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

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1 INTRODUCTION

This report is intended to provide references to works done during the triennium 1988-1990 (including references for 1987) in the general field of galactic structure.
"Astronomy and Astrophysics Abstracts" provides an exhaustive list of works related to galactic structure and dynamics and it is not the aim of this report to duplicate this already existing service. Only a selection of works, illustrating some trends and highlights (a subjective view !), are described here and will certainly allow a comprehensive view of the broad domain of galactic research.
Thanks are due to all of the contributors to this report, which are not always officers of Commission 33 but are all very active in the field of galactic research, especially in their part of the report: Ulrich Bastian, Leo Blitz, Catherine Cesarsky, Eugene de Geus, Gerard Gilmore, Michel Grenon, Francesca Matteucci, Michel Mayor, Mark Morris, Daniel Pfenniger, Catherine Turon.

2 BASIC DATA

2.1 Parallaxes

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The years 1987–1990 will probably remain in the memory of astrometrists as a milestone with respect to the measurement of trigonometric parallaxes. First, ground–based measurements are of increasing precision, reaching the milliarcsecond level for relative parallaxes with the use of CCD and photoelectric observations, and second, these years saw the start of space astrometry with the launch of the European satellite HIPPARCOS and of the HUBBLE Space Telescope.

2.1.1 Ground–based observations

The observatories involved in long–term parallax measurement programs pursued their effort, concentrating especially on late–type, degenerate and subdwarf stars (Dahn et al., 1988, Astron. J. **95**, 237; Ianna et al., 1990, Astron. J. **99**, 415; Upgren et al., 1989, Astron. J. **98**, 1100). Significant efforts were made to improve observing conditions (automation of various telescope functions and controls) as well as the conditions of measurement (use of more accurate measuring machines). In parallel, new emulsions (IIIa type) were tested and adopted (Dahn et al.), allowing

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a higher positional accuracy. As a result, knowledge of the lower part of the HR diagram, from visual absolute magnitude 10 to nearly 16 , was significantly improved (Dahn et al., 1988).

In addition, new technologies have been developed (cf. review by Monet, 1988, Ann. Rev. Astron. Astrophys. **26**, 413, and references therein), and the first results announced for some of them (CCD measurements, claimed standard error for relative parallax: down to 0.5 milliarcsec for some faint stars, Monet et al., 1987, Bull. Am. Astron. Soc. **19**, 641; Dahn and Monet, 1990, in "Fundamentals of Astrometry", IAU Coll. 100, Belgrade, 1987; 0.002 milliarcseconds obtained with 27 CCD frames in only one year, Anguita and Ruiz, 1988, CTIO 25th Anniversary Symp., La Serena, 1988), or published (Multichanel Astrometric Photometer, MAP, described in Gatewood, 1987, Astron. J. **94**, 213, announcing an average external error of 1.5 milliarcsec for the first trigonometric parallax determinations (Gatewood, 1989, Astron. J. **97**, 1189; Gatewood et al., 1988, **332**, 917; 1989, Astrophys. J. **342**, 1085).

Difficulties of ground-based parallax determinations: about 40 plates spread over a few years are required for the determination of high precision trigonometric parallaxes. In addition, the correction from relative to absolute parallaxes is very delicate and requires the use of a model of our Galaxy (stellar components, interstellar reddening and absorption, luminosity function). Differences in the model may translate into systematic deviations, from 0.5 up to 2.5 milliarcsec (Breakiron, 1987, Astron. Astrophys. Suppl. **70**, 157; van Altena et al., 1990, in preparation). Finally, there are systematic differences between observatories which are not completely understood (van Altena and Lee, 1989, in "Star Catalogues": a centennial tribute to A.N. Vyssotsky", ed. A.G. Davis Philip and A.R. Upgren, p. 83).

Note: There is a very nice review by Murray of the determination of the distances of the stars, from the first attempts to present day high technology measurements (Murray, 1988, The Observatory **108**, 199).

2.1.2 Catalogues

- A new edition of the General Catalogue of Trigonometric Stellar Parallaxes has been prepared at Yale University Observatory (van Altena et al., 1990), and is due for publication by the end of 1990 or early 1991. It will contain 14,770 parallaxes for 7,675 stars, i.e. 1,276 additional stars as compared with the previous edition (Jenkins, 1963, Yale University Observatory). This small increase in the number of stars (1,276 in 26 years) is a good illustration of the difficulty of measuring trigonometric parallaxes from the ground. On the contrary, the average accuracy of relative parallaxes is considerably higher in this new edition. The correction from relative to absolute parallaxes (computed from a three component Galaxy model, including a thick disk), and the analysis of accidental and systematic errors, have been completely revised.
- A new edition of the Catalogue of Nearby Stars is also being prepared (Gliese and Jahreiss, 1989, in "Star Catalogues: a centennial tribute to A.N. Vyssotsky", ed. A.G. Davis Philip and A.R. Upgren, p. 1), including all known stars within 25 pc from the sun (distances determined from trigonometric, spectroscopic and photometric parallaxes).

2.1.3 Trigonometric parallaxes from Space

HIPPARCOS

HIPPARCOS, launched by Ariane on 8 August 1989 for the European Space Agency, was not able to reach its geostationary orbit due to the failure of its apogee boost motor. However, a "revised" mission was defined, for a highly elliptical orbit (perigee, 500 km; apogee, 36,000 km; period, 10 h 40 m). The measurement of the degradation of the solar panels, greatly reduced with respect to the degradation observed during the first months of the mission, allows us to hope for a lifetime of three years (and perhaps a little more).

A lifetime of three and a half years would allow the attainment of the original objectives of the mission: accuracies between 1 and 2 milliarcsec for positions, absolute parallaxes and annual proper motions for stars brighter than 9th magnitude and down to 4 to 5 milliarcsec for fainter stars (down to magnitude 12.5 in V). A complete description of the mission (pre-launch status) is given in Perryman et al., 1989 (in ESA-SP 1111).

The observing programme consists of 118,000 stars, preselected from 219 observation proposals dealing with a large variety of astrophysical and astrometric topics. The choice of the programme stars from the 210,000 proposed stars was made by taking into account not only the scientific priorities and rationale of the individual observation proposals but also the observational constraints inherent in the HIPPARCOS satellite operation (Turon, 1988, in "Mapping the sky", IAU Symp. no. 133, ed. S. Debarbat et al., p. 245; 1989, in "Star Catalogues: a centennial tribute to A.N. Vyssotsky", ed. A.G. Davis Philip and A.R. Upgren, p. 65).

Special care was taken in the verification of the statistical properties of the samples selected for galactic astronomy proposals and in the inclusion of distance indicators such as Cepheids, RR-Lyrae, and galactic cluster members (Gomez et al., 1989, in ESA-SP 1111, vol. II, ed. M.A.C. Perryman and C. Turon, p. 89; Mermilliod and Turon, 1989). A complete renewal of our knowledge of the cosmic distance scale, of age determinations, and of the structure, kinematics, dynamics and evolution of our Galaxy is expected from HIPPARCOS measurements. It is expected that about 100,000 stars from the 118,000 will have parallaxes larger than their standard errors, compared with about 3800 stars (half the catalogue) for the new version of the General Catalogue of Trigonometric Parallaxes.

HUBBLE Space Telescope

Some determinations of trigonometric parallaxes were included in the GTO programme for the HUBBLE Space Telescope for a small number of astrophysically interesting objects: Hyades cluster members, RR-Lyrae, cataclysmic variables, T Tauri stars, planetary nebulae, subdwarfs and Population II stars, etc.

As of this writing (Sept. 1990), it is not yet possible to know what will be achieved with respect to trigonometric parallax determinations with the Fine Guidance Sensors.

Other space projects

Projects aimed at precisions on the order of 0.01 or even 0.001 milliarcsec are presented (Monet, 1988 and references herein, Meinel and Meinel, 1987, BAAS **18**, 1012).

2.2 Proper Motions

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Much work has been done on proper motions in the past three years and a large number of important results were published. Both the number and the quality of available proper motions have considerably improved in this time period. The subject index of Astronomy and Astrophysics Abstracts for 1988 and 1989 lists 99 publications under the header "proper motions". Many more papers dealing with instrumental and data reduction aspects of proper motion determination are not even included there. As a consequence the following can mention only a number of highlights and examples.

Most of the publications report the determination of first or improved proper motions for particular objects or specific groups of objects. Among the object classes of interest for galactic astronomy are open clusters (e.g. Zhou et al. 1988, Publ. Purple Mountain Obs. **8**, 37; McNamara et al., 1989, Astron. J. **97**, 1427), globular clusters (e.g. Tucholke et al., 1988, IAU Symposium no 126 "Globular cluster systems in galaxies", eds J.E. Grindlay, A. Philip, p. 525), pulsars (e.g. Bailes et al., 1989, Astrophys. J. **343**, L53), low-luminosity stars (e.g. Hawkins and Bessell, 1988, M.N.R.A.S. **234**, 177), R CrB stars (e.g. Torres, 1988, Acta Astron. **38**, No 1, p. 31) and radio stars (e.g. Walter and Hering, 1988, Hipparcos, Scientific aspects of the Input Catalogue Preparation II. Proceedings of a colloquium held at Sitges, Spain, eds J. Torra, C. Turon, p. 487; Johnston et al., 1988, Hipparcos, Scientific aspects of the Input Catalogue Preparation II. Proceedings of a colloquium held at Sitges, Spain, eds J. Torra, C. Turon, p. 447;). A lot of such detail work was also done in the preparation of the Hipparcos Input Catalogue (see e.g. Torra and Turon, 1988, Hipparcos Scientific Aspects of the Input Catalogue Preparation II, Proceedings of a colloquium held at Sitges, Spain, ed. M.A.C. Perryman et al., "The Hipparcos Mission", ESA publication SP–1111 (3 volumes) for references).

On the other hand there are the large "global" collections of proper motions. The Fifth Fundamental Catalogue (FK5, Fricke et al., 1988, Fifth Fundamental Catalogue (FK5), Part I, Veröff. Astron. Recheninstitut Heidelberg, no 32) has appeared, defining the new dynamical IAU system of proper motions. The spatial density of this reference system has been increased by the additon of fainter stars (to about 9 mag) with the inclusion of 40,000 "International Reference Stars". A preliminary version of the second (southern) hemisphere IRS proper motions has appeared (Smith et al., 1989, IAU Symp. no 141 "Inertial Coordinate Systems on the Sky", Leningrad, p. 457). A further densification and extension to about 11 mag is provided by the 330,000 stars of the PPM ("Positions and Proper Motions") catalogue. This is a successor to the SAO Catalog, providing a factor of three improvement in accuracy. The northern hemisphere is completed (Roeser and Bastian, 1989, "PPM – positions and proper motions of 181'731 stars north of –2.5 deg declination."), a preliminary version for the southern hemisphere has been published (Bastian et al., 1990, Astron. Astrophys. Suppl. Ser., in press).

Results from the Lick northern proper motion program – another large "global" collection – have begun to emerge (Klemola et al., 1987, Astron. J. **94**, 501). In the end it will provide about 300,000 proper motions of stars (mostly 13 to 17 mag) directly related to galaxies, i.e. independent of the FK5 system. Both the data from this project and from FK5 have already been used to recalibrate galactic rotation and solar motion (Hanson, 1987, Astron. J. **94**, 409; Schwan, 1988, Astron. Astrophys. **198**, 116).

A third big collection, Luyten's NLTT of 50,000 stars with very high proper motions, has now become available in machine–readable form (Warren et al., 1989, Astron. J. **97**, 1480).

Proper motions are derived from measured positions. A number of very large position catalogues have appeared or are emerging presently. Most notable among these are the FOKAT–Yu of 200,000 southern stars (epoch about 1984, Bystrov et al., 1989, Sov. Astron. **33**, 214; Astron. Zhournal **66**, 425), the CPC–2 of 250,000 southern stars (epoch about 1966, Zacharias and de Vegt, 1989, Astron. Ges. Abstract Series **3**, 104), the Space Telescope Guide Star Catalogue of 20 million objects (epochs about 1975 to 1985, Taff et al., 1990, Astrophys. J. **353**, L45) and a machine–readable version of the Astrographic Catalogue of roughly 5 million objects (epochs mostly around 1910, Nesterov et al., 1990b, IAU Symp. No. 141, "Inertial Reference System on the Sky" p. 482). While the former two will be useful in further improving SAO/PPM–type catalogues, the latter two have the potential of deriving proper motions for millions of stars at moderate precision.

A number of new techniques are contributing to progress in the field. Among them are radio VLBI (growing in importance because of the longer time span now available), radio pulsar timing, the widespread use of automated plate measuring machines and the advent of astrometric space facilities. Traditional techniques, on the other hand, have developed to impressive accuracy (e.g. Cudworth and Rees, 1990: 0.02 arcsec per century for photographic relative proper motions) or production rate (e.g. CMC, 1987–1988: 10,000 meridian circle positions and derived proper motions per year).

The HIPPARCOS astrometry satellite (Perryman et al., 1989), despite its wrong orbit has been in successful operation since the end of 1989. If it reaches the necessary lifetime of three years it will provide another independent source of proper motions for 100,000 stars with high individual accuracy and (presumably) very small systematic errors. A major breakthrough in the precision of proper motions will be achieved if the milli-arcsec positional accuracy of HIPPARCOS can be combined with equally precise positions measured ten years or more later. Projects promising such data for galactic astronomy are the Hubble Space Telescope, the astrometric optical interferometers (Muzorkevich et al., 1988, 45.041.012) and the Soviet space astrometry project LOMONOSSOV (Nesterov et al., 1990, IAU Symp. No. 141 "Inertial Reference System on the Sky", p. 355).

2.3 Radial velocities

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2.3.1

Due to the efficiency of photoelectric spectrometers and new detectors like multiobject spectrometers as well as to the improved reduction of prism objective plates, the flow of new radial velocities increased steadily. For example, M. Barbier mentioned in her bibliographic catalogue that published data from 1981 to 1985 are more important than the number of radial velocity measurements acquired during the whole preceeding decade. Not only has the quantity of data increased , but also much fainter objects are being studied in highly interesting regions such as the galactic center or the very remote halo. The ESA-astrometric mission HIPPARCOS, with its ambitious program aimed at determining precise positions, parallaxes and proper motions for 118,000 stars, strongly stimulates the ground based acquisition of complementary data like photometry and stellar radial velocities.

Only references to radial velocity data, related to galactic structure, radial velocity catalogues and current programmes for the acquisition of a significant number of new velocities, will be mentioned in this section.

2.3.2 Catalogues

Barbier-Brossat (Astron. Astrophys. Suppl. **85**, 885, 1990) have compiled a bibliographic catalogue of stellar radial velocities including about 24,200 references for Galactic, LMC and SMC stars from 1970 to 1985. A catalogue of mean radial velocities for galactic stars supplements the General Catalogue of Wilson (1953) and Evans (1978) with observations published through December 1980. This catalogue contains new mean velocities for 6,451 stars with radial velocity data; more than 4,500 of them were not included in the earlier General Catalogues. (Barbier-Brossat, Astron. Astrophys. Suppl. **80**, 67, 1989). Beavers and Eitter (Astrophys. J. Suppl. **62**, 147, 1986) have reported approximately 16,000 stellar radial velocity measurements of nearly 2,000 late-type stars obtained at Fick Observatory with the photoelectric radial velocity spectrometer.

A list of radial velocities (measured by prism-objective techniques) for 764 stars have been published by Denoyelle (Astron. Astrophys. Supl. Ser. **70**, 373, 1987). These stars are in three fields of the Vela-Carina region of the Galaxy. In the frame of the ground based complementary measurements to the HIPPARCOS mission, lists of radial velocities of stars have been published by Fehrenbach and collaborators (Astron. Astrophys. Suppl. **71**, 263 (1987); **71**, 275 (1987)). These velocities have been obtained by the objective prism-technique.

2.3.3 Galactic kinematics

Kinematical studies in the three cardinal galactic directions are always well represented. Sandage and Fouts (Astrophys. J. **93**, 1987) have derived U,V,W velocity components for the old disk using radial velocities of 1,295 stars in the three cardinal galactic directions. These data have been used as constraints for the density ratios in the solar neighbourhood for the thin disk, thick disks and halo populations.

Two important samples of stars in the directions of the northern galactic pole (A and F stars) and southern galactic pole (O and F8 stars) have been studied respectively by Hill et al. 1988 (Publ. DAO **16**, 297) and by McFadzean et al. 1987 (M.N.R.A.S. **224**, 393).

Radial velocities and photometry of 364 G and K stars in the galactic center and anticenter directions have been obtained for the purpose of investigating the gradients of abundance and velocity dispersion in the galactic disk. (Neese, Yoss 1988, Astrophys. J. **95**, 463).

Mean radial velocities of 914 stars, selected from the Lowell Proper Motion Survey, have been published by Carney and Latham, 1987 (Astrophys. J. **93**, 116). This material is part of their galactic kinematic survey. These radial velocity data indicate that the fraction of binaries among the high-velocity stars probably exceeds 25%. A fraction similar for SBs in the halo is also obtained by Jasniewicz and Mayor, 1988 (Astron. Astrophys. **203**, 329).

Extreme velocity stars have been searched for. The most extreme velocities in the three primary Galactic directions are used to estimate the local value of the Galactic escape velocity. (Carney, Latham, Laird, 1988 Astrophys. J. **96**, 560; Carney, Peterson, 1988, Astrophys. J. **96**, 378; Dawson, de Robertis, 1989 Astrophys. J. **98**, 1472).

Radial velocities of 6 late-type stars within 2 pc of the center of our Galaxy have been acquired by 2.0 - 2.4 μm spectra (Sellgren et al. 1987, Astrophys. J. **317**, 881). The velocity dispersion of the galactic bulge has been estimated from radial velocities of 17 RR Lyrae stars in the Baade-Window (Gratton 1987, M.N.R.A.S. **224**, 175).

2.3.4 Low mass stars

Radial velocity measurements have been carried out by Upgren and Caruso, 1988 (Astrophys. J. **96**, 719) for 225 stars, most of which are dwarf K and M stars, and by Marcy, Lindsay and Wilson (1987) (PASP **99**, 616) for 72 M dwarfs. Radial velocity measurements of 206 nearby stars were made by Tokovinin 1988 (Astrofizika **28**, 297; Astrophysics **28**, no 2). This sample is used to discuss stellar duplicity among low mass stars.

2.3.5 Surveys in progress

Ground based observations complementary to the data of the HIPPARCOS satellite are actively pursued in the northern hemisphere. Different groups collaborate in such a large task either by slit spectrosocopy for blue star (Grenier and collab. from Haute-Provence Observatory; Gerbaldi et al.: 1989, ESO Messenger **56**, 12) or by using prism objective techniques, Burnage, Fehrenbach, Duflot, 1988 (in Scientific aspects of the Input Catalogue prep. II p. 427). Late spectral type stars are currently measured by cross-correlation spectroscopy, and a large fraction of the HIPPARCOS late-type stars will have a radial velocity measurements at the time of the HIPPARCOS results (Mayor et al.: 1989, ESO Messenger **56**, 12).

We should also mention the radial velocity survey of spheroid stars (Wyse and Gilmore 1988, in “The mass of the Galaxy”, p.15), the radial velocity survey of F and G dwarfs (about 5’000 stars brighter than V=8.3) by Copenhagen and Geneva astronomers. There is also a continuation in the southern hemisphere of the measurements of selected zones at a given galactic latitude ($b=\pm 35^o$) by Griffin (1986, M.N.R.A.S. **219**, 95), and a systematic survey of NLTT stars by Grenon at Geneva and Carney and Latham and Cfa.

Certainly, this list of surveys in progress is not exhaustive, but we are already convinced that the next five years will see an explosion in the number of radial velocities available for galactic structure studies.

2.4 Photometry and spectral classification

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Detailed reviews of papers published in the fields of photometry and spectral classification may be found in dedicated reports of Commissions 25, 37 and 45. The major results and trends in the field of galactic astronomy research using stellar photometry and spectral classification as tools are summarized here.

Photoelectric data obtained in one or several of the various photometric systems are presently available for some 166,000 stars. J.C.Mermilliod and collaborators have achieved in 1990 a new critical catalogue of Johnson UBV data containing about 92,500 entries. In parallel a new compilation by the same authors gives homogenized data for 44,886 stars observed in the Strömgren system. The last edition of the Geneva photometric catalogue by Rufener (1988, "Catalogue of stars measured in the Geneva Observatory Photometric System", 4th edition) contains 29,400 entries. New catalogues of data collected in the Walraven, DDO, Washington Eggen uvby and Vilnius systems are distributed by the data centers.

Since the introduction of CCD detectors we notice some decrease of the yearly amount of data collected with classical multicolour photometers. In particular the rate of UBV data published from 1987 to 1989, i.e. 2465/year, represents only 65% of that of the past 25 years. Similar trends are expected for the other multicolour systems in the coming years. This shift of emphasis towards CCD techniques is mainly due to the magnitude and spatial resolution limitations of classical photometers equipping small to intermediate size telescopes, and to the near completion of several programmes easily executable with the full accuracy of the photometric measurements. The difficulty of reconstructing classical multicolour photometric systems, namely those with bands in the UV and in the violet, using CCDs as detectors, led some teams to discontinue observations with the whole set of filters and to take rather advantage instead of CCD sensitivity in the near IR. Distant and even heavily reddened areas like the galactic bulge or the anticenter are now investigated using broad BVRI bands. HR-diagrams of metal-rich disc globulars in Baade's window by Ortolani et al. (1990, in "Bulges of Galaxies", ESO/CTIO Workshop) are impressive applications of CCD photometry. The Washington system and the new 77–87 system are also used with CCD detectors and allow metallicity estimates in distant late type stars. The abundance distribution of Baade's Window giants was recently obtained by Geisler et al. (1990, in "Bulges of Galaxies", ESO/CTIO Workshop) from Washington CCD photometry.

Classical multicolour photometry has been used, as in the past, for applications requiring its full capacity of deriving stellar physical parameters. The young galactic component was extensively studied, in particular open clusters, stellar associations, and pulsating variables. A major contribution is the Walraven photometry of southern OB associations by de Geus et al. (1989, Astron. Astrophys. Suppl. , submitted). Investigations on radial and perpendicular abundance gradients have been carried out using the uvby, DDO and Walraven systems. Surveys of stellar samples uniformly distributed over the sky remain the best suited application of multicolour photometry. An important programme for the study of galactic chemical evolution is the Strömgren photometry of brighter G–type stars down to m_v=8.3 by Olsen. The data collection is now finished and this sample will complete that of O to G2 stars already published. A large number of proper–motion stars from the Lowell Survey, and more recently from the NLTT catalogue, have been measured in the northern sky, namely by Carney and Latham (1987, Astron. J. **92**, 116) in UBV, by Weis (1988, Astron. J. **96**, 1710) in VRI and by Figueras et al. (1990, Astron. Astrophys. Suppl. **82**,57) in UBVRI and in the southern sky by Ryan (1989, Astron. J. **98**, 1693) in UBVRI and by the Geneva team with 6,050 NLTT stars.

The proper–motion survey south of –38° is still not completed, but the existing data provide strong constraints on early galactic history. High–velocity metal–poor stars were observed by Schuster et al. (1988, Astron. Astrophys. Suppl. **73**, 225) in uvby–Hβ.

The Hipparcos mission required specials efforts for the preparation of the 16,000 stars to be measured in the UBV, UBVRI, Strömgren, Geneva, or Walraven systems. Due to the success of the astrometric mission an extension of ground-based photometry of Hipparcos programme stars is expected in the next few years. Contributions are expected from Walraven photometry for stellar associations and early-type field stars, from Strömgren photometry for early G stars, and from Geneva for B to M stars. They will concern mainly the Milky Way and a complete sample of 52,800 stars. This sample appears crucial for the understanding of the relation between the age, metallicity, scale-height and birthplaces. A substantial fraction of Hipparcos Survey stars will have been measured by the end of this space mission in 1992, thus complementing the astrometric and radial velocity data. The Hipparcos mission opens the era of accurate photoelectric photometry from space and has already shown an unprecedented accuracy in the detection of variability and multiplicity. From TYCHO half a million B and V magnitudes, complete down to 10.5, as well as serious improvements in galactic structure and dynamics are expected.

Both IRAS and infrared RIJHKLMNQ colours were used to investigate M and C stars in central galactic regions as well as low luminosity stars or brown dwarf candidates in the solar vicinity. Spectral classification has been used to investigate the galactic vertical structure by Kuiken et al. (1989, M.N.R.A.S. **239**, 605) with K dwarfs and more recently by Corbally and Garrison with G dwarfs. Carbon stars were extensively studied, in particular by Lloyd Evans (1990, M.N.R.A.S. **243**, 336), and searched for by Kurtanidze et al. (1988, Astrofizika **29**, 405) in the northern Milky Way. The galactic anticenter direction has been surveyed by Chargeishvili (1988, Abast. Bull. **65**, 1–240) who published a catalogue of 6,037 stars. The large scale structure of the galactic bulge was studied by Blanco et al. (1989, Astron. J. **98**, 843) from spectra of 2,187 late M and C stars in low absorption windows. After the publication of 33,301 spectra in the Michigan Spectral Survey Vol. 4 (1988), Houk continues to classify HD stars in the declination zone −12 to +01°. The 30,000 stars of Vol. 5 of the Michigan Survey Catalogue to appear in 1992 will significantly extend the domain where kinematically unbiased samples of stars, peculiar or not, may be constituted. Abundance effects on stellar classification, CNO anomalies and overall metallicity variations are better documented and described e.g. by Keenan (1989, "Evolution of Peculiar Red Giants", IAU Coll. 106, 2) for the red giant domain and Gray (1989, Astron. J. **98**, 1049) for the intermediate population II F stars. The seventh and eighth editions of the MK Spectral Classification Catalogue were issued in 1988 and 1990 by Buscombe and Foster ("MK Spectral Classification Catalogue", 8th ed., Northwestern University Publ.).

2.5 The HIPPARCOS Input Catalogue

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The HIPPARCOS Input Catalogue includes the 118,000 stars which are being observed by the satellite. These stars were preselected from observation proposals from the worldwide astronomical community. The Catalogue is due for publication in early 1991 (printed version issued by ESA, tape version distributed by the CDS, Strasbourg. A CD–ROM version is under consideration).

The data content of the Catalogue (the result of 8 years of intensive work within the framework of the INCA Consortium) is for obtaining positions to better than one arcsecond at epoch 1990, magnitudes and colours to better than half a magnitude and complete information on double, multiple and variable stars. In addition, a significant effort was made on cross-identifications so as to avoid as much as possible any wrong identification of target stars.

All the aspects of the construction of the Input Catalogue are extensively described in ESA-SP 1111, vol. I, II, and III (1989, ed. M.A.C. Perryman and C.Turon).

The printed version will include: the Hipparcos Catalogue running number, positions for J2000 and B1950, proper motions, parallax, V and "Hipparcos" magnitudes, and B–V, spectral type and luminosity class, variability and multiplicity information, radial velocity, cross–identifications to HD, DM, SAO, AGK3, FK5, IRS, catalogue of Nearby Stars, High proper motion catalogues, variable, multiple and galactic cluster star identifiers, etc.

3 THE STELLAR COMPONENT OF THE GALAXY

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The period under review is remarkable both for the volume and quality of new data made available, and for the amount of progress in analysing these data to determine the important aspects of the structure and evolution of the Galaxy. It is now routine for discussions of the stellar distribution in the Galaxy to involve chemical abundance distributions and their evolution, kinematic and spatial distribution functions and their dynamical significance, and age distributions and their evolutionary implications. This fortunate situation depends on the recent publication of results from several heroic surveys of the stellar populations in the Galaxy. Among the largest of these for field stars are the Mt Wilson survey (Sandage 1987, in "The Galaxy", eds G. Gilmore and R.F. Carswell, Reidel: Dordrecht, p. 321), the North Carolina/Harvard survey (see for example Laird, Carney and Latham 1988, Astron. J. **95**, 1843; the Basel survey (Fenkart 1989,); the Mt. Stromlo surveys (e.g. Norris and Ryan 1989, Astrophys. J. **340**, 739); Freeman, 1987, Ann. Rev. Astron. Astrophys. **25**, 603; and the Lick/CTIO and SAAO studies of the stars of the central Galactic Bulge). These are supplemented by continuing studies of the Lick RR Lyrae surveys and the Scandinavian F/G star surveys and a variety of smaller surveys addressing more specific questions. These optical data are in turn supplemented by the results of near infrared surveys (from satellites) by IRAS (Beichman 1987, Ann. Rev. Astron. Astrophys. **25**, 521; Habing 1987, in "The Galaxy", eds. G. Gilmore and R.F. Carswell, Reidel: Dordrecht, p. 173) and COBE (see Physics Today, July 1990, p. 19 for a picture).

Given the wealth of new data, it is fortunate that several comprehensive review articles and relevant conference proceedings have appeared. These include references to the very many original papers, as well as more detailed discussions than are appropriate here. The most extensive reviews include those in Annual Reviews (Beichman 1987, in "The Galaxy", eds. G. Gilmore and R.F. Carswell, Reidel: Dordrecht, p. 173, for IRAS; Freeman 1987, Ann. Rev. Astron. Astrophys. **25**, 603, for the Spheroid and Old Disk; Frogel 1988, Ann. Rev. Astron. Astrophys. **26**, 51, for the Bulge; Gilmore, Wyse and Kuijken 1989, Ann. Rev. Astron. Astrophys. **27**, 555, for an overview; Wheeler, Sneden and Truran 1989, Ann. Rev. Astron. Astrophys. **27**, 279, for chemical element ratios and their evolution) and in the books "The Galaxy" (Gilmore and Carswell 1987, , ed. Reidel: Dordrecht), "The Gravitational Force Perpendicular to the Galactic Plane" (Phillip and Lu 1989, L. Davis Press: Schenectady) and Saas–Fee Course "The Milky Way as a Galaxy" (Gilmore, King and van der Kruit 1990, Saas–Fee Course 19, ed. Geneva Observatory and University Science Books: Berkeley).

In discussing the stellar content of the Galaxy, one's first requirement is to decide how many (discrete) stellar components one wishes to consider. The gross features of the Galaxy defined in this way include the thin disk, the thick disk, the (subdwarf) halo, the central ($r < 3$ kpc from the Galactic centre) bulge, and a very central ($r < 1$ kpc from the Galactic centre) structure. This last component may or may not be the same as the central bulge as defined above, and there may or may not be continuity between some or all of these components. This question is important for studies of Galactic evolution (cf. Gilmore et al. 1989, Ann. Rev. Astron. Astrophys. **27**, 555) but not for descriptive purposes. Any continuum can be modelled at some level as a sum of discrete functions, and the amount and quality of existant data is such that a

model with several discrete components has more than enough degrees of freedom to describe available observations.
Given a number of (discrete) components one attempts to determine their spatial density distribution, the luminosity function, the absolute magnitude-colour relation, the distribution of chemical elements, and the distribution of stellar ages.

(i) The Central Bulge: – r < 1 kpc: (see Beichman 1987, Ann. Rev. Astron. Astrophys. **25**, 521; Habing 1987, in "The Galaxy", eds. G. Gilmore and R.F. Carswell, Reidel: Dordrecht, p. 173; and Frogel 1988, Ann. Rev. Astron. Astrophys. **26**, 51, for details and references)
The existence of a central bulge component is deduced in two ways: in a model-dependent way from the inner rotation curve, and directly from optical and IRAS counts of late-M giants and from near IR integrated-light observations. The rotation curve modelling is somewhat complicated by the possibility of non-circular motions in the gas. This is plausible, since most galaxies do not show a maximum in the inner rotation curve like that in the Galaxy, and the evidence for triaxiality in other galactic bulges (which would naturally induce non-circular kinematics) is strengthening rapidly. Analysis of the star count data is also somewhat complicated since the stars counted are in a short-lived and poorly-understood evolutionary state. Thus one cannot reliably deconvolve a density gradient from an abundance and/or an age gradient.
The IRAS sources in the central few degrees of the Galaxy and COBE (2 micron) data show a conspicuous and flattened central bulge, which is hidden from optical study by interstellar obscuration. The detectable outer edge of the IRAS bulge in fact is near Baade's Window, where optical studies are first possible. IRAS and optical data are therefore nicely complementary. The spatial distribution of the central IRAS bulge (4 deg < b < 10 deg, where the lower latitude limit is set by satellite confusion) is well described by a somewhat flattened exponential with scale height 375pc, corresponding to a half-light radius of about 600pc.
Analysis of those stars dominant at 12microns in the IRAS survey shows them to be (possibly intermediate age) long period variables The majority of the bulge population at low Galactic latitudes must be older than the Sun, and may be as old as the metal-rich globular clusters (Terndrup 1988, Astron. J. **96**, 884). Chemical abundance data for a sample of K giants in Baade's Window shows them to be metal rich, with modal abundance perhaps twice solar (Rich 1988, Astron. J. **95**, 828). The distribution of abundances for these stars is consistent with that expected from the simple model of chemical evolution with a closed box (no inflow or outflow), but with effective yield significantly higher than that derived from observations in the solar neighbourhood. Similar abundance data for planetary nebulae and RR Lyrae stars (Gratton et al. 1986, Astron. Astrophys. **169**, 111) however provides a modal abundance of one-half solar, consistent with the same effective yield as is seen near the Sun. Thus the evolutionary status of the central bulge remains unclear.
In summary, the central bulge is in part super metal rich, may contain at least some young stars and has a scale length a factor of about 5 smaller than that followed by more metal-poor halo stars.

(ii) The Main Bulge :– 1 < r < 3 kpc: (Frogel 1988, Ann. Rev. Astron. Astrophys. **26**, 51; Freeman 1987, Ann. Rev. Astron. Astrophys. **25**, 603)
The annulus between 10 deg and 30 deg from the Galactic centre is one of the least understood and yet one of the most significant regions in the Galaxy. It corresponds to the only non-disk regions of sufficiently high surface brightness in external galaxies that they can be studied, and yet has been relatively neglected in our Galaxy. Just sufficient star count data exist to show that the stellar distribution in this annulus is not consistent with models which do not include it as an extra component. Very preliminary indications suggest a scale length of 1 kpc is appropriate for the density profile, but the form of that density profile is not constrained. Star count data also suggest a rather blue main sequence turnoff, consistent with either very low metallicity or intermediate age. The available data are not adequate to define these parameters

consistently, due to difficulties with photometry in crowded fields, the complexities of patchy reddening, and the need to obtain quite large amounts of data to define the density and colour distributions adequately. First results from several radial velocity surveys indicate systemic rotation of amplitude at least 100 km/s in the bulge. This value is in good agreement with that expected from comparison of the Galaxy and other spirals, but not from the properties of metal poor stars near the Sun.

There are several fundamental properties of the bulge which could be determined from straightforward observations. These include determination of the abundance distribution for stars of sufficiently low luminosity so that dredgeup has not affected their atmospheric abundances, thereby providing a distribution function of abundances which is representative of that at the time of stellar formation. A sufficiently large sample of stars must be observed to clarify the following points:

i) Are the very metal–rich stars a tail of a distribution which is represented by the abundance distribution seen in the old planetary nebulae and RR Lyrae stars, or vice versa;

ii) Where are the very metal–rich old disk (and thick disk) stars which are expected in significant numbers if there really is a radial abundance gradient in the disk? Are they in fact the bulge;

One of the most important properties of the bulge which is amenable to test is the age range of the metal–rich stars. It would be interesting if that population of stars which is the youngest in chemical terms, in that the greatest number of generations of massive stars must have had time to evolve and explode before its formation, and which is young in dynamical terms, in that a substantial amount of dissipation of binding energy occurred before star formation, was at the same time among the oldest in a chronological sense.

(iii) The Subdwarf Halo: (see Freeman 1987, Ann. Rev. Astron. Astrophys. **25**, 603; Gilmore et al. 1989, for references)

The kinematics and chemical properties of high velocities stars near the Sun are now defined with remarkable precision. Laird et al. (1988, Astron. J. **95**, 1843) and Norris and Ryan (1989, Astrophys. J. **340**, 739) have followed on from the surveys of Sandage to show the abundance distribution is peaked at [Fe/H]=–1.6. The main subdwarf system has dynamically unimportant systemic rotation, and at best marginal evidence for correlations between kinematics and dynamics. Combination of the results from the several kinematic studies of field subdwarfs shows the local velocity ellipsoid to have the following diagonal values $\sigma_{UU}; \sigma_{VV}; \sigma_{WW} = 131 \pm 7$; 102 ± 8 ; 89 ± 5.

While this kinematic anisotropy has often been quoted as evidence to support a flattened spatial distribution of the subdwarfs, recent dynamical modelling (Arnold 1990, M.N.R.A.S.) shows that kinematic anisotropies of this order can be consistent with a round distribution. Thus, while the most recent star count studies suggest considerable flattening in the subdwarf system near the Sun (rather similar to that seen in the central bulge) the true 3–dimensional spatial distribution of metal–poor stars in the Galaxy remains poorly determined. Similarly, the local number density of subdwarfs, which is approximately 1/800 of all stars, has an uncertainty of at least 50% in its value.

For evolved halo stars one may determine some age data (Schuster and Nissen 1989, Astron. Astrophys. **222**, 69). Effectively all stars with [Fe/H] $<$ –1.2 are as old as the metal–poor globular clusters, and there is (marginal) evidence for an appreciable age spread in the field stars. Similar evidence is rapidly accumulating for the outer globular clusters, and provides strong evidence for an extended period of accretion of the outer stellar halo, rather than formation in a well mixed system. Of course, only a tiny fraction of the stellar halo is in the outer parts, so that extension of these age studies to the dominant inner population of field stars and clusters is of considerable importance in understanding the early history of the Galaxy.

(iv) The Thick Disk: (see Freeman 1987, Ann. Rev. Astron. Astrophys. **25**, 603, and Gilmore et al. 1989, Ann. Rev. Astron. Astrophys. **27**, 555, for references)

The Galaxy as seen by IRAS forms a striking disk–bulge picture which is complementary and almost completely orthogonal to optical stellar studies. The parameters of the large–scale spatial distribution have been derived by Habing (1987, in "The Galaxy", eds. G. Gilmore and R.F. Carswell, Reidel: Dordrecht, p. 173) who showed that the extended distribution forms two disks. About 80% of the stars form a thin disk (scale height < 200pc) with radial exponential scale length 4.5 kpc, and with a cutoff near 9 kpc, or about at the solar circle. The remaining 20% of stars form a thick disk, with scale height near 2 kpc, radial exponential scale length about 6 kpc, and no evident cutoff.

These disk parameters may be understood in terms of the two types of star detectable by IRAS. IRAS could see low mass stars with high optical depth dust shells, and higher mass young AGB stars with high mass–loss rates. For low mass stars there is a correlation between the optical depth of the dust shell in the late stages of evolution (the Mira variable stage) and metallicity, with those stars which have [Fe/H] above –1 having the highest optical depth shells. These same Mira variables have pulsation periods from 150 days to 200 days, and have been known for many years to outline a thick disk. In fact, the Vatican conference stellar population classification scheme used these variables to define the Intermediate Population II.

The thin disk IRAS sources are predominately higher mass AGB stars – Miras and OH/IR stars. These stars are young, and hence their distribution reflects that of the young disk and the molecular gas which corresponds to regions of current and recent star formation. The molecular gas distribution drops rapidly beyond the Solar circle, and hence so does that of the young stars.

The vertical density profile of the thick disk is adequately represented for $1000 < z < 3000$pc by a single exponential. A representative estimate from the several recent determinations for the normalisation constant and scale height are 4% and 1000pc, respectively. The normalisation constant is roughly an order of magnitude larger than that for the halo stars, though again with an uncertainty of about 50% in this value. Note that the normalisation in this case is not the fractional number of thick disk stars near the sun, but the numerical value required to model the stellar distribution a few kpc above the plane assuming an exponential density profile. The relationship of this numerical value to the actual number of thick disk stars in a volume near the sun is a steep function of the Galactic force law and the stellar velocity distribution function. We note in passing that a noticeably oblate $r^{1/4}$ density profile (c/a approx 1/4) also provides a good description of the data.

The radial profile of the thick disk is still poorly known. The Basel star count surveys suggest that a radial exponential is an adequate description (Fenkart 1989, Astron. Astrophys. Suppl.). The radial scale length based on available star count modelling and by assumption from photometry of other disk galaxies is the same as the radial exponential scale length of the thin disk, or 4 ± 1 kpc.

The mean metallicity of the thick disk has been determined to be like that of the metal–rich globular cluster system, while the age of at least the metal–poor part of the thick disk is also similar to the age of the globular cluster system. For more metal–rich thick disk stars the situation remains unclear, pending further observations, but evidence is accumulating that there is a detectable age range. Determination of the true age range of bona fide thick disk stars (and globular clusters) will provide the most important information to determine its evolutionary history.

(v) The Thin Disk: (see Gilmore et al. 1989, Ann. Rev. Astron. Astrophys. **27**, 555, for references)

Substantial recent progress in studies of the thin disk has been made in determinations of ages and abundances for open clusters and stars far from the Sun. Abundances and element ratios contain a wealth of information about the evolution of the galaxy, and determination of their spatial and temporal changes remains a crucial step in understanding the galaxy. Cluster age scales remain to be agreed. The quality and amount of data becoming available is however leading to significant improvements in understanding both stellar evolution (eg the importance of overshooting) and the galactic disk.

Another area of recent progress involves measurement of the mass distribution near the Sun. Large new surveys (see Phillip and Lu, 1989 (eds) "The Gravitational Force Perpendicular to the Galactic Plane", L. Davis Press: Schenectady, for references and details) have determined the kinematic distribution of old stars up to several kpc from the Galactic Plane, and allowed a detailed analysis of the local mass distribution. It seems that there is no dynamically significant missing mass associated with the Galactic disk on scales of 1kpc or so. Data on much smaller scales (a few parsecs, providing the "Oort Limit") remain inadequate to allow robust conclusions. Confirmation of these results, which have very considerable implications for the nature and distribution of dark mass in the Universe, from independent surveys and analyses remains a very important priority.

4 THE STELLAR INITIAL MASS AND LUMINOSITY FUNCTIONS

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The luminosity function is an important descriptor of stellar populations, being a census of stars of different absolute magnitudes, M. Specifically, it measures the number of stars in an interval M, M+dM in some specific wavelength passband and volume element dV. The luminosity function is related, through a mass–luminosity relation, to a more fundamental function, the stellar mass function. The mass function, corrected for the effects of stellar evolution and suitably averaged in time and space, provides the initial mass function (IMF), which is arguably the most important single function in observational astrophysics. It measures the relative probability of formation of stars as a function of mass at a particular time, place, chemical abundance and set of (local) physical conditions. This in turn determines the luminosity, chemical, and dissipational evolution of that place in the Universe.

The luminosity function has been determined empirically for stars of mass above roughly one solar mass in some galaxies of the Local Group, for stars of mass above the minimum mass for hydrogen burning (roughly 0.08 solar masses) up to about 2–3 solar masses in the immediate solar neighbourhood, and for stars of intermediate masses (roughly 0.3 to 0.8 solar masses) in globular and open clusters. In the review period, the greatest efforts have been expended deriving luminosity functions, and the corresponding mass functions, in open and globular clusters.

In the Magellanic Clouds, studies of clusters have been published covering the stellar mass range from about 1 to above 10 solar masses, and the abundance range from 1/20 to nearly solar. Remarkably, the resulting (initial) mass functions are similar, and consistent with the mass function in the Solar neighbourhood (see eg. Mateo 1988, Astrophys. J. **331**, 261). Similarly in our Galaxy, open clusters tend to have luminosity (and mass) functions indistinguishable from that of nearby field stars (see eg. Zakharova 1989, Astr. Nachr. **310**, 127; Leggett and Hawkins 1989, M.N.R.A.S. **238**, 145). These quite remarkable results suggest that the physical processes which determine the initial mass function are independent of the stellar density and the chemical abundance, even though the range of abundances now studied covers that in which the dominant (high temperature) cooling process changes from continuum to metallic line emission. Confirmation of these results, by enlarging the number, age range, abundance range, and if possible the observed stellar mass range of studied clusters, is of considerable importance to an understanding of star formation processes.

Globular clusters (roughly 20 have now been studied) however do show significant differences in their apparent luminosity functions. Conversion of an observed luminosity function at some place in a globular cluster to a truly representative luminosity function is complicated by the need to allow correctly for the mass segregation which inevitably occurs during the internal dynamical evolution of the cluster. Reliable analyses therefore must include detailed dynamical studies in addition to deep photometry at several distances from the cluster centre.

Conversion of the dynamically-corrected luminosity function to a mass function additionally requires an appropriate mass-luminosity relation. The mass-luminosity relation is a function of stellar age and abundance, so that "appropriate" is not a superfluous qualification. For stars with masses above about 0.5 solar masses theoretical models provide a relationship which is adequate for conversion of available luminosity data to a mass function. At lower masses however the surface temperatures are so low that molecules provide an important opacity source, so that considerable high frequency and very abundance-dependant structure in the mass-luminosity relation is expected. This is probably the largest remaining source of systematic uncertainty in the derivation of stellar mass functions in globular clusters.

In spite of the enormous observational and theoretical effort involved, such studies are underway for several clusters. Important examples have been published by Meylan (1989, Astron. Astrophys. **214**, 106) and Richer and Fahlman (1989, Astrophys. J. **339**, 178), and show that real differences are apparent in the stellar mass function from cluster to cluster. As yet no systematics in these differences (e.g. with chemical abundance, age, stellar density ...) have been reliably identified. The discordance between this diversity and the apparent similarity of available mass functions at higher masses is remarkable, and of considerable importance, if real.

Recent studies of the luminosity and mass functions for field stars have been reviewed, with emphasis on low masses, by Liebert and Dahn (1987), Buser (1987), and Jahreiss (1987). Surveys of low luminosity field stars using the technique of photometric parallax have been collated and analysed by Stobie, Ishida and Peacock (1989, M.N.R.A.S. **238**, 709). There is now good agreement between the several available surveys (though it should be noted that the recent surveys are not independent, more than one being based on the same photographic material towards the south Galactic pole) for stars more luminous than about Mv = + 16. At lower luminosities considerable systematic uncertainty remains, in part because only tiny samples of stars are available, but mostly because the absolute magnitude-colour relationship for very low luminosity stars remains very poorly determined. CCD parallax studies could resolve this uncertainty straightforwardly.

Conversion of the luminosity function for low luminosity stars to a mass function is itself a complex problem, depending sensitively on the amount of structure in the mass-luminosity relationship caused by atomic and molecular opacity sources which themselves depend sensitively on temperature. Relevant models have been well summarised by Dorman, Nelson and Chau (1989, Astrophys. J. **342**, 1003), and by Burrows, Hubbard and Lunine (1989, Astrophys. J. **345**, 939). The significance of the complex mass-luminosity relation suggested by these models for derivation of the stellar mass function at low masses was discussed by Kroupa, Tout and Gilmore (1990, M.N.R.A.S. **244**, 76), who showed that convergent mass functions (i.e. with finite total mass when extrapolated smoothly to zero mass) were consistent with available data.

Such analyses do not yet include adequate consideration of stellar duplicity, age ranges, or abundance ranges, but it is none the less encouraging that both the luminosity function and the mass function for field stars of low mass is now apparently known to within a small error factor. Further improvement will require larger samples of very low luminosity stars (which should be detectable with ease in nearby open clusters with available technology), more parallax data for low luminosity field dwarfs (which is feasible with current CCD 's), but is most dependent on a considerably improved understanding of the mass-luminosity relationship for very cool stars.

5 A SUMMARY OF RECENT RESEARCH FINDINGS ON THE GALACTIC CENTER

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5.1 The central parsec

Much recent work has focussed on determining the properties and interrelationships of sources close to the nucleus (e.g., Tollestrup et al. 1989, Astrophys. J. **98**, 204; Geballe et al. 1989, Astron. Astrophys. **208**, 255; McFadzean et al. 1989, Mon. Not. Roy. Astr. Soc. **241**, 873; Smith et al. 1990b, Mon. Not. Roy. Astr. Soc. **246**, 1). The compact radio source, Sgr A* (reviewed by Lo 1989, in IAU Symp. No. 136, "The Center of the Galaxy", ed. M. Morris, Kluwer Academic, p. 527), is variable (Zhao et al. 1989, in IAU Symp. No. 136, p. 535), and a recent VLBI study confirms that it that it is elongated (Jauncey et al. 1989, Astrophys. J. **98**, 44). A VLBI observation made at a wavelength of 2cm reveals much weaker "satellite" radio sources within a few thousand A.U. (Yusef-Zadeh et al. 1990b, Nature, in press), which might eventually help one to probe the dynamics of gas near the compact source. Continued VLBI monitoring of the position of Sgr A* tracks the solar motion around the galactic center, and sets a limit of 40 km/s on the transverse motion of Sgr A* (Backer and Sramek 1987, in "The Galactic Center", Proc. of Symp. Honoring C.H. Townes, ed. D.C. Backer, AIP:NY, p. 163). This result provides one of the strongest pieces of evidence that Sgr A* is massive. The other candidate for a massive, central object is apparently the source of much of the luminosity (Werner and Davidson 1989, in IAU Symp. No. 136, p. 423) and excitation stemming from the inner parsec (Rieke et al. 1989, Astrophys. J. **344**, L5). The ensemble of spatially separated components of IRS16 coincides with a very high velocity flow Geballe et al. (1987, Astrophys. J. **320**, 562) and Allen et al. (1990, Mon. Not. Roy. Astr. Soc. **244**, 706) find that the components of IRS16 have 2-micron spectra similar to young luminous stars in the Magellanic clouds. They suggest that the broad lines may result from one or more Wolf-Rayet winds. The supergiant IRS7, which may lie within a parsec of the nucleus (Geballe et al. 1989, Astron. Astrophys. **208**, 255), apparently has an externally ionized mass-loss envelope (Yusef-Zadeh et al. 1989, in IAU Symp. No. 136, p. 443; Rieke et al. 1989, Astrophys. J. **336**, 752). The UV sources at the nucleus are presumably responsible. Recent unpublished data show that this star also has an ionized "tail" that appears to have been caused by interaction with the nuclear wind. This object will be of continued interest as a probe of both star formation and winds in the galactic center.

5.2 Stellar kinematics and the mass distribution

Efforts to deduce the radial mass distribution in the inner few parsecs of the Galaxy were reviewed by Townes (1989, in IAU Symp. No. 136, p. 1) and Sellgren (1989, in IAU Symp. No. 136, p. 477). With observations of the integrated, diffuse 2-micron light arising from late-type stars, McGinn et al. (1989, Astrophys. J. **338**, 824) used the 2.3-micron bandhead of CO to assess the kinematics of stars near the nucleus. They separate the rotation from the radial dependence of the velocity dispersion to infer a central condensed mass of 2 – 3 x 10^6 $M_\odot$, or an increase in the mass-to-2-micron light ratio toward the nucleus. On scales up to 120 pc, OH/IR stars are being used to determine the mass distribution (Lindqvist et al. 1989, in IAU Symp. No. 136, p. 503; 1990, in "From Miras to Planetary Nebulae: Which Path for Stellar Evolution?", eds. M.O. Mennessier and A. Omont, Editions Frontieres, p. 259). Sellgren et al. (1990, Astrophys. J. **359**, 112) concentrate on the central 1.2 pc, and report that, if the mass-to-2-micron light ratio is constant, 5.5 x 10^6 $M_\odot$ must be concentrated in the inner 0.6 pc. The data indicate that the CO bandhead is not produced within a radius of 0.6 pc from

IRS16, possibly as a result of the destruction of late-type stars by collisions. Exploration of this possibility will undoubtedly be a high priority in the next few years.

5.3 The circumnuclear disk

The properties of the 3 – 10 pc circumnuclear disk have become increasingly well-defined, as many molecular line studies have been carried out (see reviews by Guesten 1987, in "The Galactic Center", Proc. of Symp. Honoring C.H. Townes, ed. D.C. Backer, AIP:NY, p. 19; Genzel 1989, in IAU Symp. No. 136, p. 393). The warm, clumpy, turbulent disk (Sutton et al. 1990, Astrophys. J. **348**, 503) has a sharp, ionized inner edge, from which gas appears to be infalling toward the central mass concentration along streamers. Whether the sharp edge is ascribable to a radial gradient in the mass distribution (Duschl 1989, Mon. Not. Roy. Astr. Soc. **240**, 219), or to magnetic stresses (Genzel and Townes, 1987, Ann. Rev. Astr. Ap. **25**, 377) remains to be determined. According to Herter et al. (1989, Astrophys. J. **343**, 696), the energy content of the disk is high enough in some locations to cause dust destruction and the released silicon is subsequently ionized. In future studies, it will be useful to derive the rate of mass inflow through the disk.

5.4 The environment of SGR A

Much work has been done to characterize the radio source Sgr A, consisting of the central thermal source Sgr A West and a nonthermal shell source Sgr A East. This complex is interacting with the nearby 20 and 50 km/s clouds, and the challenge has been to deduce the relative line-of-sight placement of these structures in order to comprehend their interactions. The extensive body of new evidence now allows this to be done with some reliability (Yusef-Zadeh and Morris 1987c, Astrophys. J. **320**, 545; Mezger et al. 1989, Astron. Astrophys. **209**, 337; Pedlar et al. 1989, Astrophys. J. **342**, 769; Zylka et al. 1990, Astron. Astrophys. **234**, 133). The understanding of the nature of the various radio sources is facilitated by high-frequency observations which constrain their spectral slopes (Salter et al. 1988, Mon. Not. Roy. Astr. Soc. **232**, 407; Tsuboi et al. 1988, Publ. Astr. Soc. Japan **40**, 665). The spatial relationships between sources on a somewhat larger scale were considered by Lasenby et al. (1989, Astrophys. J. **343**, 177), who reported on a study of HI absorption measurements made with the VLA.

5.5 Large-scale manifestations of activity in the nucleus?

While the galactic center is not currently active by comparison with the nuclei of many other spirals, there are several indications on large spatial scales that energetic activity akin to that in so-called "active" systems might have been present there in the past, or might now be present at a low level. These indications, which include the "expanding molecular ring" (EMR), the "galactic center lobe" (GCL), and the "galactic center spur", are not unambiguous, however. The velocity field of the long-known EMR, which appears as an ellipse in the longitude-velocity diagram, and which has also been interpreted as a velocity field resulting from motion in a bar potential, appears clearly in the survey of CO and CS emission carried out recently (Bally et al. 1987, Astrophys. J. Suppl. **65**, 13; 1988, Astrophys. J. **324**, 223). However, apart from a study by Saito (1990, Publ. Astr. Soc. Japan **42**, 19), little modelling has been done on the EMR, and the identification of the event or phenomenon which gave rise to this very coherent structure remains an important challenge for the future.

The GCL is a large radio continuum feature arching over one side of the galactic plane (Sofue and Handa 1984, Nature **310**, 568). It has been interpreted as a cylindrical remnant of an explosion at the nucleus (Umemura et al. 1988, Publ. Astr. Soc. Japan **40**, 25), and alternatively as a manifestation of a contracting poloidal magnetic field, twisted as a consequence of differential rotation (Shibata and Uchida 1987, Publ. Astr. Soc. Japan **39**, 559). However, these models are not consistent with the asymmetry of the GCL about the galactic plane. Also, recent studies have called into question the notion of the GCL as a single unified structure. While one of its legs is predominantly nonthermal, and is apparently an extension of the magnetic Arc (Tsuboi et al. 1986, Astrophys. J. **92**, 818; Yusef-Zadeh and Morris 1988, Astrophys. J. **329**, 729), the other has thermal characteristics and may have resulted from a strong shock associated with the dynamics of the EMR (Uchida et al. 1990, Astrophys. J. **351**, 443). Rather than being a three-dimensional structure, then, cylindrical or otherwise, the GCL may consist of two unrelated tongues of gas straddling the galactic center.

Finally, the "galactic center spur" was extracted by Sofue et al. (1989, Astrophys. J. **341**, L47) from a 408-MHz all-sky survey (Haslam et al. 1982, Astron. Astrophys. Suppl. **47**, 1). It consists of a relatively narrow, quasi-continuous, one-sided feature oriented roughly perpendicular to the galactic plane. If associated with the galactic center, it extends over at least 4 kpc, curving towards negative galactic longitudes. It cannot be followed closer to the galactic center than 4 degrees, except possibly at higher frequency (1408 MHz), where it seems to split into two "legs", so while the orientation and placement of this feature are striking, and more than a little suggestive, one cannot rule out the possibility of a coincidental superposition of a radio spur similar to the North Galactic Spur. It is noteworthy that, at even lower frequencies, a much smaller candidate for a counterjet had previously been identified (Yusef-Zadeh et al. 1986, Astrophys. J. **300**, L47; Kassim et al. 1987, in The Galactic Center, Proc. of Symp. Honoring C.H. Townes, ed. D.C. Backer, AIP:NY, p. 196).

5.6 Magnetic fields and magnetohydrodynamic phenomena

Evidence continues to mount for a strong poloidal magnetic field in the inner 50 - 100 pc of the Galaxy. Most of the evidence is based on the morphology of radio structures (Yusef-Zadeh and Morris 1988, Astrophys. J. **329**, 729; Yusef-Zadeh 1989, in IAU Symp. No. 136, p. 243; Morris 1990, in IAU Symp. No. 140, "Galactic and Intergalactic Magnetic Fields", eds. R. Beck, P.P. Kronberg, and R. Wielebinski, Kluwer Academic, p. 361; Anantharamaiah and Pedlar 1990, in IAU Symp. No. 140, p. 375; Yusef-Zadeh et al. 1990a, in IAU Symp. No. 140, p. 373). However, the linear polarization of synchrotron emission similarly reveals a poloidal geometry in a few specific regions (Tsuboi et al. 1986, Astrophys. J. **92**, 818; Reich 1989, in IAU Symp. No. 136, p. 265; 1990, in IAU Symp. No. 140, p. 369). The strength of the field, 0.1 - 1 mG, is indicated by the apparent rigidity of the filamentary structures (Yusef-Zadeh and Morris 1987a, Astrophys. J. **94**, 1178, 1987b, Astrophys. J. **322**, 721; Bally and Yusef-Zadeh 1989, Astrophys. J. **336**, 173), as well as by the large rotation measures (Sofue et al. 1987, Pub. Astr. Soc. Pac. **39**, 95). Direct Zeeman measures of field strengths are complicated by the large velocity dispersions in the galactic center, but initial efforts have begun in selected regions using OH and HI (Killeen et al. 1990, in IAU Symp. No. 140, p. 382; Schwarz and Lasenby 1990, in IAU Symp. No. 140, p. 383). Variations in the sign of the rotation measure provide information about the line of sight structure of the magnetic field. Thus, Sofue et al. (1987, Pub. Astr. Soc. Pac. **39**, 95) present evidence that a toroidal field component is present, possibly as a result of deformation of the poloidal field by disk rotation. Such field deformations are difficult to reconcile with the remarkable linearity of the radio filaments, however.

In the inner 10 pc or so, the predominant field component is evidently toroidal, as evidenced by far-IR polarimetry (Werner et al. 1988, Astrophys. J. **333**, 729; Hildebrand et al. 1990, Astrophys. J. **362**, 1). "Field-aligned dust grains in the CND are believed responsible for the polarized emission"; Hildebrand et al. 1990, Astrophys. J. **362**, 1) adopt the Wardle and Konigl (1990, Astrophys. J. **362**, 1) model of a magnetized accretion disk in a medium having a poloidal field geometry to explain their polarization measures at 7 locations.

The magnetic field in the inner parsec of the Galaxy has been probed by Aitken et al. (1986, Mon. Not. Roy. Astr. Soc. **218**, 363 and 1989, in IAU Symp. No. 136, p. 457), who performed 10-micron polarimetry on a number of the brightest infrared sources in Sgr A West. They show that the field is aligned with the "northern arm", and suggest that the field strength may be 10 mG. Polarimetric imaging done more recently at 12 microns by Smith et al. (1990a, in Proc. Workshop on "Astrophysics with Infrared Arrays", ed. R. Elston, NOAO) shows that the polarization is continuous along the northern arm; they argue that a sheared flow along the arm would have stretched any preexisting field into its observed configuration.

The question of the origin of the strong magnetic field in the galactic center is unanswered, although some interesting suggestions have been offered, including the concentration of primordial fields (Sofue and Fujimoto 1987, Pub. Astr. Soc. Japan **39**, 843; Sofue 1990, in IAU Symp. No. 140, p. 226) and the generation of ring currents by expansive motions (Lesch et al. 1989, Astron. Astrophys. **217**, 99). Other discussions of various galactic dynamo mechanisms applicable to the galactic center can be found in Rosner and de Luca (1989, in IAU Symp. No. 136, p. 319) and Beck et al. (1990, IAU Symp. No. 140).

Given the evidence for strong magnetic fields and the high velocity dispersion of clouds in the region, some investigators have suggested that various MHD phenomena may be driven by cloud-field interactions. The arched filaments of the radio Arc, and indeed the entire Arc, may thus have resulted from the anomalous motion of the molecular cloud underlying the arched filaments (Serabyn and Guesten 1987, Astron. Astrophys. **184**, 133) through the poloidal field (Benford 1988, Astrophys. J. **333**, 735; Morris and Yusef-Zadeh 1989, Astrophys. J. **343**, 703). Another case in point is provided by the 25 km/s cloud coincident with the HII region G0.18-0.04 (Serabyn and Guesten 1990, Astron. Astrophys., in press). However, this interpretation is disputed by Genzel et al. (1990, Astrophys. J. **356**, 160), whose 158-micron CII observations of this cloud lead them to believe that UV photoionization by early-type stars has produced the ionized filaments.

SGR B2. Modern studies of the "classical" galactic center GMC, Sgr B2, have exposed the structure of this unusually massive (10^7 $M_\odot$) cloud in unprecedented detail (Whiteoak et al. 1988, Mon. Not. Roy. Astr. Soc. **235**, 655; Lis and Goldsmith 1989, Astrophys. J. **337**, 704; 1990, Astrophys. J. **356**, 195; Goldsmith et al. 1990, Astrophys. J. **350**, 186; Martin-Pintado et al. 1990, Astron. Astrophys. **236**, 193). It will be of interest to determine the extent to which the high flux of ionizing radiation emerging from the forming stars, and to which the complexity of the interaction between those stars and their dense stellar environment (Vogel et al. 1987, Astrophys. J. **316**, 243; Akabane et al. 1988, Publ. Astr. Soc. Japan **40**, 459; Kobayashi et al. 1989, in IAU Symp. No. 136, p. 181) are affected by their location in the tumultuous and possibly highly magnetized galactic center region.

G0.15-0.05 AND AFGL2004. One of the most intriguing sites in the galactic center is a compact HII region lying at the terminus of a nonthermal radio filament (Yusef-Zadeh and Morris 1987a, Astrophys. J. **94**, 1178). Nearby is a quintuplet of bright infrared sources which has attracted a great deal of attention Nagata et al. (1990, Astrophys. J. **351**, 83); Okuda et al. (1990, Astrophys. J. **351**, 89); Glass et al. (1990, Mon. Not. Roy. Astr. Soc. **242**, 55). It is remarkable that, while each member of the quintuplet has a luminosity comparable to that of a bright giant or supergiant, none of them appears to produce ionizing radiation. The next few years should see a great deal of continued research on this puzzling cluster.

5.7 High energy phenomena

It has been assumed that the 511-keV annihilation line, seen since 1970 toward the galactic center, arises from both a diffuse galactic plane source and a variable point source located within 0.5 kpc of the galactic center (Lingenfelter and Ramaty 1989a, in IAU Symp. No. 136, p. 587). After some uncertainty about whether the diffuse source might account for all of the observed 511-keV flux (Share et al. 1988, Astrophys. J. **326**, 717), the point source seems to have reasserted itself (Leventhal et al. 1989, Nature **339**, 36; Neil et al. 1990, Astrophys. J. **356**, L21), and the binary X-ray source GX 1+4 has been suggested as a candidate for the point source (McClintock and Leventhal 1989, Astrophys. J. **346**, 143). Since many have considered that the compact 511-keV source may arise from the vicinity of a black hole, possibly located at the Galactic core (Lingenfelter and Ramaty 1989b, Astrophys. J. **343**, 686; Ozernoy 1989, in IAU Symp. No. 136, p. 555), it is clearly important to determine the position of this object.

Another important gamma-ray line observed toward the galactic center is the 1.8 MeV line of 26Al (Prantzos 1987, in Nuclear Astrophysics, Lecture Notes in Physics 287, eds. W. Hillebrandt, R. Kuhfuss, E. Muller, J.W. Truran, Springer-Verlag). The question of its origin is still unresolved; it may be linked to the source of positrons responsible for the annihilation radiation (Diehl et al. 1989, in IAU Symp. No. 136, p. 617; Cook et al. (1989, in IAU Symp. No. 136, p. 581) found that the source 1E1740.7-2942, located 0.7 deg from the nucleus, is the strongest source near the center at energies from 35 to 200 keV, and it may be one of the most luminous objects in the Galaxy in this energy range. X-ray burst sources are known to be concentrated toward the galactic center, and for the first time, one has been well-localized (Skinner et al. 1990, Mon. Not. R. Astr. Soc. **243**, 72).

6 THE HIGH ENERGY COMPONENT OF OUR GALAXY

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I summarize here work on large scale galactic phenomena in relation to cosmic rays, γ-rays and X-rays.

6.1 Cosmic Rays

6.1.1 Cosmic ray acceleration

As in the previous ten years, the attention these last three years has continued to focus on the mechanism of diffusive acceleration by shock-waves. An extensive review on the subject was published by Blandford and Eichler (1987, Phsyics Reports **154**, 1). One of the main problems with the hypothesis of cosmic ray acceleration by supernova shocks in the interstellar medium is that protons can only attain energies lower than 1014GeV (Lagage and Cesarsky 1983, Astron. Astrophys. **125**, 249). Völk and Biermann (1988, Astrophys. J. Letters **333**, L65) consider the free expansion of a supernova shock in a stellar wind cavity. There, the magnetic field strength can be much higher than in the regular interstellar medium, and proton energies in excess of 1015eV can be attained.

Another nagging problem is the fact that the shock acceleration theory is developped in most or all papers in the framework of the quasilinear theory; now, the calculations suggest that Alfven-wave perturbations in the vicinity of interstellar shocks should be large, in disagreement with the quasilinear hypothesis. Max, Zachary and Arons (1989, "Plasma Astrophysics", ESA SP-285, p. 45) used numerical simulations to tackle this problem; they find that when the wave amplitude is large, particle wave interactions differ from the predictions of the quasilinear theory. The maximum energy attainable by cosmic rays trapped close to a supernova shock in the interstellar medium, is then even lower than in the predictions by Lagage and Cesarsky (1983), unless extreme assumptions are made on the cosmic ray flux. While in the past most work only considered parallel shocks, an increasing number of authors are now studying oblique and perpendicular shocks (e.g. Drury 1987); relativistic shocks are being examined as well (Schneider and Kirk 1989, Astron. Astrophys. **217**, 344).

6.1.2 Radio and infrared comparisons

A fruitful line of study which is being developed for the understanding of galactic cosmic ray production and propagation is a comparison of radio and infrared data in our galaxy and in other galaxies. Let us quote two results:
i) Völk, Klein and Wielebinski (1989, Astron. Astrophys. **213**, L12) conclude from a comparison between our galaxy and the starburst prototype M82 that the total cosmic ray production rates are proportional to the supernova rates.
ii) Bicay, Helou and Condon (1989, Astrophys. J. Letters **338**, L53) claim, from comparison of infrared and radio data on two spiral galaxies, that galactic cosmic ray confinement is better described by a "leaky box" model, with a probability of escape proportional to the distance from the source, than by a diffusion model.

6.1.3 Cosmic ray propagation

Studies of cosmic ray propagation, as derived from composition data, have increasingly been taking into account a possible reacceleration of cosmic rays during propagation. A small amount of reacceleration is possibly predicted by diffusion models, and is compatible with the observations; the variation of escape length with energy is then shallower than in the case of no reacceleration, helping to understand the quasi constancy of cosmic ray anisotropy with energy. (Osborne and Ptuskin 1987, 20th Int. Cosmic Ray Conf. **2**, 142; Ferrando and Soutoul 1987, 20th Int. Cosmic Ray Conf. **2**, 231; Giler et al. 1989, Astron. Astrophys. **217**, 311). (The constancy of the anisotropy below 100 TeV may also be explained by Alfven wave trapping effects, see Axford, Daugherty and McKenzie 1990, 21st Int. Cosmic Ray Conf. **3**, 311). Reacceleration by encounters with shocks of several supernovae in the galaxy is difficult to reconcile with the data (Cesarsky, 1987, 20th Int. Cosmic Ray Conf. **8**, 87). The propagation calculations are also becoming more precise as the real nature of the interstellar medium is taken into account: existence of a slab halo of ionized hydrogen (Soutoul and Ferrando 1989, "Cosmic Abundances of Matter", AIP Conference Proceedings **183**, p. 400), Cloudy nature of the interstellar medium (Osborne and Ptuskin 1987, 20th Int. Cosmic Ray Conf. **2**, 218; Cesarsky, Ptuskin and Soutoul 1990, 21st Int. Cosmic Ray Conf. **3**, 377).
Cosmic rays may affect or be affected by the over all galactic structure. If there is infall onto the galaxy, an accretion shock may surround the galaxy which would participate in their acceleration (Cesarsky and Lagage, 1987, 20th Int. Cosmic Ray Conf. **2**, 115). If their pressure is strong enough, they may drive a weak galactic wind (Breitschwerdt, McKenzie and Völk, 1987, 20th Int. Cosmic Ray Conf. **2**, 115; 1990, 21st Int. Cosmic Ray Conf. **3**, 315). Note that a mixed, inhomogeneous situation, with outflow in certain magnetic flux tubes and inflow in others is perfectly plausible.

6.2 Gamma rays

This has been a period of dearth of data, in between COS B and the new missions, GRANAT (launched in December 1989) and GRO (still to be launched). Still, there have been some new results from old missions. Peterson et al. (1989, 21st Int. Cosmic Ray Conf. **1**, 44) released results on the distributed emission of the galaxy in the energy range 90 keV–2 MeV; its distribution is similar to that seen at higher energies by SAS 2 and COS B, indicating that low energy electrons, producing Bremsstrahlung photons, are present in the interstellar medium.
The SAS 2 and COS B results were reviewed by Bloemen (1989, Ann. Rev. Astron. Astrophys. **27**, 469). Taking advantage of the finally complete survey of CO emission from the galactic disk (Dame et al. 1987, Astrophys. J. **322**, 706), the COS B workers find evidence for a weak cosmic ray radial gradient in the galaxy (Strong et al. 1988, Astron. Astrophys. **207**, 1). As expected, several of the unidentified sources of the COS B 2CG catalogue coincide with peaks in the gas distributions: about half, according to Mayer–Hasselwander and Simpson, (1990, The

EGRET Science Symposium, NASA Conf. Publication **3071**, p. 153), who leave us with a list of 8 confirmed 2CG sources, plus 9 new sources. A study with a different method of analysis is in progress (Pollock and Hermsen 1990, 21st Int. Cosmic Ray Conf. **1**, 237). And for the next report we should have results from EGRET.

An extensive review on γ–ray astronomy has been written by V.A. Dogiel and V.L. Ginzburg (1989, Space Science Rev. **49**, 311).

6.3 X–Rays

Burrows (1989, Astrophys. J. **340**, 775) has considered the question of the region of the 1/4 KeV soft diffuse background: are we seeing an X–ray halo through clumpy interstellar gas, or just the emission of a hot bubble in which the solar system is embedded? He argues convincingly in favour of the latter hypothesis, in agreement with the conclusions of Cox and Reynolds (1987, Ann. Rev. Astron. Astrophys. **25**, 304).

Information relevant on a galactic scale can be obtained from X–ray observations at higher energies. Here, the most notable results in the past three years are due to the Japanese X–ray satellites TENMA and GINGA. Let me quote two of them here:

a) The galactic ridge in hard X–rays

Koyama (1989, Publ. Astron. Soc. Japan **41**, 665) published a definitive account of the TENMA observations of the galactic ridge. Most of the emission comes from the inner galaxy, but the Cygnus and Perseus regions are also participating in the process. The emission extends to high galactic latitudes, and its spectrum is that of a hot thin plasma with temperature in the range 3–14 keV. The helium–like iron line is present in the spectrum. At this point, it is not clear whether this emission is really extended or whether it is the sum of thin thermal sources.

b) A colony of X–ray pulsars in the 5 kpc arm?

With the GINGA satellite, Koyama et al. (1989, Publ. Astron. Soc. Japan **41**, 483; 1990, Nature **343**, 148) have discovered four X–ray pulsars and three X–ray sources in the 5 Kpc arm. As these sources are strongly variable, the authors consider that they are transient X–ray pulsars in a Be–star binary system, left over from a star forming episode which took place some 107 years ago.

In the next three years, the results of the ROSAT survey (0.5–1.5 KeV) will start to appear, and we can expect considerable advances in our understanding of galactic X–ray sources, both point like and extended, of their galactic distribution, and of the galactic diffuse X–ray background.

7 THE GASEOUS COMPONENT

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7.1 Surveys

The past triennium has seen a remarkable number of publications of surveys of the galactic plane, and to some degree, analysis of these surveys. The largest body of work has been the completion of a number of galactic plane CO surveys. Bally et al. (1987, Ap. J. Suppl. **65**, 13) published maps of the inner regions of the Galaxy in the ^{13}CO J=1–0 and CS J=2–1 lines made with the Bell Labs antenna containing 5,000 and 12,000 individual spectra respectively. The distribution and kinematics of the clouds was interpreted in Bally et al. (1988, Ap. J. **324**, 223). Dame et al. (Ap. J. **322**, 706) have produced a remarkable map of the entire galactic plane in CO covering 10°– 20° in latitude at 1/2° resolution. The map was produced from smaller scale surveys of May et al. (1988, Astron. Astrophys. Suppl. **73**, 51), and a number of other surveys published during the previous triennium using the 1.2–m Columbia University and Chile sky survey telescopes. Robinson et al. (1988, Astron. Astrophys. **193**, 60) reported the completion of a CO survey of the southern hemisphere galactic plane survey using the 4–m telescope at Epping. A ^{13}CO survey of the longitude range $l = 38^\circ - 67.^\circ5$, using the Bordeaux telescope (Jacq et al. 1988, Astron. Astrophys. **195**, 93), showed good correlations with the cold clouds identified in the Arecibo galactic plane survey (Jacq et al. 1988, Astron. Astrophys. **207**, 145). Stark et al. (1988, *Molecular Clouds in the Milky Way and External Galaxies*, p.303) presented the progress of the Bell Labs ^{13}CO survey of the galactic plane, which contained 73,000 spectra at that time, and covers the range $l = 5^\circ - 122^\circ$ and $b = -1^\circ$to 1° (*Molecular Clouds in the Milky Way and External Galaxies*, p.303).

A number of other important surveys were also published of the galactic plane. Notable among these are the first high resolution survey of the galactic plane at a frequency of 30.9 MHz using the now defunct Clark Lake TPT array (Kassim, 1988, Ap. J. Suppl. **68**, 715). The survey covers all of the galactic plane visible from southern California. Hulsbosch and Wakker made a nearly complete survey of the northern sky for high velocity HI clouds, having observed 28,200 positions with the Dwingeloo telescope (1988, Astron. Astrophys. Suppl. **75**, 191). Bajaja et al. (1989, Astron. Astrophys. Suppl. **78**, 345), have complemented an existing survey of high velocity clouds in the southern hemisphere with new, more sensitive observations. An optical survey of diffuse Hα emission was made by Reynolds in the region $l = 208^\circ - 218^\circ$ and $b = -2^\circ$ to 8° (1987, Ap. J. **323**, 118). The survey has demonstrated the important result that diffuse ionized gas is widespread throughout the galactic disk and may contain most of the ionized hydrogen in the disk. A recombination line survey of H 272α using the Ooty telescope (Anantharamaiah, J. Ap. Astron. **6**, 177; *ibid.* , 202) showed that the lines are emitted in the low density envelopes of the observed HII regions. Colomb presented results of an H 166α survey (1989 Astron. Astrophys. **208**, 239) which indicated that these lines originate in the hot, fully ionized gas of HII regions. A large scale survey of linear polarization of 2.7 Ghz emission covering the range $l = 5^\circ - 76^\circ$ and $b = -1.^\circ5$ to $1.^\circ5$ was published by Junkes et al. (1987, Astron. Astrophys. Suppl. **69**, 451). Many of the surveys published during the triennium have not been fully analyzed and they will be a rich source of data on the galactic plane emission for many years to come.

7.2 Rotation Constants and Kinematics

Two fundamentally new methods for measuring the distance to the galactic center were reported by Reid et al. (1988, Ap. J. **330**, 809), and by Brand and Blitz (1988, *The Outer Galaxy*, p.73). The first study uses the method of expansion parallaxes to the maser spots associated with the source Sgr B2 near the Galactic center measured with VLBI; the distance obtained is 7.1 ±1.5 kpc including systematic errors. What is particularly important about this measurement is that it is *independent* of any other intermediate distance measurements. The second method uses star–forming molecular clouds in the outer Galaxy in an extension of Weaver's method of solar circle observations to obtain a distance of 8.0 ± 0.5 kpc for $\Theta_0 = 220$ km s^{-1}. Weaver's method was combined with an expansion parallax to W49(N) using water maser proper motions to obtain a Galactic center distance of 7.6 ±1.6 kpc (Gwinn et al. 1989, IAU 136, p.49). These three independent measurements of R_0 are all consistently lower than the IAU value of 8.5 kpc.

Two sets of observations support earlier claims of a Π component to the local standard of rest. Kolesnik and Yurevich (1987, *Kinematics of Celes. Bod.* **3**, 72), and Yurevich (1988, *ibid.* **4**, 48) obtain a value of 6–7 km s^{-1} toward the anticenter from observations of molecular clouds containing OH. Clube (1989, IAU 136, p. 473) obtains a value of 40 km s^{-1} from analysis of the molecular ring around the galactic center. A new measurement of the inner Galaxy rotation curve using the graphic variant method of Agekian et al. was reported by Teerikorpi (1989, Astron. Astrophys. **209**, 46), who found that the derived velocities are 5–10 km s^{-1} lower than those determined by the usual tangent point analysis.

The two–dimensional velocity field of the outer Galaxy was derived from observations of stars and their associated CO clouds (Brand et al. 1987, Astron. Astrophys. Suppl. **68**, 1), which show motions consistent with spiral arm streaming motions (Brand et al. 1988, *The Outer Galaxy*, p. 40). The measured field will permit more accurate measurements of streaming motions in the second and third galactic quadrants. Other kinematic studies include an investigation of the kinematic origin of clouds associated with Gould's Belt (Olano and Pöppel, 1987, Astron. Astrophys. **179**, 202; Sandqvist et al. 1988, Astron. Astrophys. **205**, 225; Taylor, et al. 1989 Ap. J. **315**, 104), and a study of the velocity distribution of molecular clouds in the solar vicinity (Pellegatti-Franco, and Quiroga, 1987, Astrophys. Space Sci. **129**, 107). The latter study suggests that there are large velocity gradients perpendicular to the galactic plane. The velocity dispersion of molecular clouds in the solar vicinity was investigated anew by Stark and Brand (1989, Ap. J. **339**, 763), who obtained a value of 7.8 ± 0.6 km s^{-1} including streaming motion and a value 20% smaller if streaming is removed.

7.3 Local Galactic Structure

Daily flux density measurements of extragalactic radio sources showed unusual minima in the light curves that do not follow the source variations. These have been interpreted as being due to refractive focussing by small scale inhomogeneities in some ionized structure in the interstellar medium (Fiedler et al. Nature **326**, 675). Dés ert et al. (1988, Ap. J. **334**, 815), made an unbiased search for molecular clouds at high galactic latitude by examining the IRAS data base for clouds with infrared excesses; the number of potential clouds was increased by a factor of eight. A comparison of galaxy counts with HI emission and 100 μm emission from infrared cirrus found that $E(B-V)$ toward the South Galactic Pole is 0.02 *mag*, and that the HI associated with the Magellanic stream has a significant deficit of dust compared to the solar vicinity (Fong et al. 1987, M.N.R.A.S. **224**, 1059).

7.4 Vertical Structure of the Disk

Considerable evidence has been accumulating that there is a thick gaseous disk with a scale height comparable to that of the thick stellar disk. Reynolds, showed that the scale height of the free electron layer is about 1500 pc, and that diffuse HII therefore accounts for about 25% of the total interstellar atomic hydrogen near the solar circle (1989, Ap. J. (Letters) **339**, L29). Furthermore, the ionized gas is the dominant component at $|z| > 1000$ pc. A similar conclusion was reached by Savage and Massa (1987, Ap. J. **314**, 380) from IUE absorption line observations of distant stars at high galactic latitude. Bloemen (1987, Ap. J. **322**, 694), has made a detailed hydrostatic equilibrium analysis of the disk and concluded that locally, the Galaxy is stable against Parker instabilities. The analysis puts good constraints on the halo gas if it is also to be in hydrostatic equilibrium. Ikeuchi described a "chimney" model of the ISM where sequential supernova explosions deposit disk gas into the halo (1987, *Starbursts and Stellar Evolution*, p.27).

Studies of interstellar absorption lines toward stars in the halo were caried out using CII (Keenan et al., 1988, Astron. Astrophys. **198**, 205), and Si, Mn, Fe, S, and Zn using IUE by Van Steenberg and Shull (1988, Ap. J. **330**, 942). The former study found CII to be abundant out to $|z| \sim 1$ kpc, but almost absent beyond 2 kpc. No CII was found toward stars near known high velocity clouds. The latter study found that the metals correlate with the mean hydrogen density along the line of sight, but not with the physical density derived form an analysis of *Copernicus* H_2 rotational levels. The relative Fe abundance is larger in the halo, suggesting selective grain processing in shocks.

7.5 Spiral Structure

There were only a few spiral structure studies done during the past triennium. From a CO survey in the range $l = 270°-300°$, Grabelsky et al. (1987, Ap. J. **315**, 122) showed that the Carina arm is the dominant structure seen in the molecular gas in that longitude range and that it is displaced from the position of the arm identified in HI. Subsequently, Grabelsky et al. (1988, Ap. J. **331**, 181) analyzed the clouds in the Carina arm and found that the massive clouds in their catalogue trace the arm over a distance of more than 23 kpc. They suggest that the Sagittarius and Carina arms are a single structure about 40 kpc in length. Avedisova (1989, Astrophysics **30**, 140), made a study of the Sagittarius–Carina arm, and found longitudinal and transverse age gradients of the stars and gas in the arm. They concluded that an upper limit to the age of the complexes is 5×10^6y, and that there is a decrease in the pitch angle with age. Peters and Bash (1987, Ap. J. **317**, 646), looked at the correlation of HI self absorption against a background of hotter CO in the inner Galaxy and confirmed earlier studies showing the correlation to be quite good.

7.6 High Velocity Clouds (HVCs)

There was continued interest in studies of HVCs this triennium, with renewed attempts to determine their nature, with some new progress. Giovanelli (1986, NRAO Workshop 12, p.99) reviewed progress to that time, as did van Woerden et al. (*ibid.* p.115). Bajaja, et al. (1987, Publ. Ast. Inst. Czech. Acad. Sci. **69**, 237) argued that the very highest velocity components might be at the distance of the local group of galaxies (also, Bajaja, et al., 1989, Astron. Astrophys. Suppl. **78**, 345). Songaila et al. (1988, Ap. J. **329**, 580), have confirmed the detection of Ca K absorption from Complex C against stars at distances of 1–2 kpc setting an upper limit to the distance of that complex. A similar, but more uncertain limit is also placed on complex A. No absorption is detected against any nearby star with distances of $\sim$ 300 pc, ruling out the formation of the HVCs by supershells in the local disk. Haud (1988, Astron. Astrophys. **198**, 125) has used the positions and kinematics of the HVCs to argue that the Milky Way is a polar ring galaxy. This intriguing possibility should be confirmed by other workers in the field.

7.7 The Distribution and Properties of the Gas in the Plane

In addition to the large numbers of surveys of molecular gas published during the triennium, there has been a good deal of work that has gone into the interpretation of the CO surveys, including those published in the previous triennium. The Massachusetts–Stony Brook CO survey has been analyzed separately by two separate groups. The overall distribution of the CO, including attempts at obtaining a face–on distribution of the molecular gas was done by Clemens, et al. (1988, Ap. J. **327**, 139), and by Solomon and Rivolo (1989, Ap. J. **339**, 919). The properties of the molecular cloud ensemble in the inner Galaxy was derived by Solomon, et al. (1987, Ap. J. **319**, 730), and by Scoville, et al. (1987, Ap. J. Suppl. **63**, 821) from catalogues of clouds obtained from the survey. The two catalogues differ considerably in the number of clouds that were identified, and it is unclear how well the smaller catalogue correlates with the larger one. The radial distribution of the CO observed with the pair of 1.2 m telescopes was analyzed by Bronfman, et al. (1988, Ap. J. **324**, 248). This paper also presents the results form the southern hemisphere part of the survey for the first time, and combines the data with that obtained in the north. Knapp (1987, Publ. A.S.P. **99**, 1134), reviewed the overall radial and vertical distribution of CO and HI in the galactic disk.

The distribution and properties of molecular clouds was the subject of a number of different studies. A survey of clouds in the outer Galaxy (Mead, 1988, Ap. J. Suppl. **67**, 149), was analyzed by Mead and Kutner (1988, Ap. J. **330**, 399), and showed considerable differences in mean molecular cloud properties compared to those in the inner Galaxy. Polk, et al. (1988, Ap. J. **332**, 432), analyzed the CO and ^{13}CO emission from the galactic plane and concluded that a significant contribution to the large scale CO emission comes from diffuse, relatively low optical depth gas compared to that found in giant molecular clouds (GMCs).

A number of important studies and reviews compared the overall distribution of dust and gas at different wavelengths. Osborne et al. (1987, *Physical Processes in Interstellar Clouds*, p.81), and Sodrowski et al. (1987, NASA CP–2466, p. 99), made comparisons between the IRAS data, and various molecular cloud surveys of the galactic plane. The first group concluded that the CO/H_2 ratio is higher than most other studies have obtained; the latter group obtains the relative proportions of the ionized, atomic and molecular components that are found in the disk. Mooney and Solomon (1988, Ap. J. (Letters) **334**, L54) compared the CO and IRAS emission from 55 clouds observed in their survey, and found that the average star formation rate per unit mass varies widely from cloud to cloud and is independent of cloud mass. A similar study was performed by Scoville and Good (1989, Ap. J. **339**, 841), who found a mean luminosity–to–mass ratio for molecular clouds to be more than 50% smaller than the Mooney and Solomon value. They conclude that most of the 100 μm emission in areas associated with HII regions comes primarily from the surrounding molecular gas, and not from the HII region itself. Other correlative studies include a study by Haslam and Osborne (1987, Nature **327**, 211) that showed a remarkably detailed correlation between 60 μm emission and that seen at 11 cm in the radiocontinuum. Supernova remnants show up clearly as radio sources with no corresponding infrared emission.

A spectral index map of the Galaxy above $\delta = -19°$ was made by Reich and Reich (1988, Astron. Astrophys. Suppl. **74**, 7) from radio continuum surveys made at 408 MHz and 1420 MHz. They have made a critical recalibration of the surveys and found considerable variations in the temperature spectral index, with the steepest indices ocurring in the North Polar Spur and Loop III. In a subsequent paper (Reich and Reich, 1988, Astron. Astrophys. **196**, 211), they found that the spectral index, which flattens toward higher latitudes, is not consistent with a static or purely convective halo, but rather with models that include a galactic wind.

Burton (1988, *Galactic and Extragalactic Radio Astronomy*, p. 295), has written an important review of the overall distribution of atomic hydrogen in the Milky Way, updating his article in the first edition of the book written in 1975. Elmegreen and Elmegreen have identified a new category of HI clouds they call "superclouds" from the Weaver and Williams survey (1987, Ap. J. **320**, 182). They postulate that these clouds are fundamental gravitationally bound entities that also occur in other galaxies. Garwood and Dickey (1989, Ap. J. **338**, 841), have made HI absorbtion line observations toward 21 compact continuum sources and found that the cool phase of the atomic gas is less abundant in the inner Galaxy than it is near the solar circle. Using the same data, they derive a mass spectrum of interstellar HI clouds and conclude that the data are consistent with a single component mass spectrum from less than 1 $M_\odot$ to 10^6 $M_\odot$ (Dickey and Garwood, 1989, Ap. J. **341**, 201).

7.8 Galactic magnetic fields

Heiles (1987, *Interstellar Processes*, p. 171) reviewed the work on the large–scale galactic magnetic field. The field decreases with Galactocentric radius and z, has a strength of $\approx 4\mu$G near the Sun, and is not uniform. Zweibel (*ibid.* p. 195) discusses the origin and maintenance of the galactic field. She compares the theory of a primordial intergalactic field with the competing theory of a field removed and regenerated within the Galaxy. Dagkesamanskij and Shutenkov (1987, Sov. Astron. Lett. **13**) estimated the angular scale of Galactic magnetic field inhomogeneities to be approximately 8° from an analysis of 102.5 MHz radio emission near the north Galactic pole. They also found the chaotic and regular components of the field to be equally strong.

Rotation and dispersion measures of pulsars allow determination of the local magnetic field. Results of existing observations are presented by Sieber (1987, *Interstellar Processes*, p. 110), who also sketches a promising future in this area of research owing to a recent increase in the data sample. Andreasyan and Makarov (1989, in Astrophysics **30**) obtained directions and field strengths of the magnetic fields in Galactic spiral arms from analysis of Faraday rotation measures of polarization planes of a large sample of pulsars. The strengths were found to be between -1 and -2.5 μG.

8 CHEMICAL EVOLUTION OF OUR GALAXY

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8.1 Development of observations relevant to the chemical evolution of our Galaxy

8.1.1 Abundance determinations

The chemical history of galaxies is recorded in the evolution of their chemical composition. Therefore, it is extremely important to have reliable abundance determinations.

The most detailed information is available for our Galaxy. Reviews of observational work done in recent years can be found in Gustafsson (1987, in "Stellar Evolution and Dynamics of the Outer Halo of the Galaxy", ed. M. Azzopardi and F. Matteucci, E.S.O. Publ. p. 33), Gehren (1988, Rev. Mod. Phys. **1**, 52), Lambert (1988, in "Cosmic Abundances of Matter", ed. C.J. Weddington, AIP Conf. Proc. **183**, 168) and Wheeler et al. (1989, Ann. Rev. Astron. Astrophys. **27**, 279), where quantitative intercomparisons of abundance results from different investigations and discussions of the basic techniques of abundance determination can be found.

For oxygen and the so-called α-elements there seems to exist a reasonably well-established overabundance with respect to iron in metal-poor stars ([Fe/H] < -1.0). However, different conclusions concerning oxygen arise from studies of dwarfs and giants in the solar neighbourhood. Spectroscopic analyses of dwarfs (Abia and Rebolo, 1989, Astrophys. J. **347**, 186) indicate that the overabundance of oxygen increases steadily between [Fe/H] $= -2.0$ and [Fe/H] $= -3.0$, reaching values as high as $+1.0$ dex, at variance with abundances from giants indicating a more or less constant overabundance of oxygen, of the order of $+0.4$ – $+0.5$ dex, for [Fe/H] < -1.0.

Ratios of carbon and nitrogen with respect to iron seem to be marginally solar for [Fe/H] > -2.0, but the results for very metal-poor stars are still uncertain.

The situation for the odd-Z elements, such as Al and Na, is still very uncertain especially in very metal-poor stars, so that no firm conclusions can be drawn on the predicted odd-even effect.

The iron peak elements (V, Cr, Zn, Mn, Ni) generally seem to have a solar ratio with respect to iron over the whole range of iron abundances.

Observations of s-process elements suggest that they are more underabundant in metal-poor stars than r-process elements. In particular, elements such as Ba, Y and Sr seem to be underabundant with respect to iron in metal-poor stars, their ratios becoming solar at not yet clear iron abundance (between -2.3 and -1.5).

Concerning r-process elements, there is indication of an overabundance of Eu with respect to iron in metal-poor stars.

Information on the chemical evolution of our Galaxy is also provided by the age-metallicity relation, although large errors are present in the determination of stellar ages. The age-metallicity relation as deduced from stars in the solar vicinity suggests that the abundance of iron has increased during galactic lifetime, with a steeper slope during the first 2 Gyr.

Recently Geisler (1987, Astron. J. **94**, 84), using data on intermediate age open clusters showed that the rate of increase of [Fe/H] in the anticenter beyond the solar circle is shallow, similar to that of the LMC, rather than the steep increase in the solar neighbourhood. This suggests that there is not a unique age-metallicity relation but that different regions of the galactic disk have evolved at different rates.

Abundance gradients in the galactic disk are measured from radio, optical and far-infrared observations of HII regions. In particular, oxygen and nitrogen show a similar gradient in the range -0.07 -0.09 dex Kpc^{-1} over a galactocentric distance range of approximately 10 Kpc.
Recently, Langer and Penzias (1990, Astrophys. J., in press) have analyzed data from optically thin CO emissions and found a gradient in $^{12}C/^{13}C$ across the galactic disk, ranging from about 30 in the inner part at 5 Kpc from the center to about 70 at 12 Kpc, with a galactic center value of 24.
Abundance measurements in stars indicate the existence of a gradient of iron (see Grenon, 1987, J. Astrophys. Astron. **8**, 123, for a review) and that the iron gradient has increased in time.
Detailed spectroscopic studies of K giants in Baade's window have been carried out by Rich (1988, Astron. J. **95**, 828). The resulting distribution as a function of metallicity indicates [Fe/H] values between -1.0 and +1.0 with a mean around +0.3 (twice the solar value). The shape of such a distribution is different from that of the G-dwarfs in the solar neighbourhood, in the sense that in the bulge it does not seem to be a "G-dwarf problem" (the deficiency of metal-poor stars with respect to the predictions of the simple closed-box model).

8.1.2 Galactic SN rates

The way in which stars eject their processed material into the interstellar medium can be quiescent (mass loss by stellar wind) or explosive (novae and supernovae), according to their initial mass. Of these ways the supernova one is the most effective. Therefore, it is extremely important, in order to understand the chemical history of our Galaxy, to know the galactic SN rates. On the other hand, it is very difficult to measure SN rates in our Galaxy because of the paucity of historical SNe and the difficulty of estimating a total blue luminosity for the Galaxy. Recently, van den Bergh (1990, in "Supernovae", ed. S.E. Woosley, Springer-Verlag : New York, in press) has estimated that the total galactic SN rate is two SNe per century. Of these SNe 18% are expected to be of type Ia, 17% of type Ib and 65% of type II.

8.2 Chemical evolution models

In recent years there has been a considerable development of models of chemical evolution of our Galaxy.
Tosi (1988a, Astron. Astrophys. **197**, 33) studied the uniqueness of solutions to the problem of chemical evolution of galaxies by computing numerical models for the evolution of the disk of our Galaxy, using various assumptions about the main evolutionary parameters. She found that only a few (but more than one) models can reproduce the chemical features of the galactic disk. In particular, she found the following constraints: a) the star formation rate has not decreased rapidly in time, b) the star formation rate is not simply proportional to the surface gas density, c) the initial mass function has not strongly varied in space and time, d) the rate of infall decreases more slowly than the star formation rate and its present value is in the range 0.3 - 1.8 $M_\odot$ yr^{-1} for the whole disk.
In a different paper, Tosi (1988b, Astron. Astrophys. **197**, 47) studied the problem of infall of gas chemically enriched on the galactic disk. Her main conclusion was that enriched infall has little influence on the chemical evolution of the disk as long as its global metal content is lower than 0.4 times the solar global metallicity.
Matteucci and François (1989, 50.155.026) developed a model of chemical evolution for our Galaxy with different assumptions about disk formation, namely i) out of already enriched halo gas and ii) out of primordial gas coming from outside the Galaxy. Their conclusion was that, while case i) reproduces well the G-dwarf distribution but overestimates the number of halo stars, due to the simplistic assumption that the halo loses all its residual gas at once, case ii) gives reasonable agreement with the G-dwarf distribution in the disk and at the same time it does not overestimate the number of halo stars. However, it is possible that gas was

continuously lost from the halo and that also some primordial gas coming from outside the Galaxy contributed to form the disk, as suggested by Pagel (1989, Rev. Mex. Astron. Astrofis. **18**, 161). More recently, Matteucci et al. (1990, in "Chemical and dynamical evolution of galaxies", ed. F. Ferrini et al., Giardini: Pisa, in press) studying the same problem with a more sophisticated model, where the evolution of halo and disk can be followed at the same time, suggested that a time delay of the order of a few billion years between halo and disk formation, where the disk formed out of residual halo gas, could be the best solution to explain the stellar distribution in the halo and in the disk at the same time. However, no definitive conclusions cannot be drawn yet on this important point which deserves further study as well as new data on the G-dwarf distribution in the disk.

Matteucci and François's (1989, M.N.R.A.S. **239**, 885) model also assumed that the galactic disk formed by the accumulation of material, following an exponential law, with a time scale increasing linearly with the galactocentric distance, in agreement with previous results from dynamical models of Larson. This assumption is very important in order to predict abundance gradients in agreement with observations and to explain the different evolutionary status of different regions of the disk. For example, under this assumption the most external regions of the disk may be still forming now and their physical properties resemble those of systems like the Magellanic Clouds, which appear to be less evolved than the solar vicinity. On the other hand, the most internal regions of the disk show characteristics similar to more evolved systems like elliptical galaxies, and this is especially true for the galactic bulge.

Detailed nucleosynthesis prescriptions from supernovae of different type were included in Matteucci and François's model and the role of the different SNe in the chemical enrichment studied in detail. Their main conclusions were that the different roles of type I and II are fundamental to explain the observed abundance pattern in stars in the solar neighbourhood. In particular, the overabundances of O and α-elements with respect to iron in metal-poor stars.

It should be noted that if one assumes Abia and Rebolo's (1989, Astrophys. J. **347**, 186) results on oxygen, the nucleosynthesis prescriptions on iron produced by type II SNe, which are indeed very uncertain, should be drastically revised, as well as the duration of the halo phase should be longer than that estimated from models fitting a constant [O/Fe] ratio in halo stars (of the order of 1 Gyr).

Detailed calculations of iron production in massive stars would be extremely useful in clarifying this point.

Gradients of abundance ratios in the galactic disk were interpreted by Matteucci and François as a probe of stellar nucleosynthesis. In particular, they predicted a small but positive gradient of S/O, and this was interpreted as due to the small differences in the lifetimes of the progenitors of these two elements (they are both produced in massive stars but the production of S seems to be more concentrated than that of O). Pagel (1989, Rev. Mex. Astron. Astrofis. **18**, 161) developed a simple analytical model for halo and disk and introduced delayed production of certain elements such as Fe (substantially produced in type I SNe originating from white dwarfs in binary systems) and s-process elements (from intermediate mass stars). His model reproduces Matteucci and François's results for O and α-elements as well as the observed trend of Eu versus Ba, suggesting, in this case, a "primary" origin for Ba. However, the observed trend of [Ba/Fe] versus [Fe/H] is not yet understood, so that more theoretical work is necessary before drawing any conclusion.

Clarke (1989, M.N.R.A.S. **238**, 283) and Sommer-Larsen and Yoshii (1989, M.N.R.A.S. **238**, 133) investigated the possibility of reproducing the observed radial metallicity gradient (in particular O since their models do not take into account stellar lifetimes and cannot predict the behaviours of elements produced in long living stars) in galactic disks as a consequence of gas flows caused by viscous transfer of angular momentum across the disk. These authors found that the strong radial flows predicted during the early evolution of the disk gas tend to erase any strong metallicity gradients that are produced as a result of differential enrichment.

However, Clarke (1989, M.N.R.A.S. **238**, 283) has shown that strong metallicity gradients are only compatible with radial flows if an outer cut–off is imposed on the star forming disk. In this case, in fact, the gradient results from inflow of low metallicity material from beyond the cut–off at late times. The net effect of this is the same as the one obtained by Matteucci and François by assuming an increasing time scale of disk formation at larger radii, since in this case the outer disk is still experiencing accretion of primordial/low metallicity material at the present time.

Matteucci and Brocato (1990, Astrophys. J., in press), recently extended the model of Matteucci and François to the galactic bulge. The bulge is assumed to have formed and evolved much faster than the other regions of the disk. Under this assumption they showed that the metallicity distribution of K–giants in the bulge can be well reproduced and particularly good agreement is obtained if an IMF slightly flatter than a Salpeter function is assumed. Similar conclusions have been reached also by Koeppen and Arimoto (1990, in "Chemical and Dynamical Evolution of Galaxies", ed. F. Ferrini et al., Giardini: Pisa, in press).

Moreover, they showed that the majority of bulge stars, which have a metallicity twice the solar value, should show overabundances of O and α–elements like metal–poor halo stars, as a consequence of the very short evolutionary time scale as compared to the timescale for the ejection of iron from type I SNe. This prediction has been partly confirmed by a recent study by Barbuy and Grenon (1990, in "Bulges of Galaxies", ESO/CTIO Workshop, in press) who measured the ratio [O/Fe] in K–giants in the bulge.

On the other hand, systems like the Magellanic Clouds which show a slower evolution than the solar vicinity should show the same abundance pattern as the external regions of the galactic disk. In particular, young MC stars should have [O/Fe] ratios lower than zero and lower than young stars in the solar vicinity, as suggested by Russel et al. (1988, in "The impact of very high S/N spectroscopy on stellar physics", ed. G. Cayrel de Strobel and M. Spite, p. 545).

9 RECENT TRENDS IN GALACTIC DYNAMICS

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9.1 Introduction

This report highlights a few aspects of work done on galactic dynamics during the period 1987-1989 that is relevant to the Milky Way.

9.2 Physical understanding of the Milky Way

Contrary to the poor understanding of the outer part of the Galaxy with regards to the nature of the dark halo, there is a growing consensus that the mass content within the Solar orbit can be essentially accounted for by known matter, mainly stars. This is fortunate since for decades the basic assumption of Galactic dynamics was that collisionless gravitational physics is a good model. In short, the energy densities susceptible to play a role over a dynamical time are believed to be rotational and gravitational. Factors such as gas pressure, cosmic rays or magnetic fields are of second order, and can be significant only over longer time-scales.

However, the traditional view that the Milky Way is well approximated by a steady axisymmetric system, a view that is a good first order approximation, is increasingly challenged on the one hand by a large body of observational knowledge, and on the other hand by more than two decades of numerical simulations. This challenge means that a sufficient level of knowledge has been reached so that more detailed models are required, and that in order to progress, some old concepts have to be revised or made more specific. N-body simulations show that self-gravitating disks are rarely steady, especially when dissipative factors are taken into account. Dissipative effects tend to bring disks closer to dynamical instabilities, which react to heat the disk, keeping it marginally stable. Numerous dynamical asymmetries can develop, with time-scales on the order of the rotation period. In N-body simulations, typical spiral arms are evanescent waves. The only long lived structures appear to be bars, ovals and triaxial bulges. It is consequently not astonishing that the inner few kpc of disk galaxies are generally significantly non-axisymmetric. The main effect of a central triaxial deformation, especially if the central density is high, is to mix stellar populations, to heat the disk, also in the vertical direction. These relatively fast dynamical instabilities are important for the understanding of the evolution of the Galaxy after its formation phase, since they imply substantial intervening changes.

Another aspect which will undoubtedly be worked out in more detail in the near future is the interaction between dynamics and star formation, each factor being likely to influence the other, and ultimately affecting the global morphology of the disk.

Hereafter follows a list of individual contributions with a succinct summary or comment.

9.3 Textbooks on galactic dynamics:

Binney, J., Tremaine, S.:1987, *Galactic Dynamics*, Princeton University Press, Princeton
A fairly complete coverage of present day theoretical galactic dynamics, suited to astrophysics students and researchers.

Scheffler, H., Elsässer, H.: 1987, *Physics of the Galaxy and Interstellar Matter*, Springer-Verlag, Berlin
This is a general textbook on the Galaxy. It is more observationally oriented than the previous.

Gilmore, G., King, I., van der Kruit, P.: 1989, *The Milky Way as a Galaxy*, 19th Advanced Course of the Swiss Soc. of Astrophys and Astron., (Saas-Fee), Geneva Observatory, Geneva, eds: R. Buser, I. King
This course presents an original synthesis of the present knowledge of the stellar content of the Galaxy.

9.4 Conference Proceedings:

de Zeeuw, T. (ed): 1987, *Structure and Dynamics of Elliptical Galaxies*, IAU Symp. 127, Reidel, Dordrecht.

Gilmore, G., Carswell, B. (eds): 1987, *The Galaxy*, NATO ASI Series, Reidel, Dordrecht.

Palouš, J. (ed): 1987, *Evolution of Galaxies*, 10th European Regional Meeting of the IAU, Publ. of the Astron. Inst. of the Czech. Acad. of Sci. **69**.

Blitz, L., Lockman, F.J. (eds): 1988, *The Outer Galaxy*, Lectures Notes in Physics **306**, Springer-Verlag, Berlin.

Fich, M. (ed): 1989, *The Mass of the Galaxy*, CITA, Toronto.

Morris, M. (ed): 1989, *The Center of the Galaxy*, IAU Symp. 136, Kluwer, Dordrecht.

Philip, A.G.D., Lu, P.K. (eds): 1989, *The Gravitational Force Perpendicular to the Galactic Plane*, L. Davis Press, Schenectady.

Sellwood, J. (ed): 1989, *Dynamics of Astrophysical Discs*, Cambridge Univ. Press, Cambridge.

9.5 Dynamical Models:

Even if the Galaxy is only approximately steady and axisymmetric, pure static axisymmetric models are still useful in order to understand the first order relationships and gross structure. There are several studies which try to make a model from the observational data, and others developing general theoretical tools in the potential theory.

Allen, C., Martos, M.A.: 1986, Rev. Mex. Astron. Astrofis. **13**, 137
A new mass model of the Galaxy.

Bienaymé, O., Robin, A.C., Crézé, M.: 1987, Astron. Astrophys. **180**, 94,
Crézé, M., Robin, A.C., Bienaymé, O.: 1989, Astron. Astrophys. **211**, 1
Studies of a mass and dynamical model of the Galaxy constrained by star counts. Nearly no dark mass is necessary near the Sun.

Garwood, R., Jones, T.J.: 1987, PASP **99**, 453
Mass model of the Galaxy from infrared data, suggesting a flattened bulge.

de Zeeuw, T.: 1987, in *Structure and Dynamics of Elliptical Galaxies*, IAU Symp. 127, 271
Review of non-spherical models for galaxies, in particular the Stäckel class of models.

Bishop, J.L.: 1987, Astrophys. J. **322**, 618
Axisymmetric self-consistent models of Stäckel potentials with shell orbits.

Carlberg, R.G., Innanen, K.A.: 1987, Astrophys. J. **94**, 666
The effects of eccentric and chaotic orbits passing well within the bulge and having a large amplitude outside the flattened disk are examined.

Osipkov, L.P., Kutuzov, S.A.: 1987, Astrophysics **27**, 645, and Kutuzov, S.A., Osipkov, L.P.: 1988, Sov. Astron. **32**, No 3
Phase density for a thin disk and halo model.

Contopoulos, G., Grosbøl, P.: 1988, Astron. Astrophys. **197**, 83
Approximate self-consistent models of spiral galaxies.

Dejonghe, H., de Zeeuw, T.: 1988, Astrophys. J. **329**, 720
The Galaxy is modelled with a Stäckel potential, assuming shell orbits for stars.

Rowley: 1988, Astrophys. J. **331**, 124
Models for an axisymmetric box-shaped bulge.

Dejonghe, H., de Zeeuw, T.: 1988, Astrophys. J. **333**, 90
Exact analytic distribution functions that depend on three integrals of motion for realistic axisymmetric models introduced by Kuzmin.

Rohlfs, K., Kreitschmann, J.: 1988, Astron. Astrophys. **201**, 51
Model of the Galaxy from new values of geometrical and kinematic parameters.

Sellwood, J.A., Sanders, R.H.: 1988, M.N.R.A.S. **233**, 611
A model of the Galaxy with very little dark matter can account for the circular velocity at the Sun.

Einasto, J., Haud, U.: 1989, Astron. Astrophys. **223**, 89.
Haud, U., Einasto, J.: 1989, Astron. Astrophys. **223**, 95
Galactic models with massive halo.

Kuijken, K., Gilmore, G.: 1989, *M.N.R.A.S.* **239**, 571, 605 and 651
Assuming that the star energy near the Sun can be separated into radial and z components, a new determination of the Galaxy surface density is derived.

Statler, T.S.: 1989, Astrophys. J. **344**, 217
A similar approach to the latter papers towards deducing the Galaxy surface density at the Sun is worked out, but replacing the $R-z$ energy separation by a Stäckel type separation of the integrals of motion.

de Zeeuw, T., Pfenniger, D.: 1988, M.N.R.A.S. **235**, 949
A new class of potential-density pairs, in particular suited to massive halos, is presented in which Poisson's equation is solved by one-dimensional quadrature.

Evans, N.W., Lynden-Bell, D.: 1989, M.N.R.A.S. **236**, 801
Solutions of stellar hydrodynamic equations for Stäckel potentials.

Lynden-Bell, D.: 1989, M.N.R.A.S. **238**, 1099
A new method for calculating the potential of azimuthally dependent flat disks.

9.6 General Structure:

Some attempts have been made to understand the general shapes and characteristics of disk galaxies.

Lin, D.N., Pringle, J.E.: 1987, Astrophys. J. **320**, L87
The exponential disk of galaxies is proposed to result from a viscous effect the time-scale of which is comparable with the time-scale of star formation. See also: Yoshii, Y., Sommer-Larsen, J.: 1989, M.N.R.A.S. **236**, 779.

Martinet, L.: 1987, Astron. Astrophys. **206**, 253
Reasonable arguments about the properties of disks such as the thickness leads to constraints on the stability parameter Q between about 1 and 3.

Pfenniger, D.: 1989, Astrophys. J. **343**, 142
The energy minimization of non-isolated, self-gravitating, and rotating disks is shown to lead naturally to flat rotation curves.

9.7 Disk stability:

The N-body technique is still the most direct method for gaining insight, in particular to the problem of disk stability.

Sellwood, J.A.: 1987, in *Evolution of Galaxies*, Publ. Astron. Inst. Czech. Acad. Sci. **69**, 249
It is argued that spiral density waves are short lived.

Sellwood, J.A.: 1987, in *Dark Matter in the Universe*, IAU Symp. 117, 301
It is recalled that the global stability of the Galaxy depends much more on the mass of the bulge than on the mass of a massive halo.

Sellwood, J.A.: 1989, M.N.R.A.S. **240**, 991
On the recurrence of the spiral instability cycle.

9.8 Disk heating, density waves:

The collective mechanisms for heating star motions, especially if disks remain marginally unstable, emerge as very promising.

Fuchs, B., Wielen, R.: 1987, in *The Galaxy*, Reidel, 375
Review of the mechanisms and constraints which control the heating or cooling of stellar motions.

Carlberg, R.G.: 1987, Astrophys. J. **322**, 59
The nearly universal vertical structure of disks is proposed to result mainly from internal evolution, such as density waves.

Gurzadyan, V.G., Kocharyan, A.A.: 1987, Astron. Astrophys. **205**, 93
It is argued that galactic orbits are exponentially unstable, having a characteristic time scale comparable to the orbital period.

Binney, J.: 1987, in *The Galaxy*, Reidel, 399
Review of the actions as a tool to describe the Galaxy.

Binney, J., Lacey, C.: 1988, M.N.R.A.S. **230**, 597
Diffusion of stars through phase space, described by the Fokker-Planck equation and using action-angle variables.

Bertin, G., Lin, C.C., Lowe, S.A., Thurstans, R.P.: 1989, Astrophys. J. **338**, 78, 104
The modal analysis of spiral arms is investigated in order to make detailed models of disk galaxies.

9.9 Non-axisymmetric central distortions:

There is a growing number of papers dealing with the effects of a bar or triaxial central deformation. A bar is a very efficient engine for heating star motions in the radial as well as in the vertical directions.

Matsuda, T., Inoue, M., Sawada, K., Shima, E., Wakamatsu, K.-I.: 1987, M.N.R.A.S. **229**, 295
Numerical investigation of the gas response to a non-axisymmetric potential, showing that even a weak bar perturbation can generate spiral patterns.

Gerhard, O.E., Vietri, M.: 1987, in *Structure and Dynamics of Elliptical Galaxies*, IAU Symp. 127, 399
A triaxial bulge in our Galaxy is strongly suggested by observational (IR) data.

Yuan, C., Chen, Y.: 1988, in *The Outer Galaxy*, Lectures Notes in Physics **306**, 144
The 3-kpc arm is proposed to result from the excitation by a small oval central distortion.

Kreitschmann, J., Rohlfs, K.: 1989, in *The Mass of the Galaxy*, CITA, 5
The central motion of gas within 3 kpc is modelled by elongated orbits.

Sanders, R.H.: 1989, in *The Center of the Galaxy*, IAU Symp. 136, 77
A weak bar can explain the flow of the gas on elliptical streamlines seen between 2 and 4 kpc.

Ostriker, E.C., Binney, J., Saha, P.: 1989, M.N.R.A.S. **241**, 849
Analysis of the effect of a triaxial central region on globular clusters.

9.10 Warp:

Ostriker, E.C., Binney, J.J.: 1989, M.N.R.A.S. **237**, 785
The outer warp and the nuclear inclination of the Galaxy disk is proposed to be due to a secular reorientation of the angular momentum vector of infalling mass.

9.11 Dark matter, massive halo:

Even if the nature of the dark halo remains mysterious, it has at most a marginal importance within the Solar orbit. The flattening of the dark halo remains poorly constrained.

Kalnajs, A.J.: 1987, in *Dark Matter in the Universe*, IAU Symp. 117, 289
It is shown that the need for halos for disk stability is not at all compelling. A hot bulge is more efficient at stabilising a disk.

Bahcall, J.N.: 1987, in *Dark Matter in the Universe*, IAU Symp. 117, 17
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The amount of dark matter near the Sun is discussed. The unseen material should be in the form of low mass dark stars.

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The virial theorem is used to show that the relative small vertical velocity dispersion of metal-poor halo stars can not be generalized to Population II stars at other places.