Structure of galaxies and star formation

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An All-Union Conference on the Structure of Galaxies and Star Formation, organized jointly by the Astronomical Council, USSR Academy of Sciences, and the Central Astronomical Observatory of the Ukrainian Academy of Sciences, formed part of the program of the Council's section on the physics of galaxies and the universe. The meetings were held on June 21-24, 1983, in the conference hall of the Institute of Theoretical Physics of the Ukrainian Academy, in Kiev.

On the opening and closing days, review lectures were given at plenary sessions, covering topics of timely interest in star formation and the large-scale structure of galaxies. The rest of the time parallel sessions took place in three subject areas: 1) galactic structure; 2) the interstellar medium and star formation; 3) structure and star formation in other galaxies. Altogether about 100 papers and reports were presented.

Ya. S. Yatskiv, Director of the Central Ukrainian Observatory, opened the conference and welcomed the participants. The scientific agenda began with a major survey, "Supernovae and star formation," by I. S. Shklovskii. The speaker maintained that while type II supernovae no longer pose any fundamental puzzle (they represent massive stars exploding in places where star formation is currently in progress), type I outbursts, which occur even in elliptical galaxies, lack any simple evolutionary interpretation. In Shklovskii's view, a massive star will go through its terminal phase of evolution in one of three modes, which may be classified by using celestial-mechanics terminology: a) the "hyperbolic" case, where the mass of the stellar core exceeds the Chandrasekhar limit, the star exploding as a type II supernova; b) the "elliptic" case, where the core mass is below the Chandrasekhar limit, so that after passing through a planetary-nebula phase the star becomes a white dwarf; c) the "parabolic" case, where the core mass is so close to the Chandrasekhar limit that the star turns into a type I supernova – not immediately, but only after the core has cooled off or has accreted the wanting mass. This last mode is by no means exotic: numerical calculations of stellar evolution show that for a wide range of initial stellar masses the core will be close to the Chandrasekhar limit at the end of the evolution.

The supernova problem ties in directly with "bursts" of star formation in galaxies. These, Shklovskii believes, result from interactions between galaxies and mutual exchange of gas. In the M81/M82 system, for example, neutral hydrogen flows from the first galaxy to the second, a process that evidently induces star formation in the central part of M82. Curiously, what was once thought to be the nucleus of this galaxy has proved to be a young supernova remnant. In NGC 5253, the intensive star formation is due to its interaction with NGC 5256. But what is happening in the nucleus of our own Galaxy? From all evidence a burst of star formation is occurring here too. The radio source Sagittarius A East is known to be a supernova remnant about $5 \cdot 10^4$ yr old, and Shklovskii holds that the compact source Sgr A West also is the remnant of a supernova, which exploded only about 100 yr ago. This star-formation burst in our galactic nucleus might be triggered by interaction with the Large Magellanic Cloud, which is rich in interstellar gas.

In the first section of the conference, Galactic Structure, the topics discussed were the large-scale structure of our stellar system (its rotation curve, the distance scale, and so on) as well as the distribution of stars, gas, and dust in regions which, though relatively small, are important for an understanding of the star formation process.

K. A. Barkhatova and O. P. Pyl'skaya have investigated the space distribution of open clusters. The relation they find between the linear diameter of a cluster and its distance from the sun casts doubt on the currently accepted zero-age main sequence, and thereby on the luminosity of Cepheids and the Hubble constant.

L. V. Yurevich presented a galactic rotation curve derived from OH molecular absorption lines. At large galactocentric distances ($R \geq 10$ kpc) the curve is consistent with other authors' results: the rotational velocity holds steady or even rises somewhat toward larger radii. At small radii ($R < 4$ kpc), however, the Galaxy shows solid-body rotation. According to a study by E. D. Pavlovskaya and D. K. Karimova, the stellar velocity field in the extended solar neighborhood indicates that the rotational velocity of the galactic disk is constant with respect to radius.

From the Pulkovo survey of the H I distribution, N. V. Bystrova has compiled a map of the sky charting the radio-line profiles. These reveal new large-scale features in the gas distribution, chiefly in the galactic mid-latitudes. Many studies of the structure of galactic interstellar matter have been carried out with the RATAN-600 radio telescope. I. V. Gosachinskii and V. K. Khersonskii have used this instrument to investigate the H I distribution around 32 H II regions with a resolution of $2' \times 130' \times 6.3$ km/sec. Nearly all the H II zones examined turn out to be associated with H I clouds, which may be divided into two types according to their morphology. H I clouds of the first type surround the H II regions, so that they have a shell structure and display radial motions; evidently such clouds are produced by the H II regions embedded within them. Clouds of the second type are noticeably extended along the galactic plane; they are U-shaped, and the accompanying H II region is located near the apex of the U structure, where the H I is densest. In this second case the H I cloud presumably comes first, being formed through interaction of the gas with a spiral density wave; later an ionized zone develops at the edge of the cloud. Using the observed parameters of the H I and H II regions the authors have estimated the total number of exciting stars and their spectral type.

The large-scale shell structure of the interstellar medium was surveyed by N. G. Bochkarëv. H I envelopes hundreds of parsecs across, with hot gas and young stars inside, are observed both in the Galaxy and in nearby systems. Although the origin of these structures is fairly well understood in a general way, each separate case merits an investigation of its own. An example is the Cygnus "superbubble," which measures 18°× 13° in the sky. Its x-ray luminosity is $5 \cdot 10^{36}$ erg/sec; its total thermal energy, $\approx 6 \cdot 10^{51}$ erg. Early x-ray and optical observations seemed to indicate that we are dealing here with a true physical object produced either in a single gigantic supernova outburst or by a substantial number (≈ 100) of conventional supernovae. In fact, one paper at this conference by S. A. Silich and P. I. Fomin, considered how the explosion remnant of a supermassive ($\approx 10^3\ M_\odot$) star, representing an energy release of $\approx 10^{53}$ erg, might be distinguished from a cascade of a hundred ordinary supernova outbursts. But detailed analysis has shown that the Cygnus superbubble is actually an aggregate of several independent objects located in the Cygnus spiral arm and viewed in projection upon one another. In effect we are looking at a huge star formation zone—a superassociation—from the side. Such regions, from all indications, develop when the gas + magnetic field system becomes unstable at a spiral density-wave front. It is interesting to see that vast envelopes and bubbles as much as 1 kpc in diameter occur in irregular galaxies but not in spirals, suggesting different star formation conditions in the two types of systems.

Yu. V. Baryshev et al. described their RATAN-600 observations of a giant H II region at longitudes $l = 4°\text{–}10°$, carried out at 8.2-cm wavelength with high angular resolution. They have measured the parameters of 57 individual objects occurring in this region. On the whole the separate H II regions correlate in position with OB stars, but the stars tend to lie at the edge of the H II regions.

L. N. Kolesnik and M. D. Metreveli have studied the interstellar absorption and the space distribution of dust clouds observed toward the star formation region W3/W4 which is located in the inner part of the Perseus spiral arm. They find that dust is concentrated in the local spiral arm and in the Perseus arm but is missing from the space in between. The emission nebula W4 (IC 1805), which measures 42×56 pc, is practically dust-free but is surrounded by an H I envelope which does contain dust. On the northeast this envelope is not closed; the "champagne" effect seems to be operating there, with hot gas leaking from the emission nebula through the aperture into the surrounding cool envelope. The emission nebula W3 (IC 1795), 8 pc in diameter, is associated with a 25×50 pc CO cloud containing a good deal of dust.

Much emphasis was given at the conference to attempts to corroborate the density-wave theory in the Galaxy and in other nearby spirals. N. V. Kharchenko and N. G. Guseva have studied the distribution and kinematics of OB stars in the local spiral arm, while T. P. Gerasimenko has surveyed the velocity field of type O-M stars in the Perseus-arm region. The conclusions are compatible with density-wave theory.

I. V. Petrovskaya recounted the work of the Leningrad astronomers in studying the distribution and motion of neutral hydrogen in the Galaxy. This self-consistent problem has been approached by making use of full H I line profiles. The results show, in particular, that between the sun and the galactic center are four gaseous arms, the one closest to the center being the most massive. V. A. Razin and A. I. Teplykh have investigated the polarization of galactic radio emission throughout the 102–1675 MHz range. A looped magnetic field model offers a good fit not only to their observations but to data on the optical polarization of stars.

Theoretical aspects of the spiral structure of galaxies were discussed by a panel and aroused much interest. A. G. Morozov, E. M. Grivnev, B. P. Kondrat'ev, and E. M. Nezhinskii considered general questions relating to the stability and evolution of both disk and ellipsoidal stellar systems. Morozov and A. M. Fridman have shown that a large velocity dispersion (≈ 50 km/sec) for the disk stars, by no means necessary to restrain the disk from axisymmetric perturbations, is in fact required to prevent the growth of "oblique" perturbations. At the same time these authors contend that the role of the gaseous component in the density-wave theory has been seriously underestimated. Quite possibly the spiral pattern observed in some galaxies may result from hydrodynamic waves in the interstellar medium there.

Indeed a remarkably broad gamut of spiral-pattern theories was discussed at this conference. Mention was made of hydrodynamic waves in gas, of gravity waves in the disk of stars, of epidemic star formation engendering spiral-shaped superassociations, and even of mass motions near the libration points of a rotating bar, a process which in itself would account for some of the structural features of galaxies. At the close of the panel discussion Fridman expressed doubt that any single factor can account for all the diversified large-scale patterns found in the disks of rotating galaxies. He invited observers to work out a more detailed classification of spiral galaxies in light of the existing theories for the origin of spiral structure.

Several reports to the conference dealt with the spherical component of our Galaxy. V. G. Surdin outlines the evolution of globular clusters and described several scenarios for the origin of the stars comprising the halo. The dynamics of the halo stars and of the globular clusters suggests they have a common origin. Yet as A. Bartkevičius pointed out, globular clusters and old field stars differ in their chemical abundances. For example, the field stars are tens of thousands of times less rich in heavy elements than the sun, but no such stars have yet been discovered in the clusters.

At the second section, The Interstellar Medium and Star Formation, all the steps in the evolution of protostars were discussed, from the formation of molecular clouds in a spiral shock wave to the development of protoplanetary disks around young stars. V. G. Berman, Yu. M. Mishurov, and others have investigated the flow of gas in a spiral density wave. Their results indicate that the postshock interstellar medium will undergo a phase transition: clouds will emerge that are tens of times as dense as the diffuse gas. I. I. Zinchenko et al. have investigated the radio emission of the dense nuclear regions of dark nebulae. By comparing observed and theoretical CO line profiles they have shown that at the present time at least some gas–dust globules are contracting. E. E. Lekht et al. described their observations of extended radio sources in zones of active star formation, while G. M. Rudnitskii gave a survey of the compact structures with which maser radio emission is associated. The presence of masers in star formation regions serves as a good indicator of the physical conditions there. By taking advantage of the strong maser emission of compact condensations one can measure not only the radial but also the tangential velocities of batches of interstellar matter in the adjacent star formation sites, and wide vistas thereby open up for studies of the dynamics of the stellar birth process.

The collapse of protostellar clouds and the formation of massive stars were discussed by I. G. Kolesnik, S. G. Kravchuk, L. N. Arshutkin, and Yu. I. Izotov. Various aspects of the star formation process have been treated in this extensive series of investigations: the cooling of the primordial gaseous medium, accompanied by the formation of H_2 molecules, the structure of giant molecular clouds, the structure and evolution of compact infrared sources, and the origin of OB associations. Giant molecular clouds are now receiving much attention in the context of the star formation process. Although they clearly play a large role in the Galaxy, we do not yet know how they are created and how long they will survive. Surdin remarked on the major contribution that dynamical friction makes to the evolution of these massive gaseous structures. Perhaps as they are braked the most massive clouds will settle into the central part of the Galaxy, triggering bursts of star formation there typically separated by $\approx 3 \cdot 10^7$ yr. Regions of ongoing star formation are being actively observed with our largest instruments: T. Yu. Magakyan reported new results from a spectroscopic survey of interesting objects in dark clouds, as carried out with a 500-channel television scanner on the 6-m telescope of the Special Astrophysical Observatory, and N. M. Lipovka et al. have used the RATAN-600 radio telescope to study the field of the Scorpius OB 2 association.

At the sessions of the section on Structure and Star Formation in Other Galaxies, great interest was expressed in the reports by V. L. Afanas'ev et al. concerning the dynamical and photometric structure of certain galaxies, particularly ring galaxies. Spiral structure is naturaly an intriguing topic, as manifested by the large number of theoretical papers, some of which have been mentioned above. Yu. N. Efremov contributed an excellent review of the structure of the spiral arms in the Andromeda Nebula. The gradients he has detected in the periods of Cepheids and in the number of bright stars across the arms offer persuasive support for the spiral density-wave theory.

That the star formation process is a complicated one, incapable of being accommodated by any single theory, was emphasized time and again at the conference. It is hard to understand from the standpoint of density-wave theory why some galaxies should display giant star formation regions–superassociations. A. R. Petrosyan et al. have studied these objects in ultraviolet-excess spiral galaxies; they conclude, in particular, that the superassociations in "multinucleus" galaxies are almost as bright as the apparent nuclei, and that perhaps both are of the same nature. The origin of the superassociations, presumably a consequence of bursts of star formation, and their influence on the color of galaxies were discussed by P. A. Traat.

V. G. Gorbatskii considered how bursts of star formation during the early formative stage of galaxies might help to explain the enrichment of the intergalactic medium with heavy elements. A. G. Doroshkevich proposed a version of the adiabatic theory of galaxy formation in which explosions of massive primeval stars would be responsible for generating structure on the scale of small groups of galaxies. It was pointed out that the galaxy formation theories currently most popular ascribe the origin of large stellar systems instead to the clumping of smaller ones; maybe that is why the panel discussion of dwarf galaxies proved so interesting. V. E. Karachentseva told of her study of the subsystem of dwarf galaxies in the M81 group, where groupings of objects exist which are not at all comprehensible from the dynamical point of view. A. V. Zasov considered the arrangement of the dwarf blue galaxies observed toward the Virgo cluster; as expected, hardly any occur near the center of the cluster, where such galaxies would find it difficult to survive. For the most part the dwarf blue galaxies lie in between our Galaxy and the Virgo cluster, populating rarefied regions of the Local Supercluster.

Surdin discussed the formation process of low-mass stellar systems such as dwarf galaxies and star clusters. As the massive first-generation stars liberate their energy, systems of this kind should, early in their evolution, lose not only some of their residual primordial gas but also a considerable number of their stars. Such partially decayed small stellar systems might amalgamate into big galaxies, accounting both for the existence of old star clusters and dwarf companion galaxies and for the presence of field stars in the halos of large galaxies. The general problem of what mass spectrum stellar systems will acquire as they coalesce was considered by V. M. Kontorovich et al. By taking this approach the authors hope to be able to simulate the formation not only of giant stellar systems but of the stars themselves. In any event the stellar mass spectrum observed is in reasonable accord with the solutions thus far obtained.

Once again, great interest was shown in the problem of the missing mass in galaxies. On the one hand, this unseen mass can be detected from studies of large individual galaxies: V. A. Krol', for example, has calculated the mass distribution around the elliptical galaxy M87 from evidence on the distribution of the x rays emitted by the surrounding hot gas. P. L. Ten'es stated that in developing multicomponent model galaxies that incorporate both dynamical and photometric data, one has to introduce an extended corona representing the nonluminous matter and containing the bulk of the galaxy's mass. To be sure, in his review lecture on spiral galaxies Zasov emphasized that a two-component disk + halo model can adequately represent these systems; but the local M/L ratio in the halo then must be allowed to vary strongly along the radius, reaching large values at the edge of the galaxy. But on the other hand I. D. Karachentsev and A. L. Shcherbanovskii maintained in their paper that the M/L value derived from the dynamics of the central regions of galaxies will remain at a constant level if the mass of the galaxies is determined from the mutual orbital motion in double systems. This result would seem to argue against the presence of missing mass. All in all, the question of whether such mass exists in the outlying parts of individual galaxies is still unsolved.

These summary remarks merely represent the subjective impression of one participant in the Kiev conference; they do not pretend to give a full report of all the material. The conference stimulated a fruitful exchange of views on vital problems in star formation and the structure of galaxies. All those who took part are grateful to the organizers for their efforts and their cordial hospitality.

Translated by R. B. Rodman