

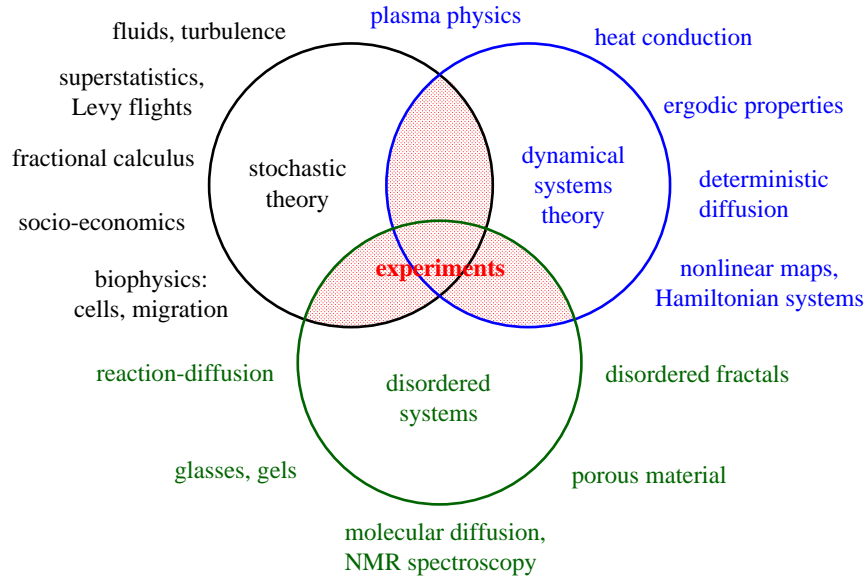
Preface

Anomalous transport refers to nonequilibrium processes that cannot be described by using standard methods of statistical physics. This novel class of transport phenomena has recently been observed in a wide variety of complex systems such as amorphous semiconductors, plasmas, glassy materials, nanopores, biological cells and epidemic spreading. The coherent description of anomalous transport in such a broad range of systems poses a fundamental challenge to the theoretical modeling and to the mathematical language in which these models are formulated. It asks for a synergy of many different disciplines, from the mathematical theory of dynamical systems over the theory of stochastic processes to the statistical physics of disordered systems.

This book gives a comprehensive introduction to the newly emerging field of anomalous transport. It discusses particularly the important examples of anomalous particle transport in high-energy plasmas and in turbulence, ageing in glassy materials, anomalous diffusion in porous media, anomalous heat conduction and chemical reaction-diffusion as well as anomalous correlations in polymer melts. Anomalous dynamics is also observed in biological and socio-economic processes for which we include anomalous diffusion in the cell membrane and in human travel as examples. The theoretical description of such different phenomena leads, in turn, to the prediction of novel physical and mathematical properties such as sub- and superdiffusion, probability distributions with infinite moments, weak ergodicity breaking, anomalous relaxation in complex systems or subdiffusion limited reactions, topics that are all explored in this book. Anomalous transport thus nicely exemplifies the saying, freely after Tolstoi, that “all simple systems are simple in the very same manner, whereas any complex system exhibits its very own type of complexity”.

The individual chapters of this multi-author monograph are written by mathematicians, theoretical physicists and experimentalists who are all internationally recognized experts in their fields. The aim of the editors was to bring together the disciplines of *stochastic theory*, *dynamical systems theory* and *disordered systems*, as sketched in the figure shown below. These three fields form rapidly growing research areas in themselves, which so far have developed quite independently from each other. However, in all these branches anomalous transport is moving more and more into the center of the activities. The book invites the reader to look beyond the scope of any of these three special disciplines. We editors hope that it will be thought-provoking by motivating researchers to establish cross-disciplinary connections between these neighbouring research areas. We would be particularly happy if it fosters further fruitful interactions between theory and experiment.

In contrast to original research articles and conference proceedings all book chapters are written in an introductory manner, which aims at making them accessible to graduate-level students. However, bringing together reviews from authors with so diverse scientific backgrounds, this book may also form a very useful reference for researchers already working in this field. All book chapters can in principle be read independently from each other, but the non-expert



reader may strongly benefit from following the path we have suggested by our ordering of the single reviews. Since each contribution was written by different authors, the style and the type of the presentation varies from chapter to chapter. The reader may also find certain central aspects presented from different viewpoints, which in our eyes leads to a deeper understanding of the subject. We believe that altogether the book gives the reader a sensible account of what the main problems and methods in this newly emerging area of research are.

The idea for this monograph originated from the international WE Heraeus Seminar *Anomalous transport: experimental results and theoretical challenges*, organized by the three editors of this book, which took place in Bad Honnef, Germany, in July 2006. The photograph displayed after the introduction shows all participants of this meeting, including many of this book's authors. Triggered by the enthusiasm of all participants for the conference topic, this book project got started. Unfortunately, one of the keynote speakers of this conference passed away right before the event took place. The first chapter of this book is therefore dedicated to Prof. Radu Balescu, one of the founders of the theory of nonequilibrium transport in plasmas, who before his death developed a very strong interest in anomalous dynamical processes.

The remainder of the book is organized into four main parts leading from mathematical foundations of anomalous transport over theoretical physical formulations to experimental results and applications. *Part 1* introduces to *fractional calculus and stochastic theory*. It starts with a two-fold opening: The first chapter provides the formal access road to the main topic of the book by introducing to fractional calculus, a mathematical technique that elegantly enables to deal with dynamical correlations in stochastic processes. The second chapter summarizes the physically intuitive side of the problem by sketching historical

developments of anomalous transport and demonstrating basic ideas in form of simple examples. These two introductory chapters are followed by expositions elaborating on important mathematical and physical aspects of anomalous transport from the point of view of stochastic processes, which are in particular continuous time random walk theory, Lévy flights, numerical solutions of fractional diffusion equations and weak forms of ergodicity breaking.

Part 2 highlights *Dynamical systems and deterministic transport*. Its three chapters introduce to basic models generating anomalous deterministic transport such as intermittent one-dimensional maps, low-dimensional Hamiltonian systems exhibiting a mixed phase space and chains of (non)linear oscillators. These simple systems enable one to understand the microscopic origin of anomalous transport in terms of nonlinearities in the microscopic equations of motion. This leads to stickiness of trajectories to regular orbits or specific eigenmodes of dynamical systems by producing anomalous deterministic diffusion and anomalous heat conduction.

Part 3 focuses on *Anomalous transport in disordered systems*. Disorder is an appropriate characterization of many systems ranging from glasses or porous materials to biological systems such as actin networks or living cells. In this part some of the rare exact results for these systems are presented. Paradigmatic examples for anomalous behavior, such as structural glasses and random fractal structures, are considered in detail. The extension of anomalous transport in these contexts to reacting species introduces new aspects and poses new challenges, which are also elaborated in this part of the book.

The final *Part 4* reports *Applications to complex systems and experimental results*. It features a superstatistical Langevin-type theory, which identifies anomalous dynamics in experimental data of turbulence, cosmic rays and train delays. Anomalous transport by human dispersal, which is intimately related to epidemic spreading, is described subsequently. An important tool for experimentally observing anomalous molecular diffusion in porous structures as well as in polymer melts are NMR techniques, which is the subject of the following two chapters. The book concludes with new insights into the anomalous properties of the plasma membrane of biological cells, which are obtained by high-speed single-molecule tracking techniques.

We are extremely grateful to the Heraeus foundation for the financial support of the conference in Bad Honnef, which motivated us to edit this book. Particularly, we thank Dr. Ernst Dreisigacker for his advice and Jutta Lang for her help in successfully organizing this event. Thanks also go to Vera Palmer and to Ulrike Werner from Wiley-VCH publishers for their kind and efficient assistance in editing this book. R.K. acknowledges financial support by a grant from the British EPSRC under EP/E00492X/1, I.M.S. is grateful to the SFB555 – Complex Nonlinear Processes for support. We finally wish to thank our colleagues for the time and efforts they have invested in writing the individual chapters, thus making their joint expertise available in form of this multi-author monograph.

London,

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