Preface

Always majestic, usually 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 large numbers of point masses orbiting under the influence of their mutual self-gravity. The main aim of this book is to provide the reader with a background in stellar dynamics at the level required to carry out research in the field of galactic structure.

Although galaxies are important in their own right, they also offer the prospect of providing clues to new laws of physics—for example, the formation of galaxies is intimately related to the properties of the early Universe; the dark matter which we believe exists in galaxies may be composed of some unknown species of elementary particle; and galaxies have frequently been used as enormous laboratories to study the laws of physics in extreme conditions. In addition, the study of galaxies offers the physicist an opportunity to apply many of the powerful tools of theoretical physics which have been developed in other fields: classical, celestial, and modern 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.

Despite the breadth of the background that is drawn upon, the study of galactic dynamics will carry the physicist 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, in part because theorists are scrambling to keep pace with the flood of new observations—a flood that will dramatically increase when the Hubble Space Telescope is launched and the next generation of large Earth-based telescopes becomes available—and, what is perhaps most important, because the theoretical effort that has been devoted to the study of galactic structure over the last few decades has been much smaller than that given to many other fields of comparable interest and importance.

The view adopted in this book is that galactic dynamics is a branch of theoretical physics. Accordingly, the book has been designed for readers with a standard undergraduate preparation in physics. By contrast, we have assumed no background in astronomy (although the reader who has had an introductory astronomy course should certainly benefit from it). The relevant observational facts about galaxies are summarized in the introductory chapter.

One of the pleasures of writing a textbook in a rapidly developing field is the opportunity to advertise one's own views on the proper organization and relative importance of various topics and areas. This is especially true in a field like galactic structure, where only a handful of influential textbooks have been written in the last half-century. The classic texts, Chandrasekhar's *Principles of Stellar Dynamics* (1942) and Ogorodnikov's *Dynamics of Stellar Systems* (1965), are now so out of date as to be principally of historical interest. The next major contribution was Dimitri Mihalas's undergraduate textbook *Galactic Astronomy* (1968), which is now out of print. The present book grew out of efforts made by J. P. Ostriker around 1975 to encourage the revision and expansion of Mihalas's book into a two-volume graduate text, with the first volume devoted to observations and the second to theory. The first (observational) volume was again titled *Galactic Astronomy*, and was published by Mihalas and Binney in 1981. The present volume is devoted to theory rather than observation, and is intended to serve as a companion and complement to *Galactic Astronomy.*

All of the chapters except the Introduction contain sets of problems at the end. Many of the problems are intended to elucidate topics that are not fully covered in the main text. The degree of difficulty is indicated by a number in square brackets at the start of each problem, ranging from [1] (easy) to [3] (difficult). Six chapters are accompanied by one or more appendixes. These will be found at the back of the book; Appendix 5.B, for example, is the second appendix related to the material of Chapter 5.

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, "$\lhd$".

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", "initial mass function" as "IMF", and "root mean square" as "RMS".

We are deeply indebted to many colleagues for their patient and enthusiastic support during the preparation of this book: John Bahcall, Mordehai Milgrom, J. P. Ostriker, Martin Rees, and Hugo van Woerden arranged extended visits to the Institute for Advanced Study, Princeton, to the Weizmann Institute, Rehovot, to Princeton University Observatory, to the Institute of Astronomy, Cambridge, and to the Kapteyn Laboratory, Groningen, during which much of this book was written; Sandra Faber, Ken Freeman, Ortwin Gerhard, Douglas Heggie, Steve Kent, Blane Little, Dimitri Mihalas, Lyman Spitzer, and Simon White provided many helpful comments on one or more draft chapters; Alar Toomre gave us detailed and constructive criticism of the entire manuscript, as did the participants in the Institute for Advanced Study "shotgun" seminar organized by Nick Kylafis and Stefano Casertano. Other colleagues have made special efforts to provide us with data and original prints and drawings for our illustrations: David Malin, Allan Sandage, and François Schweizer filled our shopping list for more than two dozen photographs of galaxies, clusters, and other objects; Alar Toomre contributed several exquisitely crafted illustrations; Tjeerd van Albada replotted an N-body simulation for our benefit; and Sverre Aarseth furnished a special compact version of one of his N-body codes for Appendix 4.B. We owe a special debt to Dimitri Mihalas for his generous contributions of time and advice in the early stages of this project.

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