Preface

When thinking about complex systems, one may naturally have the notion of disorder in mind, but in many ways this would be a misnomer. Indeed, actual disorder is often simpler to describe from a statistical point of view. In this sense, the concept of complexity lies actually more in the region where disorder mingles with order, such that complex systems result from the difficulty to understand the global dynamics, the interplay between these two opposite regimes, and the role of their interconnections, providing more or less an antagonist duality. In such a case, these systems are “hard” to describe and understand and end up being called complex.

This feature of complex organization arises naturally in nonlinear physics. Let it be by a process of successive bifurcations generating complex spatiotemporal patterns, or in the mixed phase space of chaotic Hamiltonian system, where typically in phase space one can find a mixture of a chaotic sea and regions with regular motion that can lead to statistical distributions with power law and scale-free tails. With this perspective in mind, we co-organized the *Chaos, Complexity and Transport* conference which was held in Marseilles during the spring of 2011. It is actually during this conference that the idea to create something which would be more than simply collecting proceedings in a book germinated. The idea was to unite in one book established scientific figures who would expose in their own personal terms their research and as such would cover different facets and points of view on how to handle or deal with nonlinear and complex systems. The title of this book was decided with this goal. In order to avoid the confusion of roles, we kept the spirit of the conference and contributing authors were chosen among the invited speakers of the conference, what de facto excluded the organizers. The authors had a *carte blanche* for their chapter, with the requirement that they would be the sole author. The result of these contributions ended up in various fields of nonlinear dynamics, Hamiltonian chaos and complex systems, and different perspectives from experimental one to the theoretical and mathematical one. We have organized them in a way which we thought reflected more or less the chronology evoked in the title *From Hamiltonian Chaos to Complex Systems* and grouped them in four different parts.

The first part concerns chaos and dynamical systems per se, and the first chapter starts with discussing the notion of weak chaos, and how this may generate problems dealing with infinite ergodic theory and anomalous transport. This chapter sets the tone of the book and not only introduces different notions such as continuous time random walks and fractional derivatives but also encompasses applications to biology while starting with the study of maps inspired from nonlinear fluid dynamics such as the Pomeau–Manneville one. The second chapter considers in the opposite a very specific and somewhat simple example of a Hamiltonian system with one and a half degree of freedom: a perturbed pendulum. It offers de facto a very pedagogical exercise of Hamiltonian chaos in the context of adiabatic theory. But beyond that, it displays a surprising new ratchet mechanism. Indeed, thorough analytic and numerical analysis is performed and transport properties are shown to display a ratchet effect and the generic raise of a net current, even though the time average of the acting perturbation force is zero.

In the second part, we have three chapters where we move to systems with large numbers of degree of freedom and in particular the case of hot plasmas is considered. In this context a kinetic approach is often necessary, as resonant interactions between particles or particles and fields are at play, and this kinetic theory bridges the gap between individual chaotic particle motion and collective effects. In the first chapter, the influence of nonlinear vibration of electrons is considered; most notably the collisionless dissipation of Landau damping is considered even in the strong nonlinear regime. This allows predictions on stimulated Raman scattering in the context of inertial fusion. A thorough comparison of the obtained results with a large full kinetic code is then performed, confirming the validity of the theory developed therein. The second contribution is dealing as well with hot fusion plasmas but in the context of magnetized confinement. As the author mentions himself, his contribution consists of two parts. In the first one, he presents his perspective on the *complexity* of doing research itself, such as retrieving valid information and relying on rigorous facts. Some diagnostics are made and then possible cures and improvements are proposed. In the second part, the author describes the interactions of electrons with Langmuir waves, in the context of a self-consistent Hamiltonian framework. The kinetic limit in terms of a Vlasov equation is then considered, and within the framework of quasi-linear theory, the regime leading to the destruction of the self-consistency is described. Finally, the last chapter deals with tokamak fusion plasmas. The problem of turbulence leading to troubles in confinement is discussed. Plasma models are introduced and the problem of closure to obtain fluid equations is presented. The solution to use adiabatic invariant of the microscopic motion of ions in order to derive a simplified kinetic equation, dubbed gyro-kinetics, and some of its latest results are presented. Finally, in this chapter, we get a summary of the state of the art considering transport issues related to magnetic confinement fusion plasmas. Also by introducing closure problems and fluid equations we are bridging the gap with the next part of the book.

In this third part, we deal with macroscopic nonlinear systems. In the first chapter, we continue with turbulence and heat problems. The experimental study of such phenomena in the fluid dynamics of soap bubbles allows to reveal the emergence of large vortices due to this turbulent heat convection. These vortices are studied in detail and shown to exhibit similarities with cyclones and large hurricanes which live on totally different length scales. Furthermore different behaviors from intermittent to Bogliano–Obukhov scaling depending on the imposed temperature gradients are found. Moreover, this work lays new perspectives for the analysis of transport induced by these large coherent vortices, for instance, the problematic of anomalous transport and Lévy flights. In the next chapter, we deal with solids and buckling of elastic sheets. In this situation as well, complexity arises, as energy can be focused/defocused, and creates complex patterns of singularities. Conversely to the expected behavior of having singularities only as a last resort when crumpling thin elastic sheets, it is shown that in some configurations and compression routes the rise of singularities corresponds merely to a transient necessary behavior inducing a change of topology, but that for high compressions a stress defocusing phenomena rises leading to the disappearance of the singularities which were concentrating most of the energy. The last chapter of this part of the book brings together solids and liquids; it does so in the framework of quantum mechanics. We somehow not only return to the probabilistic approach of complex systems already envisioned in the second part of the book and its kinetic descriptions but also anticipate the last part of the book for which stochasticity, noise, and statistics become prominent players. To be more precise a model of superfluidity, namely the one which is governed by the nonlinear Schrödinger equation is presented. The nucleation of quantized vortices and the possibility to describe a nonclassical behavior of the rotational inertia, giving rise to a super-solid phase are discussed.

Finally, in the last part of the book, we turn to stochastic behavior and complex systems beyond the physical realm. In the first chapter, we deal with the role of fluctuations in population dynamics. The influence of these fluctuations can alter the usual picture we get when thinking only in mean-field deterministic terms. The approach is described using the van Kampen system size expansion and applied in a pedagogical manner to autocatalytic reactions systems. Then in the last chapter of the book, we learn how statistical mechanics techniques can be used to tackle complex systems and in particular how traffic inference can be tackled using the Ising model. We start to learn about the belief propagation algorithm and then see how by using mean-field techniques and linear response theory and coupling it to machine learning techniques we can address problems related to traffic.

Before ending this preface, we are glad to follow a customarily tradition and close it with *acknowledgments*. It is simply true that we as editor only acted as instruments and glue and that this book's content belongs to its authors. It is then obvious that we would like to thank equally all the authors who agreed to contribute to this volume. We hope the result lives up to their expectation. We also hope that readers will enjoy as much as we did, the discovering of new ideas and the learning of new perspectives while reading each individual contribution. And last but not least, it is our great pleasure to thank Prof. A. Luo, who suggested the possibility to seize the opportunity of the conference to create something beyond simple proceedings.

Finally, we would like to thank the publisher for their patience and help during the assembling of this book, which resulted as a complex and chaotic intermittent process.

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