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978-0-521-58632-0 - Formation of Structure in the Universe
Edited by Avishai Dekel and Jeremiah P. Ostriker
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Formation of structure in the universe

This advanced textbook provides an up-to-date and comprehensive introduction to the very active field of structure formation in cosmology. It is written by eleven world-leading authorities.

Written in a clear and pedagogical style appropriate for graduate students in astronomy and physics, this textbook introduces the reader to a wide range of exciting topics in contemporary cosmology – from recent advances in redshift surveys, to the latest models in gravitational lensing and cosmological simulations. The authors are all world-renowned experts both for their research and teaching skills.

In the fast-moving field of structure formation, this book provides advanced undergraduate and graduate students with a welcome textbook which unites the latest theory and observations.

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The Hebrew University of Jerusalem

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To our teachers,
to whom we are forever grateful

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Preface

The study of structure formation in the universe has become a mature scientific field, where observations and theory confront one another in a quantitative way. This development has been driven by the rapid accumulation of quality data from advanced telescopes, on the ground or in space, covering the whole range of the radiation spectrum. The accompanying theoretical progress takes advantage of the rapid developments in desk-top computing and supercomputing, that now allow cosmological simulations with almost billion particles or fluid cells, and enable the comparison between the improved observations and the detailed predictions of a variety of theories. These developments make this field one of the most active areas of research in cosmology and astrophysics.

This book grew out of a winter school held in January 1996 at the Institute of Advanced Studies of the Hebrew University of Jerusalem. It contains reviews written by leading authorities, describing the current developments in their own fields of research, and is intended to serve as a supporting text for graduate or advanced undergraduate courses in astrophysics. The chapters can be used separately, or as a comprehensive collection of lectures with significant cross-talk among them. The content of the book covers most of the active topics in the research aimed at understanding the formation of structure in the universe on scales of galaxies and beyond.

We have organized the chapters into four parts. In Part one, *Introduction to structure formation*, the basics of cosmological theory are laid out. Primack opens with a comprehensive overview of the background cosmological model, the origin of fluctuations in the early universe and the dark-matter content of the universe. Then, Yahil provides a concise summary of the theory of gravitational instability, in the linear and the nonlinear regime. Silk concludes this part by addressing issues in galaxy formation, and by making the connection to the large-scale, small-amplitude fluctuations in the cosmic microwave background radiation. It was the direct observation of these fluctuations by the COBE satellite in 1991, on angular scales of order 10° corresponding to comoving lengths of $\sim 1000\,h^{-1}$ Mpc, which confirmed that our ideas for the growth of structure in the universe were basically correct.

In Part two, *Large-scale structure and flows*, we turn to observations of the local universe made at the largest scales measured to date (of order $100\,h^{-1}$ Mpc), where

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perturbations, having entered the nonlinear domain, produce great agglomerations of matter detectable in optical surveys of galaxies. The emphasis is on statistical properties of the galaxy distribution in real and velocity space. Bahcall provides a detailed review of the properties of galaxy clusters and superclusters both in the optical and X-ray bands. Strauss describes the analysis of redshift surveys and current developments towards redshift surveys of millions of galaxies. Willick provides an up-to-date account of the most useful extra-galactic distance indicators in the context of measuring the Hubble constant and peculiar velocities. Dekel concludes this part with a comprehensive discussion of the analysis of cosmic flows and their cosmological implications on the initial fluctuations and the universal mass density.

In Part three, *Structure on galactic scales and lensing*, we focus on phenomena on galactic scales, including Lyman-α clouds and black holes, for the insight that they give us into cosmological phenomena. Ostriker discusses cosmological simulations including gravity and gas processes, mostly in the context of clusters and absorption clouds, and addresses competing cosmological scenarios. Faber describes the effort to detect black holes in the centers of galaxies using the Hubble Space Telescope. Narayan & Bartelmann provide a comprehensive and pedagogical review of the rapidly developing subject of gravitational lensing, from stars, via galaxies, to clusters and large-scale structure.

Part four, *A conclusion*, is a summary by Peebles of the issues and tentative conclusions with regard to the overall background model and the nature of fluctuations. The stress is on the most important cosmological parameter, Ω, the mean mass density in the universe in units of the critical density. We highlight this contribution not because we all agree with each of the conclusions presented, but because Peebles' enormous contributions to physical cosmology warrant special prominence being given to his views.

There is certain overlap between the chapters, but the reader will notice that the discussion reflects different perspectives among the authors, where the same data may be interpreted in different ways and lead to somewhat different conclusions. For example, while Bahcall, Ostriker and Peebles conclude that the universal density parameter, Ω, must be significantly smaller than unity, which means that the universe is unbound and either open or dominated by a cosmological constant, Dekel and Primack stress the evidence for a somewhat larger value, of order 0.5 and perhaps even unity, consistent with a marginally-bound universe with no cosmological constant. This controversy reflects the honest division of opinion among experts in a rapidly developing field, and we have made no effort to impose ideological uniformity (or even consistency). However, the data expected in the early 2000s, the planned progress in simulation ability, and the quantitative scientific approach as reflected in this book, promise that we may be able to close in on the cosmological model and its parameters in the near future.

We believe that the book provides a useful summary of the principle questions being asked in worldwide cosmological investigations at the end of the 20th century. We are

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less sanguine that all the answers provided by our expert authors will stand the test of time, as the topics described are not only on the boundaries of the observable universe, but also at the cutting edge of our knowledge.

A. Dekel and J. P. Ostriker

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