GALAXY FORMATION AND EVOLUTION

The rapidly expanding field of galaxy formation lies at the interfaces of astronomy, particle physics, and cosmology. Covering diverse topics from these disciplines, all of which are needed to understand how galaxies form and evolve, this book is ideal for researchers entering the field.

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Emphasizing both observational and theoretical aspects, this book provides a coherent introduction for astronomers, cosmologists, and astroparticle physicists to the broad range of science underlying the formation and evolution of galaxies.

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Jointly and separately the authors have published almost 500 papers in the refereed professional literature, most of them on topics related to the subject of this book.

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Preface

The vast ocean of space is full of starry islands called galaxies. These objects, extraordinarily beautiful and diverse in their own right, not only are the localities within which stars form and evolve, but also act as the lighthouses that allow us to explore our Universe over cosmological scales. Understanding the majesty and variety of galaxies in a cosmological context is therefore an important, yet daunting task. Particularly mind-boggling is the fact that, in the current paradigm, galaxies only represent the tip of the iceberg in a Universe dominated by some unknown 'dark matter' and an even more elusive form of 'dark energy'.

How do galaxies come into existence in this dark Universe, and how do they evolve? What is the relation of galaxies to the dark components? What shapes the properties of different galaxies? How are different properties of galaxies correlated with each other and what physics underlies these correlations? How do stars form and evolve in different galaxies? The quest for the answers to these questions, among others, constitutes an important part of modern cosmology, the study of the structure and evolution of the Universe as a whole, and drives the active and rapidly evolving research field of extragalactic astronomy and astrophysics.

The aim of this book is to provide a self-contained description of the physical processes and the astronomical observations which underlie our present understanding of the formation and evolution of galaxies in a Universe dominated by dark matter and dark energy. Any book on this subject must take into account that this is a rapidly developing field; there is a danger that material may rapidly become outdated. We hope that this can be avoided if the book is appropriately structured. Our premises are the following. In the first place, although observational data are continually updated, forcing revision of the theoretical models used to interpret them, the general principles involved in building such models do not change as rapidly. It is these principles, rather than the details of specific observations or models, that are the main focus of this book. Secondly, galaxies are complex systems, and the study of their formation and evolution is an applied and synthetic science. The interest of the subject is precisely that there are so many unsolved problems, and that the study of these problems requires techniques from many branches of physics and astrophysics – the formation of stars, the origin and dispersal of the elements, the link between galaxies and their central black holes, the nature of dark matter and dark energy, the origin and evolution of cosmic structure, and the size and age of our Universe. A firm grasp of the basic principles and the main outstanding issues across this full breadth of topics is needed by anyone preparing to carry out her/his own research, and this we hope to provide.

These considerations dictated both our selection of material and our style of presentation. Throughout the book, we emphasize the principles and the important issues rather than the details of observational results and theoretical models. In particular, special attention is paid to bringing out the physical connections between different parts of the problem, so that the reader will not lose the big picture while working on details. To this end, we start in each chapter with an introduction describing the material to be presented and its position in the overall scenario. In a field as broad as galaxy formation and evolution, it is clearly impossible to include all relevant

material. The selection of the material presented in this book is therefore unavoidably biased by our prejudice, taste, and limited knowledge of the literature, and we apologize to anyone whose important work is not properly covered.

This book can be divided into several parts according to the material contained. Chapter 1 is an introduction, which sketches our current ideas about galaxies and their formation processes. Chapter 2 is an overview of the observational facts related to galaxy formation and evolution. Chapter 3 describes the cosmological framework within which galaxy formation and evolution must be studied. Chapters 4–8 contain material about the nature and evolution of the cosmological density field, both in collisionless dark matter and in collisional gas. Chapters 9 and 10 deal with topics related to star formation and stellar evolution in galaxies. Chapters 11–15 are concerned with the structure, formation, and evolution of individual galaxies and with the statistical properties of the galaxy population, and Chapter 16 gives an overview of the intergalactic medium. In addition, we provide appendixes to describe the general concepts of general relativity (Appendix A), basic hydrodynamic and radiative processes (Appendix B), and some commonly used techniques of N-body and hydrodynamical simulations (Appendix C).

The different parts are largely self-contained, and can be used separately for courses or seminars on specific topics. Chapters 1 and 2 are particularly geared towards novices to the field of extragalactic astronomy. Chapter 3, combined with parts of Chapters 4 and 5, could make up a course on cosmology, while a more advanced course on structure formation might be constructed around the material presented in Chapters 4–8. Chapter 2 and Chapters 11–15 contain material suited for a course on galaxy formation. Chapters 9, 10 and 16 contain special topics related to the formation and evolution of galaxies, and could be combined with Chapters 11–15 to form an extended course on galaxy formation and evolution. They could also be used independently for short courses on star formation and stellar evolution (Chapters 9 and 10), and on the intergalactic medium (Chapter 16).

Throughout the book, we have adopted a number of abbreviations that are commonly used by galaxy-formation practitioners. In order to avoid confusion, these abbreviations are listed in Appendix D along with their definitions. Some important physical constants and units are listed in Appendix E.

References are provided at the end of the book. Although long, the reference list is by no means complete, and we apologize once more to anyone whose relevant papers are overlooked. The number of references citing our own work clearly overrates our own contribution to the field. This is again a consequence of our limited knowledge of the existing literature, which is expanding at such a dramatic pace that it is impossible to cite all the relevant papers. The references given are mainly intended to serve as a starting point for readers interested in a more detailed literature study. We hope, by looking for the papers cited by our listed references, one can find relevant papers published in the past, and by looking for the papers citing the listed references, one can find relevant papers published later. Nowadays this is relatively easy to do with the use of the search engines provided by *The SAO/NASA Astrophysics Data System*[1] and the *arXiv e-print server*.[2]

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[1] *http://adsabs.harvard.edu/abstract_service.html*
[2] *http://arxiv.org/*

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