33. STRUCTURE AND DYNAMICS OF THE GALACTIC SYSTEM (STRUCTURE ET DYNAMIQUE DU SYSTÈME GALACTIQUE)

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I. INTRODUCTION

The present report is drastically shorter and, therefore, different in form from previous reports. While galactic research has increased considerably in recent years, the financial situation in the IAU made it necessary to reduce the size of the reports to half their previous size. This obliged us to adopt an almost telegraphic style in our report. However, an extended version of the report, including also the necessary references, will be published by the University of Thessaloniki and distributed to members of Commission 33. Any other interested astronomer may write to ask for a copy.

The report has been prepared by G. Contopoulos (Sections I, V, VI) and S. McCuskey (Sections II, III, IV). In our work we have been helped by Drs Kerr (radio astronomy) and Haradze (Russian contributions). Dr Elvius has written the Report of the Committee "Selected Areas". We could cover the literature up to the fall of 1969, plus work in progress, reported by members of our commission.

The reports of the following Commissions are also of interest to our Commission: 7 (Dynamics), 24 and 30 (Distances and Motions), 25, 29 and 45 (Photometry and Spectra), 27 (Variable Stars), 28 (Galaxies), 34 (Interstellar Matter), 37 (Clusters and Association), 40 (Radio Astronomy), 43 (Astrophysical Plasmas) and 44 (X-, γ- and cosmic rays, etc.).

Among the main developments in galactic research during the last three-year period we should mention: (1) The extensive application of newly discovered radio lines in the study of the structure and kinematics of our Galaxy. (2) The development of X- and γ-ray astronomy, as well as infrared astronomy. (3) A better understanding of the spiral structure by optical and radio observations. (4) The development of the gravitational theory of spiral structure. Recent developments include suggestions for the origin of spiral structure, non-linear effects, resonances, etc. Many applications of the theory to specific galactic problems have been also made. (5) The development of new methods in stellar dynamics, similar to those of plasma physics.

The most important event in galactic research during this period was probably the IAU Symposium no. 38 on *The Spiral Structure of our Galaxy*. The Proceedings, containing about 85 papers, are edited by W. Becker and G. Contopoulos.

Other meetings connected with galactic research are the IAU Symposia no. 37 (*X- and γ-Ray Astronomy*), and 39 (*Gas Dynamics of the Interstellar Medium*), the IAU Colloquia on the "Gravitational *n*-Body Problem" and on "Problems of Interstellar Dust", the International Conference on Plasma Instabilities in Astrophysics, Pacific Grove, California, the Fourth Texas Symposium on Relativistic Astrophysics, Dallas, Texas, and the Summer Institutes at the State University at Stony Brook, N. York (1968) and Lagonissi, Greece (1969); the Proceedings of the last Institute are edited by L. N. Mavridis.

Among the books that have appeared recently I would like to mention: (1) *Galactic Astronomy*, D. Mihalas, P. M. Routly. W. H. Freeman and Co., San Francisco and London, 1968. (2) *Interstellar Ionized Hydrogen*, Ed. Y. Terzian, W. A. Benjamin, Inc., New York, 1968. (3) *Nebulae and Interstellar Matter*, Vol. 7 of "Stars and Stellar Systems". Univ. Chicago Press, Chicago, 1968. (4) *Annual Reviews of Astronomy and Astrophysics*, Vols. 4, 5 and 6. Ann. Reviews, Inc., Palo Alto, 1967, 1968. (5) *Advances in Astronomy and Astrophysics*, Vol. 6, Academic Press, New York and London, 1968. (6) *Relativity Theory and Astrophysics. 2: Galactic Structure* (Vol. 9, Lectures in Applied Mathematics), Ed. J. Ehlers, Amer. Math. Soc., Providence, R. Island, 1967. (7) *Determination of Radial Velocities and their Applications*, Proceedings, IAU Symposium no. 30, Eds. A. H. Batten, J. F. Heard, Academic Press, London and New York, 1967. (8) *An Introduction to Stellar Statistics*, R. Kurth, Pergamon Press, Inc., New York, 1967. (9) *Stellar Kinematics*, W. M. Smart, Longmans, Green and Co., London, 1968. (10) *Proceedings of the Tenth International Conference on Cosmic Rays*, Ed. M. D. Wilson, *Canadian J. Phys.*, **46**, no. 10, Parts 2–4, 1968. (11) *Astronomy 1966, Kinematics and Dynamics of the Stellar Systems*, Moscow, 1968 (Review Articles in Russian). (12) *High Energy Astrophysics*, Eds. C. de Witt, E. Schatzman, P. Véron, Gordon and Breach, New York, London, Paris, 1967.

A number of new observational techniques have introduced recently new elements into galactic research. Such are the ultraviolet, X-ray, γ-ray, cosmic-ray, and infrared astronomy, the observation of many new molecular lines, radio or infrared, and the detection of pulsars and gravitational waves.

Cosmic rays are mentioned in part VI (Dynamics). Here we include some information about the distribution of X-ray, γ-ray, infrared, and molecular line sources, as well as about gravitational waves from our Galaxy.

Pulsars show a distribution near the galactic plane. Mills found a concentration of pulsars in the local and Sagittarius arms. Their mean distance from the galactic plane is consistent with that of known supernova remnants. Indications for the concentration of pulsars in spiral arms were also provided by Davidson and Terzian (1969).

X-ray and γ-ray sources

Review papers on X-ray sources were written by Friedman (*Stars and Stellar Systems*, vol. **7**, 685, 1968), and Giacconi, Gursky and van Speybroeck (*Ann. Rev. astr. Astrophys.*, **6**, 373, 1968). A Joint Discussion of Commissions 28, 33, 34 and 44 on X-ray astronomy took place during the Prague Meeting of the IAU. More recent information is contained in the articles by Maran and Cameron (*Earth and extraterr. Sci.*, **1**, 27, 1969; report about the fourth Texas Symposium on relativistic astrophysics) and Mumford (*Sky Telesc.*, **38**, 96, 1969; report from the IAU Symposium no. 37, in Rome).

Evidence is accumulating that the discrete X-ray sources are located in spiral arms and their distribution is like that of novae. O'Dell found a correlation between the positions of O-associations and X-ray sources. Dupree found no correlation of X-ray sources with cepheids or W-stars, but a good correlation with novae and planetary nebulae. Fujimoto *et al.* found a good correlation with the distribution of interstellar gas.

The region of the galactic center emits low-energy X-rays as well as hard X-rays. The diffuse X-ray radiation has probably a galactic component but part of it may be extragalactic.

General articles on the possible sources and mechanisms of γ-radiation were written by Fazio (*Ann. Rev. astr. Astrophys.*, **5**, 481, 1967) and Fichtel (*Sky Telesc.*, **35**, 85, 1968).

γ-radiation from the galactic plane was found by Clark, Garmire and Kraushaar, using a detector flown on the third Orbiting Solar Observatory. The intensity of the radiation has a broad maximum in the direction of the galactic center. Similar results from balloons were found by Fichtel *et al.*, and by Sood. The γ-ray flux observed is more than an order of magnitude larger than expected from the interaction of cosmic rays with interstellar matter, magnetic fields, and photons. Cowsik and Pal and Shen explain this flux as due to an inverse Compton scattering of the recently observed far-infrared radiation by cosmic ray electrons. However O'Connell and Verma point out that this mechanism predicts a very anisotropic X-ray flux, which is not observed. Ögelman considers the γ-radiation to be due to unresolved discrete sources.

The possibility of observing galactic quarks was discussed by Pacini and Salpeter. Observational upper limits for quarks were set by Ashton *et al.*, Fukushima *et al.*, and by Libby and Thomas. McCusker and Cairns found the first evidence for a quark from cosmic rays.

Observations of intense *Ly* α galactic background radiation were made by Venus 2 and 3 (Kurt and Syunyaev), Venus 4 (Kurt and Dostovalov), and Mariner 5 (Barth).

Infrared radiation

A general article on infrared astronomy was written by Neugebauer and Leighton (*Sci. Amer.*, **219**, no. 2, 51). A large number of infrared sources have been found in recent years. Hughs gives the distribution of 5614 infrared stars. The observed concentration towards the galactic plane indicates a mixed population of giants and supergiants.

A discussion on infrared astronomy, with many participants, was organized by Massey and Ring (*Phil. Trans. R. Soc. Lond.*, A **264**, 107–304). Much work on infrared stars has been done by groups at Caltec, Berkeley, Tucson, Houston, etc.

Besides infrared stars, infrared nebulae were also found. The infrared radiation from the galactic nucleus was studied extensively by Becklin and Neugebauer and by Low, Forbes and Aumann, and Hoffmann and Frederick. A strong source of dimensions of the order of 1pc appears in this direction.

There is an intense far infrared radiation which is probably galactic. The observations now cover all the range up to the radio region. Observations of the galactic center in the short microwave region were discussed by Foster. Some problems of submillimeter astronomy were reviewed by Salomonovic. Interstellar dust may radiate significantly in millimeter wavelengths (Litvak).

Interstellar molecules

A general review article on interstellar molecules was written by McNally (*Adv. Astr. Astrophys.*, **6**, 173, 1968). The distribution of OH is similar to that of H I (Goss). The association of OH emission sources with various galactic objects (clusters, nebulae, or special types of stars) was considered by Menon and by Turner. Results from the distribution and kinematics of OH sources begin to add valuable information to our understanding of the Galaxy.

Indications for the existence of H_2 are provided by the observed decrease of H in dark clouds, where presumably the total gas density increases. The formation of H_2 molecules in grains was discussed by Wentzel and Nishimura. Stecher and Williams calculated the amount of H_2 ejected from M giants.

Recent observations of water vapor in several regions of the Galaxy were reported by Cheung *et al.*, Knowles *et al.* and Meeks *et al.* Ammonia was also observed near the galactic center (Cheung *et al.*). The possibility of observing many other molecules has been discussed by various authors, and preliminary results have been reported.

Of special interest are the recent observations of formaldehyde (Snyder *et al.*, Buhl *et al.*, Palmer *et al.*, Zuckerman *et al.*, Whiteoak and Gardner), because of its wide distribution in the Galaxy.

Gravitational waves

The discovery by Weber of a rather large flux of gravitational waves reaching the earth (10^4 erg cm^{-2}s^{-1}) gave rise to speculations about their origin. There is a possibility that they come from the center of our Galaxy, which may contain a Schwarzschild "hole". At the same time considerable theoretical advance has been made in understanding by behavior of masses emitting gravitational radiation (Chandrasekhar). Lynden-Bell has suggested that the galactic nucleus may be a collapsed old quasar.

II. BASIC DATA AND CALIBRATION PROBLEMS

(S. McCuskey)

A. *Basic data*

No attempt will be made here to summarize completely the data on spectral types, colors, proper motions radial velocities, H I and H II observations, polarization, etc. which enter into the varied problems of galactic structure. But some of the investigations completed, or now under way, should be mentioned.

Apriamaschvili *et al.* at Abastumani have published catalogues of stellar magnitudes, color indices, spectral and luminosity classes for several of the areas embraced in the Parenago Plan for the study of galactic structure.

Particular interest centers around the high luminosity objects (OB stars, WR stars, etc.) at low galactic latitudes in the southern hemisphere. Lodén reports that the Stockholm Observatory Survey of the Southern Milky Way continues and a catalogue of very early and very late type stars brighter than magnitude 13 is in preparation. Stephenson and Sanduleak at the Warner and Swasey Observatory are completing a survey of OB stars along the galactic belt $b^{II} = \pm 6°$ in the southern Milky Way. This survey is an extension of the earlier work carried out in collaboration with the Hamburg Observatory and published in *Luminous Stars in the Northern Milky Way I–VI.*

A revised spectral classification system for the Wolf-Rayet stars and a new catalogue of these stars have been published by L. F. Smith. New criteria for classifying WN and WC stars, have been applied to southern WR stars. The catalogue containing 107 stars, of which 13 are new, gives intrinsic colors and color excesses in the *UBV* system as well as the revised classification for these objects.

While basic data for studies of variable stars is properly the concern of Commission 27 the work being done at the Royal Greenwich Observatory on statistical parallaxes for RR Lyrae stars should be mentioned here.

Two catalogues of considerable significance for investigations of the interstellar reddening in connection with problems of galactic structure have appeared during the triennium under review. The first contains photoelectric color excess data in the *UBV* system for 4697 stars and clusters by Th. Neckel. The second, by Blanco *et al.* contains *UBV* or U_cBV photoelectric magnitudes and colors for some 20000 stars, together with references, spectral classes where known, and coordinates.

In addition to the above a new photometric catalogue containing photoelectric data for some 25000 stars with 1770 bibliographical references to all kinds of photoelectric measures is under preparation at Observatorio Astronomico, La Plata, Argentina.

In connection with the studies of proper motion the listing of MK spectral and luminosity classes, *UBV* photometry and other data for 1849 stars with $\mu > 0''.5$ per year by Cowley *et al.* should be most useful. This catalogue contains data for all such stars north of $\delta = -23°$ and brighter than 10th magnitude.

Eggen has provided a catalogue of luminosities, colors and motions for 1008 giant K and M stars, with $V < 5{\cdot}5$ which should be valuable for studies of the region within 1 kpc of the sun.

Many topics concerning the role played by radial velocity measures in problems of galactic structure are described in the report of IAU Symposium no. 30, *Determination of Radial Velocities and Their Applications*, 1967.

B. *Intrinsic colors and interstellar reddening*

New determinations of intrinsic colors for various spectral groups have appeared since the last Commission 33 Report. Among them are determinations by Herr of the MK spectral classes corresponding to the OB^+, OB°, OB^- "natural groups" and hence the values of $(B - V)_0$ for these. The groups have been separated into "non-emission" and "emission" objects. Intrinsic colors do not differ significantly between these groups. By statistical methods the intrinsic colors for BOVe–B2Ve stars have been found by Rehpenning to be $(B - V)_0 = -0{\cdot}23 \pm 0{\cdot}09$ (s.d.). This value agrees well with that found by Herr for the OB-stars.

The catalogues of *UBV* photoelectric data by Neckel and by Blanco *et al.* have been used by Neckel and by FitzGerald to provide rather detailed exhibits of the run of color excess E_{B-V} with distance out to 4 or 4·5 kpc from the sun. This material is of considerable value in detailed planning of observational programs for research on galactic structure.

The known data on interstellar absorption along the northern part of the galactic equator $b^{\mathrm{II}} = 0$ to ±20° is being studied by E. P. Polishchuk with a view to determining the distribution of absorbing clouds in and between the spiral features of the galaxy within 3 kpc of the sun.

In concluding this section we mention the new intermediate band photometric system introduced by McClure and van den Bergh, which yields equivalent spectral type and luminosity data, as well as the interstellar reddening. The new filters supplement the standard *UBV* system. It is a five-color system. The authors present data for stars, clusters and galaxies to illustrate the advantages of the system. And the multicolor photometry (*uvby*) coupled with the Hβ index described by Crawford and now extensively practiced, should contribute substantially to the determination of intrinsic colors and luminosities so necessary for progress in unravelling particularly the spiral galactic structure.

C. *Absolute magnitudes*

Basic to the calibration of absolute magnitudes is the distance modulus of the Hyades cluster. Following the suggestion by Hodge and Wallerstein in 1966 that the distance modulus of the Hyades should be corrected by $+0{\cdot}39$ magnitude critical discussions of the problem by many investigators indicated that a correction, if any, should not exceed $+0{\cdot}2$ magnitude. Most recently an extensive investigation by van Altena using new proper motions for 700 stars in the Hyades region together with photoelectric data (*UBV*) yielded a mean correction of $+0{\cdot}20 \pm 0{\cdot}05$ mag (p.e.) to the distance modulus of the cluster. Van Altena derives a modulus, $m - M = +3{\cdot}23 \pm 0{\cdot}05$ magnitude for the cluster.

Petrie and Lee have published a list of 571 spectroscopically determined absolute magnitudes for O9 to B9 stars. The Hγ equivalent width method at the Dominion Astrophysical Observatory was used. Mean M_V and dispersion σ_v as a function of spectral type are given.

Herr, from his correlation of OB star groups with MK spectral classes, derives mean absolute visual magnitudes for non-emission OB$^+$, OB$^\circ$ and OB$^-$ stars of $-5{\cdot}9$, $-4{\cdot}8$ and $-3{\cdot}6$ respectively. For the emission stars of the same groups Herr finds $M_v = -5{\cdot}1$, $-5{\cdot}0$ and $-4{\cdot}4$ respectively. The last value does not differ significantly from the value $M_v = -4{\cdot}1$ for the BOVe – B2Ve found by Rehpenning.

A new calibration of M_v as a function of spectral class has been derived from 74 clusters by FitzGerald for luminosity classes, III, IV and V. In addition he lists M_v for the entire range of spectrum-luminosity groups.

A determination of the absolute magnitudes of A stars from data on trigonometric parallaxes and proper motions is underway at LaPlata by C.O.R. and M. Jaschek, A. and C. Cowley. At the same time Jaschek reports that the Am stars are under investigation by him and S. Rocha. This is a catalogue of about 1700 B9 to A9 stars north of $\delta = -21°$ which are listed in the original *Bright Star Catalogue* by Schlesinger. MK spectral types and *UBV* photometry are given.

Absolute magnitudes, as well as intrinsic colors, for the Wolf-Rayet stars have been derived by Smith, through five color narrow band photometry of 43 WR stars in the Magellanic Clouds and 77 WR stars in the Galaxy. She finds for WN3 to WN8, M_v ranges from $-4{\cdot}5$ to $-6{\cdot}2$; for WC5 to WC9, M_v ranges between $-4{\cdot}4$ and $-6{\cdot}2$.

Mention should be made of the work by Gordon on the absolute magnitudes of carbon stars.

Jõeveer *et al.* and Jõeveer have studied the kinematic properties of the K0 – K5 stars with $V < 6{\cdot}5$ magnitude in a galactic belt $b^{\mathrm{II}} = 0° \pm 6°$, and have derived luminosity distributions for three magnitude groups, $V_1 \leqslant 5{\cdot}5$, $V_2 = 5{\cdot}5$ to $6{\cdot}0$ and $V_3 = 6{\cdot}0$ to $6{\cdot}5$.

Calibration of the 4-color (UVBY) photoelectric photometry and Hβ photometry in terms of intrinsic colors and absolute magnitudes has made rapid progress at the Kitt Peak National Observatory. In particular calibrations for the B, A and F type stars are nearly finished. D. L. Crawford reports that a relation between the β index and absolute magnitudes M_v seems to be solidly established. Observational errors in the β index of $\pm 0{\cdot}01$ magnitude would yield an error in M_v from this source alone ranging from $0{\cdot}2$ magnitude for late B stars to $0{\cdot}7$ magnitude for early B supergiants.

D. *The luminosity function*

New investigations of the distribution of absolute magnitudes for the general stellar population near the sun continue to appear. Perhaps of greatest importance is that by Luyten who has determined from his large-scale proper motion survey a new general luminosity function. He finds a maximum at $M_{pg} = +15{\cdot}7$ for this new function, a value 1·2 magnitude larger than that derived in 1938. For $+3 < M_v < +12$ the 1968 luminosity function does not differ significantly from the earlier one. Luyten finds 0·064 solar masses per pc^3 for the space density of stars for stars nearer than 10 pcs.

Differential methods for determining $\log\phi(M)$ by summing the luminosity functions for spectral groups have been applied by Drilling for a region in Norma ($l^{II} = 330°$, $b^{II} = -2°$) and by McCuskey for a region at the galactic anticenter ($l^{II} = 186°$, $b^{II} = +1°$). In both instances the resulting $\log\phi(M)$ for $-1 < M_v < +3$, the range over which the data is most complete, does not differ greatly from the similar functions for the northern sky previously published.

An extensive study of the proper motions for stars brighter than $m = 15$ in a 1 sq deg area near the cluster M67 by Murray has yielded a luminosity function for $+3 < M_v < +10$. The run of $\log\phi(M)$ agrees reasonably well with the van Rhijn standard function for the region near the sun.

The methods used for determining the general luminosity function are being examined critically at LaPlata by C. Jaschek in collaboration with J. C. Muzzio. Their findings thus far indicate that the maximum in $\log\phi(M)$ depends very critically on the limits in m and μ imposed by the data.

III. LOCAL GALACTIC STRUCTURE

(S. McCuskey)

A. *General surveys*

A summary of photometric techniques employed at Basel for investigating the spatial distribution of stars in the environs of the sun has been published by W. Becker. This sets forth references to work done by Becker and his colleagues for regions in the galactic plane and in the galactic halo.

Currently, W. Becker reports that measurements in the *RGU* system and partially in the *UBV* system are being continued. New plates were taken at Mt. Palomar with the 48-inch Schmidt-telescope and at Asiago for other fields in the galactic disk and halo. Density gradients now exist for six fields in high or intermediate galactic latitude and for six fields in the galactic disk.

With the exception of S.A. 94 and 107, where faint photoelectric measures are still missing, the halo program with the 48-inch Schmidt is on its way to being finished and extended by use of plates taken with the 200-inch Palomar telescope. Space density gradients for S.A. 51 and 57 to distances of 15 and 12 kpc respectively will ensue.

Several investigations concerning the overall distribution of OB stars along the galactic equatorial belt have appeared. Sim has summarized by charts and histograms the distribution of OB stars from the catalogues *Luminous Stars in the Northern Milky Way, I–VI.* She finds an abrupt discontinuity in the frequency of OB stars at $l^{II} = 140°$. A comparison of the OB star distribution with that of the Wolf-Rayet stars shows the same gap in the galactic distribution of the latter group. This dearth of WR stars in the range $140° < l^{II} < 220°$ has been known for some time.

The space distribution of the OB stars in the northern Milky Way (data from the *Hamburg-Warner and Swasey Observatory Catalogues*) and in the southern Milky Way (data from the Heidelberg survey) have been exhibited by Klare and Neckel. The OB$^+$ and the OB^0 stars appear to be concentrated markedly in parts of three spiral arms. But the OB$^-$ stars do not exhibit such a general trend. The half-thickness of the stellar system defined by the OB stars was found to be 50 pc, while that of the general interstellar absorbing layer was found to be 30 pc. The OB star complex as presently observed extends to about 4 kpc from the sun.

Distances for individual Wolf-Rayet stars have been determined by Smith and have permitted her to outline their role in the general picture of galactic structure around the sun to a distance of some 6–8 kpc. While there is some evidence for concentrations of these objects in the recognized spiral features in Cygnus, in Sagittarius and in Carina, there is also a considerable scatter of WR stars between the sun and the inner parts of the Galaxy. All WC9 stars are within 7 kpc of the galactic center; all WN6 and WC7 stars are within 9 kpc of the galactic center. Other types are more or less scattered over the galactic plane. Smith concludes that, in general, the WR stars are concentrated along the edges of the spiral structure, as outlined by H I and OB stars, toward the center of the Galaxy. There are no WR stars between $l^{\mathrm{II}} = 140°$ and $l^{\mathrm{II}} = 220°$ at distances from the galactic center, $R > 10$ kpc.

Hidajat and Blanco have investigated the space density of giant M stars detected by infrared techniques in Groningen-Palomar variable star fields 1, 2, and 4.

Classification of M stars with a view to obtaining the run of space density with distance in three southern Milky Way fields is underway by Pik-Sin The, in a collaborative program between the Warner and Swasey Observatory and the Bosscha Observatory at Lembang, Indonesia. These fields are LF 13, 14 and 15 (*Trans. IAU*, **XIIIA**, p. 687, 1967) at $l^{\mathrm{II}} = 281°$, 298° and 330° respectively. The numbers of M-type stars in these 3° × 3° fields are 301, 459, 1007; the increase in number of stars toward the galactic center is obvious. The magnitude limit of the survey is about $I = 13{\cdot}5$.

Mavridis has discussed in considerable detail the distribution of the M stars, the S stars and the carbon stars in the Galaxy. He has now completed a study of the space distribution of these types in an area centered on the Galactic cluster NGC752, ($l^{\mathrm{II}} = 137°$, $b^{\mathrm{II}} = -23\overset{\circ}{.}4$). Similar studies are underway in two areas centered on the clusters NGC7789 ($l^{\mathrm{II}} = 116°$; $b^{\mathrm{II}} = -5\overset{\circ}{.}4$) and NGC129 ($l^{\mathrm{II}} = 120°$; $b^{\mathrm{II}} = -2\overset{\circ}{.}5$) by A. Tsioumis and C. Poulakos respectively.

The detection, cataloging and charting of carbon stars continues. B. Westerlund reports that positions have been measured and infrared and visual magnitudes have been estimated for about 1200 carbon stars within ± 5° from the galactic equator along the southern Milky Way. The limiting infrared magnitude is about $I = 12{\cdot}5$. For the northern sky C. B. Stephenson at the Warner and Swasey Observatory has compiled a catalogue of carbon stars, classified into R and N groups. The limiting B magnitude varies between 12 and 14 depending on the type of star. This is being extended to the southern Milky Way as a corollary of the OB star survey reported above.

Stars and other objects showing Hα in emission have been the subject of search, cataloguing and statistical study by Wray. The survey covers a band in galactic latitude 20° wide along the galactic equator from $l^{\mathrm{II}} = 240°$ through 0° to 10°; V magnitudes (approximate) are given. This catalogue combined with all previous listings of these objects has now been incorporated in an extensive work by L. Wackerling of Northwestern University containing data for some 5000 Hα emission stars and other objects.

Additions to the listing of Hα objects, principally faint stars and planetary nebulae, are being made by The.

In the process of completing Parenago's complex plan for investigation of the Milky Way, the distribution of hot stars and absorbing clouds in Taurus is being studied in detail by N. B. Kalandadze.

Gould's belt continues to be of interest. Clube has shown that a group of OB stars 500 pc long and 200 pc wide with its axis toward $l^{\mathrm{II}} = 160°$ can be considered a satisfactory model for this stellar aggregate. He concludes that the group moves as a kinematic unit around the galactic center, its internal intrinsic velocity dispersion being about 3 kms^{-1} and as a unit it is identifiable with the Pleiades group.

The distribution of stars and absorbing matter in the local region around the sun is being studied by A. D. Chuadze at Abastumani on the basis of colorimetry and two-dimensional spectral classification for some 5000 stars in Selected Areas 25, 48, 50, 73, 75, 97, 99 and 122.

Among the many contributions made by Eggen we mention here two. Luminosities, colors, motions, and the distribution of some 500 faint blue stars and 150 possible white dwarfs of late-type have been studied by Eggen. He finds the space density near the sun to be 0·01–0·02 stars per pc^3. Eggen also has observed many of the M-dwarf stars detected years ago by Vyssotsky. A catalogue of 472 objects, observed in the *UBV* and *RI* systems, is given. This contains colors, proper motions, radial velocities and space velocity data. The space motions seem to indicate that the stars are about evenly divided between young and old disk population and that the list probably includes at most a dozen members of the halo population.

Klare and Schaifers have identified from objective prism spectra in the near infrared (λ6800–8800Å) some 1571 late-type stars in a field at $l^{\text{II}} = 175°$, $b^{\text{II}} = +41°$ for which proper motion plates were also available. By blink methods the stars of measurable proper motion among those detected spectroscopically were sorted out as being probable main-sequence stars. These have a space density distribution given by $D(z) = 46 \exp. [-z/185]$ stars per 10^6 pc^3, where z is the distance in parsecs perpendicular to the galactic plane.

The study of population indices at the Astronomical Observatory of N. Copernicus University at Torun by W. Iwanowska, C. Iwaniszewska and others continues.

In a study of a limited region of the sky, which may or may not be typical, Heiles has shown that most of the 21-cm emission comes from sheets of hydrogen, and only a small proportion from discrete clouds. Several groups have concluded from hydrogen absorption observations that the gas is partly in cool dense clouds and partly in a hot tenuous medium. The two forms seem to be intermingled, however, so that the assumption of a uniform mean temperature is still a reasonable approximation for large-scale structure work.

The most prominent local features in the radio continuum distribution are the galactic spurs. Supernova explanations for the spurs now seem very unlikely (Seaquist), and several workers have discussed a relationship with the local magnetic field configuration. Bingham has estimated, from comparisons with optical polarization data, that the effective distance of the north polar spur is about 100 pc.

Ellis and Hamilton, and Bridle have studied the ionized hydrogen in the solar vicinity through studies of low-frequency absorption. The column density of ionized hydrogen in various directions has been measured by several groups through dispersion observations on pulsars, the pulsating radio sources which are believed to be neutron stars.

B. *Regional surveys – low galactic latitudes*

1. *The galactic center* ($350° < l^{\text{II}} < 10°$)

An extensive study by Ardeberg of an area in Scorpius ($l^{\text{II}} = 353°$, $b^{\text{II}} = +3°$) is underway at the European Southern Observatory. Photoelectric *UBV* photometry in a six sq. deg. area for all early-type stars to a limiting magnitude $B = 12{\cdot}8$ is aimed at an evaluation of the space distribution of these stars and the question of their connection with possible spiral structure.

In one rather homogeneous part of the field the space distribution of all stars by means of spectral types determined from objective prism spectra, and *UBV* photometry is contemplated. A study of the radial velocity distribution of the A stars and the B stars is planned.

Cailliatte has made an extensive study of the region around the globular cluster OHP 1 ($l^{\text{II}} = 357°$, $b^{\text{II}} = +2\overset{\circ}{.}1$) in star cloud B in Sagittarius. In the distance interval 1–3 kpc from the sun there is an infrared absorption of 2·2–2·3 magnitude (blue 5·5–5·8) with several absorbing clouds at large distances, each absorbing about 1 magnitude. Red giant stars of class M have a peak frequency at $m_{\text{Ir}} = 14{\cdot}5$–$15$. From the study Cailliatte deduces a distance of 9 to 10 kpc to the center of the galaxy.

A re-examination of the photometric-spectral data in a field at $l^{\text{II}} = 0°$, $b^{\text{II}} = 0°$, at the Warner and Swasey Observatory, previously discussed (McCuskey), has strengthened the space density analysis in this region toward the galactic center. The original photometry and spectral classifications were made by K. Purbosisswojo. New photoelectric photometry for the area was undertaken by P. A. Wehinger and B. Hidajat to strengthen the magnitude sequences used in the original study. For nearly all groups of stars, the space density decreases in the first 1·5 kpc from the sun. For the G8–K3 giant stars, an increase in density appears to set in beyond that point. The interstellar absorption is very spotty and heavy in this region.

2. $10° < l^{II} < 60°$ *(Sct, Aql)*

Two studies by Kuznetsov of the galactic structure in Aquila have appeared. In the first, an area at $l^{II} = 52°$, $b^{II} = 0°$, spectral types, photographic magnitudes and color excesses for five sub-areas have revealed that the B8–A5 stars appear to be concentrated at distances of 100–300 pc from the sun, and that no O–B2 stars are present. The interstellar absorption over the area is quite variable; in the darkest clouds $A_{pg} \sim 2$ magnitude/kpc.

The second paper by Kuznetsov displays the interstellar absorption characteristics, A_{pg}, over the galactic plane for $0° < l^{II} < 54°$ to a distance of 5 kpc. A series of histograms depicting the space densities of the B8–A0 and the A1–A5 stars as functions of galactic longitude indicate that fluctuations in these densities can be ascribed almost completely to variations in A_{pg}. Kuznetsov concludes that there is a concentration of dust between the Sagittarius and Carina-Cygnus spiral arms of the Galaxy.

Ardeberg reports that, in collaboration with S. Wramdemark, he has a region at $l^{II} = 36°$, $b^{II} = +8°$ under extensive study.

The spectrophotometric survey of stars along the Milky Way, initiated by Malmquist, Schalén, and Westerlund at Uppsala, continues. The objective is to include all stars brighter than $B = 10$ in a galactic belt $b^{II} = 0°$ to $\pm 3°$. The survey will exhibit the overall stellar distribution and that of interstellar absorbing material, and will serve for the selection of areas for future studies of the distribution of faint stars. The results for $43° < l^{II} < 73°$ are now almost complete, according to T. Oja, and plates for $133° < l^{II} < 153°$ have been taken.

Fedorchenko has made a comprehensive study of the galactic region $44° < l^{II} < 54°$. Early B stars appear to be scarce for $r < 1{\cdot}7$ kpc. For A stars the space density is rather uniform for $r < 1$ kpc but there is a general decrease at greater distances. The concentrations of A stars and of late type giant stars appear to coincide in distance with the concentrations of interstellar dust but there is no correlation with the concentrations of H I. Fedorchenko puts $l^{II} = 37°$ as a northerly limit for the Sagittarius spiral arm, whereas others indicate $l^{II} = 22°$ for this limit.

Two investigations closely allied with that by Fedorchenko are those by Voroshilov and by Voroshilov and Polishchuk.

3. $60° < l^{II} < 150°$ *(Cyg, Cep, Cas, Per)*

The spectrophotometric survey carried on at Uppsala, reported by T. Oja, and indicated in the previous section of this report, extends into the galactic longitude range embraced here. The investigation for $133° < l^{II} < 153°$ will be particularly of interest because of the spiral galactic structure (local and Perseus arms) and of the peculiar discontinuity in the populations of OB stars, and WR stars which occurs at $l^{II} = 140°$.

Observational and statistical investigations of galactic structure underway in Russia are mainly concerned with the spiral nature of the Galaxy within distances of 5 to 8 kpc of the sun, as well as with the relationship between diffuse matter and stars of various spectral types. Dr Haradze reports that these studies are based upon photometric work in the surroundings of seven galactic clusters (the Main Astronomical Observatory of the Ukrainian Academy of Science in Gollosseyevo) and upon spectral classification in these and other areas (Abastumani Observatory). T. A. Uranova and G. A. Starikova have made an extensive study of color excesses and interstellar absorption in the Rift region of the Milky Way in Aquila and Cygnus. At 50–250 pc from the sun there appears to be a dense front of interstellar material where the rate of absorption is 7 magnitude/kpc. The dust appears to border the spiral arm in Cygnus on the side toward the galactic center. A statistical analysis indicates that the fluctuations in surface brightness of the Milky Way in this region can be explained generally by interstellar dust clouds within 400–500 pc of the sun.

Among the other current activities of the Russian astronomers reported by E. K. Haradze are the investigations by L. N. Kolesnik and G. L. Fedorchenko of the distributions of stars and interstellar matter out to distances of 3·5 to 5 kpc towards NGC 6913 ($l^{II} = 77°$), NGC 6823 ($l^{II} = 59°$), NGC 7086 ($l^{II} = 94°$).

At the Warner and Swasey Observatory, an intensive study of the Cygnus-Cepheus region $70° < l^{\mathrm{II}} < 100°$ is being undertaken by M. R. Chartrand. The general stellar population and its relationship to the spiral structure is under study by means of spectral type distributions and *UBV* photometry.

A region at $l^{\mathrm{II}} = 106°$, $b^{\mathrm{II}} = +0\overset{\circ}{.}1$ in Cepheus has been studied by Masnauskas. Evaluation of data on colors and spectral types yields values of interstellar absorption in 8 subregions. The absorption at 1 kpc varies from 0·5 magnitude to 3 magnitude. This is relatively near a region at $l^{\mathrm{II}} = 103°$, $b^{\mathrm{II}} = +1°$ now being investigated for stellar space density at the Warner and Swasey Observatory. And it is close to the field at $l^{\mathrm{II}} = 104°$, $b^{\mathrm{II}} = +4°$ in which A. Ardeberg (ESO) reports that he, in collaboration with K. Särg, has observed photoelectrically in the *UBV* system some 40 stars of OB type. These authors also plan to undertake spectrophotometric observations of the same stars. It is a complex region bordering the association Cep OB2.

Several investigations of galactic structure in Cassiopeia may be mentioned. Oja has summarized 7 papers concerning the stellar and interstellar distributions at $l^{\mathrm{II}} = 128°$, $b^{\mathrm{II}} = -2°$. This is a region rich in galactic clusters and somewhat heterogeneous as regards the surface density of stars. The interstellar matter appears to be concentrated in clouds of the order of 40 pc in diameter. Most are within 1 kpc of the sun, but a few are at distances as great as 3 kpc. The implication is that these dark clouds are connected with the local and the Perseus spiral arms. Some concentration of the more luminous stars in the Perseus spiral arm is evident, but no spiral structure beyond this is apparent. This conforms to the results of a recent study of the OB stars brighter than $B = 11{\cdot}5$ in LF5 ($l^{\mathrm{II}} = 129°$, $b^{\mathrm{II}} = -2°$) from MK spectral classes and photoelectric photometry (*UBV*) by G. A. Snyder at the Warner and Swasey and the Kitt Peak National Observatories. No evidence of any concentration in space of the OB stars beyond the Perseus spiral arm was found.

The space density functions for B0 – B2 stars and A0 stars in a 45 sq. deg. region at $117° < l^{\mathrm{II}} < 124°$ have been derived by Grigoreva.

Georgelin has determined objective prism radial velocities and *UBV* photoelectric magnitude and color data for some 150 stars in Cassiopeia at $l^{\mathrm{II}} = 112°$, $b^{\mathrm{II}} = +0\overset{\circ}{.}3$. These stars range in brightness from $m_{\mathrm{pg}} = 7$ to 12, and in MK spectral type from early B to late K, and are of all luminosity classes. Distances were determined photometrically. A frequency plot of radial velocity for the BAF stars as a group shows considerable asymmetry, in the sense of a predominance of velocities between -40 and -70 km s^{-1} over that predicted by a gaussian function which best fits the maximum and the positive side of the frequency distribution. This may imply that some of the stars are distant enough to show the effects of galactic rotation appropriate to the Perseus spiral arm. The distribution of Ia, Ib, and II luminosity class stars in distance shows three maxima which coincide well with the concentrations of H I in this region. These are the local spiral arm, the Perseus arm complex from 2 to 4 kpc and another maximum at 7–8 kpc. The latter coincides with the "outer spiral arm" suggested by the radio astronomers. A very definite gap exists between 5 and 7 kpc both in the stellar and in the H I distributions. A second feature indicated by the radial velocity data, corrected for solar motion, is the considerably less rapid decrease in radial velocity with distance than is predicted by the circular rotation model.

Kharadze reports a study by V. I. Voroshilov of the region in the direction of NGC 7654 ($l^{\mathrm{II}} = 113°$, $b^{\mathrm{II}} = +0\overset{\circ}{.}5$) where, at distances between 8 and 9 kpc, the presence of the stellar population in an outer spiral arm of the Galaxy has been detected. Whether this is truly an outer arm, or has some connection with the Perseus spiral arm complex is being investigated.

A photometric investigation (*UBV*) by the Becker method of a region at ($l^{\mathrm{II}} = 143°$, $b^{\mathrm{II}} = +3°$) has been published by Karimie.

This entire region near $l^{\mathrm{II}} = 140°$ is of considerable interest because of the discontinuities there in the galactic longitude distribution of several elements of galactic structure. Brück *et al.* and Reddish have discussed this feature.

An extensive survey by Houk and McCuskey covering the entire galactic belt $b^{\mathrm{II}} = 0°$ to $\pm 3°$, and some regions at higher galactic latitude, for detecting B8–A3 stars to $V = 13$ magnitude is underway at the Warner and Swasey Observatory. Thus far, the ranges $55° < l^{\mathrm{II}} < 75°$, an interarm region, and $95° < l^{II} < 150°$, a spiral arm section of the Milky Way, have been finished. Counts of A stars indicate sizable concentrations at $l^{II} = 130°$ to 140° above the galactic plane and at $l^{II} = 98°$ to 108° below the galactic plane which cannot be accounted for by fluctuations in the interstellar absorption. Most of the variations in surface density of these stars in the interarm region seem to be due to fluctuations in the absorption there. Studies of space density are underway.

4. *The anticenter region* ($150° < l^{II} < 210°$)

Karlsson has been investigating the stellar space distribution for a region in Monoceros at $l^{II} = 203°$, $b^{II} = +2°$. The Becker *RGU* photometric method of analysis has been applied by Yilmaz to a field of 0·31 sq. deg. at $l^{II} = 179°$, $b^{II} = +1\overset{\circ}{.}2$.

Two investigations of a field at $l^{II} = 186°$, $b^{II} = +1°$ near the galactic anticenter have been completed at the Warner and Swasey Observatory. The first (McCuskey) gives spectral data, *V* magnitude and color data (*UBV*) for 3621 stars to a limiting $V = 12{\cdot}5$ for an area of 18·5 sq. deg. Interstellar absorption in the area increases linearly to $A_V = 1{\cdot}8$ magnitude at 2 kpc and much more slowly beyond that distance. The space density of OB stars decreases monotonically outward from the region of the sun. There is no trace of a continuation of the Perseus spiral arm into this anticenter region. The second paper, also by McCuskey, evaluates the distribution of gM stars in an 8 sq. deg. part of the region discussed above.

The analysis of the anticenter region at $l^{II} = 186°$, $b^{II} = +1°$, together with similar data for the galactic center, permits the determination of a cross-sectional view of the run of space density *from* 2 kpc in the anticenter direction, through the sun, *to* 2 kpc in the galactic center direction. The results will be published in the report of IAU Symposium no. 38, Basel, 1970.

5. $210° < l^{II} < 300°$ *(Pup, Vel, Car, Cru)*

Extensive and intensive studies of the southern Milky Way are underway at present. The development of first class observational facilities in Australia, in Chile, and in other southern hemisphere locations promises to remove the longstanding slow rate of growth of our knowledge of this part of the Galaxy.

An outstanding example of the way in which optical data on the distributions of OB stars, H II regions, dust clouds, young clusters, long-period cepheids, WR stars etc. can be combined with radio data to provide a comprehensive view of galactic structure has been given by Bok *et al.* This is a progress report prepared for the Basel Symposium (IAU no. 38) on *Spiral Structure of Our Galaxy.*

Velghe and Denoyelle are studying this heavily obscured region in the range $260° < l^{II} < 275°$. The absence of OB giants and supergiants between 265° and 275° seems quite definitely established. The work is being extended to $l^{II} = 284°$.

On the inner edge of the Carina complex, $290° < l^{II} < 311°$, Lyngå has observed some 284 faint OB stars and has classified 19 of them on the MK system. *UBV* photometry in $298° < l^{II} < 306°$ reveals a lane of low interstellar absorption. Here $A_V \sim 2$ magnitude at 3 kpc and there appears to be no appreciable absorption as far as 6 kpc (Lyngå).

Investigations of many Milky Way fields in the southern sky are underway at the Stockholm Observatory. A descriptive summary of the type of the present spectrophotometric work is given by Lodén. A catalogue of very early and very late type stars brighter than $V = 13$ is in preparation by Lodén and Miss Sundman. An investigation of the surroundings of η Carinae is being undertaken by Miss B. Nordström.

One of the regions being studied in depth at the Warner and Swasey Observatory is LF 13 at $l^{II} = 281°$, $b^{II} = +3\overset{\circ}{.}9$. A good photoelectric sequence (*UBV*) for stars to $V = 13{\cdot}6$ magnitude has been established in the area. Spectral classification is now being done on plates taken at the Bosscha Observatory, Lembang, Indonesia and at Cerro Tololo Interamerican Observatory in Chile. The observations and analysis are being done by W. H. Wooden II.

6. *300° < $l^{\rm II}$ < 350° (Cen, Cir, Nor, Sco)*

As a part of the investigations of galactic structure at the Warner and Swasey Observatory the region of LF 15 ($l^{\rm II} = 330°$, $b^{\rm II} = -2°$) has been studied by Drilling.

Two studies by Westerlund of the OB stars near the supernova remnants RCW86 and RCW103 indicate the coexistence in space of these emission nebulae and the hot stars. Westerlund's observations indicate distances for the OB associations in this region consistent with two spiral arms of the Galaxy. From I Ara at $l^{\rm II} = 337°$ to OB I Nor at $l^{\rm II} = 328°$ the Sagittarius arm becomes evident, the distance from the sun increasing from 1·4 to 2·5 kpc. The Norma-Scutum arm is identified by the Ara grouping at 3·5 kpc, $l^{\rm II} = 337°$ and the RCW103 association and Norma grouping at 3·9 kpc, $l^{\rm II} = 332°$. This arm contains most of the thermal radio sources and is rich in dust. A strongly absorbing dust cloud seems to be present well within 1 kpc of the sun on the north side of the galactic plane.

C. *High galactic latitude studies*

Considerable activity centers around the local galactic structure in the intermediate and higher latitudes near the sun. In particular the problem of disentangling the disk and the halo populations is in the forefront. While the researches at Uppsala and at Lund by T. Elvius and others should properly be recorded in the report of the *Sub-commission on Selected Areas* we shall also mention them here. The program involves spectrophotometric data, colors, and magnitudes for stars brighter than $B = 14$ in 33 Selected Areas in the northern sky and 19 in the southern. Data for 19 areas have been published. Most of the plates have been obtained for the southern areas and photoelectric sequences are being established by observations at the Siding Spring Station of the Mt. Stromlo Observatory. The purpose is to investigate the stellar space density as a function of distance from the galactic plane. Kirsten Lodén at Stockholm is associated with Elvius in this work.

An investigation of the south galactic polar region (including S.A. 141) is being made by Eriksson from plates taken with the Uppsala Schmidt telescope at Mt. Stromlo. In an area of 40 sq. deg. *BV* photometry has been finished for all stars brighter than $V = 15$; in 30 sq. deg. the photometry extends to $V = 16$ and is completed by spectrophotometric data for stars brighter than $B = 14$. All plates have been taken and reductions are almost complete.

An analysis of the region of 120 sq. deg. around the north galactic pole has been continued by Malmquist. In a preliminary analysis of the data he has found absorbing clouds at 200 pc and 400 pc from the sun. The determination of the stellar distribution is complicated by the irregular distribution of absorbing dust clouds, as found by Ljunggren from a study of accurate color excesses of selected stars in the same region. The stellar distribution of late-type giant stars perpendicular to the galactic plane is being studied intensively by Häagkvist and Oja at Uppsala.

An extensive program involving star counts in Scorpius, Ophiuchus, Corona Australis and Sagittarius, begun many years ago, has been completed by van Hoof.

The important research by means of 3-color photometry by W. Becker and his colleagues at Basel for intermediate and high galactic latitudes has been summarized by Fenkart. Space density gradients for several Selected Areas in the galactic halo are compared with models of the halo. Details for three such investigations are given by Becker and Fenkart.

A major attack on problems of galactic structure at high latitudes is underway at the Dudley Observatory under the supervision of A. G. D. Philip. Forty-two areas are under observation; spectral types, colors and magnitudes required for studies of the space density fluctuation perpendicular to the galactic plane are being determined. The magnitude limit for these surveys is $B \simeq 13$.

Philip reports that photoelectric photometry is being done in the *UBV* the Strömgren 4-color, and the Hβ systems of all stars of early spectral type found in these high latitude fields. In one paper it was shown that the A stars at the NGP fainter than $V = 11·5$ are predominantly of Population II, while the brighter ones are of Population I. The reddening at the NGP was found to be $E_{B-V} =$ 0·05 magnitude. A similar study for an area at the south galactic pole indicates that the reddening there is at least twice as great as at the NGP and the change from predominantly Pop. I to Pop. II is not as abrupt. This is consistent with the idea that the sun is somewhat north of the galactic plane.

J. S. Drilling is collaborating with Philip in the analysis of the areas at $l^{II}=0°$, $b^{II}=-45°$ and $l^{II}=180°$, $b^{II}=-45°$. Analysis of these areas, together with an analysis of the SGP area, will help in determining the direction of surfaces of equal star density near the sun. J. Stock is collaborating in the study of a series of fields along a strip from the SGP to the galactic equator to determine the change in distribution of the early-type stars with galactic latitude.

A study of stellar space densities at intermediate galactic latitudes is reported by A. R. Upgren. The objective is to determine the inclination to the galactic plane of layers of equal star density.

In addition to the research mentioned here several other studies of the regions around the galactic poles have been made. Slettebak *et al.* have obtained slit spectrograms and *uvby* color data for 77 A stars with magnitudes between 7 and 9·5 at the NGP. Spectral types were estimated and rotational and radial velocities were measured from the spectrograms. An investigation of an 840 sq. deg. region around the SGP has also been reported by Slettebak. An objective prism survey with the Michigan Schmidt telescope at the Cerro Tololo Interamerican Observatory in Chile has yielded a list of some 900 stars, F0 and earlier, brighter than magnitude 14. In the course of this study seven carbon stars, four of which are new, were detected. With the exception of the bright variable R Scl, all are early R-type stars at distances between 2 and 5 kpc from the galactic plane (Slettebak *et al.*).

Eggen has continued his observational investigations of stellar population samples at the galactic poles. For 130 stars at the south galactic pole listed in the Bruce proper motion survey he has given *UBV* photometry. The majority of the stars from the Bruce Proper Motion survey have elliptical orbits with $e<0{\cdot}5$ and appear to belong to an old disk population.

The detection and study of faint blue objects in high galactic latitudes is a fertile field of galactic research at present. Barbieri *et al.* have used the Schmidt telescope at Asiago to search for stars with negative $U-B$ color index in a field at $l^{II}=243°$, $b^{II}=+67°$. Here 129 objects in an area of 25 sq. deg. were found. In connection with this type of search Luyten reports on a technique developed by him and Sandage, whereby beginning with three-image plates taken in ultraviolet, blue and yellow, and following with determinations of photoelectric colors and proper motions, it has become possible to identify correctly the quasars, sub-dwarfs, white dwarfs and other objects from among the faint blue stars in high galactic latitudes.

IV. OVERALL GALACTIC STRUCTURE

(S. McCuskey)

The large-scale structure of our Galaxy depends to a large extent upon observational techniques sufficiently powerful to penetrate the interstellar absorption in our neighborhood. These include predominantly optical photometric techniques in those sections of the spectrum (the infrared for example) where the dust in space has the least effect, the radio techniques for studying the distribution of H I and H II and other gases, and polarization techniques, both optical and radio.

In the period under review, three large 21-cm line surveys of the Milky Way strip have been published by Westerhout, by Kerr, and by Weaver. There have also been extensive surveys of recombination line sources, OH emission and absorption, and of the radio continuum at various wavelengths. Studies of several other lines are still in their early stages. The Commission 40 report contains details of these surveys. The available information has been very considerably enlarged. In what follows, an attempt will be made to assess the current state of affairs concerning the large-scale view of the Galaxy.

A. *Spiral structure*

By far the most significant discussion and evaluation of spiral features in the Galaxy took place in IAU Symposium no. 38 in Basel in August 1969. In due time, a volume detailing the symposium and containing an excellent summary by B. J. Bok will appear. Here only a few essential features concerning the spiral structure will be noted.

(1) It is clear from the researches on stellar distribution to distances of 4 to 6 kpc from the sun that OB^{+} and OB° stars, WR stars, early Be stars, O associations, some S and N (carbon) stars show concentrations into spiral-like features resembling similar features in external galaxies.

(2) The classical cepheids of $P > 10$ days ($M_v < -4{\cdot}3$), possibly some of the early giant M stars, possibly the upper main sequence (B5–A2) stars, may be loosely identified with local spiral structure but the evidence is not strong.

(3) Other star groups in the solar vicinity to distances of 2 to 3 kpc show no correlation with groupings under items (1) and (2).

(4) Extended studies by W. Becker and his colleagues confirm the association of young clusters with the other optical spiral features. The Perseus, Orion, Sagittarius and Norma-Scutum spiral-like structures have very interesting counterparts in the outer regions of NGC1232. And there is a gap in the local longitude system of NGC1232 corresponding to the spiral-structure gap at $140^{\circ} < l^{II} < 180^{\circ}$ in our Galaxy where only one spiral arm appears (the local arm). It was also pointed out that a gap of 1·5 kpc extent exists between the sun and the Carina spiral feature. The large pitch angle of these optical spiral features compared to the small angle shown by the H I spiral structure persists.

(5) Optical H II regions studied by Courtés and colleagues outline spiral-arm structures with pitch angles about 20° in the following regions:

Perseus	$105^{\circ} < l^{II} < 190^{\circ}$	3 kpc at 120° minimum distance
Orion	$59^{\circ} < l^{II} < 254^{\circ}$	0·5 kpc at 180° minimum distance
Sagittarius	$274^{\circ} < l^{II} < 32^{\circ}$	1·5 kpc at 330° minimum distance
Norma-Scutum	$308^{\circ} < l^{II} < 333^{\circ}$	3·5 kpc at 330° minimum distance

The inclination of these is similar to that outlined by the young clusters (item 4). According to the French astronomers the OB stars, long period cepheids and H II regions all have the same velocity characteristics.

(6) A study of the dust lanes in 17 Sc-type galaxies by B. Lynds indicates rather conclusively that these appear first close to the galactic nucleus and gradually assume a position bordering the luminous arms on the inside edges. The dust lanes define clearly a spiral pattern in which the brightest H II regions are generally found at the edges of the dark material. Presumably a similar state of affairs would prevail in our Galaxy.

It is clear that more detailed studies of regions showing apparent spiral structure are now required. Two such investigations were reported at IAU Symposium no. 38. The first by H. Dickel and colleagues is a study of the Cygnus region $70^{\circ} < l^{II} < 90^{\circ}$, $-8^{\circ} < b^{II} < +8^{\circ}$. Here 193 optical nebulae have been catalogued and their shapes and orientations determined. Distances have been obtained for about one half of these in the Cygnus X complex by comparison of optical and radio data. The model developed by Mrs. Dickel and colleagues indicates that (1) the pitch angle of this spiral feature is about 13°; (2) the angle of tilt relative to the galactic plane is about 1°; (3) the sun is approximately 0·8 of the distance from the central axis toward the edge of the spiral structure; (4) the semi-major axis of the arm cross-section is 0·2 kpc; (5) the ratio of minor to major axes of the cylindrical cross-section is more than 0·5 and is close to 1.

A second important study is that by B. J. Bok *et al.* of the spiral-like feature in Carina, $270^{\circ} < l^{II} < 300^{\circ}$. Optical data, plus radio data from Australia and Argentina on the H I distribution and the H II distribution indicate a sharply bounded, elongated concentration in Carina extending from 2 to 8 kpc from the sun. Along $l^{II} = 283^{\circ} - 285^{\circ}$ the OB star and supergiant star distribution is sharply bounded. The other boundary of the feature is less sharply delineated at $l^{II} = 295^{\circ} - 300^{\circ}$. This inside edge of the spiral structure is not very rich in dust. At 5 kpc from the sun, the major elements of the spiral feature are between 100 and 300 pc below the galactic plane.

Clearly it is imperative to have more studies similar to the two mentioned above in order to gain any adequate picture of the large-scale spiral structure in the neighborhood of the sun.

In addition to the spiral-arm tracers mentioned above the use of stars embedded in reflection nebulae for this purpose appears feasible. Racine and van den Bergh have introduced these

"R-associations". Racine has shown by spectrographic and *UBV* photometric observation of 188 stars associated with reflection nebulae that groupings (R-associations) exist whose galactic positions and distribution correlate well with the OB associations which appear to trace out the local spiral arm. The inner part of this structure is about 350 pc from the sun toward the Perseus arm. All of the R-associations are within 1 kpc of the sun. These data imply that the local spiral arm is tilted some 10° with respect to the galactic plane. Its center is some 250 pc toward $l^{II} = 160°$; for $l^{II} < 160°$, $z > 0$ and for $l^{II} > 160°$, $z < 0$ for objects delineating the R-associations.

Dixon has made a comprehensive study of the 3-dimensional spiral structure from distributions of O and B stars, H I and H II gas. He considers both non-gravitational and gravitational forces, the former causing stars to fall away from the interstellar clouds from which they were formed. The local spiral feature, according to Dixon, has a ribbon-like structure about 200 pc thick, and 1500 pc long; it is tilted with respect to the galactic plane, rising to a $z = +100$ pc at 800 pc toward $l^{II} = 70°$ and falling to $z = -150$ pc at 700 pc toward $l^{II} = 250°$. The motions of the early and the late B stars within 1 kpc of the sun indicate that the older stars (age 3×10^7 yr) drift away from the younger (age $< 10^7$ yr).

Following his study of the Orion complex and Gould's Belt, Clube called attention to the modification in H I concentrations which would be necessary if the velocity field of Gould's Belt were taken into account.

Fernie has made a new study of the relationship of classical cepheid variables to the galactic spiral structure. No *well-defined* spiral structure is evident in the distribution of the cepheids. If one sees in this distribution some semblance of spiral structure the sun would appear to be toward the *outer* edge of the concentration.

The large-scale distribution of hydrogen in the Galaxy has been reviewed by Kerr. This paper includes a hydrogen spiral diagram, in which the arms have a small pitch angle. Weaver has derived a more open type of spiral pattern from his own observations. The various observational surveys give quite similar results; the differences are in the interpretation, mainly in the manner of joining together the observed features into large-scale patterns. In the solar vicinity, the main difference between the two patterns is that Weaver joins the Sagittarius and Carina arms, while Kerr has a Carina-Cygnus arm passing through the Sun, and a separate Sagittarius arm.

Burton and Shane have carried out a detailed model-fitting study of their observations in a restricted range of longitude $l^{II} = 22° - 56°$. They have taken the Lin density-wave theory into account, but find it necessary to introduce additional motions in order to improve the fit. They find two arms in the inner region, with a low pitch angle.

The difficulties in the interpretation of the 21-cm data arise from the restriction to kinematic distances, which are based on a limited understanding of the large-scale velocity field, and the existence of a large amount of fine structure superposed on the large-scale pattern.

The hydrogen spiral arms are found by all workers to be patchy on a scale of 500–1000 pc, and also they show a considerable amount of splitting and cross-linkage. An individual spiral arm is often centered a few tens of parsecs above or below the galactic plane, maintaining approximately the same displacement over a substantial distance (Henderson).

Recombination-line surveys can also be used to investigate large-scale structure through the distribution of H II regions (Burke, Mezger and Palmer, McGee and Gardner, Dieter, Wilson). It is found, however, that the H II observations cannot lead to a spiral structure map on their own, primarily because the velocity dispersion of the individual sources tends to smear out the spiral pattern. The H I and H II results are generally compatible, but there is an important difference between the radial distributions. The "giant" H II regions which are responsible for the recombination-line and OH emission are almost wholly confined to a ring between 4 and 7 kpc from the galactic center, whereas the maximum density of H I is found outside this ring.

Absorption studies show that hydroxyl and formaldehyde molecules are widely distributed through the Galaxy (Goss, Snyder *et al.*). The close agreement between the velocities measured in the OH, H_2CO and H I lines indicates that the molecules must have the same general distribution as the H I, and must therefore be concentrated to the spiral arms.

A number of continuum surveys have been carried out in various parts of the Galaxy. The most detailed are the 11-cm surveys by Altenhoff, and by the Australian group, which show the concentration of thermal sources to the spiral arms.

B. *The galactic disk*

The structure of the galactic disk as regards the stellar population is discussed in Section III. Here we indicate those radio astronomical studies of this part of the Galaxy which have been made during the triennium under review.

Henderson has carried out a new study of the shape of the neutral hydrogen layer on the northern side. He has delineated the small variations from a plane in the inner parts, and the twist of the outer parts. The possibility that the outer twisting was produced by the Magellanic Clouds has been rediscussed by Avner and King, and Hunter and Toomre.

Altenhoff and Andrew have shown from radio continuum studies that the ionized hydrogen is concentrated in discrete regions, with little or no evidence of any general disk-like distribution.

There have been several new studies of the spectrum of the galactic continuum emission at high latitudes (Bridle, Yates and Wielebinski, Getmantsev *et al.*).

C. *The galactic nucleus*

Optical observations of the galactic nucleus are impossible in the usual wavelength regions because of the interstellar absorption. Much effort recently, however, has been devoted to observing this galactic center region with far infrared techniques.

Beckin and Neugebauer have surveyed with relatively high resolution at $\lambda = 1{\cdot}65$, $2{\cdot}2$ and $3{\cdot}4\mu$, the galactic center region. They find a dominant source of infrared radiation 5′ arc in diameter, together with a point source centered on the dominant source. There is an extended background of radiation at these wavelengths, and additional extended hot-spots. The dominant infrared source coincides in position with Sagittarius A as determined by radio observations. Its observed energy distribution is similar to that of a black body at 900 K. The small point source has a diameter of 5″ arc, or less. Across the region surveyed the energy distribution compares favorably with that across the nuclear region of M 31.

In a second contribution Becklin and Neugebauer have extended their observations to include wavelengths from $1{\cdot}65\mu$ to $19{\cdot}5\mu$. An extremely strong source 20″ arc in diameter was observed at $\lambda = 10$ and 20μ. In summary, there appear to be three sources of infrared radiation in this region: (1) a general background source which is some 150–200 pc in diameter in which the intensity decreases with distance from its center; (2) a core source about 1 pc in diameter which stands out at $\lambda = 5$ and 10μ; (3) a pointlike source as mentioned in the paragraph above.

An intense source of far-infrared radiation, $\lambda = 100\mu$, extending for $6^\circ\!.5$, at least, along the galactic equator in the galactic center region has been observed by Hoffmann and Frederick. It is indicated that, if this is assumed to be thermal emission from interstellar dust grains, the observed intensity is 30 times greater than might be anticipated by such a mechanism.

It is clear from the paucity of present optical data concerning the nuclear region of our Galaxy that much new information should result from these important infrared techniques in the immediate future.

Radio investigations of the nuclear region have been reviewed by Kerr and Lequeux. More recent work has largely concentrated on studies of line emission and absorption in the vicinity of the galactic center. A number of OH clouds can be seen in the region. One of these, which may be very close to the center, appears to be a discrete rotating cloud of 10 pc diameter (Kerr and Sandqvist), which also contains ammonia (Cheung *et al.*) and formaldehyde (Snyder *et al.*).

Sgr B2, at $l^{\rm II} = 0^\circ\!.7$, $b^{\rm II} = 0^\circ\!.0$, is a complex object, which shows strong OH and H_2O emission, weak NH_3 and recombination line emission, and H I, OH and H_2CO absorption effects. The object shows typical characteristics of an H II region and also those of a molecular cloud, approximately coincident in position.

From lunar occultation observations, Maxwell and Taylor have derived an improved position for the source Sagittarius A, which is believed to be at the galactic center.

D. *The galactic halo*

Section IIIC has dealt with the optical stellar distributions in the high latitude regions and into the galactic halo. A brief summary of the radio astronomical investigations during the past three years follows here.

Burke and others have thrown doubt on the existence of the synchrotron-emitting halo which has been discussed for the last decade. It seems likely that, if a halo exists at all, it must be smaller in size and have a lower volume emissivity than was originally proposed by Baldwin and Mills.

Miss Keppner, Weaver and others have found neutral hydrogen in many parts of the Galaxy which appears to be at large z-distances from the plane (1 kpc or more), but is still related to the spiral structure in the plane. In these cases, the main spiral-arm concentration of gas is close to the plane, as known before, but there are lower-density extensions above and below the plane to a considerable distance.

V. KINEMATICS

A. *Stars*

Galactic rotation

Extensive work in deriving Oort's constants from proper motions of stars has been done by Fricke. From FK4 proper motions he found: $A = 12{\cdot}3 \pm 2{\cdot}4$, $B = -7{\cdot}6 \pm 2{\cdot}4$, while from distant stars (>100 pc) he found: $A = 14{\cdot}2 \pm 1{\cdot}9$, $B = -11{\cdot}8 \pm 1{\cdot}9$ (FK4 system), and $A = 17{\cdot}1 \pm 1{\cdot}9$, $B = -10{\cdot}0 \pm 1{\cdot}9$ (N30 system). Dieckvoss found $A = 14{\cdot}8 \pm 0{\cdot}7$, $B = -11{\cdot}3 \pm 0{\cdot}6$ from AGK3 proper motions.

A quite different value of $B = -24 \pm 2$ has been suggested by Aoki. He assumed that the unexplained part in the secular motion of the obliquity is due to a motion of the equatorial plane caused by friction between mantle and core of the earth. An examination of Aoki's basic assumption has been made by Lieske and Fricke, showing that there is no significant motion of the equatorial plane of unknown origin.

Crampton calculated the solar motion and galactic constants for Be stars, cepheids, young clusters and H II regions. He found the average values $U = -5{\cdot}5$, $V = +14{\cdot}0$, $A = 13{\cdot}5 \pm 1{\cdot}5$ and $K = -2{\cdot}0$. Crampton suggests that the commonly adopted local standard of rest moves outwards at 5 km s^{-1}. This value is smaller than the uncertainty in the local standard of rest, pointed out by Blaauw. In another paper Crampton and Fernie found the values $U = -8{\cdot}0$, $V = 14{\cdot}5$, $A = 12{\cdot}5$ from available data on classical cepheids. Takase found the values $U = -8{\cdot}1$, $V = 13{\cdot}9$, $W = 7{\cdot}3$, $A = 14{\cdot}3$, $B = -6{\cdot}1$, $K = -2{\cdot}6$ from 146 cepheids. Preston found values of A from 6 to 25, from the motions of Mira variables. Georgelin found a value $A = 6$ from a kinematic and photometric study of a region in Cassiopeia. The solar motion with respect to stars with enhanced metallic lines was found by Komarov. Barbier found that the velocities of O, B, A stars in a region in Cassiopeia are larger than in Schmidt's model. He derived also a value $A = 16{\cdot}0 \pm 2{\cdot}2$. The galactic motions of early type stars within 3 kpc from the sun were found by Yokoo through a statistical analysis of their radial velocities. Feast studied the radial velocities of distant cepheids. A value of $R_0 = 9{\cdot}8 \pm 1{\cdot}4$ for the distance of the galactic center was derived. Fokker derived the values $R_0 = 9{\cdot}7$ and $A = 14{\cdot}3$, using the radial velocities of distant stars. Petrie and Petrie found $A = 15{\cdot}1 \pm 0{\cdot}4$, $K = -0{\cdot}6 \pm 0{\cdot}3$ from 688 O9–B8 stars.

The solar motion with respect to the local group and exterior galaxies was found by Byrnes (341 ± 47 km s^{-1} towards $l^{\rm II} = 83^\circ\!.8 \pm 9^\circ\!.3$, $b^{\rm II} = -12^\circ\!.4 \pm 7^\circ\!.7$). Conklin found that the velocity of the earth with respect to the cosmic microwave radiation is the same as with respect to the local supercluster of galaxies. de Vaucouleurs and Peters found the velocity of the sun with respect to galaxies of various distances. While the velocity with respect to nearby galaxies is 315 ± 15 km s^{-1} towards a direction $l^{\mathrm{II}} = 95° \pm 6°$, $b^{\mathrm{II}} = -8° \pm 3°$, giving essentially the rotation around the center of the Galaxy, the velocities with respect to more distant galaxies are much larger, reaching about 4000 km s^{-1}; these velocities reflect mainly the motion in the "local supercluster".

The connection between galactic kinematics and an "absolute" system of proper motions was discussed by Clube. Further astrometric problems connected with galactic research were discussed by Murray and Blaauw during the IAU Meeting in Prague. The needs of radial velocities for deriving the local and large-scale galactic structure were pointed out by Blaauw and Thackeray. The accuracy of the calculation of the galactic constants has been considered by Mennessier and Crézé.

Velocity distribution

Martinet studied the kinematic properties of some groups of dwarfs, selected from physical criteria. He found similarities with the kinematics of A stars (vertex deviation, unusual ratio of axes of the velocity ellipsoid, etc.). Martinet and Mayor found the kinematic properties of 1000 field giants near the sun, in relation to their location in the H–R diagram.

The velocity ellipsoids of stars of different spectral classes and luminosities were found by C. Jaschek and Miss A. Gomez. The motions of bright F stars were considered by Eggen. He found that most stars belong to a few groups. Rydgren studied the distribution and kinematics of local early F stars. He found a concentration of F stars near the sun, which, however, must be a transient phenomenon. Jõeveer and Jõeveer *et al.* studied the kinematics of K stars. Philip found the radial velocities of 12 field horizontal branch stars. He derived a z-velocity dispersion larger than 100 km s^{-1}.

Smak studied the kinematics of Mira-type variables. Iwanowska considered the kinematics of late-type stars. Pavlovskaya and Karimova are determining the proper motions of many long-period cepheids, and Ap, Am stars. Crampton and Hill are determining distances and velocities of B stars, central stars of H II regions, and stars in the direction of high-velocity clouds. Froeschlé studied the kinematics of OB stars belonging to the local group. Shatsova studied the kinematics of O-B5 stars up to a distance of 3 kpc from the sun. She found that the dispersion of velocities increases towards the galactic center while it decreases slightly, or remains constant towards the anticenter. The dispersion of velocities in the region of the local spiral arm has a minimum at a distance less than 1 kpc.

The kinematics of planetary nebulae were considered by Perek, Feast, and by Webster.

Some problems of the distribution of velocities of nearby stars were discussed by Delhaye. He found that Am stars and many Ap stars have an elongated distribution in velocity space, near an axis with a vertex deviation 25°; Eggen's groups lie also along this axis.

A number of stars with velocities larger than 100 km s^{-1} perpendicular to the galactic plane were found by Eggen. Eggen found several groups of stars in the old disk population.

Ogorodnikov and Latyshev studied the kinematics of local star streams. Many stars in the solar neighborhood belong to the Hyades stream, and the Ursa Major stream. Ogorodnikov, Latyshev and Antonov plan to study the neighborhoods of known clusters to find further streams.

Groups of stars of the same spectral type were found by Meurers to have the same expansions as OB-associations. Groups of young stars were found by Crampton to have a common motion, differing by 5–10 km s^{-1} from the average motion of all the stars. Vandervoort found many moving pairs among the A-type stars within 20 pc. He suggested that they have common origin, being extreme cases of moving groups.

The kinematics of Gould's belt were considered by Clube and by Lesh. Clube found that the B stars of Gould's belt have a group motion corresponding to the Pleiades group, plus an expansion, giving an expansion age of $3{\cdot}7 \times 10^7$ yr. The A stars have the same kinematics as the B stars. Lesh proposed two models: One with a mixed population and expansion age $9{\cdot}0 \times 10^7$ yr and another one, with an expanding subset, which has an expansion age $4{\cdot}5 \times 10^7$ yr.

Crampton and Byl found evidence that some stellar rings are not physical groups.

An ellipsoidal law for the distribution of stellar velocities, which is similar to a Planck law, was proposed by Shatsova. Rudnicki has pointed out that the dependence of the velocity distribution of stars on space location is not known even in rough outline.

Bouvier found the influence of a finite velocity of escape on the ellipsoidal distribution of velocities. Massonie considered the effects of observational selection on the maximum of the velocity distribution.

B. *Interstellar matter*

Galactic rotation – non circular motions

The 21-cm rotation curve is consistently defined by radio astronomers, with only small differences, that can be attributed to differences in beamwidth and bandwidth. The "bumpy" form of the rotation curve, the north-south asymmetry and considerable fine structure are established. These effects are small with respect to the total velocity, but they are important in estimating distances. A review of these problems is given by Kerr (*A. Rev. Astr. Astrophys.*, **7**, 39, 1969).

The "bumpy" character of the rotation curve is due mainly to the gravitational forces of the spiral arms (Barbanis and Woltjer; Lin, Yuan and Shu; Yuan; Burton and Shane). The north-south asymmetry may be due to an oval distortion of the Galaxy (Hunter). Deviations from axial symmetry are observed in many external galaxies (M. S. Roberts, Robinson).

Bash found the galactic rotation curve, without assuming low optical depths, which give lower than usual velocities by 10 km s^{-1}. Petrovskaya studied the rotation of neutral hydrogen in the inner regions of the Galaxy for $z \neq 0$, assuming that the surfaces of equal angular velocity are spheroids.

The rotation curve derived from recombination line observations (Mezger *et al.*) agrees well with the H I curve. The kinematics of ionized and neutral hydrogen thus appears to be identical (Dieter, Mezger and Höglund, Kerr *et al.*, Mezger, Wilson).

Optical observations of the kinematics of H II regions were made by J. S. Miller and by Courtès and his associates. The kinematic behavior of H II regions is the same as that of other Population I components, like Cepheids and neutral hydrogen.

Velocities derived from H I, OH and H_2CO absorption lines agree with H I emission lines. The extension and intercomparison of observations of this kind will add greatly to our knowledge of gas kinematics.

Large non-circular motions have been observed in particular regions. Lindblad found several extended features in the anticenter region with radial motions up to at least 30 km s^{-1} in the Perseus arm. Explanations of such phenomena involve gravitational effects, due to the spiral arms, or big explosions. Systematic radial motions of about 10 km s^{-1} are predicted by Lin's theory of spiral waves (Yuan). Henderson has found an inward motion of the Perseus arm; however no such motion has been found in the Sagittarius arm (Kerr).

Blaauw has stressed the uncertainty of the local standard of rest, which leaves room for a (possible) lag of H I and the associated youngest stars by up to 8 km s^{-1}. An expansion of $+7$ km s^{-1} of matter near the sun, as proposed by Kerr, is also possible.

Many sections of spiral arms show a rolling motion which seems to be related to helical magnetic fields. Westerhout found a helical streaming of gas with velocity of the order of 10 km s^{-1} and a skew angle ~ 30° in the direction of galactic rotation.

Dixon presented evidence that the gas moves at about 15 km s^{-1} less than the circular velocity, because of non-gravitational forces. However Penston *et al.* found that non-gravitational forces produce a lag of the gas behind the stars by only about 3 km s^{-1}. There is much evidence that gas and the common stars move together (Takakubo, Courtès *et al.*, Kerr). Even deviations from circular motion seem to be the same for gas and stars (J. S. Miller).

This conclusion is supported by calculations of the solar motion with respect to gas and stars. Recent values of the solar motion with respect to neutral hydrogen have been provided by Takakubo ($U = -10{\cdot}4$, $V = 15{\cdot}2$, $W = 10{\cdot}9$), Venugopal and Shuter ($U = -12{\cdot}5$, $V = 14{\cdot}5$, $W = 8{\cdot}8$), Mast

($U = -11{\cdot}2$, $V = 15{\cdot}4$, $W = 8{\cdot}5$), and Nesterczuk ($U = -10{\cdot}2$, $V = 15{\cdot}4$, $W = 10{\cdot}9$); all are close to the standard solar motion.

The solar motion with respect to H II regions and Oort's constant A were found by J. S. Miller ($U = -6{\cdot}4 \pm 2{\cdot}1$, $V = 13{\cdot}3 \pm 1{\cdot}7$, $A = 15{\cdot}3 \pm 1{\cdot}4$) and by Georgelin ($U = -7{\cdot}5 \pm 1$, $V = 13{\cdot}1 \pm 1{\cdot}5$, $A = 14{\cdot}3 \pm 0{\cdot}5$).

Venugopal and Shuter, and Venugopal studied the velocity ellipsoid of the local hydrogen. The vertex direction was found aligned with the local magnetic field. The anisotropy of peculiar motions of the gas has been considered by Takakubo. Goldstein and MacDonald have studied local gas motions in the directions of early type stars with $|b^{\mathrm{II}}| > 20°$.

A number of dust clouds have been shown to be sources of OH line emission (Heiles, Cudaback and Heiles), H_2CO absorption (Zuckerman *et al.*), and H I absorption (Riegel and Jennings). The association is so well established that the velocities of gas can be regarded as referring to the dust clouds themselves; thus the kinematics of the dust can be studied for the first time.

Central region

Besides the outward motion of the bulk of the observed gas along the galactic plane evidence for outward motions at high angles has been provided by Kerr and Sinclair and by van der Kruit. The detailed motions near the center are studied by the newly discovered radio lines, particularly in the vicinity of Sgr A and Sgr B2.

Large velocities were found in the direction of the center by Mezger and Höglund through observations of the 109α recombination line. Data for ammonia have been published by Cheung *et al.*, and for formaldehyde by Snyder *et al.*

High velocity clouds

Dieter has recently (*Publ. astr. Soc. Pacific*, **81**, 186, 1969) reviewed our knowledge about the high- and intermediate-velocity interstellar gas. Detailed studies of the neutral hydrogen at intermediate latitudes have been made by Takakubo, and at high latitudes by Blaauw and his associates and by Hulsbosch. There is a correlation between deficiency in low-velocity gas and excess in intermediate-velocity gas. This may indicate a streaming in the nearby gas. Some of the intermediate-velocity clouds appear to be connected to the local disk of hydrogen (Verschuur) and it seems probable that these clouds are nearby. There are also indications of an interaction between gaseous masses of high and intermediate velocities (Dieter).

Heiles gave a dynamical model of the intermediate-velocity clouds, considering them as contracting in the halo and accelerating in the galactic gravitational field.

The nature and origin of the high-velocity clouds are still in doubt. Oort's theory of falling intergalactic matter, that sweeps the gas of the halo, is well known. Puppi, Setti and Woltjer studied theoretically the deceleration of intergalactic clouds. The collisions of high-velocity clouds with galactic gas were also studied by Savedoff *et al.*

On the other hand Kerr considers these clouds as satellites of our Galaxy, like the Magellanic Clouds, while Verschuur considers them to be extragalactic. According to Toomre the high-velocity clouds may have been broken away from the Magellanic Clouds during an earlier close passage. Rickard suggested that these clouds were produced by a large explosion, postulated to explain the non-circular velocities in the Perseus arm.

Many ambiguities concerning the high-velocity clouds will be solved if we find their distances. Kepner has published a list of 70 stars in the directions of the clouds, in which it may be possible to observe interstellar absorption lines.

VI. DYNAMICS

Stellar orbits – third integral

The general properties of orbits in two-dimensional potentials have been studied extensively by

Contopoulos and his associates (orbits in galaxies), Deprit and his associates (restricted three-body problem), Danby and Zahar, and Freeman and de Vaucouleurs (barred spirals). Particular emphasis is put on resonance phenomena (resonant periodic orbits and "tube" orbits). In the case of small perturbations the properties of orbits can be predicted by means of a "third" integral, which has special forms when conditions of near resonance are satisfied. Theoretical and experimental results connected with the "third" integral were discussed by Hénon, Saaf, Hori, Goudas, and Barbanis.

One of the most important papers in this area is Moser's construction of convergent series expansions for quasi-periodic motions in systems of 2 or more degrees of freedom.

The properties of orbits in spiral galaxies have been studied by Contopoulos and by Barbanis. Most orbits are of the general "ring-type" while resonant "tube" orbits are important in particular cases.

Indications for the existence of a "third" integral in the finite amplitude oscillations of Maclaurin spheroids were given by Rossner, and in the orbits of artificial satellites by Danby. Further applications of a "third" integral are given in the non-linear theory of spiral galaxies (Contopoulos).

Strongly perturbed dynamical systems display, to a certain degree, an ergodic behavior. Contopoulos has studied the properties of families of periodic orbits and their stability in such systems. He found many "regular" families of periodic orbits, that can be followed continuously from the unperturbed system, and many "irregular" families, independent of the above. It seems that the breakdown of the invariant surfaces is related to the appearance of "irregular" families of periodic orbits.

The breakdown of the "third" integral for large perturbations is understood as an overlapping of resonances (Contopoulos, Chirikov *et al.*, Ford *et al.*). Similar work has been done in plasma physics, in connection with the breakdown of adiabatic invariants or the destruction of magnetic surfaces (Rosenbluth *et al.*, Filonenko *et al.*). An interesting theoretical approach to these problems is contained in the book of Arnold and Avez, *Ergodic Problems of Classical Mechanics*, Benjamin, New York, 1968.

Work on systems of $N(>2)$ degrees of freedom is still at its first stages. In such cases the invariant surfaces are of N dimensions and do not separate the phase space. Thus a small dissolution of the invariant surfaces may secure ergodicity (Arnold diffusion). However recent work on three dimensional systems by Hénon and Froeschlé casts doubt on the effectiveness of such a diffusion.

Orbits in particular galactic models were calculated by Kuzmin and Malasidze, Innanen, Innanen and Southern, Ampel and Lebno, Ollongren, and Andrle.

Hori gave useful formulas for plane galactic orbits. Yuan calculated the orbits of some stars in Lin's spiral model of the Galaxy; he found that all these stars were formed in spiral arms.

Woolley and Candy found the perturbations of orbits due to irregularities in the galactic field.

Extensive numerical work has been done on the gravitational N-body problem. Many papers were published in the Proceedings of the Paris IAU Colloquium (*Bull. astr.*, 1968) by Aarseth, Cohen and Lecar, Feix and Hohl, Hayli, Hénon, Hockney, Hohl, Lecar, Peters, Standish, Szebehely, Thüring, Ulam, von Hoerner, and Wielen. This work deals with systems consisting of a few stars up to a few thousand stars. On the other hand calculations with hundreds of thousands of stars were made by Miller and Prendergast and by Hohl and Hockney.

Further work of the above type was done by Aarseth, Hockney, Hohl and Campbell, Goldstein *et al.*, Cuperman *et al.*, Hayli, and Wielen. Monte Carlo type N-body experiments were made by Hénon (many bodies), and by Agekian and Anosova, and Anosova (triple systems). Worall and van Albada studied systems of a few stars and the formation of binaries. Three special meetings, dealing mainly with plasma numerical experiments, took place in 1967 (Williamsburg, Virginia; NASA SP-153), 1968 (Los Alamos, New Mexico; LA-3990) and 1969 (Culham, England).

A comparison of various runs of the same 25-body problem calculated by different authors was made by Lecar at the Paris Colloquium. Good agreement was found only for very short times. It seems that only a few average quantities may be expected to be reliably computed by numerical experiments. A new IAU Colloquium (no. 10) on the gravitational N-body problem, will take place in Cambridge, England, during August 1970.

Models of the Galaxy

Self consistent models of galaxies have been developed by Ng, Perek, Shu, and by Vandervoort. Another model is considered by Kuzmin and Kutusov. A series of papers on galactic mass models have been published by Ejnasto, Ejnasto and Kutusov, and Ejnasto and Rümmel. Galactic models have been used by Innanen and Fox, and by Innanen and Kellett to derive the z-velocity dispersions. Relations among several dynamical quantities in galaxies were found by Takase and Kinoshita, and by Ejnasto.

Agekian and his associates constructed models of stellar systems by numerical integration of the N-body problem.

The force perpendicular to the galactic plane has been studied by Woolley and by Perry. The density near the sun was found by Woolley and Stewart to be $0{\cdot}11\ \odot/\mathrm{pc}^3$. If we compare this value with the value of $0{\cdot}08\ \odot/\mathrm{pc}^3$ of known objects, we see that the problem of missing matter is not so acute.

Spiral models of the Galaxy were used by Barbanis and Woltjer, and by Yuan.

Collisionless dynamics – stability problems

One of the most important branches of Stellar Dynamics is Collisionless Dynamics. This is applicable to systems with large relaxation times. Whenever the effects of collisions (or encounters) can be ignored we deal with cooperative phenomena. The basic equations used in such cases are the collisionless Boltzmann equation (known as Vlasov's equation by plasma physicists) and Poisson's equation.

In many cases we assume that we have an unperturbed self-consistent system undergoing small perturbations. E.g. we have an axisymmetric self consistent model of a galaxy and we study its perturbations, omitting all terms higher than the first in the collisionless Boltzmann equation. This is the linearized problem, which can be subdivided into the problem of modes and the initial value problem. The problem of modes (and, in particular, the stability problem) has attracted most of the interest.

In the case of gas we have the corresponding linearized hydrodynamical problem. In some papers the coupling between stars, gas and magnetic fields is considered.

A useful introduction to the theory of cooperative phenomena can be found in an article by Lynden-Bell (in *Relativity Theory and Astrophysics, 2, Galactic Structure*, Amer. Math. Soc., p. 131).

Hunter made an extensive study of the oscillations of disk galaxies. He studied first cold disk galaxies and he found growing leading spiral modes. He found also the appearance of continuous spectra of modes in some cases. Then he found large scale oscillations of galaxies that may explain the observed asymmetry between the northern and southern rotation curve of our Galaxy.

Local stability problems were considered by R. Graham, and by Niimi. Yabushita found that a central condensation can stabilize a differentially rotating disk. Julian investigated the possibility of the appearance of overstabilities. Lee, and Marochnik and Ptitsina studied oscillations of cylindrical systems. Hockney and Hohl found, by numerical experiments, the velocity dispersion of a disk of stars necessary to secure stability; their results agree with Toomre's theory.

Wu studied the stability of density waves in a self-gravitating stellar system with uniform rotation. Genkin found a critical wavelength for homogeneous rotating systems. The influence of a halo on the stability of ellipsoidal systems was considered by Miyamoto. Yabushita studied the instability of finite isothermal gas spheres. Maksumov studied collective effects in bounded systems.

Lynden-Bell and Ostriker gave a powerful variational principle for the stability of differentially rotating fluid bodies. Other criteria for stability were discussed by Lynden-Bell and Sanitt, Lynden-Bell, Milder, Lebovitz, Chandrasekhar and Lebovitz, Kovetz, Hohl and Feix, Robe and Brandt, Fridman, etc.

The oscillations and stability of particular types of fluid bodies were studied by Chandrasekhar and his associates, and others. A book on this subject has been prepared by Chandrasekhar.

Relativistic effects were introduced in the stability theory of spherical stellar systems by Ipser and Thorne.

Many papers on fragmentation and collapse have appeared recently. However, these problems are more related to cosmogonic problems, or problems of formation of interstellar clouds and stars.

Some particular solutions of the collisionless Boltzmann equation and Poisson's equation were given by Ehlers and Rienstra, Trümper, and Shimizu and Kitamura.

The bending modes of the Galaxy have been studied by Hunter and Toomre. The actual bending of our Galaxy is ascribed to a close passage of the Large Magellanic Cloud 5×10^8 yr ago. The influence of the Magellanic Clouds on our Galaxy was also considered by Avner and King.

An extreme case of collisionless stellar dynamics is when we have a violent mixing of a stellar system. Such extreme cases were considered by Lynden-Bell, who found a new statistical distribution, similar to the Fermi-Dirac. A number of numerical experiments were made by Hénon, Lecar and his associates, Feix and Hohl, and Hohl and Campbell, to check the applicability of this new statistics. It was found that in many cases where a violent mixing is produced this statistics represents well the observed energy distribution. In cases of less violent mixing, however, there are large discrepancies.

Dynamics of spiral structure – central region

Much work has been done on the gravitational theory of spiral structure in recent years. As indicated in the subsection on Magnetic Fields the strength of the magnetic field of our Galaxy is too small to account for the major spiral features. Thus the emphasis is placed on gravitational effects.

A review of the gravitational theories of spiral structure was given during the Basel Symposium by Contopoulos. Bok gave a very good summary of the whole Symposium.

A problem that attracted the interest of theoreticians was the "antispiral theorem" of Lynden-Bell and Ostriker. The theorem states that no stable spiral modes of oscillation exist, in general, in a gaseous galaxy. Similar theorems for a stellar galaxy were given by Yabushita, and by Shu. Kalnajs derived a similar theorem from general considerations about the symmetry of the equations of motion with respect to the plane of the galaxy and to time. However such theorems do not apply to slightly unstable systems. Thus a slightly growing wave does not contradict the antispiral theorem.

Lin and his associates have given a number of extensions and applications of the Lindblad-Lin theory of spiral structure. Shu has given the basic integral equation from which one can derive the spiral modes. A similar equation was given previously by Kalnajs. Yubashita gave a matrix equation for the eigenvalues and eigenfunctions which he solved numerically.

Shu studied density waves in the post-epicyclic approximation. He found that the action density of the waves is transported inwards with Toomre's group velocity. The oscillation modes appear to be real in this approximation also, thus no indications of instability (growing waves) or damping appear.

Lin, Yuan and Shu have pointed out a number of applications of the theory. A value of 13·5 km s^{-1} kpc^{-1} is adopted for the rotational velocity of the spiral pattern, taking into account the effects of thickness. Yuan has shown that the hypothesis of missing hydrogen between spiral arms cannot explain satisfactorily the observed irregularities of the rotation curve of our Galaxy. On the other hand a good explanation can be given by means of a spiral field amounting to about 5%, in force, of the axisymmetric field. An explanation of the bumps of the rotation curve in terms of a spiral field was given also by Barbanis and Woltjer. Recently Burton and Shane made an analysis of the observations of neutral hydrogen in the first quadrant of galactic longitude and found agreement with Lin's theory.

Yuan calculated the 21 cm profiles that should be observed in the adopted spiral field and found good agreement with observations. The theory predicts also a radial inward component in the spiral arms of 10 km s^{-1}. Such motions have been observed in the Perseus arm but not in the Sagittarius arm.

The interstellar gas moves through the spiral arms forming a shock wave on the inner edge of the arm. This phenomenon was studied by Fujimoto, and by W. W. Roberts. The shock produces a compression of interstellar matter and enhances star formation. An exposition of the applications of the gravitational theory of spiral structure was provided by Lin at the Basel Symposium.

The linearized problem for a galaxy with gaseous spiral arms was considered by Fujimoto. He used the linearized hydrodynamical equations and searched for self-consistent solutions. He found that the angular velocity of the spiral pattern is of the order of 17 km s^{-1} kpc^{-1}, and that the proportion of gas is larger when the spiral arms are more open.

Marochnik and Suchkov considered spiral waves in a galaxy composed of two Populations. Population I rotating in the usual way, and Population II with no average rotation. Then a Landau-type instability occurs, which generates a spiral pattern rotating with angular velocity smaller than that of Population I. Trailing and leading spirals have the same growth rate.

Kalnajs has developed a theory of spiral waves similar to, but independently from Lin. He attacked the linearized problem numerically, without making Lin's asymptotic assumption of tightly wound spirals, and found open spiral waves, rotating faster than the stars, which are slightly growing. He found also some global conservation theorems for spiral patterns.

Spiral modes were found by Yabushita, by integrating numerically the basic integral equation, written in a matrix form. Numerical investigations of spiral modes were made also by Miyamoto. Finite thickness effects in a spiral galaxy were considered by Shu, and by Vandervoort.

Mayor studied the local irregularities of the velocity field near the sun, due to spiral waves. One can explain, in this way, the vertex deviation of the velocity ellipsoid. On the other hand Woolley found that the vertex deviation is confined to young stars only, therefore it is probably connected with their origin and not with the spiral field of the Galaxy.

The problem of preference of trailing spiral waves attracted also the attention of theoreticians. It is known that local theories give always trailing waves. However, global theories favor equally well leading and trailing waves if boundary conditions are not taken into account. In our Galaxy a discrimination between trailing and leading spirals can be provided by Lindblad's inner resonance. Kalnajs presented some arguments that an imposed growing wave, trailing or leading, produces trailing waves near the inner Lindblad resonance. Contopoulos found a strong preference of trailing waves, by numerical calculations, using Lin's asymptotic assumption of tightly wound spirals. An imposed leading field has a trailing response near the inner Lindblad resonance.

The initial value problem can be solved relatively easily, once the problem of modes is solved, by a method similar to Landau's method in plasma physics. Contopoulos formulated this problem in Lin's terminology. In a certain sense the problem of origin of spiral waves is trivial. Any initial perturbation excites Lin's modes. These modes, however, do not have, in general, the same angular velocity. Thus there is a differential rotation of the spiral "patterns", although not equally marked as the differential rotation of the stars.

Toomre has considered the problem of the evolution of a system of waves satisfying Lin's dispersion relation. He found a "group velocity" of the waves which is directed inwards and amounts to ~ 10 km s^{-1}. In a numerical example Toomre found further that the amplitude of the waves is decreasing as the groups of waves move inwards from the co-rotation distance and vanishes near the inner Lindblad resonance.

Near the inner Lindblad resonance the linear theory is not applicable except for short times. As the wave grows from zero non-linear effects become soon very important and mask the linear effects (Contopoulos). The stars are arranged near two periodic orbits similar to two perpendicular ellipses and the system has a rough quadruple symmetry. Lin suggests that such non-linear effects transfer the energy of the inward moving groups of waves into an open spiral mode which extends outwards up to the co-rotation distance. Thus a steady state circulation may be formed.

Spiral waves were found experimentally by Miller, Prendergast and Quirk by N-body problem calculations. The waves seem to extend between the inner Lindblad resonance and the co-rotation distance.

The mechanism of origin of spiral waves has been considered by Toomre, who studied mainly the effects of an approach of the Magellanic Clouds. On the other hand Lin ascribed the spiral patterns to large scale turbulence near the co-rotation distance (in our Galaxy at about 15 kpc). At the co-rotation distance another resonance effect is important. Matter is escaping away from arms and concentrates near the Lagrangian points L_4, L_5, and the spiral arms are broken (Barbanis).

Another mechanism for the origin of spiral waves may be provided by the differential rotation (Lynden-Bell). This mechanism was considered by Kalnajs as a two-ring instability.

Non-linear spiral problems were also considered by Marochnik and Suchkov, Berry and Vandervoort, and by Niimi.

A number of authors have pointed out the importance of a bar near the center for the origin of spiral patterns. Some work on the theory of barred spirals has been done by Prendergast, Pikel'ner, and by Freeman. Freeman and Harrington, Freeman, and de Vaucouleurs and Freeman calculated orbits in barred and irregular spirals in order to explain the appearence of rings and some other characteristics of such spirals. However, no wave theory of barred spirals has yet been developed. Such a theory would be desirable in view of the continuity of form between normal and barred spirals.

Magnetic theories of spiral patterns were provided by Greyber, Piddington, and by Pişmiş. Pikel'ner pointed out that a magnetic field is essential for the existence of spiral arms, because it prevents their collapse. Arp suggested that the spiral arms are the tracks of material ejected from the nuclei of galaxies.

The dynamics of the central region of our Galaxy have been studied by Moore and Spiegel, and by Spiegel. A steady circulation of matter was found that may account for the expanding 4 kpc arm. A flow of matter from the nucleus, like the solar wind, reaches the 4 kpc arm, while its velocity drops abruptly from supersonic to subsonic. Then matter is moving outside the plane and returns at an angle to the center.

Collisional dynamics – evolution

Collisional Dynamics deals with stellar systems in which encounters are important. A particular problem of special importance is the long term evolution of stellar systems. Little progress has been made in these problems, because we are faced with many of the difficulties of the general N-body problem.

Prigogine and Severne have attacked this problem using their methods of non-equilibrium statistical mechanics. They have stressed the non-markovian character of stellar evolution, the memory effects and the fact that the entropy does not necessarily increase.

Some new approaches have been considered by Saslaw (gravithermodynamics), Gilbert ("dressed" particles) and Miller (polarization). The time of relaxation has been calculated more carefully by Ostriker and Davidsen and by Miller. Genkin found that resonance effects (motions "in phase") reduce considerably the relaxation time in rotating systems.

The effect of density waves on the relaxation of stellar systems was considered by Julian, Thorne, and by Marochnik and Suchkov. Julian found important increases of stellar velocity dispersions due to encounters of stars with density waves.

Thorne finds that cooperative phenomena at most double the dynamical friction. Ogorodnikov, Latyshev and Antonov are studying the effects of vast galactic stellar streams on stellar relaxation. Marochnik found that relaxation is faster if stars move in a field of condensing interstellar clouds. A similar mechanism for the increase of the dispersion of velocities of older stars was proposed earlier by Barbanis and Woltjer. A local model for the increase of dispersion of velocities through interactions with interstellar clouds was proposed by Woolley and Candy.

Lee considered random motions of stars in a stellar system and derived a transition probability. He concluded that the Fokker-Planck equation is not strictly valid. Shimizu studied the effects of a random force on the stars. Petrovskaya and Kaliberda considered the motion of a star in a field of irregular forces.

Relativistic effects in stellar dynamics were considered by Lee, Ipser and Thorne, Ipser, and by Fackerell.

Many hopes for an understanding of the collisional processes and of the evolution of stellar systems are based on N-body numerical experiments. In all numerical experiments up to now a dense nucleus and an extended halo are formed. The central density increases while stars escape continuously. In a few examples studied by Hénon a spherical cluster (or galaxy) tends to a homologous system, which has a (mathematically) infinite central density. According to von Hoerner infinite central density is reached in 20 initial relaxation times. The properties of homologous systems were studied also by Agekyan.

A sensational description of the "gravothermal catastrophe" of a stellar system by continuous increase of the central density was provided by Lynden-Bell. However no complete theory exists as yet for the collisional evolution of stellar systems.

The evolution of a stellar system under certain assumptions was studied by Chandrasekhar. A number of authors used, or extended, the virial theorem. A tensor virial theorem for stellar systems was proved by Chandrasekhar and Lee. Bouvier extended the Lagrange-Jacobi identity to a system of stars and diffuse matter. Bouvier and de la Reza considered the applicability of the virial theorem to an expanding system. Tadokoro used the virial theorem for the study of the local group.

Bouvier considered the distribution of residual velocities when the escape velocity is finite. The evolution of the velocity spheroid due to star cloud encounters was studied by Kitamura. Kato studied the velocity ellipsoid by using hydrodynamic equations for the stellar "gas". Genkin used the Chapman-Enskop theory to derive the Schwarzschild velocity distribution.

Magnetic fields – cosmic rays

The first positive observations of 21-cm Zeeman splitting were made by Verschuur. He found fields of 10–20 μG in the Perseus arm (Cassiopeia A). However he found no such fields in four local features. Thus Verschuur argues that fields of the order of 10 μG may be quite local. Davies *et al.* found the same fields in the Perseus arm and fields of 2·5 μG in the Orion arm.

Polarization measurements in Cassiopeia were made by T. Schmidt and a field of 12 μG was found. Polarimetric measurements of nearby stars show that there are systematic differences in the galactic field, even within 100 pc from the sun (Appenzeller). Jokipii *et al.* also stressed the turbulent structure of the Galaxy, as derived from polarimetric observations. Klare and Neckel made polarimetric observations of 1421 southern O-B stars.

There are many observations that give a field along the direction of the Orion arm. This field may be helical. In fact a number of authors explain the optical and radio polarization measurements by means of a helical field near the sun (Hornby, Mathewson, Mathewson and Nicholls). However Appenzeller could not give a satisfactory explanation of his observations by means of such a field. Bingham and Shakeshaft studied the polarization and distribution of non-thermal radio emission within 1·3 kpc from the sun and found that the magnetic field is related to the local spiral arm, but not to Gould's belt. Clube on the other hand considers that the field is related to Gould's belt.

The north galactic spur is possibly related to the radio tracers of the helical structure of the magnetic field (Mathewson). Pronik found that the local magnetic field is quite irregular. Appenzeller found that near the axis of the local arm the field is parallel to the galactic plane, while near the sun it is inclined by 27°. Davies gave two models for the local magnetic field; in both of them the field has opposite directions above and below the galactic plane.

Some of the most recent measurements of galactic magnetic field were provided by observations of pulsars. There is evidence that pulsars are concentrated in spiral arms. Observations of Faraday rotation and dispersion measures in pulsars give the field strength and the electron density. Ekers *et al.* found a field of $0{\cdot}73 \pm 0{\cdot}13\,\mu$G along the inner face of the Orion arm. Similar results were found by Radhakrishnan *et al.* Staclin and Reifenstein found fields between 0·9 μG and 2·8 μG. F. G. Smith found fields between 0·2 μG and 3·5 μG in the directions of some pulsars. Jokipii and Lerche considered the effect of the turbulent structure of our Galaxy on the Faraday rotation and the dispersion in pulsar signals. They concluded that the average value of the magnetic field is 3 μG with a disperson $\pm 1{\cdot}5\,\mu$G.

Reviews about the galactic magnetic fields were provided by van de Hulst, Davis and Berge, and more recently by G. Burbidge, and by Woltjer. A field of about 3 μG is generally acceptable to-day.

Such a small field is not sufficient to counteract the effects of differential rotation, therefore it cannot be the main cause of formation and persistence of the spiral arms (Wentzel, Woltjer). However there are some local effects where magnetic effects play an important role. Fujimoto and Miyamoto developed magnetohydrodynamical models of helical fields in spiral arms. The importance of magnetic fields in the interstellar medium has been stressed by many authors. Review articles on the dynamics of the interstellar medium were written by Spitzer, Pikel'ner, and by Field. According to Pikel'ner the spiral arms are in magnetohydrodynamic equilibrium, and the arm thickness is determined by the pressure of the magnetic field and cosmic rays. This equilibrium is unstable, thus the gas breaks into clouds.

There are two basic models of interstellar clouds. In one (Field *et al.*) the major role is played by the gas pressure. The gas is heated by subsonic cosmic rays (Pikel'ner, and others) and cooled by collisional excitation and ionization of hydrogen and helium.

In the second model (Parker and Lerche) the magnetic pressure is considered larger than the pressure of the gas. The system gas-magnetic field is subject to a universal Rayleigh-Taylor instability. We can consider a hydromagnetic self-attraction, which is 10 times larger than the gravitational self-attraction and produces the clouds.

As regards the origin of the magnetic fields of our Galaxy, Parker ascribed it to interstellar turbulence and differential rotation. He proved that any inital weak field reaches at least 1 μG in 10^9 yr. The opposite view, of a primordial magnetic field, has been supported by Thorne.

The effects of non-gravitational forces (magnetic fields, turbulence and cosmic ray pressure) on the motion of interstellar gas around the center of the Galaxy have been estimated by Penston *et al.* They find that the gas lags behind the stars by a velocity of the order of 3 km s^{-1}.

The motion of cosmic rays in a random magnetic field was studied by Jokipii, and by Jokipii and Parker. Lerche and Parker studied also the bulk motion of the cosmic ray gas in our Galaxy, by taking moments of the collisionless Boltzmann equation. Hydromagnetic waves excited by cosmic rays were studied by Lerche and by Wentzel. Evidence for the existence of such waves comes from the scintillations of pulsars.

Weltzel found how the magnetic field of the clouds is separated from the general magnetic field. The influence of a magnetic field on the stability of the galactic disk was considered by Tassoul, and Aggarwal and Talwar. A magnetic field has a stabilizing effect.

The dynamics of cosmic rays were reviewed by Parker, and by Meyer.

The scattering of cosmic rays by waves is more important than the scattering by magnetic inhomogeneities (Fermi mechanism). The interactions between cosmic rays and Alfvén waves were investigated by Kulsrud and Pearce.

According to Ginzburg and Syrovatskii cosmic rays are mainly galactic, while according to the Burbidges and Hoyle they are universal, and according to Sciama they extend throughout the local group of galaxies. We have evidence that the electron component of cosmic rays is probably galactic, as well as protons and heavier nuclei with energies up to about 10^{15} eV, while the highest energy cosmic rays are probably extragalactic.

We have not discussed abundances, composition, and other properties of cosmic rays. A large number of papers on cosmic rays can be found in the Proceedings of the Tenth International Conference on Cosmic Rays (*Canadian J. Phys.*, **46**, no. 10), and the Fourth Texas Symposium on Relativistic Astrophysics.

G. CONTOPOULOS
President of the Commission

REPORT OF THE COMMITTEE OF "SELECTED AREAS"

Progress of research

Introductory notes

At the IAU Prague meeting it was considered desirable to continue to report on work performed