiencies of the GC system only in the magnitude range of the FK4 stars (down to about 7·5 mag.). There remains a magnitude equation in the proper motions of fainter stars. An effective removal of the magnitude effects in the southern sky can only be reached after the completion of the Southern Reference Star programme. Fricke suggests that in investigations of proper motions no averages of different systems should be taken since this practice obscures the influence of the systems on the quantities to be determined.

Special Groups of Stars

Gaska (**40**) found differences between the solar motion of population I and population II F, G and K giants. A difference in the motions of M stars with and without emission lines was pointed out by Jul Kim (**41**). Comparing stars with negative and positive CN anomaly, Yoss (**42**) found that the latter have a larger velocity dispersion. Ikauniecks (**43**) investigated constant and variable red giants stars. Variables have larger mean absolute radial velocities and a steeper gradient of the density in space.

Several investigations of carbon stars (Karpowicz *et al* (**44**), Rudnicki (**45**, **46**)) lead to the conclusion that the parameters of the velocity ellipsoid are functions of the distance from the galactic plane, or more generally, the velocity ellipsoids of physically uniform subsystems of stars are functions of the space co-ordinates.

New southern subdwarfs were identified by Przybylski (**47**) and by Deeming (**48**). Deeming reported a solar motion with regard to the subdwarfs of 131 $\pm$ 27 km sec^{-1} in the direction of rotation. It appears that the dispersion in the *z*-velocities increases with increasing UV excess. Takayanagi (**49**) found that the axes of the velocity ellipsoid of subdwarfs exceed by factors of 5 to 10 the values for nearby stars. The space density is of the order of 0·0002 solar masses per cubic parsec.

New southern high velocity stars were announced by Buscombe and Morris (**50**) and by Fehrenbach and Duflot (**51**). A large number of G and K stars with high negative velocities in Selected Area 19 is reported by Duflot (**52**). The correlation between the orbital eccentricity and the position in the H-R diagram was discussed by Michalowska and Smak (**53**). A discussion of the characteristics of high velocity stars was presented by Vanderlinden and Broucke (**54**) and by Liu (**55**). Their H-R diagram was discussed by van den Bergh (**56**). A theory explaining the origin of runaway stars was proposed by Zwicky (**57**). In the vicinity of a supernova outburst the interstellar matter had been swept away and thus the attraction decreased. Hence stars which had high enough velocities became free to escape.

Variable Stars

A comparison of the Camm function of cepheids with that of neutral hydrogen gave R_0 = 8·3 kpc (Sinzi, (**58**)). Takase (**59**, **60**) derived a higher value of R_0 = 11 kpc, an angular velocity at the Sun of 31 km sec^{-1} kpc^{-1} and the constant A = 14·1 km sec^{-1} kpc^{-1}. A criterion of population I and II cepheids based on loops formed in a two-colour diagram was proposed by Mianes (**61**). Kraft and Schmidt (**62**) used recent photo-electric data and found that most cepheids within 1500 pc are located on the side of the Sun toward the centre. Only long-period cepheids show indications of spiral structure. Taking R_0 = 10 kpc, the value of A = 15 km sec^{-1} kpc^{-1} was derived.

Kinman and Wirtanen (**63**) presented preliminary results of an RR Lyrae star survey with the Lick 20-inch astrograph. Faint RR Lyrae stars down to 18 mag. were detected, which are at a distance of about 25 kpc. Plaut and Soudan (**64**) redetermined the density distribution of RR Lyrae stars and studied the correlation of the density gradient and velocities with the period. Z. Kordylewski reports on an investigation of the acceleration of the space motion of the Sun from changes of periods of variable stars.

Feast (**65**) has combined radial velocity determinations for southern long-period variables with northern data and investigated galactic motions of Me variables. He found no *K*-term and no vertex deviation. The axes of the velocity ellipsoid in the galactic plane differ less than for extreme population I objects. The high value of the density gradient leads to a high value of the velocity of rotation of 270 km sec^{-1}. With increasing R the density gradient becomes less steep. The mean height above the galactic plane varies from 1500 at short periods to about 100 pc at long periods. The derived value of $A = 8$ km sec^{-1} kpc^{-1} is considerably smaller than that of extreme population I objects but it is in agreement with the derived velocity ellipsoid. Plaut (**66**) noted that the average period of long-period variables decreases if we approach the galactic centre, and he determined systematic velocities, average peculiar velocities and density gradients of several groups of variable stars.

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VIII. GALACTIC DYNAMICS

Theoretical problems of galactic dynamics received much attention. The centre of interest was the question of the number of independent integrals of motion, in particular the form and properties of the third integral.

Lynden-Bell (1) has pointed out that only the obvious integrals of energy and angular momentum have been considered while there are five integrals in all. He has considered the role of the neglected integrals and showed that certain classes of integrals should indeed be omitted. He further (2) has devised a method for the discovery of models for unrelaxed, self-gravitating, axially-symmetrical, steady-state stellar systems and developed (3) the dynamical theory without the aid of the restrictive ellipsoidal hypothesis. For many forms of the potential the local integrals were derived and tabulated. Idlis (4) has shown that there exist three and only three independent integrals and (5) offered a new proof of the symmetry with regard to the equatorial plane of a system with a continuous phase density and with the third integral quadratic in velocities. Dynamics of a non-steady-state galaxy with a potential allowing the

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three-axial ellipsoidal velocity distribution of motion was developed by Genkin (**6**). Models of axially symmetrical self-gravitating systems for the case when the phase density is a function of the first two integrals of motion were constructed by Kuzmin and Kutuzov (**7**). The properties and applications of the third integral were discussed by Kuzmin (**8**), van de Hulst (**9**), Contopoulos and Barbanis (**10**), Contopoulos (**11**), Goudas and Barbanis (**12**) and Hori and Liu (**13**). Contopoulos reports on several papers in preparation concerning the commensurabilities of the oscillations in two perpendicular dimensions, the third integral in non-smooth potentials (together with Woltjer) and the tables of plane galactic orbits (together with Strömgren).

Methods developed for plasma physics were applied to stellar dynamics by Sweet (**14**). He treated the interstellar gas as a hydrodynamic fluid and the stars as a collisionless gas.

Kreiken (**15**, **16**) has represented stellar systems by polytropic gas spheres. The density distribution within the system of globular clusters was found to correspond to that of a polytropic sphere with $n = 5$. This index is assumed to hold for many stellar systems (**17**). The expressions for the effects of galactic rotation, derived by Kreiken, were generalized by Kizilirmak (**18**).

The influence of a slow change of the regular gravitational forces and of irregular forces on velocity dispersions was investigated by Kuzmin (**19**).

Vetesnik (**20**) discussed stars with known space velocities and found that the frequency distribution of the energy integral is of the Gaussian type with an insignificant asymmetry. Only RR Lyrae stars have a different distribution of the energy integral. About 20% of these stars may exceed the velocity of escape.

Some basic unsolved problems of galactic dynamics and possible methods of their solution were discussed by Ogorodnikov (**21**).

Galactic Orbits

Three-dimensional galactic orbits were investigated by Ollongren (**22**). The computations show that in the galactic field of force there is no conversion between the two meridional components of the motion. Empirical evidence is brought forward for the existence of a third integral of motion. In particular, the so-called box orbits were discussed which have the property that their meridional trajectory fills a region in the meridional plane having the shape of a box with rectangular corners.

Galactic orbits in the plane of symmetry and inside a spheroid with a Schmidt density-law were discussed analytically by Perek (**23**). The relation between the apsidal rotation and the stability of circular orbits was studied. Abalakin (**24**) has studied periodic orbits of stars inside a heterogeneous ellipsoidal stellar system with the density falling off from the centre along a parabola.

General behaviour of the motion of a star was discussed by Hori (**25**) in a model of the Galaxy which represents closely the Schmidt potential and admits a separability of the Hamilton-Jacobi equation. Expressing stellar motions by a generalized Keplerian motion, Hori and Liu (**26**) studied orbits with high eccentricity.

Woolley (**27**) has pointed out that if a group of stars is detected in the solar neighbourhood which had a common origin in time and in place, one would see a selection of the original group. The selection would be such that the stars had a common velocity component in the direction of galactic rotation. The older the group, the sharper the selection.

An expression giving zero for a circular orbit, a unity for a straight line orbit, and reducing to the usual definition of eccentricity e for a mass point attraction, was suggested by Lynden-Bell (**28**) as a definition of the invariant eccentricity of galactic orbits.

Stellar motions perpendicular to the galactic plane were investigated by Shimizu (**29**). The orbits were classified into three classes, the first two corresponding to resonances. The resonances are made responsible for the development of the inner structure of a galaxy into a spiral or barred form. Contopoulos and Bozis (**30**) have considered perturbations due to the ellipticity of a galaxy. They found the perturbations in radius vector and position angle negligible for time intervals of 10^7 years.

The distribution function of the orbit elements based on the ellipsoidal velocity distribution and on Parenago's expression for the potential was tabulated by Dzigvashvili (**31**). The distribution of eccentricities was investigated by Bonnino and Missana (**32**), But (**33**) and Dziewulski (**34**). A strong correlation between the eccentricities and the observed ultra-violet excess was found by Eggen *et al* (**35**). Stars with the largest excess are invariably moving in highly elliptical orbits, whereas stars with little or no excess move in nearly circular orbits. The data require that the oldest stars were formed out of gas falling toward the galactic centre in the radial direction and collapsing from the halo onto the plane. The collapse was very rapid and only a few times 10^8 years were required for the gas to attain circular orbits in equilibrium. Shimizu and Takahashi (**36**) found an age effect in the parameters of galactic orbits.

Mass and Potential

A method for estimating surface densities from the observed rotation curve was suggested by Belton and Brandt (**37**). The discrepancies between the surface densities computed from the rotation curve and those computed from the z-force analysis were explained by insufficient knowledge of the rotation curve exterior to the Sun and by simplifying assumptions in the z-force analysis. A theory of the analysis of rotation curves by means of a series of spheroidal homoeoids compressed into a disk was developed by the same two authors (**38**).

The problem of the distribution of mass in stellar systems similar to the Galaxy was discussed by Perek (**39**). A survey of galactic models based on the distribution of either velocities or mass is given.

Lohmann (**40**) has applied the virial theorem to 70 globular clusters and derived the mass of the Galaxy of $2{\cdot}1 \times 10^{11}$ solar masses with an estimated accuracy of 20%. Brandt's (**41**) estimate is 4 to 7×10^{11} solar masses from the fact that the sizes of the nearby dwarf galaxies are determined by the tidal action of the Galaxy and 2 to 4×10^{11} solar masses from a comparison with other Sb galaxies. A distance $R_0 = 10{\cdot}5$ kpc follows from the above estimates.

Nahon (**42**) has devised a method for deriving the velocity of escape from the Galaxy based on the velocity distribution. Extremal values of the velocities lead, according to Massonie (**43**), to a difference between the velocity of escape and the circular velocity of 86 km sec^{-1}.

In a discussion of the distribution of mass in the Galaxy Schmidt (**44**) arrived at the following values: $A = 15$ km sec^{-1} kpc^{-1}, $B = -10$ km sec^{-1} kpc^{-1}, $R_0 = 10$ kpc. The density of mass near the Sun falls off as R^{-4}. If this holds throughout the outer parts of the Galaxy, then the total mass becomes $1{\cdot}8 \times 10^{11}$ solar masses. The escape velocity near the Sun is 380 km sec^{-1}, or 130 km sec^{-1} more than the local circular velocity, 250 km sec^{-1}. The well-known high-velocity cut-off in the direction of rotation of 63 km sec^{-1} cannot correspond to the escape velocity.

Attraction Perpendicular to the Galactic Plane

Hill (**45**) determined K_z from K-type giants and derived a density at the Sun of $0{\cdot}13$ solar masses per pc^3. His values were made consistent with the Poisson equation by Oort (**46**) and the corrected density of $0{\cdot}15$ was derived. Eelsalu (**47**) drew attention to the effects of possible unreliability of the material underlying the above determinations. Yasuda (**48**) studied the kinematics of high-velocity stars at large distances from the galactic plane. He derived the force K_z and the density at the Sun of 0·15 solar masses per pc^3. Using a relation between the density, Oort's constants and the z-dispersion, Jones (**49**) discussed the distribution of Ao stars perpendicular to the galactic plane and derived a density of 0·14 in the same units. Sinzi (**50**) found from proper motions and the dispersion in radial velocities of the cepheids a density of 0·11.

Emoto (**51**) investigated the z-motion quite generally. He found that the motion of stars in nearly circular orbits is quite stable. On the other hand, the amplitude of the perpendicular motion of stars with small rotational velocities increases rapidly with time. A fairly great amount of stars with small rotation seem to have obtained large amplitude even if they were moving originally in the galactic plane.

The velocity distribution perpendicular to the galactic plane was studied by Rudnicki (**52**) and Kolkhidashvili (**53**) who found a non-gaussian distribution.

Dynamics of Spiral Structure

Spiral structure is closely connected with many other dynamical problems. In order to reconcile the spiral structure as derived from the Leiden and Sydney observations, Kerr (**54**) introduced an outward velocity component of 7 km sec^{-1} for the Sun and the local centre of rest. Genkin (**55**) obtained two almost symmetrical spiral arms for $K = -2$ km sec^{-1} kpc^{-1}. He showed that the galactic law of rotation permits a relatively long lifetime of the arms as logarithmic spirals. Schmidt-Kaler and van Schewick succeeded in separating the gas belonging to the spiral arms from that of the associations. Three definite spiral arms were located at 0·5, 1·6 and 2·9 to 3·6 kpc with a fourth dubious arm at a larger distance.

Rutgers (**56, 57**) applied Maxwell's criterion for the stability of Saturn's rings to the Galaxy. He found that stars oscillate around the centroid with increasing amplitudes. This leads to radial condensations and through the agency of the differential rotation to the formation of spiral arms.

Stability of elliptic rings, the influence of gas clouds and magnetic fields on the formation of spiral arms and the possibility of an approximately steady spiral structure in galaxies was investigated by Lindblad (**58, 59**). The theory points out the dynamical importance of matter returning towards the system in the outermost spiral arms and the capacity of a trailing arm to capture matter in its surroundings. Attention is directed especially to the anticentre direction where in-going motions are shown by various results for the 21 cm line. Höglund (**60**) traced branches of obvious deviations from circular motion. It seems possible that these may be proceeding inwards towards the Perseus arm. The possible presence in our neighbourhood of systematic motions outwards as well as inwards is of interest for the investigation of star streaming in our surroundings and for explaining the vertex deviation.

Gravitational instability is capable of explaining the origin of condensations which lead to the formation of spiral arms according to Pacholczyk (**61**). These considerations give also an upper limit of the magnetic field of 4×10^{-6} gauss (**62**). Stodolkiewicz (**63**) investigated the gravitational instability which limits the lifetime of the Perseus arm. The persistence of spiral structure was already discussed by Prendergast and Burbidge (**64**). They found that the present structure cannot last more than for two revolutions. A longer lifetime for spiral arms was derived by Fujimoto (**65**) who found an upper limit of $1{\cdot}5 \times 10^8$ years. Tassoul (**66**) has investigated the combined effects of the gravitational potential and a magnetic field on the dynamics of a galaxy. The differential rotation can be affected only by the component of the magnetic field in the direction of the axis of rotation. A transversal magnetic field parallel to the plane of symmetry of the system has no effect in this respect. A possible mechanism of spiral structure formation is suggested.

Spiral structure is frequently brought into connection with the outward motion from the galactic centre. Oki *et al* (**67**) considered a gravitational Keplerian field and a magnetic field as the initial stage. If the magnetic field is homogeneous and parallel with the galactic plane, the gas condenses into trailing spiral arms and has a radial outward component of motion. Grzedzielski (**68**) proposed a model of the motion of the interstellar gas in the inner regions of the Galaxy and offered a possible explanation of the spiral structure by means of the mechanism of coronal instability and expansion in the hydrogen principal plane.

Greyber (**69**) assumed a general dipole magnetic field with an axis coinciding with the axis of the Galaxy. He predicted a very thin galactic disk and a sporadic but continuous production of spiral arms. Pismis (**70**) suggested the following theory: In an already existing galaxy of population II stars, similar to an E galaxy, the development of a gaseous component is postulated. The gaseous subsystem possesses, and is held together by, a magnetic field, roughly represented by a centrally located dipole having its axis coinciding with the axis of the galaxy. Since the gaseous bulge rotates as a rigid body no distortion of the dipole field should occur. The spheroid will gradually contract and carry along the magnetic lines of force. The only two regions from where matter may escape, leaking out from the shrinking nucleus, are the two magnetic poles. The escaping matter will stay behind and through the differential rotation will delineate spiral arms. Their lifetime was estimated as 3×10^9 years for M 31. Thus the differential rotation, far from being destructive, may be the very agent that produces spiral structure.

Hoyle and Ireland (**71**) have shown that the outward motion of gas cannot arise unless at a greater distance from the galactic centre there is a corresponding inward motion. Later (**72**) they suggested that the halo magnetic field is primary and the spiral arm field secondary. In a model in which the lines of force of the halo cross the interarm regions of the galactic plane, it is possible for the whole interstellar medium to gain angular momentum at a comparatively rapid rate. For a field intensity in the halo of 3×10^{-6} gauss the windings move out to the periphery of the galaxy in a time scale of the order of 5×10^8 years.

There are empirical as well as theoretical reasons for a large scale circulation of the interstellar gas and its angular momentum between the halo and the galactic plane according to Wentzel (**73**). This would explain the persistence of spiral structure.

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