PESC-ESF Exploratory Workshop

"Stochastic Systems: from Randomness to Complexity"

1. EXECUTIVE SUMMARY

(a) Name and address of Conference Center
E. Majorana Center, Via Guarnotta 26, 91016 Erice (Italy)
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The Workshop has been incorporated in the so-called "School of Solid State Physics" run yearly at the Center under the direction of Prof. Giorgio Benedek, as the XVI course (same title).

(b) Director
MARCHESONI/ Fabio/ Professor
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Organizers
1. **HANGGI/Peter /Professor**
Institute and Address: Institut fur Physik, Universität Augsburg, Universität Str 1 D-86135 AUGSBURG (Germany)
2. **NORI/Franco/Professor**
Institute and Address: Department of Physics, University of Michigan, Ann Arbor MI 48109 (USA)
3. **WIESENFELD/Kurt/ Professor**
Institute and Address: School of Physics, Georgia Institute of Technology, Atlanta GA 30332 (USA)

Workshop web page: **http://www.pg.infn.it/erice2002**

(c) Dates: **July 26th – August 1st, 2002**

Note that thanks to additional funds granted by NATO and ONR, the organizers managed to extend the Workshop duration to 5 working days.

(d) Attendance: **40** (including the PESC-ESF representative)
Speakers: **31**
Other participants: **9**
Statistical information on participants: see item 6

(e) Workshop Proceedings
to be published in **PHYSICA A** (Elsevier Publishing Co., Amsterdam), special issue co-edited by **P. Hanggi and F. Marchesoni** – scheduled for mid spring 2003

(f) ESF presentation:
We scheduled a Round Table on July 27th, chaired by the PESC representative, Prof. M. Gyllenberg, on "**Stochastic in perspective**". On that occasion Prof. Gyllenberg outlined the structure and the scopes of the ESF; Prof. Schimansky-Geier presented the ESF Scientific Program "STOCHDYN", the funding of which entered recently the 'à la carte' phase. The present Exploratory Workshop is indeed strongly related to this initiative with respect to both the scientific contents and the participants involved.

2. SCIENTIFIC CONTENT

Complex properties of spatially or hierarchically extended non-equilibrium systems in which nonlinear interactions either within or among individual elements play a crucial role are still an extremely rewarding challenge for theoreticians and experimentalists in many fields of science. Despite the great diversity of different topics two common aspects of these systems are subject for interdisciplinary collaboration. First, many of them are necessarily subject to noise, imposed either by a rapid dynamics of internal degrees of freedom, or by extrinsic environmental fluctuations. Second, they share striking similarities in their mathematical description.

The traditional view of noise was formed during investigations of linear dynamics and systems in the vicinity of equilibrium. Therein, noise reduces the ability for an ordered behavior and destroys temporal and spatial patterns and in most cases, researchers' purpose is to minimize its effects as much as possible.

In contrast to this textbook knowledge, recently it became clear that noise in/of nonlinear non-equilibrium systems may in fact act in the opposite way: It can be used in a controlled way to constructively enhance nonlinear features, thus realizing ordered behavior or supporting signal transmission. Investigations on the dynamics of ion-channels, the synchronization and the coherent response in chemical and biological systems, on epidemics propagation or on the behavior of social insects (all involving nonlinear evolution in presence of strong noise) are examples that commonly demonstrate the subtle beneficial synergy between noise and non-linearity in creating ordered patterns out of random environments.

The Workshop program aimed at clarifying this role of noise and fluctuations in nonlinear systems far from equilibrium. The lectures presented at the Workshop can be easily grouped under five categories:

i) Breaking detailed balance: The breakdown of detailed balance is an obvious signatures of non-equilibrium situations. It is responsible for a wealth of important dynamical phenomena like noise rectification, directed motion and stochastic resonance. Noise induced oscillations in neuronal models or in excitable chemical dynamics as well as the higher dimensional motion of Brownian particles in ratchet like potentials result from a coherent structure of the stationary probability flows.

Because of its prominent importance, this issue has been of central interest at the Workshop. Detailed studies of mechanical nonlinear oscillators with inertia, of coupled over damped oscillators or of Lotka-Volterra systems, to name a few examples of model systems, raised passionate discussions among the participants.

ii) Noise-induced order: Noise-induced phase transitions, noise induced propagation of waves and noise induced transmission of signals, stochastic or coherence resonance and synchronization or control of complex dynamical systems by noise, are intriguing phenomena unveiling the generic ability of nonlinear systems to amplify an ordered response by channeling noise to special degrees of freedom. Many applications to various fields (from biology to electrical engineering) were reported at the Workshop.

For example, the noise sustained amplification of signals in bistable and in threshold systems, known as stochastic resonance, has been studied extensively during the last decade. However, only a few investigations of stochastic resonance in extended or coupled systems have been published, so far. Yet, speakers at the Workshop showed how relevant these study are for a better understanding of the interplay of signals and noise in certain classes of biological sensors or neuronal models.

Coherence resonance, a similar phenomenon, promoting coherent oscillations out of noise in excitable non-forced systems, is another mechanism discussed in detail, due to its relevance in neurophysiological systems (spiking or bursting behavior of neuronal units). Again passing from the investigation of single units to that of complex coupled architectures or networks may lead to remarkable achievements.

Noise may induce transitions from one temporal or static behavior to another, or it may modify the way in which such transitions take place. Noise may also create ordered spatial patterns. At the Workshop, purely noise-induced phase transitions were theoretically discussed in extended systems, which do not exhibit structure forming processes in the absence of noise. Furthermore, their individual units do not exhibit unusual behavior in the presence of noise. Quite surprisingly, locally uncorrelated fluctuations of control parameters can induce a phase transition of the macroscopic system to an ordered state!

iii) Molecular objects: Nano-technology has provided means to manipulate molecular scale objects and new techniques have emerged that allow the study and control of small scale biological processes. On these microscopic scales thermal fluctuations play an important and often constructive role, thus opening new largely unexplored and experimentally accessible fields for the application of stochastic methods.

The ability of ratchet-like devices to separate colloids or DNA by using micro-fabricated structures has been analyzed both theoretically and experimentally. Fluctuations have been shown to dominate conformational dynamics of proteins and might be the source of energy for Brownian motors and enzyme reactions.

SQUIDs and quantum dots allow to experimentally observe the intricate interplay between quantum properties and thermal fluctuations. Speakers at the Workshop focused in particular on biological Brownian motors, self-propelling objects, noise-induced auto-organization of Brownian particles, quantum dots, "Maxwell's demon" constructions and micro-pumps.

iv) External noise on pattern forming systems: A striking exception emphasizing the importance of external noise in extended systems is provided by recent experiments in a chemical context (the photosensitive Belousov-Zhabotinski reaction) and in lasers. It was successfully demonstrated that externally imposed fluctuations originate an organizing, supporting, dispersing or even creating of autowaves. Similar situations have also been observed in hippocampal slices of rat brains and astrocyte syncytium.

Media such as brain or cardiac tissues are natural targets to be investigated from this perspective. Control or reduction of spatio-temporal chaos by noise or in general noise-induced synchronized patterns of activity to be employed in nontrivial tasks as coherent signal processing, learning or adaptation, have been of central interest in the Workshop program.

v) Analysis of stochastic signals: In strongly fluctuating systems the distinction between deterministic behaviour and fluctuations is limited. Within the network, modern mathematical tools such as the wavelet transform, detrended fluctuation analysis, generalized entropies etc. should be elaborated to extract relevant information from almost noisy data. Descriptions by means of probability densities require more advanced techniques, like e.g. the consideration of fractional Fokker-Planck equations.

Between many possible applications in science, the Workshop focused especially on climate dynamics, neuro-informatics and synchronization phenomena in medicine. In these disciplines, stochastic methods are widely discussed while the modeling of the corresponding dynamic processes has reached apparently a high level of sophistication.

3.a Final Programme

Stochastic Systems: from Randomness to Complexity

an ESF-PESC Exploratory Workshop

July 27th, Saturday

9:00 - 9:15	Opening addresses (G. Benedek, F. Marchesoni)
morning session (chair: L. Schimansky-Geier)	
9:15 -10:00	P. Talkner
10:00-10:45	C. Masoller
10:45-11:15	*coffee break*
11:15-12:00	L. Gammaitoni
12:00-12:45	I. Goychuk
evening session (chair: K. Lindenberg)	
16:30-17:15	A.Bulsara
17:15-17:45	*coffee break*
17:45-18:30	C. Tsallis
18:30-19:15	Ch. Doering
after dinner (chair: M. Gyllenberg)	
21:15	ESF round table: *Stochastics in perspective*

July 28th, Sunday

morning session (chair: Ch. Doering)	
8:45 - 9:30	J. Prost
9:30-10:15	E. Gudowska-Nowak
10:15-10:45	*coffee break*
10:45-11:30	J. Mateos
11:30-12:15	P. Reimann
12:15-13:00	A. Ainsaar
evening session (chair: P. Hänggi)	
16:30-17:45	poster presentation
17:45-18:15	*coffee break*
18:15-19:30	poster presentation
after dinner	
21:00	poster session

July 29th, Monday

morning session (chair: F. Nori)	
8:45 - 9:30	L. Sander
9:30-10:15	L. Tsimring
10:15-11:00	A. Vespignani
11:00-11:30	*coffee break*
11:30-12.15	R. Toral
12:15-13:00	L. Kish
afternoon	

excursion (Selinunte)

July 30th, Tuesday

morning session (chair: J. Luczka)

9:30 – 10:15	F. Nori
10:15-11.00	C. Morais-Smith
11:00-11:30	*coffee break*
11:30-12:15	T. Poschel
12:15-13:00	G. F. DAnna

evening session (chair: C. Tsallis)

16:30-17.15	J-Ph. Bouchaud
17:15-17:45	*coffee break*
17:45-18:30	R. Mantegna
18:30-19:15	J. Parrondo

social dinner

July 31st, Wednesday

morning session (chair: F. Marchesoni)

9:00 – 9:45	K. Lindenberg
9:45- 10:30	A. Ordemann
10:30-11:00	*coffee break*
11:00-11:45	L. Schimansky-Geier
11:45-12:30	A. Gadomski

evening session (chair: P. Hänggi)

16:30-17:15	V. Anishchenko
17:15-17:45	*coffee break*
17:45-18:30	M. Rubì
18:30-19:15	E. Pollak
19:15-19:30	Closing remarks (G. Benedek, F. Marchesoni)

August 1st, Thursday

departure day

3.b ABSTRACTS

Ain Ainsaar *(Tallinn Pedagogical University, Tallinn, Estonia)*

Trichotomous noise: applications to stochastic transport.

The three-level Markovian noise as a model of nonequilibrium fluctuations is presented. The influence of the flatness of fluctuations on the noise-driven nonequilibrium dynamics of overdamped Brownian particles in nonlinear systems is considered. Examples of exactly soluble models of stochastic transport are demonstrated. Conditions of current reversals in ratchet systems are discussed.

V. S. Anishchenko *(Saratov State University, Saratov, Russia)*

Spectral and correlation analysis of spiral chaos

In this talk we present theoretical and numerical results of the autocorrelation formation in chaotic systems demonstrating attractors of the spiral type. We establish the interconnection between the law of correlation splitting and amplitude and phase fluctuations, and analyse the role of external noise. We show that the decay of the autocorrelation function (ACF) is characterized by two time scales which are defined by instantaneous amplitude fluctuations and the instantaneous phase diffusion.

J-Ph. Bouchaud *(CEA, Gif-sr-Yvette, France)*

Quantitative research in financial markets: what's new?

We will review some of the recent research in statistical finance. There are three main themes in this activity: (i) empirical studies and the discovery of interesting universal features in the statistical texture of financial time series, sometimes called `stylized facts' (ii) the use of these empirical results to devise better models of risk and derivative pricing, which are of direct interest for the financial industry, and (iii) the study of `agent based models' in order to unveil the basic mechanisms that are responsible for the statistical `anomalies' observed in financial time series. We will present some new empirical results and simple models to try to account for them.

A.R. Bulsara *(SPAWAR System Center, San Diego, USA)*

Noise-mediated resonance behavior near bifurcations in dynamical systems

We study the oscillator equations describing a type of nonlinear amplifier, exemplified by a two-junction superconducting quantum interference device. Just beyond the onset of spontaneous oscillations, the system is known to show significantly enhanced sensitivity to very weak magnetic signals. The global phase-space structure allows us to apply a center manifold technique to calculate the frequency of spontaneous oscillations as a function of the natural control parameters. The derived scaling form compares very well with numerical simulations. The ability to quantify the oscillation frequency permits its exploitation as a detection/analysis tool in remote sensing applications, and could also provide a pathway to a dynamic lowering of the low-frequency noise floor in oscillators exhibiting this class of dynamical behavior. The theory allows us to explore the sensitivity of this class of oscillators (exhibiting a saddle-node bifurcation) to weak external signals. Behavior that appears to be analogous (but is not the same as) Stochastic Resonance is predicted and has, in fact, been observed in experiments. We discuss the relevance of our results in neurophysiological modeling .

G. D'Anna, P.Mayor, G.Gremaud *(University of Lausanne, Lausanne, Switzerland)*

Dynamic behavior observed en route to the jammed state in shaken granular media

A wide variety of systems exhibit non-equilibrium transitions from a fluid-like to a solid-like state, characterized by a progressive slowdown and eventually a sudden arrest of their dynamics. Since similar features and behaviors appear in systems as different as supercooled liquids, granular media, or superconductors, one suspects that there could be a common conceptual framework within which to address this so-called "jamming process". In supercooled liquids the jamming process is known as vitrification. In type-II superconductors the jamming process is, e.g., the transition from flux-flow to true superconduction, i.e., with strict zero resistivity, by decreasing electric transport current. In granular materials the jamming process is, e.g., the arrest of granular flow out of a hopper, or the granular diffusivity slowdown observed under
external perturbation of decreasing intensity. Here we shall present and discuss in particular results concerning this last system. A granular medium of millimetric-size particles is submitted to external perturbations of decreasing intensity, and the process by which it reaches a "jammed" static configuration, is studied. At this effect an oscillator is immersed into the granular medium. The random motion of the oscillator reflects the granular dynamics, and statistical analysis of the oscillator motion shows
qualitative similarities between supercooled liquids and weakly perturbed granular systems. We finally provide a model which draws a parallel between the glassy/jammed behaviour and processes controlled by extreme-events.

Ch. Doering *(University of Michigan, Ann Arbor, USA)*

The stochastic Fisher-KPP equation, interacting particles, and duality

We describe a rigorous connection between the Fisher-KPP stochastic partial differential equation with multiplicative noise and the single species birth/coalescence reaction-diffusion system. The correspondence
is not in terms of a mean-field fluctuating hydrodynamic description for the reaction-diffusion model, but rather via the concept of duality, an idea that has played a major role in the probabilistic analysis of interacting particle systems in recent decades. The idea of duality will be discussed and used to derive an exact formula for the extinction probability of any initial configuration for the stochastic Fisher-KPP equation.

A. Gadomski *(University of Technology and Agriculture, Bydgoszcz, Poland)*

Model agglomeration in complex environments

A model agglomeration in complex environments is studied as a nucleation-and-growth phase transition. Basic kinetic signatures of the growth stage, being termed the agglomerate evolution, are readily explored, subject to initial and boundary conditions, finiteness, and anomalies attributed to low tension grain boundary effects. Applications for both condensed-matter as well as "soft-matter" systems are mentioned.

L. Gammaitoni *(University of Perugia, Perugia, Italy)*

Noise activated nonlinear dynamic sensors

A large class of dynamic sensors have nonlinear input-output characteristics, often corresponding to a bistable potential energy function that underpins the sensor dynamics. In realistic scenarios, the nonlinear sensors are operated in a noisy environment with just a few dynamical quantities that can be adjusted to improve their performance. Examples include magnetic field sensors, e.g., the simple fluxgate sensor, ferroelectric sensors, and mechanical sensors, e.g., acoustic transducers, made with piezoelectric materials. In many cases, the functioning of such sensors is based on a spectral technique wherein a known periodic bias signal is applied to the sensor to saturate it and drive it very rapidly between its two (locally) stable attractors (corresponding to the minima of the potential energy function, when the attractors are fixed points). Often, the amplitude of the bias signal is taken to be quite large in order to render the response largely independent of the noise. The above readout scheme has some drawbacks. Chief among them is the requirement of large onboard power to provide a high-amplitude, high-frequency bias signal. We introduce a novel dynamical description for a wide class of nonlinear physical sensors operating in a noisy environment where the presence of unknown physical signals is assessed via the monitoring of the residence times in the metastable attractors of the system. We show that the presence of ambient noise, far from degrading the sensor operation, can actually improve its sensitivity and provide a greatly simplified readout scheme, as well as significantly reduce processing procedures for this new class of devices that we propose to call noise activated nonlinear dynamic sensors. Such devices can also show interesting dynamical features such as the resonant trapping effect

<u>I. Goychuk</u> and P. Hanggi *(University of Augsburg, Augsburg, Germany)*

Ion channels, $1/f^{?}$ noise, and stochastic resonance

We study non-Markovian stochastic resonance (SR) in single ion channels within a model of two-state renewal process driven by a time-dependent external signal. Integral equations for the conditional probabilities governing the stochastic evolution of the considered random process are derived. This set of integral renewal equations generalizes the one obtained earlier by Cox et al. to the case of signal-induced nonstationarity. The fluctuation theorem is established and the corresponding linear response (LR) function is obtained for arbitrary stationary residence time distributions (RTD). Moreover, for the transition rates given by the Arrhenius rate expressions we show that the LR function and the power-spectrum of stationary, signal-free fluctuations are connected through the classical fluctuation-dissipation theorem. This important connection allows one to address the non-Markovian SR problem within a pure phenomenological setting, which is based solely on the knowledge of the experimentally determined RTD in the absence of the signal. The obtained results are used to investigate SR for a big conductance (BK) potassium ion channel exhibiting a power law distribution of the closed time intervals with huge relative variance. The connection of entropic effects with non-Markovian dynamics, intermittency and $1/f^{?}$ -noise is discussed in the context of stochastic resonance. We show that the large entropic difference between closed and open states of the channel yields a distinct SR effect within the physiologically relevant region of temperatures. The non-Markovian dynamics introduces further remarkable features making the spectral amplification of signal and the signal-to-noise ratio both strongly frequency-dependent for asymmetric bistable dynamics.

Ewa Gudowska-Nowak *(Jagellonian University, Cracow, Poland)*

Free random variables and molecular conductance

We discuss use of the Green/Blue function formalism in the physics of disordered systems. The approach is based on a representation of "free random variables" that are a generalization of the classical concepts of theory of probability to non-commuting variables. As a model problem for the study, transport properties in the molecular donor-acceptor system connected by a dimerized chain are discussed. The system is assumed to be subject to site diagonal disorder. The average spectral properties of the system are discussed by using the random matrix Wegner model (Anderson's type tight-binding Hamiltonian (TBH)) for the electronic part of the problem. For a simple one-dimensional tight-binding picture, we show that the diagonal disorder destroys the energy gap emerging as a Peierls effect in a non-perturbed system, rederiving thus the results obtained earlier using different models of site randomness.

<u>L.B. Kish</u> and S.M. Bezrukov *(Texas A&M, College Station, USA)*

Noise, information, power dissipation, size and speed in nano-ionic and nano-electronic systems

The future of nano-electronic technology strongly depends on success of how two interrelated issues, noise and dissipation, are handled. In this talk we address two quite different issues related to the topic of noise and dissipation.
In the first part of the talk, two well known, inspired non-dynamical models of stochastic resonance, the threshold-crossing model and the fluctuating rate model are analyzed in terms of channel information capacity and dissipation of energy necessary for small-signal transduction. We find that for small dissipation both models give an asymptotically linear dependence of the channel information capacity on dissipation. In both models the channel information capacity, as a function of dissipation, has a maximum at input noise amplitude that is different from that in the standard signal-to-noise ratio vs. input noise plot.
In the second part of the talk, a physical limit is shown for Moore's Law of miniaturization in microelectronics. The exponential growth of memory size and clock frequency in computers has a great impact on everyday life. The growth is empirically described by Moore's Law of miniaturization. Physical limitations of this growth would have a serious impact on technology and economy. A thermodynamical effect, the increasing thermal noise voltage on decreasing characteristic capacitances together with the constrain of using lower supply voltages due to overheating problems related to increasing clock frequency, has the potential to abruptly break Moore's Law, as early as in 6-10 years.

K. Lindenberg *(University of California at San Diego, USA)*

Pattern formation induced by global alternation of dynamics

We propose new mechanisms for pattern formation based on the global alternation of dynamics neither of which exhibits patterns. When driven by either one of the separate dynamics, the system goes to a spatially homogeneous state associated with that dynamics. However, when the two dynamics are globally alternated, the system exhibits stationary spatial patterns (rapid switching) or oscillatory spatial patterns (slower switching). The induced spatiotemporal structures depend on the ratio of two characteristic times. One time is determined by the external forcing, and the other is a time characteristic of the internal dynamics of the system. The nature of the relevant internal time is different for different mechanisms.

R. N. Mantegna *(University of Palermo, Palermo, Italy)*

Dynamics of markets after a financial crash

We use the *n* stocks traded in the New York Stock Exchange to form a statistical ensemble of daily stock returns. For each trading day of our database, we study the ensemble return distribution and we find that a typical ensemble return distribution exists in most of the trading days with the exception of crash and rally days and of the days subsequent to these extreme events. The standard deviation of the ensemble return distribution, a quantity we address as the *variety* of the portfolio, measures the width of the ensemble return distribution. We investigate the variety of a portfolio of stocks in normal and extreme days of market activity. We observe that the variety time evolution is not time reversal around the crash days. Another stylized fact observed in a non-stationary phase of the market is observed by investigating the time evolution of an index just after a major financial crash. We discuss the discovery of the analogous of Omori law in financial time series immediately after a market crash. We show that Omori law is consistent with the simultaneous occurrence of an asset return probability density function characterized by a power-law asymptotic behaviour and a power-law decaying evolution of its typical return scale. This slow dynamics has not a characteristic time scale.

C. Masoller *(University of Montevideo, Montevideo, Uruguay)*

Residence time distributions of bistable systems with time-delayed feedback and noise

We study bistable time-delayed feedback systems driven by noise. Based on a two-state model with transition rates depending on the earlier state of the system we calculate analytically the residence time distribution function. We show that the distribution function has a detailed structure, reflective of the effect of the feedback. By using an adequate indicator we give evidence of resonant behavior in dependence on the noise level. We also predict that this feedback-induced effect might be observed in vertical-cavity surface-emitting lasers with weak optical feedback.

J. L. Mateos *(National Autonomous University of Mexico, Mexico City, Mexico)*

Chaotic transport in ratchets: the battle of the attractors

The problem of the classical deterministic dynamics of a particle in a periodic asymmetric ratchet potential is addressed. When the inertial term is taken into account, the dynamics becomes chaotic and modifies the transport properties. By a comparison between the bifurcation diagram and the current, we identify the origin of the multiple current reversals as bifurcations, usually from chaotic to periodic regimes. Close to these bifurcations, we observed trajectories revealing intermittency and anomalous deterministic diffusion. We extend our previous work [J. L. Mateos, PRL 84 (2000) 258], to include the case of coexisting attractors in phase space that transport particles in opposite directions. Each attractor has its own basin of attraction and this allow us to select the direction of the current by choosing the appropriate initial conditions in phase space.

C. Morais-Smith and T. Droese, R. Besseling, P. Kes *(University of Fribourg, Fribourg, Switzerland)*

Plastic depinning in artificial vortex channels: competition between bulk and boundary nucleation

We study the depinning transition of a driven chain-like system in the presence of frustration and quenched disorder. The analysis is motivated by recent transport experiments on artificial vortex-flow channels in superconducting thin films. We start with a London description of the vortices and then map the problem onto a generalized Frenkel-Kontorova model and its continuous equivalent, the sine-Gordon model. In the absence of disorder, frustration reduces the depinning threshold in the commensurate phase, which nearly vanishes in the incommensurate regime. Depinning of the driven frustrated chain occurs via unstable configurations that are localized at the boundaries of the sample and evolve into topological defects which move freely through the entire sample. In the presence of disorder, topological defects can also be generated in the bulk. Further, disorder leads to pinning of topological defects. We find that weak disorder effectively reduces the depinning threshold in the commensurate phase, but increases the threshold in the incommensurate phase.

F. Nori *(RIKEN, Saitama, Japan and University of Michigan, Ann Arbor, USA)*

Biologically-inspired devices for controlling the motion of flux-quanta

Motor proteins employ non-equilibrium fluctuations in anisotropic media to transport cargo at the cellular level. Similarly, biologically-inspired devices could transport quanta at the nano-scale. We [1,2,3] have studied non-equilibrium thermal fluctuations in several new type of ratchet systems in superconductors with either (a) channel wall asymmetries, (b) graduated pinning density, (c) anisotropic pinning traps. We study stochastic transport of flux quanta in superconductors by alternating current (AC) rectification. Our simulated systems provide a variety of fluxon pumps, "lenses", or fluxon "rectifiers" because in them the applied electrical AC is transformed into a net DC motion of fluxons. Thermal fluctuations and the asymmetry of the potential (e.g., via channel walls, or inhomegeneous pinning distribution) induce this "diode" effect. The latter can have important applications in devices, like SQUID magnetometers, and for "fluxon optics", including convex and concave "fluxon lenses" that focus/concentrate or disperse flux quanta. Certain features are unique to these novel types of two-dimensional (2D) pumps, and different from the previously studied ratchets (mostly in 1D, with only one particle moving).

[1] J. Wambaugh, et. al., Superconducting fluxon pumps and lenses. Phys. Rev. Lett. 83, 5106 (1999).
[2] C. Olson, et al., Collective interaction-driven ratchet for transporting flux quanta. Phys. Rev. Lett. 87, 7002 (2001).
[3] B.Y. Zhu et al., Biologically-inspired Devices for Controlling the Motion of Flux-Quanta, preprint.

A. Ordemann and F. Moss *(University of Missouri at San Louis, USA)*

Pattern formation and stochastic motions of the zooplankton Daphnia in light fields

Some fish and bird species as well as zooplankton which move freely in a three dimensional environment and have a high risk to become prey of visually hunting predators are known to form swarms as a predator confusing mechanism. In the case of schools of fish and flocks of birds, the animals can be observed to form a coordinated vortex. Lately, vortex motions of so called self-propelled agents have been found of great interest to theoretical physicists, leading to variants of the two-dimensional models of Active Brownian Particles [1] and Self-propelled Interacting Particles [2] that reveal circular behavior. Unfortunately, these models lack application as the behavior of swarming fish and birds is difficult to investigate in detail, mainly due to the size of the animals. However, in rare events in the field as well as in lab environments, also swarms of the common fresh water zooplankton Daphnia have been observed to perform vortex-like motions, but the specific circumstances for this behavior to occur are difficult to define. Daphnia are known to heavily depend on their phototaxis to sense their surrounding [3] e.g. they are strongly attracted to light in the visual range, which can be assumed to act as an ëoptical markerí for swarm formation. Reproducibly inducing swarming Daphnia to carry out the vortex motion in our lab reveals that the water between the Daphnia is also circling in the same direction as the animals themselves. To learn more about this circular pattern we characterize the motion of single Daphnia, as well as swarms, with respect to a vertical shaft of light, which acts as the optical marker. We observe the development of a circular motion of Daphnia around the shaft of light. Based on experimental data we developed a simple stochastic model of random walkers with short range correlation to successfully simulate the behavior of Daphnia in light fields.

[1] F. Schweitzer et al., Phys.Rev. Lett. 80, 5044 (1998).
[2] H. Levine et al., Phys. Rev. E 63, 017101 (2001).
[3] Zooplankton: Sensory Ecology and Physiology, edited by P.H. Lenz et al., Gordon and Breach Publishers, Amsterdam, 1996.

Th. Pöschel *(Humboldt University, Berlin, Germany)*

Structures in granular gases

Granular Gases (GG) are rarefied systems of granular particles in the absence of gravity - one may think of a cloud of interstellar dust. Similar as molecular gases GG may be described by the concepts of classical Statistical Mechanics, such as temperature, velocity distribution function etc. Once initialized with a certain velocity distribution, during their evolution GG cool down due to inelastic collisions of their particles. Although, in principle, these systems are extremely simple they reveal a variety of structure formation and much work has been done recently to characterize the properties of cooling GG [1]. Most of these results have been obtained under the assumption that the coefficient of restitution ε which characterizes the loss of energy of two colliding particles, is constant. For real materials one knows, however, that ε depends strongly on the impact velocity - the assumption $e = const$ contradicts experimental observations and even some mechanical laws [2]. The simplest physically correct description of dissipative material behavior is the assumption of viscoelastic deformation, which is valid for particle collisions in a wide range of impact velocity [3]. We investigate the properties of GG of viscoelastic particles for which the impact velocity dependence of the restitution coefficient $\varepsilon = \varepsilon$ (g) is known [4]. Our results show that the properties of GG change qualitatively if one takes into account viscoelastic material properties [5], as compared with the equivalent system, but with e=*const*. The results give rise to the expectation that structure formation in GG of viscoelastic particles deviates qualitatively from the results for $e = const$. In particular, cluster formation which occurs in cooling GG will be retarded if not suppressed if viscoelastic material properties are taken into account. This speculation is supported by numerical simulations. Whereas the velocity distribution function for the case $e = const$ has a simple scaling form, the velocity distribution of gases of viscoelastic particles depends explicitely on time. This property allows to define the *age* of a GG.

[1] see eg T. Poeschel, S. Luding (Eds.), *Granular Gases* (Springer, Berlin, 2001)
[2] R. Ramìrez, T. Poeschel, N. V. Brilliantov, T. Schwager, PRE 60, 4465 (1999)
[3] N. V. Brilliantov, F. Spahn, J.-M. Hertzsch, T. Poeschel, PRE 53, 5382 (1996)
[4] T.~Schwager, T. Poeschel, PRE 57, 650 (1998)
[5] N. V. Brilliantov, T. Poeschel, PRE 61, 1716 (2000); PRE 61, 5573 (2000)

E. Pollak *(Wezmann Institute, Rehovot, Israel)*

Wigner phase space approach to dynamics of dis sipative systems

A central challenge in quantum molecular dynamics is to solve numerically for the quantum dynamics of dissipative systems. Dissipative systems are defined as a nonlinear system coupled bilinearly to a harmonic bath. Typically, one is interested in solving for a correlation function, described as the trace of a product of two operators. One, a thermal weighted density operator, the other the time dependent operator of interest. In the Wigner representation, this implies a phase space trace of the Wigner representations of the two operators. A novel method is presented for numerically exact computation of the Wigner representation of weighted thermal densities in phase space. Then, a series of convergent approximations to the numerically exact quantum real time dynamics, based on the integral form of the Wigner-Liouville equation will be discussed. Applications will include one and two dimensional systems as well as model dissipative systems. The Wigner phase space representation provides a new approach for understanding the phenomenon of quantum tunneling.

J. Prost *(Institut Curie, Paris, France)*

Collective behavior of molecular motors.

I will discuss "old" and recent results concerning both the experimental and theoretical behavior of molecular motor collections. In particular I will show that the actin-myosin system is analogous in some way to the liquid-vapor system, whearas a recently discovered motor mutant is analogous to magnetic systems undergoing the paramagnetic ferro-magnetic transition. I will discuss finite size system fluctuations as well.

P. Reimann *(University of Bielefeld, Bielefeld, Germany)*

Brownian motion exhibiting absolute negative mobility

We consider a Brownian particle in a spatially symmetric, periodic system far from thermal equilibrium which can be readily realized experimentally. Upon application of an external static force F, the average particle velocity is negative for $F>0$ and positive for $F<0$ (absolute negative mobility).

M. Rubì *(University of Barcelona, Barcelona, Spain)*

Energy transduction in periodically driven non-Hermitian systems

We propose a new mechanism to extract energy from nonequilibrium fluctuations typical non-Hermitian systems displaying a characteristic frequency. The transduction of energy between the driving force and the system is revealed by an anomalous behavior of the susceptibility, leading to a diminution of the dissipated power and consequently to an improvement of the transport properties. The general framework is illustrated by the analysis of some relevant cases: (i) field –responsive particle in a vortex flow under the influence of an oscillating magnetic field, (ii) transport of classical particles advected by a quenched velocity field (porous media) and (iii) population dynamics described by the Malthus Verhulst growth model with a time dependence of the resources. Additionally, our theory unify the explanation of resonant phenomena taking place in gases of polyatomic molecules as the Senftleben-Beenakker effect.

L. M. Sander *(University of Michigan, Ann Arbor, USA)*

Epidemics, disorder, and percolation

Epidemiologists usually model the spread of an infection by assuming that anyone in a population is equally likely to infect anyone else -- i.e., perfect mixing. However, the real situation is quite different, and when sick people can only infect their neighbors (if they don't move around much) the approximation is very bad. We show that in this case we can map a standard epidemic model onto the physical theory of percolation, and get non-trivial results for epidemic thresholds, geographic spread, etc. We also show how to account for limited movement using 'small-world' theory.

L. Schimansky-Geier *(Humboldt University, Berlin, Germany)*

Excitable systems under noise

In systems far from equilibrium an increasing noise may induce a more ordered state compared with the case without noise. Our interest is devoted to excitable systems which model a wide class of dynamical behavior in biophysics and chemistry. We formu late a noisy FitzHugh-Nagumo dynamics and discuss stochastic measures as the stationary probability density, stationary spike generation rates and the power spectrum. The analysis shows that in result of the application of noise deterministic bistable and excitable dynamics converts into oscillating systems with a high value of the oscillations for non-vanishing noise.
For strong separation of the inhibitor and activator time scales the dynamics reduces to an overdamped phase description in a periodic potential with local minima corresponding to the stable rest position of the outgoing FitzHugh-Nagumo dynamics. Application of noise induces Brownian motion and the stochastic phase is able to leave the rest position realizing a jump of $\pm 2\pi$ to one of the neighboring minima. We show typical potentials where this stochastic hopping becomes more ordered if increasing the noise to an optimal value. Thus the diffusion coefficient of the phase motion exhibits a minimum for finite noise intensities.

V. Anishchenko, A. Neiman, A. Astakhov, T. Vadiavasova, and L. Schimansky-Geier, *Chaotic and Stochastic Processes in Dynamic Systems* (Springer Verlag, Berlin-Heidelberg-New York;
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P. Talkner *(General Energy Research, PSI, Villingen, Switzerland)*

Exit, entrance, and residence times

The switching times between different states of a stochastic process constitute a point process that can be characterized by exit, entrance, and residence times. Exit and residence times have successfully been used for example to describe stochastic resonance and pulse trains of various origin. In this talk we consider the simple case of a nonstationary two state Markovian process for which we discuss the statistics of these times and give a simple expression for the density of entrance points. We further discuss the relevance of the statistics of the entrance points for stochastic resonance and introduce a statistical measure of optimal synchronization which coincides with the well known matching condition 2 k = T in the limit of weak driving. Here k denotes the transition rate between the two states in absence of driving and T the period of the driving force. We apply the synchronization measure to the stochastic resonance of a small magnetic particle with an easy axis driven by a periodic longitudinal field and compare it with other criteria for stochastic resonance.

R. Toral *(University of Illes Balears, Palma de Mallorca, Spain)*

Anticipated synchronization in neuronal systems in a noisy environment

It is well stablished by now that is is possible to synchronize chaotic systems by using unidirectional coupling in a master/slave configuration, in a way that can be used to encode and decode a message. More recently, it has been shown that a particular synchronization scheme using delayed couplings is such that the slave chaotic system can actually anticipate the signal coming from the master system. In this work, I will show that excitable systems modelling neuronal behavior can also be coupled in a master-slave configuration, in a way that allows the slave neuron to predict in advance the behavior of the master neuron when both are subjected to random external stimulus. This is remarkable since the master system is never aware of the presence of the slave system and its own dynamics is never altered.

C. Tsallis *(Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brasil)*

Nonextensive statistical mechanics - Introduction, applications and foundations

Boltzmann-Gibbs statistical mechanics is not applicable for a variety of anomalous thermodynamical situations, in one way or another related to long-range interactions, long-range microscopic or mesoscopic memory, fractal boundary conditions and similar. Nonextensive statistical mechanics aims to cover some classes of such anomalous cases. The mathematical formalism will be introduced. Some of its applications will be presented.. Finally, its nonlinear dynamical foundation will be illustrated in low-dimensional dissipative and conservative maps, as well as in many-body long-range classical Hamiltonians.
Bibliography: http://tsallis.cat.cbpf.br/biblio.htm

L. Tsimring *(University of California at San Diego, USA)*

Contact tracing and epidemics control in social networks

Spreading of certain infections in complex networks is effectively suppressed by using intelligent strategies for epidemics control. One such standard epidemiological strategy consists in tracing contacts of infected individuals. In this paper we introduce a generalization of the standard susceptible-infectious-removed (SIR) stochastic model for epidemics in sparse random networks which incorporates contact tracing in addition to random screening. We derive a deterministic mean-field description which yields quantitative agreement with stochastic simulations on random graphs. We also analyze the role of contact tracing in epidemics control in small-world networks and show that its effectiveness grows as the rewiring probability is reduced.

A. Vespignani and R. Pastor-Satorras *(ICTP, Trieste, Italy)*

Epidemiology of complex networks: computer viruses and sexually transmitted diseases.

We present a detailed analytical and numerical study for the spreading of infections in complex population networks. We show that the large connectivity fluctuations usually found in these networks strengthen considerably the incidence of epidemic outbreaks. Scale-free networks, which are characterized by diverging connectivity fluctuations, exhibit the lack of an epidemic threshold and always show a finite fraction of infected individuals. This particular weakness is found also in immunization strategies that can be successfully developed only by taking into account the inhomogeneous connectivity properties of scale-free networks. The understanding of epidemics in complex networks might deliver new insights in the spread of information and diseases in many biological and technological networks that appear to be characterized by complex heterogeneous architectures.

4. ASSESSMENT OF THE RESULTS

At a time when the scientific community on both sides of the Atlantic Ocean is grappling with the notion of **complexity**, it was timely and exciting to bring together academic researchers, who contributed significantly to lay down the paradigms and the technical tools, i.e. the foundations of the very notion of complexity, with outstanding scientists from different areas (medical, social sciences, economics, environment & ecology) and 'complexity operators', like management consultants, traffic experts, etc, all people who deal with complexity on a daily basis.
The notion of complexity has made its way into the **political jargon** both in Europe and in the US, to the point that many state legislatures are pressing our Universities to elaborate undergraduate curricula that include keywords like bio-diversity, complex systems, communication networks, etc. All of this is happening mostly 'top-to-bottom' and in the absence of a clear consensus on the meaning and implications of such keywords.
This Exploratory Workshop should helped participants (and in particular its academic component) grasp the cross-disciplinary impact of the large body of ideas known today as complexity. Passionate discussions (also during coffee-breaks and dinners) took place aimed to elaborate syllabi for innovative (under)graduate courses and, finally, appreciate the numerous options for extra-academic collaborations.
We left with the strong impression (and hope) that a closer collaboration among European scientists from different areas and nationalities could definitely foster a **European leadership** in this field over the US counterpart.

The Workshop can be called a success as proved by the fact that the Director of the E. Majorana Center, the Conference Center where the Workshop took place, agreed to host a sequel Workshop in three year time (summer 2005). The help provided by the PESC-ESF Exploratory Unit has been acknowledged throughout the Workshop activities and we rely on it for future initiatives in the field.

Furthermore, the Chief Editor of **Physica A** (Elsevier Publisher), also present at the meeting, offered to publish the Proceedings of the Workshop in a special issue of that journal -- co-edited by P. Hanggi and F. Marchesoni. The publication date is scheduled for mid spring 2003. A few copies of the volume will be delivered to the ESF Exploratory Unit in due course of time.

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41-50	**17**	
51-60	**8**	
> 61	**2**	