41.151.104), Contopoulos and Magnenat (41.151.086), Martinet and Pfenniger (43.151.034, 43.151.100), and Pfenniger (40.151.025, 43.151.092).

The transition from integrable orbits to chaotic motions was studied by Contopoulos (40.151.053, 1987a), Contopoulos and Polymilis (1987), Contopoulos, Varvoglis and Barbanis (43.151.027), Evangelidis and Neethling (38.042.007) and Innanen (39.151.156). Stochastic orbits in galaxies have been discussed by Barbanis (38.151.071, 43.151.073) and Gerhard (39.151.179, 40.151.065, 42.151.037).

The effect of dynamical friction on stellar orbits was investigated by Casertano, Phinney and Villumsen (41.151.-060), Hoffer (39.151.045), and Pfenniger (42.151.031). A general definition of orbital excentricity was given by Ninkovich (41.151.048.)

11.2 Spiral and Barred Galaxies

The orbits of stars in spiral or barred galaxies were investigated under various aspects. The occurence of Lindblad resonances in general were discussed by Dzigvashvili and Malsidze (43.151.091). Contopoulos (42.151.053) and Contopoulos and Grosbol (41.151.048, 41.151.019) investigated the orbits near the 4/1 resonance in spiral galaxies. Contopoulos (1987b) reviewed non-linear phenomena in spiral galaxies.

Periodic orbits in barred galaxies have been studied by Michalodimitrakis and Terzides (40.151.023, 40.151.052, 42.151.007), especially for explaining inner rings in barred galaxies (39.151.026, 40.151.003). The implications of the 1/1 resonance for barred galaxies were investigated by Petrou and Papayannopoulos (41.151.018), and the response density of irregular orbits by Petrou (38.151.039). Pfenniger (38.151.063) derived the velocity field in barred galaxies on the basis of orbit calculations.

11.3 Oblate Elliptical Galaxies

Orbits in classical oblate models of elliptical galaxies have been investigated by Andrie (42.151.076), Caranicolas (39.151.076), Caranicolas (39.151.009), and Caranicolas and Vozikis (42.151.054).

11.4 Triaxial Systems

De Zeeuw (40.151.014, 40.151.035) and de Zeeuw, Peletier and Franx (42.151.036) studied mass models of elliptical galaxies with separable potentials, especially of Stäckel form in ellipsoidal coordinates. The effect of a nucleus at the center of a triaxial galaxy on the stellar orbits has been investigated by Gerhard and Binney (40.151.036) and by Spyrou and Varvoglis (43.151.119). Periodic orbits in triaxial ellipticals have been calculated by Davoust (41.151.020) and Robe (39.151.006, 42.151.001). Preferred orbital planes in triaxial systems have been studied by David, Steiman-Cameron and Durisen (38.151.081, 40.151.017). Habe and Ikeuchi (39.151.047) investigated gas orbits in prolate triaxial galaxies. Schwarzschild (42.151.120) discussed the perfect ellipsoid and derived a truncated perfect elliptic disk as a model for galactic bars.

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12. Galactic Dynamics : Computer Simulations

Computer simulations have become a standard tool for investigating the structure and evolution of gravitating systems.

12.1 General Problems of Stellar Dynamics and New Methods

Reviews on numerical methodes for simulating gravitating have been given by Aarseth (42.151.078), Saslaw (40.003.011), Anosova (40.042.119), Tajima, Clark, Craddock, Gilden, Leung, Li, Robertson, and Saltzman

(39.014.043), Hut (42.151.057), and Efstathiou (42.011.002). Bettwieser and Sugimoto (39.151.001) have considered the validity of the gas mdoel for gravitational N-body systems.

New integration schemes and methods for the constuction of model galaxies have been presented by Aarseth and Bettwieser (38.042.083), Vandervoort (38.151.106), Richstone and Tremaine (38.151.079), Marciniak (39.042.088), Monaghan and Lattansio (40.021.004), Mikkola (40.042.013), White (42.151.081), and Chau *et al.* (42.151.115).

The dynamics of one-dimensional systems has been investigated by Severne, Luwel, and Rousseuw (38.151.049, 40.151.049, 40.151.071, 41.151.088) and Miller *et al.* (38.151.031).

Shapiro and Teukolsky (40.151.075, 40151.076) developed methods to realise relativistic stellar dynamics on the computer. Johns and Nelson (40.151.089) described particle simulations of three-dimensional galactic hydrodynamics. Tremaine and Weinberg (38.151.012) studied dynamical friction in spherical systems and Inagaki and Wiyanto (41.151.077) considered the effect of gravitational focusing on the dynamical evolution of stellar systems.

12.2 Clustering of Galaxies

Numerous N-body simulations of the clustering of galaxies have been reported and analysed under various aspects, especially with regard to the dynamical role of dark matter and to global effects due to tidal interactions between galaxies, by Yabushita (38.151.011), Schwekendiek and Wielen (38.151.085, 42.161.351), Shandarin and Klypin (38.160.030), Smith (38.160.047, 39.160.024), Saarinen and Valtonen (38.160.070, 40.151.079), Saarinen, Dekel, and Carr (39.151.151), Melott (38.160.075, 42.161.050), Cavaliere, Santangelo, Tarquini, and Vittorio (38.160.131, 41.160.121), Ryden and Turner (38.160.148), Miller (39.151.083), Mamon (41.160.082), Yabushita and Allen (39.160.011), Barnes (40.151.011), Barnes, Dekel, Efstathiou, and Frenk (40.161.100), Evrad and Yahil (40.161.11, 40.161.112, 42.151.050, 42.151.100, 43.151.095), Saslaw (40.161.130), Ishizawa (41.151.012, 43.151.038), Muzzio (41.151.028, 42.151.003, 43.151.067, 1987, in press), Muzzio *et al.* (38.160.046, 43.151.044), Navarro *et al.* (41.161.172), White (42.161.048), Villumsen and Davis (42.160.055, 42.161.176), and Hoffman (42.160.048).

12.3 Interacting Galaxies

Tidal interactions between galaxies have been studied in detail by Aguilar and White (40.151.032, 42.151.027), Miller (42.151.035), Borne (38.151.107), Lukkari and Salo (38.042.010), Capaccioli and Malvasi (39.151.062), Nishida and Wakamatsu (39.151.169), Song (39.151.171), Song and Stewart (42.151.047), Martel (42.151.005), and Byrd *et al.* (42.1541.033). Specifically the dynamics of satellites of galaxies and the shell phenomenon have been treated by Byrd *et al.* (41.151.111), Bontekoe and van Albada (43.151.003), Dupraz and Combes (39.151.175), Quinn and Goodman (42.151.094), Huang and Stewart (43.151.035), and Quinn and Hernquist (42.151.083). Merging of galaxies has been simulated by Duncan (38.151.061) and Mezzetti *et al.* (38.160.126). The gas dynamics in interacting galaxies has been modelled by Foster (38.151.098), Gaetz (39.151.043, 39.151.044), Noguchi and Ishibashi (39.131.366, 41.151.023, 43.151.018, 43.151.104), Appleton and Struck-Marcell (41.151.054), Tenorio-Tagle and Bodenheimer (42.151.055), and Gaetz *et al.* (43.151.116). The generation of spiral structure by tidal encounters of disk galaxies has been investigated by Sorensen (39.151.004), Icke (39.151.040), Korchagin and Prokhovnik (40.151.105), and Undelius *et al.* (43.151.036).

12.4 Collapse of Protogalaxies

Numerical collapse experiments to study the formation of galaxies and their halos have been described by May and van Albada (38.151.002), Villumsen (38.151.037), Lada *et al.* (38.151.048), White (38.151.080), Carlberg (38.151.103, 38.151.104), Carlberg *et al.* (41.151.003), Polyachenko (41.151.069), Moreno and Pismis (41.151.115), Smith and Miller (42.151.096), Arbolino (43.151.009), Burkert and Hensler (43.151.016), Quinn *et al.* (43.151.081), Kim *et al.* (43.151.083), and Nakamura and Tosa (43.151.103).

12.5 Evolution of Galactic Structures

The dynamics and evolution of elliptical galaxies have been simulated numerically by Gerhard (39.151.177), May *et al.* (39.151.033, 39.151.048, 40.151.034), Habe and Ikeuchi (39.151.047, 39.151.080), Gerhard and Binney (39.151.074), Barnes (39.151.111), Merritt and Aguilar (40.151.091), Tohline *et al.* (40.062.085), Levison and Richstone (40.151.030, 40.151.031, 43.151.064), Huang and Stewart (40.151.080), Katz and Richstone (40.157.064), Barnes *et al.* (41.151.080), Katz and Richstone (40.151.106), Dupraz and Combes (42.151.002), Madejsky and Mollenhoff (42.151.069), Sparke (43.151.042), and van Albada (43.151.080).

Numerical models of disk galaxies and their varous properties, in particular their stability, have been studied by Hayes and Comins (38.151.062), Whitmore *et al.* (38.157.231), Vandervoort *et al.* (39.151.086), Bishop (39.151.087), Zasov and Morozov (39.151.144), Fujiwara and Hosumi (39.151.163), Sellwood (40.151.078), Athanassoula and Sellwood (42.151.012, 42.151.013, 43.151.040), Carlberg and Freedman (40.151.087), Zhou and Zheng (40.151.103), Casertano *et al.* (41.151.060), Miller (41.151.061, 42.151.075), and Nishida *et al.* (41.151.063, 41.151.-076). The evolution of galactic disks due to internal relaxation has been treated by Villumsen (39.151.013, 39.151.049), Mishurov (38.151.093, 39.151.159), Balass (42.151.073), Villumsen and Binney (40.151.033), Palous (41.151.084), Kamahori and Fujimoto (43.151.072), and Zotav and Morozov (43.151.023).

The appearance and evolution of spiral structures in disk galaxies have been investigated by numerical simulations by Sellwood and Carlberg (38.151.007), Hausman and Roberts (38.151.008), Inagaki *et al.* (38.151.028), Freedman *et al.* (38.151.032), Leisawitz and Bash (38.151.047), Byrd *et al.* (38.151.070), Korchagin (42.151.011, 43.151.086), Morozov *et al.* (42.151.015, 42.151.016, 42.151.017), and Bakrunov *et al.* (42.151.049).

Numerical models of galactic bars and barred spiral galaxies have been presented by Schwarzschild (38.151.056, 42.151.120), Schwarz (38.151.003, 39.151.003, 39.151.056, 41.151.085), Combes and Gerin (40.151.048), Pfenniger (38.151.063, 39.151.180), Barnes and White (38.151.069), Sparke (38.151.070), Sparke and Sellwood (43.151.025), Weinberg (39.151.037), and Liu (43.151.113).

A review on galactic gas dynamics has been given by Roberts (41.151.015). Extensive numerical simulations of gas flow in disk galaxies have been reported by Johns and Nelson (39.151.017, 41.151.062, 43.151.013), Nelson *et al.* (38.151.021, 39.151.021), Kritsuk (38.131.045), Mikkola *et al.* (38.131.093), van Albada (39.151.008), Roberts and Hausman (39.151.031, 39.151.032), Roberts and Stewart (39.151.147, 39.151.148, 43.151.060), Carlberg (39.151.032), Fukunaga and Tosa (39.151.167, 41.151.118, 41.131.027, 43.151.017), Mulder (41.151.021), Tomisaka (41.151.037), and Varnas (43.151.069).

The conjecture of spiral structure as being due to large-scale stochastic self-organization of galaxies was developed further by Seiden (39.151.029), Feitzinger (39.151.030), and Comins and Balser (39.151.085). Spurzem and Langbein (39.151.079) and Miller and Smith (42.151.116, 43.151.124) treated the evolution of the centers of galaxies.

12.6 Evolution of Star Clusters

The dynamics of star clusters has received great interest in recent years. Various aspects of cluster evolution, including multicomponent structures, energy input by environmental effects, and the role of binaries, have been studied by numerical methods by Tomley (38.151.005), Inagaki and Wiyanto (38.151.094), Bettwieser and Fritze (38.151.095), Bettwieser *et al.* (38.151.090, 39.151.112, 41.151.0720, Spurzem *et al.* (38.151.092, 39.151.105), Giannone and Molteni (39.151.039, 39.151.116), Inagaki and Saslaw (39.151.077), Ostriker *et al.* (39.151.091), Duncan (39.151.126), Cohn (39.151.102), Aarseth (39.151.108), Lightman and McMillan (39.151.109), Jernigan (39.151.110), McMillan (39.151.119), Stodolkiewicz (39.151.124), Shapiro (39.151.125), Casertano and Hut (40.151.077), Wiyanto *et al.* (40.151.093, 41.151.075), Giannone *et al.* (40.151094), Danilov and Beshenov (40.151.-107, 43.151.029), Fritze and Fricke (41.151.120), Heggie (43.151.079), and Statler *et al.* (43.151.117).

A review on the dynamics of open star clusters has been given by Wielen (39.151.129). Further N-body simulations of open star clusters have been reported by Terlevich (39.151.131, 43.151.002), Dearborn *et al.* (39.151.092, 39.151.130), Danilov (40.153.011), and Inagaki (41.151.007).

Spitzer has given reviews on the dynamical evolution of globular clusters (38.151.1013, 39.151.100, 43.151.077). Simulations of globular cluster evolution, including core collapse, gravothermal oscillations, and effects due to compact massive objects, either inside or passing the clusters, have been presented by McMillan and Lightman (38.151.034, 38.151.035), Duncan (39.151.090), Heggie (39.151.101), Bettwieser (39.151.106), van Albada and Bontekoe (39.151.128), Inagaki (39.151.168, 42.151.107), McMillan (42.151.028), Cohn and Hut (39.154.087), Chernoff *et al.* (42.151.080), Makino *et al.* (42.151.108), Murphy and Cohn (42.151.114), Cohn *et al.* (43.151.082), and Aarseth *et al.* (1987, in press).

Binary and triple star systems are known to be of particular importance for the evolution of star clusters as well as of galaxies in general. The evolution of such star systems, as driven by encounters with further stars, has been investigated by Hills (38.151.041), Hut and Paczynski (38.151.043), Mikkola (38.151.077, 39.151.120, 42.151.098), Hut (39.151.057, 39.151.107) Ostriker (39.151.123), Baranov (39.151.173), Weinberg *et al.* (41.151.050, 43.151.020), Anosova and Orlov (42.042.010, 42.151.010, 43.151.051, 43.151.089), Alexander (42.042.043), Mikkola and Valtonen (42.151.064), and McMillan (42.154.005).

13. Galactic Dynamics : Stability and Evolution

13.1 Spiral Structure

Our knowledge of spiral structure at the beginning of the period under review has been surveyed by Athanassoula (1984). It appears that a zeroeth-order understanding of spiral structure can be obtained by treating galactic disks as resonant cavities within which almost stationary patterns of Lin-Shu-Kalnajs (LSK) density waves resonate. Losses due to Landau damping at the Lindblad resonances are made good by energy input at corotation, probably by Goldreich-Lynden-Bell-Toomre swing amplification.

Since the WKBJ approximation that lies at the heart of the LSK dispersion relation is in practice marginal, there has been continued interest in understanding disk modes without appealing to density waves. The most promising techniques for this work are N-body simulation and analysis of gaseous disks. Sellwood and Athanassoula (1986) have shown how N-body simulations may best be analysed in terms of modes, while Iye (1984) has emphasized the close connection between modes in gaseous disks and the modes of stars. Ueda *et al.* (1985) have shown how inferences about the mass distributions of galaxies may be drawn from stability analyses of gaseous disks.

Clearly there is much more to spiral structure than can be captured even by mode analyses of realistic stellar disks. In particular, Korchagin & Korchagin (1984) and Tagger (1987) have emphasized the importance of taking into account the effects of non-linearity and it is essential to consider the response of the interstellar medium to a spiral in the stellar disk. There are two aspects to this response: (i) the passive response to the non-axisymmetric components of the gravitational field; (ii) detonation waves that will arise whenever large quantities of gas are induced to fragment into young, massive stars. The paper of Roberts & Hausman (1984) explores both aspects. Another important question is whether spiral structure is responsible for the observed correlation between the ages and velocity dispersions of disk populations (e.g. Palous & Piskunov 1985; Knude *et al.* 1987; Wielen & Fuchs 1987). Sellwood & Carlberg (1984) and Carlberg & Sellwood (1985) have used N-body models and analytic treatments to argue that spiral structure can account for the dispersions of stars within the plane, but is probably unable to account for the vertical dispersions. Binney & Lacey (1987) take a slightly less optimistic view of the ability of spiral structure to produce the hotest disk populations. Since several studies have concluded that giant molecular clouds cannot unaided heat the disk (but see Kamahori & Fujimoto 1986), they suggest that we should seriously consider the possibility that massive objects in the near or far halo constitute the responsible agency (Rogers *et al.* 1981; Lacey & Ostriker 1985; Ipser & Semenzato 1985).

13.2 Bars

The prevalence of large "forbidden" velocities in the (l, v) plane at $|l| < 20°$ strongly suggests that ours is a barred galaxy. Schwarz (1984) and Combes & Gerin (1985) have considered the generation of spiral structure by such a bar. Depending on the bar's pattern speed either outer or inner rings of gas and stars can be formed. If the 3.5 kpc ring is, from the bar's point of view, an outer ring, the bar's pattern speed must be relatively large. Mulder & Liem (1986) and Gerhard and Vietri (1986) have argued that the apparent peak near $R = 0.7$ kpc in rotation curves derived from tangent velocities is an artifact of the large non-circular velocities generated by the bar.

Robust rotating bars commonly form in N-body simulations of initially cold stellar systems. Hence there is, in a sense, no mystery about the prevalence of bars in galaxies like ours. Yet we are still very far from understanding how bars work at the stellar level. Until recently nearly all studies were of strictly planar bars, which are already remarkably intricate structures (e.g. Teuben & Sanders 1985; Petrou & Papayanopoulos 1986). During the period under review we have begun to get a glimpse of the vastly greater complexity of three-dimensional bars. This complexity derives from the large number of resonances introduced when the extra degree of freedom is unfrozen (Mulder 1983; Pfenniger 1984), and from qualitative changes in the structure of orbits in phase space when the latter moves from four to six dimensions (Martinet & Pfenniger 1987). Stochasticity generated by the interaction of these many resonances probably precludes the possibility of a truly steady-state rotating bar; we should expect all rotating bars to evolve secularly as stars diffuse through the stochastic parts of phase space. The development of a framework for the calculation of this sort of evolution is an important task for the future.

Pending the development of such general machinery, Weinberg (1985) has discussed the secular loss of angular momentum from a bar to the surrounding halo by treating the bar as a rigid object and following the response of individual halo stars.

13.3 Warps and Corrugations

Mathur (1984) and Sparke (1984) have explored the possibility that warps are forced by either an off-axis or a triaxial halo. Sparke (1986) has emphasized the importance of self-gravity for the longevity of even a light inclined ring. A large body of data on the distribution of molecular gas within the Galaxy (Dame & Thadeus 1985; Sanders *et al.* 1986) is now available for comparison with calculations of dynamics of corrugation waves in this layer by Johns & Nelson (1987). Spicker & Feitzinger (1986) have studied corrugations in the HI layer.

13.4 Dynamics of the Halo Populations

Though no satisfactory working model of any halo population has yet been constructed, there has been progress in understanding how we might accomplish that task. De Zeeuw's (1986) reexamination of a class of potentials first examined by Jacobi and Stäckel has clarified the connection between distribution functions that employ non-classical integrals and the morphology of the substems such distribution functions generate (May & Binney 1986a; Binney 1987). In particular, these developments establish for the first time a clear connection between models with spherical potentials, such as those employed by White (1985) to explain the observations of Ratnatunga & Freeman (1985), and flattened and even triaxial systems. Also, if we choose to express the distribution functions as functions of action integrals, the adiabatic invariance of these integrals can be exploited to discover how each population responded to slow changes in the Galaxy's gravitational potential, such as that associated with a slowly growing disk (Barnes & White 1984; Binney & May 1986; Blumenthal *et al.* 1986; Ryden & Gunn 1987).

An important development during the period under review has been the realization that spherical stellar systems with large numbers of stars on highly eccentric orbits are prone to non-axisymmetric instabilities (Antonov 1973; Polyachenko & Shukhman 1981; Merritt & Aguilar 1985; Barnes *et al.* 1986; May & Binney 1986b). Even if the halo components on their own would be spherically symmetric, in the presence of a massive disk velocity dispersion ratios $\sigma_r/\sigma_\theta \approx 0.6$ of the order frequently derived for extreme population II objects indicate that these components are significantly flattened (Binney *et al.* 1987).

It is clear that the Galaxy owes some of its present substance to cannibalism of smaller stellar systems. It has even been suggested (Peebles & Dicke 1968) that all population II field stars were formed in clusters that have since been disrupted: the range of clusters capable of avoiding either internal disruption (of light, tight clusters) or tidal shredding (of massive, diffuse clusters) is small (Fall & Rees 1977; Goodman & Hut 1985). Fall & Rees (1985) reanalyze this problem and suggest that metal-poor proto-galactic material would have preferentially formed clusters of sizes well suited survival in the galactic halo. Terlevich (1987) has modelled the evolution of the open cluster population as clusters are dissolved by tidal interaction with giant molecular clouds.

Whatever the Galaxy's gains at the expense of the cluster populations, the Magellanic Stream constitutes vivid evidence that cannibalism of dwarf galaxies is probably an important process. Tremaine & Weinberg (1984), Quinn & Goodman (1986) and Bontekoe & van Albada (1987) have studied the action of dynamical friction on the orbits of such systems. Lance (1987) has accumulated an impressive body of evidence that the young stars observed 1 kpc and more above the plane are the debris of disrupted late-type systems. These studies raise an important question: are the Galaxy's stars strongly clumped into groups associated with different accretion events rather than being smoothly distributed through phase space as we have tended to assume in the past? From the work of Malin & Cater (1983), Quinn (1984) and others we suspect clumping in phase space is important for many elliptical galaxies. Perhaps it is not too fanciful to imagine a field of galactic archaeology opening up, in which painstaking sifting of the contents of each element of phase space will enable us to piece together a fairly complete picture of how our Galaxy grew to its present grandeur and prosperity.

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