Preface

Always majestic, often spectacularly beautiful, galaxies are the fundamental building blocks of the Universe. The inquiring mind cannot help asking how they formed, how they function, and what will become of them in the distant future. The principal tool used in answering these questions is stellar dynamics, the study of the motion of a large number of point masses orbiting under the influence of their mutual self-gravity. The main aim of this book is to provide the reader with an understanding of stellar dynamics at the level required to carry out research into the formation and dynamics of galaxies.

Galaxies are not only important in their own right, but also provide powerful tools for investigating some of the most important and fundamental problems in physics: our current expectation that the great majority of the matter in the universe is made up of weakly interacting elementary particles of unknown nature arose from studies of the outer reaches of galaxies; the standard theory of the origin of structure in the universe, which rests on exotic hypotheses such as inflation and the cosmological constant, is tested and challenged by observations of the structure of galaxies; and galaxies are frequently used as enormous laboratories to study the laws of physics in extreme conditions.

The study of galactic dynamics carries the student to the frontiers of knowledge faster than almost any other branch of theoretical physics, in part because the fundamental issues in the subject are easy to understand for anyone with an undergraduate training in physics, and in part because theorists are scrambling to keep pace with a flood of new observations.

The tools required to reach the research frontier in galactic dynamics are for the most part ones developed in other fields: classical, celestial, and Hamiltonian mechanics, fluid mechanics, statistical mechanics, and plasma physics provide the most relevant backgrounds, and, although there is little need for quantum mechanics, the mathematical techniques developed in an introductory quantum mechanics course are in constant use. Brief summaries of the required background material are given in Appendices B (mathematics), C (special functions), D (mechanics), and F (fluid mechanics).

This book has been designed for readers with a standard undergraduate preparation in physics. By contrast, we have assumed no background in astronomy, although the context of many discussions will be clearer to the reader who has a broad grasp of basic astronomy and astrophysics, at the level of Shu (1982). A brief summary of the relevant observations is provided in §1.1. Introductions to galactic astronomy are given in Marochnik & Suchkov (1996), Elmegreen (1998) and Sparke & Gallagher (2000). For a comprehensive description of the properties of galaxies and other stellar systems, see *Galactic Astronomy* (Binney & Merrifield 1998), which is a companion to the present book and will be referred to simply as BM.

A one-semester graduate course on galaxies might be based on the following sections from the two books:

Galactic Astronomy: 1.1, 1.2, 2.1, 2.2, 2.3, 3.6, 3.7, 4.1, 4.2, 4.3, 4.6, 9.1, 10.3, 11.1

Galactic Dynamics: 1.1, 1.2, 2.1, 2.2, 2.3, 2.9, 3.1, 3.2, 3.3, 3.4, 4.1, 4.3, 4.7, 4.8, 4.9, 5.1, 5.2, 6.1, 7.1, 7.2, 7.3, 8.1, 8.3, 8.5

This selection assumes that the students will be exposed in other courses to the material on cosmology (GD §§1.3 and 9.1–9.3), stellar structure (GA §§3.1–3.5 and 5.1–5.4), and the interstellar medium (GA§§8.1–8.4 and 9.2–9.6).

The first edition of this book appeared in 1987, and after two decades major revisions were in order, both to accommodate the many important advances in the field and to reflect changes in the perspectives of the authors. The present edition makes more extensive use of Lagrangian and Hamiltonian mechanics, and includes new theoretical topics such as basis-function expansions for potential theory, angle-action variables, orbit-based methods of constructing stellar systems, linear response theory, stability analysis using the Kalnajs matrix method and energy principles, energy and angular-momentum transport in disks, the fluctuation-dissipation theorem, and the sheared sheet. N-body simulations of stellar systems have grown enormously in importance and sophistication, and we have added extensive descriptions of modern numerical methods for evaluating the gravitational field and following orbits.

The last two chapters of the first edition have been eliminated; much of the material of the old Chapter 9 is now covered in *Galactic Astronomy*, while the topics from the old Chapter 10 have been integrated into earlier chapters.

The most dramatic change in this subject since the publication of the first edition has been the development of a theory of structure formation in the universe of remarkable elegance and predictive power, based on concepts such as inflation, cold dark matter, and the cosmological constant. The study of galactic structure and the study of cosmology are now inseparable, and one of our struggles was to incorporate the rich new insights that cosmology has brought to galactic dynamics without writing a superfluous textbook on cosmology. We have chosen to devote the final chapter to a short but self-contained outline of the contemporary theory of large-scale structure and galaxy formation. We introduce the theory of random fields and the linear theory of the growth of fluctuations in the universe, and give a simple treatment of nonlinear structure formation through the spherical-collapse model and extended Press–Schechter theory. The final, speculative section summarizes our still incomplete understanding of how the complex physics of baryons gives rise to the galaxies we see about us.

There are problems at the end of each chapter, many of which are intended to elucidate topics that are not fully covered in the main text. Their degree of difficulty is indicated by a number in square brackets at the start of each problem, ranging from [1] (easy) to [3] (difficult).

One vexing issue in astrophysical notation is how to indicate approximate equality. We use "$=$" to denote equality to several significant digits, "$\approx$" for equality to order of magnitude, and "$\simeq$" for everything in between. The ends of proofs are indicated by a sideways triangle, "$\triangleleft$".

Although we have tried to keep jargon to a minimum, we were unable to resist the economy of a few abbreviations: "distribution function" is written throughout the book as "DF", "cosmic microwave background" as "CMB", "initial mass function" as "IMF", "interstellar medium" as "ISM", "line-of-sight velocity distribution" as "LOSVD", and "root mean square" as "RMS".

We are deeply indebted to many colleagues, both for thoughtful comments on the first edition and for their patient and enthusiastic support during the preparation of the second.

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