DIVISION VII - GALACTIC SYSTEM

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33. STRUCTURE AND DYNAMICS OF THE GALACTIC SYSTEM

PRESIDENT: J.J. Binney
VICE-PRESIDENT: K.C. Freeman
ORGANIZING COMMITTEE: L. Blitz, H. Bloemen, A. Fridman, R. Genzel, A. Kalnajs, F. Matteucci, M. Morris, J. Palous, D. Spergel, Yoshii

1. Introduction

Notwithstanding the decline in the level of funding for astronomy in many countries, the number of papers published continues to grow triennium by triennium. The volume of current research is such that it is no longer practicable for Commission reports to provide a complete guide to everything published within the relevant field during a given triennium. Correspondingly, at the XXIInd General Assembly in the Hague it was resolved that future reports would be of a selective nature rather than general surveys of the literature.

Any selection is bound to be subjective and is likely to neglect unfairly some important work. We apologize in advance to authors of significant papers which are not mentioned in this report. Moreover, the balance of the report will inevitably reflect the research interests of those that compiled it, with the result that the amount of space accorded to a topic will not always reflect its objective importance for the development of Galactic astronomy as a whole. Please excuse any lack of balance!

The authors of draft sections were as follows: §2 – K.C. Freeman; §3 – M. Morris; §4 – D.N. Spergel; §5 – L. Blitz; §6 – H. Bloemen; §7 – F. Matteucci; §8 – J. Palous.

2. The Stellar Component

The metal-poor halo of the Galaxy probably formed at least partly from the debris of accreted dwarf systems. Support for this view comes from the discovery by Preston et al. (1994) of a population of metal-poor blue main-sequence stars in the galactic halo. These stars have ages as low as 3 Gyr, their metallicity [Fe/H] < -1 and they show unusual kinematics, with a galactic rotation velocity $V_{\rm rot} = (128 \pm 30)\,{\rm km\,s^{-1}}$, and a velocity dispersion which is an apparently isotropic $90\,{\rm km\,s^{-1}}$. For comparison, a sample of old halo stars with similar [Fe/H] distribution would have $V_{\rm rot} = (55 \pm 9)\,{\rm km\,s^{-1}}$. These stars are young, metal-poor and kinematically intermediate between the disk and the old halo. Where would such stars form? Preston et al. note that the nearby Carina dwarf spheroidal galaxy has a prominent intermediate-age metal-poor component, and it seems possible that the galactic blue metal-poor halo stars may have come from the accretion of such systems. They estimate that the accreted population represents about 10% of the local halo density and that the total accreted mass would be about $10^8\,{\rm M_\odot}$: this is equivalent to several dwarf spheroidal galaxies.

The discovery of the Sagittarius dwarf galaxy by Ibata et al. (1994) is another important element in understanding the formation of the galactic halo. This tidally disrupting galaxy, which brings with it several globular clusters, is now extended over many degrees on the sky. Its metallicity [Fe/H] is about -1 and its stars appear to be mainly old; see Fahlman et al. (1996) for a recent discussion.

If the halo did indeed form from accreted dwarf systems (and continues to form from systems like the Sgr dwarf), we might expect to see kinematical evidence of incomplete dynamical mixing. The evidence for moving groups of halo stars in the solar neighborhood has long been controversial. New deep proper motion studies of halo stars towards the North Galactic Pole, reaching out to 8 kpc from the sun, show evidence for stellar streams in the galactic halo (Majewski et al. 1996). The most prominent stream in their NGP field is metal-poor and has a retrograde galactic orbit.

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Stars in the outer galactic halo provide insights into the formation of the halo. For example, Sommer-Larsen et al. (1994) used a sample of halo blue horizontal branch stars with galactocentric distances between 5 and 50 kpc to study how the shape of the velocity ellipsoid of halo stars changes with radius. They find that the radial component of the velocity dispersion decreases with radius from about 140 $\mathrm{km\,s^{-1}}$ near the sun to about 80 $\mathrm{km\,s^{-1}}$ at large radius, with a corresponding increase in the tangential component from about 95 $\mathrm{km\,s^{-1}}$ to 130 $\mathrm{km\,s^{-1}}$. So the shape of the velocity ellipsoid changes from radial anisotropy near the sun to tangential anisotropy in the outer halo. In the inner galaxy, they find that the radial anisotropy is even more extreme than in the solar neighborhood. This behaviour is probably more consistent with the formation of the halo by accretion of small subsystems than by the early collapse of a monolithic overdensity in the early universe.

Evidence accumulates that the bulge of our Galaxy is bar-like, and that small box-shaped bulges like the galactic bulge may arise from bar-forming instabilities of the galactic disk. For a recent overview, see Buta et al. (1996). The COBE/DIRBE survey (Dwek et al. 1995) in the near-IR provides further evidence for a bar in the inner regions of the Galaxy. Projection of a 3-D model for the luminous density suggests that the bar has axes in the ratio 1:0.3:0.2, with the long axis pointing into the first galactic quadrant at an angle of about 20 deg to the sun-(galactic center) line. This is consistent with a study by Stanek et al. (1994) of red clump giants towards the galactic bulge, which shows that the stars at positive longitudes are closer than those at negative longitudes. The optical depth to microlensing is higher than expected for an axisymmetric bulge, which further supports the view that the bulge is bar-like (e.g., Zhao et al. 1995).

The Galaxy has a dark corona similar to that of other spirals. Kochanek (1996) has summarized the evidence. It appears that the dark corona has an enclosed mass distribution $M(R) \approx 10^{10} \times R(\mathrm{kpc})\,\mathrm{M}_\odot$, extending out to radius $R > 100$ kpc. From HST observations, Bahcall et al. (1994) show that faint main sequence stars with $M_\mathrm{I} > 10$ contribute no more than 6% of the unseen matter. Recent microlensing results from the MACHO experiment (Alcock et al. 1996) indicate that about half of the mass of this dark corona may be in the form of compact dark objects of about 0.5 $\mathrm{M}_\odot$: these estimates come from 8 microlensing events observed for stars in the LMC, and still have substantial uncertainties.

In addition to the dark corona of the Galaxy, the problem of the dark matter content of the disk of the Galaxy has a long history. Recent estimates by Flynn and Fuchs (1994) suggest that the disk dark matter may not be significant. From dynamical arguments, they argue that the total surface density of disk matter near the sun is $52 \pm 13 \mp 2$, compared with $49 \pm 9 \mp 2$ for the known matter. If this is correct, then the radial component of the gravitational field near the sun is dominated by the dark corona.

The fundamental properties of the galactic disk near the sun are nicely illustrated by a sample of nearby F stars, for which Edvardsson et al. (1993) measured precise motions, abundances and ages. They find a large spread of abundance among the disk stars at a given age, indicating inhomogeneous enrichment. Their sample also shows the secular heating of the disk for stars younger than about 3 Gyr, and the appearance of the hotter thick disk for stars older than about 12 Gyr. Gilmore et al. (1995) studied the properties of galactic thick disk stars up to about 3 kpc from the galactic plane. They found that the abundance distribution for the thick disk peaks at $[\mathrm{Fe/H}] \approx -0.7$, with no vertical abundance gradient; this argues against dissipational settling as the formation process for the galactic thick disk.

3. Galactic Center

In the past three years, three major reviews have been published on the state of Galactic Center research (Genzel et al. 1994, Morris & Serabyn 1996, and Mezger et al. 1996), and two conference volumes have appeared on the subject (Genzel & Harris 1994, Gredel 1996). Therefore, rather than giving a complete summary of the vast amount of research that has been done on the subject, we offer a few of the highlights.

3.1. STELLAR MOTIONS IN THE CENTRAL PARSEC

An important series of papers giving the strongest evidence yet for a compact, central concentration of dark mass appeared in 1996. Using 2-μm imaging spectroscopy, Genzel et al. (1996) were able to measure radial velocities for 223 stars within the central parsec and thereby probe the mass distribution to spatial scales of 0.1 pc. The radial velocities are corroborated by proper motion measurements made over the past four years (Eckart & Genzel 1996a, b). Using high-resolution shift-and-add imaging, these authors measured proper motions for 39 stars between 0.03 and 0.3 pc from the compact radio source and black hole candidate, Sgr A*. One important conclusion drawn from the comparison between the radial velocity and proper motion measurements is that the velocity dispersion appears to be isotropic at all radii; this is crucial evidence allowing the velocity dispersions measured by either technique to be used with some confidence to determine the mass distribution. The measured increase of the stellar velocity dispersion with decreasing radius, to $180\,\mathrm{km\,s^{-1}}$ at $\sim 0.1\,\mathrm{pc}$, is fully consistent with a dark mass of $(2.4 \pm 0.4) \times 10^6\,M_\odot$ concentrated within several hundredths of a parsec of Sgr A*. The remaining possibilities are a single, supermassive black hole, a tight cluster of stellar-mass black holes (Morris 1993; Lee 1995) or some mixture of both. The large implied mass density at this location apparently excludes white dwarfs and neutron stars.

The next step in delimiting the mass distribution is to determine velocities in a compact cluster of stars that is found in the immediate vicinity of Sgr A* (Eckart et al. 1995). This "Sgr A*(IR) cluster" has a radial extent of about 0.02 pc and by using stellar H_2O and SiO masers to link the radio reference frame to the near-infrared reference frame Menten et al. 1996 were able to show that it is centred on the Sgr A* radio source to high accuracy. Eckart and Genzel (1996a,b) have reported the first measurements of proper motions in this cluster. They suggest large values consistent with the compact mass derived from velocities measured further out. More precise measurements from other telescopes are on the horizon (Klein et al. 1996).

3.2. STAR FORMATION AT THE CENTER

The hot, windy stars in the central parsec and their implications for star formation in this rather hostile environment have been studied by a number of groups (Libonate et al. 1995; Krabbe et al. 1995; Blum et al. 1995; Tamblyn et al. 1996). Krabbe et al. (1995) deduce that the collection of luminous, young stars there is consistent with a starburst between 3 and 7 Myr ago.

The central cluster of the Galaxy has long been know to have an r^{-2} density profile, at least within the central degree or so (Becklin & Neugebauer 1968), and it has frequently been considered as an inward extension of the Galactic bulge. However, Serabyn & Morris (1996), noting that this cluster has approximately the same physical scale as the central reservoir of molecular gas (the Central Molecular Zone, or CMZ), suggested that the central cluster is a separate stellar component resulting from sustained star formation throughout the Galaxy's lifetime. The estimated star formation rate in the CMZ, and the overall mass of this stellar component, are consistent with this hypothesis.

3.3. THE ORIGIN OF NONTHERMAL RADIO FILAMENTS

Of the 7 or 8 known systems of nonthermal radio filaments inhabiting the central 150 pc of the Galaxy, every one which has been sufficiently well observed seems to be interacting with a molecular cloud, raising the possibility that a molecular cloud may be an important element of the process which generates them (Serabyn & Morris 1994; Uchida et al. 1996; Yusef-Zadeh et al. 1996; Liszt & Spiker 1995). Serabyn & Morris (1994) argued, on the basis of their interferometer observations of G0.18-0.04, that another requisite element is a source of ionizing photons, which ionizes the surface of a cloud clump and yields a supply of free electrons which can be accelerated along the external field lines, and thus induced to illuminate the magnetic flux tube they happen to be travelling along with synchrotron radiation. The acceleration mechanism is more difficult to identify, although magnetic field line recombination seems to be a good candidate.

3.4. CORONAL GAS ABOVE THE CMZ, AND SCATTERED X-RAYS.

Extended X-ray emission on hundred-parsec scales in the Galactic center has been known for some time. The presence of the 6.7-keV line from He-like Fe clearly reveals the existence of a high temperature, low-density plasma ($T \sim 10^7 - 10^8\,\mathrm{K}$). The energy and mass requirements are severe at the upper end of this temperature range, with the plasma containing some 10^{53} erg and $3000\,M_\odot$ (Yamauchi et al. 1990; Ozernoy et al. 1993; Koyoma 1996; Koyama et al. 1996). This would require either a large number of supernovae or a recent energetic explosion at the Galactic center. Certainly, such energy release is not manifested at present. The image of emission in the 6.4-keV K-α transition of neutral iron is particularly interesting (Koyama 1996, Koyama et al. 1996). It shows a clear correlation with dense clouds in the region, and Koyama et al. suggest that it results from the scattering of X-rays by the high-column-density material in molecular clouds. An X-ray source having luminosity exceeding 10^{39} ergs is needed to account for the neutral iron line emission by scattering, but no current source of this strength is present. Koyama et al. (1996) conclude that a source of this luminosity must have been present several hundred years ago. This is the kind of event that may, for example, have occurred as a result of stellar disruption by the central black hole (e.g., Khokhlov & Melia 1996).

3.5. MOLECULAR LINE SURVEYS

While molecular line surveys of the Galactic center have been carried out since the early 1970's (see Morris 1996 for a compilation), several new surveys have recently appeared, including the largest-scale survey yet made of main-line OH absorption (Boyce & Cohen 1994), the first relatively complete HCN survey, with a detailed comparison to CO emission (Jackson et al. 1996), and a survey of $J = 2 - 1$ CO line emission, yielding the first large-scale view of the 2-1/1-0 line ratio (Oka et al. 1996).

4. Stellar Dynamics

There is growing evidence for a black hole in the Galactic center (Krabbe et al. 1995; Haller et al. 1996), as well as evidence for black holes in external galaxies (van der Marel 1994; van der Marel et al. 1994). Perhaps, the strongest dynamical evidence is the observations of water masers in NGC 4258 (Miyoshi et al. 1995).

Our galaxy appears to be undergoing a merger event; albeit, a minor merger. The recently discovered dwarf galaxy, Sagittarius, appears to be undergoing tidal disruption (Ibata, Gilmore & Irwin 1995; Mateo et al. 1996). Simulations of this event (Johnston et al. 1995; Velazquez & White 1995) suggest that it is consistent with the tidal disruption of a dwarf spheroidal.

In numerical simulations, galactic bars appear to be fragile objects. They are easily destroyed by central galactic nuclei (Norman et al. 1996). They also rapidly lose angular momentum to stellar halos (Weinberg 1985; Sellwood & Dibattista 1996) and are also affected by the gas accretion (Friedli & Benz 1995). Yet, they appear to be remarkably common.

There has been growing evidence that the Milky Way contains a bar: kinematical evidence (de Vaucouleurs 1964; Binney et al. 1991; Jenkins & Binney 1994) has been supplemented by star counts (Nakada et al. 1991; Whitelock & Catchpole 1992; Stanek et al. 1994) and most dramatically by the DIRBE image of the galactic bulge (Weiland et al. 1994; Dwek et al. 1995). The presence of the bar may also account for the high event rate seen in microlensing experiments (Paczynski et al. 1994; Zhao et al. 1995). M31 may also have a central bar (Stark & Binney 1994). Many external peanut shaped bulges may also be bars viewed edge-on (Kuijken & Merrifield 1995). These thick bars may have been formed through the bending instabilities seen in numerical simulations (Hernquist, Heyl & Spergel 1993; Merritt & Sellwood 1994).

Improved observations suggest that galaxies are dynamically complex systems: some ellipticals show kinematically distinct cores (Forbes et al. 1996); spiral galaxies can have counter-rotating disks (Rubin 1994a; Rubin 1994b); and many spiral galaxies show large amplitude non-axisymmetric distortions, even in the infrared (Rix & Zaritsky 1995). Some of these distortions may be due to the presence of weakly damped modes in galaxies (Weinberg 1994), which can be easily excited by close encounters with neighboring galaxies (Weinberg 1995).

There continues to be progress in our modelling of self-consistent stellar dynamical systems. New analytical models have been developed for spherical systems (Evans 1993; Evans 1994). There have also been advances in modelling axisymmetric systems (van der Marel et al. 1994; Qian et al. 1995; Sevenster, de Jonghe & Habing 1995). *Zhao (1996) constructed* a dynamical model for the Galactic Bar. This model used a modified form of Schwarzschild's technique that populated orbits in a potential consisting of a disk, halo and bar. This model reproduces both the DIRBE photometry and the stellar kinematics in a number of low absorption windows (e.g., Minnitti 1996). The model has a large number of chaotic orbits, which suggests that chaos may play an important role in the secular evolution of galaxies. Merritt & Fridman (1996) have constructed dynamical models for triaxial galaxies with cusps. These models also contain large numbers of chaotic orbits. Chaos may also play an important role in the dynamics of globular clusters (Breeden & Cohn 1995).

Violent relaxation plays an important role in determining the structure of galaxies (Soker 1996). Numerical simulations suggest that galaxy formation from "CDM-like" initial conditions produces a halo with a characteristic density profile (Navarro et al. 1996)

5. Gas and Dust in the Milky Way

5.1. LARGE-SCALE SURVEYS

The past triennium saw several fundamentally new investigations of the large-scale distribution of gas and dust in the Milky Way. The low resolution FIRAS (7 deg) and the higher resolution DIRBE (0.7 deg) experiments on board the COBE satellite figured prominently among these. COBE's extraordinary sensitivity and absolute calibration have made it possible to produce the best all sky maps at frequencies from 1 μm to 240 μm. From these it has been possible to obtain the most reliable overall distribution of near infrared extinction in the plane of the Galaxy as well as mapping the dust emission at the longest infrared wavelengths. The large-scale extinction measurements were done in several infrared wavebands allowing consistency checks to be made and to be able to obtain the underlying stellar scale length (3 kpc) of the Milky Way. This is probably the most reliable measurement of the stellar scale length to date, and is consistent with a number of other measurements.

5.2. RESULTS FROM COBE

The mapping of the $1 - 240\,\mu$m continuum emission yielded a number of new results. The first of these is an apparently new thermal component of the interstellar dust: in addition to the $\approx 16 - 21$ K component, there is also a widespread cold ($4 - 7$ K) dust component, distinct from the higher temperature dust but spatially correlated with it (Reach et al. 1995). Because the power radiated by this component is very low, the dust mass associated with it must be correspondingly low. Significant support for a conundrum that was first recognized from analysis of the COS-B results, was also obtained from 240 μm mapping. It had been unclear why no high-energy diffuse gamma rays had been detected from the galactic center in spite of the large column density of gas. The DIRBE results imply a significant change in the CO/H_2 conversion ratio in the central few degrees of the Milky Way implying far less H_2, and consequently far less molecular mass, than had been previously thought (Sodroski et al. 1995). The DIRBE data provided both confirmation that the outer gaseous disk of the Milky Way is warped and provided the first good evidence that the stellar disk is also warped (Freudenreich et al. 1994). Specifically, the dust distribution traced by the DIRBE data is consistent with the known gaseous warp, but the stellar warp (from the near IR maps) is less evident on the sky, implying either that the stellar disk is less strongly warped than the gaseous disk, or, more likely, that the gaseous disk extends to greater radii than does the stellar disk. A good characterization of the dust was made by Arendt et al. (1994) who showed that the ground-based near infrared extinction laws provide a good description of the dust, and that the unreddened near-IR colors of the background stars in the plane are consistent with being from late K and M giants.

5.3. RESULTS OF OTHER SURVEYS

Coarse, low-resolution maps were made of a number high-J transition molecules using the FIRAS satellite, which made the first all sky maps at sub-mm wavelengths (Bennett 1994). Transitions of CII, NII, CO as high as $J = 5 - 4$ were mapped for the first time allowing large scale averages to be made over the entire Galaxy. Interestingly, CO ($J = 1 - 0$) was not detected; its emissivity was too low compared to the other transitions. The CII line emission is closely correlated with HI and is therefore argued to come almost entirely from the cold ISM.

A significant improvement to mapping the HI distribution of the Milky Way was made with the completion and publication of two major new surveys of HI in the Milky Way. The first, made with the Bell Labs horn antenna had been completed more than a decade ago, but was not published until 1992 (Stark 1995). The second, the Leiden-Dwingeloo survey (Hartmann, 1994; Burton & Hartmann 1994) is completed, and first results have been published in Hartmann's thesis, but the survey is not yet generally available as of this writing. Both surveys represent a great improvement over previous surveys because of the removal of sidelobe responses to levels more than a factor of ten better than previous surveys, allowing reliable measurements of faint HI features down to about $50 - 100$ mK. This will be an especially important complement to the Dwingeloo survey of high-velocity clouds (Wakker 1990) which was incompletely sampled, and will have good reliability for weak features at Galactic velocities. The Bell Labs survey has a spatial resolution of 2 deg, a velocity resolution of 5 km s^{-1}, and covers only the northern sky. The sidelobe response is suppressed by the inherently low sidelobes of the horn antenna (used originally in the discovery of the 3 K microwave background) used in the survey. The Leiden-Dwingeloo survey has a resolution of 0.5 deg, has a velocity resolution of 1 km s^{-1}, and has a sensitivity a factor of about 3 better than the Weaver and Williams (1974) HI survey. Although currently only completed in the north, it is also being extended in Argentina for full sky coverage. Both the Bell labs and Leiden- Dwingeloo surveys have about the same sensitivity when convolved to the same resolution.

5.4. A VERY COLD COMPONENT OF THE ISM

Considerable interest was generated during the past triennium with the announcement of a new cold component of the molecular ISM; very cold CO ($\leq$ 5 K) from absorption experiments toward extragalactic millimeter continuum sources in the plane of the Milky Way (Lequeux 1993). Although of some importance if confirmed, interferometric observations suggested that while there is indeed some very cold H_2 in the Milky Way, its ubiquity and total mass is far less than originally claimed (de Geus & Phillips 1996). This finding was central to two theoretical studies suggesting that the dark matter halo of the Milky Way is composed of cold (near 3 K), near Jeans-mass molecular clouds (Combes & Pfenniger 1994a,b; Silk & Gerhard 1996). Although stimulating, these ideas have received scant confirmation to date.

5.5. VERTICAL DISTRIBUTION OF THE ISM

The warp of the gas layer in the central bulge of the Milky Way received observational support as well as confirmation that molecular gas (both CO and OH) is coincident with the highly warped HI gas (Liszt & Burton 1996; Boyce & Cohen 1994). The warp of this gas is very difficult to understand because at longitudes 5 deg from the center it is projected more than a degree from the stellar midplane, which is seen to be very flat from COBE observations (Freudenreich et al. 1994).

The vertical distribution of CO was found to have a unexpectedly long tail, suggesting that there is a thick molecular disk that has a scale height about three times greater than that of the cold CO layer (Dame & Thaddeus 1994; Malhotra 1994). In the latter work, the emission was found to be fainter and the clouds smaller than typical GMCs, and appear not to be gravitationally bound, like the high latitude molecular clouds in the solar neighborhood. Malhotra (1994) also found that the CO scale height increases monotonically with Galactic radius and is associated with an increase in the velocity dispersion from $2 - 11$ km s^{-1}. A value of the local density of molecular gas can be obtained from the CO measurements and this value, 0.2 $M_{\odot}$ pc^{-3}, is consistent with that derived by other means. CO was also used to measure the rotation curve of the outer Galaxy and to obtain the two dimensional velocity field (Brand & Blitz 1993). The rotation curve was found to be quite flat, and the velocity field showed deviations consistent with spiral-arm streaming.

5.6. HIGH-LATITUDE CLOUDS

Studies of ultraviolet absorption lines with HST along several lines of sight toward the extragalactic source 3C 273 produced a wealth of data on the metallicities and column densities of a number of ionization states of C, N, O, Mg, S, Si, Fe, and Ni at high Galactic latitude (Savage et al. 1993). Much more data of this type should become available in the coming triennium. Savage, et al. find that many of the lines have broad wings and are similar to damped Lyα systems in QSOs. They suggest that the results are consistent with gas in a cooling flow as part of a galactic fountain.

ROSAT observations of molecular clouds at high galactic latitude (Snowden et al. 1993; Benjamin 1996) showed that the clouds are seen in absorption against the soft X-ray background, confirming the relatively near distances of these clouds. In the case of MBM 12, where the distance is known independently, it is possible for the first time to obtain distance information on the emissivity of the soft X-ray gas in the solar vicinity.

6. High-Energy Phenomena

The past triennium has seen important progress in X-ray and gamma-ray studies of the Galaxy. The EGRET and COMPTEL telescopes aboard the Compton Gamma-Ray Observatory have continued their observations and are producing all-sky gamma-ray surveys with unprecedented accuracy. The high-energy gamma-ray continuum emission from the Galactic disk is providing new insight into the distribution of energetic particles and interstellar gas in the Galaxy. The origin of the *low-energy* gamma-ray and hard X-ray emission from the Milky Way has been subject of several studies but remains uncertain. Studies of the diffuse soft X-ray emission seen in the all-sky ROSAT maps has just started. There is increasing evidence that violent phenomena (such as high-velocity clouds interacting with the Galactic disk) may play an important role in understanding the (high-latitude) diffuse X-ray sky. Also evidence for low-energy gamma-rays associated with high-velocity clouds is found.

The COMPTEL telescope offers for the first time extensive possibilities for spatially resolved spectroscopy at MeV energies. The study of gamma-ray lines turns out to have great potentials. In addition to lines originating from radioactive nucleosynthesis products (e.g. an all-sky map of the 1.8 MeV emission from ^{26}Al has become available), evidence is seen now for lines due to nuclear interactions. The latter involves low-energy accelerated particles interacting with ambient matter, thus initiating the production of gamma-ray lines which result from the deexcitation of excited nuclei in both the ambient matter and the accelerated particles. The possible presence of large fluxes of low-energy particles in the Galaxy has stimulated new studies of the origin of light elements (Li, Be, B).

The OSSE instrument aboard the Compton Observatory has performed numerous observations of the galactic plane and galactic-center region to measure the distribution of 511 keV positron annihilation radiation and to search for time variability of the emission. A strong line near 511 keV and a positronium-like continuum are present. No time variability of the line flux has been observed. The OSSE data can be described by a point source within a few degrees of the galactic center (or a galactic bulge component), superimposed on a disk component producing significant emission at longitudes up to about 20 degrees.

7. Chemical Evolution

Thanks to HST and to large-aperture ground-based telescopes, the last three years have seen an enormous growth in measurements of abundances in high-redshift objects such as damped Lyman-α (DLA) systems. These measurements have stimulated the field of cosmic chemical evolution. DLA systems are absorption-line systems detected in the spectra of QSOs which originate in intervening galaxies or protogalaxies. Hence their study enables us to compare the interstellar media of intervening galaxies with observed abundance patterns in stars and with theoretical models of galactic chemical evolution.

Several observational papers on DLA systems have appeared recently, in particular Pettini et al. (1994), Fan and Tytler (1994), Wolfe et al. (1994), Pettini et al. (1995), Lu et al. (1995a,b), Steidel et al. (1995), Green et al. (1995) and Molaro et al. (1996). The most commonly observed elements in these systems are Fe, Si, Cr, Zn and O, although C and N have also been detected. Nitrogen is a key element in chemical evolution since it can be used to date galaxies, because it is probably for the most part a "secondary" element. That is, we expect a low N abundance in very young objects since N should be produced in proportion to the initial stellar metallicity. However, the situation is still not clear from a theoretical point of view due to the possibility of a primary nitrogen production both in intermediate and massive stars. Some DLA systems, observed by Green et al. (1995) and Molaro et al. (1996) seem to show a very high N abundance compared with the theoretical expectations. This results is discussed by Matteucci et al. (1996), who suggest possible explanations of it.

The high-redshift abundance of deuterium is always of particular interest because the primordial D-abundance provides a sensitive test of standard Big-Bang cosmology. In fact, we believe that D is only destroyed inside stars and therefore its abundance in the interstellar medium should decrease with time. As a consequence, the abundance of D observed in high-redshift objects should be close to its primordial value. Contradictory measurements have appeared recently: specifically, Songaila et al. (1994) and Carswell et al. (1994) found a primordial value of D/H which is a factor of $\simeq 10$ higher than its value at the present time. This result suggests that the baryon density in the Universe is close to the value that one estimates from consideration of luminous matter only, and that much of the proposed dark matter is non-baryonic. On the other hand, Tytler et al. (1996) suggested that the primordial value of D/H is much lower and consistent with the value measured in the present-day interstellar medium. This low value of

D/H implies from that the baryon density is 5% of the critical density required to close the Universe. Tytler et al. suggested that the earlier estimates may have been skewed by strong contamination. The situation is not yet clear but is already challenging existing models of the chemical evolution of galaxies.

Other interesting results related to the early stages of galactic evolution are relative abundances in extremely metal poor stars - stars with [Fe/H] $\simeq -4.0$ (Primas et al. 1994; McWilliams et al. 1995). McWilliam et al. (1995) find some previously unnoticed trends of [Cr/Fe], [Mn/Fe] and [Co/Fe] with [Fe/H]: both [Cr/Fe] and [Mn/Fe] show a decline of about 0.5 dex as [Fe/H] decreases from -2.4 to -4.0. On the other hand, at low metallicities the α-elements are over-abundant relative to Fe as is the case in halo stars of higher metallicity.

Beers and Sommer-Larsen (1995) present the most recent and complete study of kinematical properties of low metallicity Galactic stars. They find two kinematically distinct populations, the halo and the thick-disk, which largely overlap at low metallicities and conclude that $\simeq 30\%$ of solar-neighbourhood stars with [Fe/H]< -1.5 can be associated with the thick-disk. Their study also indicates that any metallicity gradient in the halo is negligibly small, just as studies of globular clusters have indicated.

8. The ISM

8.1. SUPERNOVAE AND SUPERNOVA REMNANTS

Chevalier & Blondin (1995) study the formation of a very thin expanding shell that is bounded on the outside by a forward shock and on the inside by a reverse shock as a result of its interaction with the surrounding ISM. They examine the growth rate of instabilities within the shell both through linear perturbation analysis and through numerical hydrodynamical simulations.

Two-dimensional magnetohydrodynamic simulations have been performed by Hideyuki et al. (1996). A supernova event in a galactic disc that is permeated by a horizontal magnetic field forms an Ω-shaped field structure. However, during the first several Myr the ISM can only blow out into the halo if an unrealistically large number of SNe occur. Tens of Myr after a SN explosion, the Parker instability triggers a blowout of disc material into the halo.

The hydrodynamics of the ISM and the dispersal and mixing of heavy elements have been analyzed by Tenorio-Tagle (1996). The long excursions of ejecta from the type II supernovae and the main physical processes that take place in the ISM - cloud crushing, thermal evaporation and hydrodynamical instabilities - are described. True mixing occurs upon the birth of new generation of massive stars though photoionization and diffusion of heavy elements into the volume occupied by an HII region.

8.2. SHOCK - CLOUD INTERACTIONS, MOLECULAR CLOUDS AND MODELS OF THE INTERSTELLAR MEDIUM

Three-dimensional hydrodynamical simulations of shock-cloud interaction have been preformed by Jianjun & Stone (1995). For the strong shocks studied (Mach number = 10), the original dense clouds are strongly fragmented in a few dynamical times, and the cloud material is mixed with the ambient medium resulting in very complex filamentary structures. The origin of the observed spin angular momenta of Galactic molecular clouds have been discussed by Chernin & Efremov (1995). They show that at radii at which the rotation curve is flat or rising, vorticity generated in large-scale spiral shock fronts can cause the spins of molecular clouds to be antiparallel to the spin vector of the Galaxy. A two-dimensional model for the global structure of the interstellar medium in a disc galaxy, in which star formation, mass loss, stellar heating of the gas, and optical thin radiative cooling takes place, has been proposed by Rosen, Bregman & Norman (1993). This simulation produces the observed separation of high and low temperature regions and HI 'worms' and the different components have the correct vertical scale heights. An extension of the model to include an impulsive form of heating that represents supernovae, and to allow for 10^6 K gas is analyzed by Rosen & Bregman (1995). The simulations create a three-phase medium in which filaments of dense, cold and warm gas surround bubbles of hot gas, which are usually hundreds of parsecs across and can exceed 1 kpc in size. The topology of filaments is very similar to that seen in the Galaxy. The evolution of filaments is dominated with filament-filament collisions and the consequent loss of their identity. With given energy injection rate the hot gas is rising while cooler gas is falling to the galactic plane, just as in the galactic fountain model. To reproduce the nature of the ISM in our Galaxy a narrow range of energy injection rates from stars and supernovae is required.

8.3. SPH AND LARGE-SCALE HYDRODYNAMICAL SIMULATIONS

The response of the gas to an imposed axisymmetric + spiral galactic potential is analyzed using smooth-particle hydrodynamics by Patsis et al. (1994). The formation of a gaseous ring near the Outer Lindblad Resonance and the -4/1 resonance, as well as the formation of box-like structures near the 4/1 resonance are described. Gas dynamics in barred galaxies using time-dependent hydrodynamic simulations has been simulated by Piner, Stone & Teuben (1995). The formation of the nuclear rings between the two Inner Lindblad Resonances of bars with low axial ratio, and the properties of these rings are described. Mass inflow into the nucleus of the galaxy is analyzed. It is the highest for high-axial-ratio bars, in which they find that gas flows into the inner 0.1 kpc at a rate of 0.25 $M_\odot\,yr^{-1}$. The estimation of density with in smooth-particle hydrodynamics is discussed by Whitworth et al. (1995).

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