fects are the extra forces exerted on bodies in the magnetospheres of large planets; these will give the bodies fanciful orbits. For a medium-sized body, electrostatic charge will chiefly produce a distinctive phenomenon: levitation, with the planet's attraction being replaced by a repulsion.

The last section is headed Modelling of Galaxies; it describes some numerical methods for simulating interacting galaxies. In the first paper, "Interacting galaxies," P. Stewart (Manchester) considers collisions between equal-mass galaxies. Each galaxy is simulated by a batch of 10^4 points initially forming a spheroidal configuration of uniform density with axial ratio 0.6. Three problems have been investigated: direct collision of two fast-moving galaxies whose angular momentum vectors are parallel to the collision line; a direct but slower penetration causing merger, with the initial rotations mutually parallel or antiparallel along the line joining the spheroids's centers and finally, a collision when the angular momenta are perpendicular to the center line. The results of the calculations are shown by pictures of the computer screen that depict various stages in the evolution of the mathematical galaxy models.

A second paper, by R. A. James (Manchester), analyzes the general advantages and shortcomings of simulating galaxies and their interactions on a computer. Various modelling algorithms are compared. The author concludes that for sparse groups of galaxies the "mesh segmentation" procedure is the most efficient. To persuade readers of that fact James argues that a complete determination of the gravitational potential on a $257\times 257\times 257$ point mesh would take only 50 sec of CRAY 1 machine time.

*Edited by F. D. Kahn. Astrophysics and Space Science Library, Vol. 91. Reidel, Dordrecht, 1981. x + 458 pp.

Translated by R. B. Rodman

Internal Kinematics and Dynamics of Galaxies*

Reviewed by V. G. Surdin

(Submitted September 23, 1983)
Astron. Zh. **61**, 409–411 (March–April 1984)

Surely the theme of this one hundredth IAU Symposium was not chosen by chance: studies of the structure and evolution of galaxies today represent a prime trend in astrophysical research. Nor was the site of the Symposium an accident, for 1982 marked the centennial of the Observatoire de Besançon. The participants included 166 scientists from 22 countries; there were 23 review lectures, 53 contributed papers, and 39 poster presentations on the program. These materials with some editing are published in the book at hand, and the reviews are accompanied by transcripts of the discussions.

Seven chapters make up the volume: gas kinematics and the underlying mass distribution, spiral structure, warped disks, barred spirals, spheroidal systems, galaxy mergers, and galaxy formation. There are two concluding summaries, from the observational and the theoretical viewpoints, and the book closes with name, object, and subject indexes.

Vera C. Rubin (Carnegie Institution of Washington) opens by reviewing the H II rotation curves of galaxies. Enough material has now been gathered that one can organize the rotation curves by the Hubble type and luminosity of the galaxy. For each type the form of the rotation curve can serve as a good luminosity indicator. But there is also a systematic dependence on type: for given luminosity the rotational velocity of spirals diminishes from type Sa toward Sc. Luminosity and peak rotational velocity satisfy the Tully–Fisher relation $L \propto V^4_{max}$, but when V_{max} is held fixed, Sc's prove to be $\approx 2^m$ brighter than Sa's. The M/L ratio is independent of luminosity for each galaxy type, but it does vary from type to type: for Sa, Sb, Sc galaxies, M/L = 6.1, 4.4, 2.6 (taking H = 50 km · sec^{-1} · Mpc^{-1}). The parameters of spirals are so tightly correlated [for example, the radius of the $25^m/(1'')^2$ isophote correlated uniquely with the galaxy's luminosity, whatever its type] that six fundamental parameters (type, M/L, absolute magnitude M_B, radius, mass, and V_{max}) can all be combined into a single diagram. While these results all pertain to field spirals, the spirals in sparse clusters seem to have the same properties. Studies of spirals in rich clusters are just beginning. If the cluster spirals should turn out to have rotation curves similar to those of field galaxies, significant constraints could be placed on the halos of spirals.

Aperture-synthesis rotation curves obtained in the 21-cm radio line are reviewed by A. Bosma (Leiden). Several dozen galaxies have now been studied in this manner. In some of them the orientation and tilt of the gas plane are quite different from what is observed optically; the spiral structure is distorted and the mass distribution is asymmetric. Even for the nearby galaxy M33, the optical and radio data differ by fully 15° in inclination and 25° in position angle.

Rotation curves have lately been derived to very good accuracy from measurements of the CO radio line. In the Galaxy this method enables the rotating gas to be traced as far our as R = 20 kpc. P. M. Solomon (Stony Brook) describes observations of the CO millimeter emission in spiral galaxies. The Sc I spiral investigated most fully is M101, the largest such galaxy in angular size. M101 and other similar systems show no evidence of the central decline in CO surface density that is observed in our Galaxy. On the contrary, their CO intensity correlated closely with the optical surface brightness in the blue. In

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some Sb galaxies, however, the CO (and thereby the H_2) surface density does fall off, as in the Galaxy, in their central zone.

Several papers and reviews deal with galaxies viewed edgewise. Such an orientation permits accurate measurement of the halo/disk luminosity ratio: the rotation curve can be determined as well as the deflection of the disk from the plane of the galaxy. When a disk is observed edgewise its surface density becomes much greater and it can be traced farther from the center than galaxies turned face-on. From the z-distribution of the gas one can compute the mass distribution not only in the disk but in the halo of the system. In this way it has been found that the portion of the halo within the optical radius of a spiral galaxy accounts for at least half the total mass. Although the M/L ratio remains practically constant along the radius inside the disk, at the edge of the galaxy it will jump to at least 100.

U. Haud and J. Einasto (Tartu) consider the dynamical evidence for massive but invisible halos around galaxies. The Local Group has been investigated with special care for this purpose, for one can measure the radial velocities of dwarf companion galaxies and distant stars. The Galaxy and the Andromeda Nebula are currently believed to have halos extending 200-300 kpc out from the center, with a mass of $(1.7, 3.3) \cdot 10^{12}\ M_\odot$, respectively. Haud and Einasto maintain that only the very largest galaxies, and evidently not all of those, have massive halos. Using the VLA, S. T. Gottesman et al. (University of Florida) have observed H I emission from the barred spiral NGC 3992 and its three Magellanic-type companions. According to the rotation curve for the gas in the galaxy itself as far as $R = 14$ kpc, its mass is $3 \cdot 10^{11}\ M_\odot$, while the companions' radial velocities suggest that the mass of the entire system within $R = 60$ kpc is no more than $4 \cdot 10^{11}\ M_\odot$. Apparently, then, NGC 3992 lacks a massive halo. If it did have one, the probability of the companions' velocity differentials being as small as observed would be only 3%.

It is by no means fully clear what role massive halos play in galaxy evolution, if they exist at all. But the portion of a massive halo within the disk of a galaxy will certainly make an important contribution. A massive spherical component will serve to stabilize not only the bending and barlike modes of disk instability but even the spiral modes. Perhaps the presence of a large halo mass may explain why S0 galaxies lack spiral arms. In NGC 3115, for example, a galaxy investigated by M. Iye et al. (Tokyo), the halo mass does seem to surpass the disk mass.

A number of papers in the volume describe theoretical studies of every imaginable interpretation of spiral structure: density waves, material arms produced by tidal interaction, even quasi-arms emerging from spontaneously triggered star formation. This last concept is winning more and more adherents among galaxy researchers. The process of self-propagating star formation is being invoked especially often to interpret facts bearing on our Galaxy. Another possible way to explain spiral structure is the magnetohydrodynamic approach. R. Beck's observations (Bonn) of magnetic fields in spiral galaxies have shown that as galaxies become more luminous their field strengthens and its structure becomes more regular. The field runs along the spiral arms, but this behavior accords both with density-wave theory and with the theory of stochastic star formation.

By the close of the 1950s it was realized that the gaseous galactic disk is not flat: beyond the sun's orbit one side of the disk is deflected north, the opposite side south. In the past few years S-shaped galaxy disks have turned out to be no rare phenomenon. What is the explanation? W. A. Mulder (Leiden) develops a classical celestial-mechanics approach toward this problem. By numerically integrating star orbits in the field of a rotating triaxial ellipsoid (representing the bar in a galaxy), Mulder has found a family of closed prograde orbits tilted relative to the plane of the galaxy. These orbits are stable and, in the author's opinion, the motion of stars and gas along them might account for the warped-disk phenomenon.

A completely different approach to the same problem is demonstrated by A. Dekel (Yale University) and I. Shlosman (Tel-Aviv). They seek not internal but external causes for the distorted disks. A flat stellar system is modelled by a disk embedded in a massive oblate halo whose minor axis is tilted to the disk rotation axis. The halo flattening increases radially. The interaction of the disk with the halo's internal gravitational field bends the edge of the disk and stretches it along the equatorial plane of the halo. This warp of the disk will persist until dynamical friction causes the disk to settle into the halo equatorial plane, but estimates suggest this process would require cosmological time spans. Theoretical studies of this problem are summarized by A. Toomre (MIT), who discusses the current hypotheses as to the warping of galaxy disks. Delusions and error have long reigned here. The most plausible model, Toomre believes, is the tilted oblate halo mentioned above. But as several speakers remarked, not even that model can be universal, since we know of cases (M33) where the disk is warped but a halo is decidedly absent.

On the basis of extensive observational material, F. Simien (Lyon) and G. de Vaucouleurs (University of Texas) have once again demonstrated the practically unique relationship between the morphological type of a galaxy, the luminosity of its bulge, and the bulge/disk luminosity ratio. Clearly this correlation must bear directly on the origin of galaxies. But how? The internal kinematics of a galaxy will preserve traces of the past stellar system for a long time and can tell us much about its formative experience and its interactions with other galaxies or even with whole clusters. Thus, R. H. Miller (European Southern Observatory) and B. F. Smith (NASA Ames Research Center) describe their numerical modelling of a galaxy's motion in the tidal field of a cluster. Although the field would be unable seriously to distort the equilibrium form of the galaxy, its steady action over a reasonable length of time could appreciably alter the galaxy's own angular momentum. Perhaps this is the effect responsible for the small V/σ ratio observed in some elliptical galaxies. The tidal forces will orient the axes of the member galaxies relative to the cluster center, an effect encountered in certain actual clusters.

Many of the communications to the Symposium compared the empirical properties of galaxies and systems of galaxies against the predictions of various theories of galaxy formation. The results are not always consistent. In Dekel's opinion the properties of superclusters of galaxies find a ready explanation in terms of the theory of dissipationless collapse. Hence either the member galaxies were formed prior to the superclusters, or the bulk of the mass in a supercluster is concentrated in noninteracting particles. J. E. Gunn (Princeton) believes that the standard isothermal (entropic) theory, which implies a hierarchical clumping of stellar systems, offers a good interpretation of the properties of disk galaxies. Support for the clustering theory is expressed as well by S. D. M. White (Berkeley), but now from comparison of the properties of E galaxies with numerical simulations of the collision and coalescence of stellar systems. A number of examples of close interaction and, to all appearances, merger of galaxies are cited by F. Schweizer (Carnegie Institution).

From one-fourth to one-half of all bright E galaxies of the field show signs of accreting external matter. Apparently they have been capturing neighbor galaxies. Such events may well occur repeatedly during the life of every massive galaxy. Quite likely our own Galaxy exemplifies the process. D. Lynden-Bell (Cambridge University) believes that the Magellanic Stream with its associated dwarf galaxies may comprise the remnant of a companion galaxy torn apart by tidal forces not too long ago. The LMC is destined to share that fate.

The Galaxy's oldest constituents should be able "to remember" the process in which it was formed. Globular clusters have traditionally been thought the oldest objects. but this contention is criticized by K. C. Freeman (Mt. Stromlo Observatory). In fact it has long been recognized that field stars exist substantially more deficient in heavy elements than globular clusters, and thereby formed even earlier. By comparing the dynamical parameters and chemical composition of the globular clusters in the Galaxy, in M31, and in the LMC, Freeman shows that the Galaxy and M31 have had similar cluster formation histories: the clusters developed during the era when the galaxies were collapsing and being chemically enriched. In the LMC, on the other hand, the clusters only began to form after the galaxy had developed a disk (the old clusters in this system comprise a disk distinct from the young-population disk) and are still continuing to be born.

C. A. Christian (Hawaii) and R. A. Schommer (Rutgers University) have investigated the kinematics of the star clusters in M33. They compare their radial velocities measured for 10 clusters against the velocities of the neutral hydrogen in the disk of the galaxy. As expected, the young blue clusters are moving along with the interstellar gas, while the old red ($B - V > 0^m.6$) clusters show motions independent of the disk.

In a remark at the close of the Symposium, Jan H. Oort (Leiden) indicated his delight not only with swift buildup of new observational data and theoretical models but with the real progress being made in understanding many of the puzzles as to the structure and dynamics of galaxies. Perhaps the day is not far off when the same clarity can be brought to the problem of how galaxies originated. In any event, that is the impression one gains after perusing these Symposium proceedings.

The book is now available in the Shternberg Astronomical Institute library.

*International Astronomical Union Symposium No. 100, Besançon, August 9-13, 1982. Edited by E. Athanassoula. Reidel, Dordrecht, 1983. xvi + 432 pp.

Translated by R. B. Rodman