Editorial

The analysis of noise and fluctuations plays an increasingly important role in physics, biology, and other scientific fields. The study of nano-sized physical objects in different geometries and under the influence of nonlinear force fields, for instance, has led to a number of novel diffusion problems. Interacting particles outside thermodynamic equilibrium are another topic explored by means of stochastic theory. Biological motility at various levels (ranging from coupled molecular motors within cells to entire flocks of animals) is currently successfully explored by models which incorporate dynamical randomness. Furthermore, many other biophysical phenomena on the cellular and sub-cellular scale are nowadays considered by means of nonlinear stochastic models, for instance, intracellular calcium dynamics, the dynamics of filamentous networks, or complex reaction-diffusion systems of proteins in the cell membrane, to name only a few examples. The theory of nonlinear stochastic systems plays also an increasingly important role in the neuroscience, for which it provides the indispensable tool to study spontaneous noisy neural activity and signal transmission and processing by neurons and neural networks. Last but not least, noise-induced phenomena continue to reveal unexpected aspects of nonlinear stochastic systems; their study is certainly beneficial for the research in the fields mentioned above.

The nontrivial interaction of fluctuations and nonlinear dynamics is what makes all these problems so fascinating for statistical physicists and applied mathematicians. In this *Special Topics* issue, we present a collection of research papers and reviews which illustrate the broad range of applications and the many facets of the current research on nonlinear stochastic systems.

We start with a classical topic of stochastic theory: transport and diffusion. A standard model with rich statistical features is the Brownian motion in nonlinear potentials, e.g. in a periodic or random field of force. In particular, in the nonequilibrium setting where the potential force exhibits a finite bias, the dependence of mobility and diffusion reveals unexpected features, including sub- and superdiffusion, dispersionless transport, and giant diffusion, which are discussed in this volume in the minireview by Sancho and Lacasta. Yet other combinations of nonlinearity and noise appear if the spatial extension of Brownian particles is taken into account (Güell et al.) or if the Brownian motion is spatially constrained and periodically forced (Ghosh and Marchesoni). Other systems in which stochastic movements in space are of interest include the quantum mesoscopic currents studied by Rogoziński et al. and the propagation of waves in media with static disorder which is subject of the article by Alonso et al. If particles can chemically react, we can ask how diffusion in a heterogeneous spatial setting affects formation of certain compounds. This question is addressed in the study by Long et al. on trimer formation in cellular membranes and has implications for the biological functionality of space-dependent diffusion coefficients.

One of the more surprising effects of noise in nonlinear dynamical systems is that it can induce regularity emerging in the form of oscillations. Several of the papers in this volume are devoted to the analysis of this phenomenon. Schwabedal and Pikovsky discuss different phase concepts for noise-driven nonlinear oscillatory and excitable systems. Aust et al. explore the effect of temporal delay on noise-induced oscillations due to coherence resonance. Anishchenko et al. review the effect of noise on self-sustained oscillations and attempt to generalize the

notion of self-sustained oscillations to the stochastic case (including noise-induced oscillations). Zülicke and Peters investigate how a correlation time (persistence time) can be generalized to the case of stochastic oscillations and apply their measures to a geophysical time series. The synchronization effect of common noise under the influence of a delay term is studied by Senthilkumar and Kurths. Finally, how noise in a spatially extended system can suppress spatio-temporal irregular oscillations (chaos) is the subject explored by Sieber and Malchow.

The physical complexity increases if interacting stochastic systems, e.g. coupled Brownian particles, are considered. Interesting physics emerges in particular if these particles are active (modeling phenomenologically various biological entities); phase transitions for ensembles of such coupled active Brownian particles are studied by Romanczuk and Erdmann. Here, a transition from a moving to a standing/rotating mode of a swarm and vice versa has been observed and derived analytically. A microscopic model of active motion in the system of dumbbells, couples of rigid spheres connected by an oscillating spring, and their hydrodynamic coupling is the subject of the study by Putz and Dunkel. A further problem of interest is how coupled particles may escape over potential barriers; this is addressed by Hennig et al. for the case of Brownian motion in a periodic potential and a point force acting on only one of the particles in the coupled chain; the authors contrast their findings also with the deterministic case (no friction and no noise). The paper by Ebeling et al. uses yet another approach to model interacting stochastic particles: the interaction is replaced by an effective non-Gaussian noise, which leads to velocity distributions very similar to those observed in exploding Coulomb clusters as also convincingly demonstrated here.

The combined effects of noise and nonlinear dynamics are particularly prominent in the neuroscience. Many neurons fire stochastically either on their own (spontaneous activity) or in response to sensory stimulation. Noise can be incorporated in standard neuron models like those of the Hodgkin-Huxley type (Li et al., Nguyen and Neiman, and Finke et al.), of the FitzHugh-Nagumo type (Sancristóbal et al. and Postnov et al.), or of the simple integrate-and-fire type (Nikitin et al.). A number of papers in this issue address a variety of questions about the biological functions of neural activity. The propagation of spikes through a chain of neurons is investigated independently in the studies by Li et al. and by Sancristóbal et al. Different sources of noise and how they shape the spontaneous activity of a specific heat receptor cell is studied by Finke et al. Including a number of realistic features like slow adaptive ion currents and narrow-band noise resulting from afferent input, Nguyen and Neiman study the signal transfer in a complex model neuron and elucidate effects of the narrow-band character of the noise (harmonic noise); they find a significant enhancement of the information transfer if the noise characteristics is properly taken into account. Nikitin et al. explore the encoding of information in a simpler model but for the spike trains of neural ensembles; they compare mutual information rates for different stimulus paradigms. Besides these numerical studies, Schwalger and Lindner put forward a novel analytical method to calculate negative correlations among interspike-intervals, as they are observed in some sensory neurons.

Stochastic processes play an important role in the biochemical reactions of the cell. The proper modeling of an important mediator, namely, calcium and, in particular, calcium oscillations are the subject of the contributions by Jung and Talkner and by Skupin and Falcke. The effect of an medium in the extracellular space (e.g. extracellular potassium) on neural activity is discussed in the numerical study by Postnov et al. Finally, the paper by Kschischo gives a comprehensive review of important relations in biochemical networks that may help in the modeling of these complex stochastic systems.

We hope that the contributions in this volume provide inspiration and encouragement for those working on stochastic problems. The many interesting results in this volume show that the exploration of stochastic nonlinear systems is a fascinating and lively field of current research.

We dedicate this *Special Topics* issue to Prof. Dr. Lutz Schimansky-Geier, who celebrates his 60th birthday this year. Lutz is a preeminent researcher in the field of nonlinear stochastic dynamics, who has pioneered and initiated the study of many of the subjects covered in this volume. In addition to this, Lutz has furthered the research on noise in nonlinear systems by many organizational efforts and as an excellent teacher for a large number of

students (including two of the Guest Editors). Last but not least, he is our dear friend whom we would like to wish a fruitful continuation of his outstanding research for the years to come!

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