ΣΤΑΤΙΣΤΙΚΗ ΦΥΣΙΚΗ

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STATISTICAL PHYSICS 2017

Abstracts

International Conference on
ΣΤΑΤΙΣΤΙΚΗ ΦΥΣΙΚΗ
Corfu - Greece 10-14 July 2017

Corfu Holiday Palace
Corfu - Greece

Editors: G. Kaniadakis and A.M. Scarfone

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$\Sigma\,\Phi$ 2017

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ISBN 13 **978-88-9052-969-6**

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A1. Stochastic Processes in Complex Environments
Special Session organized by: J. Talbot and C. Mejia-Monasterio

A2. Kinetic Theory and its applications
Special Session organized by: G. Palasanzas and A. Rossani

A3. Information Geometry
Special Session organized by: D. Johnston, H. Matsuzoe, G. Ruppeiner and T. Wada

Topical Workshops

1. Kappa Distributions and Statistical Mechanics
Workshop organized by: G. Livadiotis, P. Yoon and K. Dialynas

2. Statistical Physics for the Digital Economy
Workshop organized by: T. Aste, G. Caldarelli, T. Di Matteo and G. Livan

3. Quantum Matter
Workshop organized by: S. Kourtis, D. Ellinas and J. Pachos

4. Statistical Physics of Environment, Climate and Ecosystems
Workshop organized by:P. Ditlevsen, D. Hristopulos and D. Valenti

5. Complexity and self-organization in biology and physiology
Workshop organized by: P. Paradisi and R. Metzler

6. Sociophysics and Econophysics
Workshop organized by: M.L. Bertotti and V. Constantoudis

Preface

The present volume contains the abstracts of the invited talks and the selected contributed oral or poster presentations submitted to the International Conference on ΣΤΑΤΙΣΤΙΚΗ ΦΥΣΙΚΗ held at Corfu in Greece, from July 10 - 14, 2017.

The Conference is organized in the following three Areas to cover all the Topics of Statistical Physics:

Area A: Foundations and Theoretical aspects of classical, quantum and relativistic statistical physics and thermodynamics. Mathematical aspects and methods, formalism, rigorous results, exact solutions, connections with the methods of high energy physics, string theory, mathematical statistics and information theory, information geometry, classical, quantum and relativistic transport theory, Boltzmann and Fokker-Planck kinetics, nonlinear kinetics, dynamical systems, relaxation phenomena, random systems, pattern formation, fractal systems, solitons, chaotic systems, strongly correlated electrons, soft quantum matter, mesoscopic quantum phenomena, fractional quantum Hall effect, low dimensional quantum field theory, quantum phase transitions, quantum information and entanglement, power laws, stochastic optimal controletc.

Area B: Applications to Physical Systems: quantum systems, soft condensed matter, liquid crystals, plasmas, fluids, surfaces and interfaces, disordered and glassy systems, percolation, spin glasses, structural glasses, jamming, critical phenomena and phase transitions,fluids and interfacial phenomena, molecular and ionic fluids, metastable liquids, hydrodynamic instabilities, turbulence, growth processes, wetting, surface effects, films, crystals, confined systems, surfaces and interfaces, chemical reactions, cold atoms, etc.

Area C: Applications to non-Physical Systems: Interdisciplinary applications of statistical physics, networks and graphs, applied networks, biophysics, genomics, environments, climate and earth models, seismology, linguistics, econophysics, social systems, traffic flow, algorithmic problems, complex systems, nonlinear time-series analysis, novel data analysis tools, extreme events, tipping points, prediction, classification, etc.

The Conference is organized in Symposia/Sessions dealing with general aspects and applications of statistical physics.

Some special sessions within the thematic Area A will cluster talks dedicated to the following theoretical topics: Stochastic Processes in Complex Environment; Kinetic Theory and its applications and Connections of Statistical Mechanics with Information Geometry.

Furthermore topical workshops on Kappa Distributions and Statistical Mechanics; Statistical Physics for the Digital Economy; Quantum Matter; Statistical Physics of Environment; Climate and Ecosystems; Complexity and self-organization in biology and physiology; Sociophysics and Econophysics have been organized as parallel events.

G. Kaniadakis and A.M. Scarfone
(Editors of the Abstract Booklet)

Study of kappa distribution function on EMIC waves in space plasma

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In this paper, we have presented some results of previous work on EMIC waves. Electromagnetic ion-cyclotron (EMIC) waves have been studied are discuss the effect of kappa distribution by using the method of kinetic approach are evaluated. The dispersion relation, growth rate and growth length on electromagnetic ion-cyclotron waves in low * case (* is the ratio of plasma pressure to magnetic pressure), homogeneous plasma have been obtained. The wave is assumed to propagate parallel to the static magnetic field. In this paper, the effect of kappa distribution on EMIC waves in space plasma is to enhance the growth rate with increases the growth length of EMIC waves in low case. It is found that the increasing value of kappa distribution function on electromagnetic ion-cyclotron wave is enhancing the growth/damping rate (*) with increase the growth length (*L) RE may be due to EMIC emissions.
The presence of such distributions in different space plasma suggests a universal mechanism for the creation of such super thermal tails. The super thermal particles have impotent consequences concerning the acceleration and the temperature that are well evidenced by the kinetic approach. EMIC waves play an important role in the overall dynamics of space plasma. Electromagnetic ion cyclotron (EMIC) waves generated in the equatorial region of earths magnetospheric as well as waves are left-hand circularly (LHC) polarized. EMIC waves are usually measured with frequency are 0.1-5.0 Hz range. Distribution function of kappa type is power laws with the power-index * determining the slope of the high-energy tails in the velocity spectrum of plasma particles Lazer et al., (2013).
The results are interpreted for the space plasma parameters appropriate to the auroral acceleration region. The interpreted may be applicable to explain the ion heating and acceleration of plasma particle in the solar wind as well as auroral acceleration region. The results of the work is consistent for EMIC emissions observations by Polar, FAST satellite of the auroral acceleration region as reported by Mozer, et al., 2000.

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Contribution of higher order correction to nonlinear dust acoustic soliton in dusty plasma with suprathermal ions

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From its beginnings with the initial observations of micron-sized particles in astrophysical1 and processing plasmas, the study of dusty plasmas has rapidly matured as highlighted in recent books. In fact, the ubiquitous presence of dust in the interstellar medium was recognized in the 1930s. Besides affecting the equilibrium quasineutrality condition and modifying the existing plasma wave spectra of an electron-ion plasma, charged dust grains also introduce new types of waves in a dusty plasma and are presumed to play an important role in many astrophysical plasmas. The dust particles are many orders of magnitude heavier than ions, are a source of ionization and recombination for electrons, and their charge is not fixed, but depends on local plasma parameters. Wave propagation in such complex systems is therefore expected to be substantially different from the ordinary two component plasmas and the presence of charged dust can have a strong influence on the characteristics of the usual plasma wave modes, even at frequencies where the dust grains do not participate in the wave motion. The most well studied of such modes are the so called dust-acoustic wave (DAW) and dust ion-acoustic wave (DIAW). Numerous observations clearly indicate the presence of suprathermal electron and ion structures as ubiquitous in a variety of astrophysical plasma environment [1], [2] and measurements of their distribution functions revealed them to be highly nonisothermal. [3] Such suprathermal populations may arise due to the effect of external forces acting on the natural space environment plasmas or to the wave-particle interaction, which ultimately leads to -like distributions. As a consequence, a high-energy tail appears in the distribution function of the particles. In this communication, our motive is to study the effects of both the higher order corrections and the suprathermality ions on the amplitude, width and velocity of dust acoustic soliton in an unmagnetized, collisionless dusty plasma containing dust grains, Maxwellian electrons and suprathermal ions.

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Quantum many-body physics with interacting photons: From Mott transitions to many-body localization

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The progress in quantum technologies involving manipulating light and matter at the microscopic level ranging from cold atoms coupled to nano-photonic structures, to superconducting quantum circuits, allow now to robustly observe nonlinear optical interactions at the quantum level. The latter has recently motivated the birth of a new area where strongly correlated states of light generated in such optical set ups are exploited for implementing quantum computation and for quantum simulation of a range of condensed matter and high energy physics effects. These include simulations of quantum phase transitions, topological effects, as well as gauge and relativistic field theories. I will briefly review the main theory results in this area along with our recent efforts for realizing models exhibiting strongly correlated phases and topological protected modes in out of equilibrium driven slow light and circuit QED set ups [1,2]. I will conclude by presenting a recent experiment done in collaboration with the John Martinis UCSB/Google group in probing many-body

localization with interacting photons in superconducting circuits.

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Torus random numbers generators

G. Makris, I. Antoniou

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We construct a class of mathematical models of random number generators based on chaotic Torus Automorphisms, called Torus-RNG. The proposed Torus-RNG are designed to have any desired entropy production and provide aperiodic sequences of non-negative integers of a given desired length that are uniformly distributed. The construction is based on our previous work on Torus Automorphisms [1], [2]. The Torus-RNG is a co-called linear RNG, satisfying all criteria proposed by Knuth [3], namely: 1) Randomness. The Torus-RNG has successfully passed the standard DIEHARD and NIST tests. 2) Long Period. The length of the random sequence is limited only by the maximal integer representable by the computer. This number depends of course on the processor and on the programming language. 3) Efficiency. As the memory requirements are limited to the bytes required to store the Torus-RNG parameters, the software runs very fast without any observable limitations. 4) Repeatability. The produced random sequence is the orbit of the seed, considered as an initial condition of the Torus Dynamical System. The seed may take any non-negative value smaller than the desired period. 5) Portability. The Torus-RNG can be implemented in any operating system and any programming language producing identical sequences. The Torus-RNG is a grid simulation of discretized Torus Automorphisms. The integer seed is inserted in the plane grid and transformed iteratively according to the selected Torus Automorphism. The product of the dimensions of the grid should be equal to the selected period. Although, the Torus Automorphisms act by definition on the unit square, we have transformed any rectangular grid to a square grid, in order to increase the parameters of the generators. The input parameters defining the Torus-RNG are the following: 1) The selected Period T. 2) The length m of the specific Random Sequence. 3) The three Torus parameters, selected independently are either three Integers, or two Integers and the desired Entropy Production. 4) The number of iterations of the Torus Automorphism. After fixing the Torus-RNG by specifying the input parameters, any selected seed defines a unique random sequence. The Torus-RNG is applicable to cryptography, steganography, simulation applications, gaming applications, statistical sampling, computer programming, numerical analysis, decision making.

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Kappa distributions and magnetospheric processes

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Magnetohydrodynamic (MHD) approach is overall used for the study of large-scale processes in the magnetosphere of the Earth. However the correct using of MHD requires the existence of collisions, which are extremely rare in the magnetosphere (the length of the free path is larger than the distance between the Earth and the Sun). The collisionless character of the magnetospheric processes requires the creation of the adequate substitution of the standard MHD on the system of equations taking into account a long-range interactions and based on the principles of non extensive statistical mechanics. Such substitution will permit to considerably modify the description of magnetospheric processes and improve the coincidence of theoretical predictions with the results of experimental observations. The real progress in such direction is now obtained [Livadiotis, 2015].
Experimental justification of using laws of non extensive statistical mechanics is connected with the possibility to comparatively precisely describe the really observed non-Maxwellian distribution functions by kappa-distributions. We made sure in the applicability of kappa-distributions analyzing electron and ion distribution functions in the magnetosheath (see [Kirpichev et al., 2015] and references therein), inside the magnetosphere and in the plasma sheet [Antonova and Stepanova, 2015]. Problems of such approximations are connected with different sensitivity of devices measured particle fluxes in different energy ranges and pitch angles. Another difficulty is connected with frequently observed mixtures of plasmas of different origins. For example, we observe mixture of plasma of solar wind origin and magnetosheric origin in the magnetosheth. The bi-kappa approximations are used in such cases.
The main difficulty of the approach development is connected with the absence of proper information about the processes of non-Maxwellian distribution function relaxations due to long-range interactions to kappa distributions and radial particle transport in the magnetosphere. Such information is obtained using data of multisatellite observations. We summarize the obtained results of the study of kappa-distribution parameters and spatial variations of the local entropy. We show that using of kappa approximations greatly improve the analysis of magnetospheric transport processes.

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Reaction diffusion limit of a kinetic model for chemically reactive gas mixtures

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Within the kinetic theory for chemically reactive gases, we consider the simple reacting spheres model for a mixture of four monatomic gases participating in a reversible chemical reaction of bimolecular type. Collisions between the species are either elastic or reactive and are both of hard sphere type. At the macroscopic level, one can describe how the concentration of the species in the reactive mixture changes under the influence of two processes, namely: diffusion, which causes the species to spread in space, and chemical reaction, which results in the transformation of the species into each other. Since the Boltzmann equation can in principle be used to describe convective phenomena, to achieve the macroscopic description of reaction and diffusion processes, the Boltzmann-type equations for the species in the mixture are scaled in a proper way. In particular, we consider the physical situation in which elastic collisions play the dominant role in the evolution process of the species, while chemical reactions are slow, together with the assumption that the Mach and Knudsen numbers are very small and of the same order of magnitude. Furthermore, we assume that the bulk velocities of the species are small and go to zero in the vanishing Knudsen and Mach numbers limit as well as that Isobaric and isothermal conditions are valid. The macroscopic equations are then obtained from the concentration and momentum balance equations of the species, and both the elastic and the reactive production terms appearing in these equations can be explicitly evaluated using Maxwellian distribution functions centered at the mass average velocity of the species. Such input functions define a state close to thermodynamical equilibrium, but they are able to capture the reaction diffusion effects until the equilibrium is reached. In the limit of vanishing Knudsen and Mach numbers, we formally derive the reaction diffusion equations of Maxwell-Stefan type as the hydrodynamic limit of the Boltzmann-type equations for the species in the chemically reactive gas mixture.

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Kinetic theory of Lorentzian distributed twisted wave.

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The orbital angular momentum states have been studied in the regime of Classical and Quantum Optics. However, recently Mendonca et al. have predicted the theoretical foundations of intense Laser beam having orbital angular momentum state for Laser-Plasma interaction. It exhibits paradigmatic alteration of Inverse Faradays effect. The orbital angular momentum states are being studied for plasma vortices. In this regard, Kinetic theory developed for the orbital angular momentum state is based on Maxwellian distribution of the plasma constituents. However, most of the Space Plasmas and some of the Laboratory Plasmas exhibit non-thermal/non-Maxwellian behavior due to spatial variation of number density, temperature, magnetic field intensity and background turbulence. In this regard, it would be very interesting if we can develop a kinetic theory that can help us in understanding the effect of orbital angular momentum part of the waves on these non-thermal plasma systems.
The kinetic theory of electrostatic twisted waves instability in a dusty plasma is developed in the presence of orbital angular momentum of the helical (twisted) electric field in plasmas with kappa distributed electrons, ions, and dust particles. The kappa distributed electrons are considered to have a drift velocity. The perturbed distribution function and helical electric field are decomposed by Laguerre-Gaussian mode functions defined in cylindrical geometry. The Vlasov-Poisson equation is obtained and solved analytically to investigate the growth rates of the electrostatic twisted waves in a non-thermal dusty plasma. The growth rates of the dust ion acoustic twisted mode (DIATM) and dust acoustic twisted mode (DATM) are obtained analytically and also pictorial presented numerically. The instability condition for the DIATM and DATM is also discussed with different plasma parameters. The growth rates of DIATM and DATM are larger when the drifted electrons are non-Maxwellian distributed and smaller for the Maxwellian distributed drifted electrons in the presence of the helical electric field.

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Multifractal urban morphology of historic city centers and of typical metropolitan areas in Greece

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The morphology of urban environment, as defined by street layout, is highly heterogeneous. A city may comprise a historic center with small intersecting boulevards, areas with contemporal regular street patterns and even amorphous sprawling urban neighborhoods at the outskirts. Such heterogeneity gives rise to diverse aspects of social, economic and commercial activity in different areas that couple to the morphological characteristics of urban patterns. Our work investigates perspectives of such coupling.
The method we follow for the characterization of the urban morphology focuses on multifractal analysis, using Space Syntax tools on ArcGIS environment. In particular, we obtain Rényi spectra of generalized fractal dimensions for typical city districts, of area as small as $\approx 1\ km^2$. It appears that a single fractal dimension may not suffice to describe the street configuration, even in such relatively restricted region. Our

results do not drastically vary when we analyze axial maps generated from the city street network compared to analysis of the original street network itself.
Two types of neighborhoods are considered: First, historic city centers (e.g. in Athens, Rhodes) with irregular morphology that reflects a century-long development, under diverse economic conditions and state administrations; second, contemporary districts, either residential or commercial, with more regular morphology. We find that the first type of areas exhibits multifractal behavior, while the second type is more similar to a monofractal description. Our analysis confirms the potential of the multifractal approach, as our results are consistent with examined cases in Spain (Ref. 1), albeit with a wider range of fractal dimension spectra.
Finally, we consider how the fractal dimensionality projects on the social activity and the technical infrastructure networks in the corresponding areas (e.g. transportation and telecommunication networks), by correlating their network metrics to the urban morphology.

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Predictive modeling for a complex world: a data-driven perspective

T. Aste, T. Di Matteo
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We all experience complexity in everyday life where simple answers are hard to find and the consequences of our actions are difficult to predict. Understanding and modeling the complex nature of markets, peoples and societies have become a crucial scientific challenge with great practical impact. The current big-data revolution has provided unprecedented access to large amount of data for modeling and forecasting complex systems. However, analyzing, understanding, filtering and making use of such a large amount of data have also become a challenge in itself.
I will present methodologies based on the combination network theory, statistical physics, data science, multiscale analysis and computational methods to unwind complexity and produce robust and meaningful models that are capable to make reliable predictions.

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Casimir force of geometrically confined Bose gas with a trapping potential

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An analogy of the Casimir effect (Casimir, 1948) can be found in a geometrically confined Bose-Einstein condensation (BEC) system. It is known that this geometry dependent Casimir-like effect in BEC systems caused by the long-range quantum fluctuation at zero temperature or thermal fluctuation at finite temperature. To understand the nature of the Casimir effect in BEC systems, it has been attracted a lot of interest both in experiment and theory (P. A. Martin and V. A. Zagrebn, 2006; A. Gambassi and S. Dietrich 2997; S. Biswas, 2007; M. E. Fisher, P.G. de Gennes, 1978). However, the role and importance of the Casimir force in the BEC systems has not been understand yet although there are many theoretical and experimental attempts. In experiments, to create BEC, the bosonic particles are generally trapped by external harmonic magnetic and optical lattice potentials. The optical lattice potential leads sinusoidal trapping of the particles and also allows to investigate quantum phase transition from a super-fluid to a Mott insulator while particles are trapped down to low energy levels of the system by the magnetic harmonic potential. With this motivation, we investigate the Casimir force of a geometrically BEC system due to the thermal fluctuations in the presence of a harmonic magnetic and optical trap potentials. To our knowledge this has not been studied before although the Casimir force of confined Bose gas with harmonic potential has been investigated in several studies. The aim here is to clarify the contribution of harmonic and optical potentials simultaneously to Casimir force in a well. In order to investigate the Casimir force we consider ideal Bose gas trapped in a two dimensional harmonic-optical potential between two infinite parallel plates at the xy planes that are separated by a distance d in the z-direction. We clarify the contribution of harmonic and optical potentials simultaneously to Casimir force in a well for present model. We show that the Casimir force of condensate Bose gas in a potential well decays with inversely proportional to d^5 when $T \approx T_c$ depends on Riemann's Zeta function and frequencies of harmonic-optical potential, however, in the case of $T > T_c$, it decays exponentially depending on separation d of the plates. Additionally, we report that the Casimir force and also related potentials for the present model have resonances in frequencies.

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Chaotic dynamics of the universe

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The dynamics of the universe at large scale and large time is a very important problem area in physics. Modern cosmology roughly suggest four main periods to explain the evolution of the universe such as vacuum (Planck), radiation, matter and dark energy era. However dynamics of the universe have not been completely understood yet (See Refs. [1-4]) At present, the universe is composed of approximately 5% baryonic matter, 20% dark matter, and 75% dark energy. The effect of interactions between different kinds of components on the dynamics of the universe are unknown yet. Whereas, the mutual interactions between dark energy-dark matter, dark

energy-matter and matter-dark matter etc., can be suggested as a possible scenario of universe evolution since mutually interactions of these components may play important role on the dynamics at large scale. For this fact, last decade, the interacting models have been considered to solve coincidence, fine tuning and singularity problems. Another unexpected surprise comes from a recent reports that self-interaction mechanism in dark sector has been predicted and detected in theoretical and experimental studies.
In this study, considering mutual and self-interactions between fluid components dark energy, dark, matter etc., I discuss universe dynamics. Choosing suitable and physically meaningful interaction I show that interacting two-fluid model with linear EoS can be transformed to the Lotka-Volterra equations of the competing two species. On the other hand I show that interacting two-fluid model with quadratic EoS can be transformed to the self-interacting Lotka-Volterra equations. I find fixed points of these equations and discuss the dynamics of universe. Finally I generalize these equations to N interacting Lotka-Volterra equations for more interacting fluids. Obtained results clearly show that dynamics of universe at large scale and within the time may have stable, unstable or chaotic behavior in the presence of the interaction and self-interaction in between dark energy, dark matter, matter and others components of the universe See Ref.[5].

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Thermogeometric phase transition in a unified framework

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Using geomterothermodynamics (GTD), we investigate the phase transition of black hole in a metric independent way. We show that for any black hole, curvature scalar (of equilibrium state space geometry) is singular at the point where specific heat diverges. Previously such a result could only be shown by taking specific examples on a case by case basis. A different type of phase transition, where inverse specific heat diverges, is also studied within this framework. We show that in the latter case, metric (of equilibrium state space geometry) is singular instead of curvature scalar. Since a metric singularity may be a coordinate artifact, we propose that GTD indicates that it is the singularity of specific heat and not inverse specific heat which indicates a phase transition of black holes.

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Residual entropy and waterlike anomalies in the repulsive one dimensional lattice gas

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Water is special fluid for its biological relevance and technological applications but most intriguing is that it presents thermodynamic and dynamic properties with anomalous (or unusual) behavior. The origin of its anomalous properties is actively discussed in the literature, with different thermodynamic scenarios competing to describe its behavior on regular and metastable regimes. Among alternative views on water thermodynamics, it should be relevant to mention the second critical point hypothesis and the singularity free scenario, which will be relevant in the context of the current work.
In this work, we proceed on this direction by investigating the repulsive 1D lattice gas, which is even simpler than our previous models and presents waterlike anomalies in density, thermodynamic response functions, and self-diffusion constant. The model was studied through transfer matrix technique, the Takahashi method (within a two-states approximation, as will be discussed later), and Monte Carlo simulations. With the results obtained from these techniques, a connection between temperature of maximum density and GSTP was found as in a previous work with more complex models. In addition, it was also found that GSPT does present a residual entropy, due to phase mixing, and it is shown that this property is fundamental in determining waterlike anomalies for the model considered here. Finally, a comparison between regions with density and diffusion anomaly indicated that this model presents so called hierarchy of anomalies.
In the ground state, the model presents a phase transition between a softened fluid and a dense fluid, which is characterized by a mixture between two states. The main consequence of this mixed state is a residual entropy in a single point in the pressure vs. temperature phase diagram. Using thermodynamic relations, it was argued that the presence of a residual entropy in a single point is consistent with a temperature of maximum density line ($= 0$) emanating from the ground state phase transition. Considering this it is possible to state that ground state phase transition, residual entropy, and density anomalies are the thermodynamic properties of our model which are intrinsically related and cannot be dissociated from each other.

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Directed percolation and the onset of turbulence in shear flows

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The transition to turbulence in wall-bounded shear flows has been studied for well over a century, and yet, only recently have experiments, numerical simulations, and theory advanced to the point of providing a comprehensive understanding of the route to turbulence in such flows. Of late, research has focused on how turbulence first appears and becomes sustained. The issue is that typically wall-bounded shear flows undergo subcritical transition, meaning that as the Reynolds number is increased, turbulence does not arise through instability of laminar flow, but instead appears directly as a highly nonlinear state. Moreover, the flow does not simply become everywhere turbulent beyond a certain Reynolds number. Rather, turbulence initially appears as transient patches interspersed within laminar flow. The resulting flow takes on a complex spatiotemporal form with competing turbulent and laminar domains. This, in turn, greatly complicates the quantitative analysis of turbulent transition in subcritical shear flows.
In the 1980's the connection was developed between spatially extended dynamical systems and subcritical turbulent flows. Pomeau [1] observed that subcritical fluid flows have the characteristics of systems exhibiting non-equilibrium phase transitions and therefore that these flows might fall into the universality class of directed percolation. This would imply a continuous transition to sustained turbulence with certain very specific power laws holding at onset. Since then considerable effort has been devoted to investigating these issues.
We will discuss the status of our understanding for prototypical subcritical shear flows: pipes [2,3], channels [4], and Couette flow [5]. We will emphasize that the case of two spatial dimensions is fundamentally different from that of one spatial dimension. We present a numerical study of a planar shear flow of unprecedented lateral extent and show that the onset of turbulence in this flow is continuous and is in the universality class of directed percolation.

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Marginal threshold condition for ordinary mode instability for Non-extesnsive anisotropic distribution

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The distribution function has different forms in the different region of space plasmas. These change in the distribution significantly affects the dispersion properties of the waves especially their free energy source (if exist) can make the wave unstable under certain conditions. These instablities as an effect of free energy source is a great deal of interest in space plasma community to their application to different solar wind problems e.g., particle acceleration etc.
The non-extensive distributions have received renewed attention due to the better agreement with the space plasma observations as compared to the Maxwellian distribution.The temperature anisotropy is one of the available free energy sources in the space plasma in particular to the solar wind. The temperature anisotropy makes the wave unstable based depending upon whether the anisotropy ratio ($A = Tx/Tz$) is either greater ($A > 1$) or smaller ($A < 1$) than one.
The Bale-diagram [1] obtained by the solar wind data is clear indication of this relation showing four different region of anisotropy-plasma beta space. These different regions are bounded by the instabilities. Davidson and Wu [2] first discussed the electromagnetic ordinary (O) mode instability can become unstable for anisotropy ratio greater than one and high plasma beta. Ibscher et al. [3] revisited the work [2] and obtained the marginal and threshold conditions of the o-mode instability for electrons for the bi-Maxwellian distribution. Ref. [4] extended the to the solar wind proton anisotropy and related to the Bale-diagram. The exact numerical analysis contrary to the above theoretical results is predicted by Hadi et al. [5] and clearly proved that the lower left bound of Bale-diagram is bounded by the O-mode instability in the counter-streaming plasmas.
In this work, the marginal instability threshold condition of ordinary mode(O-mode) is obtained using the exact numerical analysis to explain the Bale-diagram obtained from the solar wind data at 1 AU for Non-extesnive distribution. It is shown that the lower bound of the Bale-diagram is bounded by the O-mode instability. The effects of non-extensivity parameter q on the marginal stability curve are also highlighted to better model the Bale-diagram through Non-extesivity index q as compared to the usual Maxwellian distribution.

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Pedestrian Mobility: a statistical physics approach based on GPS data

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Modeling human mobility has been considered a paradigmatic example for the application of the Complex Systems Physics since one may take advantage from a Statistical Physics approach introducing cognitive effects in the microscopic dynamics. The problem of crowd dynamics in a complex road network has both relevance for safety reasons and for the sustainability of the future great tourist flows in the historical cities like the Venice. Various authors have proposed statistical laws to describe the complex features of human mobility using the large data bases (Big Data) provided by the Information Communication Technologies, but the definition of dynamical microscopic models able to describe transient or non-equilibrium states of the systems and to perform a forecasting of mobility state on a road network is still a debated problem due to the difficulty of recording dynamical data at microscopic level. Here, we show a study of pedestrian mobility in Venezia during Carnival 2017 based on the GPS localization of mobile phones. These data provides the lat-lon coordinates of a smart-phone that activates specific application on a relevant sample of the population(30% of the smart-phone population). The mobile phone data sample is validated using the pedestrian flows estimated from videos and photos recorded during the Carnival on locations of particular interest.
Our results concern the daily evolution of tourist distribution in the city during the Carnival detecting and quantifying the most crowded areas, the reconstruction and the characterization of the individual paths on the road network and of the individual mobility demand, and the study of the predictability of the mobility state using a nonlinear random walk dynamical model on the road network. We analyze the properties of the Master equation that describes the stochastic evolution of the system where the transition probabilities depend on the time-varying mobility demand and the crowding effects. We also study the fluctuations properties of local densities and flows to understand their correlation with the presence of criticalities (overcrowding) in the considered area.

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Complex systems in heterogeneous environments

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Many complex driven nonequilibrium systems are effectively described by a superposition of several statistics on different time scales, in short a 'superstatistics'[1-2]. A simple example is a Brownian particle moving in a spatially inhomogeneous medium with temperature fluctuations on a large scale, or a collection of different Brownian particles with different diffusion constants, but the concept is much more general. Superstatistical systems typically have marginal probability distributions that exhibit fat tails, for example power law tails or stretched exponentials. In most applications one e

nds up with three relevant universaliy classes: Lognormal superstatistics, chi-square superstatistics and inverse chi-square superstatistics. These can be effectively described by methods borrowed from nonequilibrium statistical mechanics. In my talk I will provide an easy-going introduction to these types of statistical mechanics methods relevant for heterogeneous or inhomogeneous environments, and discuss some recent examples of applications. These applications are from very different subject areas, but we will see what is common to all of them. The applications that I will discuss will be (time permitting) from turbulent flows (both classical and quantum turbulence), share price dynamics, diffusion processes of cancerous cells, rainfall statistics, fluctuations of demand and supply in local electricity markets, high energy scattering processes, and magnetic flux noise phenomena [3-5]. In these applications there is always a local parameter that fluctuates on a much larger spatial or temporal scale scale than the local relaxation time of the system. This parameter can be a local inverse temperature, a local variance parameter of a time series, a fluctuating mobility, or a fluctuating energy dissipation rate. Occasionally one also observes a transition from one type of superstatistics to another when a system parameter is varied.

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Dust acoustic dressed solitons in dusty plasma in the presence of polarization forces

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Recently, low-temperature plasmas containing, in addition to electrons and ions, finite-sized highly charged particulate matter have been studied by many authors because of the frequent occurrence of such plasmas in space, astrophysical plasma environments and even laboratory. These dust particles are many orders of magnitude heavier than ions and source of ionization and recombination for electrons. Wave propagation in such complex systems is therefore expected to be substantially different from the ordinary two component plasmas and the presence of charged dust can have a strong influence on the characteristics of the usual plasma wave modes. It has been found that the presence of static charged dust grains modifies the existing plasma wave spectra. Furthermore, dust dynamics introduces new eigenmodes, such as dust-acoustic mode[1], dust lattice mode[2] and dust Bernstein Greene Kruskal modes. Dust particles embedded in plasma are subject to various forces. Most likely, the electric force, which is a direct consequence of

the charging of the dust particles. The electric force is mainly responsible for the confinement of the negatively charged particles in the positive plasma potential. Another force acting on the dust is the polarization force which results to the deformation of the Debye sheath around the particulates in the background of nonuniform plasmas. Solitary wave propagation in unmagnetized plasmas without the dissipation and geometry distortion can be described by Korteweg de Vries equation or Kodomstev Petviasville equation. Recent studies in certain regions of space such as Earth's mesosphere, Jupiter's magnetosphere, Cometary tail, etc. suggest that KdV or KP description do not match well with experimental observations. This leads a modification to amplitude and width of the solitons[3]. One such modification is followed using higher order perturbation corrections in velocity, amplitude and width of KdV solitons. This work aims is to study, in presence of polarization forces, small-amplitude dust acoustic dressed soliton in a three components plasma consisting of a Boltzmann distributed electrons and ions and dust grains. We show, by introducing the effect of fourth order nonlinearities of electric potential in Sagdeev potential approach, the existence, and possible realization of dressed acoustic soliton and compared the result with the soliton's exact solution.

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Quantum walk algorithm in chaos based cryptography

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The system exhibiting dynamical chaos is characterized by the pseudorandom local instabilities of trajectories in the phase space. This is essentially deterministic nonlinear system, highly receptive to initial conditions and environmental inputs. As a result, numerical errors during computations on classical computers increase exponentially with time by perturbing the dynamical trajectories from the statistics of initial parameters after a few cycles of the periodic motion. In order to prevent the accumulation of errors, the simulation of trajectory distributions in total phase space even for moderate times demands an exponential number of orbits and soon exceeds the capacity of classical information systems [1]. On the other hand, the ergodicity of chaotic orbits and the fact that amply set of unstable periodic orbits are embedded within the chaotic attractor, lay foundation for the control of chaos by guarantying that the system evolution, within the attractor, will always reach close proximity of any point of any unstable periodic orbit in finite time. Quantum computing appears to redefine the problem of chaos control in terms of quantum cryptography by utilizing the development of quantum keys with Shor discovery of efficient algorithms for factorization of large integers and findings of discrete logarithms. The difficulty of factoring and discrete logarithms feasibility is at the core of present public-key cryptography. Furthermore, the implementations of realistic quantum simulators which utilize the quantum interference of various computational paths to reduce computation complexity and suppress erroneous outcomes of computations can produce extensive computational speedup.
In this paper we will outline the construction of quantum walk algorithm considered to solve plethora of problems [2] such as triangle-finding, commutativity testing, matrix product verification and data clustering. Moreover, quantum walk [3] relies on intrinsically unpredictably 'chaotic' nonlinear dynamic behavior resulting that it can be employed as an excellent key generator. The infinite resources of the permutations over the coin states make quantum walk a prime candidate for producing a theoretically infinite key manifold to resist brute-force attacks.

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Efficient detection of plastic events in emulsions simulations

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Emulsions are complex systems formed by a number of non-coalescing droplets dispersed in a solvent leading to non-trivial effects in the overall flowing dynamics. Such systems possess a yield stress below which an elastic response to an external forcing occurs, while above the yield stress the system flows as a non-Newtonian fluid, i.e. the stress is not proportional to the shear. In the solid-like regime the network of the droplets interfaces stores the energy coming from the work exerted by an external forcing, which can be used to move the droplets in a non-reversible way, i.e. causing plastic events.
The Kinetic-Elasto-Plastic (KEP) theory is an effective theory describing some features of the flowing regime relating the rate of plastic events to a scalar field called fluidity that can be interpreted as the inverse of an effective viscosity. Boundary conditions have a non-trivial role not captured by the KEP description. In this contribution we will compare numerical results against experiments concerning the Poiseuille flow of emulsions in microchannels with complex boundary geometries. The simulations are based on the Lattice Boltzmann (LB) methods. A suitable combination of attractive and repulsive interactions among the LB populations allow the simulation of a collection of droplets above the jamming point, displaying salient features of soft-glassy materials, including yield stress and non-local rheology. We implemented the model in a highly tuned CUDA code running on GPU. For the detection of plastic events we enhanced the code with a novel CUDA procedure for finding and comparing Delaunay triangulations that can be applied to the general problem of detecting topological changes in case of dynamic centroidal Voronoi diagrams (we recall that the Delaunay triangulation corresponds to the dual graph of the Voronoi diagram) whose generating points move in time. Possible examples of application include clustering analysis, a general tool used in many disciplines including (but not limited to) pattern recognition, computer graphics, combinatorial chemistry or the study of the behaviour of animals when they stake out a territory.

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Economic inequality: a moral and political issue that statistical physics may help to address

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The emergence of economic inequality constitutes a major moral and political issue, which is attracting growing interest in different contexts. Also within the mathematics and physics community various models have been recently formulated to describe the evolution in time of income and wealth distributions based on a myriad of microscopic (individual) interactions. In fact, statistical physics provides appropriate methods and tools for the understanding and explanation of mechanisms leading to such collective phenomena and may hence help to address the concern. We here review and discuss some models we have developed over the last few years within this research stream.
The models take the form of systems of nonlinear differential equations of the kinetic discretized-Boltzmann kind. Society is described as an ensemble of individuals divided into a finite number of income classes; the interactions between the individuals represent direct money exchanges, taxation (with tax rates depending on the income classes of the involved individuals) and redistribution processes (possibly weighted according to a means-tested welfare system). Tax evasion to different extents is taken into consideration too. We study the behavior of the Gini index as indicator of economic inequality and we also introduce an indicator of social mobility. In particular, we check the correlation of the latter with economic inequality. Our findings confirm that the correlation is negative in agreement with empirical evidence.

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Directed transport in equilibrium and modified Boltzmann distribution

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It is generally believed that to get directed transport of a mesoscopic object in contact with a heat bath one has to drive the system out of equilibrium. With the help of a model of a symmetry broken dimer I will show that directed transport can be achieved in equilibrium. Obviously one cannot extract energy from such a system, but, this is a dissipation less transport through a heat bath. I will show a generalization of the model taking into account coordinate dependent damping and will propose an alternative equilibrium distribution for such generalized systems involving coordinate dependent damping. In a conventional theory for such stochastic systems with coordinate dependent damping (multiplicative noise) I will show that one goes by the conflicting demand of a Boltzmann distribution in equilibrium and existence of no current. The procedure of handling multiplicative noise is convention dependent and also requires an ad hoc cancellation of the so called spurious current present in equilibrium. Moreover, in the presence of a coordinate dependent damping, the damping term itself breaks the homogeneity of space apart from the interactions. In such a situation the Boltzmann distribution only takes into account a part of the spatial homogeneity breaking cause and does not involve the other one i.e. damping. Simple understanding indicates that the damping being a homogeneity breaking cause of space must also reflect on the equilibrium distribution because it can make two different points over space inequivalent. I will show that, considering the over-damped dynamics, instead of starting from conflicting postulates, if one takes the sufficient condition that in equilibrium there is no average current in the system one can map the dynamics of such a system on the standard Langevin dynamics of a Brownian particle with coordinate independent damping. Thus, the particle would equilibrate at a minimum of a relevant potential giving rise to a modified Boltzmann distribution in equilibrium. This distribution obviously involves damping and since the solution comes through a mapping to constant damping model it becomes an additive noise problem and no convention and associated conflicts of conventions is required to solve the stochastic problem. I will generalize these results of the Langevin dynamics to the situation where the inertial term is present and a velocity distribution appears.

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Large scale Geophysical phenomena as emerging properties from fast complex systems: the El Niño case.

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In geophysical fluid dynamics, and in particular in large scale oceanography, we always need to simplify the description of very complex phenomena, like El Niño-La Niña, the Gulf Stream, the MOC etc., introducing some approximations, while still preserving the qualitative (if not quantitative) features of the phenomenon of interest.
Typically, a Low Order Model (LOM) is thus obtained, which is a closed finite set of Ordinary Differential Equations. The LOM aims at describing the time smooth dynamics of the interesting slow part of the whole system, while the interaction with the fast part (usually some external variables, like the atmosphere and/or some internal ones, like the chaotic part of the advection process) are included by hand as a white or a correlated noise. In this way, for example, is obtained the famous Recharge Oscillator Model (ROM), mimicking the slow part of the dynamics of the El Niõ Southern Oscillation (ENSO), forced by a noise. This approach, however, overlooks

some relevant details and it is open to pitfalls, from which the underlying assumption (usually not verified in this context) of the validity of the central limit theorem. Here we change the point of view. First of all we assume that it is possible to simplify the description, arriving to a LOM for the *whole* system. However, we do not make explicit the equation of motion of the fast non interesting part, because we shall see that we dont need to know it. Then, we apply a Zwanzig projection approach to obtain the large scale dynamics of the sole part of interest, that emerges as a universal property of the system, weakly dependent on the details of the fast part. We present here some results stemming from the implementation of this approach to the ENSO. In particular we obtain analytic results for the stationary probability density function of the NINO3 index (East equatorial Pacific sea surface temperature anomaly), and for the recurrence timing of strong El Niño events.

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Kinetic models and hydrodynamic limits for reacting mixtures of polyatomic gases

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Gases involved in real world applications, for instance in simple dissociation and recombination problems or in the evolution of dust in the atmosphere, are usually composed of polyatomic particles. In the paper [1], a possible generalization to polyatomic gases of the classical Boltzmann model has been proposed. Non-translational degrees of freedom of polyatomic molecules are modelled allowing the distribution function to depend even on a continuous internal energy variable. Proper options for the internal energy measure allow to reproduce the well known energy laws for polytropic or non polytropic gases. However, Boltzmann collision operators turn out to be quite awkward to deal with, especially in reactive frames. For this reason, we are proposing a consistent BGK relaxation approximation, able to retain most properties of the original Boltzmann equations (correct conservation laws, collision equilibria, H-theorem). We follow the lines of papers [2, 3], where the BGK equation for each gas shows a unique collision operator of relaxation type (towards a suitable Maxwellian attractor), which takes into account all collisional (mechanical and reactive) effects on the gas itself. Auxiliary parameters appearing in the attractor are made explicit in terms of actual macroscopic fields of the gas mixture by imposing that the BGK model preserves the correct collision invariants. In collision dominated regimes, by applying a Chapman-Enskog asymptotic procedure to our BGK model it is possible to analytically derive consistent hydrodynamic equations for the main macroscopic fields. We focus our attention on balance equations for species number densities, which are not preserved by chemical reactions (only suitable combinations of them are collision invariants). At the Euler level, the main analytical steps leading to the computation of the pertinent collision contributions are presented, while at the Navier-Stokes accuracy even constitutive equations for diffusion velocities and number density corrections are required.

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Predicting failure in power grids

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The stability of the power generations and supply networks, much like other large infrastructures, depends on the collective well functioning of its individual elements. In other words, a major power failure or outage has its root in preceding, apparently unrelated, failure events. In this work we ask whether it is possible to predict the susceptibility of power grid networks by monitoring these precursory signals.
The main objective of our work is to analyze the statistical trends in the power outage data and devise a risk assessment map for future outages.
Statistical regularities in the response of driven disordered system, of which a power grid is an example, are already well known (see Ref.[1] for a review). A more recent discovery is the departures from those regularities, such as the lowering of the exponent value in the Gutenberg Richter law for earthquakes magnitude size distributions, prior to large events [2]. Monitoring the amount of departures of the exponent from the regular values in the case of earthquake has led to construction of a heat map of risk for major earthquakes.
For power grids, extensive data for outages for the US and the EU countries have shown GR law like tendencies. A preliminary analysis show similar lowering of exponent values for power grid outage statistics during the time of the day when outages are more likely. Therefore, our aim is to evaluate the risk of power outages at different times and places by monitoring the changes in the outage statistics at those times and places. In contrast with earthquakes, in power grids a risk map is not only a predictive tool, but more importantly can be used for prevention of major failures by suitable mitigation strategies. This work is particularly relevant in view of the current design and large scale upgrades of the grids and its proposed integration to a super grid in the future [3]. Large outages are extreme event phenomena that have a higher chance of occurring as the system size grows. A suitable extrapolation of risk from a mathematical modeling of statistical data is, therefore, crucial.

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Changes in the long-term properties of the Danube river flow induced by damming

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We have studied scaling properties of the Danube river discharge process in the vicinity of two dams in Serbia, using the detrended fluctuation analysis (DFA) and the wavelet transform (WT). The dams were built in 1970 and 1982, respectively, along the Djerdap canyon of the Danube river, and are 80 km apart. We compared the scaling of the time series of daily Danube discharges in three periods (before damming, after the construction of the first dam, and after the construction of the second dam) and in the three measuring stations in the Djerdap canyon region. We have then compared our results, for all three periods of interest, with the scaling we obtained for the corresponding time series of discharges of Danube affluents in Belgrade, 200 km upstream from the region.
The comparison of the WT spectra and the DFA slopes for the three recording stations on the river Danube reveals dam(s)-induced changes in the scaling. Changes in scaling emerge after the damming in a) the small scales region, for time periods smaller or equal to one week, for the recording stations that are positioned downstream from the dam(s), and b) in the large scales region that encompasses periods longer than one week, for the measuring stations upstream from the dam(s). In both cases the scaling exponents became significantly smaller. We were also able to see the effect of lowering of the scaling exponents on the longer time scales even for river flows in Belgrade, 200 km upstream from the region, which could indicate the range and the nature of damming influence.
While the obtained change in scaling in the very small scales region, downstream from the dams, can be attributed to the alteration of the flow velocity, our findings reveal human-made lowering of the river discharge long-term persistence in the areas upstream the intervention. We discuss how these results should be further assessed in view of the possibility that the observed change in the long-term river flow persistence influences local climate, and significance of external trends.

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Record dynamics as the origin of aging

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We provide a unified description of "aging", the increasingly sluggish dynamics widely observed in the jammed state of disordered materials, in terms of record dynamics. Structural evolution in aging materials requires ever larger, record-sized rearrangements in an uncorrelated sequence of intermittent events (avalanches or quakes). According to record statistics, these (irreversible!) rearrangements occur at a rate $\approx 1/t$. Hence, in this log-Poisson statistics, the number of events between a waiting time t_w and any later time t integrates to $\approx \ln(t/t_w)$, such that any observable inherits the t/t_w-dependence that is the hallmark of pure aging. Based on this description, we can explain the relaxation dynamics observed in a broad range of materials, such as in simulations of low-temperature spin glasses and in experiments on high-density colloids and granular piles [1]. We have proposed a phenomenological model of record dynamics that reproduces salient aspects of the experiments, for example, persistence, intermittency, and dynamic heterogeneity [2]. Here, we compare the predictions of the model with the data available from experiments by Yunker, et al. [3]. These experiments provide the first opportunity to confront both the central assumption of record dynamics on quake statistics and one of its predictions, namely the emergence of growing mesoscopic real-space structures. The data shows that they concur with the fundamental assumptions as well as with the predictions of the theory. For the first time, direct experimental evidence for record dynamics as a coarse-grained description of dense colloids in particular, and of a broad class of aging materials in general, is provided. We complement the analysis of the data with a simple, coarse-grained lattice model of an aging colloid that matches the experimental results in great detail and allows predictions regarding observables to measure dynamic heterogeneity and the growth of length scales in the system. A mean-field rate equation even allows analytic predictions about the growth of domains with system age.

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Exploring quantum search algorithms with the renormalization group

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We explore Grover's quantum search algorithm on fractal networks with the renormalization group (RG) and determine its computational complexity in terms of the random walk exponent d_w and the spatial (fractal) dimension d_f. We obtain exact – and likely general – results for the complexity which grows as N^α with $\alpha = 3d_w/(2d_f) - 1$, which the Tulsa-Method can optimize to $\alpha = 1/\min\{d_s, 2\}$, referring to the spectral dimension $d_s = 2d_f/d_w$ of the network [1]. To this end, we develop the real-space renormalization group analysis of the quantum walk equation and analyze the probability to overlap with the sought-after site asymptotically in time and system size N. We establish a large universality class of search algorithms by considering entire families of quantum coin and search operators. The derivation of generalized unitarity conditions allows us to chose highly efficient implementations with coin-dimensions smaller than the site-degrees of the network.
We proceed by describing Grover's quantum search algorithm, which can provide a significant speed-up over classical computation. Grover (in 1997) has shown that a quantum

walk, starting from a uniform initial state, can locate an entry in an unordered list of N elements (i.e., sites in some network) almost certainly in a time that scales as $\sim \sqrt{N}$, a quadratic speed-up over classical search algorithms. However, that finding was based on a list in which all elements are interconnected with each other, thus, raising the question regarding the impact of geometry on this result. We have to split the search-task into two questions: (1) How fast can the weight of the wave function be moved to the desired location? And (2), how likely are we going to discover the desired element when a measurement is taken?
We then describe how to apply RG to answer those questions [2-3]. Regarding (1), the RG predicts that the weight of the wave function can be accumulated in a time $t_{\rm walk} = O\left(N^{d_w/(2d_f)}\right)$ via Grover's amplitude amplification, which competes with the fundamental Grover-limit of taking $t_{\rm opt} = O\left(\sqrt{N}\right)$ steps to rotate in Hilbert space the initial (uniform) state into the eigenstate of the sought-after site. For instance, in a regular lattice, where $d_w = 2$, the Grover-limit can always be achieved in dimensions $d_f = d > 2$. Regarding (2), our RG finds that the probability to locate the desired element in a measurement at the optimal time falls off as $O\left(N^{1-d_w/d_f}\right)$ when $d_w/d_f > 1$. The combination of these results leads to the above prediction for α.

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The interaction between like-charged colloids mediated by multivalent, stiff polyelectrolytes

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Interactions between charged objects in aqueous solutions are of fundamental importance in many technological and biological systems. These interactions can be altered by the presence of multivalent ions that possess a spatially distributed internal charge. In this presentation, we examine the influence of stiff, multivalent polymers on the interaction between charged surfaces [1-4]. Mean field theory is not able to describe these systems when the surfaces are highly charged. We extend and employ a self-consistent field theory that is accurate from the weak to the intermediate through to the strong coupling regimes [3]. The results show that close to the charged surface, the counterions are oriented parallel to the surface, whereas at distances greater than half of the ion length, they are randomly oriented. Due to the restriction of the orientations of the rod-like counterions at the surfaces, the ion density at the charged surface decreases to zero. We also calculate pressure between the surfaces [1]. For large surface charge densities, the interaction between like charged surfaces becomes attractive due to charge correlations, while the interaction is repulsive at low surface charge densities. Zwitterionic counterion systems are also examined. For large surface charge densities, the force between like charged surfaces becomes attractive, as a result of charge correlations. The theoretical results are found to agree well with Monte Carlo simulation results.

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On the eigenvalue representation of observables and probabilities in a high-dimensional euclidean space and its relation to informational geometry

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In this work we will present the basic concepts of the Eigenvalue Representation of Observables and Probabilities in a High-dimensional Euclidean (EROPHILE) space (Boulougouris Georgios C. .; Theodorou, Doros N. Journal of Chemical Physics , 2009, 130, 044905):. EROPHILE is a general approach that it was initially designed to address discrete systems where the dynamics can be described using a Master Equation and where detail balance is expected to hold. The main aspect of the EROPHILE is that describes perturbations from thermodynamic Equilibrium using the Eigenvectors of the Master Equation (or the time evolution operator in the more general case) and results in a geometrical description of both the dynamics and thermodynamics around Thermodynamic Equilibrium expressing statistical quantities as inner products in a Euclidian space. In systems that obey detail balance it has been shown the Eigenvalue Representation of Observables and Probabilities in a High-dimensional Euclidean (EROPHILE) approach can be used to identify relaxation modes in dynamical response experiments and most importantly express in the same Euclidian space both probabilities and observables as vectors providing us with the possibility of expressing either the deviation from equilibrium based on observables or the variances of observables as a function of the eigenvectors of the time evolution operator. For example, it has been shown that sub glass relaxations modes in atactic polystyrene simulations can be identified as the net result of the redistribution of the population of inherent structures that coincide with one of the eigenvector of the Master Equation that describes the dynamical transitions between inherent states. Alternatively the subglass relaxation mode can be identified as the observable for which the auto-correlation has only one characteristic time (decay via a single exponential that corresponds to a single eigenvalue). Finally, we will present its relation to the Information Geometry approach used to describe equilibrium thermodynamics.

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A one dimensional model of irreversible aggregation

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Irreversible aggregation of clusters of arbitrary size arises in many physical-chemical processes as aerosol physics, polymer growth, and even in astrophysics. The ability to control aggregation of proteins could be an important tool in the arsenal of the drug development. However, in biochemistry of life this process may play a destructive role as well. For example, many neurodegenerative diseases, including Alzheimers disease, Parkinsons disease, prion diseases, to mention some, are characterized by intracellular aggregation and deposition of pathogenic proteins [1]. Moreover, the abnormal irreversible aggregation of ribosomes leads to irreparable damage of protein synthesis and results in neuronal death after focal brain ischemia [2].
We define and study one-dimensional model of irreversible aggregation of particles obeying a discrete-time kinetics, which is a special limit of the generalized Totally Asymmetric Simple Exclusion Process [3,4] on open chains. The model allows for clusters of particles to translate as a whole entity one site to the right with the same probability as single particles do. A particle and a cluster, as well as two clusters, irreversibly aggregate whenever they become nearest neighbors. Non-equilibrium stationary phases appear under the balance of injection and ejection of particles. By extensive Monte Carlo simulations it is established that the phase diagram in the plane of the injection-ejection probabilities consists of three stationary phases: a multi-particle (MP) one, a completely filled (CF) phase and a 'mixed' (MP+CF) one. The transitions between these phases are: an unusual transition between MP and CF with jump discontinuity in both the bulk density and the current, a conventional first-order transition with a jump in the bulk density between MP and MP+CF, and a continuous clustering-type transition from MP to CF, which takes place throughout the MP+CF phase between them. By the data collapse method a finite-size scaling function for the current and bulk density is obtained near the unusual phase transition line. A diverging correlation length, associated with that transition, is identified and interpreted as the size of the largest cluster. The model allows for a future extension to account for possible cluster fragmentation.

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Effective potential for cellular size control

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For various species of biological cells, experimental observations indicate the existence of universal distributions of the cellular size, scaling relations between the cell-size moments and simple rules for the cell-size control. We address a class of models for the control of cell division, and present the steady state distributions. By introducing concepts such as effective force and potential, we are able to address the appearance of scaling collapse of different distributions and the connection between various moments of the cell-size. The effective potential dictates the properties of the cell size distribution, which attains the regular Boltzmann form. Our approach allows us to derive strict bounds which a potential cell-size control scenario must meet in order to yield a steady state distribution. The so-called "adder" model for cell-size control exhibits the weakest control that still enables the existence of stable size distribution, a fact that might explain the relative "popularity" of this scenario for different cells. While symmetric cellular division corresponds to a particle in an effective potential, the asymmetric division is described by a particle in effective potential that is performing stochastic jumps between two states. The mathematical formalism that we use is a continuous approximation for for general non-linear stochastic and deterministic discrete maps. For the stochastic map, by successively applying the Itô lemma, we obtain a Langevin type of equation. Specifically, we show that for a general class of non-linear maps, the Langevin description involves multiplicative noise. The multiplicative nature of the noise implies additional effective forces, not present in the absence of noise. We further exploit the continuum description and provide an explicit formula for the stable distribution of the stochastic map. Our results are in good agreement with numerical simulations of several maps. Applications of the presented formalism are not limited to description of cellular growth and can be applied to any system where stochasticity and temporal discreetness are of essence.

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Spatial evolution of human dialects

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When the speakers in a geographical region share a set of linguistic idiosyncrasies, these define a dialect. Language surveys may be used to define dialect regions, measure dialect differences, and map boundaries isoglosses between language features. We claim that dialect domain formation is driven by individuals tendency to conform. We show that the evolution of isoglosses is driven by two opposing effects: Surface tension makes isoglosses smoother over time, but variations in population density create curvature. These two effects, encapsulated in a single equation, make the final spatial distribution of dialects predictable.
Using census data for UK population density, we predict the most likely pattern of English dialects. Our predictions are derived by generating large numbers of synthetic isoglosses, and using these to define a local dialect at each point in space. Cluster analysis is then used to define coarse grained dialect regions which may be compared to linguistic maps prepared by dialectologists. Using standard metrics such as the Rand index and areal overlap, we find substantial similarity between our pattern and their predictions. In addition, our theory explains several observed phenomena, including isogloss

bundles which often divide two major linguistic areas in a given country: for example High from Low German, or Northern from Southern English. We are also able to explain fanning, the expansion of urban dialects, the transition from dialect continua to distinct zones, and the relationship between linguistic distance and geographical distance. This relationship, of longstanding interest to dialectologists, is known as Seguys Curve.
Our assumptions are extremely simple. Observations about human mobility and linguistic behaviour suggest that long range correlations, memory, differences between individuals, and social network structure are important to language evolution. Our model, and its predictive power, lays a theoretical foundation to investigate these.

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Electrostatic correlation-induced like-charge macromolecular attraction

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The characterization of electrostatic macromolecular interactions is crucial for the optimization of modern biological applications involving DNA molecules. In particular, the understanding of like-charge polymer-membrane and interpolymer attraction is a key step for improving the current gene therapeutic techniques. The like-charge attraction effect cannot be explained from the perspective of mean-field (MF) electrostatics that always predicts repulsion between similarly charged molecules. In this talk, I will introduce a beyond-MF test charge theory that allows to enlighten charge correlation effects driving the like-charge attraction phenomenon.
In the first part of the talk, I will characterize the recent experimental observation of DNA adsorption onto similarly charged substrates. Within the one-loop test charge theory, I will consider the electrostatic coupling between a polyelectrolyte and a like-charged membrane. The counterions adsorbed by the membrane locally enhance the electrostatic screening of the polymer and lowers the polymer self-energy in the vicinity of the membrane surface. At strong membrane or polymer charges, this effect dominates the MF-level DNA-membrane repulsion and results in the binding of the DNA molecule to the negatively charged substrate. Within the same theoretical framework, I will show that this enhanced polymer screening mechanism also explains several features of the experimental phase diagrams on the condensation of like-charged polymer solutions. The addition of multivalent counterions to the solution turns the interpolymer interactions from repulsive to attractive. Upon the rise of the monovalent salt density, the MF-level shielding of the average potential weakens the multivalent cation binding and suppress like-charge attraction. Due to the same shielding mechanism, the multivalent cations that trigger like-charge condensation at low densities results in the precipitation of the polymer aggregates at large densities. This reentrant behaviour can be beneficial to gene delivery methods where the control over polymer-DNA interactions is the key factor.

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Excess reciprocity distorts reputation in online social networks

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The digital economy is increasingly self-organizing into a "platform society" where individuals exchange knowledge, goods and resources on a peer-to-peer (P2P) basis. In recent years we have indeed witnessed how a number of well-established business-to-consumer sectors, such as the taxi and hotel industries , have been disrupted by the emergence of the novel sharing economy P2P marketplaces.
The peer-to-peer economy relies on establishing trust in distributed networked systems, where the reliability of a user is assessed through digital peer-review processes that aggregate ratings into reputation scores.
Given the expected growth of the P2P paradigm, digital reputation will increasingly become central in our online lives, as it will determine access to substantial economic opportunities. Hence, it is crucial to ensure that digital peer-review systems produce reliable reputation scores.
Being decentralised, P2P systems are often thought to promote more economic freedom and democratisation. Yet, their current lack of regulation exposes them to a number of biases which can distort their functioning .Game theoretic considerations, and plenty of anecdotal evidence, suggest that users are often incentivised to reciprocate both positive and negative ratings.
Here we present evidence of a network effect which biases digital reputation, revealing that P2P networks display exceedingly high levels of reciprocity. In fact, these are much higher than those compatible with a null assumption that preserves the empirically observed level of agreement between all pairs of nodes, and rather close to the highest levels structurally compatible with the networks' reputation landscape. This indicates that the crowdsourcing process underpinning digital reputation can be significantly distorted by the attempt of users to mutually boost reputation, or to retaliate, through the exchange of ratings. We uncover that the least active users are predominantly responsible for such reciprocity-induced bias, and that this fact can be exploited to obtain more reliable reputation estimates. Our findings are robust across different P2P platforms, including both cases where ratings are used to vote on the content produced by users and to vote on user profiles.

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Information and Thermodynamics of feedback controlled systems

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We present the general equations to compute the entropy reduction in feedback controlled systems due to the information gathered through the repeated operation of the controller. We illustrate some of the consequences of our general results by deriving the maximum work that can be extracted from isothermal feedback controlled systems. As case examples, we study a simple system that performs an isothermal information-fueled particle pumping, and the efficiency at maximum power of a discrete feedback ratchet. The discrete feedback ratchet considers a feedback control protocol, which works against an external load. Efficiency at maximum power is found to be of the same order for this feedback ratchet and for its open-loop counterpart. However, feedback increases the output power up to a factor of five. This increase in output power is due to the increase in energy input and the effective entropy reduction obtained as a consequence of feedback. Optimal efficiency at maximum power is reached for time intervals between feedback actions two orders of magnitude smaller than the characteristic time of diffusion over a ratchet period length. The maximum power output is found to be upper bounded. After, we compute an upper bound for the efficiency of this isothermal feedback ratchet at maximum power output. We make this computation applying the general equation for entropy reduction due to information. However, this equation requires the computation of the probability of each of the possible sequences of the controllers actions. This computation becomes involved when the sequence of the controllers actions is non-Markovian, as is the case in most feedback ratchets. We here introduce an alternative procedure to set strong bounds to the entropy reduction in order to compute its value. In this procedure the bounds are evaluated in a quasi-Markovian limit, which emerge when there are big differences between the stationary probabilities of the system states. These big differences are an effect of the potential strength, which minimizes the departures from the Markovianicity of the sequence of control actions, allowing also to minimize the departures from the optimal performance of the system. This procedure can be applied to other feedback ratchets and, more in general, to other control systems.

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Spatial scales of population fluctuations of two species ecosystems: effects of harvesting, competition or predator prey coupling.

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Synchronous fluctuations in the size of populations separated in space strongly affect their persistence to variations of the environment. We show that proportional harvesting and competition modify the spatial structure of population fluctuations of two competing species living in a variable environment. Proportional harvesting always increases the spatial scale of population synchrony. The effects of interspecific competition on the geographical scaling are dependent on the pattern of spatial covariation of environmental variables. If the environmental noise is uncorrelated between the competing species, competition will always increase the spatial scale of synchrony in the population fluctuations of both species. In contrast, if the environmental stochasticity is strongly correlated between the species, competition may increase the spatial synchrony of one or both species. The magnitude of these spatial scaling effects is strongly modified by the migration capacity of the two competing species. The strength of competition between the species may strongly modify the effects of harvesting on the spatial scale of the synchrony in the population fluctuations. For example, harvesting of one species may affect the spatial distribution of competing species that are not harvested. These analytical results indicate that harvesting may synchronize population dynamics over large geographical areas, affecting the vulnerability of harvested species to environmental changes. This shows that potential effects on distribution of individuals in space should be included in the design of multi-species harvest strategies. We will also advance our more recent results for spatial scale of population synchrony in predator prey ecosystems.

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Mechanics, thermodynamics, and kinetics of ligand binding to biopolymers

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Ligands binding to polymers regulate polymer functions by changing their physical and chemical properties. This ligand regulation plays a key role in many biological processes. We propose here a model to explain the mechanical, thermodynamic, and kinetic properties of the process of binding of small ligands to long biopolymers. These properties can now be measured at the single molecule level using force spectroscopy techniques. Our model performs an effective decomposition of the ligand-polymer system on its covered and uncovered regions, showing that the elastic properties of the ligand-polymer depend explicitly on the ligand coverage of the polymer (i.e., the fraction of the polymer covered by the ligand). The equilibrium coverage that minimizes the free energy of the ligand-polymer system is computed as a function of the applied force. We show how ligands tune the mechanical properties of a polymer, in particular its length and stiffness, in a force dependent manner. In addition, it is shown how ligand binding can be regulated applying mechanical tension on the polymer. Moreover, the binding kinetics study shows that, in the case where the ligand binds and organizes the polymer in different modes, the binding process can present transient shortening or lengthening of the polymer, caused by changes in the relative coverage by the different ligand modes. Our model will be useful to

understand ligand-binding regulation of biological processes, such as the metabolism of nucleic acid. In particular, this model allows estimating the coverage fraction and the ligand mode characteristics from the force extension curves of a ligand-polymer system. We illustrate the power of the method based in this model with the analysis of experimental results of Human mitochondria SSB (HmtSSB) binding to single stranded DNA (ssDNA), which has allowed to characterize the binding modes and coverage of HmtSSB-ssDNA complexes in several configurations, including ssDNA generated during DNA replication.

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Non-equilibrium properties of memristive circuits

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LANL

Networks with memristive elements (resistors with memory) are being explored for a variety of applications ranging from unconventional computing to models of the brain. However, analytical results that highlight the role of the graph connectivity on the memory dynamics are still a few, thus limiting our understanding of these important dynamical systems. In our talk we discuss various aspects of the dynamics which analyzed in recent work. We derive an exact matrix equation of motion that takes into account all the network constraints of a purely memristive circuit, and we em- ploy it to derive analytical results regarding its relaxation properties. We are able to describe the memory evolution in terms of orthogonal projection operators onto the subspace of fundamental loop space of the underlying circuit. This orthogonal projection explicitly reveals the coupling between the spatial and temporal sectors of the memristive circuits and compactly describes the circuit topology, and provide a bound on the strength of interaction. For the case of disordered graphs, we are able to explain the emergence of a (universal) power law relaxation as a superposition of exponential relaxation times with a broad range of scales using random matrices, and derive a Lyapunov functional which is equivalent to a disordered Ising model. In the case of circuits subject to alternating voltage instead, we are able to obtain an approx- imate solution of the dynamics, which is tested against a speci

c network topology. These result suggest a much richer dynamics of memristive networks than previously considered. In particular, we show that the number of independent memory states in a memristive circuit is constrained by the circuit conservation laws, and that the dynamics preserves these symmetry by means of a projection on the physical subspace. Also, we are able to show that for the case of purely passive or active systems, the eigenvalues of the Jacobian are always real, implying that oscillations can emerge only for mixtures. Our last result concerns the weak non-linear regime, showing that the internal memory dynamics can be interpreted as a constrained gradient descent, and provide the functional being minimized.

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Geometry of dissipative driven phase transitions

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We explore the geometrical properties of reservoir-induced phase transitions of lattice fermions in a non-equilibrium steady-state of an open system with local reservoirs. We confine ourselves to a class of models quadratic in the Lindbladian evolution which admits Gaussian fermionic states as steady state solutions. These systems may become critical in the sense of a diverging correlation length on changing the reservoir coupling[1-3]. We will introduce the quantum Fisher tensor[4](QFT) as a mean to explore the geometrical and topological features of such systems. The QFT is a mixed state generalisation of pure state quantum geometric tensor. Similarly to the latter, the QFT induces a geometrical structure in the manifold of the quantum states: its symmetric part defines a metric, the Bures metric, whereas its antisymmetric part induces a symplectic structure on the same manifold, which is related to the Uhlmann-Berry curvature.
We show that the imaginary part of the QFT is sensitive to the presence of non-equilibrium phase transitions. Indeed, in analogy with Halmitonian quantum phase transitions, non-equilibrium criticalities can be associated with a vanishing gap in the damping spectrum, and correspondingly, with a point of non-analicity in the parameter space of the steady-state solutions. Such a point of non-analicity induces a non-trivial geometrical structure in the steady-state manifold, which can be observed through the Uhlmann-Berry phase. Indeed, we show that both real and imaginary part of the QFT diverge super-extensively with the system size in critical regions, and that their scaling behaviour provides a mapping of the phase diagram. Moreover, in systems with translationally invariant symmetries we analytically demonstrate how discontinuities in the imaginary part of the QFT, in the thermodynamical limit, uniquely identify regions of diverging correlation lengths.
Thanks to its differential-geometric and information-theoretic nature, the QFT provides insights into dissipative quantum critical phenomena, as well as new and powerful tools to explore them.

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Quantum Sensing by Stochastic Quantum Zeno

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A system under constant observation is practically freezed to the measurement subspace. If the system driving is a random classical field, the survival probability of the system in the subspace becomes a random variable described by the Stochastic Quantum Zeno Dynamics (SQZD) formalism. Here, we study the time and ensemble average of this random survival probability, and demonstrate how time correlations in the noisy environment determine whether the two averages do coincide or not. These environment time correlations can

potentially generate non-Markovian dynamics of the quantum system depending on the structure and energy scale of the system Hamiltonian. We thus propose a way to detect time correlations of the environment by coupling a quantum probe system to it and observing the survival probability of the quantum probe in a measurement subspace [1].
Recently, an ergodicity breaking effect in SQZD has been experimentally observed by atom-chips [2]. More specifically, we have shown how the ergodicity property is present when an open quantum system is continuously perturbed by an external environment effectively observing the system at random times while the system dynamics approaches the quantum Zeno regime. In this context, by large deviation theory we analytically show how the most probable value of the probability for the system to be in a given state eventually deviates from the non-stochastic case when the Zeno condition is not satisfied. These results were then tested by ultra-cold Rubidium atoms prepared on an atom-chip platform.
Finally, we demonstrate how the sensitivity of the measurement is described by a functional version of the Fisher information [3,4], as well as sensing protocols based on Optimal Control. In particular, we analytically study the distinguishability of two different stochastic measurement sequences in terms of a Fisher information measure depending on the variation of a function, instead of a finite set of parameters. Therefore, we expect that these results will further contribute to the development of new schemes for quantum sensing technologies, where nanodevices may be exploited to image external structures or biological molecules via the surface field they generate.

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Numerical results for a bidimensional stability analysis of detonation waves

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The role that instability plays in practical detonation-based propulsion is of primary importance and largely unexplored [1].
The modern theory of detonation stability started with Erpenbeck, in 1962 [2] with the study of the linear stability problem using the Nyquist winding theorem to develop a numerical procedure that, for a given set of parameters, would determine unstable solutions of the stability problem. Since then many authors, such as Lee and Stewart [3], dedicated part of their work to the study of this problem. They introduced a normal-mode approach and a numerical shooting method to develop a simpler and more efficient search for unstable solutions and obtained very interesting numerical results. The linear approach for the stability problem is an idealised situation. Notwithstanding it reflects some important features of more complex problems and serves as an useful guidance in many real world applications.
In the hydrodynamic bidimensional stability study, a small transverse disturbance induces a rear boundary perturbation and there is a distortion on the shock wave location. Assuming that the instability of the detonation solution results uniquely from the interaction between the perturbed shock and the reaction zone, the stability problem consists in studying the evolution of the state variables disturbances in the reaction zone. It constitutes a step further in the study of the response over time, of a detonation wave to small rear boundary perturbations. This problem has been addressed by several researchers in works such as [1] and [4].
In 2015, the authors of the present study participated in a work (to be published in Proc. AIDAA 2015) which was the first theoretical attempt to do a bidimensional analysis of the instability spectrum of a detonation wave in an Eulerian mixture of ideal gases where the chemical rate law is derived from the reactive Boltzmann Equation. Here we present a more detailed and complete picture and explore numerically the introduction of the wave number in the stability analysis.

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D-wave superconductivity in boson+fermion dimer models

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The Rokhsar-Kivelson quantum dimer model (QDM) originally was introduced to describe a possible magnetically disordered phase - the resonating valence-bond phase in high-temperature superconducting materials. The arena where the QDM has been deployed has greatly expanded since its inception, and the model has taken on a key role in the study of a variety of magnetic quantum systems. The study of QDMs led to an abundance of new phenomena including deconfined quantum criticality and new routes to deconfinement. It also provided one of the earliest known examples of topologically ordered states in a lattice model.
Recently QDMs have been revisited as models of high-temperature superconductivity. This was motivated by the need to reconcile transport experiments and photoemission data in the underdoped region of cuprate superconductors: Whereas photoemission data show Fermi arcs enclosing an area 1+p (with p being the doping), transport measurements indicate plain Fermi-liquid properties consistent with an area p. In order to resolve this issue and produce a Fermi liquid which encloses an area p, Punk et al. [PNAS 112, 9552 (2015)] introduced a model for the pseudogap region of the cuprate superconductors which consists of two types of dimers: one spinless bosonic dimer representing a valence bond between two neighboring spins and one spin-1/2 fermionic dimer representing a hole delocalized between two sites. The boson+fermion QDM (bfQDM) was introduced and studied numerically using exact diagonalization, supporting the existence of a fractionalized Fermi liquid enclosing an area p.
We present a slave boson and fermion formulation of the bfQDM. We find that four symmetric fermion pockets,

located in the vicinity of $(\pm\pi/2, \pm\pi/2)$ in the Brillouin zone, naturally appear at mean-field level. The total area of the four pockets is given by the hole (fermionic) doping, for a range of parameters consistent with the t-J model for high temperature superconductivity. We find that the system is unstable to d-wave superconductivity at low temperatures. The region of the phase diagram with d-wave rather than s-wave superconductivity matches well the region with four fermion pockets. In the superconducting phase, the fermionic dimers (holes) acquire a Dirac dispersion at eight points along the diagonals of the Brillouin zone.

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Effect of savings on a gas-like model of economy with credit and debt

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In order to model a simple economy, the models of exchange agents have been introduced, which present an analogy with the molecular models of gases formed by colliding particles from the statistical physics. In the same way that the particles of a gas exchange energy during the collisions, in these models agents exchange a fraction of their capital, which is determined by the fraction that they do not save. This analogy is possible given the conservation of total capital. The capital of the agents comes mainly from their income, however, such agents can increase their capital through a credit, which in the long run will generate a debt.
In this work we study the thermostatsical properties of kinetic models of exchange agents that describe a closed economy with income, savings, credit and debt. Debt and credit are introduced as a further variable different than income, so that the lower limit of it represents the debt. The economic system including credit and debt was first studied by Viaggiu and collaborators using the tools of the statistical assemblies. They adopt the Boltzmann-Gibbs distribution where energy is replaced by total money including income, credit and debt. On the other hand, the savings propensity is not introduced as usual in kinetic models, like in the paper by patriarca et al, where saving propencity was firts introduced. In such work was shown that this agents follow at equilibrium the so called Gamma distribution, this was done by numerical simulation. In this work we use an analytical geometrical formalism. The geometric model for distributions of agents that save money was first introduced by Lopez-Ruiz et al. In this work they consider that the interacting agents obey an additive constraint that defines an N-dimensional surface of equiprobability. In this case the Hamiltonian constraint contains the propensity of saving as an exponent of the monetary variable. We calculate the canonical partition function, the economic temperature and other relevant variables. In these quantities we observe that there is an interaction between the fraction of money that agents can save and the debt that they can acquire.

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Analysis of enhancement in game system with the random walk model

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The random walk model has been used to analyze stochastic systems. Now we apply a random walk model to enhancement of an item in online game system. In some game system, equipment is enhanced with some risks. In the process of enhancement, sometime equipment is broken or enhanced. We analyze the statistical properties of enhancements with failure through the random walk model. The model is simply described by follows. First, let's assume that we have m-th enhanced item. When we try to enhance our m-th enhanced item, the item is successfully enhanced and become $(m+1)$-th enhanced item with probability p_{m+1}. Otherwise, the m-th enhanced item is broken and become 0-th enhanced item with probability $1-p_{m+1}$. The model is simple. Let's assume that an 1D lattice. A random walker is moved to the right position $x = m+1$ with probability p_{m+1} if the walker was in position $x = m$. With probability $1-p_{m+1}$, the walker go to the origin of the lattice. If we assume the simplest case $p_m = p$, the average number C_n of tries of enhancement for n-th enhanced item is calculated as follows. C_1 is clearly driven as $1/p$. C_2 also calculated as $C_2 = (C_1 + 1)/p$, because, in the average sense, C_1 step is needed for the walker is in 1st position. Similarly, the recursive relation $C_{n+1} = (C_n + 1)/p$ is driven. Finally, C_n is calculated as $C_n = \frac{p^{-n}-1}{1-p}$. Only the average number C_n of tries for the simplest can be simply obtained. The average, variance, and the number of failed tries (and return to the origin) are also considered for the general case. We first suggest a numerical analysis using matrix analyze. The model is considered analytically by partition function. Finally, we perform a Monte-Carlo simulations of the model to verify the analytical and numerical results. We also confirm that the analytic and numerical results are consistent. Finally, we suggest an analytical form of expected costs for enhancement of item in online-game through the random walk model.

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Thermal inclusions in the many-body localized phase in higher dimensions

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Many-body localized (MBL) systems fail to locally equilibrate themselves under their quantum dynamics and thus lie outside the framework of equilibrium statistical mechanics. They have been observed experimentally in cold atom and trapped ion systems in many different physical settings. Although a lot is known about the MBL phase in one dimension, even basic

features like the stability of MBL systems to thermalizing inclusions in dimensions greater than one, and the nature of the dynamical transition between the MBL and thermalizing phases are poorly understood. In this talk, I will present a simple model to address these questions: a two level system interacting with strength J with N 1 localized bits subject to random fields. On increasing J, the system transitions from a MBL to a thermalizing phase on the scale $J_c(N)1/N$, where these interactions do not contribute to the $N \to \infty$ thermodynamics, but have strong effects on the dynamics. I will argue that the transition is sharp in the thermodynamic limit and derive a modified Harris criterion for the transition. The transition is driven by second order flip-flop processes of certain pairs of l-bits that proliferate at $J_c(N)$. In the transition region, the single-site eigenstate entanglement entropies (and other single-site observables) exhibit bi-modal distributions, so that localized bits are either on (strongly entangled) or off (weakly entangled) in eigenstates. The clusters of on bits vary significantly between eigenstates of the same sample, which provides evidence for a heterogenous discontinuous transition in single-site observables. We obtain these results by perturbative arguments at small J and also by using numerical exact diagonalization of the full many-body system up to N=11 localized bits. Our results also imply that the MBL phase is unstable to large thermal inclusions in systems with short-range interactions in dimensions d that are high but finite. Our work leaves open the possibility that MBL phases can remain stable in higher d in nonrandom systems with quasiperiodic fields or potentials that do not produce such rare thermalizing inclusions.

Dynamical Networks characterization of space weather events

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The plasma and magnetic field of earths near-space environment is highly dynamic, with its own space weather. Space weather impacts include power loss, aviation disruption, communication loss, and disturbance to or loss of satellite systems, on some of which a range of technologies depend for navigation or timing. Space weather observations are increasingly becoming a data analytics challenge. Constellations of satellites observe the solar corona, the upstream solar wind (the suns expanding atmosphere that drives space weather at earth) and throughout earths magnetosphere (earths near-space environment). Space weather effects on the ground are monitored by 100+ magnetometer stations in the auroral region. Ionospheric currents can be detected by magnetometers on (for example the 60+ Iridium) polar orbiting satellites in low earth orbit (LEO). These data are multipoint in space and extended in time, so in principle are ideal for study using dynamical networks. There are several challenges however. The spatial sampling points are not uniformly spatially distributed and are moving w.r.t. the plasma-current system under observation, and the plasma-current system itself is non-linear and highly dynamic. Whilst networks are in widespread use in the data analytics of societal and commercial data, there are also additional challenges in their application to physical timeseries. Determining whether two nodes (here, ground based magnetometer stations) are connected in a network (seeing the same dynamics) requires normalization w.r.t. the detailed sensitivities and dynamical responses of specific observing stations. We present the first dynamical network study of the auroral current system which is observed by the SuperMAG set of over a hundred ground based magnetometers. The dynamics of this current system reflect the dynamical response of the earths magnetosphere to solar wind driving where energy is stored and then released in a bursty manner (substorms). Spatio-temporal patterns of correlation between the magnetometer time series can be used to form a dynamical network [1], the properties of the network can then be captured by (time dependent) network parameters. This offers the possibility of characterizing detailed spatio-temporal pattern by a few parameters, so that many events can then be compared [2] with each other and with theoretical predictions.

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Data quantile-quantile plots: model independent quantification of the evolution of the full distribution and application to solar wind turbulence and extremes

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Characterizing turbulence, and complex systems more widely, often requires quantitative characteri-zation of the full distribution of observed variables and how it varies with control parameters or driving of the system. We will discuss data-data quantile-quantile plots which quantify how the underlying statistical distribution of a given observable is changing in time or with scale. Importantly this method does not require any assumptions concerning the underlying functional form of the distribution and can identify multi-component behaviour that is changing. This can be used to determine when a sub-range of a given observable is undergoing a change in statistical distribution, or where the moments of the distribution only are changing and the functional form of the underlying distribution is not changing [1]. The method is quite general and we will apply it to the solar wind which is inherently variable across a wide range of spatio-temporal scales. Embedded in the solar wind flow are the signatures of distinct non-linear physical processes from evolving turbulence to the dynamical solar corona which also shows scaling. In-situ satellite observations of solar wind magnetic field and velocity are at minute and below time resolution and now extend over several solar cycles. Each solar cycle is unique, with different space climatology and we use this methodology to quantify how solar wind turbulence, and extremes respond within, and across, each distinct solar cycle; for this application we use data from the WIND satellite to compare the solar wind across the minima and maxima of solar cycles 23 and 24. We consider in-situ solar wind plasma parameters in fast and slow solar wind such as the magnetic

energy density and the Poynting flux. The core of the plasma parameter distributions retains a log-normal functional form simply varying in amplitude with the solar cycles, in agreement with previous work and suggestive of a multiplicative underlying physical process consistent with turbulence. The DQQ method also identifies the threshold energy flux at which solar wind plasma parameters depart from the lognormal regime; this extremal component exhibits its own dependence on the solar cycle which is distinct between fast and slow wind.

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Slow and fast timescale dynamics of global mean temperature

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Global mean temperature (GMT) provides a simple means of benchmarking a broad ensemble of global climate models (GCMs) against past observed GMT which in turn provide headline assessments of the consequences of possible future forcing scenarios. The slow variations of past changes in GMT seen in different GCMs track each other and the observed GMT reasonably closely. However, the different GCMs tend to generate GMT time-series which have absolute values that are offset with respect to each other [1]. Subtracting these offsets is an integral part of comparisons between ensembles of GCMs and observed past GMT. We will discuss how this constrains how the GCMs are related to each other. The GMT of a given GCM is a macroscopic reduced variable that tracks a subset of the full information contained in the time evolving solution of that GCM. If the GMT slow timescale dynamics of different GCMs is to a good approximation the same, subject to a linear translation, then the phenomenology captured by this dynamics is essentially linear; any feedback is to leading order linear in GMT. It then follows that a linear energy balance evolution equation for GMT is sufficient to reproduce the slow timescale GMT dynamics, provided that the appropriate effective heat capacity and feedback parameters are known. As a consequence, GMT may not be a sensitive indicator of non-linear dynamics and may underestimate the impact of, and uncertainty in, the outcomes of future forcing scenarios. The offset subtraction procedure identifies a slow time-scale dynamics in model generated GMT. Fluctuations on much faster timescales do not track each other from one GCM to another. This suggests that the GMT time-series can be decomposed into a slow and fast timescale which naturally leads to stochastic reduced energy balance models for GMT.
On the other hand local adaptation requires quantifying the geographical patterns in changes at specific quantiles or thresholds in distributions of variables such as daily surface temperature and precipitation. Model independent methods [2] can transform daily observations into patterns of local climate change by estimating how fast different quantiles across the distributions are changing. We demonstrate this approach [3,4] using E-OBS gridded data timeseries from specific locations across Europe over the last 60 years.

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Emergence of complexity in urban morphology: building distributions and transportation networks

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Social systems have recently attracted much attention, with attempts to understand social behavior with the aid of statistical mechanics of complex systems. Among them, the city is a representative system, where interactions between individuals give rise to emergent collective properties in its morphology. Among various collective properties, criticality is known as a characteristic property of a complex system, which helps the systems to respond flexibly to external perturbations. This work considers the criticality of the urban morphology, specifically, of the building distributions and transportation passenger flows. Analyzing the big data on every building in Seoul City, we specify the relevant interactions among constituents and probe the emergence of complex land use patterns. In particular, based on the empirical observations, we illustrate that interactions between land uses are frustrated, which serves as a basic postulate of the theory of urban morphology. We examine this conjecture with the help of a layered Ising-type model and disclose that the actual land use pattern emerges at the criticality of the system in the presence of heterogeneously distributed fields. In addition, we consider the mass transportation network and examine passenger flows, entailed in the massive smart card data on the Seoul transportation network. Observed are skew distributions and criticality manifested by power-law correlations. Such criticality is probed by means of the scaling and renormalization analysis of the modified gravity model applied to the system. Here a group of nearby (bare) bus stops are transformed into a (renormalized) block stop and the scaling relations of the network density turn out to be closely related to the fractal dimensions of the system, revealing the underlying structure. Specifically, the resulting renormalized values of the gravity exponent and of the Hill coefficient give a good description of the Seoul bus system: The former measures the characteristic dimensionality of the network whereas the latter reflects the coupling between distinct transportation modes. It is thus demonstrated that such ideas of physics as scaling and renormalization can be applied successfully to social phenomena exemplified by the passenger flow.

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Microscopic computation by biochemical systems

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Information thermodynamics is a relatively recent field that attempts to understand the physical basis of computation.

An important emphasis of work in the field is placed on feedback processes, entropy production in stochastic systems and copying processes. While this is valuable, it is often unclear how this relates to theoretical computer science.
In this talk, I will attempt to clarify this connection. I will focus on computation by stochastic systems, more specifically Markov Chains. In the first part of the talk, I will define in what sense stochastic systems compute. As a model system, I will consider biochemical computers. These have recently attracted significant interest as an important type of microscopic computation. Examples are biological systems, such as kinetic proof-reading, sensing, DNA copying or translation. I will propose the concept of entropy driven computer (EDC) as a general formal model of chemical computation. I will find that EDCs are subject to a trade-off between accuracy and entropy production. Similar trade-offs are frequently found in biological computations, for example in gene regulation. However, these biological systems usually also display a trade-off in time in the sense that the speed of the computing can only be increased of the noise is also increased or more energy is used for the computation. EDCs do not show this time-trade-off. The latter only arise when it is taken into account that the observation of the state of the EDC is not energy neutral, but comes at a cost. I will discuss the significance of this conclusion in relation to biological systems and in relation to microscopic computation in general.
The performance - cost trade-offs of EDCs mean that deterministic computation is difficult to achieve in those systems at finite cost. However, we know that deterministic computers do exist. In the second part of the talk, I will then extend the discussion and ask under which conditions systems are able to compute deterministically. I will relate deterministic computation to EDCs and calculate minimal resource requirements for a deterministic computation.

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Algorithms for reputation and quality in scientific e-communities

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The ever-increasing quantity and complexity of scientific production have made it difficult for researchers to keep track of advances in their own fields. This, together with growing popularity of online scientific communities, calls for the development of effective information filtering tools. Here we discuss a general ranking method to simultaneously compute reputation of users and quality of scientific artifacts in an online scientific community where researchers share relevant papers. The method is based on an iterative procedure built on the network representation of the community, and relies on the different kinds of actions that the members of the community can undertake. Evaluation on artificially-generated data and real data from the Econophysics Forum is used to determine the method's best-performing variants. We show that when the method is extended by considering author credit, its performance improves on multiple levels. In particular, top papers have higher citation count and are published on more prestigious journals, and top authors have higher h-index than top papers and top authors chosen by other algorithms. Note that the range of applicability of the algorithm is not strictly limited to scientific online communities, as it can be used in any environment where i) shared perceptions of quality can emerge, ii) quality induces popularity, and iii) individual artifacts have multiple authors. We finally discuss the application of reputation metrics to social recommender systems, namely automated tools that cope with the problem of information overload relying on the social environment of the users. Using an adaptive recommender model based on epidemic-like spreading of news on a social network, we show that incorporating user reputation in the recommendation process do not necessarily harm the personalization of recommendations and thus the users' satisfaction. Instead, such an add on can substantially improve the outcome of the system—both in terms of filtering efficiency of the model as well as of its robustness against malicious and spamming behavior.

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Entangling credit and funding shocks in interbank markets

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Recently, both researchers and regulators realized that the financial system is actually more fragile than previously thought, because of the complexity of interconnections between financial institutions. Indeed, while interconnectedness means diversification and thus reduces individual risk, it can however increase systemic risk: financial distress can spread between institutions through such exposures and propagate over the market, leading to amplification effects like default cascades. In the context of interbank lending markets, the main channels of financial contagion are represented by credit and liquidity risk. On one hand, banks face potential losses whenever their counterparties are under distress and thus unable to fulfill their obligations. On the other hand, solvency constraints may force banks to recover lost fundings by selling their illiquid assets, resulting in effective losses in the presence of fire sales (that is, when funding shortcomings are widespread over the market). Building on Debt Rank, we define a systemic risk metric that estimates the potential amplification of losses in interbank markets accounting both for credit and liquidity shocks. The underlying assumption is that equity losses experienced by a bank do imply both a decreasing value of its obligations and a decreasing ability to lend money to the market.

We implement our method on a dataset of 183 European banks that were publicly traded between 2004 and 2013, quantifying individual impact and vulnerability of these financial institutions over time. Our analysis confirms that liquidity spillovers substantially increase systemic risk (the overall equity loss increases by a factor up to 1.5 and almost doubles the individual systemic impact of banks, especially in years after 2008), and thus cannot be neglected in stress-test scenarios. We also provide additional evidence that the interbank market was extremely fragile up to the 2008 financial crisis, as in those years even the smallest initial shock would have caused all banks to default. By contrast, after

the crisis the market became able to absorb an increasing amount of financial distress. Our analysis supports the thesis that liquidity requirements on financial institutions may be as effective as capital requirements in hindering financial crises.

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Random walks on regular networks generated by fractional Laplacian matrices

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We analyze some characteristic features of random walks generated by power law matrix functions $L^{\alpha/2}$ ('fractional Laplacian matrices'). 0ge world network with only next neighbor connections such as for instance of the classical Polya walk [1,2]. We confine in this model on 'regular networks' having constant degrees for all nodes and specify our calculations on $n = 1; 2; 3; 4$-dimensional periodic and infinite lattices.
We demonstrate that the non-locality of the fractional Laplacian matrix generating connections with 'intensities' of asymptotic power law decay between all nodes, leads to the emergence of a small world property and of Lévy flights (anomalous diffusion with long-distance jumps).
In this presentation we further discuss characteristics such as first passage probabilities including first return probabilities and mean first passage times (MFPT) for the fractional random walk. Our results confirm our recent findings [3,4] that a search strategy based on a fractional random walk is faster than a search strategy based on the normal random walk ($\alpha = 2$).

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Dynamics of a probe pushed by Physarum polycephalum under electrotaxis

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One of the main considerations on the operation of Lab-on-Chip (LOC) devices are the source of energy to drive micrometer-sized actuators. Proposals for source of force generation includes the use of electromagnetic mechanism, high pressure gases, optical forces among others. Currently, there is also rapid development in the area of biologically inspired driving mechanisms for actuator devices. Already, active baths composed of E. coli were used to drive micrometer sized gears. Furthermore, bacterial bath composed of E. coli was shown to drive passive colloidal beads thereby allowing such beads to undergo super-diffusion. On the other hand, it is also possible to utilize the tactic response of biological organisms to drive micro actuators. This latter approach gives an important benefit of control, i.e. by changing the external stimuli one can change the force exerted by the biological organism. One possibility is the use of the slime mold, Physarum polycephalum (P. polycephalum). P. polycephalum has already been used as active component for a biological transistor, proposed biological computer among others. In this study, we performed experiments to measure the movement of a probe, 0.9 mm in diameter, along a 1 mm diameter channel being after being pushed by a plasmodium of P. polycephalum under electrotaxis. Fresh samples of plasmodium of P. polycephalum were exposed to DC electric field with strengths from 0.48 V/mm to 6.25 V/mm. The movement of the starved plasmodia were observed for several hours where the mean node position was found to move towards the cathode signifying a negative electrotactic response. Three dynamical modes of the probe were also observed: pure translation, translation + swinging and translation + rotation. All three dynamical modes of the probe were observed for the electric field strengths that were used. Furthermore, using single particle tracking and for the case of pure translation, it is apparent that the trajectory contains periodic component which is reminiscent of shuttle streaming. Our work opens up the possibility of using P. polycephalum to exert force on interfaces under electrotaxis.

Inhomogeneity and dynamical complexity in space plasmas

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Space plasmas and their evolution are generally described as fluid media coupled with self-consistent magnetic fields in the framework of magneto-hydrodynamics (MHD). However, the MHD description is a mean field description whose variables are generally analytically smooth functions of position and time. This regularity of the MHD description is not able to take into account of the inherent inhomogeneity and stochastic nature of actual plasma media. Indeed, real magnetized space plasmas are turbulent and non-equilibrium matter media that display dynamical complexity, scale-invariance and non-Gaussian probability distribution functions of several physical quantities. The inherent irregularity of actual space plasma media can be due to the formation of macroscopic/mesoscopic multiscale magnetic field and plasma coherent structures, whose evolution is at the basis of the dynamical complexity of the entire plasma medium.
Examples of space plasmas environments characterized by such a complex dynamical features are heliospheric and magnetospheric space plasmas [Bruno and Carbone, 2016; Consolini and Chang, 2001]. In these space regions there is indeed a wide evidence of the formation of stochastic coherent structures [see e.g. Bruno et al., 2001] and of how the evolution of such coherent structures can explain the observed coherent coarse-grained dissipation [Chang et al., 2003].

Here, after a brief review of the complex dynamical features of some space plasma media, the role that extreme event statistics, multiscale structures and inhomogeneity might play in the emergence of non-Gaussian probability distribution functions in such matter media, is discussed. In particular, following the statistical approach by Lavenda [1995] on the thermodynamics of composite systems, we attempt a description of the irregular nature of space plasmas and of the non-Gaussian features of fluctuations of several quantities. Some examples of the application of such approach to heliospheric and magnetospheric plasma environments will be also presented and discussed.

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Multifractal correlations in natural language written texts: Effects of language family and long word statistics

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During the last years, several methods from the statistical physics of complex systems have been applied to the study of natural language written texts. They have mostly been focused on the detection of long-range correlations, multifractal analysis and the statistics of the content word positions. During the last decades, several research groups have applied methods inspired by the statistical physics of complex systems to the detection and characterization of LRC and found that they are present in almost all mathematical representations of written texts at any scale of language hierarchy (letters, syllables, words, sentences, . . .) [1]. In the present paper, we show that these statistical aspects of language series are not independent but may exhibit strong interrelations [2]. This is done by means of a two-step investigation. First, we calculate the multifractal spectra using the word-length representation of huge parallel corpora from ten European languages and compare with the shuffled data to assess the contribution of long-range correlations to multifractality [3]. In the second step, the detected multifractal correlations are shown to be related to the scale-dependent clustering of the long, highly informative content words. Actually, we seek the link of the detected multifractal correlations to the positional scaling statistics of long words. We find that the clustering behavior of long words in real WLS presents an interesting crossover when we move to smaller inspection scales. In particular, at small scales a repulsing regime occurs where the long words repel each other and exhibit less clustering than the shuffled WLS. This crossover from clustering to anti-clustering behavior is responsible for the difference between real and shuffled multifractal spectra and dictates the footprint of LRC on multifractality. Furthermore, exploiting the language sensitivity of the used word-length representation and the benefits of our analyzed corpus (parallel texts in ten European languages), we demonstrate the consistent impact of the classification of languages into families on the multifractal correlations and long-word clustering patterns.

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The multiple faces of spatial complexity: From galaxies to cities and to nanostructures

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Nonequilibrium statistical processes usually derive spatiotemporal complex behaviour where multiple factors activated in different degrees of freedom are involved in a nonlinear but coordinated fashion to output emergent and self-organized patterns. Recently, a bunch of methods inspired by various fields of science has been applied to model and characterize the complex spatiotemporal behaviour comprising what is usually called complexity science. To get better understanding of spatiotemporal complexity, one can decompose it to the time and space domain. Time complexity is related to the nonlinear and chaotic dynamics observed even in low-dimensional systems and has been largely investigated during last decades in both Hamiltonian and dissipative systems [1]. On the other hand, spatial complexity though close to the notions of pattern formation and surface growth studied in the past, has not been accepted a unified view and a systematic report of the methods for its characterization and modelling is still missing. The aim of this talk is to fill this gap and provide a review of the methods used to reveal patterns and information enclosed in complex spatial morphologies when they considered frozen in time. The examples will range multiple scales starting from the spatial arrangement of stars in galaxies then moving to the scale of cities and looking for the spatial patterns of city features and finally going to even smaller scales of technological structures at micro and nanoscale devices [2]. Special emphasis will be given to the mathematical and statistical characterization of nanostructure complex morphologies since they largely dictate the properties and functionalities of nanostructures in the nanodevices and nanosystems and therefore have attracted a lot of interest during the last years [3]. The critical impact of these mathematical and statistical methods on the development of nanometrology of complex nanostructures will be demonstrated along with their potential industrial relevance in nanotechnology applications.

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Coarsening and percolation in a disordered ferromagnet

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We study numerically the phase-ordering kinetics of a two-dimensional ferromagnetic Ising model quenched from above to below the critical temperature. Upon computing usual quantities used to assess percolation properties, such as the pair connectedness function, the wrapping probabilities, or the winding angle, we show that these quantities attain the exact behaviour of random percolation theory after a characteristic time t_p. This shows that a critical percolation spanning cluster forms during the coarsening kinetics at t_p. This fact comes as a surprise, since percolation is a paradigm of a non-interacting problem, whereas coarsening embodies exactly the opposite. The time t_p when the percolative spanning cluster form is shown to increases algebraically with the system size. After that time, the percolation structure is rendered more and more compact by the ensuing coarsening process and the spreading of ferromagnetic correlations. In order to assess the generality of this phenomenon we also study the effects of quenched disorder. Specifically we consider the two-dimensional ferromagnetic Ising model in the presence of random bonds or random external fields. Our results show that the phenomenon whereby the percolative structure is formed att_p and later dismantled are largely independent on the presence of quenched disorder, pointing towards a general character. This can be interpreted within a dynamical scaling framework where the typical domains size plays the role of a rescaling length. This approach holds true both in the case of clean or disordered systems, despite the fact that the rescaling length grows much slower in the latter. Our results not only opens the way to further studies on more general disordered systems (for instance, randomly diluted models where a more complex scaling structure has been recently observed), but also prompts the attention on a possible generalisation of analytical theories where the properties of phase-ordering are traced back to percolation effects, originally developed for clean systems, to the disordered cases.

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Sample Space Reducing process and the emergence of arbitrary scaling exponents

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Path dependence, non-stable phase spaces and the emergence of scaling patterns are key aspects of statistical physics of non-equilibrium systems. Sample Space Reducing processes (SSRps) are minimally path dependent stochastic processes which reduce their sample space as they unfold [1]. In addition, SSRps offer a new mechanism to understand the emergence of scaling. Therefore, they define a privileged framework to explore the above mentioned aspects of non-equilibrium systems in countless processes. In the simplest SSRps power law exponents can be related to noise levels in the process. Nevertheless, the emergence of scaling is not limited to the simplest SSRPs, but holds for a huge domain of stochastic processes that are characterised by non-uniform prior distributions. In the absence of noise the scaling exponents converge to a universal -1 exponent (Zipf's law) for almost all prior distributions [2]. As a consequence one can understand targeted diffusion on networks and its associated scaling laws in node visit distributions. The emergence of Zipfs law in node visiting statistics is expected in any random processes with a target in a network as, for example, a search, regardless the topological details of the graph [2].
SSRps theory is generalized by SSR cascading process, able to produce power laws with arbitrary exponents [3]. It can be shown analytically that the frequency distributions of states are power laws with exponents that coincide with the multiplication parameter of the cascading process. In addition, imposing energy conservation in SSR cascades, i.e., mimicking a desintegration/fragmentation process, allows us to recover an universal exponent -2, which is independent of the multiplication parameters of the cascade. This matches, for example, with Fermis classic result on the energy spectrum of cosmic rays.
The domain of application of SSRps and SSR cascades is huge, and includes general theory of dissipative systems, search patterns towards targets, traffic-, transport- and supply chain management, fragmentation processes or cascading processes on networks, such as rumour or epidemic spreading.

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X-ray spectra from plasmas with high-energy electrons: kappa-distributions and electron-electron bremsstrahlung

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Shocks, turbulence and winds all influence the electron velocity distribution in hot plasmas, exciting lower-energy electrons and generating a high-energy tail with approximately a power-law shape. This effect, often modeled via a kappa distribution, can affect both the line and continuum X-ray spectrum emitted by the plasma. Hahn & Savin (2015) proposed a Maxwellian decomposition to generate the rate coefficients of kappa distributions. The AtomDB atomic database collects the astrophysical plasma emission data relevant to X- ray emission from collisionally ionized, optical thin astrophysical plasmas with temperature 1e4 hot Maxwellian plasma, can also emit via an electron-electron (e-e) bremsstrahlung, a process not previously included in the AtomDB. I will present the kappa model, the comparison between our kappa results for the charge state distribution and spectra of oxygen to those from KAPPA package with the ion data available within CHIANTI atomic database (Dzifcakova et al. 2015), and the application of AtomDB after added e-e bremsstrahlung to the temperature gradients,

as well as the total spectra from the post-shock regions of an accreting magnetic cataclysmic variable (CV). After using the updated APEC model to calculate the X-ray spectra from a numerical post-shock accretion region model of a magnetic CV, we can find the difference for total emissivity with and without e-e bremsstrahlung. We compare the oxygen charge state distribution and spectra to the results from the KAPPA package and find the caution has to be taken when de-composing Maxwellian rate for kappa-distributed coefficients when plasma temperature approached to the boundaries of [1e4 1e9] K and the kappa less than about 15.

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Consistent thermodynamic framework for a nonextensive system and the concept of effective temperature

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Recent works have associated systems of particles, characterized by short-range repulsive interactions and evolving under overdamped motion, to a nonlinear Fokker-Planck equation within the class of nonextensive statistical mechanics, with a nonlinear diffusion contribution whose exponent is given by $\nu = 2 - q$. These identifications were reached through both a coarse-graining approach and molecular-dynamics simulations of the equations of motion and were achieved for $\nu \geq 2$. The particular case $\nu = 2$ applies to interacting vortices in type-II superconductors, whereas $\nu > 2$ covers systems of particles characterized by short-range power-like interactions, where correlations among particles are taken into account. In the former, several studies presented a consistent thermodynamic framework based on the definition of an effective temperature θ, conjugated to a generalized entropy S_ν (with $\nu = 2$), typical of nonextensive statistical mechanics. In these type-II superconductor analyses, the variable θ presents values much higher than those of typical room temperatures T, so that the thermal noise was neglected ($T/\theta \approx 0$). Herein, the whole scheme is extended to systems of particles interacting repulsively, through short-ranged potentials, described by an entropy S_ν, with $\nu > 1$, covering the $\nu = 2$ (vortices in type-II superconductors) and $\nu > 2$ (short-range power-like interactions) physical examples. The thermodynamic framework follows from the equilibrium state of the Fokker-Planck equation, obtained after a sufficiently long-time evolution, and approached due to a confining external harmonic potential, $\phi(x) = \alpha x^2/2$ ($\alpha > 0$). The main results achieved are: (a) The definition of an effective temperature θ conjugated to the entropy S_ν; (b) The construction of a Carnot cycle, whose efficiency is shown to be $\eta = 1-(\theta_2/\theta_1)$, where θ_1 and θ_2 are the effective temperatures associated with two isothermal transformations, with $\theta_1 > \theta_2$; (c) Applying Legendre transformations for distinct pair of variables, different thermodynamic potentials are obtained, and furthermore, Maxwell relations and response functions are derived.

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Study of the behavior of the persistence length in self-avoiding random walks using the pivot algorithm

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The self-avoiding random walk (SAW) can be seen as a path on a lattice that visits a site just once [1]. The characterization of the set of trajectories with N steps is based on the scaling behavior of conformational quantities. In our study, the quantities of interest include the mean square end-to-end distance, $\langle \vec{R}_N^2 \rangle_N = AN^{2\nu_0}(1 + a^{(0)}N^{-1} + b^{(0)}N^{-\Delta_1} + \cdots)$, and the persistence length $\lambda_N = \langle \vec{R}_N \cdot \vec{u}_1 \rangle_N$, defined as the projection of the end-to-end vector along the first step. The N^{-i} and $N^{-\Delta_i}$ terms are the analytical and non-analytical corrections (i being integer and $\Delta_i > 0$). There exist controversial estimates of λ_N for the square lattice, such as $\ln(N)$ and N^δ or even $\lambda = cte$ [2], on which we shed some light after establishing the Inner Persistence Length: $\mathcal{I}_j = \langle \vec{R}_j \cdot \vec{u}_j \rangle_N$ [3]. Starting from $\mathcal{I}_j$, the relation $\langle \vec{R}_N^2 \rangle_N = \langle \vec{R}_{N-1}^2 \rangle_N + 2\lambda_N - 1$ could be written. Observing that λ_N is not the discrete derivative of $\langle \vec{R}_N^2 \rangle_N$, one formulates the scaling ansatz: $\lambda_N = \lambda_\infty + \alpha_1 N^{\varpi_1} + \alpha_2 N^{\varpi_2} + \cdots$, where the values $\varpi_1 = 2\nu_0 - 2$ and $\varpi_2 = 2\nu_0 - \Delta_1 - 1$ provided a good fitting of λ_N. By using walks with $N < 100$ steps one finds the asymptotic value $\lambda_\infty = 2.52$, and $\lambda_\infty = 1.42$, for square and cubic lattice respectively [3]. Here, we investigate the convergence of λ_N with accurate data obtained with the pivot algorithm [4]. We performed the simulations for SAWs up to $N = 1000$ and $N = 800$ steps in the square and cubic lattice, respectively. Preliminary results confirm the $\lambda_\infty \approx 1.42$ value for the cubic lattice. However, the estimates for the square lattice, using the fitting or extrapolation graphs, provide λ_∞ from ≈ 2.60 to ≈ 2.78. We expect more accurate estimate of λ_∞ with the data obtained with up to $N = 8000$ steps, currently being generated. Simulations are being carried out with hexagonal and diamond lattices in order to check the universal behavior of λ_N. Also, we generalize the scaling approach to obtain λ_N using only one N-step ensemble.

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Manipulation and amplification of the Casimir force in systems with continuous symmetry: Exact results

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Casimir forces result from, and provide insight into, the behavior of a medium confined to a restricted space. In the case of the electromagnetic Casimir force the medium is the vacuum, and the underlying mechanism is the set of quantum zero point or temperature fluctuations of the electromagnetic field. The now widely-investigated critical Casimir force (CCF) results from the fluctuations of an order parameter and more generally the thermodynamics of the medium supporting that order parameter in the vicinity of a critical point.

One of the principal influences on the thermodynamic Casimir force, we will be dealing with, is the nature of the bounding surface. With respect to the CCF, published investigations have been focused, almost exclusively, on systems belonging to the Ising universality class. Here we present results aiming to close that gap by presenting results for systems with continuum symmetry of the order parameter. In order to do so, we review some recent and present some new both exact and numerical results for the behavior of the Casimir force in systems with a continuous symmetry and a film geometry with a finite extension L in one direction. We will consider the cases when the system is subjected either to surface fields or to twisted boundary conditions that induce helicity in the order parameter. We show that for such systems the Casimir force in certain temperature ranges is of the order of L^{-2}, both above and below the critical temperature of the bulk system. An example of such a system would be one with chemically modulated bounding surfaces, in which the modulation couples directly to the system's order parameter. We demonstrate that, depending on the parameters of the system, the Casimir force can be either *attractive* or *repulsive*. The exact calculations presented are for the one dimensional XY and Heisenberg models under twisted boundary conditions resulting from finite surface fields that differ in direction by a specified angle, the three dimensional Gaussian model with surface fields in the form of plane waves that are shifted in phase with respect to each other, and the spherical model under twisted boundary conditions. Where applicable, we will present results both for the transverse and the lateral Casimir force. Additionally, we present exact and numerical results for the mean field version of the three dimensional O(2) model with finite surface fields on the bounding surfaces. We find that all significant results are consistent with the expectations of finite size scaling. From the experimental point of view the different types of liquid crystals seem the best candidate to study the above mentioned effects. For such systems it is well known that director fluctuations in nematics induce long-range interactions between walls, which are attractive with symmetric boundary conditions, but may become repulsive with mixed ones. In smectics such forces are longer ranged than van der Waals ones.

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Communities detection and dynamics: Estonian economic network of payments

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Community detection helps understanding the local organization of the components of networks. In this study, we identify and study the community structure of the Estonian network of payments. We also analyze specific scale-free characteristics and explore certain aspects of the evolution of the traced communities. In this network the nodes are Estonian companies and the links are payments done between the companies. Our results indicate that there is a fair matching between the classification of nodes found through a community detection algorithm and the real economic groups classifications. Moreover, we found that the investigation of the structure and evolution of overlapping communities in our network helped finding ties with economical events.

Community detection is a graph partitioning process that provides insight of the organizational principles of networks. Thus far, recent advances and knowledge of the underlying mechanisms that rule dynamics of communities in networks are limited, and this is why an extensive and wider understanding of communities is important. Locating the underlying community structure in a network allows studying the network more easily and provides clarity on the function of the system represented by the network as communities often correspond to functional units of systems. The study of communities and their properties also helps on revealing relevant groups of nodes, make classifications with them, discover similarities or reveal unknown linkages between them. Communities have a strong impact in the behavior of a network and studying communities, particularly in economic networks, represents an important step towards the knowledge (beyond local organization of their components) of a specific category of complex systems.

In this study, we present a static and dynamic community detection analysis by using the Clique Percolation Method where we examine the structure of the communities of a novel and interesting network: the large-scale payments network of Estonia. The main objective of this study is to detect communities, observe their structures and characteristics, analyze the changes in such structures within a period of time and find if there is any meaningful connection between the communities classifications obtained theoretically and the real economic classifications. Additionally, we observe the evolution of the detected communities during a period of 15 months.

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On the learning dynamics of complex living systems

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In the framework of our study of Complex Systems we propose a systems approach to the theory of perception and learning in populations composed of many living entities.

Starting from a phenomenological description of these processes, a mathematical structure is derived which is deemed to incorporate their complexity features. The modeling is based on a generalization of kinetic theory methods where interactions are described by theoretical tools of game theory. As an application, the proposed approach is used to model the learning processes that take place in a classroom. The aimof the paper is to provide a foundational mathematical framework which may incorporate the main features of the learning process in view of applications to modeling complex systems, including crowds, swarms, and social systems.cast into a differential framework. This paper, based on the aforementioned motivations and on some perspective ideas proposed in , pursues the objective of developing a mathematical theory of perception and learning in view of their application to modeling complex systems, which can develop a collective intelligence. We believe that our formulation can be viewed as an extension of the concept of population thinking and of the theory of evolution reported in. Indeed, this aspect will motivate us to relay on the tools of the evolutionary game theory. The mathematical tools are derived from the methods of the classical kinetic theory, statistical dynamics,stochastic evolutionary game theory and their development toward the theory of active particles . The latter was specifically developed to model living systems constituted of several multi-agents interacting by linear or nonlinear rules. Over the years this approach has been applied in a variety of different fields such as spread of epidemics , social systems , micro-scale Darwinian evolution and selection [23]and collective learning process. It is worth stressing that important motivations to the contents of this paper are induced by the idea that the mathematical structure might include features which could make it interesting in different field of life sciences.

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Time scales at quantum phase transitions

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The time evolution of quantum wave packets may lead to interesting collapse and revival phenomena. Propagating wave packets initially evolve quasiclassically and oscillate with a classical period but eventually spread and collapse. At later times, multiples of a revival time Tr, wave packets regain their initial wave form and behave quasiclassically again. Additionally, at times that are rational fractions of Tr, the wave packet temporarily splits into a number of scaled copies called fractional revivals. Revivals and fractional revivals have attracted a great interest during the past decades. They have been investigated theoretically in nonlinear quantum systems, atoms and molecules (including Graphene), and observed experimentally in, among others, Rydberg atoms, molecular vibrational states or Bose-Einstein condensates. Recently, methods for isotope separation, number factorization as well as for wave packet control have been put forward that are based on revival phenomena.
Here, the concept of quantum revivals is extended to many-body systems and the implications of traversing a quantum phase transition are explored. By analyzing three different models, the vibron model for the bending of polyatomic molecules, the Dicke model for a quantum radiation field interacting with a system of two-level atoms, and Lipkin-Meshkov-Glick model, we show evidence of revival behavior for wave packets centered around energy levels as low as the fundamental state. Away from criticality, revival times exhibit smooth, nonsingular behavior and are proportional o the system size. Upon approaching a quantum critical point, they diverge as power laws with associated critical exponents and scale with the system size, although the scaling is no longer linear.
Excited states quantum phase transitions also influence the revival behavior of wave packets, but in this case revival times appear to show softer singularities. In particular, for the vibron model the singularities are logarithmic in nature.

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Exact results for quenched disorder at criticality

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Quenched disorder plays a particularly interesting role within the theory of critical phenomena. The Harris criterion says that when the specific heat critical exponent of the pure model is positive, weak disorder drives the system towards a new (random) fixed point. Perturbation theory can be used to study these new fixed points but can hardly establish whether they possess qualitative features distinguishing them from those of pure systems. Looking for non-perturbative methods, attention turns to the two-dimensional case, in which conformal field theory has provided an exact and essentially complete characterization of universality classes of critical behavior for pure systems. It is a fact, however, that no conformal field theory for two-dimensional systems with quenched disorder has been identified.
The two-dimensional random bond q-state Potts ferromagnet allows for random criticality for $q > 2$ and has played a central role in the study of quenched disorder. While Monte Carlo simulations by Chen et al and a simplified interfacial model by Kardar et al found evidence of q-independent critical exponents, a numerical transfer matrix study by Cardy and Jacobsen first found a q-dependent magnetization exponent consistent with the perturbative results of Ludwig and Dotsenko et al. The solution suggested for this puzzle, namely that different conclusions may refer to two critical lines with different disorder strength, found no alternative in the last twenty years.
We recently showed that an exact replica method can be introduced for the study of renormalization group fixed points of two-dimensional systems with quenched disorder. For the q-state Potts model we found that all the above mentioned results actually correspond to the same critical line, for which the disorder strength grows from weak to strong as q grows from 2 to infinity. Remarkably, this critical line possesses a symmetry-independent sector, and allows at the same time

for a q-independent correlation length exponent and a varying magnetization exponent. These surprising features shed light on the peculiarities which may characterize random fixed points and open a new perspective for their study.

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Kuramoto oscillators in a ring-like topology

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Identical Kuramoto oscillators with nearest neighbor coupling are considered in a 1D ring-like topology. In agreement with previous results obtained for such systems [1-3], we find that the system exhibits nontrivial collective behavior patterns. We interpret these emergent structures as different synchronization modes. One can also consider these dynamically stationary states as rotating waves with a well defined winding number or phase shift between the oscillators.
As a first task we have reproduced all the results known for such systems. By performing a standard linear stability analysis we link the stability of the stationary states to the winding numbers. Our results are in agreement with the stability conditions given in [3]. Starting the dynamics from random initial conditions the probability of appearance for the stable collective modes was computationally studied. We found that these probabilities are well approximated by a Gaussian envelope curve. We also show that variance of the distributions scales linearly with the system size. These results are in agreement with the ones communicated in [2].
Novel and interesting results are also obtained. Using multidimensional geometry we investigate the dynamics of the system and the basin of attractions for different stationary states. The used image for the phase space enables us to take a deeper look on the processes governing the dynamics. In such manner we attempt a theoretical explanation for the observed normal distribution of the stable states and the scaling properties for its variance. We show that the motion of the characteristic point is limited only to a restricted subspace of N-1 dimensional hyperplanes confined in the N dimensional phase space of the system. A series of two dimensional cross sections of the attraction basins suggest that the structure of the attractor domains are complicated, and hence the time-evolution of the system is simple only in the vicinity of the stable states. Empirically we find an interesting restriction for the dynamics of the characteristic point in the used N dimensional hyperspace. Generalizing the Kuramoto order-parameter for the rotating wave-like states we give an empirical estimate for the time-length of the state-selection process.

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Functional motifs in protein families

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The structural organization of a protein family is investigated by devising a method based on the random matrix theory (RMT), which uses the physio chemical properties of the amino acid with multiple sequence alignment. A graphical method to represent protein sequences using physio chemical properties is devised that gives a fast, easy, and informative way of comparing the evolutionary distances between protein sequences. A correlation matrix associated with each property is calculated, where the noise reduction and information filtering is done using RMT involving an ensemble of Wishart matrices. The analysis of the eigenvalue statistics of the correlation matrix for the β-lactamase family shows the universal features as observed in the Gaussian orthogonal ensemble (GOE). The propertybased approach captures the short as well as the long range correlation (approximately following GOE) between the eigenvalues, whereas the previous approach (treating amino acids as characters) gives the usual short-range correlations, while the long-range correlations are the same as that of an uncorrelated series. The distribution of the eigenvector components for the eigenvalues outside the bulk (RMT bound) deviates significantly from RMT observations and contains important information about the system. The information content of each eigenvector of the correlation matrix is quantified by introducing the entropy of eigenvector components, which shows that for the β -lactamase family the smallest eigenvectors (low eigenmodes) are highly localized as well as informative. These eigenvectors corresponding to the smallest eigenvalue when processed gives clusters involving positions that have well-defined biological and structural importance matching with experiments. The approach is crucial for the recognition of structural motifs as shown in β-lactamase (serine protease, HSP70, G protein, HTH 1 and other families) and selectively identifies the important positions for targets to deactivate (activate) the enzymatic actions.

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Oscillations and waves in populations of cells which tend to homeostasis

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To achieve homeostasis, i.e. maintain a uniform and constant density in a whole organ, living cells need to balance cell death with cell proliferation in an active and relatively controlled

way. If they proliferate too much, they can leed to a tumour, then cancer. If they don't proliferate enough, at the right place and at the right time, the function of the tissue will be impaired and the organ will be defective. Therefore, cell proliferation must exactly compensate, in the long term, cell death or cell loss, while responding as quickly as possible to disturbances like (relatively small) injuries.
In the case of oligodendrocyte precursor cells (OPC), which build up the most abundant proliferating cell population in the adult brain and are believed to trigger some of the brain tumours, it has recently been showed experimentally that homeostatis is achieved through several phenomena including induction of cell death in regions where cells are too dense and induction of cell prolieferations in the boundaries of regions where cells have been lost. In some circumstances, this can lead to detectable oscillations in the local density of cells.
We model quantitatively these phenomena in an ideal population of identical cells thanks to a cellular automaton, both in discrete and continuous space, in 2D and in 3D. In the case of almost uniform conditions, we observe oscillations of the cell number during relaxation to homeostasis. Using a simple mean-field like analytical approach, we are able to reproduce these collective oscillations and understand how their features (notably their period) are related to parameters of the cells' individual behaviour.
In the case of non-uniform conditions, we observe intriguing phenomena such as propagating waves, spiral waves, large transient oscillations, and even population extinction. They depend sometimes in counter-intuitive ways on parameters like the rate of proliferation and the rate of apoptosis. We verify that they are robust against changes of dimensionality or even space structure (lattice or free space). This shows that achieving homeostasis is not a straightforward task.

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Isolation statistics in temporal spatial networks

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Many kinds of complex networks such as transport, power, social and neuronal networks are spatial in character, that is, the nodes and perhaps also the links have a physical location. Geometry can structure the network in that the probability of a link between two nodes is related to their mutual distance. Longer links are typically more expensive to build, maintain, or operate (e.g., motorways) than shorter ones, yet offer fast information flow or transport through different parts of the network. Consequently, spatially embedded networks often exhibit interesting topological features such as clustering, modularity, or small worldness. Spatial structure is also particularly important in many multiplex and/or dynamic networks.
Here we focus on temporal and small world spatial networks and, unlike studies which are data or algorithmically driven, derive deep analytical results relating to the connectivity. We obtain statistics (all moments and the density) for the probability of isolated (i.e., disconnected) nodes in networks with local or small world connection models, static or with temporally uncorrelated or correlated links. Isolation statistics are vital for understanding bottlenecks in transporting people, resources or information throughout the network. The enabling approach leverages tools from stochastic geometry and statistical mechanics via the probability generating functional to extract spatial averages and Ising lattices to model time correlated links.
Consider spatial networks in which the nodes remain fixed, but for which the links break and reconnect, thus forming a temporal network. For example, this is a good model of a wireless ad-hoc network where nodes (devices) communicate directly with each other rather than a central router and where their locations may be considered random; examples include sensor and vehicular networks, the Internet of Things, or smartphone networks interconnected via Wi-Fi Direct. The link probability decreases with the distance between nodes. The communication channel exhibits rapid fading, so that some time later, the state of the system has the same distance-dependent link probabilities, independently or in a time correlated manner. The nodes remain fixed in space, at least on the rapid fading timescale. We are interested in how the link probability and temporal correlations affect the time required to distribute information packets throughout the network, limited by the isolated nodes.

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Spatial networks with random connections

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Many networks of current interest have a spatial structure, in that the nodes and/or links are located in physical space. Examples include climate, communications, infrastructure, nanowire, neuronal and transport networks. An early and still popular model of spatial networks is the random geometric graph, where nodes are located randomly and links formed between sufficiently close nodes.
Recent studies have considered random connection models, in which there is a link probability $H(r)$, a function of the mutual node distance r. The links are chosen independently and form a second source of randomness (in addition to the node locations). In principle, a distance-dependent link probability can be defined in any spatial network. Also, the (non-spatial) constant function $H(r) = p$ leads to the well-studied Erdos-Renyi model.
One important application is to wireless ad-hoc networks, in which devices (nodes) communicate directly with each other rather than with a central router; this can enhance scalability, flexibility and power requirements. These have been used in for example sensor networks, vehicular networks and robot swarms. There are detailed models based on physical propagation assumptions; one of the simplest is Rayleigh fading, which leads to

$$H(r) = e^{-(r/r0)^{\eta}}$$

where $2 \leq \eta \leq 6$ is a constant called the path loss exponent. The limit eta to infinity leads back to the original random geometric graph.
Network characteristics can now be investigated as a function of the model parameters. The overall connection probability

is well approximated by considering the expected number of isolated nodes. Applying Laplace's method to relevant multidimensional integrals, we find that it can be estimated from just a few moments of $H(r)$ for a wide variety of domain geometries. Furthermore, there are qualitative differences as a result of the random connections. In particular, the more realistic model allows a more accurate estimation of connectivity and resilience (as quantified by k-connectivity) than the original.
Recent work has also considered networks where the nodes are mobile and/or inhomogeneously distributed. We investigate when this breaks the connection between connectivity and isolation, and find it leads to a number of interesting and largely unexplored phenomena.

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Ion acoustic solitary waves in space plasmas having kappa velocity distributed electrons

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Electrostatic waves are often observed in the several regions of space plasma environments such as, the bow shock, magnetosheath, polar cusp and auroral field lines. Ion-acoustic waves are one of the possible mode to explain the observed solitary structures [1-2]. Various in-situ satellite observations reported the presence of excess energetic electron with high-energy tails. Their particle distribution deviates from the Maxwellian and are well modelled by kappa (κ)-like distributions [3]. To study the nonlinear evolution of ion acoustic solitary waves in magneto-plasmas having superthermal particles, we consider a four component plasma model consisting of Protons, Helium ions, a drifting electron beam and superthermal hot electrons. We have modeled the superthermal hot electrons by a kappa distribution function in our study [4]. We have derived the Korteweg-de-Vries-Zakharov-Kuznetsov (KdV-ZK) equation to study the characteristics of small amplitude ion acoustic solitons and have applied our theoretical work to model the solar wind observations made at 1 AU [5]. We have done a detailed parameteric study of the effects of nonthermality, obliquity and electron beam velocity on the ion acoustic solitons. We have found both slow and fast ion acoustic solitons in our study. The maximum electric field amplitudes of slow ion-acoustic solitons vary from (1.26 -2.59) mV/m for $\kappa = 2 - 10$. The calculated fast ion acoustic solitary electric field amplitudes are in the range of (0.43-0.51) mV/m for $\kappa = 2 - 10$ and is comparable with solar wind observation considered in our study.

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Forecasting financial markets by means of information filtered graphs

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In this talk we propose network-theoretic tools [1] to filter information in large-scale datasets and we show that applications to financial data-sets can meaningfully identify industrial activities and structural market changes. Network filtering procedures are valuable tools for risk management and portfolio optimization too [2,3] and they allow to construct probabilistic sparse modeling for financial systems that can be used for forecasting, stress testing and risk allocation [4,5].
In particular we look at correlation-based information filtering networks, we show that there exists a deep interplay between past changes in correlation structure and future changes in market volatility and we use such empirical evidence to provide a new tool to forecast portfolio risk [4].

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Kappa distributions in Saturns magnetosphere: a model for the energetic ion moments using Cassini/MIMI measurements

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Following our previous analyses (Dialynas et al. 2009) and the techniques described in Dialynas et al. (2017), in the present study we use kappa distribution fits to combined Charge Energy Mass Spectrometer (CHEMS, 3 to 236 keV/e), Low Energy Magnetosphere Measurements System (LEMMS, $0.024 < E < 18$ MeV), and Ion Neutral Camera (INCA, $\approx$ 5.2 to $>$ 220 keV for H+) proton and singly ionized energetic ion spectra to calculate the $>$ 20 keV energetic ion moments inside Saturns magnetosphere. Using a realistic magnetic field model (Khurana et al. 2007) and data from the entire Cassini mission to date (2004-2016), we map the ion measurements to the equatorial plane and via the

modeled kappa distribution spectra we produce the equatorial distributions of all ion integral moments, focusing on partial density, integral intensity, partial pressure, integral energy intensity; as well as the characteristic energy ($Ec = Ie/In$), Temperature and κ-index of these ions as a function of Local Time (00:00 to 24:00 hrs) and L-Shell (5-20). A modified version of the semi-empirical Roelof and Skinner [2000] model is then utilized to retrieve the equatorial H+ and O+ pressure, density and temperature in Saturn's magnetosphere in both local time and L-shell. We find that a) although the H+ and O+ partial pressures and densities are nearly comparable, the $>$ 20 keV protons have higher number and energy intensities at all radial distances ($L > 5$) and local times; b) the $\approx 12 < L < 20$ Rs region corresponds to a local equatorial acceleration region, where sub-adiabatic transport of H+ and non-adiabatic acceleration of O+, dominate the ion energetics (compared to the contribution of charge exchange with the Saturnian neutral cloud); c) non-radiation-belt energetic ions are heavily depleted inside the orbit of Rhea (≈8 Rs), i.e. the energetic ion lifetimes due to charge exchange decrease significantly with decreasing distance in the innermost parts of Saturns magnetosphere, so that pressure and density drop to minimum inside ≈8 Rs and the behavior of the energetic ions appears to be sub-isothermal; d) energetic ion bundles in the outer parts of Saturns magnetosphere, that possibly result from rotating energetic particle blobs shown in previous studies, produce durable signatures (enhancements) in the H+ and O+ pressure, density and temperature.

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Identifying the dynamics of abrupt climate changes using high resolution ice core records.

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In dynamical systems of high complexity structural and abrupt changes and transitions often characterize the long-term behavior more than does the periods of quiescence. The geologic record witnesses mass extinctions and abrupt changes, caused by external disruptions as massive impacts or catastrophic internal reorganizations, suggesting the dynamics to be characterized as punctuated equilibrium. Ecosystems show sudden collapses and reorganizations, with a suggested possible bifurcation between rain-forest and grassland state describing a collapse of the Amazon forest. The paleoclimatic record, mainly obtained from ice cores shows that the climate system has undergone abrupt changes, both as non-linear response to orbital changes and as internally caused jumps between meta-stable states, the Dansgaard-Oeschger events.
We hypothesize that these abrupt changes are due to non-linear responses inherent in the climate system, specifically, so-called tipping points. This behavior result from non-linear climate response to either external forcing, internal stochastic fluctuations or a combination of both. At some point the forcing will cause the climate to jump from one stable state to another. This scenario is termed a tipping point. The concept of a tipping point is quite broad, but here we shall refrain from any general definitions and consider the following more restricted framework: We consider the climate or some components of the climate as a dynamical system depending on a set of parameters. Factors, not included in the system interacting with components of the system, can then be considered external forcing or stochastic fluctuations. Two common, and often competing, hypotheses are: The climate systems steady state loses its stability and disappears as an external system (control-)parameter slowly changes, so-called b-tipping, b for bifurcation-induced; or fluctuations spontaneously push the climate system from one stable state to another, so-called n-tipping, n for noise-induced.
The cause of the tipping can be very different in the two cases, and especially the possibility of predicting a tipping will be different. In the case that the underlying dynamics or the control-parameter are not completely known, there could still be early warning signals in the statistics of the observed fluctuations prior to a tipping point.

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Fluctuating hydrodynamics of complex fluid mixtures

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Fluctuating hydrodynamics is a powerful tool for modeling of nonequilibrium phenomena at the mesoscale, where it is no longer possible to use fully atomistic models, but where fluctuations still need to be explicitly modeled. This talk will contain a review of our recent work on computational FHD of complex multispecies liquid mixtures.
In [1] we developed a low Mach number FHD formulation describing transport of mass and momentum in a multispecies mixture of incompressible miscible liquids at specified temperature and pressure. The formulation applies to non-ideal mixtures of arbitrary number of species, without the need to single out a 'solvent' species. We studied the development of giant nonequilibrium concentration fluctuations in a ternary mixture subjected to a steady concentration gradient.
In [2] we formulated and studied computationally the compressible FHD equations for reactive multi-species fluid mixtures. We studied the suppression of non-equilibrium long-ranged correlations of concentration fluctuations by chemical reactions, as well as the enhancement of pattern formation by spontaneous fluctuations. In [3] we developed numerical methods for FHD of reaction-diffusion systems. We demonstrated and quantified the importance of thermodynamic fluctuations to the formation of a two-dimensional Turing-like pattern, and examined the effect of fluctuations on three-dimensional chemical front propagation, to show that fluctuations accelerate pattern formation in spatially homogeneous systems, and lead to a qualitatively-different

disordered pattern behind a traveling wave. In ongoing work that will be discussed, we propose a low Mach FHD formulation for reactive mixtures that combines the methods developed in [1] and [3].
In recent work [4], we have formulated and studied computationally the low Mach number fluctuating hydrodynamic equations for (non-reactive) electrolyte solutions. This enables the study of hydrodynamic transport in mixtures of charged species at the mesoscale, down to scales below the Debye length, where thermal fluctuations have a significant impact on the dynamics. In the stochastic setting, our model captures the predicted dynamics of equilibrium and nonequilibrium fluctuations. We also identify and model an instability that appears when diffusive mixing occurs in the presence of an applied electric field.

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The nonextensive parameter for the rotating astrophysical systems with power-law distributions

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We study the nonextensive parameter for the rotating astrophysical systems with power-law distributions, including both the rotating self-gravitating system and the rotating space plasmas. We extend the equation of nonextensive parameter to a complex system with arbitrary force field $F(r, v)$, and then derive a general equation of the q-parameter, most generally including both the rotating self-gravitating systems and the rotating space plasmas. This equation presents clear physical meanings of the q-parameter different from one, showing the nonequilibrium properties of the power-law distributions in the complex systems under external force fields.
When we apply the equation of the q-parameter to the rotating astrophysical systems and the rotating space plasmas, respectively, we show that the q-parameter is related not only to the temperature gradient, the gravitational force and the electromagnetic force (Coulomb force and magnetic induction intensity) in the systems, but also to the inertial centrifugal force and Coriolis force if the systems are rotating. These forces all introduce significant effects on nonextensivity of the astrophysical systems. We have given the expressions of the q-parameter for the rotating self-gravitating systems, which may be suitable for describing the distributions of self-gravitating gases, galaxies and dark matter haloes.
At the same time, we have also given the expressions of the q-parameter for the rotating space plasmas. By defining the physical temperature in the space plasmas and making parameter replacements, we can reproduce the famous kappa-distribution in space plasmas, obtain the expressions of the kappa-parameter, and thus present clear physical meaning of the kappa-parameter. It is shown that the kappa-parameter can be quantificationally determined by the temperature gradient, the electromagnetic forces (Coulomb force and magnetic induction intensity), the inertial centrifugal force and the Coriolis force in the rotating space plasmas.
We also list several examples to illustrate the nonextensivities introduced by the rotation effects.

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The RPA correction to the Helmholtz free energy of simple liquid metals within variational calculations

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The thermodynamic perturbation theory (TPT) is widely used for investigating the structure and thermodynamics of liquid and amorphous substances including metals [1]. The TPT is based on Zwanzigs approach [2] which treats a liquid that obeys the laws of classical statistical mechanics as the sum of two subsystems. One of them, called reference system, mainly includes the forces of repulsion between molecules, whereas the other, called perturbation, mainly includes the forces of intermolecular attraction.
When calculating the structure functions and macroscopic properties of a liquid with a given pair interaction potential, the TPT helps to avoid computational problems connected with solution of the Ornstein-Zernike (OZ) integral equation. This is of particular importance for calculations of the thermodynamic properties of metals. Indeed, on the one hand, metallic state is usually described using complex pair potentials. On the other hand, calculations of thermodynamic properties require additional numerical operations. Taken altogether, these features make direct calculations of the thermodynamic properties of metals using the OZ integral equation difficult.
Studies of liquid metals within the framework of the TPT began in the early 1970s and since then became an integral part of the physics of condensed matter. It is of importance that the TPT without any additional relatively to the theory of simple liquids restrictions can be applied to metals. In fact, to use the TPT instead of integral-equation theories of liquids means to search for some integral-equation approximation for the reference system rather than the entire system under study. There are two groups of the TPT methods: methods of the high temperature approximation (HTA) proposed by Zwanzig [2] and methods of the field theory (FT). In the HTA the entropy and structure functions of the entire system are respectively equal to those of the reference system. The FT approximations allow avoiding these equivalences and giving the correction to the HTA Helmholtz free energy. In the present work, the HTA+FT formalism [3] is developed for liquid metals described by the nearly-free-electron (NFE) approximation for the case when the HTA method is the variational one, the FT method is the random phase approximation (RPA) and the reference system is the hard-spheres (HS) model.

The work is supported by the Russian Government assignment N. 0396-2015-0076

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Exact results for steady-state probability characteristics of Verhulst and Hongler models with multiplicative Poisson white noise

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Many stochastic processes occurring in population dynamics, neurodynamics and ecology exhibit instantaneous discrete jumps and therefore can not be provided by excitation in the form of white Gaussian noise. They must be modeled differently in terms of delta-pulse noise which characteristics are determined by the statistics of pulse amplitudes and intervals between stimuli. The nonlinear dynamical systems perturbed by Poisson white noise can be analyzed in the framework of Markovian theory on the basis of integro-differential Kolmogorov-Feller equation which is a generalization of the Fokker-Planck equation. The analytical treatment of such nonlinear dynamical systems poses more difficulties compared to those driven by white Gaussian noise. As a result, the exact expressions for the stationary probability characteristics of these systems have been obtained only for very limited cases, in particular, when the amplitudes of pulses have one-sided exponential probability distribution.
In this report, for a nonlinear dynamical system, described by the Langevin equation with the multiplicative Poisson white noise having exponentially distributed amplitudes of delta-pulses, new exact analytical results for the steady-state probability density function are derived from the Kolmogorov-Feller equation using the technique of inverse differential operator [1,2]. Specifically, we examine well-known Verhulst equation for the density of isolated population with fluctuating saturation parameter. This model with multiplicative Poisson white noise having pulses of positive polarity can adequately describe the effect of pandemics, natural disasters and other negative phenomena, leading to a significant reduction in the population size within a short time period. Further we consider the stochastic Hongler equation which is a good approximation for the model of genetic selection because it retains some features of the latter [3]. In the case of multiplicative Poisson white noise having bipolar exponentially distributed amplitudes of delta-pulses we find noise-induced transitions in the steady-state probability distributions when changing the noise parameter such as the mean rate of pulse appearing.

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Interdisciplinary applications of a periodically modulated Poisson noise process with regulated periodicity

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Random pulse processes with regulated periodicity, such as dead-time-distorted Poisson pulse noise and pulse process with fixed time intervals, are widely used for modeling noise-induced effects. These processes are used in different fields ranging from stochastic thermodynamics, nanotechnology, and electronics to population dynamics and epidemiology. Experimental and computational studies presented in literature have explored the similarities in the behavior of these systems. For population dynamics and epidemiology this model helps to take into account the influence of seasonal changing of environment on some unpredictable events, such as huge increases of a population, epidemics, and other environmental modifications. In the case of quantum optics, the parameter of periodicity can be used as criterion to distinguish between quantum and classical optics. If the quasi-period of the pulses is the average time between photons registration and the period is the inverse frequency of the light, then the condition of small parameter of periodicity is equivalent to the condition that light intensity is much less than Planck constant. In billiard theory, this noise can be used to describe the acceleration of a billiard particle by periodically moving scatterers. The correlation time of this process is estimated to verify, for Markovian behavior, the applicability of the Fokker-Planck equation to obtain the probability distribution of the velocity and to calculate the Fermi acceleration.
We present a new stochastic process, consisting of delta pulses modulated by a periodical function, which is suitable to be treated both by analytical and numerical approach. This modulated Poisson process is characterized by a random time interval between two successive pulses. The mean value of these random time intervals is called quasi-period of the Poisson process. The ratio between the period of the amplitude modulating function and the quasi-period of the pulses is called parameter of periodicity. The larger the parameter of periodicity the larger the correlation of the process. This process can be used as noise source, with a different degree of randomness ranging from white noise to quasi-periodical process, in stochastic differential equations describing fluctuating parameters in physics and biology. We analyze the spectral density, the correlation function and the moments and their dependence on the parameters characterizing this new stochastic process.

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Wavelet Monte Carlo dynamics: hydrodynamics without the calculation

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Probing the dynamical properties of large, hydrodynamically interacting soft-matter systems remains a challenge in simulations because of the computational cost of either evolving all the solvent molecules in explicit solvent methods such as Lattice Boltzmann (LB), or the decomposition of the diffusion matrix in Brownian dynamics (BD). We have recently developed the Wavelet Monte Carlo dynamics (WMCD) algorithm to approach this problem with an implicit solvent Monte Carlo method [1], which faithfully replicates the correct hydrodynamic interactions in the low Reynolds number regime without needing any calculation involving the diffusion matrix.
This is achieved using the wavelet representation of the diffusion matrix, from which we find the probability distributions of wavelet parameters to generate the correct correlated motion when these wavelets are taken as the Monte Carlo moves in the simulation. Further to this, occasional plane wave moves are included to supply long-range correlations that the wavelets omit for computational efficiency. These can be tailored for either periodic or unbounded systems, adding a negligible cost in both cases. Thus WMCD removes the largest contributions to the cost in established algorithms, leading to cost with the number of particles, N, scaling at worst as NlnN. Comparisons against LB and BD simulations of identical polymeric systems have shown the constant prefactor for this cost to be very competitive, even for an unoptimised implementation of WMCD, owing to the simplicity of the Monte Carlo method [1-3].
Correct equilibrium and dynamical behaviour has been verified in simulations of simple polymeric systems, with the relaxation of chain size and centre-of-mass diffusivity both exhibiting expected behaviour and absolute values matching those from previous work. Finally, we have collected higher accuracy data to observe the difference between long- and short-time centre-of-mass diffusivity and to quantify the effect of using a finite time step size on the dynamics observed.

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Theory and diagnostics of the kappa-distribution in the solar atmosphere

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Solar radiation is an important source of information about physical properties of the solar corona and transition region. The presence of the kappa-distribution influences the emissivity of the spectral lines by changing the rates of electron collisional processes such as the ionization, recombination, and collisional excitation. The calculated ionization equilibria for the kappa-distribution showed that the ion abundance peaks are wider and lower in the comparison with the Maxwell distribution and can be shifted in temperature. The shift to lower temperatures in the solar transition region can be very significant. In the solar corona and for temperatures above one million K, maximum abundances can be slightly shifted in the temperatures in the both directions, preferably to higher temperatures for the low kappa values [1]. The electron excitation rates of the high-energy levels of ions are increased and the relative population of these levels are enhanced [2]. The changes in the ionization and excitation equilibrium allow us to propose spectral diagnostics of the kappa-distribution using line intensity ratios involving lines with different excitation energies and/or belonging to different ions [3]. The kappa-distributions also affect the emitted continuum at flare temperatures and hard X-ray energies. The bremsstrahlung is greatly increased, exhibits a strong high-energy tail, and the ionization edges are significantly enhanced [4]. The kappa-distributions modify the responses of EUV and UV filters typically used for the Sun observations, their temperature responses are typically shifted in temperature and widened [2]. The changes of the ionization equilibrium with the kappa-distributions are reflected in the reconstructed differential emission measures, they can move and be either more multi thermal or isothermal [5]. Furthermore, the kappa-distributions of ions can be exhibited in the profiles of the emitted lines measured with high precision. The proposed diagnostics methods for determination of the kappa-distribution were successfully applied to the observed spectra. The values of kappa obtained in the solar transition region, corona and during the flares are typically very low, i.e. the electron distribution in these regions can be strongly non-Maxwellian.

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Continuum equations of active matter based on Gaussian approximation

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A method is proposed to derive continuum equations from microscopic equations of motion of interacting self-propelled particles. In this method, it is supposed that the direction of particles is distributed approximately Gaussian. This helps to introduce a closed form for equations of Fourier modes. Comparing the solutions of obtained hydrodynamics equations and the results of truncation method with the microscopic simulations, it shows that in low noise intensities the former is much better approximation.

Separable qubit X states statistics: A lattice quantum simulator

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Separable bipartite states of qubits constitute a valuable resource of general computation and communication tasks in the area of quantum technology. Despite a large number of analytic and numerical works the verification of the statistics with which separable states are distributed is still an open problem based largely on numerical evidence e.g. the probability that a generic two-qubit system is separable/unentangled is 8/11; a value constant along the radius of the Bloch ball representing either of the two single-qubit subsystems. Here a novel operational point of view is put forward that addresses the problem in the special class of the so called two-qubit X states. A lattice of 6 X states (hence the "6X lattice"), properly processed and measured is shown to provide a probability generating function for studying separability statistics. Treating separability probabilities as geometric probabilities i.e. a ratio of volumes, in the manifold of parameters of bipartite states, appropriate volume multi-qubit observable operators are introduced and measured within the context of an algorithm acting in the 6X hexagonal lattice. Explicitly, two different quantum implementations of the simulating algorithm are introduced : one is based on a multi-qubit Hamiltonian with non-local couplings described by a hypergraph, and another one is based on a conditional quantum walk (QW) and its unitary CP map. Borrowing concepts and techniques from the field of topological phases, the simulating 6X hexagonal lattice as well as the volume observables and the Kraus generators of the simulating QW map are constructed by multi-qubit control-Z gates that connect control and target qubits according to a hypergraph connectivity matrix. The ensuing symmetries and invariances of the simulating 6X lattice are investigated, and utilized to generalized cases of separability that include statistics of e.g. real qubits, statistics of qudits, as well as seperability distributions based on volumes other than the Hilbert-Schmidt metrics.

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Intermediate-time dynamics in out-of-equilibrium spin chains

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I discuss some aspects of quench dynamics in quantum many-body systems. In the first part of the talk, I present an unusual mechanism of prethermalization. This is based on the presence of a symmetry of the pre-quench Hamiltonian which is spontaneously broken at zero temperature and is explicitly broken by the post-quench Hamiltonian.
In the second part of the talk, I focus on the non-equilibrium time evolution of piecewise homogeneous states. The inhomogeneity of the initial state gives rise to a peculiar intermediate-time dynamics that is captured by a hydrodynamic description. I present the solution to the dynamics in the XXZ spin-1/2 chain and describe some remarkable properties of the profiles of charges and currents.

Comparing NMR and X-ray protein structure: Lindemann-like parameters and NMR disorder

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Disordered protein chains and segments are fast becoming a major pathway for our understanding of biological function, especially in more evolved species. However, the standard definition of disordered residues: the inability to constrain them in X-ray derived structures, is not easily applied to NMR derived structures. We carry out a statistical comparison between proteins whose structure was resolved using NMR and using X-ray protocols. We start by establishing a connection between these two protocols for obtaining protein structure. We find a close statistical correspondence between NMR and X-ray structures if fluctuations inherent to the NMR protocol are taken into account. Intuitively this tends to lend support to the validity of both NMR and X-ray protocols in deriving biomolecular models that correspond to in-vivo conditions. We then establish Lindemann- like parameters for NMR derived structures and examine what order/disorder cutoffs for these parameters are most consistent with X-ray data and how consistent are they. Finally, we find critical value of L = 4 for the best correspondence between X-ray and NMR derived order/disorder assignment, judged by maximizing the Matthews correlation, and a critical value L = 1.5 if a balance between false positive and false negative prediction is sought. We examine a few non- conforming cases, and examine the origin of the structure derived in X-ray. This study could help in assigning meaningful disorder from NMR experiments. Intuitively this tends to lend support to the validity of both NMR and X-ray protocols in deriving biomolecular models that correspond to in-vivo conditions. We then establish Lindemann- like parameters for NMR derived structures and examine what order/disorder cutoffs for these parameters are most consistent with X-ray data and how consistent are they. Finally, we find critical value of L = 4 for the best correspondence between X-ray and NMR derived order/disorder assignment, judged by maximizing the Matthews correlation, and a critical value L = 1.5 if a balance between false positive and false negative prediction is sought. We examine a few non- conforming cases, and examine the origin of the structure derived in X-ray. This study could help in assigning meaningful disorder from NMR experiments.

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On the agreement between small-world-like OFC model and real earthquakes from different regions

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Despite all the existing knowledge about the production of seismic waves through slips on faults, much remains to be discovered regarding the dynamics responsible for these slips. A key step in deepening this knowledge is the study, analysis and modeling of the seismic distributions in space and time. The concept of self-organized criticality (SOC), widely used in statistical physics, refers, generally, to the property that a large class of dynamical systems has to organize spontaneously into a dynamic critical state without the need for any fine tuning of some external control parameter. Aiming to contribute to the understanding of earthquake dynamics, in this work we implemented simulations of the model developed by Olami, Feder and Christensen (OFC model), which incorporate characteristics of self-organized criticality and displays a phenomenology similar to the one found in actual earthquakes. We applied the OFC model for two different topologies: regular and small-world, where in the latter the links are randomly rewired with probability p. In both topologies, we have studied the distribution of time intervals between consecutive earthquakes and the border effects present in each one. In addition, we also have characterized the influence that the probability p produces in certain characteristics of the lattice and in the intensity of border effects. Furthermore, in order to contribute the understanding of long-distance relations between seismic activities we have built complex networks of successive epicenters from synthetic catalogs produced with the OFC model, using both regular and small-world topologies. In our results, distributions arise belonging to Tsallis family distributions functions. We also performed the complex network analysis for real earthquakes, taking in account two different ways. The first one, considering only regional earthquakes separately (in regions with high seismicity, as Japan and California, and low seismicity, as Brazil). In the second, considering events for the entire world, with magnitude larger or equal than 4.5, in Richter scale. It is noteworthy that we have found a good agreement between the results obtained for the OFC model with small-world topology and the results for real earthquakes. Our findings reinforce the idea that the Earth is in a critical self-organized state and furthermore point towards temporal and spatial correlations between earthquakes in different places.

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Models of polymer translocation through motor driven channels

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This presentation concerns the translocation of a polymer through narrow pores where a time dependent force is acting. Translocation of long biochemical structures through channels is a normal process in biology. Drug absorption, protein and DNA/RNA passage through cell membranes and nuclear pores, DNA injection by phage viruses are only few examples of a broad biological phenomenology.
Following the seminal paper by Kasianowick in 1996, both theoretical and experimental investigations have been developed in order understand the basic physics involved in this process.
In the recent years technological advances have permitted to manipulate single molecules, and to observe translocation under time dependent driving. In fact, beside the fluctuating opening/closing gate of the pore channels due to ligands or the reaction of the pore walls, the translocation can be driven by molecular protein motors.
Because of the high number of particles involved in molecular kinetics, the theoretical computational study of translocation of real molecules presents the inconvenience to be extremely time consuming when using full atom simulations. For this reason, many gross grain polymer models have been developed not only to describe the translocation process in affordable conditions, but also to better control the specific contribution of the different parameters involved in the dynamics.
In this contribution, some recent results using Rouse-based models will be presented, in order to describe the active translocation of a polymer through a narrow pore, i.e. the translocation assisted by time dependent forces, from sinusoidal to random dichotomous. Moreover, the most recent results of translocation of a polymer enriched with the flexibility degree of freedom under the specific force provided by the action of a molecular motor, will be presented. This kind of motors are characterized by an actuation triggered by the bonding of an ATP molecule (the fuel) to the protein motor. The bonding is modeled as a Poisson process and the overall motor actuation presents a paradigmatic dichotomous driving for ATP-based motors that provide a Michaelis-Menten kinetics outcome.

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Dynamical theory of spin noise and relaxation - Beyond extreme narrowing

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Recent developments in spin noise and relaxation and their interrelationship in terms of a modified spin density (MSD) have focussed on the case of extreme narrowing where the timescale of the field fluctuations that give rise to the spin

process are negligibly small. It is customary in this case to model the random magnetic field as a(n) (isotropic) white noise process and thereby formulate a stochastic differential / Langevin type equation for the spin ensemble. It is notable in this case that the usual perturbation treatment becomes exact since the perturbation expansion truncates at second order, a characteristic familiar feature of the Wiener process, which has finite quadratic variation but whose higher order infinitesimal moments vanish. In terms of the field spectrum the Larmor frequency plays no essential role here, since such a flat spectrum is invariant to frequency shifts.
Of much greater experimental relevance is the non-extreme narrowed case where the field fluctuations have a finite auto-correlation time and a corresponding power spectrum with finite bandwidth. In such cases the Larmor frequency plays a special role in terms of its situation within this narrowed spectrum. Provided the strength of the fluctuations is small it is possible to formulate the spin dynamics (perturbatively) while retaining the full spectral character of the random field - more recently a non-perturbative treatment has also been possible. This is achieved through the description of the field in terms of an (3-dimensional) Ornstein-Uhlenbeck process, consistent (via Doob's theorem) with the requirements that the process be Gaussian, Markov and stationary. The result is significant in that it predicts a non-Lorentzian spectrum - it is interesting therefore both theoretically and experimentally.
In turn we derive a spin noise / relaxation process that inherits spectral features from both the amplitude and frequency characteristics of the driving random magnetic field. The intimate connections that exist between spin noise and relaxation in the extreme narrowed case persist in this more general context, whereby standard relaxation emerges as the ensemble average of spin noise, the latter being essential to describe non-ensemble averaged (real time) properties of spin systems.

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Kappa distribution and active regions at the sun: probing with microwave gyroresonant radiation

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A true distribution of tenuous astrophysical plasmas often deviates from the classical Maxwellian one. The reasons for such deviations can be several fold: sporadic energy releases resulting in acceleration of charged particles, long relaxation times due to infrequent binary collisions, important role of far interactions by means of plasma waves and MHD turbulence etc. [1]. In particular, the time intervals between the energy release episodes can be shorter than needed for the plasma to fully relax towards a Maxwellian; in such cases the Maxwellian distribution will never be established, so another distribution will play a role of a quasi-stationary distribution. It is known that under certain conditions, a so-called kappa-distribution plays a role of this quasi-stationary distribution. Detecting the deviation of the true distribution of the plasma from the Maxwellian one is fundamentally important, but difficult to perform given that for many observations the Maxwellian distribution is hard to distinguish from the kappa distribution with a reasonably large index, say kappa=10. Interestingly, in case of plasma with the kappa distribution, the microwave gyroresonance emission with its large optical depth is extraordinarily sensitive to the kappa index value, because the optically thick emission is highly sensitive to small variations at the tail of the distribution. To demonstrate the power of the method, we consider microwave emission from a 3D model [2] of active region and demonstrate that its brightness changes measurably with the kappa index up to kappa = 50 at least. In our study we adopt an AR thermal model to reproduce the optically thin EUV data on average, but allow a kappa distribution with unknown index rather than the Maxwellian distribution. We vary the kappa index and compute the radio brightness maps from the same 3D model using theory developed in [3]. These synthetic maps are convolved with the point spread function of a given radio interferometer and compared with the observed radio brightness maps. The synthetic radio brightness increases rapidly as the kappa index decreases, which allows, perhaps, the ever most stringent constraints on the kappa-indices consistent with the data. We found that the allowable kappa indices are well above the value around 15 and the best consistent with values of 25-30 or above. We discuss implications of this finding and potential ways to further constraint the kappa distribution shape in the solar plasma.

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Stochastic community dynamics and time scale dependent turnover rates

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The current rate of biodiversity change is widely debated because of the pivotal role biodiversity plays for the functioning of ecosystems. Based on time series of planktonic foraminifera (amoeboid protozoans), sampled at different sites across the globe, and by using different community metrics we show how community turnover rates vary with respect to the temporal distance. While pronounced changes are found on the time scale of years to decades and on the millennial time scale, community evolution seems to slow down on intermediate time scales.
To assess the significance of these observations we employ a stochastic model of the community dynamics that preserves all linear correlations by constructing a surrogate ensemble of multivariate time series. Combining spectral information from different data sets (recent and palaeontological) we can model evolving ecological communities consistently across time scales ranging from seasons to millennia. Each realization of the modeled multivariate stochastic process is then transformed to the same format as related sample time series which includes at each instant the transition from concentrations to sample abundances and normalization yielding a sample distribution. Applying the same community metrics as before we can relate

time scale dependent turnover rates to underlying mechanisms of ecological and evolutionary processes.
At the same time we highlight the importance of choosing adequate measures for quantifying community changes beyond the plain but widely used species diversity. While the latter may remain essentially unchanged either the rank-abundance curve or the species identity in rank assignment can change. While dominance shifts result quite naturally from species succession on the seasonal time scale, species origination and extinction are typically effective on the millennial time scale.
Finally, by using the available database we compare the temporal and spatial variability, thus challenging the space-for-time substitution frequently invoked in biodiversity change research.

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Charging of interstellar dust grains in the non-equilibrium inner heliosheath plasma

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Interstellar dust grains flow into the heliosphere together with interstellar gas. The heliosheath plasma provides a barrier to the smallest charged grains, while larger grains with larger gyroradii penetrate to the inner heliosphere. Interstellar Boundary Explorer (IBEX) observations of Energetic Neutral Atoms (ENAs) trace the thermodynamics of the plasma where ENAs are born via charge-exchange and where many interstellar dust grains are deflected away from the inflowing stream. Most (75 percent) of the heliosheath plasma can be described with a stationary state kappa-distribution that represents a composite of a thermal core and a high-energy non-thermal tail (Livadiotis et al. 2011). The thermodynamic properties of the stationary non-equilibrium plasma, temperature, kappa-index, pressure and densities, provide the information needed for grain charging currents specific to the heliosheath regions. Ulysses tracked the dust at several AU for 16 years and found a deficit of submicron-sized grains compared with the canonical interstellar grain populations (Krueger et al. 2015). Previous simulations of the grain trajectories through the heliosphere have utilized Maxwellian plasma temperatures, and shown that grain charging in the heliosheath regions yields high charge-to-mass ratios that impede submicron grain propagation through heliosheath plasma. Grain-charging calculations are made using a charging-code (Weingartner and Draine 2001) that includes charging by grain interactions with protons, electrons, as well as the photo-ejection of electrons. Electron currents are expected to play a dominant role in grain charging in the heliosheath for most temperature regimes. However, given the absence of benchmark data on heliosheath electrons there is no consensus viewpoint about the electron thermodynamic state for this region. Consequently electron population thermal properties are generally also characterized using a kappa distribution. We assume that the same thermodynamic parameters characterize both the proton and electron heliosheath populations and perform grain charging calculations for the heliosheath regions based on the thermodynamic properties described by the kappa-distribution derived from IBEX ENA data. The balance between electron and proton currents on the grains, including photoionization, then provides the equilibrium grain charges. Grain gyroradii calculated based on these charging currents differentiate between interstellar grains able to penetrate the heliosphere, versus those that are excluded.

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Mixed-order phase transition in a minimal, diffusion based spin model

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We present and analyze a minimal exactly solved model that exhibits mixed-order phase transition [**?**, **?**]. Mixed-order or hybrid transitions do not fit into the modest classification of thermodynamic transitions and as such, they used to be overlooked or incorrectly identified in the past. The recent series of observations of such transitions in many diverse systems suggest that a new taxonomy of phase transitions is needed.
The model is defined as follows: We study N distinguishable and noninteracting spins, which can have two states (+1 and -1). With a probability q, we randomly select one of positive spins and change its state to the opposite. With a probability $1-q$ we perform the reverse action, i.e. a randomly selected negative spin is flipped.
We call the model "diffusion-based" because its hamiltonian can be recovered from a simple dynamic procedure, which can be seen as an equilibrium statistical mechanics representation of a biased random walk.
We analyze the model within both: canonical and grand canonical ensembles. In the canonical ensemble, the model exhibits first order transition with power-law fluctuations. In the grand-canonical approach, phase diagram of the model is much more complicated. We outline derivation of the phase diagram, in which the triple point has the hallmarks of the hybrid transition: discontinuity in the average magnetization and algebraically diverging susceptibilities. At this point, two second-order transition curves meet in equilibrium with the first-order curve, resulting in a prototypical mixed-order behavior. Finally, we show that, given fixed system size, our model can be seen as a highly simplified version of the dynamic social network model discussed in [**?**]. In the network model mentioned, nodes are separated into two groups representing opposing interests. Members of the first group (introverts) seek to get rid of their connections, whereas these who belong to the second group (extroverts) want to accumulate their highest possible number. It was suggested that the model exhibits the extreme Thouless effect in which the density of connections between introverts and extroverts jumps from a value which is close to zero, to a value close to unity, when the number of extroverts becomes larger than the number of introverts. Results obtained for the minimal spin model suggest that the phenomenon observed in these

networks is a discontinuous phase transition with power-law fluctuations.

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How transfer flights shape structure of the airline network

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For many decades, the gravity models have been successfully applied in many different contexts for analyzing socio-economic flows of varying types. The well-known examples include: migration, consumer spatial behavior, inter-city telephone communication flows, hospital-patient flow systems and the international trade. All these models predict or describe certain behaviors that mimic gravitational interaction as described in Isaac Newton's law of gravity. They assume that a flow between the two places is directly proportional to their importance (expressed in, e.g., population size, gross domestic product (GDP), or some attractiveness index) and is inversely proportional to the physical distance between them. Gravity models work particularly well in the systems where all the places are directly connected (i.e. where the underlying structure is the complete graph). International trade network is a typical example of such a system. In opposite to the above example, most transport networks involve a series of intermediate stops, which are, themselves, generators of originating and terminating traffic. In such networks, especially for large distances, it may happen no direct connection from the location i to the location j. In these cases, the potential, but not realizable, flow predicted from the gravity model, is realized by the increase of the other subsequent flows among the successive links of a path from i to j. Obviously, this scenario must lead to the observed flows among some places, which differ from the expected ones. It means that, in the case of airline networks, the standard gravity model can not be directly used to estimate weights of the existing connection flights. Here, we analyze the gravity model in the world passenger air-transport network. We show that in the standard form the model is inadequate to correctly describe the relationship between passenger flows and typical geo-economic variables that characterize connected countries. We propose a model of transfer flights which allows to exploit these discrepancies to discover hidden subflows in the network. We illustrate its usefulness by retrieving the distance coeffcient in the gravity model which is one of the determinants of the globalization process. Finally, we discuss the correctness of the presented approach by comparing the distance coeffcient to several well known economical events.

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Disassortative degree mixing and fractality of scale-free networks

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From the viewpoint of the relation between the shortest path distance and the network size, we can classify most of the complex networks in the real world into two classes, namely, small-world and fractal networks [1,2]. It has been clarified that the small-world property originates from the existence of short-cut edges. On the other hand, the formation mechanism of fractal networks in the real world is still an open question. Nevertheless, we empirically know that fractal scale-free networks exhibit disassortative degree mixing [3]. Conversely, if disassortative mixing makes a scale-free network fractal, the origin of fractality would be found in disassortativity. At first sight, this hypothesis seems to be false, because the fractal property is a consequence of long-range structural correlations beyond the nearest neighbors, while disassortativity is a short-range property characterizing nearest neighbor degree correlations. It has been, however, demonstrated that even short-range disassortative degree mixing induces a long-range correlation if the network exhibits the scale-free property [4]. It is, thus, not obvious whether disassortativity is the origin of fractality in scale-free networks.
In this work, we examine the above possibility. To this end, we create maximally disassortative (MD) networks formed by rewiring edges starting from an initial uncorrelated scale-free network, while keeping the degree sequence. If the MD network possesses the fractal property, one can conclude that disassortative degree mixing makes scale-free networks fractal. Initial uncorrelated networks are formed by rewiring randomly edges of the (u, v)-flower [5]. As a result, there are many MD networks with different topologies, but most of them are not fractal. This result shows that disassortativity does not always induce fractality of scale-free networks. Also, we suggest that the fractal property requires a long-range repulsive correlation between similar degrees in scale-free networks.

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The scientific and technological competitiveness of nations: A network analysis

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We use citation data of scientific articles produced by individual nations in different scientific domains to build a bipartite country - scientific domains network to determine the structure and efficiency of national research systems [1]. We characterize the scientific fitness of each nation, i.e. the competitiveness of its research system, and the complexity of each scientific domain by means of a non-linear iterative

algorithm able to assess quantitatively the advantage of scientific diversification [3]. We find that technological leading nations, beyond having the largest production of scientific papers and the largest number of citations, do not specialize in a few scientific domains. Rather, they diversify as much as possible their research system. On the other side, less developed nations are competitive only in scientific domains where also many other nations are present. Diversification thus represents the key element that correlates with scientific and technological competitiveness. A remarkable implication of this structure of the scientific competition is that the scientific domains playing the role of markers of national scientific competitiveness are those not necessarily of high technological requirements, but rather addressing the most sophisticated needs of the society. We complement this analysis with a correlation study between the scientific impact of a nation with a normalized measure of RD funds and the level of internationalisation [2]. Finally, we present some new results of a similar approach to the interactions between scientific, technological and industrial innovation dynamics based on mutual citations and co-occurrence in national research systems. This permits to determine the main flows of information from the different sectors of the multilayered innovation space, science-technology-market, and to study and compare the innovation trajectories of different countries in this space. Moreover, it is possible to discover the typical delay for a technological innovation or scientific progress to impact in other innovation layers. In particular we find that disrupting technological innovations typically impact in science and industry with a typical delay of 10-15 years.

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Detecting early signs of the 2007-2008 crisis in the world trade

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Since 2007, several contributions have tried to identify early-warning signals of the financial crisis. The vast majority of analyses, however, has focused on financial systems and little theoretical work has been done, so far, on the economic counterpart, though the definition of better early-warning indicators for economic systems is advocated by many organizations, as the International Monetary Fund, the United Nations and the national central banks.
With the aim of filling this gap, and complementing the existing vast amount of literature on financial markets, in the present paper we analyse the bipartite World Trade Web (hereafter WTW), by employing a novel method to assess the statistical significance of a number of topological network properties across the period 1995-2010. We have, thus, explored the evolution of the bipartite WTW both before and after 2007. Our analysis suggests this year to mark a crossover from a phase characterized by a steep increase of randomness of the WTW topology (the WTW becomes increasingly compatible with the picture of a network where correlations between countries and products are progressively lost) to a phase during which a stationary regime seems to be finally reached. Indeed, the abundances of the considered family of motifs point out that the crisis explicitly manifests itself after a period of four years during which the WTW has undergone a dramatic structural change. Moreover, the WTW structural modification can be considered as concluded in 2010, after a seemingly stationary phase of three years.
We have also refined our analysis by considering specific subsets of countries and products: our analysis evidences that some sectors/groups of countries are more sensitive to the cycles of the worldwide economy, providing robust early-warning signals of the 2007 crisis (and confirming the trends individuated at the global level); others, instead, provide little information on its build-up phase. Our study reveals also the existence of subsets of nodes which do not show any relevant internal correlation throughout the whole 1995-2010 window, thus questioning the correctedness of the reasoning leading to the individuation of such groups as homogeneous sets. Anyway, the most statistically significant early-warning signals are provided by the most volatile macrosectors, especially when measured on developing countries, suggesting the emerging economies as being the most sensitive ones to the global economic cycles.

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Obliquely propagating waves in bi-kappa plasmas

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The effects of velocity distribution functions (VDFs) that exhibit a power-law dependence on the high-energy tail have been the subject of intense research by the space plasma community. Such functions, known as kappa (or superthermal) distributions, have been found to provide a better fitting to the VDFs measured by several spacecraft in the solar wind, in contrast to models that employ combinations of Maxwellian VDFs. Among the relevant problems pertinent to the physics of the solar wind, one can mention the origin of the temperature anisotropy displayed by both the protonic and electronic VDFs. The existence of these nonthermal characteristics implies that the particles contain a large amount of free energy that can be used to excite waves present in the thermal radiation background. Conversely, the wave-particle interaction is important to determine the shape of the observed distributions. The majority of studies concerning wave-particle interactions in the solar wind were carried out employing Maxwellian distributions. It is just recently that kappa VDFs have been considered. In the literature, the general treatment for waves excited by bi-Maxwellian plasmas is well-established. However, for kappa distributions (isotropic or anisotropic), the wave characteristics have been studied mostly for the limiting cases of purely parallel or perpendicular propagations. The general case of obliquely propagating waves have been scarcely reported so far. The

absence of a general treatment prevents a complete analysis of the wave-particle interaction in superthermal plasmas. This situation is being remedied by a series of papers published by the authors. In a first work (Gaelzer & Ziebell, 2014), we have obtained expressions for the dielectric tensor components and subsequent dispersion relations for the dispersive Alfvén waves resulting from a kappa VDF. Subsequently, Gaelzer & Ziebell (2016) extended the initial formalism for the general case of electrostatic and/or electromagnetic waves propagating in an isotropic kappa plasma in any frequency range and for arbitrary angles. In the present work (Gaelzer et al., 2016), we generalize even further the formalism by the derivation of the general dielectric tensor for an anisotropic bi-kappa plasma. We present the formalism and show how it enables a systematic study of electromagnetic/electrostatic waves propagating in arbitrary directions and polarization and in any frequency range in a bi-kappa plasma.

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Ground-state and finite-temperature phase diagrams of the decorated Ising triangular lattice in a longitudinal magnetic field

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The mixed spin-(1/2, s) Ising model on a decorated triangular lattice with decorating spins placed into the longitudinal magnetic field is rigorously solved by means of the generalized decoration-iteration mapping transformation [1]. This technique allows one to find a precise analytical mapping relationship between the partition function of the considered mixed-spin model and the partition function of the spin-1/2 Ising model on a simple isotropic triangular lattice, which is well known [2,3]. By assuming the effect of the uniaxial single-ion anisotropy acting on decorating spins, we construct the ground-state phase diagrams for two representative values of decorating spins $s = 1$ and $s = 3/2$. It is demonstrated that the mutual interplay between the applied magnetic field and uniaxial single-ion anisotropy leads to relatively rich zero-temperature phase diagrams involving several long-range ordered ground states as well as intriguing paramagnetic phases for both mixed-spin systems. In latter phases, the investigated planar models are broken into sets of $3N$ spin atoms taking the same spin states due to a frustration of nodal spins. As a result, the non-zero residual entropy $S = Nk_B \ln 2$ can be detected in the paramagnetic phases.
The critical temperature of the decorated Ising triangular lattice as a function of the longitudinal magnetic field and uniaxial single-ion anisotropy parameter is also particularly examined for both the investigated values of decorating spins $s = 1$ and $s = 3/2$. In general, the critical temperature terminates the existence of the long-range order in the two-dimensional system at finite temperatures. As expected, the critical temperature corresponding to both the investigated mixed-spin planar models always vanishes at those zero-temperature phase transitions, where the long-range ordered ground state coexist with the paramagnetic one. Moreover, an interesting reentrant phenomenon can also be detected at finite temperatures when the uniaxial single-ion anisotropy is zero or negligibly weak and the intensity of the longitudinal magnetic field is comparable to the intensity of the exchange interactions between the nearest-neighboring spins due to a relatively high coordination number of the lattice. The observed phenomenon is more pronounced for the spin case $s = 3/2$ in comparison with the spin case $s = 1$.

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A mathematical realization of entropy through neutron slowing down

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A classic problem in neutron transport theory is time dependent slowing down in a homogeneous medium. Neutrons (test particles) collide with nuclei (field particles) and lose energy via elastic scattering. In addition, some neutrons are captured and thus represent dissipation. One can analytically solve the neutron slowing down equation, a balance between neutron loss from elastic scattering and absorption and gain from scattering in phase space, in the simple case of uniform cross sections. These solutions provide examples of how entropy tracks mathematics and vice versa through collisions with nuclei. In particular, the solution exhibits oscillations in lethargy (logarithm of the energy), called Placzek transients. The oscillations originate from the continuity of the derivatives of the solution. With increasing number of collisions, the initial sharp discontinuity from the highly singular delta function source become submerged in subsequent higher order derivatives. Hence, with collisions, the solution becomes mathematically smoother. This is a perfect physical example of the mathematical representation of entropy since one begins with a source with no uncertainty (zero entropy) as represented by a delta function; and, with an ever increasing number of collisions, uncertainty is generated (non-zero entropy).
Our focus will be the time dependent case, where the time transient of the scalar flux builds to a steady state. One finds the time dependent solution in an infinite medium through a multigroup formulation coupled to a numerical Laplace transform inversion in time. Included will be consideration of high precision. Specifically, convergence acceleration in the form of the Wynn-epsilon algorithm will generated highly precise numerical solutions in the multigroup form including resonances, where possible. In this way, one can assess the influence of numerical error relative to entropy generation. In addition, test particle dissipation through loss by escape from a slab will be considered in the diffusion approximation.

Transport in sheared granular suspensions

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Although in nature granular materials are usually immersed in a fluid phase (like the air, for instance), the influence of the latter on the dynamics properties of solid particles is generally neglected in most theoretical and computational studies. However, in many situations of practical interest the impact of the gas phase on grains cannot be ignored. At a kinetic theory level, the description of such multiphase flows is quite intricate since the system involves two different phases. However, most of the models proposed in the literature consider a Boltzmann kinetic equation for the solid particles where the influence of the gas phase is accounted for via a viscous drag force proportional to the peculiar velocity of the particles [1]. In addition, the solid particles are modeled as a gas of inelastic hard spheres with constant coefficient of normal restitution.

The aim of this contribution is to analyze momentum and heat transport of a granular suspension under uniform shear flow (USF). This flow is defined by constant density and temperature and a constant shear rate. The rheological properties of the granular supension under USF has been recently [2] obtained analytically from Grads method and by means of Monte Carlo simulations. A said before, our objective here is to study transport around USF. Thus, we assume that the reference base state (USF) is perturbed by small spatial gradients. This will give rise to new contributions to the momentum and heat fluxes that can be characterized by generalized transport coefficients. Since the system is strongly sheared, the corresponding transport coefficients are highly nonlinear functions of both the shear rate and the coefficient of restitution. As in previous works [3,4], the Boltzmann equation is solved by means of a Chapman-Enskog-like expansion around the reference USF distribution. To first order in the expansion, the momentum transport is characterized by a viscosity tensor of rank 4 while the heat flux is expressed in terms of a thermal conductivity tensor and a Dufour-like tensor. These tensors are given in terms of the solutions of a set of coupled linear integral equations, which are approximately solved by employing a BGK-like kinetic model. Explicit expressions for the set of generalized transport coefficients are obtained and illustrated for conditions of practical interest. The results show that the functional forms of these tensors differ clearly from their elastic forms.

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On a cancer discrete-continuous model that explains Peto's paradox.

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Blood of mammals is composed of a variety of cells suspended in a fluid medium known as plasma. Hematopoiesis is the process for the generation of all cellular blood elements. A continuous supply of cells is necessary to compensate for the loss of cells due to apoptotic senescence or migration out of the circulating compartment. Blood cell formation has at its root hematopoietic stem cells that have the dual property of self renewal and the ability to differentiate into all types of blood cells. Despite of being essentially a stochastic phenomenon followed by a huge number of discrete entities, blood formation has naturally an associated continuous dynamics, because the cellular populations can on average easily be described by (e.g.) differential equations. This deterministic dynamics by no means contemplates some important stochastic aspects related to abnormal hematopoiesis, that are especially significant for studying certain blood cancer deceases. For instance, by mere stochastic competition against the normal cells, leukemic cells sometimes do not reach the population thereshold needed to kill the organism. Of course, a pure discrete model able to follow the stochastic paths of billons of cells is computationally impossible. In order to avoid this difficulty, we seek a trade-off between the computationally feasible and the biologically realistic, deriving an equation able to size conveniently both the discrete and continuous parts of a model for hematopoiesis in terrestrial mammals, in the context of Chronic Myeloid Leukemia. Assuming the cancer is originated from a single stem cell inside of the bone marrow, we also deduce a theoretical formula for the probability of non-diagnosis as a function of the mammal average adult mass. In addition, this work cellular dynamics analysis may shed light on understanding Petos paradox, which is shown here as an emergent property of the discrete-continuous nature of the system.

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Propagation of initial correlations and effective equations in collisional kinetic theory

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In the talk we consider a new approach to the problem of the rigorous description of kinetic evolution of large hard sphere systems within the framework of the marginal observables governed by the dual BBGKY hierarchy. The relations of the hierarchy of evolution equations for marginal observables and the nonlinear kinetic equations for states described by means of a one-particle marginal distribution function are established.

The Boltzmann-Grad asymptotic behavior of a nonperturbative solution of the Cauchy problem of the dual BBGKY hierarchy for systems with hard sphere collisions is considered. In case of initial states specified by means of a one-particle distribution function the interplay between the Boltzmann–Grad asymptotic behavior of marginal observables and a solution of the Boltzmann kinetic equation is established.

One of the advantages of the stated approach to the derivation of kinetic equations from underlying hard sphere dynamics consists in an opportunity to construct the Boltzmann-like kinetic equation with initial correlations and it gives to describe the process of the propagation of initial correlations in the Boltzmann-Grad scaling limit.

Moreover, using suggested approach, we derive the non-Markovian Enskog kinetic equation with initial correlations and construct the marginal functionals of states, describing the creation of all possible correlations of particles with hard sphere collisions in terms of a one-particle distribution function governed by the Enskog equation. The Boltzmann–Grad asymptotic behavior of a non-perturbative solution of the derived Enskog equation and the marginal functionals of states are also established.
The obtained results we extend on systems of hard spheres with inelastic collisions. In particular, we established that in a one-dimensional space the kinetic evolution of a large system of hard rods with inelastic collisions is governed by the certain generalization of the known Boltzmann equation for one-dimensional granular gases.

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Mechanical and chemical-diffusive instabilities in high density strange nuclear matter

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One of the very interesting aspects in nuclear astrophysics and in the heavy-ion collisions experiments is a detailed study of the thermodynamic properties of strongly interacting nuclear matter away from the nuclear ground state. At high temperature (about 170 MeV) and very low baryon density a deconfined matter of quark-gluon plasma (QGP) is expected and confirmed by QCD lattice calculations. In the absence of a converging method to approach QCD at finite density one has often to resort to effective and phenomenological model investigations to obtain qualitative results.
The main goal of this contribution is to show that thermodynamic instabilities and phase transitions can take place at finite net baryon density and temperature, where the onset conditions of deconfined QGP should not still realized. Similarly to the low density nuclear liquid-gas phase transition, we show that a high density phase transition is characterized by pure hadronic matter with both mechanical instability (fluctuations on the baryon density) that by chemical-diffusive instability (fluctuations on the strangeness concentration).
The analysis is performed by requiring the Gibbs condition of the global conservation of baryon number and zero net strangeness in the framework of an effective relativistic mean field theory with the inclusion of the Delta (1232)-isobar resonances, hyperons and the lightest pseudoscalar and vector meson degrees of freedom. The main goal is to investigate how the constraints on the global conservation of the baryon number, electric charge fraction, and strangeness neutrality, in the presence of Delta-isobar degrees of freedom, hyperons, and strange mesons, influence the behavior of the EOS in a regime of finite values of baryon density and temperature. Moreover, we show the relevance of Delta-isobars for different coupling constants and how their presence influences several particle ratios and strangeness production for three different parameters sets, compatible with experimental constraints. Referring to QCD finite-density sum rule results, which predict that there is a larger net attraction for a Delta-isobar than for a nucleon in the nuclear medium. It turns out that in this situation hadronic phases with different values of strangeness content may coexist, altering significantly meson-antimeson ratios.

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Where higher order of interactions matters?

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Susceptible-Infective-Susceptible (SIS) and Susceptible-Infective-Recovered (SIR) are two successful models for understanding spreading dynamics -non-linear dynamics- like disease spreading. However, the complexity of the problem is even higher, as diseases can interact between themselves in several ways, inducing higher susceptibility or cross-immunity. These interactions increase in any public contact networks. For example, several cases of coinfection in hospitals have been reported. As another example, Murray et.al. estimated a potential pandemic could kill between 50 and 80 million people by having a virulence strain similar to the 1918 influenza today. In these cases, the number of affected agents vs infection rate may dramatically change, i.e. first order phase transitions. Here we want to understand how microscopic mechanisms might lead to unexpected macroscopic outbreaks; Thus in this work, we study spreading of two dynamics: either cooperative or competitive interacting as a SIS or/and a SIR dynamics and address similarities and differences in comparison to other minimal cooperative models, i.e. SIR-SIR [1] and SIS-SIS [2]. We propose a model and treat it in mean field approximations as well as stochastic agent based models. We show an emerging region in the parameter space where the stable endemic and stable free-disease states co-exist. This region appears differently in presence of cooperation or competition. Also we show how this region might be affected by topological features of the contact networks, e.g. generated random networks as well as empirical networks. These mathematical modelling of disease spreading can help on one hand to widen our views on critical phenomena, specifically hybrid transitions. On the other hand, these can help us to improve our understanding how diseases spread in networks and guide policy makers for better strategies to avoid large outbreaks.

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The physics of climate sensitivity: a tale of deterministic and stochastic dynamical systems

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The climate system is a nonlinear, heterogeneous and complex physical system that exhibits variability on many scales of time and space. Its dynamical behavior results from a plethora of physical, chemical and biological processes. Hence, it is typically studied across a hierarchy of models, from low-dimensional systems of ordinary differential equations to infinite-dimensional systems of partial and functional differential equations. The theory of differentiable dynamical systems (DDS) has provided a road map for climbing this hierarchy and for comparing theoretical results with observations.
The climate system is also subject to time-dependent forcing, both natural and anthropogenic, e.g. solar luminosity variations, volcanic eruptions and changing greenhouse gas concentrations. Hence increased attention has been paid recently to applications of the theory of non-autonomous and random dynamical systems in order to describe the way that this complex system changes on time scales comparable to a human lifetime and longer. This talk will review the road from the classical applications of DDS theory to low-dimensional climate models with no explicit time dependence to current efforts at applying non-autonomous and random dynamical systems theory to high-end climate models governed by partial and functional differential equations, deterministic as well as stochastic.
We discuss the pullback and random attractors associated with such high-end models and the non-uniqueness of the invariant measures supported on these attractors. The presentation moves from observations of the geophysical phenomena to modeling them and on to a proper physical and mathematical understanding of the models thus obtained.
This mathematical approach complements the statistical physics approach, via fluctuation-dissipation theory, to climate sensitivity, by permitting the treatment of a system that is very far from equilibrium. Issues of distinguishing between forced climate change and intrinsic climate variability will be discussed and connections between the two approaches will be made as time permits.

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On the statistical model of the atom

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The Thomas-Fermi statistical model for the ground state of an atom has been usually used for the determination of its non-uniform electron density n(r) and self-consistent electric field V(r). This model assumes that the functions n(r) and V(r) vary slowly enough within an electron De Broglie wavelength, so that the quasi-classical description can be used. The Thomas-Fermi model has proved to be very useful in deriving properties such as the binding energy of heavy atoms. Besides, after suitable modifications, it has been applied to molecules, solids and nuclei. One of the most remarkable difficulties to overcome in order to get results is due to the determination of the self-consistent space-dependent field deriving by the interaction among the electrons of the atom. This field, that has to satisfy the Poisson Equation, has been previously solved only numerically, and then it has been used to calculate the total binding energy of the atoms electron cloud. In this work we propose a different method that, starting from the Fermi-Dirac distribution function of the completely degenerate state of the electron cloud, allows to obtain the space-dependent electron density function n(r). This electron density, which contains the chemical potential too, is obtained straight from the model assumptions without any lack of strictness, and overlaps exactly to what has been obtained in previous works. Then, with the purpose of gaining deeper insight into the physics of the problem, we introduce an approximation for the electron density, and thereafter we solve analytically the Poisson Equation. This analytical solution of the homogeneous part of the Poisson equation, yielding the self-consistent electric field V(r), turns out to be a Bessel function. Besides, we of course calculated the particular integrals for satisfying also the boundary conditions imposed by the physics of the problem. Now, an important and nontrivial point fulfilled by our model is the condition represented by the finite number of the electrons. Hence a finite value for the radius of the electron cloud comes naturally out. Now, from all this, upon integrating over the volume the electron density, also the discrete energy levels of the completely degenerate cloud of electrons in the extra-nuclear space and the ionization potentials of the atom are obtained. This model can also be applied to a completely degenerate plasma and obtaining for instance the pair correlation function for the electrons.

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Influence of particle acceleration on the heating of the solar coronal plasma and a data-driven model on nanoflares in solar active region loops.

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The solar coronal plasma is heated to more than one million Kelvin, which is 2 to 3 orders of magnitude higher than the solar surface temperature. The heating is caused by the diffusion of electromagnetic energy, a process still not fully understood despite many decades of research. Many works suggest that accelerated particles and the formation of suprathermal particle distributions are important for the heating of the solar corona. The nanoflare model, described by E. Parker (1972,1988), suggests that coronal heating is caused by eruptive energy releases, each one being of the order of 1.E24 ergs, corresponding to 1.E-9 times the energy released in a typical solar flare. A large number of such nanoflares, taking place on all the solar surface may explain the high coronal temperatures and the steady coronal emission in X-rays. The energy release in nanoflares is triggered by magnetic reconnection which accelerates particles, connecting, in such

a way, suprathermal distributions with coronal heating.
In this presentation, we give a brief review on the topic of suprathermal particles, kappa distributions and their connection with nanoflares and coronal heating. This include the presentation of numerical models and observations.
Secondly we introduce a data-driven model of coronal heating based on nanoflares (Gontikakis et al 2013). The model is applied to observations of a solar active region which had not an important flaring activity. The Poynting flux generated from photospheric motions and supplied to the coronal plasma is calculated using measurements of photospheric magnetic fields and photospheric plasma velocities. Coronal loops, composing the active region, are represented by magnetic field lines, anchored on the solar surface and computed by the extrapolation of the photospheric magnetic field measurements. Using analytic calculations, the model computes the transformation of the photospheric Poynting flux into accelerated electrons and protons and then into plasma heating.
Finally the calculated heating is introduced into a time dependent hydrodynamic calculation to model the coronal loop plasma response to that heating. With this model we estimate the accelerated electron and proton kinetic energies. Finally, we compute X-rays emitted by accelerated electrons when they interact with the dense chromosphere.

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Breath figures of two immiscible substances as a pathway to structure emulsions

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In this work, we report experimental results on the long term evolution of the Breath Figures BF) formed by vapors of two immiscible substances on a repellent substrate. The experimental setups comprising an open condensation chamber where the vapors are streamed at a controlled flow rate, wherein the substances are water and hexamethyldisyloxane (HDMSO) oil, which interact to each other during the BF evolution. At the beginning of each experiment it is observed that water condenses first and well after HDMSO does. This can be explained due to the difference of dew point temperature which delays the condensation of HMDSO vapor: water has higher dew temperature than HMDSO oil. Other factors could be the surface tension between the water vapor in the local atmosphere, and the surface tension respect the substrate of each substance. Therefore, the water droplet-pattern forms first and all the dynamics of this system depends on the amount of water condensed because the size of HDMSO oil droplets is limited to the empty spaces between water droplets, and time after, when the amount of HDMSO mass reaches certain occupation area, water and HDMSO interact to form chains and other soft arrangements with well-defined edges. These chains and arrangements could differ in size and in configuration depending on the saturation pressure of vapors flowed to the condensation chamber. We capture time series of digital images using a microscope and a magnification of 2X during the BF formation. Those digital images are processed with C++ routines with OpenCV's libraries. The main outcomes of this analysis are geometrical properties of the condensation patte (e.g. perimeter, centroid, area, eccentricity) Also a histogram of grayscale range is computed in local regions where the centroid of a droplet is detected and classified to distinguish whether observed droplets are made of water or oil. Time-resolved distributions of size of the complete droplet-pattern and separated water droplet-pattern and oil droplet-pattern are considered as inputs in the Smoluchowski's equation which is applied to obtain the potential coefficient of droplets interaction and to understand the rules of emulsion formation under controlled conditions. The results are applied to describe the droplet size evolution of other experiments wherein the flow rate of first vapor is interrupted until is obtain certain average radius of droplets, then the flow rate of the other vapor is maintained until the structure and a large arrangement is obtained. Our results and observations may lead to design structured emulsions.

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Nonequilibrium properties of Levy noises

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A system at equilibrium exhibits microscopic reversibility, i.e. any path in phase space is just as often traversed in one direction as that it is traversed in the backward time direction. On the other hand, microscopic reversibility implies a more general condition of the detailed balance which is the requirement that net flow between any two states is zero. Following definitions of detailed balance and microscopic reversibility, we show how Gaussian white noise can be associated with microscopic reversibility and how the presence of more general Levy fluctuations can lead to its violation. In our example the Levy noise itself is symmetric in the sense that each fluctuation in the positive direction is as likely as its negative-direction counterpart. However, when applied to a dynamic system within the Langevin formalism, the non-Gaussian Levy white noise leads to breaking of the time reversal symmetry pointing to its inherent nonequilibrium character. We extend this analysis to investigations of fluctuations in mechanical energy of a linear oscillator perturbed by Levy noise. Derived distributions of kinetic and potential energies in stationary states clearly deviate in this case from equipartition showing nontrivial correlation between the positions and velocities. We further discuss thermodynamic interpretation of energy flows in the system. In particular, we demonstrate that with Levy fluctuations the concepts of thermalization and equilibrium need be addressed with much care. First, Langevin equations driven by non-Gaussian Levy

white noises lead to non-Gibbsian stationary distributions. Next, the Levy noise has infinite variance and so there is no standard fluctuation-dissipation relation to connect the variance of the noise to the strength of the friction. This pathology does not take place however in cases when the noise is regarded as an external pulse-like forcing and not just as a part of the heat bath for the system at hand. Alltogether our work shows that actions of Levy fluctuations drive systems away from equilibrium states and are strongly manifested even in weakly perturbed linear systems.

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Finite-time and -size scalings in the evaluation of large deviation functions. Numerical analysis in continuous time

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Rare events and rare trajectories can be analyzed through a variety of numerical approaches, ranging from importance sampling, adaptive multilevel splitting to transition path sampling. Population dynamics provide a numerical tool allowing their study, by means of simulating a large number of copies of the system, which are subjected to a selection rule that favors the rare trajectories of interest. By exponentially biasing their probability it makes possible to render typical the rare trajectories of the original dynamics in the simulated dynamics.
The idea is to perform the numerical simulation of a large number of copies N_c of the original dynamics, supplemented with selection rules which favour the rare trajectories of interest. The version of the population dynamics algorithm introduced by Giardin, Kurchan and Peliti provides a method to evaluate the large deviation function (LDF) associated to the distribution of a trajectory-dependent observable. The LDF is obtained as the exponential growth rate that the population would present if it was not kept constant. Under this approach, the corresponding LDF estimator is in fact valid only in the limits of infinite simulation time t and infinite population size N_c. The usual strategy that is followed in order to obtain those limits is to increase the simulation time and the population size until the average of the estimator over several realizations does not depend on those two parameters, up to numerical uncertainties.
In a previous analytical study of a discrete-time version of the population dynamics algorithms, we derived its convergence-speed in the large-N_c, and -t limits to be $1/N_c$ and $1/t$, respectively. In principle, knowing the scaling a priori means that the asymptotic limit of the estimator in the $t \to \infty$ and $N_c \to \infty$ limits may be interpolated from the data at finite t and N_c. However, whether this idea is actually useful or not is a non-trivial question, as there is always a possibility that onset values of N_c and t-scalings are too large to use these scalings. Here, we consider a continuous-time version of the population dynamics algorithms. We show numerically that one can indeed make use of these scaling properties in order to improve the estimation of LDF, in an application to a many-body system (contact process).

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Synchronization and finite size scaling on hierarchical lattices

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We study the transition to synchronisation in hierarchical lattices[1] using the evolution of Chate Manneville maps placed on a triangular lattice. Connections are generated between the layers of the traiangular lattice assuming that each site is connected to its neighbours on the layer above with probability half. The maps are diffusively coupled, and the map parameters increase hierarchically, depending on the map parameters at the sites they are coupled to in the previous layer. The system shows a transition to synchronisation which is second order in nature, with associated critical exponents. However, the V-lattice, which is a special realisation of this lattice shows a transition to synchronisation which is weakly discontinuous [2,3]. This transition can thus be said to belong to the class of explosive synchronisation with the explosive nature depending on the nature of the substrate.
A finite time, finite size analysis was carried out for the order parameter for different lattice sizes for synchronization on the branching hierarchical lattice, where the order parameter is defined to be the fraction of synchronized sites of the maximal cluster on the lattice. In the case of the $V-$ lattice, the data for lattices of sizes for lattice sizes of order 20×20, 30×30, 50×50, and 100×100 was seen to collapse nicely on the same smooth scaling surface. Two dimensional slices have been used to find the scaling exponents. In the case of the branching hierarchical lattice, scaling analysis carried out the order parameter for the synchronizing realizations. The order parameter plotted as a function of the coupling parameter shows a dip at a certain value of the parameter, indicating that the tendency to synchronize decreases at certain parameter values. We discuss the implications of our results, and draw parallels with avalanche statistics on branching hierarchical lattices[1].

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Vortex states in Bose-Einstein condensates with a nonlocal interaction

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An action principle is proposed for the nonlocal Gross-Pitaevskii equation with an integral term due to long range, attractive forces.The main interest of the long range, attractive force is the realization of Bose-Einstein condensation without any external trap. The action principle is used in a time-dependent variational formalism, where the spatial form of the trial wave function is defined in advance, associated to vortex configurations. A suitable attractive interaction is proposed, modeling the off-resonant dressing of ground state atoms with high level Rydberg states. The effective model nonlocal potential is chosen so as to reproduce both strong van der Walls forces of Rydberg atoms at long distances, and the saturation of the attractive force at small distances, due to the van der Walls shift. Moreover, the parameters present in the effective potential are directly related to the physically quantities of the system, namely interaction strength, laser detuning and Rabi frequency. Using the Lagrangian method, the spatio-temporal problem is mapped into a set of nonlinear dynamical equations for the wave function parameters, with a two-dimensional confining potential well. The equilibrium vortex states and the linear oscillation frequencies are numerically obtained. The precise conditions on the nonlocal interaction strength are derived, allowing for bounded vortex linear oscillations. While previous studies relied on the stationary, equilibrium solutions, the present one allows the assessment of the time-dependent dynamics. Nonlinear oscillations are also numerically investigated. We perform the detailed comparison with the localized irrotational solution, known in the literature as Rydberg soliton, now extended to the non-stationary regime. Simulations are considered for a large span of interaction potential ratio between the coupling parameters of the contact repulsive and nonlocal attractive potentials in the condensate. The stability of the variational solution is briefly examined vis--vis direct numerical simulation of the nonlocal Gross-Pitaevskii equation. The results are useful for experimental realization of vortices in Bose-Einstein condensates without an external trap.

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Quasi volume law of entanglement entropy in nonequilibrium steady states

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Recently, the entanglement entropy S in ground states, i.e. equilibrium states at zero temperature, has been attracting much attention. In particular, its size dependence has been studied intensively. For the ground states of translationally-invariant (extensive) Hamiltonians in one dimension, it was revealed that $S = O(1)$ (i.e., area law) if the excitation spectrum has a finite gap, whereas $S = O(\ln L)$ (logarithmic law) for gapless systems of length L [1]. However, the case of nonequilibrium steady states (NESSs) is almost unknown, even at zero temperature.

To reveal the size dependence of S in NESSs, we study a mesoscopic conductor driven by electron reservoirs, using a well-established model that reproduces many experimental results. The model is a non-interacting electron system on a one-dimensional chain composed of a conductor of finite length and two reservoirs of semi-infinite length. There is a random potential of mean strength W in the conductor region, which causes multiple scatterings of electrons and the wavefunctions of electrons have complicated shapes.

We assume zero temperature for the reservoirs. Then, the total quantum state is simply given by a single Slate determinant of left- and right-coming single-particle states, which are occupied up to the two Fermi seas of left and right reservoirs, respectively. Since the total quantum state is pure, its entanglement entropy is the von Neumann entropy. The difference $\Delta\mu$ of the chemical potentials of the two Fermi seas induces a finite current in the conductor, and a NESS is realized. Using this state, we calculate S in the conductor, and examined its L dependence.

In equilibrium states ($\Delta\mu = 0$) without random potential ($W = 0$), we obtain $S = O(\ln L)$, in consistency with the previous result [2,3]. The same bahavior is obtained for equilibrium states ($\Delta\mu = 0$) with random potential ($W > 0$). However, the behavior changes dramatically in NESSs ($\Delta\mu > 0$) with random potential ($W > 0$). In this case we find an anomalous increase of S; $S = L\eta(L) + O(\ln L)$, which we call the quasi-volume law. Here, $\eta(L)$ is a positive function gradually decreasing with increasing L. Moreover, we find that the quasi-volume law appears only when both $\Delta\mu$ and W are non-vanishing. i.e., only when the driving force and multiple scatterings coexist.

We clarify the physical origin of the quasi-volume law.

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Generalized Gibbs ensemble in nonintegrable systems with an extensive number of local symmetries

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Recent experimental realizations of almost isolated quantum systems have encouraged theorists to study dynamics that follow unitary time-evolution. One of the important topics is whether systems approach stationary states that are described by the canonical ensemble. In nonintegrable systems that conserve energy alone, the canonical ensemble is justified by the eigenstate thermalization hypothesis (ETH). On the other hand, in integrable systems or systems that show many-body localization, the stationary state cannot be described by the canonical ensemble because of nontrivial conserved quantities. The generalized Gibbs ensemble (GGE) is a promising candidate for describing stationary states in integrable systems. The applicability of the GGE is verified for systems whose Hamiltonian can be mapped to a quadratic form or solved by

Bethe ansatz. These integrable systems have sets of conserved quantities from which each energy eigenstate can be identified. To clarify the importance of conserved quantities for the appearance of non-thermal stationary states, it is interesting to study models with less numbers of conserved quantities than the usual integrable systems. Previous studies showed two extreme cases: the stationary state seems to be described by the canonical ensemble if the system conserves only energy, and the GGE is necessary when sufficiently many conserved quantities exist so that every eigenstate is identified. Then, how many conserved quantities should systems possess for the appearance of the stationary states that are described by the GGE?

In this talk, we show that the stationary state is described by the GGE if the system has an extensive number of local symmetries, even when it is a nonintegrable system. We have investigated a nonintegrable model of hard-core bosons with an extensive number of local Z2 symmetries. We show that the expectation values of macroscopic observables in the stationary state are described by the GGE rather than the canonical ensemble. In this case, the usual ETH does not hold true. Instead, the ETH for each symmetry sector, which we call the restricted ETH (rETH), holds true. We argue that the rETH plays an important role for our system to approach the GGE. We have also examined models that have less numbers of local Z2 symmetries. We show that the canonical ensemble well describes the stationary states and that we do not have to use the GGE for these two models.

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History dependence and entropy How one can use entropy to solve Polya processes

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History-dependent stochastic processes are often non-ergodic and values of observables can no longer be predicted within the ensemble picture. The resulting mathematical difficulties pose severe limits to the analytical understanding of path-dependent processes. The statistics of such processes typically is not described by multinomial distributions. As a consequences, the multiplicities of similar paths of a process (or configurations of a system) is in general no longer given by the multinomial factor [1]. The maximum entropy principle based on Shannon entropy is tightly related to Bernoulli processes, systems with independent components, and to the ensemble picture; it loses its meaning for history-dependent processes, [2]. It is known that entropy, which takes the functional form of Shannon-entropy, is an equilibrium concept and that no unique generalization of entropy to systems operating out of equilibrium exist. However, this in fact implies that there may exist various useful generalizations of entropy to history-dependent processes, which all share the property that for Bernoulli processes they coincide with Shannon entropy, but take different functional forms if applied to other classes of processes. This is not entirely new. For instance, the information theoretic definition of entropy as information rates yields Shannon entropy for Bernoulli but the conditional entropy for Markov processes. Similarly, also the functional form of entropy used in maximum entropy principles to predict distribution functions, will depend on the process class of interest. Here we show how the ensemble picture can be avoided and the statistics of the underlying dynamical process is captured correctly in a functional that plays the role of a relative entropy, by construction. We demonstrate this for self-reinforcing Polya urn processes, which explicitly generalize multinomial statistics in a history dependent way. We demonstrate the adequacy of this constructive approach towards non-multinomial entropies by computing frequency and rank distributions of Polya urn processes [3].

We show how microscopic update rules of a path-dependent process allow us to explicitly construct a non-multinomial entropy functional, that, when maximized, predicts the time-dependent distribution function.

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Statistical mechanics of porous media flow

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Immiscible fluids fighting for the same pore space when simultaneously flowing in a porous medium produce complex and correlated structures which today may be modeled with a previously unattainable precision due to the rapid growth of both experimental visualization techniques (CT, MR etc.) and computational techniques (e.g. the Lattice Boltzmann algorithm). What is, however, still lacking today is a theoretical framework that describe these complex patterns; that is able to bind the observations and modeling together so that they become more than catalogues of data. I will in this talk review the current status on using statistical mechanics as a tool to device such a description.

I will demonstrate that the configurational probability, that is the probability that a given distribution of the immiscible fluids is proportional to the inverse of the total flow rate. This paves the way for a new Monte Carlo technique to simulate immiscible flow in porous media. An early version of this Monte Carlo technique was published in Ref. [1]. I will here present a new version of the technique which rectifies some weaknesses that has appeared in the published algorithm.

I will discuss the ensemble distribution relating the joint probability between different pore-scale parameters [2] such as flow rate and position of interfaces in the pores. I will present constraints on the form this distribution may take and demonstrate their physical consequences. I then use the ensemble distribution to construct a generating function that produces among other macroscopic flow parameters, the average flow velocity of each fluid and the volume flow rate of each fluid.

Lastly, I make contact between the statistical mechanics framework presented so far and non-equilibrium thermodynamics based on a budget of the entropy production in the system due to viscous dissipation. The interplay between

intensive and extensive variables plays a key role in this discussion.
This work has been done in collaboration with Dick Bedeaux, Signe Kjelstrup, Isha Savani, Santanu Sinha and Morten Vassvik.

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Quantum statistical mechanical design of nanomachines

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Nanomachines have been attracting much attention, and have been studied and developed both experimentally and theoretically in recent years. In particular, experimental studies of molecular machines have made remarkable progress, which, however, have been designed empirically or intuitively. Thus theoretical studies that are capable of providing some insights for those experiments are required.
We here propose a quantum statistical-mechanical method of designing nanomachimes that fully takes quantum effects and entropy effects into consideration. The method enable one to calculate properties and performances of nanomachines, including the response times when they are controlled by physical stimulations such as an external magnetic field. Furthermore, one can applies the method to any minute quantum system, so that the method will open a way to designing nanomachines made of almost minimum degrees of freedom.
We couple mainly two theoretical techniques for the method: One is the thermal pure quantum (TPQ) formulation of statistical mechanics [1, 2], which we here generalize to systems without translational invariacne to analyze nanomachines. The other is the Chebyshev polynomial expansion method [3], which we here apply to nanomachines with the help of the TPQ formulation.
As the first nanomachine that is obtained by our method, we present a novel minute machine whose shape is changed by application of a pulsed external field, like a catalyst whose catalytic property is changed by redox. The system shows a characteristic shape before application of an external field, and by application of a pulsed external field the system exhibits a uniform shape. Further application of an external field makes the system to show another characteristic shape. This shape can be erased by even further application of an external field. By utilizing both quantum effects and entropy effects, we realize this system on a lattice without fine tuning of parameters on individual lattice points and with the number of principal parameters less than the number of shapes the system shows.

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Statistics of the generalized maximum likelihood estimation in deformed exponential families

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An exponential family plays an important role in statistics and it is well-known that the maximum likelihood estimation can be geometrically explained in terms of information geometry. That is, an exponential family is a dually flat space with respect to the exponential and the mixture connections and the maximum likelihood estimator is obtained by the orthogonal projection of the mixture geodesic.
A deformed exponential family is a generalization of exponential families, which was originally introduced in the context of anomalous statistical physics [1]. From a viewpoint of information geometry, Matsuzoe and Henmi (2013) [2] showed that a deformed exponential family has two different kinds of dually flat structures as a statistical manifold. One of them is related with the U-divergence geometry in machine learning [3] and with robust statistics for the special case of q-exponential families. However, the statistical meaning of the other geometrical structure, which is a geometry of the generalized maximum likelihood estimation, is still not so clear although it seems to be quite natural from a geometrical point of view.
In this talk, we discuss a role and some properties of the generalized maximum likelihood estimation, which is defined by the maximization of the deformed log-likelihood function, in a deformed exponential family from a statistical point of view. Although there are some studies on it for an i.i.d. sample [4], [5], we especially focus on the case where there exists some correlation in the sample, which is implied by the generalized independence.

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Classification of 3D Kitaev spin liquids

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The Kitaev honeycomb model has become one of the archetypal spin models exhibiting topological phases of matter, where the magnetic moments fractionalize into Majorana fermions interacting with a Z_2 gauge field. In this talk, I discuss generalizations of this model to three-dimensional crystal structures; in particular, what types of metallic states the emergent Majorana fermions can form, and how these Majorana metals depend on the details of the underlying lattice structure. Besides (almost) conventional metals with a Majorana Fermi surface, one also finds various realizations of Dirac semi-metals, where the gapless modes form Fermi lines or even Weyl nodes. I also discuss how this zoo of gapless quantum spin liquid phases can be comprehensively classified using a projective symmetry analysis.

General theory of detrending-operation-based scaling analysis methods and applications

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Detrending-operation-based analysis methods such as detrending fluctuation analysis (DFA) and detrending moving average analysis (DMA) have become widely used to characterize long-range correlations and fractal scaling behaviour in nonstationary time series. Here we present a general framework by the example of DFA to facilitate the understanding of the mathematical foundations of such scaling analysis methods. DFA is based on the random walk theory and provides the fluctuation function which is the square root of the mean square deviations of the integrated time series substracted by a polynomial trend averaged over time windows of the same length. In our framework DFA can be described as mean square displacement statistics estimated by detrending-operation-based analysis with a displacement as weighted partial sum of the original series. Using this background we can derive a rigorous relationship between the fluctuation function of DFA and the autocorrelation function. The fluctuation function is an integral transform of the autocorrelation function with detrending kernel working as filter. This fluctuation function can be estimated via segmentation of the time axis just as it is originally constructed in DFA. With the relationship between the fluctuation function and autocorrelation function we can derive analytical solutions of the fluctuation function for short-range and long-range correlated processes. Thereby we investigate the long known problem of the crossover behaviour in the scaling of short-range correlated processes and provide an analytical expression of the crossover point which depends on the detrending order of the method and the characteristic correlation time of the process. This is important for practical applications where usually complicated trends exist. Furthermore our framework provides a tool to understand the detrending operation in the case of intrinsic nonstationarities such as fractional Brownian motion (FBM). By the construction of DFA only external nonstationarities are removed naturally. Nevertheless DFA with linear detrending also gives the correct scaling exponent for FBM. Our framework provides a unified picture of the detrending operation for both extrinsic nonstationarities such as trends and intrinsic nonstationarites such as fractional Brownian motion (FBM).

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Percolation transition to turbulence

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The transition to turbulence in simple shear flows (e.g. pipe, channel and Couette flow) has remained an open problem for over a century. Typically here turbulence arises despite the linear stability of the laminar flow and results from perturbations of finite amplitude. Turbulence at first appears in the form of localised patches (e.g. puffs, spots or stripes) which coexist with laminar flow, resulting in complex, disordered flow patterns (spatio-temporal intermittency).
Individual turbulent domains can collapse or they can proliferate and seed other patches of turbulence. The time scales on which flows evolve are extremely large and likewise are the relevant length scales. Characterizing the transition process hence requires experiments of very large aspect ratios and extremely long observation times. In detailed experiments and direct numerical simulations of Couette flow we could for the first time determine the critical exponents that characterize this transition and show that it falls into the directed percolation universality class.

Study of nonlinear kinetic equation for grain growth

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The motivation for this study is the technological process of sintering. During this process grains of ceramic powders are compacted to a single body without grain liquefaction by exerting heat and/or pressure. Sintering is a complex process in which many physical mechanisms contribute. A common observation in sintering studies is that grains (crystallites) grow either normally, leading to a uniform grain distribution, or abnormally leading to large non-homogeneities in grain size.
We study a nonlinear kinetic model of mass exchange between interacting grains introduced in [1]. The transition rates follow the Arrhenius equation with an activation energy that depends dynamically on the grain masses and an activation parameter. In the two-grain system the activation parameter can be absorbed in the initial conditions for the grain masses, and the total mass is conserved. We obtain numerical solutions of the coupled, nonlinear, ordinary differential equations of mass exchange for the two-grain system, and we compare them with approximate theoretical solutions in specific neighborhoods of the phase space. Using phase plane methods, we determine that the system exhibits regimes of diffusive (normal) and growth-decay (abnormal or reverse diffusion) kinetics. The equilibrium states are determined by the initial conditions, and they are defined by the mass equipartition and mass separation nullcline curves.
Using numerical simulations we show that the grain system maintains the diffusive and growth-decay regimes, even if the transfer rates are perturbed by white noise. However, the presence of the noise can reverse the sign of the equilibrium mass difference leading to the growth of the initially smaller grain at the expense of the larger.
We also investigate a multi-grain chain with nearest-neighbor interactions. Diffusive (normal) and growth-decay (abnormal) regimes are established as well, but the approach to equilibrium is considerably slower than in the case of the two-grain system and includes non-monotonic changes of grain mass. We then add a cellular automaton step to the evolution of the system which enforces the coalescence of neighboring grains if their size ratio exceeds a specified threshold. We study the average grain radius evolution of the modified system as a function of the activation parameter, and we compare the temporal evolution of grain sizes with the Ostwald ripening coarse-graining behavior.

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A connection between the damped harmonic oscillator in a heat bath and spatial data modeling

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The problem of missing spatiotemporal data is common in signal and image processing applications. Environmental data sets often include gaps, due to incomplete time coverage, sensor failures, or measurement problems. For example, parts of remotely sensed images may be obscured by clouds, aerosols, or heavy precipitation. The continuously increasing volume of spatial information calls for efficient data reconstruction and simulation methods. Such tasks can be performed with geostatistical methods from Spatial Statistics or with Gaussian Process Regression methods from Machine Learning. Both frameworks rely on the use of covariance functions. The latter incorporate the spatial correlations of the studied process and are thus instrumental in the formulation of predictive equations.
In this presentation we focus on a family of so-called Spartan covariance functions which were developed using a Gibbs random field with a specific energy structure [1]. This random field is equivalent to a statistical Gaussian field theory. Spartan covariance functions include an additional parameter compared to standard covariance models (e.g., Gaussian, exponential). The rigidity parameter describes the resistance of field realizations to gradients. We show that the Spartan covariance function is corresponds to a classical, d-dimensional-time, damped harmonic oscillator in a heat bath. This system is described by a stochastic partial differential equation driven by white noise. Only a handful of covariance functions with explicit expressions are solutions of partial differential equations that result from stochastic partial differential state equations (to our knowledge only the Spartan and the Whittle-Matern [2] covariance functions share this property. Covariance functions originating from ordinary differential equations, such as the OrnsteinUhlenbeck process, are more common [3].
We also show that the trajectories of the noise-driven classical damped harmonic oscillator can be expanded within a compact time or space interval as a bi-orthogonal series of eigenfunctions with random coefficients using the Karhunen-Loeve (K-L) expansion [4]. The K-L expansion allows reduction of dimensionality and efficient simulation of time series and random fields with Spartan covariance functions. Variations of the rigidity coefficient of a Spartan random field or process with a given correlation length can further decrease the random dimensions needed in the expansion.

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The square lattice Ising model on the rectangle

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The partition function of the square lattice Ising model on the rectangle, with open boundary conditions in both directions, is calculated exactly for arbitrary system size $L \times M$ and temperature. We start with the dimer method of Kasteleyn, McCoy & Wu, construct a highly symmetric block transfer matrix and derive a factorization of the involved determinant, effectively decomposing the free energy of the system into two parts, $F(L,M) = F_{\text{strip}}(L,M) + F^{\text{res}}_{\text{strip}}(L,M)$, where the residual part $F^{\text{res}}_{\text{strip}}(L,M)$ contains the nontrivial finite-L contributions for fixed M [1]. It is given by the determinant of a $M/2 \times M/2$ matrix and can be mapped onto an effective spin model with M Ising spins and long-range interactions. While $F^{\text{res}}_{\text{strip}}(L,M)$ becomes exponentially small for large L/M or off-critical temperatures, it leads to important finite-size effects such as the critical Casimir force near criticality.
In the finite-size scaling limit $L, M \to \infty$, $T \to T_{\text{c}}$, with fixed temperature scaling variable $x \propto (T/T_{\text{c}} - 1)M$ and fixed aspect ratio $\rho \propto L/M$, we derive exponentially fast converging series for the related universal Casimir potential and Casimir force scaling functions [2]. At the critical point $T = T_{\text{c}}$ we confirm predictions from conformal field theory. The presence of corners and the related corner free energy has dramatic impact on the Casimir scaling functions and leads to a logarithmic divergence of the Casimir potential scaling function at criticality.

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Percolation controls on vegetation growth and soil formation

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Topics of interest for North Sea oil exploration as investigated by Gene Stanley and associates include solute transport times and distances in disordered networks that represent the pore space. The theoretical results were expanded to treat disordered networks with a wide range of pore sizes. The most important percolation parameters turn out to be the fractal dimension of the backbone and for optimal paths. The theory turned out to predict entire solute arrival time distributions without use of adjustable parameters. Near the Earths surface, solutes transported vertically by rainwater, and described by 3D backbone fractal dimensionality, relate to the formation of soil. Plant roots search for nutrients in the top decimeters of the soil, with growth controlled by 2D optimal paths exponent. Derived results turn out to describe the spatio-temporal scaling of vegetation growth and soil formation. In each case the fundamental spatial scale is fixed by the pore separation, most commonly about 30 microns, while the time scale is fixed by the pore size and the water flow rate, corresponding to deep infiltration for soil formation and transpiration for plant growth. Problems disturbing plant physiologists and ecologists, to those of carbon cycling and chemical weathering are solved simultaneously. In vegetation growth, these span the range from the size dependence of

trees of the same species on substrate, soil characteristics, fertilization, climate, and topography, to discrepancies in allometric scaling, the scaling of net primary productivity on transpiration, and the ability to predict the maximum underground size of vegetation on time scales up to 100,000 years. In the area of soil formation, the time scales treatable predictably exceed 50 million years, and the problems solved include the dependence of calcic and gypsic horizon depths on precipitation and evapotranspiration, as well as soil formation rates with their dependence on climate and topography, slope and surface water convergence, and erosion rate. Related problems that are solved include soil C and N sequestration rates, and the puzzling behavior of the field rates of chemical weathering. To give specific examples of just one relationship, we find that steady-state soil depths are given as the product of the particle size and the ratio of the soil infiltration rate to the erosion rate to the power 1.15. This result generates soil depths within 20 or 30% of observed soil depths around the world.

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Addressing the challenges in hydrology with percolation theory

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It has been decades since groundwater hydrologists, attempting to predict flow, together with conservative, and reactive solute transport, became aware of the necessity of addressing the complications of structural disorder, connectivity, and scale. Although many techniques have been applied, and are mentioned in the workshop description, one technique that is absent is percolation theory, which addresses the scale and heterogeneity dependences of such properties by upscaling the connectivity. Percolation theory is applicable not only to systems in which flow or conduction is either allowed or disallowed, but also to those systems where local flow rates are distributed over a wide range of values, such as in pore networks with widely varying geometrical characteristics. In such a case, percolation theory applied to a network model of the pore space describes the upscaling of the dominant flow paths and the associated effects on transport, including scaling of the dispersivity, solute velocity, and moisture transport. Applications of these results are to a fully predictive treatment of the climatic, substrate, and time dependence of soil development, as well as the scaling of chemical weathering and other reactions in porous media. Further, the entire context of the discussion regarding scaledependent geostatistical properties (variograms), hydraulic conductivity, and dispersivity is changed. When, in the context of ecohydrology, interactions between plant roots and the soil are considered, treatments of the soil as a network using percolation concepts lend themselves to predictions much more naturally than do the standard differential equation treatments of solute and moisture transport. In particular, it becomes possible to predict vegetation growth rates as a function of transpiration and of time. Combined with the predicted scaling of vertical and horizontal moisture transport (transpiration), it becomes possible to predict net primary productivity and its dependence on transpiration. Additional problems that can be solved within this framework include the spatial-, substrate-, climatic-, and soil characteristic-dependences of tree growth rates, and the observed relationship of tree diameter to height. These results represent solutions to problems that have evaded other researchers using different methods, and show the advantage in matching across the land surface the network models of plants and soils.

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Structure and spontaneous symmetry breaking in the fluctuations of driven systems

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Macroscopic fluctuations have become an essential tool to understand physics far from equilibrium. This interest is rooted in the prominent role that fluctuations play in equilibrium, where their statistics is directly linked to the relevant thermodynamic potentials via the Einstein formula. Similarly, it is nowadays expected that a deeper understanding of nonequilibrium fluctuations will pave the way to a sound definition of nonequilibrium potentials, though we already know that these functions do typically have some striking features peculiar to nonequilibrium behavior (as e.g. non-local behavior leading to long- range correlations).
The optimal path leading to a fluctuation encodes key information on this problem, shedding light on e.g. the physics behind the enhanced probability of rare events out of equilibrium, the possibility of dynamic phase transitions and new symmetries. This makes the understanding of the properties of these optimal paths a central issue. In this talk we will unveil a fundamental relation which strongly constraints the architecture of these optimal paths for general d-dimensional nonequilibrium diffusive systems, and implies a non-trivial structure for the dominant current vector fields. Interestingly, this general relation (which encompasses and explains previous results) makes manifest the spatio-temporal non-locality of the current statistics and the associated optimal trajectories.
Another key problem concerns dynamic phase transitions (DPTs) at the fluctuating level. DPTs constitute one of the most intriguing phenomena of nonequilibrium physics, but their nature in realistic high-dimensional systems remains puzzling. In this talk we will also describe a DPT in the current statistics of an archetypal two-dimensional (2d) driven diffusive system, and characterize its properties using macroscopic fluctuation theory. The complex interplay among the external field, anisotropy and currents in 2d leads to a rich phase diagram, with different symmetry-broken fluctuation phases separated by lines of 1st- and 2nd-order DPTs. Order in the form of coherent jammed states emerges to hinder transport for low-current fluctuations, revealing

a deep connection between rare events and self-organized structures which enhance their probability, an observation of broad implications.

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Autonomous thermal motors

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We present a minimal model of autonomous thermal motor, made of two interacting Brownian particles, sitting on two periodic potentials, and kept at different temperatures. We show that such a system does not require ratchet potentials (with, e.g., an asymmetric saw-tooth shape) in order to exhibit direct transport, but presents a spontaneous symmetry breaking.
Both the dynamic and thermodynamic properties of the model are discussed.
We find that while the model can be solved exactly in the limit of strong coupling between the particles, the optimal operation regime occurs at moderate coupling strength.

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Positioning experts in knowledge networks

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Knowledge has been recognized as the keynote for economic growth [1]. As innovative firms are highly knowledge-based, the effective management of Knowledge Networks is the key for attaining competitive advantage [2]. Applications of Knowledge Networks Analysis already include consulting firms, manufacturing firms, telecommunications firms, healthcare and pharmaceuticals industry, biotechnology industry, banks and financial services companies, petroleum companies, strategic alliances, etc [3]. Knowledge attainment is conditioned by two main factors: (1) the order of implementation of Selection (s) and Filtering (f) by the agents of the network, and (2) the position of the highly knowledgeable agents (experts) within the network. Knowledge attainment can be accelerated by implementing Filtering before Selection (sf prioritization), compared to the conventional prioritization Filtering after Selection (fs prioritization). The sf prioritization is more efficient simply because every Selection (s) realized for obtaining knowledge after Filtering (f) is fruitful, resulting certainly in some knowledge upgrade. In this way, there is no waste of valuable time. The non-commutativity of Selection (s) and Filtering (f) reveals a Non-Boolean Logic of these two network operations. We investigate here two key questions: (Q1) How is Knowledge Dynamics influenced by positioning experts randomly or on central positions, with respect to selected centralities (Degree, Closeness, Betweeness, Eigenvector), and (Q2) How the order of implementation of Selection (s) and Filtering (f) is influencing the effect of positioning experts in the network? These two questions are addressed in terms of Knowledge Attainment Times and Knowledge Attainment Diagrams. Results are presented for 4 typical classes of network structures, namely (i) Regular, (ii) Random (Erds-Rnyi Model), (iii) Small-World (Watts-Strogatz Model), (iv) Scale-Free (Barabsi-Albert Model). The main result found is that implementing Filtering before Selection (sf prioritization) is much more important than positioning experts in central positions. Therefore, if agents are Selecting (s) after Filtering (f), then knowledge is diffusing fast, regardless the location of experts. The real-world implication is that knowledge-based organizations should establish appropriate Net-Awareness procedures, operating in real time.

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Effect of mass media, word-of-mouth and town rumor in social media reputation analyzed using social physics approach

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Searching for equations describing the behavior and decision making of people in society is a major goal of social physics. Since interest in entertainment is far away from the daily life of people, it can be said that it is the simplest problem as people's decision making in society. There is a mathematical model of hit phenomenon as the theory of social physics dealing with this problem[1]. In the mathematical model of the hit phenomenon, we think that there are three means for people in society to get information, influence of mass media, information from friends, and rumors in town.
Consider a differential equation describing the interest of a person with specific topics. We treat the influence of mass media as external force. Information from a friend is considered to be a two-body interaction with a friend. Rumors in the street are considered by three body interactions, thinking that another person hears the conversation of the two people. The mathematical model of the hit phenomenon thus constructed well describes people's interest in entertainment[2].
In this research, we take hydrogen water which was popular in Japan in May 2015 as an example. Think about the role of mass media, information from friends, rumors in town, and how they each play their roles by comparing model calculations with analysis of hydrogen water on actual social media. Actual reputation on social media is analyzed by the mathematical model of hit phenomenon. In model calculation, analysis of actual reputation and parameters are changed to investigate the difference.
As a result obtained, there was a limit to becoming a reputation on social media only by the influence of mass media, and it was shown that word-of-mouth and town rumors are important.

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Property price distributions of Taiwan and the UK

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Many complex systems exhibit heavy-tailed distributions in observables that characterise the systems in question. Amongst these are naturally occurring phenomena such as wildfires, ranking of words used in literature, earthquakes or landslides.
In this work we add to the above knowledge by reporting on the residential property price distributions of Taiwan and the UK.
The behaviour of residential house prices in the UK and elsewhere has attracted growing interest in recent years. This is, perhaps, not surprising as prices appear to have only recently come out of one of their prolonged downturns in the UK.
The residential property markets of Taiwan and the UK, which are markedly different to each other, are analyzed, and compared and contrasted. Whereas for the Taiwanese market, the main interest lies in the footprint (area) of the property, for the UK market, the focus tends to be on the number of bedrooms. Of course, the area covered by the property is also an important factor in the UK but the headline figure tends to be the number of bedrooms (as well as the location).
We study the tail of the cumulative distribution function and find that it follows an approximate power law. The exponent for the data from Taiwan is compared and contrasted with that from the UK. We find that the house price per unit area in Taiwan and property prices in the UK display a log-normal distribution. We discuss the implications of our results.
For the UK housing market, we also study the variations in property prices since 1953 by evaluating three different measures of inequalities for similar properties in different regions of the country: the Gini index, the squared coefficient of variation and the mean logarithmic deviation. The three different measures are tracked over time, highlighting key features in property prices. Of the three measures studied, we find that it's the Gini Index which is the most useful for our purpose. Indeed, we find that the Gini index increases when the underlying market prices are also increasing and, hence, indicates that there is greater variation (inequality) in property prices in a rising market. This conclusion is consistent with a recently proposed Housing Wealth Inequality Index.

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Symbolic co-occurrence networks in bird calls, human music, and other language forms

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We characterize and compare symbolic co-occurrence networks in animal sounds, language forms, and music networks. Finding common motifs and degree distribution patterns in these symbolic networks may provide insight to the evolutionary history of these forms. Music, for example, remains a problem to scientists since it provides no clear direct developmental advantage. A previous study has discussed a possible shared pre-cursor (a protolanguage) for music and language characterized by an intermediate evolutionary communication system more similar to music than known spoken language [1]. Previous comparative studies focus more on how humans perceive and process them as information [2].
A complex network is a system of interconnected components called nodes. These components are connected by edges, which may represent any form of relationship. Complex networks have been used on written language by treating texts as interconnected systems, and analyzing semantic and structural characteristics [3].
Bird calls were obtained from various sources, and transcribed musical scores of Filipino folk songs were obtained from the University of the Philippines. The nodes in the co-occurrence networks represent each note (pitch) in the bird call or folk song, and weighted edges denote the duration between consecutive notes.
Poems were acquired from PoemHunter.com, and prose from Project Gutenberg. Letter networks were made from texts not included in previous data sets. Chinese character (logograms) networks were constructed from a translated Bible online. The text was divided into 1,180 chapters to produce parts of comparable length. Unique words, letters, or characters were represented as nodes, and are connected by an edge if they appear consecutively in the text.
The mean degree distribution of letter, poetry, and Chinese character networks followed a power law. Thus, the most common elements in each text have exponentially higher frequencies than the rest. Texts with lesser unique components have exponentially higher word repetitions than larger texts.
Music networks have more repetitive small subgraphs compared to language networks, which confirms that more complex bird calls are characterized by repetitive notes [4], and folk songs by short, repetitive melodic patterns. Chinese characters, prose, and poetry networks have comparable average shortest path lengths. Thus, Chinese characters behave more like words and phrases (semantics) than letters (phonetics) [5].

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Parameter estimation via reluctant discrete quantum walks: an operational approach

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We consider the applicability of the maximum likelihood formalism for inference and parameter estimation, in the context of measurement on quantum simulations. We set up the likelihood function, and consider the maximum likelihood estimation of a free parameter which controls the behaviour of a quantum system. Specifically, we reformulate such problems in terms of an equivalent quantum random walk scenario: the estimation, via position measurements on the walker, of the parameters of the reshuffling operator in the coin space of the walker.
In the simplest case, this parameter is the angle of an orthogonal rotation in a two dimensional coin space. We investigate the case of the 'reluctant' quantum walker, which, after k steps, is always measured to be displaced from its initial position by a fixed number d of lattice units. As the number of evolution cycles increases, the likelihood function exhibits ever sharper maxima at certain rotation angles θ^*, governed by the 'reluctance index' $r = k/d$, which gives rise to the possibility of reliable and accurate parameter estimation.
A quantum channel formulation of the original quantum walk provides for an operational approach to the determination of likelihood-maximizing intervals, and its optimal value therein.

For the periodic case, and with a unitary reshuffling matrix operating on the compound coin-walker system, the maximum likelihood analysis is shown to lead to a measurement problem for a novel quantum system, describing circularly coupled quantum walks on a ring lattice.
For this work we develop novel analytical expressions for the probability distribution function and likelihood function of the walker, in the case of a two dimensional coin space, for the random walker on the line, or on a discrete interval (including periodic boundary conditions). The technical details rely on well-known properties of generalized Laguerre polynomials, arising from traces of powers of the 2×2 coin reshuffling matrix. For example for the 'very reluctant' walker which always returns to the origin with $d = 0$, the outcome is a ${}_2F_1$ polynomial, sharply-peaked around $\theta^* = \frac{1}{2}\pi$.

Evolutionary dynamics of neighborhood economic status in cities

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We extend our variant[1] of the Schelling mode[2]l incorporating an agent wealth gain function to study the long term evolution of the economic status of neighborhoods in cities. We find that the long term patterns of neighborhood relative economic status (RES) simulated by this model reasonably replicate the empirically observed patterns from American cities[3]. Specifically, we find that larger fractions of rich and poor neighborhoods tend to, on average, retain status for longer than lower- and upper-middle income neighborhoods. The use of a Potential function that measures the relative wealth of neighborhoods as the basis for agent wealth gain and agent movement appears critical to explaining these emergent patterns of neighborhood RES. This also suggests that the empirically observed RES patterns could indeed be universal and that we would expect to see these patterns repeated for cities around the world. We also find that the sharp transformation from a segregated to de-segregated state we observed in the earlier model still obtains in the current model as well.
We have here extended our variant of the Schelling model to study the long term behavior of economic status of neighborhoods in cities. We add a simple wealth increment function and find that the model reasonably replicates the empirically observed patterns of neighborhood economic status over long periods of time. Very rich and very poor neighborhoods tend to retain status more often than middle income neighborhoods. The use by agents of simple heuristics, such as the Potential function, to compare the wealth of their neighborhoods relative to the wealth of the city in deciding if they want to move neighborhoods or stay back appears significant in driving the dynamics that yield the observed patterns of neighborhood economic status. We also find that our previous result on the sharp transformation from a segregated to a de-segregated state upon the realization of disallowed moves (moves in contravention of the threshold condition) still holds in the modified model. The Schelling model therefore offers an excellent basis to study not only segregation but also the long term evolution of neighborhood economic status in cities.

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Non-additive entropies for black holes?

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One of the most fundamental proposals of the last few years has been the holographic principle, which states that the effective degrees of freedom of a system reside at its boundary rather than its bulk. A concrete realization of this principle is the gauge/gravity duality (AdS/CFT correspondence) which has attracted very substantial attention, in the community of string theorists and some condensed matter physicists.
The motivation for the formulation of the holographic principle lies In the thermodynamic entropy of black holes, which shows that is it proportional to the boundary area rather than the bulk volume of a space-like section of a properly defined horizon. The microscopic origin of the black hole entropy, has been a subject of much speculation during the last four decades. Due to lack of experimental data, there is a feeling that it is unlikely that it will be definitively settled In the near future. However, the form of the black hole entropy is a litmus test that is widely believed that any credible candidate for a quantum of gravity should confront and pass.
A recent proposal has been to use non-additive entropies in an attempt to reconcile the holographic principle with the more conventional statistical systems. This is reasonable and largely expected, especially since the non-additive entropies seem to involve systems with thick boundaries where the marginal probabilities between such systems and the environment do not factorize. In particular, an interpolation between the Boltzmann/Gibbs (exponential) and the Tsallis (power-law) entropies has been put forth as a form that may have a role to play in this direction.
In this talk, we state that this is not necessarily so: it is entirely possible that the Boltzmann/Gibbs entropy may be adequate. The issue remains largely unsettled.
We begin by examining the concept of the interior volume of a black hole, a concept that does not have an invariant meaning, but is completely observer-dependent. This is in stark contrast to the area of a spacelike section of the horizon of a black hole. We examine some recent proposals for definitions and corresponding calculations of the volume of the interior of a black hole and conclude with a speculation regarding the relationship between hyperbolicity and the holographic principle.

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The Legendre transform and non-additive entropies

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Our goal is to elucidate the properties and the underlying dynamics of systems described by non-additive entropies. We expect that, on the way, we should also get a better understanding that may allow us to choose which entropic functional should be most appropriate for which system. In this work, we argue that the conventional Legendre transform that is extensively used in Classical Mechanics, Statistical Mechanics, Thermodynamics, Quantum Field Theory etc, has to be modified In the case of systems described by non-additive entropies.
We use a combination of statement from the theory of optimal transportation on the one hand, and convex geometry/analysis on the other hand. To be concrete in our proposal, we apply the underlying argument to the case of the Havrda-Charvat / Vajda / Daroczy / Lindhard-Nielsen / Cressie-Read / Tsallis

entropy. We point out its pertinent convexity displacement properties that naturally lead us to the use and significance of s-concave functions. We combine this with some relatively recent results of Artstein-Avidan, Milman and Klartag which study the Legendre transform in such spaces of functions, propose a modification that preserves its essential properties and eventually prove its uniqueness for the class of s-concave functions.
If true, the present proposal may have far-reaching consequences for the use of Legendre transforms in Physics. Such transforms cease to have a universal form in Statistical Mechanics and Thermodynamics and their use should largely depend on the convexity properties of the corresponding entropic functional. As a result, the thermodynamic formalism based on the non-additive entropies may have to be reworked to reflect the current suggestion.
Naturally the ultimate test of such a suggestion is the confrontation of its predictions with experimental data. Due to the difficulty in performing explicit analytic computations for most models conjecturally pertinent to non-additive entropies, the present work can also be partly checked by performing numerical computations on such models.
More details about this proposal can be found in the preprint by the author The Legendre Transform in Non-additive Thermodynamics and Complexity available as arXiv:1704.08508 and references therein.

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Spectral properties of atoms/ions in kappa-distribution plasmas

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The study of atomic systems under the influence of plasma environments is of great importance as this process has been used for plasma diagnostics and several other spectroscopic applications. Several spectral or structural properties of plasma-embedded atoms, ions, molecules have been studied extensively within the framework of weakly coupled plasma environments ([1], references therein). In weakly coupled thermal plasmas, the screened interaction between the plasma particles can be modeled by the standard Debye-Hückel potential obtained by the thermal Maxwellian distributions. It is well-known that charged-particle velocity distributions in space and astrophysical plasma environments are commonly non-Maxwellian. In space environments, plasmas are generally observed to possess a non-Maxwellian high-energy tail that can be well-modeled by a generalized Lorentzian (or kappa) distribution function containing the spectral index κ [2]. The kappa distribution provides a replacement of the Maxwell distribution when dealing with systems in stationary states out of thermal equilibrium. Investigation on atomic processes in non-Maxwellian plasma environments has also been performed in the recent years ([3], references therein). The details of atomic processes in weakly coupled thermal (Maxwellian) and weakly coupled nonthermal (non-Maxwellian) plasma environments can be found from the earlier works [1, 3], reference therein. In the conference, we intend to present our most recent works on the plasmas screening effects on transition wavelength and polarizability of atoms/ions in kappa-distribution plasmas.

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Stepwise magnetization curves and anomalous thermodynamics of an exactly solvable spin-1/2 Ising-Heisenberg branched chain

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The spin-1/2 Ising-Heisenberg branched chain composed of regularly alternating Ising spins and branched Heisenberg dimers is rigorously solved in a presence of the external magnetic field by the transfer-matrix approach following the partial trace over degrees of freedom of the Heisenberg dimers. The magnetic structure of the investigated spin-1/2 Ising-Heisenberg branched chain is inspired by the magnetic structure of the heterometallic one-dimensional coordination polymer [(Tp)2Fe2(CN)6(OAc)(bap)Cu2(CH3OH).2CH3OH.H2O] (HOAc = acetic acid, Tp=tris(pyrazolyl)hydroborate, bapH = 1,3-bis(amino)-2-propanol), which incorporates the highly anisotropic trivalent Fe(3+) cations and the almost isotropic divalent Cu(2+) cations [1]. Within the framework of exact transfer-matrix calculations we have examined in detail the magnetization process and basic thermodynamic quantities (entropy, specific heat, susceptibility). We have found three different ground states depending on a mutual interplay between the magnetic field, Ising and Heisenberg coupling constants, two of which have character of the quantum antiferromagnetic phase and the quantum ferrimagnetic phase, while one ground state is the classical ferromagnetic phase. The two quantum ground states are manifested in zero-temperature magnetization curves as intermediate plateaux at zero and one-half of the saturation magnetization, respectively. The quantum antiferromagnetic state presented as the zero magnetization plateau occurs regardless of the relative strength of the interaction parameters, while the quantum ferrimagnetic state presented as the intermediate one-half magnetization plateau emerges only if the relative ratio between the ferromagnetic Ising interaction and the antiferromagnetic Heisenberg interaction is sufficiently small. Interestingly, the two quantum ground states with an outstanding quantum entanglement of the Heisenberg spin dimers coalesce with the trivial fully polarized ferromagnetic state at a special triple point. It will be demonstrated that one detects anomalous thermodynamics in a vicinity of the triple point as well as in a close neighbourhood of phase boundaries between individual ground states.

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Measuring 2-time correlation functions in many-body quantum systems

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Dynamic (2-time) correlation functions have widespread applications in theoretical statistical physics, both in and out of equilibrium. In quantum systems these correlation functions are complex-valued quantities, and their experimental accessibility is complicated by measurement backaction. To facilitate measurements of 2-time quantum correlations we introduce a protocol based on weak ancilla–system couplings, which reduces disturbances due to the early-time measurements to a minimum. Different choices of the coupling operator give access to the real and imaginary parts of the dynamic correlation function. For spin-1/2 models and single-site observables we prove that measurement backaction can be avoided altogether, allowing for the use of ancilla-free protocols. Through these results, experimental measurement of dynamic correlations in nonequilibrium quantum systems becomes feasible, and may be used for the detection of ageing in quantum glasses and other statistical physics applications.

Implementations of the protocol in trapped ions and other experimental platforms are discussed. An outlook will be given on the measurement of out-of-time-ordered correlation functions. (Preprint available at arXiv:1611.08123.)

Order parameters in the cuprate superconductors and the new fermion index

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We perform a systematic microscopic study of order parameters such as charge density wave (CDW) and pair density wave (PDW) for the copper oxide high T_c superconductors (cuprates). There are ample relevant experimental data on these order parameters, calling for elucidation of their origin, and pointing to concrete directions for the understanding of the true ground states in these important materials.
In our previous work G. Kastrinakis, Ann. Phys. **349**, 100 (2014), hereafter (I), the new fermion index was introduced. This is, roughly, an additional degree of freedom for all fermions, and for the electrons in particular. It allows for complex correlations between electrons to be systematically accounted for, something which is otherwise impossible in the thermodynamic limit. This index has no classical analogue, does not correspond to an observable, and is consistent with known fermionic physics.
In this work, we treat a single band model for the cuprates. We use realistic band structures and realistic (non-separable) fully momentum dependent electron-electron potentials.
Using the new index, we assume simultaneous correlations between singlet electron pairs with momenta $(k, -k)$, (k, k_*), and $(k, -k_*)$, where $k_* = (k_x, -k_y)$. These correlations are incorporated in an appropriate variational wavefunction, as in (I). There is no a priori restriction on the momenta k which may (or not) participate in these correlations, which are responsible for charge density wave and pair density wave orders. This procedure allows for the (highly complex) self-consistent numerical calculation of the ground state and, subsequently, of various observables.
We compare our results for charge density wave and pair density wave orders with relevant (uni-directional etc.) experimental data (X-ray diffraction, nuclear magnetic resonance etc.) for a range of system parameters. These include the electron filling factor, the band structure parameters, and the type and strength of the potential used. The ground states have characteristic unusual fermionic occupation factors equal to *one half* (instead of unity - c.f. (I)) deep below the Fermi surface.

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Numerical simulation of Barchan Corridor using a lattice model

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Sand dunes are found in many places such as deserts, the sea bottom and the surface of Mars. They are formed through interplay between sand and air flow or water flow. When a strong flow blows, sand grains are dislodged from the sand surface. The entrained sand grains collide with the ground and are sometimes deposited. This process takes place repeatedly, resulting in the formation of a dune. The profile of the wind flow is modified by dune topography. Most fascinated dune is barchan, which is crescent dune. These barchans often present a corridor-like structure. Thus we reproduced many barchans in numerical simulations and investigate the dynamics.
The motion of sand grains is realized by two processes: saltation and avalanche. Saltation is the transportation process of sand grains by flow. The saltation length and saltation mass are denoted L and q, respectively. Saltation occurs only for cells on the upwind face of dunes. The saltation length L and the amount of transported sand q are modeled by the following rules, L = a+bh(x,y,t)-ch2(x,y,t), where a=1.0, b=1.0, and c=0.01 are phenomenological parameters. The last term is introduced for L not to become too large. Note that L is used only in the range where L increases as a function of h(x,y,t). The saltation mass is fixed at 0.1 for simplicity. In the avalanche process the sand grains slide down along the locally steepest slope until the slope relaxes to be (or be lower than) the angle of repose which is set to be 34^0.
We reproduced a few hundred of barchans in numerical field by above model. Barchan releases sand from tips of two horns. The downwind barchan can capture the sand stream. Also, barchans sometimes collide each other. These direct and indirect interaction forms complex barchan fields. The size distribution of a few thousand of barchans is fitted by lognormal distribution well. This indicated that the small barchans exist around the large ones and the large barchans are around small barchans. The average size of barchans increase as the amount of supplied sand do. Next, when two barchan corridors collide, the size of barchan in the boundary between corridors has two type. Type (I) is not decoupling distribution, which shows superposition of each distribution. Type (II) is a distribution of uniform size. Through collision and inter-dune sand stream, the size of each barchan become uniform.

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Soliton excitations in a polariton condensate with defects

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We consider a polariton Bose-Einstein condensate with defects. We describe it by Gross-Pitaevskii equation with an additional term which takes into account the finite lifetime of the polaritons. We want to study soliton excitations in this system. We use the Madelung transformation to obtain .hydrodynamic equations from the Gross-Pitaevskii equation.. The reductive perturbation method reduces these hydrodynamic equations into a modifed Korteweg-de-Vries equation in the long wavelength limit.. The resulting equation can have solitons as solutions when the damping and the external potential equal zero. We have chosen a set where the damping and the defects are non-zero but small enough to be treated as perturbations; we have written the solution of the system as a sum of a soliton function and a response function. In the case of traveling excitations, a full analytical solution is given using the variation of constants method. The results are valid for any external perturbation . We calculated the solution for a constant perturbation and noticed that it deforms the soliton in an asymetrical way., we have noticed that the response function always oscillates. So the external perturbations (damping and defects) disturb the solitons: they make dark solitons oscillate. We have found that the response function is more sensitive to the damping than to the external potential intensity.
In a more general form of excitations we have solved the Gross-Pitaevskii numerically. We notice that the response function always oscillates around an equilibrium value. These oscillations exist even if there are no defects. We have also noticed that the oscillation period and intensity depend on the velocity of the flow (the period is shorter and the intensity

is lower for higher velocity). We notice also that the density variation induced by the modification of the damping is more important than the one caused by the external potential intensity; this is more obvious when the velocity of the flow is The oscillation of the dark soliton response functions suggests that these waves are stable. These oscillations exist even if there are no defects,i.e, they are caused by the continuous gain and loss of polaritons. The polariton self-interaction nature is now responsible for their stability. The repulsion between the polaritons promotes the creation of dark solitons in nonlinear systems and consequently helps also their stability. This results are consistent with those obtained by the soliton perturbation theory where it was found that dark solitons oscillate after interaction with an obstacle and maintain their shape and velocity. It was also demonstrated that dark solitons are stable in the case of a saturated gain.

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Coarsening and Persistence in 1-D arrowhead model system

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We have studied a system of stochastically reorienting left- and right-pointing arrowheads (< and >) in one dimension. A typical configuration can be ....<<>>><>><>>><>>><<>>>>.... The kinetics involves lateral flipping of an arrowhead around its vertex and displacement along the line. The arrowheads can not overlap or cross each other due to hardcore interaction between them. Our study includes the static properties and the dynamics of approach to the steady state. The equilibrium state of our system approaches an orientationally ordered state as the density increases. The spatial extent of this order is quantified by the correlation length. Using transfer matrix formalism it is shown that the correlation length diverges exponentially with increase in arrowhead density.
It can be seen from a typical configuration above that there are two types of domain walls, >< (A) and <> (B).
In the very high density limit, the displacement of an arrowhead is ineffective so kinetics is reduced to move of flipping only. Thus, owing to non-overlap constraint due to hardcore interaction, A-type domain walls can diffuse and B-type walls are static. In time, the approach to the ordered state is described by a coarsening process governed by the kinetics of domain wall annihilation $A + B \to 0$, quite different from $A + A \to 0$ kinetics pertinent to the Glauber-Ising model.
The survival probability of a finite set of walls is analytically shown to decay exponentially in time, in contrast to the power law decay known for $A + A \to 0$.
In the thermodynamic limit with a finite density of walls, coarsening as a function of time is studied by simulation. It is observed that the number of domain walls falls as $t^{-\frac{1}{2}}$. The fraction of persistent arrowheads is found to decay as a power law $t^{-\theta}$ where θ is close to 1/4, quite different from the exact value 3/8 for the Ising case. The global persistence also decays with same power θ=1/4. In a generalization where the B-type walls can diffuse slowly, θ varies continuously, increasing with increasing diffusion constant.

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Statistical analysis of NIH 3T3 fibroblasts motility

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In recent years, in connection with the current problems of bio-engineering, much attention was paid to the analysis of the movement of bacteria and cells. An approach to cell motility as a random motion is well-known and fruitful [1]. It enables, applying powerful methods related to the theory of random processes, to understand more deeply very slow motion of these biological objects and, as a result, be able to control it. Undoubtedly, such models should adequately describe the available experimental results. The statistical analysis of cell motility on a at homogeneous surface was performed in the report. Namely, based on experimental data for coordinates of thirty cells (NIH 3T3 fibroblasts) with the time-lapse of 5 minutes, we found the correlation functions of velocity projections and the mean-square displacement (MSD) using averaging over ensemble of cells and time. The velocity correlation function has two significantly different time scales and represents approximately the sum of two exponentials [2,3]. The MSD of cells demonstrates two different regimes: the ballistic diffusion at small time scales transforms to Brownian diffusion in asymptotic. At the same time, we observed only one small time scale in the correlation function of velocity modulus. Based on the results of statistical analysis processing of time series the theoretical model of cell motility is proposed. Specifically, the cell velocity is governed by linear integro-differential Langevin equation with exponential memory function and additive white Gaussian noise having two statistically independent components. Using the Laplace transform we solve this equation and obtain the exact formula for the spectral power density of velocity. Then, applying the Fourier transform we find the velocity correlation function and mean-square displacement. Our model contains some parameters, which can be determined from the experimental data for the velocity correlation function and asymptotic of the mean-square displacement. The velocity correlation function graph for both projections, reproduced from experimental data, is in a good agreement with theoretical predictions. At the same time, analysis of high-order moments of cell velocity indicates non-Gaussian nature of considered random processes.

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Active Brownian particles and run-and-tumble particles separate inside a maze

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Flocking birds, colonies of bacteria and schools of fish are only a few examples of active systems that display variety of fascinating collective patterns. Due to the continuous absorption of energy by their constituents, active systems are always out of equilibrium and their behavior are not able to be explained by ordinary statistical physics. Therefor studying their properties and thinking about their possible applications has attracted a lot of attention in many different areas of science and engineering.
Active or self-propelled particles can be distinguished by their moving strategies. Accordingly, there are two main classes of these particles; Active Brownian particles and run-and-tumble particles. The former refers to active particles that move with constant speed and reorient gradually due to rotational diffusion. Synthetic Janus particles move with this strategy. The latter also moves with constant speed but reorient suddenly to a random direction. E. Coli bacteria and some other microorganisms move in this way. Despite of having different moving strategies, active Brownian particles and run-and-tumble particles behave very similarly in many situations which makes them difficult to be distinguished or separated well.
Here we have proposed an special kind of geometry analogous to a nested Matryoshka-like maze that is able to separate these two particles from each other excellently. By reporting their mean first passage times to start from the outer region of the nested maze, we show that persistent run-and-tumble particles reach the center very fast while persistent active Brownian particles does not reach the center at all. In addition, by measuring their long time steady state densities, we show that active Brownian particles accumulate in the inner regions of the maze while run-and-tumble particles are found almost everywhere. Therefor by using appropriate boundaries or tools, different types of active particles are separable from each other, without need to any chemical or biological agents.

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Geometric aspects of thermodynamics and transport in strongly correlated matter

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Recently, a significant progress has been made towards a reformulation of the general theory of, both, equilibrium transport and non-equilibrium 'quench' phenomena that appears to be particularly well suited for describing strongly correlated many-body systems governed by inelastic scattering between their constituents. Specifically, such analyses seek to establish novel and often unexpected relations between the otherwise independent thermodynamic and transport coefficients, alongside their universal bounds, which predictions can be amenable to a direct experimental verification. The corresponding mathematical framework which is often referred to as 'holographic' exposes the intrinsically geometric nature of certain physical observables as well as their formal similarities with the various gravitational and hydrodynamic phenomena. In this talk, we ascertain the underlying origin of such emergent 'geometrization' of the various aspects of many-body dynamics, alongside its resemblance to and differences from the popular naive adaptations of the 'bona fide' string-theoretical holography. In the latter, the corresponding techniques have been opportunistically applied at the 'ad hoc' level to a large variety of condensed matter systems, such as 'strange' Fermi and Bose metals describing quantum-critical spin liquids, itinerant (anti)ferromagnets, quantum nematics, multi-channel Kondo problem, Mott transitions, Hall effect, graphene and other Dirac/Weyl fermion systems, etc. A recent flurry of such applications resulted in a number of rather tantalizing predictions whose status, however, remains largely undetermined. Indeed, the systems in question are generically neither conformally, nor Lorentz (or even translationally and/or rotationally) invariant and lack any supersymmetry or even an ordinary gauge symmetry with respect to some (let alone, large) rank non-abelian group, thus making questionable any overly straightforward extensions of the string-theoretical holography. To that end, we systematically review the body of the earlier work, focusing on those situations where some of the holographic predictions might indeed turn out to be right (albeit, for a potentially wrong reason).

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Zero-temperature directed polymer in random potential on higher dimension

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Zero-temperature directed polymer in random potentials on $d = 4 + 1$ dimension is described. Consider a discrete directed polymer model on a discrete "hyper-pyramid" structure with random potential $\mu(\mathbf{x}, t)$ assigned to each site $(\mathbf{x}, t)$ where $\mathbf{x}$ is the $d - 1$ dimensional transverse vector and t is the longitudinal length of the polymer.
The polymer starts from the substrate at $t = 0$ and its path is restricted by $|\mathbf{x}(t) - \mathbf{x}(t + 1)| = 0$ or 1. There is a bending energy γ against a transverse jump $|\mathbf{x}(t) - \mathbf{x}(t + 1)| = 1$. It represents the stretched energy of the polymer for the transverse jump. As an initial condition, $E(\mathbf{x}, t = 0) = 0$ is given. Then the minimum energy $E(\mathbf{x}, t)$ among all polymers arriving at $(\mathbf{x}, t)$ can be obtained recursively.
Here, we have presented numerical analysis of the directed polymers in $4 + 1$ dimensions. The energy fluctuation $\Delta E(t)$ of the polymer grows as t^{β} as function of polymer length t with $\beta = 0.158 \pm 0.007$ and ΔE follows $\Delta E(L) \sim L^{\alpha}$ at saturation with $\alpha = 0.272 \pm 0.009$, where L is the system size. The dynamic exponent $z = \alpha/\beta \approx 1.72$ is obtained. The estimated values of exponents satisfy the scaling relation $\alpha + z = 2$ very well. Our results show that the upper critical dimension of the Kardar-Parisi-Zhang Equation is higher than $d = 4 + 1$ dimension.
It is known that the directed polymer problem in random potentials belongs to the KPZ universal class. Our results are good agreement with the recent results $\beta \approx 0.158$, $\alpha \approx 0.273$ from the RSOS model in $4 + 1$ dimensions. The estimated β is slightly less than but close to our conjecture 1/6. Considering the finite size effects, our numerical data do not exclude the conjecture. We also estimate z independently from the end to end fluctuation of the path using $\Delta X \sim t^{2/z}$ and obtain $z \approx 1.73$. The transverse fluctuation of the polymer becomes super diffusive.

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Popularity dynamics and preference of memes on complex networks

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We study the origin of the criticality of the meme-spreading dynamcis on non-growing and growing networks based on the competition induced criticality model. From the direct Mote Carlo simulations and the exact mapping into the position dependent biased random walk (PDBRW), we find that the meme popularity distribution sat- isfies a very robust power- law with exponent $\alpha = 3/2$ if there is an innovation process. On the other hand, if there is no innovation, then we find that the meme popularity distribution is bounded and highly skewed for early transient time periods, while it satisfies a power-law with exponent $\alpha \neq 3/2$ for intermediate time periods. The exact mapping into PDBRW clearly shows that the balance between the creation of new memes by the innovation process and the extinction of old memes is the key factor for the criticality. We confirm that the balance for the criticality sustains for relatively small innova- tion rate. Therefore, the innovation processes with significantly in uential memes should be the simple and fundamental processes which cause the critical distribution of the meme popularity in real social networks. We also explain the log-normal distribution of popularity of the trending memes from the meme propagation model with fitness. In this model, each meme has its own fitness. In the propagation process, a meme is selected by considering the fitness of the meme and those of the other memes on the network. If there occurs the innovation in which a meme with a suitably-high fitness is created among the background of the memes with low fitness, then the popularity distribution of the created meme satisfies the log-normal distribution under the condition that only the propagation processes happen after the innovation. Of course, the created meme stands for the trending meme in social networks. If the fitness of the created meme is very high, we find the delta-function type distribution instead of the log-normal distribution.

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Search for novel topological Weyl semimetal phases

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Topology in various guises plays a central role in modern condensed matter physics. Although the original applications of topological ideas to band structures in semiconductors relied on the existence of a fully gapped bulk spectrum, more recently it has been recognized that protected surface states can arise even in gapless systems. The prototypical example of a gapless topological phase is a Weyl semi-metal showing linear dispersion around nodes termed as Weyl points, as the three-dimensional analog of graphene. Surface Fermi arcs are the most prominent manifestation of the topological nature of Weyl semi-metals. I will present predictions of the emergence of Weyl semimetal phase in two distinct cases:
(1)The topological crystalline insulator, Pb1xSnxTe exhibits topological phase transition upon the band inversion strength which can be tailored by the substitutional mixing ratio, strain, thermal expansion, ferroelectric displacement, and/or material thickness via quantum confinement effect. The SnTe building block of the compound is also known to exhibit a ferroelectric transition at low temperatures which leads to inversion symmetry breakdown. Using ab-initio-tight-binding calculations we have explored the parameter space associated with both band inversion and ferroelectric displacement. The calculated topological phase diagram shows the emergence of a Weyl semimetal phase which can be tuned with an external magnetic field [1].
(2)The interfacial phase-change memory (iPCM) GeTe/Sb2Te3 continues to attract a great deal of interest not only because they are promising candidates for the next generation non-volatile random-access memories but also for their fascinating topological properties. Depending on the atomic-layer-stacking sequence of the GeTe block the iPCM can be either in the "SET" (Ge-Te-Ge-Te) or "RESET" (Te-Ge-Ge-Te) states where the former exhibits a ferroelectric polarization and an electric conductivity which is two orders of magnitude higher than that of the RESET state. Ab initio electronic structure calculations reveal that the ferroelectric polarization in the "SET" phase which breaks the inversion symmetry results in the emergence of a Weyl semimetal phase with a large electric conductivity due to the gapless Weyl nodes.

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Phase transitions in evolutionary games combinig two or three pair coordinations on a square lattice

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Multiagent evolutionary potential games with pair interactions when players are located on the sites of a lattice are equivalent to classical spin models if strategy updates are governed by the logit rule [1]. The concept of payoff matrix decomposition has revealed that such a suitable potential can only exist if the defining two-player game is composed of non-strategic self- and cross-dependent or elementary coordination-type game components [2]. Following our earlier systematic investigations we studied games whose pair interactions are composed of two or three equally strong non-overlapping elementary coordinations (i.e. Ising-type interactions) between strategy pairs. According to Monte Carlo simulations performed on a square lattice both of these models possess a continuous order-disorder phase transition that is accompanied by the spontaneous breaking of the symmetry of one of the coordinated strategy pairs. The ordered states of these systems can be characterized by two order parameters that vanish differently when approaching the critical point. In the four-strategy evolutionary game the system exhibits a critical phase transition where the first order parameter reproduces Ising type behavior when the temperature approaches the critical point while the second order parameter shows different algebraic behavior. As this model can be considered as a special case of the Ashkin-Teller model [3,4] with vanishing four-spin interactions, we could exactly determine the critical point with the utilization of a duality relation. The Monte Carlo simulations also indicated that the fluctuations of both order parameters diverge with the same critical exponent in the vicinity of the critical point. For the six-strategy version of these models a significantly different critical behavior was observed. Applying the method of mean-field approximation gives a qualitatively correct description of both the four- and six-strategy games and also predicts the presence of a first order phase transition for similar models with high enough strategy numbers.

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Intertrade times non-stationarity and its impact on autocorrelation of price changes absolute values

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Continuous-time random walk (CTRW) is a stochastic process with continuous and fluctuating waiting (interevent) time. It was firstly introduced to physics by Montroll and Weiss [1]. Since then it has been used to model anomalous transport and diffusion, hydrogen diffusion in nanostructure compounds, electron transfer, aging of glasses, transport in porous media, diffusion of epicenters of earthquakes aftershocks, cardiological rhythms, human travel and many more [2].
CTRW is also successfully applied in econophysics [3], for example it is used to describe stock price dynamics. We can consider the stock price as the price of the last transaction, so the value of a process represents the stock price and waiting times correspond to times between transactions. If we take into consideration only the memory between price changes it may describe empirical autocorrelation function (ACF) of price changes satisfactorily (one-step memory [4], two-step and infinite-step memory [5]). However, empirical ACF of price changes absolute values decays much slower than ACF of price changes and cannot be fully explained only by dependencies between price changes.
By using empirical financial data we study the autocorrelations of the following quantities: price changes, their absolute values and corresponding waiting times. We present analytical solutions for one-step memory CTRW model. We argue that it is crucial to include long memory of waiting times to explain slowly decaying ACF of price changes absolute values. We present that considering only short-term dependencies is not enough to explain empirical ACF, we show the decisive role of long-term correlations.
Additionally, we investigate nonstationarity of waiting times. We show that there exist power-law memories other than daily and hourly structures of market activity.

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Variance optimization with no short positions

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The variance of a portfolio of independent, but not identically distributed, returns is optimized with a ban on short positions, in the high-dimensional limit where the number N of different assets in the portfolio and the sample size T are large with their ratio $r = N/T$ finite. To the best of our knowledge, this is the first time such a constrained portfolio optimization is carried out analytically, which is made possible by the application of methods borrowed from the statistical physics of disordered systerms. The no-short-selling constraint acts as an asymmetric l_1 regularizer, setting some of the portfolio weights to zero and keeping the out-of-sample estimator for the variance bounded, thereby avoiding the divergence present in the non-regularized case. However, the ban on short positions does not prevent the phase transition in the optimization problem, only shifts the critical point from its non-regularized value of $r = 1$ (see e.g. [1]) to 2, and changes its character: at $r = 2$ the out-of-sample variance stays finite and the in-sample variance vanishes, while a susceptibility-like quantity diverges. Numerical simulations support the analytic results for N/T.

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Quantum models based on finite groups: statistical description

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The trajectory of a quantum system is a sequence of unitary evolutions of vectors in a Hilbert space interspersed with observations (measurements). The observations are described mathematically as orthogonal projections of the vectors on subspaces that are specified by measuring devices. The result of quantum observation is random and its statistics is described by a probability measure defined on subspaces of the Hilbert space. Gleason's theorem gives a general construction of all possible probability measures on subspaces of a Hilbert space. In fact, this construction reproduces the Born rule for quantum probabilities. Quantum mechanical description can be made constructive if we replace the general group of unitary transformations of the Hilbert space with unitary representations of finite groups. It is known that any linear representation of a finite group is unitary and can be realized as a subrepresentation of some permutation representation. Thus, quantum mechanical problems can be formulated in terms of groups of permutations. This approach allows us to clarify the meaning of a number of physical concepts. In particular, the quantum randomness can be naturally explained by the fundamental impossibility to trace the individuality of indistinguishable objects in their evolution: only invariant relations among the objects are available in observations. The emergence of complex numbers in the formalism of quantum mechanics follows quite naturally from the general properties of finite groups. A finite quantum model is given by specifying a finite group and its unitary representation. An elementary step in the study of the model is the calculation of the probability distribution of transitions between adjacent observations. The probability of the entire trajectory is calculated as the product of the probabilities of the elementary transitions. An important task is the search for the most probable trajectories. This task is equivalent to the computationally simpler search for the trajectories with minimum entropy (negative logarithm of probability). The entropy of transition between adjacent observations and the entropy of the entire trajectory become, respectively, the Lagrangian and the action in the continuum approximation. Thus, the principle of selection of the most likely trajectories goes into the principle of least action in the continuum limit. In our study we use the Monte Carlo simulation and the system for computational group theory GAP.

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Subdiffusion-reaction process in a composite system with a thin membrane

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We consider subdiffusion–reaction process in a composite system consisting of two homogeneous media which are sepa-

rated by a partially permeable thin membrane. Subdiffusion parameters and reaction rates can be different in both media. In each part of the system the process under consideration is described by means of the subdiffusion–reaction equations with a fractional Riemann–Liouville time derivative. In order to derive the Greens' functions for the considered process we use a simple random walk model with reactions in a system with discrete both time and space variables. Particles' random walk is then described by a set of difference equations which can be solved by means of the generating function method. We assume that a particle performs its single jump at a discrete time to the least neighboring sites only. Additionally, a particle is not allowed to stay at any discrete position when the time of a jump is achieved with the exception of stopping a particle by a membrane what takes place with a some probability; then the particle remains in its position. Using the generating function obtained for the discrete equations mentioned above we pass from discrete to continuous time and space variables by means of the procedure presented in this contribution. Based on the obtained functions we derive boundary conditions at the border between media. One of them demands a continuity of a flux and the other takes rather unexpected form which contains fractional time derivatives.
We also show that a discrete model of random walk appears to be a very useful tool in modeling subdiffusion or normal diffusion. A definite advantage of this method is as follows. We can obtain the Greens' functions without necessity of assuming boundary conditions which are required when solving subdiffusion–reaction equations. The other advantage of this method is that processes described by it have a relatively simple interpretation. The presented method can be also useful in describing the various subdiffusion–reaction processes occurring in biology. We use this model to describe the process of releasing drugs from a subdiffuion medium into a medium in which normal diffusion occurs through a thin membrane.

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On the modelling principles of electrostatic solitary waves and shocks in non-Maxwellian plasmas: A survey of recent results

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Space plasmas are often characterized by the presence of energetic particles, due to various electron acceleration mechanisms [1], leading to a power-law dependence at high (superthermal) velocity values. Various theories have been proposed to model this phenomenon; the most promising scenario seems to be the kappa-type (family of) distribution function(s), which reproduces observed data more efficiently that the standard Maxwell-Boltzmann approach [2].
Electrostatic Solitary Waves (ESWs) [3] and shock structures [4] are ubiquitous in Space observations, and also in the laboratory experiments on beam-plasma interactions [5]. It has been shown from first principles that excess electron superthermality may alter the dynamical properties of electrostatic nonlinear modes, and does in particular modify the propagation characteristics of solitary waves [6]. Recent studies have also indicated that the dynamical characteristics of expanding plasma fronts are affected by excess electron superthermality [7].
In this presentation I will review, from first principles, the effects of a non-Maxwellian electron distribution on the characteristics of electrostatic plasma modes. A kappa distribution function [1] is employed to model the deviation of a plasma component (e.g. electrons) from Maxwellian equlibrium. It will be shown that the excess in superthermal population modifies the charge screening mechanism, affecting the dispersion laws of both low-frequency (ion-acoustic) and high frequency (Langmuir) modes. Various experimental observations may thus be interpreted as manifestations of excess superthermality [2, 5]. Focusing on the features of nonlinear excitations (shocks, solitons), we investigate the role of superthermality in their propagation dynamics (existence laws, stability profile) and dynamical profile [6].
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Reversible computation via classical and quantum many-body numerical methods

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Boolean satisfiability is a class of complex computational problems with many important applications in cryptography and artificial intelligence, as well as deep connections to statistical physics. Recently, a subclass of circuit satisfiability problems was cast into a class of planar vertex models, which were subsequently studied via Monte-Carlo thermal annealing [1]. The vertex models are constructed so that they have no thermodynamic phase transitions and represent circuits of universal reversible classical computations. Imposing mixed boundary conditions with (subsets of) boundary degrees of freedom pinned and finding the ground state is thus equivalent to performing a computation. In this talk, I shall review the performance of classical annealing as a solver for these planar vertex models in terms of correlation length and relaxation rate. I will then discuss the alternative protocol of quantum annealing for relaxing into the ground state. Finally, I will describe a tensor network-based coarse-graining approach for the efficient solution of the planar vertex models. As a concrete example, I will demonstrate the application of the above approaches to semiprime factorization.

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Physical nature of electrons with anomalous energies in Fast atmospheric discharges

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Extensive number of experimental studies connected with runaway electrons beams generation convincingly shows the existence of the electrons group with energies above the maximum voltage applied to the discharge gap [1-3]. Such electrons are also known as electrons with "anomalous" energies. Their fraction of the total number of runaway electrons usually does not exceed 10%. The existence of such high-energy group of fast electrons in principle cant be explained in terms of

simplified theoretical models of macroparticles (PIC) or with different hydrodynamic approaches. In this presentation, we propose novel method for the modelling of gas discharge with runaway electrons explaining the appearance of anomalous energies [4]. The method we use is based on fundamental principle of physical kinetics, namely, we describe the ensemble of fast electrons with the distribution function. Its evolution obeys Boltzmann kinetic equation, while the motion of heavy particles (positive and negative ions, and neutrals) is described in terms of hydrodynamic drift-diffusion approximation widely used today in plasma discharge physics. The dynamics of self-consistent electromagnetic field is taken into the account by adding complete Maxwells equation set to the resulting system of equations. For the first time our kinetic-hydrodynamic hybrid model made possible explaining the existence of "anomalous" energies in the spectrum of fast electrons, and accurately predicting fast electrons number of particles in gas discharge of the certain configuration [5]. The model we consider also provides some essential details on the formation of runaway electron beams with respect to different experimental conditions. The numerical results we obtain fit the existing experimental data for discharges in air and sulfur hexafluoride at atmospheric pressure [6].

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Ballistic motion in periodic Lorentz gas model with magnetic field.

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Quantum antidots systems have been manufactured with high perfection in the last years. This open the possibility to control the geometry of the array where electrons will move. The change of the geometry translate in a change of the electronic properties. In addition, when we apply a magnetic field, the electrons have circular motion, and thus, the resistance change (there is magnetorresistance). At low temperatures, electrons can be considered as non-interacting. Also, if the lattice constant of the quantum antidots array is larger than the Fermi wave length of the electrons, of the order of 50nm, it is expected that the transport properties can be approximated by a classical model. Then, the system can be well approximated by a Lorentz gas-like model, where particles follow a circular trajectory. Periodic and quasiperiodic Lorentz gas models usually exhibit normal diffusion or weak super-diffusion with logarithmic correction in the mean square displacement (MSD) due to channels where particles can move with straight trajectories without collide with any obstacle. Adding a magnetic field to this model would destroy these straight trajectories. However, as it has been shown, (and we will show it as well in this work), there are stable trajectories that effectively move only in one direction with constant velocity. Then, adding a magnetic field can make the system super-diffusive, with ballistic motion. On the other hand if the stability of the ballistic-like trajectories is broken, the system should exhibit normal diffusion i.e., MSD goes like t, but we also know that when the magnetic field is zero, the system has weak super-diffusion, i.e., MSD goes like $tlog(t)$. Finally, if the magnetic field is strong enough, the particles will be localized, which means there is no diffusion. We are interested on which kind of diffusion (conductance) exhibit the system for intermediate magnetic field.
In the case where there is a positive probability to fall in a ballistic-like trajectory, the diffusive properties of the system will be dominated by those trajectories. Therefore, the velocity of those trajectories will determinate the diffusive properties. In this work we discuss, numerically and theoretically, the stability of the ballistic-like trajectories, the velocity distribution of these trajectories, and the critical values of the magnetic field.

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Leader's benefits of network regeneration after consecutive splits

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The idea of the network resistance to attack is well established in literature, and an influence of numerous characteristics of the network topology has been investigated [1]. Up to our knowledge the process of regeneration of a network after its split has not been discussed directly. Here we investigate the evolution of the network structure under periodic splitting and regeneration. The process of splitting once has been considered in [2]. There, the largest hub has been identified as a leader, and links are cut successively as to cut off a rival hub, which is the second largest hub in a distance not smaller than three links. Here the splitting is intended to mimic a conflict between leaders. The regeneration is the grow with or without preferential attachment. Accordingly, we can expect scale-free or exponential topology of the network.
During the grow, some information can be preserved in the network structure. In [3] marks of the shape of the cluster, on which the growth process was initialized, have been encoded in the node-node distance distribution. Here we expect that successive splittings modify the topology of the core cluster with the hub. Our aim is to detect these modifications. To refer to the topology of social networks, the calculations are performed for scale-free and exponential networks with enhanced clusterization coefficient [4].
We measure the parameters of the largest hub: the degree, the closeness centrality and the betweenness centrality. These characteristics have been attributed to measure prestige in a social network [5]. Our numerical results indicate, that both kinds of centrality are strictly correlated. Also, during the consecutive splits and regeneration all the three parameters increase in the long run. These results indicate, that conflicts can be profitable for a leader in a social network. On the other hand, the clustering coefficient of the hub decreases during the simulated process. This result suggests an analogy to the ability of a leader to profit communication through weak ties. Our conclusions can be relevant for an identification of techniques of 'management by conflict'.

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Modelling nanostructure growth on a one-dimensional substrate: islands, gaps and statistics

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We study the nucleation and growth of islands during ultrathin film deposition. After the deposition of monomers or atoms onto a substrate, the nucleation and growth processes involve surface diffusion and reversible attachment to the surface and/or other monomers leading to islands forma-

tion. Islands subsequently grow either through the capture of monomers that diffuse in their corresponding capture zones or by having monomers deposited directly on them (impingement). We replicate this behaviour in kinetic Monte Carlo (kMC) simulations on a one dimensional lattice, which mimics the behaviour of monomers diffusing along a step edge, and limit our study to the scale invariant aggregation regime. We use a point island model where islands occupy a single space on the lattice and the record of their size is being incremented through the simulation. From these simulations we collect the data needed to build and test an analytic model of the system.
In an analytical description, on a one-dimensional substrate, the nucleation process translates to the fragmentation of a line into inter island gaps. Upon nucleation we describe newly created gaps by tracking the fragmentation of the old, larger one. This novel, retrospective approach gives a description of the nucleation process through Distributional Fixed Point Equations which lead to integral equations for gap and capture zone distributions. These equations belong to the broad class of Fredholm integral equations of the first kind, and they incorporate information about the critical island size and the nucleation mechanism (diffusion or impingement driven nucleation). This offers a possibility of analysing statistical data about the nucleated structures, either experimental or obtained from a simulation.
To test this model and extract more information about the system we need to solve the integral equation with no prior assumptions, with kMC data as an input. This leads us to a case of an inverse problem that is ill-posed and we use regularisation techniques to solve it.
The obtained solutions reflect different critical island sizes and fit fairly well within the expected bounds, however they also contain a high level of uncertainty due to the ill-posedness of the problem and the noise present in the input data, so further refinement of the regularisation is currently under way.

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Kappa distributions and their relation to wave-particle interactions and particle dynamics in space plasmas

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Wave-particle interactions, ion acceleration, and magnetic turbulence are closely interlinked and the physical processes occur on different time and length scales in space plasmas. These scales range from the kinetic scale (ion/electron scales) to the macro/fluid at which the dynamic of single particles is not considered. These processes are likely universal and the same basic processes occur in laboratory settings, at the Earth's environment, the solar wind, around the heliosphere, and likely on astrophysical scales. Undoubtedly, the Earth's environment as well as the close interplanetary space are the best plasma environments to study these processes using satellite measurements. Several operating satellite missions such as, ACE, STEREO, IBEX and Voyager observations clearly showed that turbulence and wave-particle interactions and turbulence are extremely important in interplanetary space and in the heliosphere to understand the underlying physics of these measurements. Measures particle distributions provide information on acceleration, scattering, transport processes but not on the particle dynamics.
Using data from STEREO, Wind, we have investigated the spectral properties of so-called suprathermal ion distributions. The results show that spectral slopes are very variable and depend on the plasma properties and most of them show extended tails at higher energies. To study the particle dynamics on the micro-scale we have performed 3D hybrid simulations. In these simulation ions are treaded as particles following the electric and magnetic fields. The results of these simulations show that the particle dynamics in the turbulent magnetic wave field is Levy-Flight like which leads to a kappa distribution, which is often found in various space environments. In fact, maybe this ion dynamic explains why theses distributions are frequently found in space plasmas. Data of future mission such as THOR and IMAP and currently operating missions such as STEREO, IBEX, and MMS will allow to study this topic in much more detail.

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Predictability of extreme rainfall events via a complex network approach

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We analyse climate dynamics from a complex network approach. This leads to an inverse problem: Is there a backbone-like structure underlying the climate system? For this we propose a method to reconstruct and analyze a complex network from data generated by a spatio-temporal dynamical system. This approach enables us to uncover relations to global circulation patterns in oceans and atmosphere. This concept is then applied to Monsoon data; in particular, we develop a general framework to predict extreme events by combining a non-linear synchronization technique with complex networks. Applying this method, we uncover a new mechanism of extreme floods in the eastern Central Andes which could be used for operational forecasts. Moreover, we analyze the Indian Summer Monsoon (ISM) and identify two regions of high importance. By estimating an underlying critical point, this leads to an improved prediction of the onset of the ISM.

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Investigation of a dilute solution of ring polymer chains in a slit geometry of two parallel walls with mixed boundary conditions

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Investigation of a dilute solution of ring polymer chains with the excluded volume interaction in a good solvent immersed in a confined geometry of two parallel walls with mixed boundary conditions was performed. The mixed boundary conditions assumes that we have one wall at the Dirichlet boundary condition and the other one at the Neumann

boundary condition what corresponds to the situation that one surface is repulsive for polymer chains and the other one is at the adsorption threshold. We consider a dilute solution of ring polymers with the excluded volume interaction immersed in a slit geometry of two parallel walls and allow the exchange of polymer coils between the slit and the reservoir. Thus a polymer solution in a slit is in equilibrium contact with an equivalent solution in the reservoir outside the slit. We follow the thermodynamic description of the problem as it was given in [1,2]. Taking into account the well known polymer - magnet analogy developed by de Gennes we calculated in the framework of the field theoretical ϕ^4 $O(n)$-vector model in the limit $n \to 0$ the dimensionless scaling function of the depletion interaction potential and the dimensionless scaling function of the depletion force for the above mentioned case using the massive field theory approach at fixed space dimensions d=3 up to one-loop order. The obtained results for a dilute solution of ring polymer chains with the excluded volume interaction in a good solvent indicate that the depletion force in the case of mixed boundary conditions becomes repulsive in contrast to the case of linear polymer chains (see [2]) and give some additional insight in comparison to Gaussian model of phantom ideal ring polymer chains in such solutions (see [3]). This result for the dimensionless scaling function of the depletion force is in agreement with the scaling predictions proposed by de Gennes some time ago [4]. Besides, it should be mentioned that the presented results give possibility better to understand the complexity of physical effects arising from confinement and chain topology and can find practical application in new types of micro- and nano-electromechanical devises.

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Diagnosing kappa distribution in the solar corona with the polarized microwave gyroresonance radiation

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There is a growing evidence that the equilibrium electron distribution in the solar corona (especially in the active regions) may be not Maxwellian, but described by the kappa distribution [1]. However, remote detection of the kappa distribution is difficult, because many of its observable effects are subtle and/or indistinguishable from a properly chosen Maxwellian (or combination of Maxwellians). It was recently shown [2] that the gyroresonance microwave emission (which is produced by thermal electrons gyrating in a magnetic field and is typical of the solar active regions) offers a straightforward observational test: while the optically thick gyroresonance emission from a Maxwellian plasma is unpolarized, the emission from the kappa distribution should have a noticeable circular polarization (up to $\sim 10\%$, corresponding to the extraordinary wave). Albeit theoretically evident, practical implementation of this effect is difficult due to a) limited spatial resolution of the radio telescopes, and b) the fact that the distribution of polarization is sensitive also to the magnetic field structure in the corona, which is usually poorly known. In this study, we simulate the gyroresonance emission of a solar active region using an elaborated 3D model [3]; both the Maxwellian and kappa distributions with different indices are considered. We consider different orientations of the active region (following its rotation across the solar disk) and different techniques of the magnetic field reconstruction. The results (i.e., the synthetic intensity and polarization microwave maps) are compared with the spatially resolved microwave observations of the Siberian Solar Radio Telescope (at the frequency of 5.7 GHz); the best-fit model parameters and their confidence limits are determined. We discuss the constraints imposed by the observations on the thermal electron distributions in the solar corona, the sources of ambiguity and the ways to improve the diagnostic capabilities of the radio observations.

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Space-time structure of climate variability

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The spatial scale of climate variability is closely linked to the temporal scale. Whereas fast variations such as weather are regional, glacial-interglacial cycles appear to be globally coherent. Quantifying the relationship between local and large-scale climate variations is essential for mapping the extent of past climate changes. Larger spatial scales of climate variations on longer time scales are expected if one views the atmosphere and oceans as primarily diffusive with respect to heat. On the other hand, the interaction of a dynamical system with spatially variable boundary conditions for example: topography, gradients in insolation, and variations in rotational effects will lead to spatially heterogeneous structures that are largely independent of time scale. It has been argued that the increase in spatial scales continues across all time scales, but up to now, the space-time structure of variations beyond the decadal scale is basically unexplored. Here, we show first attempts to estimate and interpret the spatial extent of temperature changes at up to millennial time-scales, using instrumental observations, paleoclimate archives and climate model simulations. Although instrumental and climate model data show an increase in spatial scale towards slower variations, paleo-proxy data, if interpreted as temperature signals, lead to ambiguous results. An analysis of a global reconstruction of the last 10000 years (Holocene), for example, suggests a jump towards more localized patterns when leaving the instrumental time scale. Localization contradicts physical expectations and may instead reflect the presence of various types of noise. We further discuss the potential to separate externally forced climate signals from internal variability, by their respective and potentially different space-time structure. Ultimately, more complete knowledge of space-time scaling should improve physical understanding of climate variability and allow for better use of the paleoclimate record to map past variations.

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Model and performance of simple autonomous agents learning to avoid incoming vehicular traffic for two observational learning algorithms

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In recent years, we have observed a rapid advancement in the development of autonomous driverless vehicles and other types of autonomous robots of various levels of sophistication. Autonomous driverless vehicles and many of the autonomous robots must learn how to operate in dynamically changing environments, e.g. to avoid other vehicles or various other obstacles. Building of autonomous driverless vehicles or autonomous robots requires their priory modeling, development and analysis of performance of various decision-making pro-

cesses and learning algorithms before they are implemented to be used in the real world.
Individual autonomous robots (including autonomous driverless vehicles) can be identified with cognitive agents capable of performing cognitive acts; i.e. a sequence of the following activities: (1) Perceiving information in both the environment and that provided by other agents (2) Reasoning about this information using existing knowledge; (3) Judging the obtained information using existing knowledge; (4) Responding to other cognitive agents or to the external environment, as it may be required; (5) Learning; i.e. changing (and hopefully augmenting) the existing knowledge if the newly acquired information allows it.
In this talk, we describe a model of autonomous cognitive agent learning to avoid incoming vehicular traffic. The agent is a minimal cognitive agent that could be used as a virtual experimental platform to explore its ability to learn. The emphasis is on minimal storage and logical primitives. Thus, formal methods of computational intelligence and established algorithms such as reinforcement learning algorithms are not used in this model. Instead, inspired by biomimicry, simple learning algorithms based on an observational social learning principle, i.e. each agent learns from observing the outcomes of the decisions of the other agents, are designed and their performance is investigated. We provide the mathematical description of the model and consider various statistical performance indicators to assess the agents performance in learning to avoid incoming vehicles for two decision-making algorithms. We investigate the effects of the agents knowledge base accumulation through observation and repetition on the success of their decisions.

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Autonomous agents with risk takers and risk avoiders performance in learning to cross CA based highway

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With the rapid development of autonomous robots operating in dynamically changing environments, e.g. autonomous driverless cars, drones, swarm robots, it is important to study how robots learning performance may be affected by various parameters. Some of these studies may be carried out through modeling and simulations in which autonomous robots are identified with cognitive agents capable of performing cognitive acts; i.e. a sequence of the following activities: (1) Perceiving information in both the environment and that provided by other agents (2) Reasoning about this information using existing knowledge; (3) Judging the obtained information using existing knowledge; (4) Responding to other cognitive agents or to the external environment, as it may be required; (5) Learning; i.e. changing (and hopefully augmenting) the existing knowledge if the newly acquired information allows it.
We consider a model of cognitive agents learning to cross a cellular automaton based highway under various traffic conditions. The agents use an observational social learning strategy in which agents learn by observing the performance of other agents, mimic what worked for them and avoid what did not in the past. Our work focuses on simplicity of the agents learning algorithms in which their decision-making process depends only on the evaluation of the agents crossing decisions, or both crossing and waiting decisions. We investigate how the presence of risk takers and risk avoiders in a population of agents affects their success in learning to cross the highway without being hit. The agents learning performance is measured by various statistical indicators. Also, we investigate the effects of transfer of agents knowledge base built in one traffic environment to the agents learning to cross in a different traffic environment on their success and their decisions. We consider various statistical indicators to assess these effects. We present variety of simulation results and outline the future work.

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Suprathermal kappa populations: From observations to realistic interpretation

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Suprathermal populations enhance the high-energy tails of the velocity distributions of particles in space plasmas (i.e., solar wind, and planetary magnetospheres). Standard Maxwellian models cannot describe the observed distributions, which are instead well reproduced by the Kappa power-laws. However, the family of Kappa distribution functions do not offer a unique representation of the suprathermals. Here we contrast the alternative methods proposed in the last decades in the attempts to describe these populations and, implicitly, their effects in the solar wind. A realistic interpretation is conditioned by a rigorous modelling in accord with the observations, and in turn, the effects predicted for the same suprathermal populations must also be confirmed by the observations.

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Absorbing phase transition in continuous media

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The nonequilibrium absorbing phase transition of interacting particles in continuous media is studied via Monte Carlo simulations. Initially ρL^d spherical particles are distributed randomly in a cubic box of side L, and those particles which overlap with other particles are considered to be active and isolated particles are inactive. The dynamics proceed with sequential updates of active particles; an active particle is selected randomly and it repels those particles which overlap with it, with an increment of the evolution time $\Delta t = 1/N_a(t)$, where $N_a(t)$ is the number of active particles at time t. If the density of particles is larger than a critical density, i.e., if $\rho > \rho_c$, the density of active particles saturates as dynamics proceed and, if $\rho < \rho_c$, it decreases to 0 and the system falls into an absorbing state. At ρ_c, the density of active particles ρ_a decreases following the power-law behavior $\rho_a(t) \propto t^{-\alpha}$. Therefore, the system undergoes a phase transition from an active phase to one of many absorbing states. The steady-state density of active particles is considered to be an order parameter and exhibits the power-law behavior $\rho_{\rm sat} \propto (\rho - \rho_c)^{\beta}$, where β is the order-parameter exponent.
The critical exponents α and β were calculated in two dimensions and found to be similar to those of the lattice Manna model, suggesting that both the continuum and lattice

models belong to the same universality class. This is in strict disagreement with recent observation for the same model but with parallel updates, in which the order-parameter exponent was found to be similar to that of the directed percolation universality class [1].
When the system started from the natural initial states [2], the exponent α was found to be distinct from that of the lattice Manna model generated also from the natural initial states prepared by the same method as for the continuum model. The different behaviors were interpreted using the distribution of particles; the density fluctuation of hyperuniform distribution of active and background particles [3] was found to be different for the lattice and continuum models, and the different critical behaviors of absorbing phase transition appear to be attributed to different distributions.

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Statistical physics insight into photonics: light amplification and propagation in complex and random media

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In recent years a valuable description of the properties of waves in random media by means of the tools of statistical mechanics has led to a deeper understanding and a wider range of predictions on the behavior of complex photonic systems. These are systems where disorder, non-linearity and wave interference all play significant, non-perturbative, roles possibly causing the onset of a collective behavior of light modes. After giving a concise account of the formal translation of the dynamics of the electromagnetic field of light into a statistical mechanical description we report on recent ideas and results on random lasers, in particular on those compounds displaying glassy behavior, and on the transmission of light waves trough complicated, disordered media.

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Spreading dynamics of forget-remember mechanism

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We study extensively the forget-remember mechanism (FRM) for message spreading, originally introduced in Eur. Phys. J. B 62, 247 (2008). The freedom of specifying forget-remember functions governing the FRM can enrich the spreading dynamics to a very large extent. The master equation is derived for describing the FRM dynamics. By applying the mean field techniques, we have shown how the steady states can be reached under certain conditions, which agrees well with theMonte Carlo simulations. The distributions of forget and remember times can be explicitly given when the forget-remember functions take linear or exponential forms, which might shed some light on understanding the temporal nature of diseases like flu. For time-dependent FRM there is an epidemic threshold related to the FRM parameters. We have proven that the mean field critical transmissibility for the SIS model and the critical transmissibility for the SIR model are the lower and the the upper bounds of the critical transmissibility for the FRM model, respectively.
We study extensively the forget-remember mechanism (FRM) for message spreading, originally introduced in Eur. Phys. J. B 62, 247 (2008). The freedom of specifying forget-remember functions governing the FRM can enrich the spreading dynamics to a very large extent. The master equation is derived for describing the FRM dynamics. By applying the mean field techniques, we have shown how the steady states can be reached under certain conditions, which agrees well with theMonte Carlo simulations. The distributions of forget and remember times can be explicitly given when the forget-remember functions take linear or exponential forms, which might shed some light on understanding the temporal nature of diseases like flu. For time-dependent FRM there is an epidemic threshold related to the FRM parameters. We have proven that the mean field critical transmissibility for the SIS model and the critical transmissibility for the SIR model are the lower and the the upper bounds of the critical transmissibility for the FRM model, respectively.

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When panic makes you blind: a chaotic route to systemic risk

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We present an analytical dynamical model of financial systemic risk to investigate the effects of microprudential changes on macroprudential outcomes. Specifically, we study the consequence of the introduction of a financial innovation that allows reducing the cost of portfolio diversification in a financial system populated by financial institutions having capital requirements in the form of Value at Risk (VaR) constraint and following standard mark-to-market and risk-management rules. We provide a full analytical quantification of the multivariate feedback effects between investment prices and bank behavior induced by portfolio rebalancing in presence of asset illiquidity and show how changes in the constraints of the bank portfolio optimization endogenously drive the dynamics of the balance sheet aggregate of financial institutions and, thereby, the availability of bank liquidity to the economic system and systemic risk. The model shows that when financial innovation reduces the cost of diversification below a given threshold, the strength (because of higher leverage) and coordination (because of similarity of bank portfolios) of feedback effects increase, triggering a transition from a stationary dynamics of price returns to a nonstationary one characterized by steep growths (bubbles) and plunges (bursts) of market prices. We then introduce a slow-fast random dynamical system to study the role of expectation feedbacks on systemic stability of financial markets. We then study how the expectations of risk by financial institutions play a central role in determining the systemic stability of the financial system and how wrong risk expectations may create panic-induced reduction or over-optimistic expansion of the balance sheets. The fixed point equilibrium of the system breaks into leverage cycles when institutions do not have enough memory of the past history in estimating the risk of their portfolios. When they become more and more myopic, a bifurcation cascade leading to chaos follows. We study the role of the financial policy for the expectation feedback system and we also discuss the effects of some market frictions as the cost of diversification and the Tobin tax. Finally we present some empirical evidences of the dynamics of bipartite network of US bank portfolios and investment classes showing that before the crisis the similarity of portfolios has significantly

increased and that systemic risk measures based on portfolio overlaps can be used as

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Network representation of geographical landscape data and their correlation to transportation networks in mountainous Greece

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Our work addresses the problem of how socio-technical networks, such as rural telecommunication infrastructure, grow on the background of spatially variable fields. The method we follow is to analyze both the geo-morphological terrain and the road web as complex networks, using the visibility algorithm that converts the georeferenced points into a graph. Such algorithm has been shown to relate in a unique way properties of the point series to stochastic features of the associated graph, so that fractal series lead to scale-free networks (Ref. 2). Thus, it proposes a novel representation that takes advantage of the analytical tools of complex network theory.
Our data are drawn from the geographical mountainous landscape in the mainland of Greece. Such areas consist of highly variable terrain geomorphology, ranging from high mountain peaks to land plateaus. The population of typical settlements in this region does not exceed a few hundred inhabitants. The rural road infrastructure, which connects the various settlements, follows the complex landscape formation. This road network is the evolution of the existing older routes and excludes modern national highways and motorways.
The terrain data we analyze firstly correspond to the altitude of geographical pixels in a line $\approx 30\,km$ long. We convert these sets to networks, using the visibility tool in an ArcGIS platform. Each terrain pixel corresponds to a network vertex, connected to other vertices of the set with a clear line of sight. We find that the topology of the network does not depend on the specific position, length or orientation of the terrain data set in the mountainous region we examine. Moreover, the degree distribution exhibits a fat tail with power exponent ≈ 1.2. This characteristic is indicative of an underlying fractality of our terrain data, as it appears in networks associated through the visibility method to fractal series, such as the Conway fractal (Ref. 2). This power law exponent is fairly robust. We find the same form of the degree distribution if, instead of the height of the digital terrain pixels, we analyze the set of profile curvature points.
We finally compare these results to the transportation road data. The degree distribution of the associated network exhibits again a power law with exponent ≈ 1.2. However, we find differences in other network topological parameters, such as the local clustering coefficient, the closeness and betweenness centrality.

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Kappa distributions: Theory and applications in plasmas

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Statistical Mechanics is frequently used to determine the average behavior of a particle system when it resides at thermal equilibrium - the concept that any flow of heat (thermal conduction, thermal radiation) is in balance. When a particle system is at thermal equilibrium (typical behavior of earthy gases, e.g., the air), the particles are distributed in a specific way: There are many particles with small velocities and very few with large velocities. It is possible to write a mathematical equation describing how many particles are found at each velocity; this mathematical expression is called a Maxwellian distribution. However, space plasmas are particle systems distributed such that there are more high velocity particles than there should be if the space plasma were in equilibrium. The mathematical equation used to describe the space plasma is called a kappa distribution [Livadiotis, G., 2017, Kappa distribution: Theory & Applications in plasmas (Elsevier; Netherlands, UK, US; ISBN:9780128046388); https://www.elsevier.com/books/kappa-distributions/livadiotis/978-0-12-804638-8].
Empirical kappa distributions have become increasingly widespread across space and plasma physics. Space plasmas from the solar wind to planetary magnetospheres and the outer heliosphere are systems out of thermal equilibrium, described by kappa distributions. A breakthrough in the field came with the connection of kappa distributions to the solid background of non-extensive statistical mechanics. Understanding the statistical origin of kappa distributions was the cornerstone of further developments of these distributions, by means of the (i) Foundation theory, (ii) Plasma formalism, and (iii) Space plasma applications. some of which will be presented in this talk: (1) The physical meaning of thermal parameters, e.g., temperature and kappa index; (2) the N-particle description of kappa distributions; (3) the generalization to phase-space kappa distribution of a Hamiltonian with non-zero potential; (4) the Sackur-Tetrode entropy for kappa distributions, and (5) the existence of a large-scale phase-space cell in collisionless space plasmas, indicating a possible large-scale quantization constant 12 orders of magnitude larger than the Planck constant.

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Multidimensional complex measures for functional connectivity analysis

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There is a growing interest in assessing functional connectivity from fMRI data for human brain mapping. Functional connectivity analysis is based on the concept of synchrony between the signal responses in spatially distinct brain areas [1]. If on one hand, the great spatial resolution offered by magnetic resonance imaging could far improve the identification of functional regions of interest for clinical purposes, on the other hand, its low temporal resolution limits the number of methods that can be used to assess the interactions between the time series associated with such regions. Pairwise

fMRI time series associations are usually estimated through zero-lag correlation metrics [2], however the human brain can be modeled as an inherently nonlinear complex system [3], so linear correlation techniques might reveal only partial aspects of the functional interactions between brain areas and could result quite ineffective in modeling complex behaviors. In this work, a set of simulated fMRI data are generated following a block-related experimental design with the aim of comparing different connectivity metrics and providing further insights into the links between the coupling strength of each metric and the parameters of the time series. We propose generalized cross recurrence complex measures to fully capture dynamic coupling behavior between fMRI time series and show their robustness against noise as well as their effectiveness to reveal correlation even in presence of nonlinearity. fMRI data are constructed under the assumption that activations result from underlying neural events as well as noise. Specifically, strong neural events follow a block design, while spontaneous neural fluctuations and spiking events are treated as random deviations from resting baseline. Finally, blood oxygenation level dependent signals are generated with both a linear canonical hemodynamic response function and a nonlinear vascular model. We added different levels of physiological noise and applied progressive phase shifts to signals to investigate whether the correlation metrics reflect various conditions.

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Statistical physics of active matter: microswimmers in complex environments

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Differently from passive Brownian particles, active particles, also known as self-propelled Brownian particles or microswimmers and nanoswimmers, are capable of taking up energy from their environment and converting it into directed motion. Because of this constant flow of energy, their behavior can be explained and understood only within the framework of nonequilibrium physics. In the biological realm, many cells perform directed motion, for example, as a way to browse for nutrients or to avoid toxins. Inspired by these motile microorganisms, researchers have been developing artificial particles that feature similar swimming behaviors based on different mechanisms. These man-made micromachines and nanomachines hold a great potential as autonomous agents for health care, sustainability, and security applications. With a focus on the basic physical features of the interactions of self-propelled Brownian particles with a crowded and complex environment, this talk will discuss the basic principles, the development of artificial self-propelling microparticles and nanoparticles, and their application to the study of nonequilibrium phenomena, as well as the open challenges that the field is currently facing [3]. In particular we discuss some recent advances in this rapidly developing field including:
i) active Brownian articles in externally steered motility landscapes [1]: Many microorganisms, with phytoplankton and zooplankton as prominent examples, display phototactic behaviour, that is, the ability to perform directed motion within a light gradient. Here we experimentally demonstrate that sensing of light gradients can also be achieved in a system of synthetic photo-activated microparticles being exposed to an inhomogeneous laser field. We observe a strong orientational response of the particles because of diffusiophoretic torques.
ii) fission and fusion in magnetic microswimmer clusters [2]: Fission and fusion processes of particle clusters occur in many areas of physics and chemistry from subnuclear to astronomic length scales. Here we study fission and fusion of magnetic microswimmer clusters as governed by their hydrodynamic and dipolar interactions. Rich scenarios are found that depend crucially on whether the swimmer is a pusher or a puller. Our predictions are obtained by computer simulations and verifiable in experiments on active colloidal Janus particles and magnetotactic bacteria.

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Long-lasting but transient anomalous diffusion

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The theory of Brownian motion has played a guiding role in the development of statistical physics. It provides a link between the microscopic dynamics and the observable macroscopic phenomena such as diffusion. The latter has been in the research spotlight already for over 100 years. One century after pioneering Einsteins work it remains both a fundamental open issue and a continuous source of developments for many areas of science. Normal and anomalous diffusion can be detected in diverse systems: both physical and biological, sociological and economical ones. We show that anomalous diffusion can be observed in simple, one dimensional classical systems assisted by thermal equilibrium noise of Gaussian nature, i.e. without the need to introduce heavy-tailed distributions nor disorder or many-body physics. We analyze a standard ac-driven Brownian ratchet (which has many real physical realizations like SQUID devices and cold atoms in optical lattices) and demonstrate that the mean square deviation of the Brownian particle coordinate evolves in three following stages: initially as superdiffusion, next as subdiffusion and finally as normal diffusion in the asymptotic long time limit. The lifetimes of superdiffusion and subdiffusion can last many many orders longer than characteristic times of the system, thus being comfortably detectable experimentally. These lifetimes turn out to be extraordinarily sensitive to the system parameters like temperature or the potential asymmetry. E.g small parameter changes of order 10^{-2} are accompanied by the giant increase of order 10^3 in the superdiffusion lifetime. We explain the underlying mechanism standing behind the emergence of diffusion anomalies and control of their regimes which are related to ergodicity of the system and ultraslow relaxation of the particle velocity towards its non-equilibrium stationary state. The proposed setup for experimental verification of our findings provides a new and promising testing ground for investigating anomalies in diffusion phenomena.

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Linear waves and instabilities in plasmas with kappa velocity distributions

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Until fairly recently, the customary approach to wave and instability studies in space plasmas relied on the Maxwellian

distribution or one of its variants. This approach prevailed despite a body of evidence indicating that the plasmas being considered were effectively collisionless and in dynamical states far from equilibrium. Modelling the widely observed superthermal power law tails on nonthermal particle velocity distributions by sums of Maxwellians was a well established tradition among the community of space plasma researchers despite some early recognition [1] that the less well known kappa distribution provided a better fit.
The kinetic theory of waves and instabilities in space plasmas based on the kappa distribution or variant is now more widely adopted by researchers. A barrier to its widespread acceptance, the perception that the kappa distribution had no physical theory underpinning its existence, began to fall with the emergence in statistical mechanics of non-extensive Tsallis statistics. The primary advantage of kinetic theory based on the kappa distribution is that it more accurately represents the velocity distributions measured in space plasmas, especially those having power law tails. Use of a kappa distribution model does not change any microphysical processes, but it does alter their probabilities of occurrence, which in turn affects important average quantities such as instability growth and wave damping rates. Dispersion relations also often show features distinguishable from their Maxwellian equivalents, providing valuable signatures for out of equilibrium plasma behaviour.
After briefly reviewing the theoretical framework for kinetic studies of plasma waves, this talk presents results from some of the investigations of waves and instabilities in plasmas modelled with kappa distributions carried out by the authors and collaborators. Amongst others, the whistler [2] and EMIC [3] instabilities driven by thermal anisotropy will be discussed, as well as perpendicularly propagating electron and ion Bernstein waves. In addition, some recent results of 1D and 2D simulations of oblique waves in plasmas having a kappa distribution, will be presented.

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Kinetics of the long single - stranded RNA: nonequilibrium steady state

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The event of single-stranded (ss) nucleic acids hybridization is a key process in any DNA or RNA sensor activity and in many molecular biology techniques such as polymerase chain reaction (PCR), *in situ* hybridization, etc. Two types of conformational rearrangements in RNA are possible: rearrangement of the secondary structure with characteristic time scale τ_2 and tertiary structure fluctuations with characteristic time scale τ_3. The difference between timescales τ_2 and τ_3 is well-pronounced. The following mental experiment has been considered [1,2]. The ssRNA molecule is dissolved initially in the solvent at temperature T' which satisfies inequalities $\Theta < T' < T_m$, where T_m is the melting temperature and Θ is the Flory temperature. Under these conditions the RNA molecule is a random coil with a well defined secondary structure. Next, transfer a very small amount of our RNA containing solution into the same kind of solvent but with temperature T, such that $T < \Theta$. Now the content of the secondary and tertiary structures does not correspond to the temperature of the thermostat, and the system appears in a non-equilibrium state. In the beginning, the secondary and spatial structures in this state still correspond to the temperature T' but they start to relax to the new temperature T. At the end of the process, the RNA will arrive at a compact globular state with some secondary structure pattern. On the timescale τ, such that $\tau_3 \ll \tau \ll \tau_2$, the secondary structure and spatial arrangement of the effective monomers (non-paired regions) are not in thermal equilibrium, and this stationary non - equilibrium steady state can be described in terms of the effective partition function [3]. The replica technique method was applied to address the non equilibrium steady state of the coarse-grained model for the RNA molecule. A non-equilibrium phase transition of second order between the glassy phase and the ensemble of freely fluctuating structures has been observed. The non-equilibrium steady state is investigated as well and the thermodynamic characteristics of the system have been evaluated. The non equilibrium behavior of the specific heat is discussed. Based on our analysis, we point out the state in the kinetic pathway in which the RNA molecule is most prone to hybridization.

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The volume of Gaussian states by information geometry

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The notion of phase space is often gotten rid of in quantum mechanics because of the non-commutativity of canonical variables. Nevertheless, the phase space can be considered as a common playground for both classical and quantum states when one employs for the latter a description in terms of the so-called quasi-probability distribution functions, such as the Wigner function. Then, one can address the computation of the volume of different classes of states in the phase space framework. The issue of the volume of sets of states is of uppermost importance. It can help in distinguishing classical from quantum states as well as to find separable states within all quantum states. Determining the volume of physical states is also relevant for defining the typical properties of a set of states.
Describing the geometric properties of sets of states is intimately connected with the evaluation of their volumes. The sets of classical and quantum states are both convex sets. In finite dimensional systems, several metrics are introduced in order to compute the volume of physical states. However, when going to infinite dimensional systems, problems arise also from the non-compactness of the support of states.
Thus, on the one hand, we have the difficulties in analysing infinite dimensional systems, while on the other hand we still lack a unifying approach for evaluating volumes of classical and quantum states. To deal with these problems, we propose to exploit information geometry.
Actually we exploit methods of information geometry in order to associate a Riemannian manifold to a generic Gaussian system. In such a way, we consider a volume measure as the volume of the manifold associated with a set of states of the system. We start by considering N identical and indistinguishable particles, i.e., bosonic modes, characterized by their positions and momenta, and we assume that a Gaussian pdf with zero mean value describes the whole system state. Such a pdf is characterized by a set of parameters, i.e., the entries of the covariance matrix (depending on their values, we can have various classes of states). Then, thanks to these parameters, to each class of states is associated a statistical model which turns out to be a Riemannian manifold endowed with the well-known Fisher-Rao metric. We are able to overcome the difficulty of an unbounded volume by introducing a regularizing function stemming from energy bounds, which acts as a form of compactification of the support of Gaussian states. We then proceed to consider a different regularizing function which satisfies some nice properties of canonical invariance. Finally, we find the volumes of classical, quantum, and

quantum entangled states for two-mode Gaussian systems, showing chains of strict inclusions.

Laminar-turbulent patterning in transitional flows, a review of recent results

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Wall-bounded flows typically experience a subcritical transition to turbulence due to linear stability of the laminar base flow at values of the Reynolds number R for which nontrivial solutions to the Navier-Stokes equations can exist. It is characterized by the coexistence of laminar and turbulent domains in a transitional regime extending above a lower threshold Rg below which any form of turbulence decays, possibly at the end of overlong chaotic transients. At sufficiently high R, uniform (featureless) turbulence is recovered, and depending on the geometry, either one-dimensional, pipe-like, or two-dimensional, along or between plates, this coexistence can take different forms [1]. I will focus on the second case marked by the presence of a more or less regular pattern of alternatively laminar and turbulent bands obliquely inclined with respect to the stream-wise direction [2]. On general grounds, this organization disappears above a second threshold Rt bounding the transitional regime from above. I will review several systems recently under focus, with shear flow between coaxial cylinders or parallel plates (Couette geometry) viewed as a prototype. Decay of the bands at Rg has been the subject of many studies recently, pointing out the relevance of directed percolation and criticality in the sense of statistical-physics phase transitions [3]. As of today, the nature of the transition at Rt where bands develop remains more mysterious. Usual pattern forming instabilities such as convection develop at increasing control parameter on a laminar background. In contrast, the bands emerge at Rt out of a uniform turbulent background at decreasing control parameter but quantitative results are still scarce [2]. While local collapse of turbulence can be understood as an immediate consequence of large deviations associated with sub-criticality, the mechanisms for a progressive large scale organization of laminar troughs with abrupt and fluctuating laminar-turbulence interfaces are still poorly understood. In this respect, the relevance of the Reaction-Diffusion scheme found valuable to discuss the one-dimensional case of transitional pipe flow [4] will be examined in view of interpreting band formation in terms of a Turing instability of featureless turbulence [5], while probing the role of large scale flow inside the laminar patches.

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Price discovery and market liquidity at NASDAQ Nordic OMX exchanges

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We investigate the process of price discovery of several financial assets traded at the Nasdaq Nordic OMX exchange. Specifically, we empirically investigate the dynamics of the order book of financial assets belonging to the categories of stocks, warrants, equity warrants, and index fund units. By investigating the mean cancelation time of the limit orders submitted to the market we infer about the presence of high frequency trading for a specific financial asset traded in the market. We verify that the presence of high frequency order submission is not always associated with high frequency of transactions. We perform a cross sectional analysis of the order submission and cancellation procedure to detect characteristics of the multivariate nature of high frequency order submission. A discussion of the relationship between high frequency order submission activity and asset liquidity is provided for different categories of financial assets.
We perform a statistical test of the repeated market transactions occurring between different pairs of market members. With this approach we are able to detect over-expression and under-expression of high-frequency market transactions for different pairs of market members. These over-expressions and under-expressions are used to set up a statistically validated network [Tumminello et al 2011, Hatzopoulos et al 2015] describing the networked structure of the market with respect to high-frequency transactions. This investigation is done monthly for the time period covering the 2010 and 2011 calendar years. During this period, for each month we are able to obtain a network describing the high-frequency networked relationships observed in the market. The networked relationships are presenting both regularities and a dynamics that can be interpreted in terms of specialization of some market members allowing them to be active (and/or to sell services) in the field of high-frequency trading. The topological properties of the networks obtained are therefore informative with respect to the ability and infrastructures of different market members. The statistical robustness of our empirical results shows that the introduction of heterogeneity with respect to the ability to perform high-frequency algorithmic trading are making an anonymous market a networked market.

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K-shell decomposition method applied in patent citation network

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Patent Citation Network is the network that is formed from the references of a patent to other patents [1]. The nodes of the network are the patents and the links between the nodes exist if a patent cites another patent. All links are directed as they point only to one direction and the network is acyclic as the references are only to prior patents. The network of all patents in the European Patent Office (EPO) and the Patent Cooperation Treaty (PCT) for the period 1978-2016 was formed. Data was taken from OECD [2]. The network includes 14,031,393 patents and 22,107,570 links. At first, the degree distribution was studied and it was found that both the in- and out- degree distributions follow a power law, with a slope of 2.9 and 2.8, respectively. Consequently, the majority of patents have only a few citations, while there are not many highly cited or citing patents.
The k-shell decomposition [3] method was applied in the undirected network to identify its core. Using this method once can find the most important patents for a networks stability and robustness. The result showed that the core of the patent citation network is at k-shell=90. Surprisingly, this shell was not comprised of the patents with the highest number of citations. On the contrary, it contains 226 patents with citation degree (sum of both in and out degrees) in the range of 94-462, while the highly cited patents (degree up to 2500) are in much lower shell number. The highest concentrations of highly cited patents are in cells 57 and 70, where there are 510 and 155 patents, respectively. Additionally, it is important to note that the geographic region where patents of the highest shells come from, is often

that of only one continent. This points to some form of spatial separation in the highest shells. Further investigation of the time patents were issued in each shell, hints to a possible continental level organization of citations for shells with old patents, and an intercontinental one for shells with newer ones.

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A time-respecting null model to explore the structure of growing complex networks

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Network representations of real systems have been used to gain insights in phenomena as diverse as the epidemics spreading in social networks and the ranking of web sites. When analyzing a network, statistical null models are essential in assessing if an observed property is a sign of a particular feature of the networks organization, or rather an outcome of randomness and basic constraints such as the network size, for example. While many network null models have been proposed in the past, we still lack a reliable model to assess the significance of structural properties for networks that grow in time as many networks do. We bridge this gap by proposing a null model specifically aimed at growing networks. One of the simplest and most popular null models, the Configuration Model, has been applied to many distinct problems. This model can be used to generate random networks with a given number of connections of each node. We propose the Dynamic Configuration Model that produces networks where not only the final number of connections of each node, but also its time evolution are fixed. Thus-generated random networks can closely reproduce temporal growth patterns of any given network.
We provide several examples that illustrate how the new model can be used to distinguish between fundamental and accidental observations in networks. In particular, we show that the dynamic configuration model brings important insights for three classes of network properties: (1) degree-degree correlations, (2) correlations between centrality metrics, (3) centrality metrics ability to uncover significant nodes in the network. Furthermore, we use the dynamic configuration model to build a new quality function for community detection, called temporal modularity. We use the data produced by a growing network model to show that temporal-modularity optimization outperforms modularity optimization in identifying the planted ground-truth communities for a wide range of model parameters, and clarify how the relative performance of the two methods depends on the systems aging timescale.
In the future, many more properties of growing networks can be re-examined with the Dynamic Configuration Model, leading to a better understanding of how do networks change in time and why.

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Early identification of significant nodes in growing networks

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In a world where we need to make many choices and our attention is inherently limited, we often rely on automated scoring and ranking algorithms to orient ourselves in the copious amount of available information. An important class of ranking algorithms is based on the network representation of many real datasets. Network-based ranking algorithms use network representations of the data to compute the inherent value, relevance, or importance of individual nodes in the system. Widely-used examples of ranking algorithms include ranking by degree (i.e., by the number of connections received by a node) and Google's PageRank. The latter is of particular interest for the physics community since it is built on statistical-physics concepts such as diffusion and random walk. Despite the broad use of network-based ranking algorithms, we still lack a clear understanding of which network properties determine whether a given algorithm will succeed or fail in identifying the most valuable nodes in the network.
In this presentation, we focus on the dependence of degree and Google's PageRank performance on network aging effects. We start by using a recent model of growing information networks to understand PageRanks bias by node age and show how this bias damages the algorithms performance. Motivated by the observed regularities in PageRank performance patterns, we introduce a new node-scoring metric for growing networks, called rescaled PageRank score, which combines PageRank score with the explicit requirement that node score is not biased by age. Model-data analysis shows that rescaled PageRank score markedly outperforms PageRank score for a broad range of model parameters. We analyze the network of citations between the 449937 papers published in American Physical Society journals between 1893 and 2009. We find that in contrast with classical PageRank score, the rescaled PageRank score allows us to compare papers of different age on the same scale. As a positive consequence, rescaled PageRank identifies much earlier the Milestone Letters of physics, which are papers of exceptional significance selected by the editors of the APS. Finally, we show that rescaled PageRank can also early identify Oscar-awarded movies in a movies' inspiration network, and significant expert-selected patents in the US patents citation network.

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A difficult choice for a bacterium: Escherichia coli's decision between fermentation and respiration.

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Many microbial systems are known to actively reshape their proteome in response to changes in growth conditions induced e.g. by nutritional stress or antibiotics. Part of the re-allocation accounts for the fact that, as the growth rate is limited by targeting specific metabolic activities, cells respond by fine-tuning their proteome to invest more resources into the limiting activity (i.e. by synthesizing more proteins devoted to it). However, this is often accompanied by an overall re-organization of metabolism, aimed at improving the growth yield under limitation by re-wiring resource through different pathways. By focusing on E. coli's 'acetate switch', we show that the transition from a predominantly fermentative to a predominantly respirative metabolism in carbon-limited growth results from the trade-off between maximizing the growth yield and minimizing its costs in terms of required the proteome share. In particular, E. coli's metabolic phenotypes appear to be Pareto-optimal for these objective functions over

a broad range of dilutions.

Matching microscopic and macroscopic responses in glasses with the Janus II computer

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The dynamics of glass formers (such as polymers, supercooled liquids, colloids spin glasses, superconductors,...) is so slow at low temperatures that thermal equilibrium is never reached in macroscopic samples: in analogy with living beings, glasses are said to age. Simulating aging poses such an enormous challenge that computers has been specially designed to this end. In particular, the computers Janus and Janus II, custom-built for the simulation of spin glasses, have been constructed by the Janus Collaboration, a consortium of researchers from Spain (U. Zaragoza, U. Complutense and U. Extremadura) and Italy (La Sapienza, U. di Roma and U. Ferrara).
Here, we report a study of both the linear [1] and the non-linear [2] responses of an aging spin-glass to an external magnetic field, carried out by means of large-scale simulations on Janus and Janus II.
We show that linear responses relate experimentally relevant quantities with the experimentally unreachable low-temperature equilibrium phase. We have performed a very accurate computation of the non-equilibrium fluctuation-dissipation ratio for the three-dimensional Ising spin glass. This ratio (computed for finite times on very large, effectively infinite, systems) is compared with the equilibrium probability distribution of the spin overlap for finite sizes. The resulting quantitative statics-dynamics dictionary, based on observables that can be measured with current experimental methods, could allow the experimental exploration of important features of the spin-glass phase without uncontrollable extrapolations to infinite times or system sizes.
Our study of the non-linear response emphasizes the coherence length, a crucial, yet elusive quantity in glass experiments. We first reproduce a milestone experiment that measures the spin-glass coherence length through macroscopic response (i.e. the lowering of free-energy barriers induced by the Zeeman effect). This "macroscopic" correlation length turns out to be quantitatively consistent with the coherence length estimated through the analysis of microscopic correlation functions. We also determine the scaling behavior, which allows a quantitative analysis of a new experiment [3].

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Kappa parameter estimations using quasi-thermal noise spectroscopy

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Quasi-thermal noise (QTN) spectroscopy is an accurate technique for in situ measurements of electron density and temperature in space plasmas. The QTN spectrum has a characteristic noise peak just above the plasma frequency produced by electron quasi-thermal fluctuations, which allows a very accurate measurement of the electron density, a thermal plateau at lower frequencies where signal scales with electron core temperature, and a power law decay towards higher frequencies, which has an intensity scaled with total plasma pressure. The size and shape of the peak, as well as properties of the spectral region below the plasma frequency, are determined by suprathermal electrons. Since this nonthermal electron population is well described by a generalized Lorentzian κ velocity distribution, it is possible to determinate the distribution properties in the solar wind from a measured spectrum. In this work, we discuss some basic properties of the QTN spectrum dependence of the κ distribution parameters - total electron density, temperature and the κ index, and give overview on how instrument characteristics and environment conditions affect quality of the measurements. As value of the κ is expected to be approximately 4-5 in the slow solar wind at 1AU, it turns out that the spectral resolution of an instrument is needed to be of the order of $2-3\%$ for accurate determination of the κ index. This requirement hasn't been fulfilled in most of the previous missions due to very large number of frequency channels required in order to cover the given spectral range. However, the high spectral resolution is not required on the entire spectral domain, but only on specific areas around and just below the peak, while for other spectral regions the resolution can be significantly (2-5 times) lowered without increasing the measurement uncertainties. This is the reason why usage of adaptive spectrum is proposed for some future missions, like Solar Probe Plus, where the spectral resolution will not be constant on the entire domain, but rather adapted to the changes in estimated local electron density.

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Unbiasedness of generalized score functions and sequential structures of expectations

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Information geometry is one of differential geometrical methods for mathematical sciences. In Riemannian geometry, a pair of a Riemannian metric and its Levi-Civita connection is important, whereas a triplet of a Riemannian metric and a pair of dual affine connections is important in information geometry. In the case of an exponential family, such as the set of all Gaussian distributions, we can naturally obtain a pair of dually flat affine connections, and this pair of affine connections has essential roles in geometric theory of statistical inferences. In particular, it is known that the dually flat structure can be obtained from the unbiasedness of score functions. A maximum likelihood method is characterized by a geodesic projection with respect to the dually flat structure, and a Legendre transformation structure is also obtained from this dually flat structure.
In the theory of nonextensive statistical physics, long-tailed probability distributions are also useful. For long-tailed probability distributions, the standard expectation does not exist in general. Therefore, the notion of escort distribution has been introduced, and the expectation with respect to the escort distribution has been studied. An escort distribution gives a suitable weight for tail probability, and the weight is characterized by an unbiasedness of generalized score functions.
In this presentation, we consider a sequential structure of escort expectations on a deformed exponential family. A deformed exponential family is a generalization of exponential families, which includes important classes of long-tailed probability distributions. It is known that a deformed exponential family naturally has at least three kind of different Riemannian metrics endowed with dual affine connections. In other words, we obtain three kind of

different statistical manifold structures. We can find that such statistical manifold structures are obtained from a sequential structure of escort expectations. In particular, in the case of a q-deformed exponential family, the Fisher metric can be obtained from the second escort expectation. In this presentation, after reviewing the q-exponential case, we will consider the kappa-exponential case. Then we will obtain a new divergence function for a kappa-exponential family.

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How the abundance in the universe of components determines the statistics of the shared components

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Several complex systems of diverse nature consist of realizations which can be broken into their elementary constitutive components, for example, books into words, genomes into genes, and men-made systems into building blocks. The statistics of the components (e.g., words) across realizations (e.g., books) shows several quantitative laws, such and the well-known example of the power-law distribution of component abundances, known as Zipf's law in the context of in the context of natural languages [1].
Central to the current debate in evolutionary genomics is a different law [2], the "distribution of shared genes", or "occurrence distribution", where a component occurrence is defined as the fraction of realizations in which the component is present. In genomes, the occurrence distribution shows a peculiar U-shape due to a large number of rare (i.e. belonging to very few species) and common genes (present in almost all the species), compared to genes at intermediate occurrences. While several possible theoretical explanations of the U-shaped gene occurrence distribution have been proposed, its causes are still under debate [3,4].
Here, we consider occurrence distributions in three datasets from genomics, linguistics (literary texts), and technology (LEGO toy constructions), showing that it is characterized by a general power law decay, and a dataset-specific size of the common component peak.
By means of a theoretical null model based on multinomial sampling we show that the characteristic U-shape can emerge as a statistical consequence of the abundance distribution (the Zipf's law) with some crucial small deviations.
This similarity between the empirical occurrence distribution and the null one allows also us to establish an analytical relationship between the law and the abundance statistics, identifying the crucial parameters affecting the power law decay and the size of the common component peak.
Our results suggest that several features of the occurrence distribution can be predicted by the knowledge of the abundance statistics, and therefore its global shape it is not so informative by itself. However, the distribution shows also small deviations from the null predictions, which are in fact its most interesting features, providing information specifically contained in the occurrence statistics.

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Interstellar boundary explorer (IBEX) overview and recent results

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The Interstellar Boundary Explorer (IBEX) has now operated in space for over seven years and returned nearly continuous observations of the Energetic Neutral Atoms (ENAs) with energies from 0.1 to 6 keV, emanating in for the outer heliosphere. Here we review the review IBEXs scientific discoveries that have reshaped our entire understanding of the outer heliosphere and its interaction with the local interstellar medium. IBEX observations have underlined the absolutely critical role of suprathermal ions in dominating the internal pressure and thus plasma processes in the inner heliosheath plasma between the termination shock and heliopause, as well as informing the interaction beyond the heliopause, well out into the local interstellar medium. IBEX provides the only global observations of the particle distributions in the outer heliosphere, and thus is a unique resource for understanding the plasmas in these key regions. Finally, with over half a solar cycle of observations, IBEX has now measured significant time variations in the ENA fluxes from the outer heliosphere and shown that the Ribbon has evolved differently than the globally distributed flux (GDF), suggesting different sources, or at lease sources at different distances. In these observations, ENAs from the GDF have leveled off and even partial recovered, owing to solar wind output flattening and recovery several years prior. The Ribbon exhibits a greater time delay than for the surrounding GDF and has lost its energy-latitudinal ordering, which reflects the breakdown of solar minimum solar wind conditions. Together, the IBEX observations strongly support a secondary ENA source for the Ribbon, which we now adopt as the nominal explanation of the Ribbon. These and other discoveries from IBEX will be summarized in this talk.

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From Hamilton to Boltzmann: The dynamical road toward equilibrium

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Can Hamiltonian dynamics explain the ubiquity of the Boltzmann factor? That isolated systems with many degrees of freedom evolve asymptotically in time towards thermal equilibrium lies at the heart of classical thermodynamics. Statistical mechanics teaches that for systems described by a Hamiltonian H, the thermal states are those described by the canonical Boltzmann relation $\rho = Z^{-1}\exp(-\beta H)$. This follows from original arguments of Maxwell, marginal distributions that arise from microcanonical ensembles, and the properties of the maximum entropy states to which systems thermodynamically tend. While such statistical arguments identify the thermal state, they provide no insight into the problem of how the microscopic dynamics of diverse large systems each lead towards equilibrium from an arbitrary initial state. Demonstrating how microscopic dynamics cause large systems to approach thermal equilibrium remains an elusive, longstanding, and actively pursued goal of statistical mechanics.
We explore this issue by studying the convergence toward thermal equilibrium of Hamiltonian (and mechanical) systems of interacting particles in contact to a bath of other systems. We focus on interactions that occur through collisions and explore the conditions under which the system reaches equilibrium after repeated and random interactions with the bath's degrees of freedom.
We identify a dynamical mechanism for thermalisation in

a general class of two-component dynamical Lorentz gases and prove that each component, even when maintained in a nonequilibrium state itself, can drive the other to a thermal state with a well-defined effective temperature, yielding a two-stage process for the thermalization of all the degrees of freedom. If the system is in contact with a bath out of equilibrium, equilibration of the system is always attained when the coupling with the bath is weak. Beyond the weak-coupling limit, equilibration is not always attained and it strongly depends on the details of the bath's energy distribution.

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Negative response to an excessive bias by a mixed population of voters

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We study an outcome of a vote in a population of voters exposed to an externally applied bias in favour of one of two potential candidates. The population consists of ordinary individuals, that are in majority and tend to align their opinion with the external bias, and some number of contrarians individuals who are always hostile to the bias but are not in a conflict with ordinary voters. The voters interact among themselves, all with all, trying to find an opinion reached by the community as a whole. We demonstrate that for a sufficiently weak external bias, the opinion of ordinary individuals is always decisive and the outcome of the vote is in favour of the preferential candidate. On the contrary, for an excessively strong bias, the contrarians dominate in the population's opinion, producing overall a negative response to the imposed bias. We also show that for sufficiently strong interactions within the community, either of two subgroups can abruptly change an opinion of the other group.

A unified approach to percolation processes on multiplex networks

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Networks are a powerful tool to represent the heterogeneous structure of interactions in the study of complex systems. But in many cases there are multiple kinds of interactions, or multiple interacting sub-systems that cannot be adequately represented by a single network. Examples include financial infrastructure, informatic and ecological systems. There are many representations of multi-layer networks, appropriate in different Circumstances (see e. g. for a summary). We focus on multiplex networks, which are networks with a single set of nodes present in all layers, connected by a different type of edge (which may be represented by different colours) in each layer. Some interdependent networks, in which different layers have different sets of nodes as well, but the nodes arent connected between layers by interdependency links, are able to be captured by this construction. One of the fundamental structural properties of a network is its response to damage, that is, the percolation transition, where the giant connected component collapses. In multi-layer networks, interdependencies between layers can make a system more fragile. Damage to one element can trigger avalanches of failures that spread through the whole system. Typically a discontinuous hybrid phase transition is observed, similar to those observed in the network k-core or in bootstrap percolation in contrast to the continuous transition seen in classical percolation on a simplex network. Under a weaker definition of percolation, a more complex phase diagram emerges, with the possibility for both continuous and discontinuous transitions. When invulnerable or seed nodes are introduced, we can define activation and pruning processes, which have different phase diagrams. In a single-layer network (simplex), two nodes are connected if there is at least one path between them along the edges of the network. A group of connected nodes forms a cluster. The giant connected component (GCC) is a cluster which contains a finite fraction of the nodes in the network. The existence of such a giant component is synonymous with percolation. We can study its appearance by applying random damage to the network. A fraction p of nodes are removed, independently at random, and we check whether the remaining network contains a giant connected component. Typically the GCC appears linearly with a continuous second-order transition, although when the degree distribution is very broad (as in scale-free networks) the

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Anomalous diffusion in membranes and cytoplasm of biologigal cells

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Lipid molecules are amphiphilic molecules with a hydrophilic head group and two hydrophobic tail groups. In water the lipids self-organise into micelles or bilayer sheets in order to avoid contact between the tail groups and the water molecules. Such bilayers form the basis of all biological membranes in living cells, and they are also at the heart of bio-compatible containers envisaged in drug delivery into biological cells.
This talk will focus on the dynamics of lipid molecules in lipid bilayer membrane systems as well as that of proteins embedded in the bilayer. It combines information from extensive all atom and coarse grained Molecular Dynamics simulations as well as single potassium channel trajectories measured in the membranes of living human cells. Particular focus is laid on deviations of the lipid and protein motion from normal diffusion. Such anomalous diffusion, characterised by a non-linear power-law scaling of the mean squared displacement will be demonstrated to characterise both lipids and proteins. While in a pure lipid system at room temperature this anomalous diffusion crosses over to normal diffusion at around 10 nanoseconds, it will be shown that the addition of disorder in the form of membrane-embedded cholesterol or protein molecules extends the range of the anomalous diffusion regime by several orders of magnitude. In the case of the membrane of the living cell, the anomalous diffusion reaches macroscopic time scales, at least of the order of hundreds of seconds. The stochastic motion of both lipids and proteins corresponds has its origin in the viscoelastic nature of the lipid bilayer-protein system, similar to the motion of a monomer in a Rouse chain.
When the concentration of proteins in the lipid bilayer becomes appreciable (protein crowding) it will be shown that the previously Gaussian nature of the probability density function of the particles is replaced by a stretched Gaussian form. This is shown to be connected with strongly varying mobilities in the system. Remarkably, very similar features are observed in a simple two dimensional argon systems, and thus a major contribution of the complexity of the motion is due to geometric constraints. In the protein motion in the living cell, the anomalous diffusion is dominated by waiting time motion with diverging time scale, and thus the motion becomes both ageing and non-ergodic.

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Physical aging and emerging long-period orbits in deterministic classical oscillators

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Physical aging is understood as the breaking of time translation invariance in the measurement of autocorrelation functions and long intrinsic time scales. In previous work [1] we had shown physical aging of repulsively coupled classical oscillators under the action of noise. Noise led to the migration of oscillator phases through a rich attractor space. To explore the role of stochastic fluctuations in physical aging, we here replace noise by a quenched disorder in the natural frequencies. Again we identify physical aging, now in a deterministic system of repulsively coupled Kuramoto oscillators, where the attractor space is explored quite differently. Tracing back the origin of aging, we identify the long transients that it takes the deterministic trajectories to find their stationary orbits in the rich attractor space. The stationary orbits show a variety of different periods, which can be orders of magnitude longer than the periods of individual oscillators. The smaller the width of the distribution about the common natural frequency is, the longer are the emerging time scales on average. Among the long-period orbits we find self-similar temporal sequences of temporary patterns of phase-locked motion on different time scales. The ratio of time scales is determined by the ratio of widths of the distributions about the common natural frequency, as long as the width is not too large. The effects are particularly pronounced if we perturb about a situation in which a self-organized Watanabe-Strogatz phenomenon is known to happen, going along with a continuum of attractors and a conserved quantity. We expect similar phenomena in coupled FitzHugh-Nagumo elements with a certain disorder in the model parameters and antagonistic couplings as guarantee for a rich attractor space.

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A matrix function approach with analysis of fractional random walks on regular n-dimensional lattices

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The study of random walks on networks has become a rapidly growing interdisciplinary research field within the last two decades. Networks are omnipresent structures in nature occuring in biology, human cities, transportation networks, electricity networks, the internet, social networks, crystalline lattices, and many further examples can be found. Networks appear as structures of communicating subsystems (nodes) which are somehow connected. A very successful approach to describe the stochastic dynamics of information exchange between the nodes in a network is the *random walk* concept [1]. Random walks appear naturally in a diversity of problems such as in the development of search strategies on networks such as the world wide web (google), but also in the context of a diffusing interstitial atom in a crystalline lattice.
In this presentation we develop an approach for time-discrete and continuous random walks on undirected regular networks with some explicit expressions for cubic periodic lattices in $n = 1, 2, 3, ..$ dimensions in the framework of Markovian process. First we invoke necessary conditions for 'good' Laplacian matrices to describe random walks. To this end we consider first the random walk on a regurlar network having only next neighbor connections [1]. Then we analyse random walks generated by matrix functions of the above mentioned simple Laplacian matrix. We consider a series of examples for admissible matrix functions to define various kinds of random walks. We demonstrate that the frational Laplacian matrix $L^{\frac{\alpha}{2}}$ defined by a power of an admissible Laplacian matrix L is admissible in the range $0 < \alpha \leq 2$.
The associated fractional random walk dynamics is governed by a master equation involving *fractional powers of Laplacian matrices* $L^{\frac{\alpha}{2}}$ where $\alpha = 2$ recovers the normal random walk. We derive for regular networks, in particular n-dimensional cubic lattices key quantities such as the transition matrix, fundamental matrix and closely related generating functions for the fractional random walk. We obtain in this way for the fractional random walk the mean relaxation time (Kemeny constant), return probabilities and first passage probabilities. We show that the transition matrix exihibits for large cubic n-dimensional lattices a power law decay and for large times characteristic $t^{-\frac{n}{\alpha}}$ behavoir, indicating emergence of levy flights. It follows from our results that the efficiency to explore the network is increased when instead of a normal random walk ($\alpha = 2$) a fractional random walk ($0 < \alpha < 2$) is chosen.

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Rank-size distribution of person names and place names

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Family names are handed down from ancestors to their descendants in many cultures. Therefore, they can be regarded as a kind of biological heredity. There are many studies on this subject, such as their origin, family histories and extinction phenomena. Among them, Miyazima et al. focused on the statistical distribution of Japanese family names and found several power law behaviors in the rank-size distribution and the relationship between the population and the number of distinct names. The former corresponds to Zipf's law and the latter is Heaps' law. Several works followed with mathematical models, with better fitting or using data of other countries with various exponent values.
Compared with those of family names, systematic studies of the statistical distribution of given names are fewer. We can, however, set the same problems as those for family names, e.g., the rank-size distribution and the relation between the population and the number of distinct names.
In this study, we exemplify a statistical analysis of family names and given names in several countries by using a telephone directory and lists of scientist. A power law behaviour is observed in the rank-size distribution of given names as in the case of family names. It is interesting that their statistical property resembles each other though the elemental processes of naming are different. We introduce a Galton-Watson type model with a generalized Yule-Simon process combined with an Exclusion Principle in Family for the given name distribution. We also discuss about the locality of the name distributions.
The size frequency distribution of Japanese place name is also analyzed. The list of municipalities and town-area names are extracted from the zip code table and their rank size distributions are measured. The distribution of town-area

names obeys a power law behavior while the distribution of municipality names is well fitted by a log normal distribution. A similar mathematical model of the municipality and town-area evolution and their naming process is suggested.

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Exploiting global buyer-supplier networks to improve supply chain due diligence

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What are the responsibilities of multinational corporations amid economic globalization in dealing with environmental degradation, widespread poverty, refugee displacement, racial discrimination, terrorism, regional conflicts, and other global challenges? Certainly one initiative that would nudge the world in the right direction would be for companies to assume greater responsibility for the environment and human rights issues by improving the transparency of entire supply chains from a global perspective. However, since the global supply chain has this feature of small-world connectedness [1], it is exceedingly difficult to check every supplier and client upstream from each firm. In this paper we propose a scheme that markedly improves transparency by exploiting this network structure.
In global supply-chain, companies group themselves into communities that might be called cartels or associations, and companies are most closely associated with other companies in the same community. Small world connectedness or globalization is brought about by a relatively small number of companies that act as intermediaries between communities [2]. We will employ negative information about a company that is widely covered by the global mediaa company is reported to employ child labor, for example. We will statistically prove situations in which companies sullied with adverse information are concentrated in certain communities making up the global supply chain. In other words, if the mediating company between communities is able to check that no products from the discredited company have found their way into the market, then the mediating company would be in a position to prove transparency of a vast number of products from a vast number of downstream companies. There are very few of these mediating companies. We will evaluate increased transparency of the supply chain by pinpointing companies that mediate with communities harboring companies with adverse information using the connectivity and path length between companies in the global supply chain, and offer policy proposals for dealing with supply chain risk. We will provide some examples of the proposed scheme. First, it will be illustrated how the scheme might work for dealing with the conflict mineral crisis in the Democratic Republic of Congo. Next, we will also show how this approach could be applied to identify goods produced by companies exploiting slave labor or other labor issues.

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Statistics of correlations and fluctuations in a stochastic model of wealth exchange

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In our recently proposed stochastic version of discretized kinetic theory, the exchange of wealth in a society is modelled through a large system of Langevin equations. The deterministic part of the equations is based on non-linear transition probabilities between income classes. The noise terms can be additive, multiplicative or mixed, both with white or Ornstein-Uhlenbeck spectrum. The most important measured correlations are those between Gini inequality index G and social mobility M, between total income and G, and between total income and M. We describe numerical results concerning these correlations and a quantity which gives average stochastic deviations from the equilibrium solutions in dependence on the noise amplitude.
The Gini index G is a widespread measure of income inequality in a society, expressed as a non-dimensional ratio of the relative mean absolute difference of income between two income classes to double their mean. The social mobility M can be identified with multiple definitions, but in essence it is defined as the probability for an individual to pass to the upper income class in a given unit time, averaged over all classes.
Empirical evidence shows a clear correlation between these two quantities, namely it is found that mobility reduces when inequality rises, thus implying a negative correlation between G and M. This correlation, nicknamed the "Great Gatsby Curve", is important since it means that the increase of inequality (as presently observed in several countries) tends to be a self-reinforcing phenomenon, unless it is complemented by suitable social policies. This holds for societies at near equilibrium.

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Nonlinear time series analysis of atmospheric gravity waves

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Internal gravity waves in the Earths atmosphere are a very interesting and complex research subject in modern atmospheric physics. These gravity waves couple different atmospheric regions both in vertical as well as in the horizontal directions by means of momentum and energy transport. They can propagate upwards, and also in the opposite direction, from the troposphere to the stratosphere, mesosphere and thermosphere where they eventually break. They transfer energy, momentum and chemical species between the different atmospheric layers and therefore play an important role on atmospheric winds, temperatures, chemistry and especially turbulence. A better understanding of the excitation and propagation of these waves would contribute to climate models.
Nonlinear network based analysis of multidimensional meteorological time series has led to new insights in climatology [Ref1, Donges]. We apply techniques from nonlinear time series analysis to nonlinear data sets of simulated multidimensional time series of wind velocities and other atmospheric parameters and combine them with complex networks analysis. The simulations are adapted to measurements of the GW-LCYCLE coordinated field program [Ref2, Rapp]. Specifically, we analyze the vertical component of the wind speed in 137 horizontal layers of the atmosphere ranging from the ground level up to an altitude of approximately 40 km. A comparison of Pearson correlation and the mutual information reveals linear and nonlinear dependencies between certain altitude levels. In order to identify continuing signals traversing different height levels over time we test the approach of varying time lags between the time series of different layers. A maximization of the correlation measures, whether linear or nonlinear, could enable the identification of such signatures.

These signatures might resemble the signatures of atmospheric gravity waves. A family of networks is constructed from the time series correlation analysis. The network analysis allows to compare different network topologies. Our findings give new insights into the processes of momentum and energy transfer into higher layers of the atmosphere.

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Confotronic of biofilaments

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Many biofilaments like those of the cytoskeleton show anomalous behaviors in various experiments. As we will show, this can be explain by the existence of internal degrees of freedom, usually inaccessible by direct observation, but crucial for the understanding of the collective dynamics of the biofilaments. This is the case for coiled helices squeezed flat onto two-dimensional surfaces. Under such 2-d confinement helices form "squeelices", peculiar squeezed conformations often resembling looped waves, spirals or circles. The shapes as well as the unusual statistical mechanics of squeelices can be understood in terms of moving and interacting localized conformational quasi-particles called the twist kinks. These theoretical results will be interpreted in the light of recent experiments realized on actin and intermediate filaments. As a second example we will consider tubular lattices like microtubules. Despite significant effort, understanding the unusual mechanics of microtubules remains elusive. Based on recent experimental evidences for a conformational switch of the tubulin dimer we will introduce prestress in tubular structures and see that localized conformational quasi-particles called confloplexes emerge naturally. When we switch on additional mechanical coupling terms in the lattice, these quasi-particles will exhibit cooperative interactions. The cooperativity will lead to the formation of larger scale quasi-polymer superstructures called confostacks which will govern the collective shape dynamics of the lattice via elastically mediated interactions. The notion of quasi-particles/-polymers is the most natural language to quantitatively describe many new phenomena that we named confotronic dynamics. In particular, these internal degrees of freedom lead to a microtubule lattice that coexists in discrete super helical polymorphic states that have very unique characteristics in the world of macromolecules: microtubules are helices that are permanently but coherently reshaping due to thermal fluctuations. This particular zero energy motion could be the clue to explain the observed anomalous elastic and dynamic behavior of microtubules. Another persistent mystery is the formation of long lived arcs and rings in kinesin driven gliding assays. Our theory predicts that metastable curved states can be induced via a mechanical hysteresis involving torques and forces typical of a few molecular acting in unison in agreement with experiments.

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Emergence of compositional representations in restricted Boltzmann machines

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Machine learning has undergone spectacular achievements in the recent years, thanks in particular to the development of the so-called deep learning methods. However, unsupervised learning, that is, the automatic extraction of the complex set of features composing real high-dimensional data still faces formidable challenges. In this talk I will review one of the simplest approach for unsupervised learning, the so-called Restricted Boltzmann machines (RBM), proposed about 30 years ago. RBM are empirically known to be efficient for modelling data distribution, and to be able to generate distributed and graded representations of the data, a property sometimes referred to as compositional phase. RBMs may also be seen as the elementary building bricks of more complex, deeper architectures.
Despite empirical evidence, our understanding of how and why RBMs function is still not satisfactory. Based on analytical calculations using the tools and concepts of the statistical physics of disordered systems, I will discuss the structural conditions (sparsity of the weights, low effective temperature, nonlinearities in the activation functions of hidden units, and adaptation of fields maintaining the activity in the visible layer) allowing RBM to operate in such a compositional phase. In addition, I will show that RBM exhibit remarkable energy landscape properties, which allow them to equilibrate very quickly despite the presence of multiple low-lying configurations. This fast mixing dynamics is at odds with the usual dynamics taking place in other models, such as the Hopfield model, in which equilibrations requires activated processes overcoming large barriers and is very slow. Evidence will be provided by the replica analysis of an adequate statistical ensemble of random RBMs and by RBM trained on the handwritten digits data set MNIST. Finally I will discuss the dynamics of learning of RBM, and, in particular, how they learn distributions with invariances. This study suggests practical way of improving the existing learning algorithms.

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Significance and popularity in popular music production

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In the world of artistic production there is a constant struggle to achieve fame and popularity. This fierce competition between artistic creations results in the emergence of highly popular elements that are usually well remembered throughout the years, while many other works that did not achieve that status are long-forgotten [1,3]. However, there might be other levels of importance that must be considered in order to have a more complete picture of artistic production world.
For example many works that have influenced the production itself, both due to their aesthetic and cultural value, might have not been or might not be popular anymore. In other cases, works being developed in a particular field might cross the fields borders and have an impact on the society at a global level. In this paper we focus on the duality between popularity and significance in the context of popular music, trying to understand the features of music albums belonging to one or both of these classes.
By means of user-generated data gathered on Last.fm, an

on-line catalog of music albums, we define a growing conceptual space in the form of a network of tags[2] representing the evolution of music production during the years. We use this network in order to define a set of general metrics, characterizing the features of the albums and their impact on the global music production.
We then use these metrics to implement an automated prediction method of both the commercial success of a creation and its belonging to expert-made lists of particularly significant and important works. We show that our metrics are not only useful to asses such predictions, but can also highlight important differences between culturally relevant and simply popular products. According to our findings, popular artworks exploit stylistic heterogeneity in order to gather the attention on the largest part of the public. On the other hand, significant albums are very related to the emergence of new styles and features in a precise time period and are not necessarily popular. Finally, our method can be easily extended to other areas of artworks creation, also including scientific production.

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Modelling delay dynamics on railway networks

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Railways are a key infrastructure for any modern country, so that their state of development has even been used as a significant indicator of a country's economic advancement. Moreover, their importance has been growing in the last decades either because of the growing Railway Traffic and to governments investments, aiming at exploiting railways means to reduce CO2 emissions and hence global warming.
To the present day, many extreme events (i.e. major disruptions and large delays compromising the correct functioning of the system) occurs on a daily basis. However these phenomena have been approached, so far, from a transportation engineering point of view while a general theoretical understanding is still lacking. A better comprehension of these critical situation from a theoretical point of view could be undoubtedly useful in order to improve traffic handling policies.
In this work we move toward this comprehension by proposing a model about train dynamics on railways network[1] aiming to unveil how delays spawn and spread among the network. By means of two datasets about Italian and German Railway traffic, we characterized the sources of delay as "endogenous (due to the interactions between the trains) and "exogenous (coming from adverse conditions such as bad weather and malfunctions). We show that exogenous delays can be modeled as a universal delay-generation mechanism depending on the topological properties of the Railway Networks and originated by the same amount of external sources, independently from the considered spot on the network. Inspired by models for epidemic spreading[2,3], we model the diffusion of delays among train as the diffusion of a contagion among a population of moving individuals, where the seeds of the contagion are represented by the spontaneous occurrence of exogenous delays.
The model reproduces adequately delays dynamics in the Italian and German systems, meaning that it captures its underlying key factors. In particular, our model predicts that the insurgence of clusters of stations with large delays is not due to external factors, but mainly to the interaction between different trains, suggesting that the reduction of such interaction is the main objective in order to reduce the occurrence of extreme adverse conditions.

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Refractory period in a network of excitable nodes leads to dynamical stability, extended region of criticality as well as oscillatory behavior

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Various physical, biological and chemical systems are composed of interacting excitable agents and thus networks of excitable nodes are widely used to model the behavior of such systems. Examples of such systems include tectonic plates, Neural networks, models of self-organized criticality (SOC), and epidemic (contagion) spreading. In particular, excitable nodes have been used extensively in models of neuronal dynamics where criticality is proposed to be a fundamental property. Refractory behavior, which limits the excitability of neurons is thought to be an important dynamical property. We therefore consider a simple model of excitable nodes which is known to exhibit a transition to instability at a critical point ($\lambda = 1$), and introduce refractory period into its dynamics. We use mean-field analytical calculations as well as numerical simulations to calculate the activity dependent branching ratio that is useful to characterize the behavior of critical systems. We also define avalanches and calculate probability distribution of their size and duration. We find that in the presence of refractory period the dynamics stabilizes while various parameter regimes become accessible: a subcritical regime, a standard critical point with exponents close to the critical branching process with $\lambda = 1$, a regime with $1 < \lambda < 2$ that exhibits an interesting scaling (critical) behavior, and an oscillating regime for $\lambda > 2.0$. The critical regime is characterized by power-law avalanche statistics in both time and space, as well as activity-dependent branching ratio that converges to one in the thermodynamic limit. We have therefore shown that refractory behavior leads to a wide range of scaling as well as periodic behavior which are relevant to real neuronal dynamics. We note that the existence of extended criticality is of particular interest since it provides an answer to how complex systems exhibit scaling behavior without any apparent tuning to a specific critical point.

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State equation of a relativistic ideal gas

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The hydrostatic pressure of an ideal gas is defined as being two thirds of the average kinetic energy of the gas: $p = 2 < K > /3$, where $< K >$ is the average kinetic energy. To calculate this average the kinetic energy of the molecules is to be weighed with the equilibrium distribution function of the gas. For the purpose of this work the relativistic

equilibrium distribution function will be considered, both for the classic (i.e., non-quantum) case, to wit the relativistic maxwellian, and for the quantum relativistic equilibrium distribution function, i.e., the Fermi-Dirac and Bose-Einstein distribution functions. In both cases, the relativistic equilibrium distribution function contains in turn the relativistic hamiltonian.
As is well known, starting from the relativistic maxwellian and resorting to ad hoc changes of variables, integration of the former can be performed and the normalization constant of the equilibrium distribution function can then be obtained as a function of number density and temperature: the normalization constant contains a modified Bessel function [1].
In the present work, starting from this well established result the average kinetic energy is calculated through further integration, yielding a result in closed form containing again modified Bessel functions. A large-argument approximation is then taken, and it is then shown how the equation of state can be broken into the classic part plus a correction term accounting for relativistic effects.
The same procedure is then applied starting from the quantum relativistic equilibrium distribution function developed by the same authors [2], and the cases of bosons and weakly degenerate fermions are considered. Here too, further integration leads to an expression for the average kinetic energy containing a number of modified Bessel functions: once again, large argument considerations are applied to underline the effect of the quantum equilibrium distribution functions writing the equation of state as a zeroth order term plus a quantum correction.

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Differential emission measure as a sum of gamma and kappa distribution functions in solar flares based on X-ray and EUV observations

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In recent years there is a growing interest in various analytical distributions, for example, a kappa distribution, which is close to the Maxwellian distribution at low energies and have a power-law tail at high energies [e.g. (Kašparova & Karlický 2009; Oka et al. 2013, 2015)]. For energies much larger than the energy k_BT, it approaches a power-law spectrum and for kappa-index close to infinity - a Maxwellian distribution. It should also be noted that the kappa-distribution is supported by theoretical considerations on the acceleration of particles in collisional plasmas. In addition to kappa-distribution to describe a differential emission measure (DEM), mean electron flux spectrum $\langle nVF\rangle$ and obtain the plasma parameters (emission measure (EM), temperature (T)) a gamma-distribution was introduced [Motorina & Kontar, 2015]. It has an analytical representation of DEM and $\langle nVF\rangle$, which contains the modified Bessel function of the second kind, with three parameters (EM, T_{max}, spectral index α) and approaches to the Maxwellian distribution when α tends to infinity.
EUV observations with Atmospheric Imaging Assembly on board the Solar Dynamic Observatory (AIA/SDO) and X-ray observations with Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) provide information about hot flaring plasma and energetic particles accelerated during solar flares. RHESSI is more sensitive to hot plasma above ∼10 MK and AIA/SDO characterizes the thermal response at lower temperatures at∼ 0.6-16 MK. Simultaneous observations with AIA/SDO and RHESSI allow to investigate the energy distribution of electrons heated/accelerated over a wide energy range from ∼0.1 keV up to tens of keV [Inglis & Christe, 2014, Motorina & Kontar, 2015, Battaglia et al. 2015]. Using both gamma- and kappa-DEM functions based on RHESSI and AIA/SDO observations one limb flare event was considered. The results of temporal evolution of plasma parameters, DEM functions and mean electron flux spectrum are discussed.

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Temperature profile and boundary condition in anomalous heat transport

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A framework for studying the effect of the coupling to the heat bath in models exhibiting anomalous heat conduction is described [1]. The framework is applied to the harmonic chain with momentum exchange model where the non-trivial temperature profile is calculated. In this approach one first uses the hydrodynamic (HD) equations to calculate the equilibrium current-current correlation function in large but finite chains, explicitly taking into account the boundary conditions resulting from the coupling to the heat reservoirs. Making use of a linear response relation, the anomalous conductivity exponent and an integral equation for the temperature profile are obtained. The temperature profile is found to be singular at the boundaries with an exponent which varies continuously with the coupling to the heat reservoirs expressed by the boundary conditions.
The linear response relation obtained in this work should be valid for other systems when the temperature difference is small and the system size N is large. In this regard, the Harmonic Chain with Momentum Exchange (HCME) model constitutes a landmark in which hydrodynamic boundary conditions can be obtained, the hydrodynamic equations can be solved exactly and the solution is valid for any temperature difference. Our analysis shows that a single reflection of the sound peaks can be enough to modify the asymptotic temperature profile. It would be interesting to apply the same approach to other systems and obtain the temperature profiles for systems such as Fermi-Pasta-Ulam chains or gas models.
An interesting result of the present study is the clear analytical and conceptual connection between the Lévy flight picture which was proposed for accounting for anomalous heat conduction[2,3] and the HCME. The equation governing the temperature profile is found to be the same as that obtained for the density profile of a system of particles performing Lévy flights with a length distribution decaying with a power 5/2. In the HCME the fluctuations of the sound modes are identified with the quanta of heat being carried by the Lévy flyers and the spreading of the peaks corresponds to the decrease of the flight length probability with distance.

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Emergent Berezinskii-Kosterlitz-Thouless phase in low-dimensional ferroelectrics

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In two-dimensional systems with continuous symmetry and short-range interactions, strong fluctuations prevent the formation of long range order, and rather than a spontaneous symmetry breaking, a topological phase transition driven by the unbinding of vortex-antivortex pairs can occur, the so-called Berezinskii-Kosterlitz-Thouless or BKT transition. It is an infinite-order phase transition and is paradigmatically captured by the two-dimensional XY-model that has attracted much interest for it astutely describes, amongst others, the physics of superfluid helium films, superconducting films, the Coulomb gas model, Josephson junction arrays, and nematic liquid crystals. Ferroelectrics on the other hand, which constitute an important class of materials, are prima facie not expected to exhibit BKT transition, owing to their discrete symmetry stemming from the cubic anisotropy of both the lattice and the ferroelectric interactions, which include the long-range dipolar ones. Whether the BKT behavior would be robust against the introduction of symmetry-breaking ferroelectric anisotropy remains unsettled. Here we show, using Monte Carlo simulations of a first-principles-based effective Hamiltonian scheme as well as scaling, symmetry, and topological arguments, that an intermediate critical BKT phase underlain by quasi-continuous symmetry emerges between the ferroelectric phase and the disordered paraelectric one in tensily strained thin-film of BaTiO3, a prototypical ferroelectric. We find that this overlooked intermediate phase supports quasi-long-range order reflected in the algebraic decay of the correlation function and sustained by the existence of neutral bound pairs of vortices and antivortices, in accordance with defining characteristics of a BKT phase. Its lower and upper critical temperatures, T_c and T_{BKT}, are associated with the condensation and unbinding of vortex-antivortex pairs, respectively. Moreover, we also find that upon reaching T_{BKT}, the correlation function's critical exponent acquires a value close to the theoretical predictions 0.25 of the XY-model, further indicating that the upper transition is likely to be of the BKT type. Our results therefore highlight the subtle, fundamental richness of low-dimensional ferroelectrics and widen the realm of BKT transitions.

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Kinetic model to interpret Whistler waves in multi-component non-Maxwellian space plasmas

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Whistler waves are right handed circularly polarized waves and are frequently observed in space plasmas. The Low frequency branch of the Whistler waves having frequencies nearly around 100Hz, known as Lion roars, are frequently observed in magnetosheath. Whistler waves are generally observed in the frequency range, i.e. observations of at top electron distributions with single as well as two electron populations. In the past, lion roars were studied by employing kinetic model using classical bi-Maxwellian distribution function, however, could not be justi ed both on quantitatively as well as qualitatively grounds. We studied Whistler waves by employing kinetic model using non-Maxwellian distribution function such as the generalized (r, q) distribution function which is the generalized form of kappa and Maxwellian distribution functions by employing kinetic theory with single or two electron populations. We compare our results with the Cluster observations and found good quantitative and qualitative agreement between them. At times when lion roars are observed (not observed) in the data and bi-Maxwellian could not provide the su cient growth (damping) rates, we showed that when generalized (r, q) distribution function is employed, the resulted growth (damping) rates exactly match the observations. We compare our results with the Cluster observations and found good quantitative and qualitative agreement between them. In this paper, by deriving the general dispersion relation for R and L waves, we studied the Whistler waves with two electron temperature (r,q) distribution function. The numerical values of plasma parameters are taken from Cluster data and plot the whistler wave's real frequency and damping/growth.

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Jahn-Teller phase transitions in icosahedral molecules

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Non-linear molecules undergo distortions when the orbital degeneracy of the highest occupied level is lifted by the JahnTeller effect. If such molecules or clusters of atoms are coupled to one another, the system may experience a cooperative JahnTeller effect (CJTE). In this paper, we describe a model of how the CJTE leads to the crystallization of the disordered phase. The model Hamiltonian is based on a normal mode decomposition of the clusters in order to maintain the symmetry labels. We take account of the electron-strain and the electron-phonon couplings and, by displacing the coordinates of the oscillators, obtain a term that explicitly couples the JahnTeller centers, enabling us to perform a mean-field analysis. The calculations can be done by coupling the clusters via the infinite-range strain fields where the mean-field approximation becomes exact. The calculation of the free energy then becomes straightforward, and obtaining phase diagrams in various regimes follows from the minimization of this free energy. The results show that the character of the phase transition may change from strong to weak first order and even to second-order, depending on the coupling to the vibrational modes. Taken together, these results may serve as a paradigm for crystallization near the transition temperature, where the atoms tend to form clusters of icosahedral symmetry. These results have already been obtained and published in Journal of Physics. Nonetheless, more accurate results are achieved by explicitly coupling the clusters through their normal-modes interactions. Hence the main challenge is the transformation of the spatial-coordinate Hamiltonian into one solely in terms of the normal modes of the clusters. The translation-symmetry of the system enables Fourier transformation of the coordinates, while the point group symmetry gives insight to the general form of the Hamiltonian. The phase diagrams happen to be easily deduced from the Hamiltonian in the phonon coordinates.

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Dually flat geometries in the state space of statistical models

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The study of the geometry of models of statistical physics started with the work of (Weinhold, 1975) and (Ruppeiner, 1979). A key notion is the thermodynamic length which is a measure for distances in the space of equilibrium states of the model. Appealing is the relation between model interactions and the curvature of the state space. On the other hand, (Amari, 1985) showed that the state space of a statistical model can be equipped with a dual set of flat geometries. The duality between the two geometries is based on Legendre transforms and is the same duality which in thermodynamics relates inverse temperature to energy and Massieu's function to entropy. One of the two geometries is flat in intensive coordinates such as inverse temperature and external magnetic field. The other is flat in the extensive variables energy and total magnetization. Because geodesics are straight lines it is easy to calculate a thermodynamic length in these flat geometries. The ideal gas is discussed as an example.
The relative entropy is the central quantity. It is called the Kullback-Leibler divergence in the mathematics literature. It determines the Fisher information matrix, which in the geometric approach plays the role of the metric tensor. By taking derivatives of the metric tensor one obtains the Christoffel symbols. They determine whether the geometry is flat or curved. The geodesics are calculated from the Euler-Lagrange equations.
The talk is intended for an audience of physicists knowing basics of statistical physics and thermodynamics. The mathematical language of differential geometry is avoided and replaced by familiar notions coming from classical mechanics and relativity theory.

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Large coordination number expansion for quantum lattice systems

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The quantum lattice systems are encountered in many field of physics: solid states, ultra-cold gas and quantum meta-materials. The typical examples are the Bose or Fermi Hubbard models, or the Heisenberg spin model. An important application of these models is towards the investigation of essentially non-equilibrium and non-stationary effects such as quenching in a cold gas or evolution of a quantum annealer.
Our investigation is based on the general approach of 1/Z expansion (where Z is the lattice coordination number [1-4]). This formalism provides a general framework for building a hierachy of equations for the reduced n-site density matrices, which allows a systematic approach to the calculation of the equilibrium properties [3, 4] as well as to describe its non equilibrium dynamics [1, 2]. In our latest work [4], we use the 1/Z expansion to determine the ground state and the quench dynamics of the quantum Ising model in one, two and three dimensions. Our method reproduces quite well the physics of this model such as the quantum phase transition between the paramagnetic and ferromagnetic phases or also the excitation spectrum. Such a model describes the dynamics of an array of quantum magnetic moments (e.g., qubits) perturbed by an external magnetic field under the conditions of long de-coherence time. Such structures containing over 2000 qubits are being currently produced for the use as quantum annealers, but despite intensive research the question of the degree of their "quantumness" and the character of their evolution remains open [5]. Our recent results [4] provide insight into the non-equilibrium correlations in these devices.

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Ruin game on random garphs

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A monopolist type ruin-game [1,2] is considered on one-component Erdos-Renyi type random networks [3]. Players with equal initial wealth are placed on the nodes of the graph. At each time-moment a monopolist game is performed on the active links. In such a game the two connected players puts a unit wealth in the pot and the pot is won with equal probability by one of them. Active links are those that connect players with non-zero wealth. The game ends when there is no active link in the graph, i.e. nodes that remain with non-zero wealth are not connected by links.
We give a compact analytical prediction for the expected number of nodes that remains with nonzero wealth at the end of the game, their wealth distribution and the duration of the game. Our theoretical prediction relies on the simple assumption that the final state of the system can be well approximated as a random selection of nodes in the graph that are not directly linked, and the distribution of wealth on these nodes is also random: each distribution of the total wealth being equally probable. The hypothesis on which our theoretical approximations are built and the theoretical predictions are confirmed by Monte Carlo type computer experiments.
We find that the number of nodes remaining with non-zero wealth depends linearly on the initial number of nodes and roughly inversely proportional with the average degree of the nodes. The wealth distribution of these nodes can be well approximated by an exponential distribution, and the expected time-duration of the game is proportional with the square of the players initial wealth and has a linear trend as a function of the logarithm of the graph size. The dependence as a function of the average degree of the nodes is more complicated, but for dense graphs it can be considered to be roughly linear.
The ruin-game considered in the present study can find several applications in modeling various social or economic phenomena like: opinion formation, voting, clustering of a society according to some social and/or economic preferences or even wealth (or customer) redistribution among economic agents.

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Consensus formation times in anisotropic societies

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We developed a statistical mechanics model to study the emergence of a consensus in societies of adapting, interacting agents constrained by a social rule B.
The term consensus is understood to be the level of agreement amongst the agents in favor or against the predetermined socially accepted position delivered by B [1]. B represents the set of rules that determine what is socially acceptable. Such rules are the result of previous consensus-forming processes, typically observed in any functioning society [2,3].
Agents form their opinions on social issues based on partial information received regularly during the process. The volume of information increases over time and, the agents being adaptive, they update their opinions accordingly. At the end of the process the level of agreement between agents and B is measured to determine whether a consensus is formed supporting or rebutting the social order.
The model we work with was presented in reference [4] and possesses the following characteristics:
1) There is a mechanism for the agents to assimilate information and update their opinions.
2) The model considers the existence of a set of rules B that determine what is socially acceptable.
3) The model considers the interaction H_0 of the agents with their neighbors [5], with a strength proportional to the credibility of the neighbors, their number and their proximity to the agent.
In the mean field approximation we find that if the agents' interaction H_0 is weak, all agents adapt to the social rule B, with which they form a consensus; but if the interaction is sufficiently strong a consensus is built against the established status quo. We observed that, after a transient time α_t, agents asymptotically approach complete consensus by following a path where they neglect their neighbors' opinions on socially neutral issues (i.e. issues for which the society as a whole has no opinion). α_t is found to be finite for most values of the inter-agent interaction H_0 and temperature $1/\beta$, with exception of the values $H_0 = 1$, $\beta = 0$ and the region determined by the inequalities β

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Probing many-body localization with neural networks

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Machine learning is a booming technique for analyzing big amounts of data, in particular since the rise of deep neural networks a few years ago. Very recently, these methods have been applied to quantum many-body systems in various contexts. I will discuss how artificial neural networks can be employed to classify phases of matter. While the approach that I will present can be applied to various classification problems of this type, I will use the example of distinguishing a thermalizing from a many-body localized phase. Many-Body localization is a phenomenon by which interacting quantum systems evade following the rules of conventional statistical mechanics, in particular they are not ergodic. Instead they retain memory of their initial conditions for arbitrary long times. Specifically, I will use entanglement spectra of the Heisenberg spin-1/2 chain in a random external field , which exhibits a many-body localized phase at strong disorder, as input for the neural network. While the network is trained on entanglement spectra deep in either phase, it is then applied to classify spectra belonging to states in the phase transition region. The resulting phase diagram is in remarkable agreement with the one obtained by more conventional methods and can be computed for small systems. I furthermore discuss the entanglement structure of individual eigenstates which can be mapped out with spatial resolution using this method. The structure elements of the network that are crucial for the correct classification are presented. In particular, the network features an element that encourages confident classification of states close to the phase transition. This conference optimization as well as other regularization that I will discuss are important for a reliable operation of the network. Finally, I will mention how the robustness of these results can be tested using a neural network technique called dreaming, where a known power law behavior of entanglement spectra in the many-body localized phase is recovered.

Determining the kappa index of space plasma distributions from observations in a limited energy range

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The fluid parameters of space plasmas can be derived from the distribution function of the plasma in the velocity space, which can be constructed from observations. Two common methods to derive the plasma parameters from the distribution function i) by calculating the distributions moments via integration and b) by fitting the distribution with an analytical function of the plasma parameters. When the first method is used, the full 3-dimensional distribution function of the ions species should be constructed from the observations in order to be integrated. For the second method, a specific analytical expression of the distribution function should be determined in order to explore for which parameters the expression fits the observations. Space plasmas are often described by kappa distributions. The core of such distributions is a Maxwell-like distribution while the high energy tails are power law- like distributions. The kappa index of the distribution should be defined for the accurate description of the plasma and its fluid parameters. For example, previous studies have shown that the plasma temperature can be significantly misestimated if the Maxwell distribution is used to describe plasmas that follow the kappa distribution. Typically, the kappa index is determined by fitting the high energy tails of the distribution, thus it gets very difficult or not possible to do so, when the high energy tails are not clearly observed. This can be illustrated with the observations of solar wind using an electrostatic analyzer (measures energy per charge); the proton distribution peaks at ≈1keV/q but the high energy tail is covered by the alpha particle distribution which peaks at ≈2keV/q. We demonstrate how the kappa index of plasma distributions can be still determined from observations at limited energy range, near the distributions maximum value. The approach reduces the free parameters when we perform complicated fittings of 3-D distribution functions. We first explain the mathematical formulas used for our approach and then demonstrate the techniques with pseudo-observations of plasma particles.

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Plasma temperature misestimation when the Maxwell distribution is assumed for the analysis of plasma that follows the kappa distribution

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The fluid properties of the plasma can be derived from plasma instrument observations following various methods of data analysis. Typically, the form of the plasma distribution has to be defined prior the analysis, whereas two common methods that are used to derive the plasma fluid properties are the fitting i) directly to the distribution function, and ii) to the forward modeling of the instrument's response in given plasma conditions. In this work, we examine how the plasma temperature can be misestimated if the Maxwell distribution is assumed for the analysis of a plasma that actually follows the kappa distribution. We simulate several observations of plasma populations that follow kappa distributions and then derive the plasma properties using the two fitting methods above by forcing them to fit Maxwell distributions instead. We show that under this procedure, the plasma temperature can be significantly misestimated. We quantify the temperature misestimation for the two fitting methods as a function of the kappa index, the temperature and the flow direction of the observed plasma; the instruments field of view plays also an important role in the analysis when the forward modeling is being used. It is shown that the misestimation of the derived temperature is highly depended on the kappa index of the distribution function. The temperature can be significantly lower than the actual plasma temperature as the kappa index approaches its limit value $\sim$ 1.5. In the case of forward modeling, we have detected high correlation between the temperature misestimation and the instruments field of view. On the contrary, however, there is only a minor dependence on the plasma temperature and flow direction. For each case, we examine the goodness of the fitting by calculating the reduced chi-squared value and other statistical measures, showing that the temperature misestimation is always accompanied with relatively large reduced chi-squared values, indicating how the choice of the wrong distribution could lead to misinterpretation of the plasma states, even when the fitting is restricted in the core of the distribution.

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Methods of traveling waves in solutions of hyperolic phase field equation

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Fast transitions exist when the phase interface moves with the velocity comparable or even larger than the characteristic speeds of transport processes. In the present work, we use the phase field theory of fast transitions which is described by the system of hyperbolic equations for the heat and mass transport and dynamics of interphase propagation [1]. Traveling wave solutions for the interface propagation described by the hyperbolic CahnAllen equation are found. To obtain the solution for the transition from an unstable state with the Landau potential, we use the first integral method, which directly follows from the well-known Hilbert-Nullstellensatz theorem. The obtained complete class of traveling waves consists of continual and singular solutions. Continual solutions are represented by tanh-profiles and singular solutions exhibit unbounded discontinuity at the origin of coordinate system. With the neglecting inertia of the dynamical system, the obtained traveling waves include the previous solutions for the parabolic CahnAllen equation. The proven existence of traveling waves in a form of hyperbolic tangent function for the Cahn-Allen hyperbolic equation provides the ability to construct more complicated and much more rigorous analytical solutions of problems having an essential scientific merit and practical significance for the phase field crystal model. In particular, using the amplitude wave representation, one may reduce the phase field crystal equation, which is sixth order in space, to the hyperbolic PDE, which has a form of advanced CahnAllen equation [2]. To obtain the solution for the transition from a metastable state with the Landau de Gennes potential, we use the tanh-method which self-consistently defines the amplitude of the traveling wave, correlation length within it and its characteristic velocity. Qualitative analysis the phase interface velocity and correlation length for the given driving force of phase transition is given in comparison with the previous traveling wave solutions obtained for the crystalline front invading liquid metastable states [3].

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Effect of clasterization and disorder-order transition in undercooled liquid on kinetics of solidification of glass forming melts

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Experimental and theoretical results obtained in the MULTIPHAS-project (ESA-European Space Agency and DLR-German Aerospace Center) are critically discussed regarding solidification kinetics of congruently melting and glass forming Cu50Zr50 alloy samples. The samples are investigated during solidification using a containerless technique in the Electromagnetic Levitation Facility [1]. Applying elaborated methodologies for ground-based and microgravity experimental investigations, the kinetics of primary dendritic solidification is quantitatively evaluated [2]. Electromagnetic Levitator in microgravity (parabolic flights and on board of the International Space Station) and Electrostatic Levitator on Ground are employed. The solidification kinetics is determined using a high-speed camera and applying two evaluation methods: Frame by Frame (FFM) and First Frame Last Frame (FLM). In the theoretical interpretation of the solidification experiments, special attention is given to the behavior of the cluster structure in Cu50Zr50 samples with the increase of undercooling. A disorder-order transition in the cluster structure of undercooled melts allows us to explain viscosity behaviour and solidification kinetics in glass forming Cu50Zr50 alloy samples. Cluster structures in Cu50Zr50 melt obtained via molecular dynamics simulations and Voronoi tesselation analysis [3] provide basis for the current mesoscopic model for disorder-order transition in the undercooled melt. Particularly, we describe formation of the net of connected and penetrated clusters consisting of growing chains from the single atoms and clusters. Using the developing mesoscopic model, we interpret its predictions as a fragility crossover which characterizes structural changes in the undercooled liquids. These structural changes proceed in the form of transition from strong liquid, which has single atoms and unconnected clusters, to the fragile liquid, which is mainly consist from the net of connected and penetrated clusters.

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Burgulence in random matrix theories

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Traditional description of the dynamics of eigenvalues origins from the seminal paper by Dyson, who proposed stochastic description of the evolution of eigenvalues.
One can, hovever, rephrase this problem in another language, similar to the toy-model of turbulence formulated by Burgers. The basic objects in this formalism are the characteristic determinant and the inverse characteristics determinant. In this picture one can identify spectral viscosity as the inverse of the dimension of the matrix and spectral shock waves in the limit when the size tends to infinity. The limiting produre determine critical exponents of the emerging universal behavior, which can be verified in lattice simulations. This phenomenon of spectral shock waves is a generic phenomenon and appears in Hermitian, Laguerre, Jacobi and Fourier (circular) random matrix models. It explains also the origin of Airy-like, Bessel-like, Pearcey-like and Bessoid-like type of spectral oscillations in the vicinity of the critical points. One can also point at several analogies to other systems, e.g. to caustics phenomena in diffractive optics. The same concept of shock waves appears also naturally in non-hermitian random systems, but the shocks are linked to critical behavior of certain left-right eigenvector correlators (Petermann factors). Stochastic evolution of non-hermitian systems requires therefore a subtle entanglement of eigenvalues and eigenvectors, in contrast to the stochastic evolution of hermitian systems, where eigenvectors decouple.
We propose the formalism, which takes this simultaneous evolution into account. We also point out , why standard approaches to non-normal random systems have missed that coevolution. This result leads to the paradigm shift, pointing at the crucial role of eigenvectors for non-normal systems. As a particular and important application, we augment so-called single ring theorem with the new result for squared mean condition numbers. We give several examples and confirm positively our predictions by large scale numerical simulations. Finally, we analyze the consequences of this new result for some popular matricial models of neuronal networks.

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Gene regulation as a nonlinear noise filter

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A common knowledge is that positive feedback loop in gene regulation can give rise to bistability, resulting in a phenotypic differentiation of a population of genetically identical cells. But what happens if a positively self-regulated transcription factor initiates the activity of other genes? If gene expression were a deterministic process, then bistability at the level of transcription factors would propagate downstream to the proteins that they regulate. Gene expression is, however, an inherently stochastic process. At each level of gene regulation, be it self-regulation of regulatory gene, or regulation of target gene by the upstream regulator, the fluctuations in protein concentrations are filtered in a nonlinear manner, which distorts their probability distributions. As a result, the mapping between the shapes of the transcription factor distribution and target protein distribution is no longer as simple as unimodal to unimodal, and bimodal to bimodal. Instead, it depends on the overlap, or lack thereof, between the sensitivity regions of dose-response curves of each promoter. We show that, in this way, a single regulator can induce qualitatively different responses of different targets to increasing levels of an external signal: Some responses can be graded (unimodal distribution with varying position of its peak), and some others can be binary (unimodal-bimodal-unimodal transition). The problem of differential interpretation of the same input by different target genes is an emerging field in quantitative biology. It has been known to date that more and less sensitive promoters respond sequentially to increasing signal, as this is intuitively obvious from the comparison of dose-response curves of different promoters. However, the shapes of these responses (binary or graded) and their interdependence have been rarely investigated in systematic experimental studies, especially in the case of multiple targets of a single regulator. Our study demonstrates a possible mechanism based on both stochasticity and nonlinearity of biochemical reactions, due to which different genes can interpret the same biological signal in a different way.

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Properties of suprathermal electrons associated with discrete auroral arcs

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The space-plasma particle distributions are generally not in thermal equilibrium due to their collisionless nature, and cannot be explained by only Maxwell-Boltzmann distributions. Although many theoretical studies of the auroral particle acceleration mechanisms have been based on the Maxwell-Boltzmann distributions as source plasma electron populations, their approximate distributions from observations in the plasma sheet are predominantly described by kappa distributions [e.g., Vasyliunas, 1968]. However, there are few reliable observations of electrons covering the suprathermal energy range with a single instrument due to the technical limitations of conventional detection techniques. In this study, data from a new instrument [Ogasawara et al., 2016], dedicated to the suprathermal electrons, were analyzed to investigate the suprathermal electron properties observed in the discrete auroral arcs. Based on optical measurements, the rocket flew over the three auroral arcs, and the features of these suprathermal electrons were explained by shifted kappa distribution functions with the parameters (density, temperature, and kappa) consistent with former observations of the near-Earth tail plasma sheet: the expected source of the auroral precipitating electrons.
The statistical data analyses showed three novel features of the suprathermal electrons. First, the auroral potential drop was proportional to the inverse-square of kappa, consistent with previous theoretical investigations by Dors and Kletzing [1999]. The observed dependency was slightly stronger than their calculations, suggesting additional contribution from non-linear plasma processes. Second, the polytropic relation showed non-adiabatic (near isothermal) state of the source electrons. This can provide a restriction on the pressure balance issues in the plasma sheet convection. Third, there was a clear difference in the polytropic and the kappa index for the first arc as opposed to the second and the third arcs, suggesting different source locations in the plasma sheet for precipitating electrons that causes these near-by arcs.

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Challenges to measure kappa distributions in the terrestrial ionosphere

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Low energy ion distributions in the terrestrial ionosphere often show power-law tails with an exponential core, described by kappa distributions. For example, in the polar wind, a combination of the polarization electric field acceleration and the Coulomb collisions can produce the suprathermal tail (Barghouthi et al., 2001) because Coulomb collisions mainly affect low energy particles while the high energy particles are more efficiently accelerated by the upward directed ambipolar electric field. As another example, the ring beam relaxation (Moore and Khazanov, 2010) generated via perpendicular velocity diffusion can also produce kappa distributions. In the ionosphere, the transversely accelerated ions lower-hybrid wave activities (Andre et al., 1994) or ion pick-up processes. k-distribution-like tails have been observed in the vicinity of the space shuttle (Gurnett et al., 1988) and were attributed to the products by the water-group ion pick up processes. These mechanisms are ubiquitous in space plasmas, and it is important to characterize these suprathermal distributions in situ. However, there have been difficulties with making this observation.
Current state-of-the-art instruments to cover these low-energy ions from Low-Earth Orbit (LEO) are either Retarding Potential Analyzers (RPA) or Ion Drift Meter (IDM). RPA and IDM present a planar energy barrier to incoming supersonic charged particles and collect the charged particles that are able to overcome the barrier with a plate at the back of the instrument. When coupled with good spacecraft velocity data and attitude knowledge, analysis of the current-voltage (I-V) relationship provides the thermal ion flow speed in the direction of the spacecraft, the ion temperature and the fractional composition of the plasma. IDM can calculate the ion drift velocity by using split collector plates and the current ratio between plates. However, a fundamental shortcoming of this technique is determining the ionic concentrations (e.g., Knudsen et al., 1966). Thus, the suprathermal portions of lighter ions are always contaminated by heavier particle contributions. In addition, the precise determination of the ring distribution is impossible with the coarse angular distribution of IDM. In this paper we discuss new techniques to advance the study of ionospheric particles.

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Analysis in structural features of polymer systems by persistent homology

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Polymer is made up of monomers that are repeating structural units to form a long chain structure. As a result of its snake-like form, polymers flexible move and deform, which can be curled, elongated, and tangled. Thus, the polymer system, called soft matter, involves various local structures and unique responses because of the structural features of polymers. Our question is how polymers are becoming loose or entangled depending when the system deforms. As a first step, we investigate structural features of facture process of a polymer system using persistent homology. The fracture process of a polymer system is examined by molecular dynamics simulation in three dimension. At first, a condensed polymer system is in an equilibrium state. After stretching whole system in one direction, polymers are clearly elongated and finally the system is almost fractured. The polymer system contains different local structures at the initial state and the finial state. However, the detailed structures in three dimension is hard to distinguish because of its complexity. Thus, we use persistent homology, which is an algebraic tool for systematically characterizing geometric objects. Persistent homology can capture the topological properties such as rings and cavities, and provide the metrics of these topological properties. In recent years, persistent homology and its graphical representation, persistent diagram (PD), can be computed efficiently. Some types of condensed systems are well distinguished its local structures using persistent homology and PDs [1,2,3]. As a first test, we analyze the configurations of polymers of the initial and final states using the persistent homology. It successfully distinguishes a difference of local structures. For example, the system in the final state contains larger and more elongated pores comparing with those in the initial state. In addition, there are small structures which are kept during the fracture process. Persistent homology may shed light on a structural feature of fractures of a polymer system. In this talk, we will introduce persistent homology and structural features of polymers in a fracture process.

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Doubly autoparallelism on the space of probability distributions

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One of the important feature of information geometry studied in [1,2] is a pair of mutually dual affine connections with respect to Riemannian metric. A manifold with such geometric structure is called a statistical manifold.
In statistical manifold there exists a submanifold that is simultaneously autoparallel in terms of both of the affine connections. Such submanifolds, which we call *doubly autoparallel* (DA), play important roles in several applications, e.g., MLE of structured covariance matrices, semidefinite program (SDP) [3,4], the self-similar solutions to the porous medium equation [5] and so on.
In this presentation, we consider doubly autoparallelism on a parametric family of probability distributions with the Fisher information as a Riemannian metric, which is an important and familiar example of statistical manifold.
Consequently, we give a characterization of DA submanifolds (, i.e., statistical models of probability distributions) in a algebraic way, and discuss its interesting properties. In particular one of them is that DA submanifolds admit the unique minimizers with respect to the alpha-divergences [1,2](Tsallis relative entropies [6]) for all alpha, which implies that there uniquely exist the maximum entropy distributions with respect to not only the Boltzmann-Gibbs entropy but also Tsallis entropy with constraints of the normalized q-expectations. Finally, we show examples of DA submanifolds. The obtained results would provide us with information and insights to consider statistical models in statistical physics.

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Using network motif analysis to characterize the international trade network

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Countries build international relationships through economic activities. Recently, international trade between countries has been studied from complex network perspective [1,2]. Complex networks have numerous patterns of connections. Subgraphs that occur significantly more often in the real network than in randomized networks are referred to as motifs, while those occurring less frequently are anti-motifs. Network motifs have attracted attention as a tool for studying directed networks [3]. To identify characteristic patterns of interactions, motif analysis is applied to the international trade network of commodity-specific trade relations between countries for years 1962-2005. We use world trade data from MIT's Observatory of Economic Complexity. This data contains trading data about more than 200 countries and 700 commodities classified according to a 4-digit level SITC code. By dropping digit from the classification, we can reduce the number of different commodity categories: there are about 70 and 10 commodity categories at 2-digits and 1-digit level, respectively. To take into account the difference in sizes and total export of different countries, we use Revealed Comparative Advantage (RCA) which measures a country exports more of commodity than the average country. The commodity-specific trade network is constructed by connecting each pair of countries with RCA larger than 1. To detect significant three-node motifs, we calculate the number of appearances of these subgraphs in real and randomized networks. The randomized networks are generated from the real network by a series of edge rewiring operations. In the operation, we randomly choose two pairs of edges and exchange the destinations of the two edges between them, keeping the number of incoming edges, outgoing edges and mutual edges of each node unchanged. Because the number of appearances of two-node subgraphs is the same in both networks, the detected significant deviation is independent of significant subpatterns. For each commodity-specific trade network, we discover that particular motifs are significantly more abundant than expected by chance. The obtained motifs characterize the country and reflect particular economic functions. These findings provide a valuable insight into the relationship between the economic function and the network structure.

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Designer curved-space geometry for relativistic fermions in Weyl metamaterials

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Simulating relativistic phenomena in table-top systems has become a major theme in condensed matter physic. Topological materials, exhibiting a myriad of connections to high-energy physics, have been a significant inspiration for these developments. An important source of fascination has also been provided by semimetals which display emergent relativistic dynamics at low energies. This has given rise to a wide-spread interest in engineering artificial gauge fields in graphene and 3d Dirac and Weyl semimetals. The phenomenology of general rel- ativity and curved-space dynamics has also penetrated into condensed-matter research. In addition to fundamental interest, curved-space physics may also have striking practical applications as electromagnetic metamaterials and transformation optics demonstrate.
Weyl semimetals are recently discovered materials supporting emergent relativistic fermions in the vicinity of band-crossing points known as Weyl nodes. The positions of the nodes and the low-energy spectrum depend sensitively on the time-reversal (TR) and inversion (I) symmetry breaking in the system. We introduce the concept of Weyl metamaterials where the particles experience a 3d curved geometry and gauge fields emerging from smooth spatially varying TR and I breaking fields. The Weyl metamaterials can be fabricated from semimetal or insulator parent states where the geometry can be tuned, for example, through inhomogeneous magnetization. We derive an explicit connection between the effective geometry and the local symmetry-breaking configuration. This result opens the door for a systematic study of 3d designer geometries and gauge fields for relativistic carriers. Particle motion in Weyl metamaterials results from an interplay of classical and quantum geometric effects. The general theory is illustrated by proposing simple magnetic textures giving rise to remarkable 3d chirality-selective electron lensing effects. More generally, Weyl metamaterials pave the way for novel 3d electronic devices through curvature engineering.

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Alpha Engine: Designing an Automated Trading Engine

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The emergence of blockchain technology will transform the finance industry and give rise to a global marketplace with millions of traded financial instruments. The emergent digital economy necessitates fully automated trading strategies for managing assets and efficient price discovery. I propose a new approach to algorithmic investment management that yields profitable automated trading strategies. A paradigm change is proposed for the way time is defined in financial markets, based on intrinsic events. This definition lead to the uncovering of a large set of scaling laws. An additional guiding principle was found by embedding the trading model construction in an agent-base framework, inspired by the study of complex systems. The approach is a parsimonious method for building a new type of investment strategy that not only generates profits, but also provides liquidity to financial markets and does not have a priori restrictions on the amount of assets that are managed.

Collective motion of repulsive Brownian particles in single-file diffusion with and without overtaking

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Particles in dense liquids are hindered from free motion and constantly pushed back by their neighbors, which is often described as a "cage" that confines each particle. The cage effect makes the motion subdiffusive and, in certain cases, eventually leads to the glass transition [1]. The behavior of the mean square displacement (MSD) in dense liquids reflects at least three aspects of the caged dynamics: nearly free motion within the cage for short time, possible drift of the cage enclosing the particle at longer timescale, and hopping of the particle out of the cage as a rare event. Proper characterization of these processes is known to require space-time description, as the cage effect actually emerges from many-body dynamics and involves collective motion, which needs to be captured typically in terms of some four-point space-time correlation [1,2].
In search of methodological insight into theoretical treatment of such collective motions, we have developed a formalism to calculate the displacement correlation of interacting Brownian particles [2,3], in one-dimensional (1D) and two-dimensional (2D) cases, on the basis of the Dean–Kawasaki equation for the fluctuating density field. In the purely 1D case, known as the single-file diffusion (SFD), the theory gives an analytical expression for the displacement correlation [2], which includes the well-known asymptotic behavior of MSD $\propto \sqrt{t}$ as a special case. The 2D theory [3,4] predicts vortical cooperative motion, with negative velocity autocorrelation—a manifestation of the cage effect.
Here we extend the above formalism to SFD with finite interaction potential, allowing the particles to overtake each other as a rare event [5]. By calculating the displacement correlation as an indicator of collective motion, it is shown that overtaking ("hopping") events destroy the short-range correlation, while the long-range weak correlation remains almost intact. Thus we obtain quantitative description of the nested space-time structure of cages, such that small cages are confined in larger cages with longer lifetime.

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Quantifying interactions

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Interacting bosons or fermions give rise to some of the most fascinating phases of matter, including high-temperature superconductivity, the fractional quantum Hall effect, quantum spin liquids and Mott insulators. While these systems are promising for technological applications, they also present conceptual challenges as they require approaches beyond mean-field and perturbation theory. I will present a general framework for identifying the free theory that is closest to a given interacting model in terms of their ground state correlations. I will quantify the distance between them using the entanglement spectrum. When this interaction distance is small, the optimal free theory provides an effective description of the low energy physics of the interacting model. This construction of the optimal free model is non-perturbative in nature, thus it offers a new theoretical framework for investigating strongly correlated systems.

Two-order parameter model for phase transitions in the presence of an intermediate metastable state with applications

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The previously proposed model for the kinetics of first-order phase transitions [1] was generalized for r-order and m-control parameters. The generalized parametric model is based on the Landau-type kinetic potential. Bifurcation and stability analysis for the first order phase transition was performed in the presence of an intermediate metastable state. We have also analysed the impact of an external field on phase transition. The control parameters presented in the kinetic potential are associated to the diffusion and viscosity as intrinsic characteristcs of the material, as well as to the system heterogeneity and the influence of constant or periodic external field. Anomalous generation and extinction phenomenon of crystal nuclei at very low temperatures in non-equilibrium supercooled liquids containing hydroxyl group, namely o-benzylphenol, salol, and 2,2'-dihydroxybenzophenone, observed during the progress of crystal nucleation and growth below the glass transition temperature reflect the impact of real structural fluctuation on the irreversible structural relaxation in supercooled liquids and glasses [2, 3].The values of control parameters are estimated accordingly to the experimental data for the mean transition time between stable liquid and crystalline phases in the region of coexistence of two liquid states for lysozyme protein [4]. The study of the influence of constant or periodic external field on transition dynamics in the presence of two fluctuating order parameters was achieved by the construction of phase portraits for different values of the field coupling parameter. The impact of constant external field on the system in the presence of an intermediate metastable state would reduce the stability of system and, therefore, decrease the transition rates from the stable liquid state to the solid state in the presence of metastable liquid state, thats why the presence of the constant external field would increase the mean transition time, similar to the model involving a single order parameter [1]. On the other hand, the presence of an external periodic forcing would lead to the acceleration of phase transition in the presence of an external periodic field [5]. In general, the obtained results are related to the theory of structural relaxation in complex systems, and some aspects of kinetics of phase transitions in the presence of an intermediate metastable state, including generation of crystal nuclei as clusters of the new phase.

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How to measure the relaxation time of an stochastic Markov dynamics in a numerical simulation by using the concept of dynamical temperature

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The computation of relaxation times in generalized stochastic dynamics has shown to be a very elusive aim as it goes beyond any linearized approach or numerical strategy based on some truncation scheme. In Monte Carlo simulations of physical models one normally encodes the stochastic dynamics by using a Markov process, which after to a transient time -called thermalization- drives the system to its equilibrium. In [1] we have found an ensemble-free estimator for the dynamical

temperature for spin systems, which allows a direct measure of the thermalization path of the underlying Markov process used in the numerical simulation. It represents a generalization to previous articles on the concept of configurational temperature for spin systems [2], in the sense that it has the useful property to be independent of the ensemble . It further allows to test ergodicity and to measure the absolute errors associated to the statistical fluctuations. Another interesting feature of the present approach is that it gives valuable information about the efficiency of the algorithm and its associated autocorrelation time. In the present article we discuss these ideas by studying the two-dimensional XY-model numerically simulated with a Wolff unicluster algorithm [3].
The main idea is as follows: when performing a Monte Carlo simulation in the canonical ensemble one uses the value of the system temperature or the temperature of the thermal bath -which defines the ensemble- in the weighted Gibbs factor, but on the other side one can directly measure the inverse of the temperature by computing the thermal average of the microscopic estimator found in [1]. This strategy allows us to monitor the thermalization process of the stochastic Markov dynamics, as the measured value for β must coincide with the input β-value used in the Gibbs factor.
This method can be generalized to other ensembles as well as to other spin models, since the microscopic estimator for the inverse of the temperature was proven to be independent of the ensemble.

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Multidimensional integration and covariance matrix

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In this paper we study the possibility to integrate numerically a multivariate normal distribution, with given mean and covariance matrix, over 16-, 32-, 64-dimensional spaces, by mean of the ellipsoidal nested sampling method (a multidimensional integration technique). In other words, we consider the problems of identifying the most appropriate model for a given physical system and of assessing the model contribution to the measurement uncertainty. These problems are studied in terms of Bayesian model selection and model averaging. As the evaluation of the "evidence" Z (i.e. the integral of Likelihood x Prior over the space of the measurand and the parameters) becomes impracticable when this space has 20 - 30 dimensions or even more, then it is mandatory to elaborate an appropriate numerical strategy. Among the many algorithms for calculating Z, we focus on the ellipsoidal nested sampling, which is a technique based on three pillars: the study of the iso-likelihood contour lines of the integrand, a probabilistic estimate of the volume of the parameter space contained within the iso-likelihood contours and the random samplings from hyperellipsoids embedded in the integration variables. Using the points collected by the chosen algorithm, i.e. the list of the discharged likelihoods, we also obtained the post-data distributions and the relevant samples.
The consistency of the covariance matrices, which are calculated by the discharged likelihoods or by the samples using the input covariance matrices and the aspected Wishart distribution, has also been investigated.
As possible test of the obtained results, we applied the present statistical method to gamma-ray spectroscopy with HpGe detectors, that is a common technique in many fields such as nuclear physics, radiochemistry, nuclear medicine and neutron activation analysis. The use of HpGe detectors is chosen in situations where isotope identification is needed because of their excellent resolution. Our challenge is to obtain the "best" spectroscopy data possible in every measurement situation, i.e. to extract the most physical information. In the present case "best" is a combination of statistical (number of counts) and spectral quality (peak, width and position) over a wide range of counting rates. In this framework, we applied Bayesian methods and the Ellipsoidal Nested Sampling, in order to study the most likely distribution for the shape of HpGe spectra. In treating these experiments, the prior information suggests to model the likelihood function with a product of Poisson distributions. We present and discuss the efforts that have been done in order to optimize the statistical methods to HpGe detector outputs with the aim to evaluate to a better order of precision the detector efficiency, the absolute measured activity and the spectra background.

Noise-induced effects in Josephson junction arrays

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The aim of the present talk is to give a short review of interplay of effects of suppression of noise and noise delayed switching in Josephson junctions subjected to above-threshold periodic or pulse driving [1,2]. The effect of noise suppression shows up as a minimum of the standard deviation of the switching time (jitter) versus a pump signal frequency or a pulse width, either through existence of a signal-to-noise ratio maximum as a function of a driving frequency. The noise delayed switching is the nontrivial increase of switching time versus the noise intensity, where noise works against switching signal, intended to switch the system into new state. The applications to the important problem of high-speed switching of electronic devices are considered. In particular, minimization of noise-induced errors during high-speed switching of ac SQUIDs and Josephson junctions [2] are analyzed. When solitons in long Josephson junctions are used for the information storage, the noise immunity of the system strongly depends on the system length, configuration and current distribution. In particular, the optimal system length, there maximal decay time is achieved, corresponds to the soliton size for a linear system and to double soliton size for an annular system [3]. Another type of noise suppression effect occurs in relativistic propagation of solitons across Josephson junction arrays. Here due to Lorentz contraction and increase of mass, solitons become more immune to noise than at low propagation speeds [4]. However, due to discreteness of Josephson array the soliton can have Cherenkov tail, which interplaying with thermal noise can lead to a dramatic splash of the propagation time jitter. These effects have important application for design of superconducting fluxonic ballistic detectors as an example of the device in which the soliton scattering is utilized for quantum measurements of superconducting flux qubits. Here the soliton dynamics can be optimized for the measurement process varying the starting and the stationary soliton velocity as well as configuration of the inhomogeneities. Also, mutual effect of quasi-chaotic dynamics and thermal fluctuations has been studied and it has been shown that it can drastically increase the overall effect of noise, as demonstrated for spectral linewidth of Josephson junction arrays [5].
This work is supported by Russian Science Foundation grant 16-19-10478.

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Drift velocity of bacterial chemotactic response with two alternating turning events and arbitrary persistence parameters

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Bacterial chemotaxis has been extensively studied in the past decades [1-5]. One of the most interesting issues is the strategies used by bacteria to reach (or leave) the place with the maximal concentration of the chemical. Experimental observations revealed various types of random walk-like patterns produced by bacteria when drifting towards the source of the attractant. One of the best known example is the run-and-tumble strategy of *E. coli*. Reorientations of these bacteria during the tumble events exhibit persistence of the direction: the mean angle between the new and the previous directions is near 62° [1]. The chemotactic efficiency of the bacteria utilizing strategies with constant persistence (*E. coli*, *S. putrefaciens*, *P. haloplanktis*, to name a few) was theoretically studied by using the idea of de Gennes [2,3]. Recently, this approach was generalized to a strategy that is composed of two types of alternating tumbling events, namely, tumbles with some constant persistence ("tumbles") and random turns at the plane perpendicular to the direction of the current motion ("flicks") [4]. Since every flick erases the memory on the motional history, the analytical calculation of the net drift velocity is relatively simple in this case. Results obtained for the corresponding model show that the run-reverse-flick strategy (which is a good approximation, for instance, for the walk performed by *V. alginolyticus*) yields larger net velocity (and thus much more efficient) when compared to the *E. coli*-type run-and-tumble strategy.
Recent experimental analysis of *V. alginolyticus* chemotactic motility showed that for these bacteria the flick angle depends on the size of the cell body and only after averaging over the ensemble of cells it results in $\sim 90°$ [5]. Thus there is a need to consider a strategy with two turning angles, both are different from 90°. Following de Gennes idea, we analytically calculate drift velocity for the strategy with two alternating tumbling angles. We demonstrate complete agreement of the obtained result with the specific cases considered in Refs. [3,4]. It is noteworthy that our model allows to take into account size inhomogeneity of cellular population (specified with the persistence parameter variation) thus allowing to relate a chemotactic pattern to the size structure of the cell population that produced it.

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The analysis financial stability based investor trading behavior

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The concept of contagion is one of important areas into every field of the theoretical and empirical studies. Forbes, Rigobon define contagion as a significant increase in linkage after a shock. Along with interdisciplinary combinations, the approach based information flow benefit from theoretical frameworks of statistical method such as complex network. In this paper we focus on the relationship between information flow among investors and financial volatility. One of earlier observations about financial instability was made by Mishkin (1991) when shocks to the financial system interfere with information flows so that the financial system can no longer do its job of channeling funds to those with productive investment opportunities. In our opinion, this definition is widespread from the standpoint of financial residence. Namely, price stability and a monetary policy play a role in financial stability. Although less conceptually persuasive, the more directly observable definition of financial stability is situation, which is without financial crisis and with smooth inflation rate. (e.g. Olsson, 2003). At the same time, Renihart and Rogoff (2009) noted the longer term macroeconomic implications of much higher public and external debt after financial crisis. Campbell, and Diebold (2005) explored the macro interface in the context of equity markets. Benchmark of financial stability would still have found for on account unapparent definition. Therefore, it is realistic that the study find factors contributing to systemic risk in crisis. A more recent strand of the literature has focused on the view of the individual firm. (e.g., Billio et al., 2012). Diebold, Yilmaz (2014) provided an overview of this literature, and explored connectedness among financial asset returns and volatilities through variance decomposition method (VDM). The investor activities in financial markets can impact the price formation and might influence the financial stability. We investigate whether the information flows among the investors with different investment strategies have influence on the market stability. We used the aggregated trading volume of both buyer and seller as an investor activity and adopt the variance decomposition method to quantify the information flows among the investor activity. We find that the degree of information flows have a positive relation with the market volatility, irrespective of used data sets.

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Effect of pruning on co-authorship network topology

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We applied two pruning schemes, the marginal likelihood filter (MLF) and the thresholding by bill author count, on the bill co-authorship networks of the Philippine Congress and determined the effect of each scheme on their topologies. MLF, proposed by Dianati, evaluates weighted edges by calculating their p-values based from their proposed null model. For the MLF, the higher the weighted degrees of the nodes are, the larger the edge weights should be for these edges to be significant. The thresholding by bill author count scheme deletes in-degree nodes of the bipartite origin of the network (bill-author network) based from an in-degree threshold value (author count of bills) as the maximum value to be included in creating the unipartite network. To characterize the network, the measures calculated were the node count N, density D, average weighted degree kw,

weighted and unweighted average clustering coefficient C and Cw, connected component count, modularity Q and degree assortativiy R.
We found that both pruning schemes effectively increase Q and decrease C, D and kw as the number of retained edges decreases. In fact, their graphs for D are coinciding. They also preserve the connectivity of the network until 10 percent of the edges are retained. These suggest that at region with connected network, the networks are sparser and the qualities of community partition are better than the original graphs.
Comparing the two pruning schemes, subtle differences are found. In MLF, N is constant until around 6 percent of the edges are retained. Also, the networks become positively assortative as the edges retained decreases. Furthermore, Q increases smoothly and rapidly. In kw, it decreases linearly but the Cw is preserved.
In the thresholding by bill author count, a pattern of constant N at long irregular intervals and subtle decrease occurs repetitively until a sudden drop of N at 12 percent of retained edges. Unlike in MLF, the networks' dissassortativeness is preserved in this scheme. In Q, it increases but small second peaks are found. In kw, there is a distinct "elbow" found at around 90 percent of edges retained. The elbow in kw is seen in the Cw. The Cw in this scheme suddenly decreases and then stays constant at values very close to 0.

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Non-extensive statistical analysis of magnetic field during the March 2012 ICME event using a multi-spacecraft approach

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In this study we present some new and significant results concerning the dynamics of interplanetary coronal mass ejections (ICMEs) observed in the near Earth at L1 solar wind environment, as well as its effect in Earths magnetosphere. The results are referred to Tsallis non-extensive statistics and in particular to the estimation of Tsallis q-triplet, (qstat, qsen, qrel) of magnetic field time series of the ICME observed at the Earth resulting from the solar eruptive activity on March 7, 2012 at the Sun. For this, we used a multi-spacecraft approach based on data experiments from ACE, CLUSTER 4, THEMIS-E and THEMIS-C spacecraft. For the data analysis different time periods were considered, sorted as quiet, shock and aftershock, while different space domains such as the Interplanetary space (near Earth at L1 and upstream of the Earths bowshock), the Earths magnetosheath and magnetotail, were also taken into account. Our results reveal significant differences in statistical and dynamical features, indicating important variations of the magnetic field dynamics both in time and space domains during the shock event, in terms of rate of entropy production, relaxation dynamics and non-equilibrium meta-stable stationary states.
So far, Tsallis non-extensive statistical theory and Tsallis extension of the Boltzmann-Gibbs entropy principle to the q-entropy entropy principle (Tsallis, 1988, 2009) reveal strong universality character concerning non-equilibrium dynamics (Pavlos et al. 2012a,b, 2014a,b; Karakatsanis et al. 2013). Tsallis q-entropy principle can explain the emergence of a series of new and significant physical characteristics in distributed systems as well as in space plasmas. Such characteristics are: non-Gaussian statistics and anomalous diffusion processes, strange and fractional dynamics, multifractal, percolating and intermittent turbulence structures, multiscale and long spatio-temporal correlations, fractional acceleration and Non-Equilibrium Stationary States (NESS) or non-equilibrium self-organization process and non-equilibrium phase transition and topological phase transition processes according to Zelenyi and Milovanov (2004). In this direction, our results reveal clearly strong self-organization and development of macroscopic ordering of plasma system related to strengthen of non-extensivity, multifractality and intermittency everywhere in the space plasmas region during the CME event.

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Self-organization of cancerous cell populations in leukemia progression under targeted therapy

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Leukemia is a form of cancer of the blood cells. Healthy white blood cells grow and divide in an orderly and controlled way, but in leukemia the process gets out of control and the cells divide too quickly. In Chronic Myeloid Leukemia (CML), too many myeloid cells (one of the main types of white blood cells) are produced and released into the blood when they are immature and unable to work properly, leading to an increased risk of infection and strongly limiting the production of healthy red cells and platelets. Front line therapy for the treatment of patients affected by CML is based on the administration of Tyrosine Kinase Inhibitors (TKIs), such as imatinib, dasatinib, nilotinib or axitinib [Faber et al. 2006]. Despite the fact that they represent the first example of a successful molecular targeted therapy, the development of resistance to these drugs is observed in a proportion of patients, especially those in advanced stages.
In this work, effects of environmental randomness and fluctuations on the occurrence of self-organization phenomena in the evolutionary dynamics of cancerous cell populations are investigated. Complexity features in cancer development and progression are modeled by using a Monte Carlo method to simulate the stochastic evolution of initially healthy cells which can experience genetic mutations, modifying their reproductive behavior and becoming leukemic clones [Pizzolato et al. 2011]. In particular, we simulate a TKIs-like treatment of patients affected by CML by modifying the fitness and the death rate of cancerous cells and we study the fluctuations on cancer growth dynamics and the developing of resistance to the standard therapy [Pizzolato et al. 2016]. We also consider the possibility of varying the drug administration dosage within specific temporal windows. Several scenarios in the evolutionary dynamics of white blood cells, as a consequence of the efficacy of the different modelled therapies, periodic or continuous, are described. The best results, in terms of a permanent disappearance of the leukemic phenotype, are achieved with a continuous therapy and higher dosage. However, our findings demonstrate that an intermittent therapy could represent a valid choice in patients with high risk of toxicity, when a long-term therapy is considered. Moreover, a suitably tuned therapy can enhance the treatment efficacy and reduce the probability of developing resistance.

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Topological data analysis for complex systems

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The statistical mechanical approach to complex networks is the dominant paradigm in describing natural and societal complex systems. The study of network properties, and their implications on dynamical processes, mostly focus on locally defined quantities of nodes and edges, such as node degrees, edge weights and more recently correlations between neighboring nodes. However, statistical methods quickly become cumbersome when dealing with many-body properties and do not capture the precise mesoscopic structure of complex networks. Here we discuss recent progress coming from algebraic topology and the type of novel insights they provide. Topology is one of the oldest and more relevant branch of mathematics.
It studies the properties of spaces and maps between such spaces that are preserved under transformations that continuously deform the object under study. Besides being of theoretical interest in itself, topology has provided an expressive and affordable language which is progressively pervading many areas of mathematics, computer science and physics.
Indeed, these new goggles are able to extract information about the mesoscopic structures that are typically very hard to capture –if not invisible– to standard statistical and combinatorial tools. We will for example show that real-world networks divide themselves in two classes based on their homological properties, which cannot be reduced to known local or quasilocal properties.
We will then show that the homological information describes well the large-scale interaction between communities, e.g. research groups within and across scientific disciplines, and the spatial distribution of migrant communities within a large Italian city. In both cases the underlying reason is the capacity of topological tools to capture a notion of high-dimensional shape which eludes statistical mechanical tools.
We will then introduce an appropriate null model for simplicial complexes, which is akin to a configuration model and allows the validation of observed homological features. Finally, using examples from structural and functional brain networks, we will show how it is possible to encode the rich homological information in simplified network representations which localize homological features and facilitate the interpretation.

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Characteristics of electron velocity distributions in space plasmas

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Space plasmas are essentially collisionless systems out of thermal equilibrium, where enhanced populations of suprathermal particles are observed. The typical distributions are generally better described by kappa distributions than by Maxwellians, especially for electrons [Pierrard and Lazar, 2010]. This has large consequences since the small electron mass makes them major agents for plasma energy transport.
More than 120 000 velocity distributions measured by Helios, Cluster and Ulysses in the ecliptic have been analyzed within an extended range of heliocentric distances from 0.3 to over 4 AU [Pierrard et al., 2016]. The velocity distribution of electrons reveal a dual structure with a thermal (Maxwellian) core and a suprathermal (Kappa) halo. A detailed observational analysis of these two components provides estimations of their temperatures and temperature anisotropies. For low values of the power-index kappa, these two components manifest a clear tendency to deviate from isotropy in the same direction. The existence of plasma states with anti-correlated anisotropies of the core and halo populations and the increase of their number for high values of the power-index Kappa suggest a dynamic interplay of these components, mediated most probably by anisotropy-driven instabilities. Estimating the temperature of the solar wind particles and their anisotropies is important for understanding the origin of these deviations from thermal equilibrium.
Kappa-distributed populations of electrons were used to develop a kinetic solar wind model. Low values of the parameter kappa are associated to an enhanced population of suprathermal electrons leading to higher velocities at large radial distances [Pierrard and Pieters, 2014]. Boundary conditions are based on observational input photospheric magnetograms. The model provides an extended radial profile of the velocity distribution functions of the particles from the corona to the whole heliosphere. The results are compared with solar wind observations at 1AU to obtain the best prediction of solar wind characteristics.

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Economic Complexity

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Economic Complexity (EC) is a new field of research that consists in a radically new methodology. It describes economics as evolutionary process of ecosystems made of industrial and financial technologies that are all globally interconnected. The approach is multidisciplinary addressing emerging phenomena in economics from different points of view: analysis of complex systems, scientific methods for systems and the recent developments in Big Data. This approach offers new opportunities to constructively describe technological ecosystems, analyse their structures, understand their internal dynamics, as well as to introduce new metrics. This approach provides a new paradigm for a fundamental economic science based on data and not on ideologies or interpretations, which is becoming a necessary choice in a highly interconnected and globalized world, especially after the great financial and economic crisis of recent years.
Economic Complexity, in addition to a new vision for a data-based scientific approach for fundamental economics, offers a new set of metrics able to quantify the competitiveness of countries, of technological sectors, measuring future development prospects for nations as well as for large companies. Those metrics have already shown to have a major impact for policy makers and for industry applications economics and finance. Over the last year, the World Bank (WB) has extensively tested and adopted this new methodology for its strategic analysis.
A crucial element of our methodology is a radically new approach to the problem of Big Data. Big Data is often associated with "big noise" as well as a subjective ambiguity related to how to structure the data and how to assign them a value that should reflect many arbitrary parameters. In the case of the evaluation of the industrial competitiveness of a country, the required parameters for such an analysis could more than one hundred. A key point approach EC is to go from 100 parameters to zero parameters and obtain results which can be tested in a scientific perspective. This is done by focusing on the data in which the signal to noise ratio is optimal and developing iterative algorithms in the spirit, but other than Google, and optimized to the economic problem in question. In particular the study of a country or a

company is not done at the individual level but through the global network in which it is inserted. In this way you get the Fitness of the countries and the Complexity of the products. The dynamics in the new GDP-Fitness space [1] (opens up to a completely new way for monitoring and forecasting. Then, the taxonomy of products and their evolutionary dynamics is built through machine learning methods. Finally, the same thing is applied to patents and technologies, two elements that open up the possibility of analyzing the core elements of the innovation process.

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Firms complexity: Technological scope, coherence and performance

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The aim of this work is to shed light on the relationship between firms performance and their technological portfolios using tools borrowed from the complexity science. In particular, we ask whether the accumulation of knowledge and capabilities related to a coherent set of technologies leads firms to experience advantages in terms of productive efficiency. To this end, we analyzed both the balance sheets and the patenting activity of about 70 thousand firms that have filed at least one patent over the period 2004-2013. From this database it is possible to define a monopartite network of technological codes, in the spirit of [1], that can be used to assess the firms configuration, defined as the set of technologies in which the given firm is active. We then introduce firms coherent diversification [2], a quantitative assessment that evaluates a technological portfolio taking into account the number of fields it encompasses and weighs each of them on the basis of their coherence with respect to the firms global knowledge base. Differently from what is usually done for countries [3], such a measure implicitly favors companies with a diversification structure comprising blocks of closely related fields with respect to firms with the same breadth of scope, but a more scattered diversification structure. In this respect, our work points out a qualitative difference between the industrial production of goods and services and the technologies, in terms of patenting activities, that are needed to produce them and to be competitive at the market level. We find that our measure of the coherent diversification of firms is quantitatively related to their economic performance and, in particular, we prove on a statistical basis that it explains labor productivity better than standard diversification. This is an empirical evidence that this measure of the coherent diversification of technological portfolios captures relevant information about the productive structure of the firms. As a consequence, it can be used not only to investigate possible synergies within firms but also to recommend viable partners for merging and acquisitions.

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Second order structure of a finite sample space exponential manifold

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On a finite sample space Ω, all strictly positive densities have the exponential form $q = \exp(u - K_p(u)) = e_p(u)$, where p is a strictly positive reference density, u is a random variable such that $E_p(u) = 0$, $K_p(u)$ is a normalising constant. As $u = \log(q/p) - E_p(\log(q/p))$, all densities are parameterized by the chart $s_p \colon q \mapsto u$. Given a subspace $V_p \subset L^2_0(p)$ of p-centered random variables, the exponential family $\mathcal{E}$ is the family of densities $e_p(v)$, $v \in V$. In the atlas of the charts s_q, $q \in \mathcal{E}_p(V)$, the transition mappings from the reference p to the reference q are $V \ni u \mapsto \exp(u - K_p(u)).p \mapsto u - K_p(u) - \log(q/p) = u - E_q(u) - (E_q(u) + K_p(u))$. Hence, we have an *affine atlas*, with *exponential transport* $U^q_p \colon V_p \ni u \mapsto u - E_q(u) \in V_q$. The velocity of a curve $t \mapsto p(t)$ in the chart centered at p is $(d/dt)(log(p(t)/p) - E_p(\log(p(t)/p))) = \dot{p}(t)/p(t) - E_p(\dot{p}(t)/p(t)) = \dot{u}(t) - E_{p(t)}(\dot{u}(t)) = U^{p(t)}_p \dot{u}(t)$. The velocity at $t = 0$ in the chart $s_{p(0)}$ is $Dp(0) = \dot{u}(0)$ so that the expression of the *tangent space* at p is $T_p\mathcal{E} = V_p$. The expression of the tangent bundle is the *statistical bundle* $S\mathcal{E}$ consisting of of couples (q, v), $q \in \mathcal{E}$ and $v \in V_q$. The *statistical gradient* of a mapping $\phi \colon \mathcal{E} \to \mathbb{R}$ is the section $\operatorname{grad}\phi$ such that $(d/dt)\phi[p(t)] = E_{p(t)}(\operatorname{grad}\phi(p(t))(D/dt)p(t))$. There is a Riemnnian metric $V_p \times V_p \ni (u, v) \mapsto E_p(uv)$ and the dual of the exponential transport is the *mixture transport*. The Levi-Civita connection and the two affine transports define three different geometries on the statistical bundle. The different covariant derivatives and their Hessians result. We consider applications of this set-up and shortly discuss the relation of these geometries with the Gini dissimilarity index.

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A different route to unconventional superconductivity: new spectroscopy on bismuth oxides

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A central challenge for understanding unconventional and/or high-Tc superconductors is elucidating how superconductivity emerges from adjacent phases whose interactions might foster or inhibit electron pairing. Addressing this question requires digging even deeper, since often those phases Mott insulator, spin/charge density wave, strange metal, and so on are complicated in their own rights. Our group has begun investigating a family of bismuth oxide compounds that can be doped to reach Tc just over 30 K [1]. Similar to, e.g., cuprates, the parent compound BaBiO3 is insulating, even though simple electron counting says it should be metallic. This insulating behavior is shockingly robust with respect to temperature, doping, and even structural transitions. Understanding the origin and nature of this phase and whether/how it is connected to superconductivity has led to various theories invoking phenomena such as charge ordering, attractive effective Coulomb interactions, reverse charge transfer effects, and bipolarons. It has been difficult to judge the merits of these models or answer any of the deeper questions, in part because the field has lacked a detailed experimental view of the electronic structure in any of the bismuthates. Thanks to a unique experimental toolkit, we have finally 50+ years after its first synthesis obtained the momentum-resolved band structure of BaBiO3 by performing angle-resolved photoemission spectroscopy (ARPES) in situ on freshly-grown thin films [2]. The pattern of Brillouin zone

folding contrasts with core level measurements, showing that BaBiO3 lacks formal Bi charge ordering, despite a distorted structure that would suggest otherwise. We have been able to understand this by combining the photoemission data with density functional theory to uncover the orbital compositions of the bands. Our results confirm a model in which a negative charge transfer energy combines with structural distortions, driving hole pairs to condense onto molecular-like combinations of the oxygen p orbitals [3]. The findings carry implications for our understanding of the insulating phase and its doping evolution, as well as superconductivity in bismuthates. They also may shed light on other problems in oxide physics, such as the metal-insulator transition in rare earth nickelates.

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An empirically calibrated large-scale agent-based model for an entire national economy

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With the digital transformation of all aspects of human society the quality and quantity of economic data is expanding rapidly. Public sector data, such as tax records and social security data as well as private collections of consumer spending and business information like credit and financial data are available on an astonishing level of detail on individuals and companies. At the same time computing power has grown in line with Moores law for decades, allowing large-scale computer simulations that helped advancing various research fields. These developments allow for a new approach to economic modeling. We present the first empirically calibrated large-scale agent-based model (ABM) for a national economy. Our ABM includes all economic activities (producing and distributive transactions) as classified by the European system of accounts (ESA) and all economic entities, i.e. all juridical and natural persons, as represented by agents (at a scale of 1:10). The economy is structured into four sectors households, firms, banks and government entities where each of them is populated by a number of heterogeneous agents that all interact with each other on different markets. The structure of our model is standard in the ABM literature and all equations follow well-established relationships from economic theory. The results of our model simultaneously fit observed macroeconomic time series, stylized facts, and observed distributions between agents on the micro-level. Our proposed procedure of embedding ABMs in observed empirical data allows ABMs to be used not only for theoretical arguments, but also to make forecasts and predictions. Potential applications of this ABM include economic forecasting of various sectors, quantify systemic risk in various economic networks, predicting responses of the economy to endogenous shocks, e.g. from the financial system, and exogenous shocks like transformative technological innovations or unintended consequences of political interventions such as subsidies and tax policies.

Marginal time-reversal and effective fluctuation relations

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The response of thermodynamic systems slightly perturbed out of an equilibrium steady-state is described by two milestones of early nonequilibrium statistical mechanics: the reciprocal and the fluctuation-dissipation relations. At the turn of this century, the so-called "fluctuation theorems" extended the study of fluctuations far beyond equilibrium. All these results rely on the crucial assumption that the observer has complete information about the system: there is no hidden leakage to the environment, and every process is assigned its due thermodynamic cost. Such a precise control is practically unattainable and philosophically untenable, hence the following questions are compelling: Will an observer who has marginal information be able to perform an effective thermodynamic analysis? Given that such observer will only be able to establish local equilibrium amidst the whirling of hidden fluxes, by locally perturbing the stalling currents will he/she observe equilibriumlike fluctuations? Furthermore, the second law of thermodynamics is tightly intertwined with the concept of (global) time-reversal of the dynamics of a stochastic process, with the fluctuation relations for a complete set of currents quantifying the extent by which forward processes are more probable than backward ones. What if instead we restrict to a marginal subset of currents? We propose a notion of marginal time-reversal of a Markov jump process that allows to prove effective fluctuation relations for subsets of currents, and thus to establish thermodynamics (including the 2nd law and the fluctuation-dissipation relation) for an observer that only has partial information about a system. Marginally time-reversed generators have interesting mathematical properties related to concepts in graph theory and large deviation theory.
In particular we establish that: 1) While marginal currents do not obey a full-fledged fluctuation relation, there exist effective affinities such that an integral fluctuation relation holds; 2) Under reasonable assumptions on the parametrization of the rates, effective and "real" affinities only differ by a constant; 3) At stalling, i.e. where the marginal currents vanish, a symmetrized fluctuation-dissipation relation holds while reciprocity does not; 4) There exists a notion of marginal time-reversal that plays a role akin to that played by time-reversal for complete systems, which restores the fluctuation relation and reciprocity.

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New kinetic models of dense reactive and inert mixtures

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I consider the modified simple reacting spheres (MSRS) kinetic model that, in addition to the conservation of energy and momentum, also preserves the angular momentum in the collisional processes. In contrast to the line-of-center models, in the MSRS kinetic models, the microscopic reversibility (detailed balance), is built-in and thus all mathematical aspects of the model can be fully justified. In the MSRS model, the molecules behave as if they were single mass points with two internal states. Collisions may alter the internal states of the molecules, and this occurs when the kinetic energy associated with the reactive motion exceeds the activation energy. Reactive and non-reactive collision events are considered to

be hard spheres-like. We consider a four component mixture A, B, C, D, in which the chemical reactions are of the type A+B C+D. I provide fundamental physical and mathematical properties of the MSRS model, concerning the consistency of the model, the entropy inequality for the reactive system, the characterization of the equilibrium solutions, the macroscopic setting of the model and the spatially homogeneous evolution. Moreover, I show that the MSRS kinetic model reduces to the previously considered model simple reacting sphere, if the reduced masses of the reacting pairs are the same before and after collisions.
I also consider stochastic variants for both reactive and inert mixtures. In *Transport coefficients in some stochastic models of the revised Enskog equation*, J. Stat. Phys. 109, 569–590 (2002), Polewczak and Stell developed a new liquid-state kinetic theory for particles with interaction potentials that are continuously varying (such as Lennard-Jones particles and inverse-power-law potentials), rather than discontinuous (such as the hard-sphere or square-well potentials). A stochastic smoothing term that represents a distribution of interaction diameters into the kinetic equation was introduced into the revised Enskog equation. This idea is extended to inert and reactive mixtures.

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An application of geometrization in generalized statistical mechanics

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Geometrical aspects of the space of parameters for a physical system are discussed within the framework of a nonextensive statistical setting. For this purpose, generalized quantities are employed, based on general measures of information gain. The overall scenario is provided by a combination of differential geometry and information theory. Indeed, as geometry studies mutual relations between elements such as distance and curvature, it provides the information sciences with powerful tools. Information geometric methods allow for the study of physical systems that undergo a phase transition, where the formalism gives a characterization of critical phenomena from a geometrical point of view. The mechanism is to generate a distance in the space of thermodynamic parameters of the problem, and to study its variation in order to detect critical behavior which reveals in the metric tensor and the scalar curvature of the thermodynamic manifold. Generalized entropic measures of information can be used for this purpose. Previous studies comprise applications to noninteracting as well as interacting systems, like fluid and spin systems. It is seen that the scalar curvature measures interatomic interactions, acquainting for the size of organized fluctuating microscopic structures, and even indicating whether the interactions are effectively attractive or repulsive. Here we consider the geometrization of thermostatistics for systems of interest as is the case of type-II superconductors, for which the best description involves a mixing of nonextensive entropies with different entropic indices. The thermodynamic parameters that control the behavior of the system are taken as the temperature and external magnetic fields. The solution of the physical problem under study can be given in terms of a probability distribution which can be obtained from maximization of generalized nonextensive entropic forms. In terms of those thermodynamic parameters, the geometric magnitudes of the statistical manifold are analyzed.

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An approach for early stage of opinion formation

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In this work we propose to calculate the opinion for a pair of individuals using the model of XY 2D magnets. Here the opinion observable is described with a two dimensional vector O, and the issue asked on the society is described with the vector F. The temperature is defined as proposed by Stauffer (Stauffer, 2007). Assuming that initially the opinion agents strive to find an agreement with an only with its nearest neighbor which practically could be the closest relative, only two opinions will interact directly in this stage which we call the early stage of opinion formation. The common opinion of pair after the agreement between its individuals is represented with the sum of two individual opinion vectors. This agreement process is driven by satisfaction (happiness or unhappiness) which is measured using the energy-like function (utility) in the term of Stauffer description (Stauffer, 2007). So, we start from the Hamiltonian of 2D XY magnets proposed in (Ciftja, 2016) say $H = \frac{J}{2}(O^2 - 2) - \cos\phi(O^* f)$ where an $O = O_1 + O_2$ and f are algebraic values of O and F whereas ϕ is the angle between them. Considering that the satisfaction or unhappiness might not be additive, we propose to add an extra term in the Hamiltonian similarly as of q-addition used in Tsallis statistics for other observables (Tsallis,2009) so $H = \frac{J}{2}(O^2 - 2) - \cos\phi(O + f) + \alpha\frac{J}{2}\cos\phi(O^* f)$. Using this last, we perform the standard statistical mechanics calculation to evaluate the opinion value O, and afterwards analyze its behavior according to α value. Particularly we obtain that for specific choice of parameter α, the opinion found for ferromagnetic-like interaction will be similar with anti ferromagnetic ones and vice-versa. It seems that changing the structure of the satisfaction in those systems represented in α -parameter could result in a final agreement between initially adversaries opinions and vice versa. Next, for the all society composed by n-pairs we presume that inner satisfaction for each one represented in quantity $\frac{J}{2}(O^2 - 2)$, would have specific relationship with the exterior satisfaction term $\cos\phi(O^* f)$, therefore so we apply uniformly distributed α -values for each and analyze the distribution of the opinion values in this society again. Herein, in the case of moderate temperature and exterior field, we obtained a near to power law distribution for opinions values. Other scenarios have been analyzed too. In a final conclusion we propose to use the opinion values as found herein instead of randomly chosen in some standard approaches as Deffuants model for example (Castellano, 2009).

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Fluctuations and topological defects in ferroelectrics

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Topologically nontrivial patterns like vortices, hedgehogs (monopoles), skyrmions are not commonly expected to play an

important role in statistical mechanics of lattice models whose Hamiltonians possess only a finite set of symmetries. Indeed, in the absence of quenched disorder, the ground state of such models is defect-free, while the classical "topological protection" mechanisms cannot be realized due to a nearly trivial topology of the order parameter space that reduces the set of possible topological defects to domain walls (kinks). Proper ferroelectric materials correspond to one of the real-world prototypes for such models. Specifically, bulk ferroelectric crystals exhibit neither depolarizing nor random local fields that can render topological defects energetically favorable, while strong crystalline anisotropies characteristic for these materials reduce underlying Hamiltonian symmetries to point groups comprising finite number of elements. It is therefore not surprising, that until the recent experimental observation of ferroelectric vortices, domain walls very thought to be the only topological defects exhibited by ferroelectric materials.
In this study, we combine homotopy theory and first-principles-based effective Hamiltonian approach to explore stability of topological defects in bulk BaTiO3 and resolve the aforementioned controversy between theoretical expectations and recent experimental results. Specifically, our results show that this proper ferroelectric material can exhibit stable topological point defects in its tetragonal polar phase and stable topological line defects in its orthorhombic polar phase. The stability of such defects originates from a novel mechanism of topological protection related to finite-temperature fluctuations of local dipoles. Large-scale effective Hamiltonian Monte Carlo simulations are then conducted to confirm these theoretical predictions. The results of our work, hence, reveal a novel mechanism of topological protection that can be realized in proper ferroelectrics and provide a theoretical framework for investigations of topological defects in systems with finite underlying symmetries.

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Chimera states in oscillatory dynamics

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Chimera states emerge in systems of nonlocally coupled identical oscillators and are characterised by coexistence of coherent and incoherent domains. These hybrid states appear unexpectedly since all elementary oscillators in the system are identical and are identically coupled. A characteristic feature of chimera states is their mean phase velocity (frequency) profile: in the coherent regions all elements have equal, constant mean phase velocity, while in the incoherent ones the frequency profiles take arc shapes. Experimental evidence of chimera states include coupled laser systems, coupled chemical oscillators and mechanical experiments of two subpopulations of linked metronomes. Applications are found in the unihemispheric sleep of birds and mammals and in brain dynamics, in general. Here we present synchronization properties leading to chimera states in networks of coupled neuronal oscillators. We study synchronization patterns and we show that the chimera multiplicity (number of coherent and incoherent regions) decreases as the coupling range increases. In systems consisting of limit cycles undergoing Hopf bifurcations we show that the incoherent regions merge as the parameters approach the bifurcation point, while the mean phase velocity of the oscillators shrink to zero. To understand the influence of connectivity in the chimera form we investigate the Leaky Integrate and Fire (LIF) model under different connectivity architectures. In the case of nonlocal connectivity we show evidence of a coexistence state where multileveled chimera patterns are formed and they coexist with domains consisting of near-threshold elements. The oscillating elements form complex mean phase velocity profiles while the potentials of the near-threshold elements present small fluctuations and never drop to the resting state. We study different synchronization patterns in the parameter space of the LIF system when the oscillators are nonlocally coupled in 1, 2 and 3 spatial dimensions. We also investigate the effects of different connectivity schemes: nonlocal connectivity, reflecting coupling, diagonal or hierarchical (fractal) connectivity.

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Low frequency instabilities based on electron and ion temperature anisotropies in non-Maxwellian plasmas

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In space plasmas, velocity distribution functions are often observed with high energy tails and /or flat tops in the profile of distribution function. Such distributions are frequently observed by CLUSTER space craft in the solar wind and magnetosphere. Since now we have numerous observations non-Maxwellian distribution functions from different regions of space plasmas, we need to employ real observed distribution rather using the same classical idealized Maxwellian distribution function. Therefore, in this study we first observe Alfven waves in the solar wind using CLUSTER space craft data when the CLUSTER space craft is well immersed in the solar wind. We then by using kinetic theory study the Alfven cyclotron instability using both the ion and electron temperature anisotropies for the first time. In this study, the distribution which we employed is a non-Maxwellian distribution function such as the generalized (r,q) distribution function which is the generalized form of kappa and Maxwellian distribution functions. Here the spectral index r represents the shoulders or flat tops in the distribution and spectral index q represents the percentage of high energy particles or high energy tails in the profile of the distribution function. The (r,q) distribution reduces to the kappa distribution function in the limit when r=0 and q+1 and reduces to the classical distribution function in the limit when r=0 and q. We then calculate the numerical values of the ion and electron temperature anisotropies from that time interval when Alfven waves are observed in the data. We study the role of electron to ion temperature ratios and found that by increasing the perpendicular electron temperature to parallel ion temperature ratio, growth rate of Alfven cyclotron instability decreases whereas by increasing the parallel electron temperature to parallel ion temperature ratio growth rate increases. We also found that left-hand circularly polarized wave becomes unstable not only when perpendicular ion temperature is greater than the parallel ion temperature as reported in the literature but also when perpendicular ion temperature is smaller than the parallel ion temperature. Theoretical values of frequency and growth rates are then compared with Maxwellian results.

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Statistical mechanics approach to coevolving spin system

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Studies of the network structure of real systems, like financial markets, social and biological structures, networks of information, transportation networks, showed that their topology has numerous non-trivial properties. Characteristics of analyzed empirical networks could have not been explained with the classical random graph model, what gave birth to new network models, able to recreate some of the observed phenomena. Initially, most of these models focused on the graph evolution, often growth in the number of nodes and edges, with an arbitrary type of dynamics. On the other hand, we could observe the development of a different approach considering the statistical ensemble of graphs [1], also referred to as exponential random graphs. This formalism, borrowed from statistical physics, proved successful in equilibrium description of uncorrelated graphs [2] and networks with simple structural interactions [3]. It also led to a phenomenological theory of topological phase transitions in evolving networks [4]. Newly discovered concept of networks with a complex structure quickly echoed around spin models community, especially spin glass and agent-based models. One of the motivations for using complex networks in agent-based modeling was their much higher resemblance to the real-world structures, than regular lattices or Poissonian graphs.
We propose a statistical mechanics approach to a coevolving spin system with adaptive network of interactions. The dynamics of nodes states and network connections is driven by both spin configuration and network topology. We consider a hamiltonian that merges the classical Ising model and the statistical theory of correlated random networks. As a result, we obtain rich phase diagrams with different phase transitions both in the state of nodes and in the graph topology. Adjusting values of two parameters describing ratio between the topological and the spin part of the hamiltonian we can observe a whole variety of different effects including: multiple-star configurations, high degree clustering, network disintegration and recombination, continuous and discontinuous phase transitions in magnetization, energy, and the largest degree. We argue that the coupling between the spin dynamics and the structure of the network is crucial in understanding complex behavior of the real-world systems, and omitting one of the approaches renders the description incomplete.

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Formation probabilities, Post-measurement entanglement entropy and Casimir effect

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To discuss different properties of a quantum system it is customary to use energy basis. This is mostly because the evolution of the system looks much more simple in this basis. In addition the Hamiltonian plays an important role in the equilibration properties of a quantum system. A great deal of universal properties can be studied in the energy basis. However, in this talk I would like to study a quantum system in local configuration bases. I will show that by studying a quantum system in local basis one can extract a lot of universal properties. I will first introduce formation probability as a quantity which can determine the universality class of a quantum critical system. In other words, by calculating this quantity one can find the central charge and critical exponents of a quantum system and determine the universality class uniquely. I will show that calculating this quantity boils down to finding Casimir energy of two needles. Then using boundary conformal field theory (BCFT) techniques we find exact results for the formation probabilities. Numerical results for transverse field Ising model will be presented to support the analytical results. Then we will briefly talk about Shannon mutual information as another quantity which can play similar role. We will present a conjecture which connects Shannon mutual information to the central charge of the underlying conformal field theory. We will support the conjecture with many numerical calculations. Finally, we will introduce post-measurement entanglement entropy as a tripartite measure of entanglement. We will show that this quantity is related to the Casimir energy of needles on Riemann surfaces and can be calculated exactly for conformal field theories. To do that we use a slightly different method than twist operator technique. Many analytical results, such as, Renyi entropy, entanglement Hamiltonian, distribution of the eigenvalues of entanglement Hamiltonian, the effect of the boundary and Affleck-Ludwig boundary entropy can be discussed naturally in our framework. Few numerical results regarding free bosons and transverse field Ising chain will be presented as support for analytical results.

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A multilayer approach for price dynamics in financial markets

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The dynamics of financial markets, with its erratic and irregular behavior at different time scales, has stimulated important theoretical contributions by several physicists and mathematicians since long time. In particular statistical physics has provided the newborn field of Econophysics with new tools and techniques that allow to model and characterize in a quantitative way the apparently unpredictable behavior of price and trading time dynamics. The recent use of agent-based approaches in financial markets models has also given very useful insights in understanding the often counterintuitive interactions among heterogeneous agents operating in realistic markets. Recently, herding and imitative behavior among agents has been successfully simulated with Self-Organized-Criticality (SOC) models and the adoption of random strategies has been shown to be an efficient and powerful way to moderate dangerous avalanche effects, diminishing the occurrence of extreme events. Often these models have adopted topologies like scale-free and small world networks to describe the social interaction among agents. Such topologies can be further refined for a detailed and realistic description. Very recently multilayer networks have been introduced for a more appropriate framework of several social networks. In this paper we use a multilayer network, to investigate price dynamics by means of an order book based on two assets. In order to simulate the operations of a financial market, the model here presented considers two layers: one for the exchange of information among traders and one for the order book mechanism. In brief, the role of

the two layers is the following:
i) in the informative layer, according to the link configuration given by the network topology, agents collect and share information, therefore deciding their status (bidder, asker or holder) and the (ask or bid) price of their possible orders for the two assets, depending on the global price of the assets at time t and on the herding effect, which induces avalanches of identical investments;
ii) in the trading layer, investors put their orders in the order book, which provides a sort of compensation room to execute them, and the next global prices for the two assets emerge from the mutual interaction among all the agents.
This realistic framework produce interesting numerical results, which adhere to some typical features of real financial markets.

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Synchronization in systems with linear, yet nonreciprocal interactions

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Synchronization of oscillatory subsystems is a widespread phenomenon with examples in biology, neuroscience, chemistry and physics. A common feature of all these systems is that they are somehow connected to the synchronization theory of nonlinear limit cycle oscillators. It is thus often argued that the presence of nonlinearities is a necessary prerequisite for synchronization to happen. In this contribution we study synchronization in complex plasmas, which are plasmas containing microparticles in addition to ions, electrons and neutral gas atoms of the plasma. These microparticles show a strong (nonlinear) Coulomb interaction. The systems can form so-called plasma crystals. In experiments under gravity conditions the plasma crystals are two-dimensional hexagonal crystalline structures. They show a plasma specific melting mechanism called mode-coupling instability (MCI). MCI is a consequence of the effective nonreciprocal interactions of the microparticles. Nonreciprocal means that Newton's third law "actio = reactio" is violated if focusing on the microparticles. This is possible because the effective interactions of the microparticles are mediated by a nonequilibrium environment of flowing plasma ions. Recently, the observation of synchronized particle motion during such a mode-coupling instability induced melting of a two-dimensional plasma crystal was reported. In order to disentangle the effects of nonlinearity and nonreciprocity on the emergence of synchronization, we solved numerically the nonlinear and the linearized system for identical lattice and system configurations, where the interaction force was linearized around the equilibrium configuration of the crystal. Analyzing the onset of the synchronization with a newly developed, Kuramoto-inspired order parameter reveals that a linearized version of the interaction model exhibits exactly the same synchronization patterns as the complete nonlinear interaction model. Further theoretical considerations then naturally show that the nonreciprocal interactions of the microparticles provide a mechanism for the selection of dominant wave modes causing the system to show synchronized motion. In conclusion, we demonstrate numerically and analytically that - in contrast to common belief - also linear systems can synchronize and that the nonreciprocity of the interaction is the decisive property for a linear n-body system to synchronize.

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Entropy production in electro-thermal dielectric breakdown in solid materials

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In the present work we applied the non equilibrium thermodynamic theory in the analysis of the dielectric breakdown process. From the thermodynamic viewpoint all phenomena in nature have a tendency to reduce their energy, is the case of the propagation of electrical tree structure. As the tree channel front moves, the intense field near the front moves electrons and ions irreversibly in the region beyond the tree channel tips where electromechanical, thermal and chemical effects cause irreversible damage and from the non equilibrium thermodynamic viewpoint: entropy production. From the non equilibrium thermodynamics analysis the entropy production are due to the product of fluxes J_i and conjugated forces X_i: $\sigma = \sum_i J_i X_i \geq 0$. We consider that the coupling between fluxes can describe the dielectric breakdown in solids as a phenomenon of transport of heat, mass and electric charge. Where J_q, J_μ and J_Φ are the fluxes of heat, matter and electric charge respectively. The forces of transport conjugate to the fluxes are the thermal force: $[\nabla(1/T)]$, the chemical force: $[-(1/T)\,\nabla(\mu\,T)]$ and the electrical force: $[-(1/T)\,\nabla\Phi]$. L-coefficients are the phenomenological coefficients, L_{ij} are the coupling coefficients, $L_{ij} = L_{ji}$ by the Onsager Theorem. The diagonal coefficients are described by λ (thermal conductivity) D (diffusion coefficient) and κ (the electrical conductivity) following the classical laws of Fourier, Fick and Ohm respectively. Coupling coefficients are small in some cases but large in others. Large coupling coefficients may lead to a low Entropy production. When an insulating material is subjected to an electric field, the material gets heated up due to conduction current and dielectric losses due to polarization. The conductivity of the material increases with increase in temperature and a condition of instability is reached when the heat generated exceeds the heat dissipated by the material and the material breaks down. If we consider only the electric current and heat flux in terms of the local electric field $E = -\nabla\Phi$ and local temperature field $\nabla(1/T)$ in a system where there is no transport of mass $J_\mu = 0$.

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Dynamical system modelling of human-environment interactions: the case of the Classic Maya collapse

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The collapse of the society of the Maya has found much attention in the literature and different theories about the collapse have been suggested in the past, especially regarding drought [1]. However, to date there is little quantitative modelling to test the consistency of the various hypotheses proposed. In this study we try to fill this gap by investigating the societal development of the Maya in the Southern Lowlands over a span of approximately 1400 years and exploring whether societal dynamics linked to depletion of natural resources can explain the rise and fall of the Maya civilisation. We propose a dynamical systems model that accounts for the state of the land, population and workers employed in swidden and intensive agriculture and monument building.

Recent models focused on the Maya collapse [2] show a sensitivity to changes in parameters that precludes robust prediction making. Furthermore, they do not address the issue of monument construction which could prove important in constraining model dynamics. In contrast to previous approaches, we explicitly compare our model output with the archaeological record for population growth and monument construction.
By optimising parameters related to demographic growth and shifts in agricultural specialisation we find that an excellent match to empirical time series of population, growth rates, and monument building can be obtained, provided a drastic increase in the usage of intensive agriculture is assumed to have occurred around 550 CE. When the harvesting rate increases beyond a certain point a (Hopf) bifurcation takes place that leads to large amplitude oscillations in the system. A similar conclusion has been reached for another model of a society that has collapsed, namely Easter Island [3]. The findings here lend support to a more general thesis that societal collapse can be modelled as a certain type of critical transition (supercritical Hopf bifurcation). Our results are found to be robust to sensitivity testing for a wide range of parameters. This qualitative picture persists even if including assumptions of droughts and drastic changes in precipitation.

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Topology-dependent rationality and quantal response equilibria in structured populations

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Nash equilibria of games are frequently used to reason about the decision-making. However, the underlying assumption of perfect rationality has been shown to be violated in many examples of decision-making in the real world. Accordingly, we explore a graded notion of rationality in socio-ecological systems of networked actors. We parametrise an actors' rationality via their place in a social network and quantify system rationality via the average Jensen-Shannon divergence between the games' Nash and Logit Quantal Response equilibria [1].
Previous work by [2] has argued that scale-free topologies maximise a system's overall rationality in this setup. Here, we show that while, for certain games, it is true that increasing degree heterogeneity of complex networks enhances rationality, rationality-optimal configurations are not scale-free. For the Prisoner's Dilemma and Stag Hunt games, we provide analytic arguments complemented by numerical optimisation experiments to demonstrate that core-periphery networks composed of a few dominant hub nodes surrounded by a periphery of very low degree nodes give strikingly smaller overall deviations from rationality than scale-free networks. If isolated nodes are allowed to form during optimisation, optimal networks are found to consist of a core made up by a complete graph with all other nodes being isolated. Similarly, for the Battle of the Sexes and the Matching Pennies games, we find that the optimal network structure is also a core-periphery graph but with a smaller difference in the average degrees of the core and the periphery. If no connectivity constraints are enforced, then in the case of the Battle of the Sexes a graph with a strongly bi-modal degree distribution emerges, while for the Matching Pennies game we obtain a quasi-regular graph. So, in contrast to [2], we have demonstrated that highly heterogeneous degree distributions do not necessarily maximise system rationality for all classes of games.
These results provide insight on the interplay between the topological structure of socio-ecological systems and their collective cognitive behaviour, with potential applications to understanding wealth inequality and the structural features of the network of global corporate control [3].

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A complete multifluid model for bipolar semiconductors

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If electrons (e) and holes (h) in metals or semiconductors are heated to the temperatures T_e and T_h greater than the lattice temperature , the electron-phonon interaction causes energy relaxation [3]. In the non-uniform case a momentum relaxation occurs as well. In view of such an application, a new model, based on an asymptotic procedure for solving the kinetic equations of carriers, phononsand photons is proposed, which gives naturally the displaced Maxwellian at the leading order.
Several generation-recombination (GR) events occur in bipolar semiconductors. In the presence of photons the most important ones are the radiative GR events, direct, indirect and exciton-catalyzed. Phonons and photons are treated here as a participating species, with their own equation. All the phonon-photon interactions are accounted for. Moreover carrier-photon (Compton) interactions are introduced, which make complete the model.
After that, balance equations for the electron number, hole number, energy densities, and momentum densities are constructed, which constitute now a system of macroscopic equations for the chemical potentials (carriers), the temperatures (carriers, and bosons), and the drift velocities (carriers, and bosons). In the drift-diffusion approximation the constitutive laws are derived and the Onsager relations recovered, even in the presence of an external magnetic field.
The treatment resorts here strictly to kinetic theory, so that the model is closed. This means that we do not need to adjust the relaxation times by means of comparisons with Monte Carlo calculations. The fulfilment of Onsager symmetry is not trivial, since it cannot given for granted in many macroscopic models.
We stress the following extensions, with respect to a previous paper [1]:
i)photons are described as a participating species, with their own kinetic equation; ii) Phonon-photon and carrier-photon (Compton) interactions are introduced; iii) exciton-catalyzed generation-recombination is accounted for; iv) a detailed discussion on Onsager symmetry is given.

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Broadband low-frequency electric field structures in non-thermal auroral plasma

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Broadband electrostatic noise (BEN) have been observed with frequencies fluctuating from the ion cyclotron upto and higher than the ion plasma frequency (frequency range of several hectohertz (hHz) to a few kilohertz (kHz)) in the auroral acceleration region of the Earth's magnetosphere. Several spacecraft missions have reported that BEN has a potential of dynamical characters with small-scale, large-amplitude, magnetic aligned electric fields in different regions of the

magnetosphere, e.g., in the auroral acceleration region, the plasma sheet boundary layer (PSBL), polar cup boundary layer (PCBL) , the Earth's high altitude polar magnetosphere, on cusp field lines and magnetosheath, etc. Further investigations revealed that BENs consist of nonlinear, quasi-static, time domain parallel or/and perpendicular electric field structures such as spiky, sawtooth and sinusoidal structures in an electrostatic ion cyclotron (EIC) wave reported by S3-3, Viking, FREJA, POLAR and FAST satellite. Various theoretical investigations of the nonlinear EIC waves that generate spiky electric field structures in both parallel and perpendicular to the geomagnetic field line have been done by several authors.
FREJA satellite instruments have detected the low-frequency electrostatic structures associated with density depletions in the Earth's upper ionosphere. The theoretical explanation of the observed electric field structures is presented in this study. Motivated by the spacecraft measurements, several theoretical attentions have been focused on the interpretation of the mechanism generating density depletion in the observed fluctuation phenomena, in terms of non-thermal distribution function which deviated completely from the Maxwellian (Boltzmann distribution) equilibrium. Example of such velocity distribution are Kappa, Tsallis q-nonextensive and Cairn's non-thermal distribution. For a magnetized auroral plasma system consisting of energetic non-thermal electrons and a cold ion, the nonlinear evolution of low-frequency ion cyclotron and ion-acoustic waves is investigated. The dynamic of the cold ion is governed by the fluid equations and the background electron is treated as energetic hot species withCarin's non-thermal density distribution. Numerical computations appear in a series of periodic oscillations such as signal, sawtooth and sinusoidal waveforms. The present results show an excellent agreement with the spacecraft measurements.

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Out-of-equilibrium physics in spontaneous synchronization

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Spontaneous synchronization is a cooperative phenomenon common in nature which makes oscillators of different frequencies, if strongly coupled, operate together with a single common frequency. Such cooperative effects occur in physical and biological systems over length and time scales of several orders of magnitude. Examples: are flashing of fireflies, rhythmic applause in a concert hall, animal flocking behavior, electrical power-grids, etc. The most celebrated model of synchronization is the Kuramoto model, introduced in 1975, which is simple enough to allow quite a detailed analytical treatment, at the same time capturing several features of realistic systems. After discussing the general dynamical and statistical features of synchronization, I will discuss its out-of-equilibrium physical aspects when uncorrelated Langevin noise is added to the model.

Extension of black hole thermodynamics with information geometry

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Information geometry represents probabilities with Riemannian metric spaces. This is an idea dating back to the work of Fisher and Rao. That the resulting stochastic manifolds have applications in statistical mechanics and thermodynamics, with their probabilistic structures, is thus no surprise. My talk involves the logical theme that the unique Ricci curvature scalar R of these stochastic manifolds extends the reach of thermodynamics. I propose that it illuminates fluctuations at mesoscopic size scales. I put special emphasis on some recent ideas in black hole thermodynamics, a field of study originated by Bekenstein, Hawking, and others. Despite much effort by the scientific community, there is no consensus on any underlying microstructure at the foundation of black hole thermodynamics. This constitutes a significant gap in physical theory. Thermodynamic fluctuation theory, extended with ideas from information geometry, offers perhaps some insight for this physical problem.
Thermodynamic Ricci curvature R is an element of thermodynamic metric geometry, originated by Weinhold in 1975. Weinhold introduced a thermodynamic energy inner product. Ruppeiner then wrote a Riemannian thermodynamic entropy metric to represent thermodynamic fluctuation theory, a branch of information geometry, and began systematically calculating the thermodynamic Ricci curvature scalar R. A parallel effort was by Andresen et al. who began the systematic application of the thermodynamic entropy metric to characterize finite-time thermodynamic processes.
There is substantial evidence that R is a thermodynamic measure of intermolecular interactions. It appears that $|R|$ gives the characteristic size of organized mesoscopic fluctuations in fluid and magnetic systems. The sign of R also appears to be significant: for fluid systems, R is positive/negative for systems in states dominated by repulsive/attractive intermolecular interactions. R for systems with no interactions between microscopic constituents have $R = 0$.
Information geometry, via the invariant thermodynamic curvature R, presents a unifying theme encompassing fluid systems, magnetic systems, and perhaps black holes.

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Topology, dynamics and the optimisation of spreading processes

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The modern world can be best described as interlinked networks, of individuals, computing devices and social networks; where information and opinions propagate through their edges in a probabilistic or deterministic manner via interactions between individual constituents. These interactions can take the form of political discussions between friends, gossiping about movies, or the transmission of computer viruses. Winners are those who maximise the impact of scarce resource such as political activists or advertisements (Epstein and Robertson, 2015), or by applying resource to the most influential available nodes at the right time. We developed an analytical framework, motivated by and based on statistical physics tools, for impact maximisation in probabilistic information propagation on networks (Lokhov and Saad, 2016); to better understand the optimisation process macroscopically, its limitations and potential, and devise computationally efficient methods to maximise impact (an objective function) in specific instances.
The research questions we have addressed relate to the manner in which one could maximise the impact of information propagation by providing inputs at the right time to the most effective nodes in the particular network examined, where the impact is observed at some later time. It is based on a statistical physics inspired analysis, Dynamical

Message Passing (Lokhov, Mezard and Zdeborova, 2015), that calculates the probability of propagation to a node at a given time, combined with a variational optimisation process. The work has successfully addressed the following questions: 1) Given a graph and a propagation/infection process, which nodes are best to infect to maximise the spreading? given a limited budget, how many nodes one can infect within a given time? how long will it take one to infect all nodes? 2) Maximising the impact on a subset of particular nodes at given times, by accessing a limited number of given nodes. 3) Identify the most appropriate vaccination targets in order to isolate a spreading disease through containment and islanding of an epidemic. We also point to other potential applications, such as identifying the source of an epidemic and design of the best monitoring points to facilitate it. Numerical studies on benchmark problems show the efficacy of the method both for information propagation in time and vaccination.

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A Model for the Diffusion of Polymeric Melts based on the Generic van der Waals Equation of State and the Free Volume Theory

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In this paper, we investigate the dynamics of diffusion of polymer melts by developing a phenomenological model based on the integral equation theory for site-site pair correlation functions, the generic van der Waals equation of state, and the modified free volume theory. The integral equations are used to find the pair correlation functions necessary for the generic van der Waals equation of state. This later, in turn, is used to calculate the self-diffusion coefficient on the basis of the modified free volume theory. A random distribution is assumed for minimum free volumes for monomers along the melt chains. Actually, a stretched exponential is used for the distribution function. For polymer melts of N monomers, the N dependence of the self-diffusion coefficient is N^{-1} for small values of N, as predicted by the Rouse theory. But in the range $2.3 \leq \ln N \leq 4.5$, the N dependence smoothly crosses to N^{-2}, as predicted by the reputation theory. For $\ln N > 4.5$, the N dependence of the self-diffusion coefficient becomes $N^{-2-\delta}$ $(0 < \delta < 1)$, which is consistent with experimental results on polymer melts in the same range. This semi-empirical N dependence of diffusion allows also the prediction of the dependence of the self-diffusion coefficient on temperature. The theory is successfully tested against experimental and simulation data on polyethylene and polystyrene melts.

Some new aspects of dust-acoustic structures in space plasmas out of equilibrium

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Some features of linear and nonlinear dust-acoustic (DA) structures is investigated in a space plasma consisting of superthermal electrons, positrons and positive ions in the presence of negatively charged dust grains with finite-temperature by employing a pseudo-potential technique in a hydrodynamic model. For this purpose, it is assumed that the electrons, positrons and ions obey a Kappa-like distribution in the background of adiabatic dust population. In the linear analysis, it is found that the dispersion relation yield two positive dust-acoustic branches, i.e., the slow and fast DA waves. The upper branch (fast DA waves) corresponds to the case in which both (negatively charged) dust particles and (positively charged) ion species oscillate in phase with electrons and positrons. On the other hand, the lower branch (slow DA waves) corresponds to the case in which only dust particles oscillate in phase with electrons and positrons, while ion species are in antiphase with them. On the other hand, the fully nonlinear analysis shows that the existence domain of solitons and their characteristics depend strongly on dust-charge Z_d, ion-charge Z_i, dust-temperature and the spectral index κ . It is found that the minimum/maximum Mach number increases as the spectral index κ increases. Also, it is found that only solitons with negative polarity (rarefactive solitons) can propagate and that their amplitudes increase as the parameter κ increases. Furthermore, the domain of Mach number shifts to the lower values, when the value of dust-charge Z_d increases. Moreover, it is found that the Mach number increases with an increase in dust temperature. Our analysis confirms that in space plasmas with highly charged dusts, the presence of superthermal particles (electrons, positrons and ions) may facilitate the formation of DA solitary waves. Particularly, in two cases of hydrogen ions H^+ $(Z_i = 1)$ and two times ionized Helium atom He^{2+} $(Z_i = 2)$ the mentioned results are the same. Additionally, the mentioned dusty plasma don't supports DA solitons with positive polarity (compressive solitons). Furthermore, our analysis confirms that DA double layers cannot exist in such a system. Moreover, the positron density has not a considerable effect on the behavior of DA solitons in our model.

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Ruppeiner geometry and thermodynamic ensembles of anti-de Sitter black holes

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We discuss the role of Ruppeiner's geometry in describing restricted thermodynamic fluctuations in the context of anti de Sitter (adS) black holes which have a negative cosmological constant. We explicitly work out the relation between constrained thermodynamic fluctuations in black holes and the instrinsic as well as extrinsic thermodynamic geometry of the relevant codimension one hypersurfaces in the thermodynamic state space. Thus, for example, it turns out that the constrained moments of fluctuations of thermodynamic quantities have a geometrical interpretation as the Lie derivatives of induced thermal metrics on the relevant ensemble hypersurface. We show that Ruppeiner's geometry encodes instabilities and critical points associated with different ensembles. We then discuss the thermodynamic geometry of the extended state space of adS black holes, wherein the cosmological constant is a fluctuating thermodynamic variable. The quantity conjugate to the cosmological constant is the thermodynamic volume while the black hole mass is in fact its enthalpy. A detailed study is undertaken of the curvature contour of the 4D Kerr-AdS black hole. It turns out that geometry is able to shed light on hitherto unforeseen instabilities in various ensembles in the extendded state space of Kerr-AdS black holes. In particular, thermodynamic geometry suggests an instability in the Schwarzschild-AdS limit for all the ensembles except the pressure ensemble, which is equivalent to the unextended state space of the Kerr-AdS black holes.
In addition, we provide our perspective on the physical interpretation of the state space thermodynamic curvature for black holes and further revisit its connection with the singular part of the free energy especially in relation to a non extensive

system like the black hole. We further discuss the possible significance of the thermodynamic curvature in the context of the AdS/CFT correspondence in string theory, which is a duality between a bulk gravity theory and a gauge theory living on the boundary. We end the talk with conclusions and some future plans.

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In-situ observations of solar wind electrons: Interplay between thermal core and suprathermals

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The non equilibrium characteristics of the solar wind electron velocity distribution functions (eVDFs) at 1 AU are of great importance in understanding heat conduction, plasma microinstabilities and transport in weakly collisional plasma, as well as in the scenario at the origin of the solar wind. Solar wind eVDFs display a thermal Core and a suprathermal Halo populations present at all pitch angles, as well as a third antisunward field-aligned component, called Strahl. The usual model used to characterize the solar wind eVDFs has been a sum of two bi-Maxwellians, the core-halo model, with a core-halo drift velocity oriented along the interplanetary magnetic field. This model was used in the past to derive micro-instabilities and calculate wave growth rates.
Other works have emphasized the Lorentzian nature of eVDFs, i.e. the importance of their suprathermal tails, which should play a crucial role in the exospheric expansion of the slow and fast solar wind. However both models are not appropriate to accurately characterize the solar wind EDFs because they do not account properly for some important features of the observed EDFs. It is therefore important to determine and characterize more precisely the nature of the EDFs, and in particular the nature of their suprathermal tails, in the slow and fast solar wind. The associated problem of the electron heat conduction has also attracted space plasma physicists for a long time. Yet, the mechanisms that determine the electron energy transport and dissipation in the solar wind are far from being understood.
We present a review of our latest work based on statistical analysis of solar wind electrons at 1AU using a newly developed dataset of (several years of) accurate measurements of core, halo and strahl electron parameters from the 3D-Plasma experiment on NASAs Wind spacecraft. We investigate the properties of these different populations. We explore the physical processe(s) that likely act to control and regulate them. We review new results obtained on: electron temperature anisotropies and their variation with collisions and/or solar wind fluctuations and instabilities; properties of core and halo drifts in the solar wind frame; electron heat flux; and electron strahl. These new observations emphasize the non-negligible role of Coulomb collisions in shaping the eVDFs and regulating core and suprathermals, combined to that of electromagnetic fluctuations (turbulence/waves/instabilities).

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Diffusion on surfaces: from theory to experiments and back

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Diffusion is an ubiquitous phenomena. It permeates physics, mathematics chemistry, biology and even sociology and economics. In physics, it has been associated to several works made by scientists like Maxwell, Stefan, Einstein, Smoluchowski and Boltzmann, among others. Over the past decade, great theoretical attention has been given to the possibility, as in general relativity, that the curvature of the environment could change a particle diffusing behavior [1,2]. For instance, It was found that the root mean square displacement, which behaves linearly with time for the classical Euclidean diffusion phenomena, may have polynomial corrections if the diffusion occurs in a curved surface,b.e.g. for a sphere, as demonstrated in [1]. Very recently, these theoretical predictions were verified experimentally using single-particle tracking for a nanoparticle diffusing on a spherically curved oil/water interface by Zhong et al.[3]. However, for some specific radii of the spherical water-oil interface, an unexpected behavior was observed for the root mean square displacement that requires further theoretical investigation. In fact, It was observed that that the diffusion slows down significantly when the oil droplet becomes smaller [3]. It is our aim in this work trying to theoretically explain this novel experimental finding. Since the nanoparticle size can be commensurable with the spherical oil droplet size, we need to take into account the perturbations on the interface metric due to the spherical nano-particle volume. We symbolically computed the corrections to the root mean square displacement in the perturbed metric, using a perturbed metric analogous to the one in [2]. By doing so, we try to explain analytically the recent unexpected experimental results found by Zhong *et al* in [3]. This phenomena may have potential applications in the context of biological, interface and surface physics.

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Study of the characteristics of dust acoustic solitary waves and dust acoustic shock waves in electron free dusty space plasma

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In this paper a theoretical investigation of small amplitude nonlinear dust acoustic wave propagation in electron free Lorentzian dusty plasma has been studied considering positively charged cold, inertial dust grains and Kappa distributed inertia less positive and negative ions . Dust grains are positively charged as negative ion flux to the dust grains is less than positive ion flux because higher negative ion mass. OML theory has been used to calculate positive and negative ion currents. Charges on the dust grains is not fixed . This dust charge variation may be of adiabatic or non adiabatic type. For adiabatic dust charge variation dust charging frequency is very high compared to dust plasma frequency and hence dust charging time is very low which causes the grain charging very fast. On the other hand for nonadiabatic dust charge variation dust charging frequency is low compared to the case of adiabatic dust charge variation and hence the charging process is comparatively slower. In this paper both adiabatic and nonadiabatic dust charge variation has been considered. For adiabatic dust charge variation propagation of dust acoustic wave is governed by KdV

equation possessing soliton solution whereas for nonadiabatic dust charge variation it is governed by KdV-Burger equation possessing shock solution. Numerically it has been found that for adiabatic dust charge variation in the permissible range of normalized grain charge number compressive dust acoustic soliton exists whose amplitude decreases and width increases with increasing number of suprathermal positive ions. If some region in such electron free dusty space plasma exists where number of suprathermal positive ions is fixed, increasing negative ion population will increase the amplitude and decrease the width of the compressive dust acoustic soliton. Numerical estimation also shows that for nonadiabatic dust charge variation in electron free ion-ion Lorentzian dusty plasma with positively charged dust grains, dust acoustic shock wave is monotonic. This montonicity is low for high suprathermal positive ion population.

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Statistical physics of earthquakes: Natural time analysis and Tsallis non-additive entropy

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We shortly review the application of Tsallis non-additive entropy [1] statistical mechanics -in the frame of which kappa distributions arise [2]- to the case of earthquakes. Within this context, a derivation of the fundamental Gutenberg-Richter law of seismicity is discussed and examples from various seismic prone areas, for example Japan and California, are provided. The results obtained when analyzing these seismic data in natural time are also summarized. We show that although some properties of seismicity may be recovered by the non-additive entropy approach, the correlations between successive earthquake magnitudes should be also properly captured by natural time analysis [3] in order to achieve a more accurate description of the experimental data. The importance of such correlations is strengthened by the observation that periods of long range correlated earthquake magnitude time series have been identified [4] a few months before all earthquakes of magnitude 7.6 or larger in the entire Japanese area from 1 January 1984 to 11 March 2011 (the day of the magnitude 9.0 Tohoku-Oki earthquake) almost simultaneously with characteristic variations of seismicity [5]. If geoelectrical and geomagnetic measurements are carried out, these characteristic variations appear approximately when low frequency abnormal changes of the electric and magnetic field of the Earth (less than around 1Hz) preceding strong earthquakes are recorded. The generation of such abnormal changes can be understood in the frame of Thermodynamics of point defects in solids when the gradually increasing stress in the future earthquake focal area reaches a critical value. A typical example is the case of the aforementioned magnitude 9.0 Tohoku-Oki earthquake in Japan in which anomalous geomagnetic field variations have been observed from 4 to 14 January 2011, i.e., almost two months before the main shock occurrence. The simultaneous appearance of precursory phenomena in two independent datasets (geomagnetic measurements, seismicity), which are shown to be also linked in space, is of key importance for understanding the physics of earthquakes.

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Hyperbolic Anosov C-systems. Exponential decay of correlation functions

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The uniformly hyperbolic Anosov C-systems defined on a torus have exponential instability of their trajectories, and as such C-systems have mixing of all orders and nonzero Kolmogorov entropy. The mixing property of all orders means that all its correlation functions tend to zero and the question of a fundamental interest is a speed at which they tend to zero. It was proven that the speed of decay in the C-systems is exponential, that is, the observables on the phase space become independent and uncorrelated exponentially fast. It is important to specify the properties of the C-system which quantify the exponential decay of correlations. We have found that the upper bound on the exponential decay of the correlation functions universally depends on the value of a system entropy. A quintessence of the analyses is that local and homogeneous instability of the C-system phase space trajectories translated into the exponential decay of the correlation functions at the rate which is proportional to the Kolmogorov entropy, one of the fundamental characteristics of the Anosov automorphisms. This result allows to define the decorrrelation and relaxation times of a C-system in terms of its entropy and characterise the statistical properties of a broad class of dynamical systems, including pseudorandom number generators and gravitational systems. We study statistical properties of observables defined on N-dimensional torus phase space of the Anosov C-system diffeomorthisms and specify the rate at which the exponential decay takes place. The decorrelation time and the relaxation time are inversely proportional to the entropy of the system and indicate that these time scales become shorter as entropy increases. This is an intuitively appealing result because the entropy measures the uncertainty in the description of the physical systems and here it is translated into the important time scales characteristics. As a result a perfectly deterministic dynamical system shows up a fast thermalisation and well developed statistical properties. When measuring different observables of the hyperbolic Anosov C-system it will be difficult to recognise that in reality the data are coming out from a perfectly deterministic dynamical system.

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Cascades, Lvy-Clifford algebra of generators of vector multifractals to analyse and simulate intermittent dynamical systems

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In the 1980s, multifractals were a major breakthrough in the key question of intermittency that thus became understood as resulting from an infinite hierarchy of fractal supports of the singularities of the underlying equations. This opened an alternative to numerical, scale truncated simulations of these equations (e.g. Royer et al., 2008, Lovejoy and Schertzer, 2013 for climate).
However this was mostly done for scalar fields, whereas the fields of interest, e.g., the velocity for turbulence, are

generally vector fields. The gap between arbitrary large dimensions of the domain and the restriction to 1D codomain has prevented many developments. In particular, it prevented to investigate the pivotal question of interactions between vector components and their non trivial symmetries. The latter are unfortunately indispensable for most applications and challenging issues such as the climatology of (exo-) planets based on first principles (Pierrehumbert, 2013) or to fully address the question of the relevance of quasi-geostrophic turbulence and to define an effective, fractal dimension of the atmospheric motions (Schertzer et al., 2012).
Fortunately, considering the Lie algebra of stochastic generators of cascade processes enabled to generalise multifractals to arbitrarily large codomains, e.g. large dimensional manifolds. Simple considerations on spherical and hyperbolic rotations have led to investigate the neat example of stable Levy generators on Clifford algebra. Both provide a number of seductive properties, respectively universal statistical and robust algebraic properties that define the basic symmetries of the corresponding fields (Schertzer and Tchiguirinskaia, 2015).
These properties provide first elements of a convenient multifractal calculus and should help to overcome current obstacles to the use of multifractal analysis and simulation at their full extent. This will be illustrated with the help of atmospheric turbulence simulations for two practical applications: wind energy and rainfall nowcasting.

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Monte Carlo study of four body interaction Potts models

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We study three different four site interaction Potts models on the square lattice, with $q = 3; 4; 5$ states per spin, using the Wang-Landau entropic sampling algorithm. We use in our simulations lattices with linear sizes $L = 4; 8; 12 \ldots ; 52$ and periodic boundary conditions. With the aid of conventional finite size scaling methods and homogeneity arguments we give estimates on the infinite volume transition temperatures. The three models exhibit strong finite size effects. In addition, for $q = 3$, there are also indications for non-universal logarithmic-power correction to scaling terms associated with the specific heat. While the three and five states models show significant evidences of second and first order transitions, respectively, the $q = 4$ finite size behaviour is very ambiguous. This is particularly manifested in a double-peak reweighed energy pdf, in the vicinity of the transition point. Although one would expect such a scenario in first order transition models, the minima between the peaks does not decay exponentially with L. Moreover, the width of the distribution does not have a typical $1/\sqrt{N} = 1/L$ behaviour, which is clearly observed in the five states case. Thus, although we cannot exclude a first order transition, our analysis supports a continuous transition when $q = 4$. The critical correlation length and specific heat indices α and ν are then predicted for this marginal model. Finally, for the five states model, we estimate the correlation length. We do this independently in two ways: First, we perform a double Gaussian fit to the pdf for each lattice. We then measure the distance between the fitted two maxima (the positions of the energies of the ordered and disordered phases), and use a conventional reciprocal volume scaling relation. Second, we use a known formula which associates the volume dependent divergence of the specific heat to the latent heat. The results in both ways fairly agree.

The underlying non-equilibrium features of trapped active swimmers

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We consider the analysis of out-of-equilibrium phenomena, specifically, the analysis of the patterns of motion of trapped *active swimmers*, which absorb energy from the environment and transform it into self-locomotion, generally, through very complex mechanisms. Though the out-of-equilibrium nature of the motion of these systems is well recognized, is generally difficult to determine with precision, how far from equilibrium these systems are [1]. In some simple situations, the motion of active particles –at large length- or time-scales– can be understood as the diffusive motion of *pasive* Brownian particles in a uniform medium at an effective temperature determined, on the one hand, by the parameters of active motion, namely, the swimming velocity v and the persistence time τ, and on the other, by the coupling of the particle motion with the medium taken into account by the mobility μ [2,3].
In this work we elucidate the out-of-equilibrium features of diluted systems of trapped active particles, with constant v and τ, whose pattern of motion are described by one dimensional run-and-tumble and one-dimensional active Brownian dynamics. The former, describes the overdamped motion of organisms in a fluid, such as bacteria E. Coli, that moves in almost straight lines during random periods of time and, for very short periods, it randomly changes its direction of motion. Active Brownian motion on the other hand, has been realized through different phoretic mechanisms that furnish the Brownian particles with a self-propelling force, such as in the well known demixing of a binary fluid mixture by the laser-heating of gold half-coated Janus active particles. We show that the stationary distributions for the positions of run-and-tumble and active Brownian particles, moving under the effects of an external trapping potential, are equivalent to the stationary distribution of non-interacting, passive Brownian particles, moving in the same trapping potential but in an inhomogeneous source of heat (or effective local temperatures). The resulting thermophoretic forces are elucidated for standard trapping potentials analyzed in the literature, namely the sedimentation process (linear potential with impenetrable boundary condition at one end), the harmonic potential and the symmetric double well potential. The interest in this topic has recently regrown due to the experimental possibility to design man-made active particles that emulate the ones that exist in the biological realm.

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Gaussian theory for spatially distributed self-propelled particles

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The collective behavior of active matters, e.g. colony of micro swimmers and flocks of birds is modeled with self-propelled particles. It is evident that a continuum description of such systems is useful in determining the collective behavior in large scales. One can make continuum equations in active matter with the help of symmetry arguments. However, the equation is in a phenomenological level with undetermined transport coefficients.
It is possible to construct the continuum equations from microscopic rules to find the transport coefficients in terms of microscopic parameters with approximations. One of the

usual approximations called truncation method is to truncate the Fourier series of the orientation distribution of the particles. The truncation method gives a reasonable description of ordered to disordered transition. Nevertheless, in low ordered truncation approximation, the resulting transport coefficients are not correct in low noise limit.
In this presentation, we are going to introduce another technique in obtaining transport coefficients from microscopic rules. In this technique the distribution of the particles orientations is approximated by a wrapped Gaussian distribution function. This assumption, let us to derive the continuum equations from Fokker-Planck equations. The resulting continuum equations describe qualitatively all features of the system in all range of noise intensities. Therefore we can accurately describe the collective behavior of the system in low noise. Gaussian approximation is an applicable method which is easy to apply and gives astonishing accurate behavior of the system, specially in low noise intensities.
The structure of our talk is as following. First we describe the problem and its importance. Then we shortly give the general idea of the derivation of continuum equations. After that, we present the result of solving the continuum equations and we compare it with the result of particle based simulations. Finally we conclude the comparison.

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Towards bifurcation theory for rhythmogenesis in neural networks

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Rhythmic motor behaviors such as heartbeat, respiration, chewing, and locomotion on land and in water are produced by networks of cells called central pattern generators (CPGs). A CPG is a neural microcircuit of cells whose interactions can autonomously generate an array of polyrhythmic patterns of activity that determine motor behaviors in animals and humans. Modeling studies have proven to be useful to gain insights into operational principles of CPGs. Although various models, reduced and feasible, of specific CPGs have been developed, it remains unclear how the CPGs achieve the level of robustness and stability observed in nature. Whereas a dedicated CPG generates a single pattern robustly, a multifunctional CPG can flexibly produce distinct rhythms, such as temporally distinct swimming and versus crawling locomotion, and alternation of direction of blood circulation in leeches. Switching between various attractors of a CPG network causes switching between locomotion behaviors. Each attractor is associated with a definite rhythm running on a specific time scale with well-defined and robust phase lags among the constituting neurons. The emergence of synchronous rhythms in neural networks is closely related to temporal characteristics of coupled neurons due to intrinsic properties and types of synaptic coupling. We identify and describe the key qualitative rhythmic states in network motifs of a multifunctional central pattern generator. Such microcircuits of cells whose synergetic interactions produce multiple states with distinct phase-locked patterns of bursting activity. To study biologically plausible CPG models we develop a suite of computational tools that reduce the problem of stability and existence of rhythmic patterns in networks to the bifurcation analysis of fixed points and invariant curves of a Poincare return maps for phase lags between cells. We explore different functional possibilities for motifs involving symmetry breaking and heterogeneity. This is achieved by varying coupling properties of the synapses between the cells and studying the qualitative changes in the structure of the corresponding return maps. Our findings provide a systematic basis for understanding plausible biophysical mechanisms for the regulation of rhythmic patterns generated by various CPGs in the context of motor control such as gait-switching in locomotion. Our approach is applicable to a wide range of biological phenomena beyond motor control.

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On the crack pattern formation in drying starch slurries

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Desiccation cracks are ubiquitous and exist commonly in everyday life. Examples include those that develop in dried mud, old paintings, ceramic glaze, and so on. These cracks usually exhibit a specific network structure, splitting the entire surface of the fractured media into many polygonal cells. Earlier studies have elucidated the mechanism of desiccation crack formation for various grain-liquid mixtures. Upon drying, liquid content evaporates from an air-exposed surface, which causes shrinkage in the volume of the solidified mixture. As a consequence, cracks occur when the tensile stress induced by shrinkage exceeds the bonding strength of grains. In particular, corn starch-water mixture under drying has been found to exhibit a regular array of tiny polygonal prisms, as a reminiscent of columnar joints, a type of impressing geological structure that spontaneously occurs in cooling lava flows.
Here we point out the possibility that the geometry of polygonal cracking network, which we commonly observe on the dried surface of starch slurries, will be affected by the degree of the irregularities with respect to the size and shape of the constituent starch grains. This is because the irregularities cause wide structural variations in the pore spaces between adjacent grains; the pores regulate the local transport of water content. Therefore, from a statistical perspective, it is anticipated that the irregularities are responsible for local volume shrinkage, and thus for the geometric properties of the polygonal cracks. To examine the conjecture, we performed the desiccation-cracking experiments using starches made from two different ingredients, potato and corn, which showed different grain shapes and different-sized distributions. It was experimentally confirmed that dried potato-starch slurries showed remarkable suppression of cracking at the initial stage as well as a strong dependence of the polygonal cell-area distribution on the slurry thickness, as manifestations of the large-sized, oval-shaped geometry of the constituent starch grains. We also found the predominance of pentagonal cells in the polygonal cracking, which is attributed to the relatively high drying rate of the starch under the present condition, as a reminiscence of pentagon-dominated columnar joints that typically occur in the fast-cooling lava flow.

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Enhancement of the robustness of evolving open systems by the bidirectionality of interactions

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An essential and universal feature of many social, economical, ecological, and biological systems is that they are open. In these complex systems the constituting elements are not fixed and the complexity emerges or at least persists under successive appearances or introductions of new elements and disappearances or eliminations of old elements. Those systems sometimes grow or are stationary, but also some other times they collapse or go extinct. Hence one can ask a fundamental question why and when, in general, can such open and complex systems exist.
A recently proposed simple model has revealed a general mechanism by which such systems can become robust against inclusion of elements with random interactions when the elements have a moderate number of uni-directional links ([1], [2], [3] and talk in SigmaPhi2014). This happens as a result of two opposing effects such that while the inclusion of elements with more interactions makes each individual element more robust against disturbances, it also increases the net impact of the loss of any element in the system. The interaction is, however, in many systems often intrinsically bidirectional like for mutual symbiosis, competition in ecology, and the action-reaction law of Newtonian mechanics, etc.
This presentation reports the strong reinforcement effect of the bidirectionality of the interactions on the robustness of evolving systems. We show that the system with purely bidirectional interactions can grow with two-fold average degree, in comparison with the purely unidirectional system. This drastic shift of the transition point comes from the reinforcement of each node, not from a change in structure of the emergent system. For systems with partially bidirectional interactions we find that the area of the growing phase gets expanded. In the dense interaction regime, there exists an optimum proportion of bidirectional interactions for the growth rate at around 1/3. In the sparsely connected systems, small but finite fraction of bidirectional links can change the systems growth behaviour from non-growing to growing (F. Ogushi, J. Kertesz, K. Kaski, and T. Shimada, arXiv:1703.04383).

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Entanglement entropy of nonequilibrium steady states

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The entanglement entropy has been attracting much attention recently in various fields of physics, because it is found useful not only for quantifying the amount of resources for quantum information tasks,but also for analyzing physical properties such as quantum phase transitions. For concreteness, consider a one-dimensional quantum system, whose length is very large, posssibly infinite. For its pure state, the entanglement entropy is defined as the von Neumann entropy S_L of the reduced density operator, obtained from the pure state of the total system, of a subsystem of finite length L. Of particular interest is the size scaling, i.e., the L dependence of S_L, on which numerous works have been reported.
Most previous works studied S_L of energy eigenstates. According to thermodynamics and the eigenstate thermalization hypothesis, it is expected that $S_L = O(L)$ for eigenstates of energy $O(L)$ whereas $S_L = o(L)$ for eigenstates of energy $o(L)$ including the ground state. The former behavor is universal (under the eigenstate thermalization hypothesis) and therefore has no information on the system because it just says that the entropy is extensive. By contrast, more detailed behaviors of the latter reflect important properties of the system.

When the ground state is unique and separated from excited states by a finite gap, the *area law* $S_L = O(1)$ is obtained [1] under the physically reasonable condition that the Hamiltonian is the sum of local interactions that are bounded. For gapless systems, where the ground state is not separated by a finite gap, S_L can be larger. For example, the *logarithmic law* $S_L = O(\ln L)$ is found in many systems [2-4], including the system of free fermions [5]. Larger S_L, such as $S_L = O(L^{1/2})$, is found in some systems with internal degrees of freedom (such as a large spin) [6]. For systems *without* translational invariance, even larger S_L is possible, such as the *volume law* $S_L = O(L)$ [7,8]. The L dependence of S_L of the ground states, i.e. equilibrium states at zero temperature, have thus been studied extensively. By contrast, S_L of nonequilibrium steady states (NESSs) remains almost unexplored.
In this talk, we discuss the size scaling of the entanglement entropy S_L in the NESS of a one-dimensional noninteracting fermionic system in a random potential. It models a mesoscopic conductor, composed of a long quantum wire, with a random potential, and two electron reservoirs. The difference $\Delta\mu$ of the chemical potentials of the reservoirs induces a steady current, and a NESS is realized in the quantum wire. We assume zero temperature for the reservoirs, and consequently the total system is in a pure quantum state. The S_L is defined as the von Neumann entropy of a subsystem of length L in the quantum wire. At equilibrium ($\Delta\mu = 0$), S_L obeys the logarithmic law $S_L = O(\ln L)$. In NESSs ($\Delta\mu > 0$), however, S_L grows anomalously fast obeying the 'quasi volume law,' $S_L = L\eta(L)|\Delta k_F| + O(\ln L)$. Here, $\eta(L)$ is a positive function gradually decreasing with increasing L, and Δk_F is the difference of the Fermi wavenumbers of the reservoirs.
This anomalous behavior arises from *both* nonequilibrium and multiple scatterings by the random potential, which change drastically the correlations of *all* local observables up to two-site operators.
More details will be presented at Hakoshima's talk [9].

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Diffusion enhancement of chemically driven molecular motors

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The Brownian motion of a particle subject to a periodic potential is suppressed due to the potential barrier. Therefore, it is surprising to see that the application of a constant external

force to such a system in one dimension can greatly enhance the diffusion compared to the free diffusion [1]. The enhancement occurs if the magnitude of the force is close to the maximum slope of the potential. In this situation, the particle hesitates whether to stay or to go when it comes close to one of the locations of maximum slope, which results in the increase in the variance of the particle position and hence increase in the diffusion coefficient. This phenomenon was observed in F_1-ATPase, a biological rotary motor, in the absence of adenosine triphosphate (ATP), the fuel molecule for this motor [2]. The rotor of F_1-ATPase is subject to a periodic potential due to the interaction with the stator of three-fold symmetric structure, and it was forced to rotate by a constant external torque. From the value of the torque at which the largest enhancement in the rotational diffusion occurs the strength of the rotor-stator interaction was inferred.

The purpose of our study is to demonstrate another mechanism of diffusion enhancement for a related system, a model for molecular motors driven by chemical reactions, and to suggest that this phenomenon can be observed in F_1-ATPase. The model consists of a Brownian particle and potential wells placed periodically on a line; the particle is subject to one of these at a time. The potential acting on the particle switches to either of the adjacent wells on the right and left by a chemical reaction (ATP hydrolysis or synthesis). This potential switching, which corresponds to a conformational change in a motor protein, results in a unidirectional motion of the particle. We have numerically calculated the diffusion coefficient of this model in the presence of a constant external force. It turns out that if the switching rates depend on the particle position in an appropriate way the diffusion coefficient as a function of the external force exhibits peaks (i.e., diffusion enhanc! ement occurs) and the peak position depends on the ATP concentration and other parameters. The diffusion enhancement results from the competition between the potential switching and the relaxation of the particle in a potential well. Some results of our work have been reported in Ref. [3].

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Communities as cliques

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High-diversity species assemblages are very common in nature, and yet the factors allowing for the maintenance of biodiversity remain obscure. The competitive exclusion principle and May's complexity-diversity puzzle both suggest that a community can support only a small number of species, turning the spotlight on the dynamics of local patches or islands, where stable and uninvadable (SU) subsets of species play a crucial role.
We [1,2] mapped the question of the number of different possible SUs a community can support to the geometric problem of finding maximal cliques of the corresponding graph. This enables us to solve for the number of SUs as a function of the species richness in the regional pool, N.
When the interspecific and the intraspecific competition terms have the same scale, we show that the growth of the number of SUs is subexponential in N (if the competition is symmetric) and sublinear in N (if it is asymmetric), contrary to long-standing wisdom [3]. To understand the dynamics under noise we examine the relaxation time to an SU. Symmetric systems relax rapidly, whereas in asymmetric systems the relaxation time grows much faster with N, suggesting an excitable dynamics under noise.
In the limit of weak competition and large variance [4] we use the same mapping to examine the number of SUs, which now corresponds to the number of maximum cliques in a network close to its fully connected limit. Now the number of SUs grows exponentially with the number of species, unless the network is completely asymmetric. In the asymmetric limit the number of SUs is order one. Numerical simulations suggest that these results are valid for models with continuous distribution of competition terms.
Our results in this regime agree with two recent works, by Fisher and Mehta [5] and Bunin [6], both suggest that the number of SUs grows exponentially with the number of competing species, implying that the system may undergo a glass transition at finite "temperature" (i.e., strength of stochasticity).

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Solution of the spatial neutral model yields new bounds on the Amazonian species richness

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Neutral models, in which individual agents with equal fitness undergo a birth-death-mutation process, are very popular in population genetics and community ecology. A neutral community is a collection of different populations, such as different species (in ecological models) or different groups of individuals with identical genetic sequence (haplotypes, for example, in population genetics). All individuals undergo a stochastic birth-death process, where in most of the interesting cases the overall size of the community is kept fixed or almost fixed (zero-sum game). An offspring of an individual will be a member of its parent "group" (species, genotype) with probability $1-\nu$, and with probability ν it mutates or speciates, becoming the originator of a new taxon. A neutral process does not include selection: all populations are demographically equivalent, having the same rates of birth, death and mutations, and the only driver of population abundance variations is the stochastic birth-death process (also known as drift or demographic stochasticity).
Usually these models are applied to populations and communities with spatial structure, but the analytic results presented so far are limited to well-mixed or mainland-island scenarios. Here we combine analytic results and numerics to obtain an approximate solution for the species abundance distribution and the species richness for the neutral model on continuous landscape. We show how the regional diversity increases when the recruitment length decreases and the spatial segregation of species grows.
Our results [1] are supported by extensive numerical simulations and allow one to probe the numerically inaccessible regime of large-scale systems with extremely small mutation/speciation rates. Model predictions are compared with the findings of recent large-scale surveys [2-3] of tropical trees across the Amazon basin, yielding new bounds for the species richness (between 13100 and 15000) and the number of singleton species (between 455 and 690).

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Empirical analysis of vegetation dynamics and the possibility of a catastrophic desertification transition

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Systems governed by nonlinear dynamics may support alternative steady states. When such a system is driven by external force it may change its state abruptly at the tipping point, where one of the equilibrium states loses its stability. In ecological systems these shifts are often harmful, causing a loss of bioproductivity and biodiversity, which, in turn, may negatively affect ecosystem functions and stability. Therefore, the possibility that ecosystems may undergo such an irreversible transition in response to small and slow environmental variations raises a lot of concern. In particular, the process of desertification in the semi-arid climatic zone is considered by many as a catastrophic regime shift, since the positive feedback of vegetation density on growth rates yields a system that supports alternative steady states.
However, in spatial systems positive feedback and alternative steady states of the local dynamics are not sufficient conditions for a catastrophic transition. Even in the presence of these factors, the transition from one stable state to another may be gradual. Two main scenarios of gradual transitions were pointed out in the literature. First, the effect of stochasticity may lead to a continuous transition, depending on its strength and on system's spatial features [1,2], second, local disturbances may generate a moving front between the two states [3].
We present, for the first time, a large-scale analysis of vegetation dynamics 2.5 million squared kilometers of the African Sahel region, with spatial resolution of 30X30 meters, using three consecutive snapshots. The density dependence of the local growth rate is shown to be purely negative, while the spatial response of vegetation patches indicates a positive feedback at small-intermediate geographic scales. These apparently contradicting results emerge naturally in a model with positive feedback and strong noise, a model that allows for a catastrophic shift only in a certain range of parameters [2,4]. Our results cast serious doubt on the assumption that the desertification transition is a catastrophic shift, and call for an interpretation of the results using models that stress spatial structure and the effects of stochasticity. Static patterns, like the double peak in the histogram of vegetation density, are shown to vary between censuses, with no apparent correlation with the actual dynamical features.

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Stability of two-species communities: drift, environmental stochasticity, storage effect and selection

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The dynamics of two competing species in a finite size community is one of the most studied problems in population genetics and community ecology. Stochastic fluctuations lead, inevitably, to the extinction of one of the species, but the relevant timescale depends on the underlying dynamics. The persistence time of the community has been calculated for neutral models, where the only drive of the system is drift (demographic stochasticity) and for models with strong selection. Following recent analyses [1-2] that stress the importance of environmental stochasticity in empirical systems, we present a general theory of persistence time of two-species community with N individuals where drift, environmental variations and time independent selective advantage are all taken into account.
Our analysis implements the backward Kolmogorov Equation, together (numerically inspired) dominant balance argument. It allows us to extend the scaling theory suggested recently by Hidalgo et al. [3] in the following senses:
1. An explicit, closed form for the scaling functions (in terms of a single or a double integral) is derived, so the answer covers all the range of parameters. In particular our formulas converge to the pure demographic limit when the environmental stochasticity vanishes.
2. The expressions suggested in Hidalgo et al. for the large N limit are recovered, but we can calculate also subleading terms in this asymptotic series. This allows us to identify the parameter region where the asymptotic is accurate, and to suggest simple analytic approximations that cover a much wider region of parameters.
3. We can calculate the persistence time for a single mutant. This is an important quantity, as it sets the threshold for clonal interference and may be relevant to the small island effect in island biogeography.
Moreover [3], we have extended the work of Hidalgo et al. to include the case where one species has a time independent selective advantage with respect to the other species, superimposed on the environmental variations.

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Emergence of community structure in networks from local preferential attachment

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We present a new model for generating networks with community structure and show that it produces networks with stronger community structures than the basic triadic closure model. We address the issue of what local processes can cause community structure to emerge and be influenced.
The basic triadic closure model for generation of networks, shown by Bianconi et al to form networks with communities, has two features: a random growth step, where a node i is added to a network and is attached to another random node j in the network, and a proximity bias step, where, with a probability p, node i is attached to a random neighbor of j and to random node in the network otherwise. The proximity bias step is repeated m-1 times, and then the random growth step happens until the network has n nodes.
In our model, we modify this proximity bias step to include preferential attachment in three forms. First, we have global preferential attachment in the proximity bias. Instead of a random neighbor of node j, we instead select the random neighbor with probability directly proportional to their degree. We also have the local preferential attachment, where the selection probability is only proportional to the number of edges that attach to other neighbors of j. Finally, we include the neighbors of neighbors for selection in the proximity bias and selection probability calculation.
We ran the four models with n = 5000, m = 2, 3, 10, 20, and p from 0.05 to 1.00, generating 20 networks for each set of parameters. We found that the local preferential bias model produced networks with the strongest community structures, especially outperforming all three for m = 10 and 20. Meanwhile global preferential attachment and the widened radius models produced networks that have weaker community structure than the basic triadic closure model. The ability of these model to produces networks with stronger or weaker community structures than the basic model provides new insight into the emergence of communities.

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A novel model for anomalous transport in biological systems

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Recent advances in experimental methods of single-particle tracking gave rise to challenges in biophysical systems, in particular, in the investigations of bacteria foraging and biological cell transport. These studies proved the presence of strong inhomogeneity in the statistical ensemble of trajectories, thus determining power-law statistics and anomalous diffusion. Anomalous scaling laws are ubiquitous in nature: blinking nanocrystals, light propagation in optical glasses, foraging patterns of animals, epidemic spreading, human travel. Consequently, the understanding and modeling of processes governing anomalous transport is nowadays a crucial task.
Although such models as the Continuous time random walks (CTRW), the Lévy flights (LF) or the Lévy walks (LW) are successfully used to describe these anomalous behaviors, they all have pros and cons. The CTRW is based on a concept of waiting times, or trappings, and can not be used in case of a continuous motion. Further, CTRW does not reproduce some statistical indices, such as the p-variation, of experimental data. The Lévy flights have diverging moments starting from the second one, and allow for infinite velocity.
The Lévy walks are devoid of these limitations, but instead imply a strong coupling between jump lengths and time.
In our work we suggest a novel model that features both anomalous (but non-diverging) time-scaling of the mean-squared displacement, and power-law alpha-stable-like tails of the coordinate probability density function. Our model is based on a non-ergodic Langevin equation and accounts for random properties of the medium and/or the walker itself. We present a rigorous comparison with the Lévy walk models. In particular, we show that, apart from the tails, the probability density of our model is very similar to that generated by the Lévy walk, while the comparison of several statistical indices display very different behaviors. We suggest that this analysis, applied to experimental data, could help in selecting the best modeling approach.

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Transport properties in chemically reactive mixtures of dilute gases

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The description and modelling of chemically reactive gases is a topic of great interest due to several engineering applications. In particular, the investigation of transport processes and non-equilibrium regimes within physical and chemical systems is fundamental in many industrial applications developed by chemical engineers [1].
The theoretical analysis of the transport processes and non-equilibrium regimes in chemically reactive mixtures can be conducted using the Boltzmann equation (BE) if a kinetic model extending the BE to chemically reactive systems is used.
Here we consider a dilute reactive mixture of four constituents undergoing a reversible chemical reaction of bimolecular type. The mixture is described by the simple reacting spheres (SRS) kinetic model developed by Xystris, Dahler and Qin in a series of papers published in the seventies and nineties of the past century, see, for example, Refs. [2,3].
The SRS model treats both elastic and reactive collisions as hard spheres type and the molecules behave as if they were single mass points with two internal states. Collisions may alter the internal states and this occurs when the kinetic energy of the colliding pair exceeds the activation energy of the molecules. The microscopic reversibility (detailed balance) reduces to a simple condition and all mathematical aspects of the model can be fully justified [4]. Moreover a correction term is introduced in the elastic operator in order to prevent double counting of the events in the collisional integrals.
In the present work we use the Chapman-Enskog method, at the first-order level of the Enskog expansion, to determine the non-equilibrium solution to the SRS kinetic system. The chemical regime is such that both elastic and reactive collisions occur with comparable characteristic times. In this case, the elastic and the reactive source terms in the kinetic equations account for comparable processes and the chemical reaction can be considered in its final stage, close to chemical equilibrium (fast process).
We determine the transport coefficients associated to the chemical reaction rate and shear viscosity and investigate how they are influenced by the chemical reaction and by the "correction" term proper of the SRS model. Some comparisons with results obtained with other models available in literature [5] are also presented.

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Energy scaling in optimal control of networks

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Recently, it has been shown that the control energy required to control a large dynamical complex network is prohibitively large when there are only a few control inputs. Most methods to reduce the control energy have focused on where, in the

network, to place additional control inputs. We show that by controlling the states of a subset of the nodes of a network, rather than the state of every node, the required energy to control a portion of the network can be reduced substantially. The energy requirements exponentially decay with the number of target nodes, suggesting that large networks can be controlled by a relatively small number of inputs as long as the target set is appropriately sized. We also see that the control energy can be reduced even more if we relax the constraint that the prescribed final states are satisfied strictly. We introduce a new control strategy called balanced control for which we set our objective function as a convex combination of two competitive terms: (i) the distance between the output final states at a given final time and given prescribed states and (ii) the total control energy expenditure over the given time period. We also see that the required energy for the optimal balanced control problem approximates the required energy for the optimal target control problem when alpha, the coefficient of the second term, is very small. We discuss the effect of several parameters on the minimum balanced control energy, and in particular the time horizon and the number of input nodes. We extend our study to real datasets. We see that for small values of alpha, in the case of metabolic networks, the control energy for balanced control reduces significantly from the output control energy. On the other hand, the Food Webs and Social networks are not benefited as much as the balanced control energy remains approximately the same, in comparison. However, for large values of the parameter alpha, all of the networks need approximately the same amount of energy for balanced control. We validate our conclusions in model and real networks regardless of system size, energy restrictions, state restrictions, input node choices, and target node choices.

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Equilibration, memory loss and memory preservation in one-dimensional quantum gases

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Ergodicity, one of the fundamental assumptions of statistical physics, is known to be violated in systems that exhibit localisation. By studying quantum dynamics in isolated lattice systems, it has been recently argued that the emergence of local equilibrium is linked to two broadly applicable physical conditions: clustering of initial correlations and delocalising dynamics. We demonstrate this connection in the context of continuous models, focusing on field theoretical descriptions of one-dimensional quantum gases of both experimental and theoretical interest. Using the standard Luttinger model, the more general theory of nonlinear Luttinger liquids, the Tonks-Girardeau limit and recent advances in the emerging field of one-dimensional quantum hydrodynamics and in particular the quantum KdV equation, we show that the information content of the large time steady state is strongly related to the presence or absence of ballistically moving localised excitations. More specifically we show that in the standard Luttinger model, memory of all initial correlations is preserved by the dynamics up to infinitely large times, as a result of the purely ballistic dynamics due to the linear dispersion relation. However, nonlinear dispersion or interactions, when separately present, lead to loss of memory of the initial correlations as a consequence of the spreading of initially localised fluctuations. This memory loss is reflected in the fact that for any initial state that satisfies sufficient clustering of correlations, the steady state is simply Gaussian in terms of the bosonised or fermionised fields respectively. When nonlinear dispersion and interactions are simultaneously present on the other hand, they could cancel each other's effect and restore localisation through the emergence of solitary waves, as suggested at least by the semiclassical approximation. We therefore find that quantum solitary waves, whose existence and stability beyond the semiclassical approximation remains a challenging open problem, would lead to a novel type of hydrodynamic localisation that opens up a new way to evade decoherence in closed quantum systems.

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Recent progress in the random field ising model

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Thanks to intensive numerical simulations a lot of progress has been made recently in our understanding of the Random Field Ising model. I will review these recent developpents.
Contrary to previous claims,random fields generated by different probability distributions and diluted antiferromagnets in a field, belong to the same universality class as predicted by the perturbative renormalization group (PRG). It is well known that dimensional reduction predicted by the PRG is not valid in three dimensions.
It was shown recently that, as it was anticipated some time ago, this breaking of the PRG is a low dimensional phenomenon and that dimensional reduction is restored in five dimensions. I will argue that the validity of PRG at higher dimensions explains universality in three dimensions.

Driven quantum metastable states: stabilization by dissipation and resonant activation

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Normally, quantum fluctuations enhance the escape from metastable states in the presence of dissipation. We show first that dissipation can enhance the stability of a quantum metastable system, consisting of a particle moving in a strongly asymmetric double well potential, interacting with a thermal bath. We find that the escape time from the metastable region has a nonmonotonic behavior versus the system-bath coupling and the temperature, producing a stabilizing effect. We also find that the behavior of the escape time versus the temperature is nonmonotonic, and in particular is characterized by the presence of a minimum. Therefore, as the temperature increases, an enhancement of the escape time is observed, increasing the stability of the metastable state. These results shed new light on the role of the environmental fluctuations in stabilizing quantum metastable systems.
We investigate then, how the combined effects of strong Ohmic dissipation and monochromatic driving affect the stability of a quantum system with a metastable state. We find that, by increasing the coupling with the environment, the escape time makes a transition from a regime in which it is substantially controlled by the driving, displaying resonant peaks and dips, to a regime of frequency-independent escape time with a peak followed by a steep fall off. The quantum noise enhanced stability phenomenon is observed in the system investigated.
Thirdly, we analyze the resonantly activated escape from a

quantum metastable state by tunneling in the spin-boson model at strong Ohmic dissipation in the presence of fluctuating and periodical driving fields. Resonant activation, the presence of a minimum in the mean escape time, occurs when the time scale of the modulations is the same as the characteristic time scale of the systems dynamics, essentially determined by dissipation-induced renormalization of the bare tunneling amplitude. The simple quantum system considered displays as well the general features that at slow modulations the mean escape time is dominated by the slowest configuration assumed by he system, while at fast modulations the escape dynamics is determined by the average configuration.

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Noisy dynamics in long and short Josephson junctions

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The transient dynamics of different Josephson junctions (JJ) in noisy environments is computationally explored, looking several interesting cases.
First, the lifetime in the superconducting metastable state of a long JJ (LJJ) is studied. Specifically, we study the dynamics of the phase , i.e., the phase difference between the macroscopic wave functions in the two electrodes, governed by the perturbed sine-Gordon equation. We focus on the mean switching time (MST) from the superconducting state to the resistive state, in the presence of an external noise source modeled by -stable Lvy distributions. These statistics allows to describe real situations, in which abrupt jumps and very rapid variations of the order parameter occur (Lvy flights). The MST shows non-monotonic behaviors, according to the influence of noise induced solitons.
The features of a short ballistic graphene-based JJ is also studied through the RCSJ model. The supercurrent deviates from the usual sinusoidal behavior expected for tunnel JJs, nevertheless this system is still characterized by metastable states. In our work, the mean first passage time from these metastable states is calculated in the presence of white and correlated Gaussian noise sources, and noise induced phenomena are observed. The study of the probability density function of the escape times is also performed. Moreover, we investigate the noise induced switching, when the external bias current is linearly ramped to retrieve the switching current distribution (SCD), i.e. the probability distribution of the passages to finite voltage as a function of the bias current, that is the information more promptly available in the experiments. We consider two different noise sources, i.e. Gaussian for the thermal bath and non-Gaussian Lvy distribution. We show how it is possible to discriminate the noise source features through the analysis of the SCD.
We also investigate the generation of breathers in LJJ, as a proper external magnetic field drives the system. Considerable amount of theoretical study about breathers exists, despite the absence of experimental works devoted to their detection in LJJ. This study is devoted to establish an efficient experimental setup to generate breathers in a LJJ. For specific values of the drive amplitude A and frequency , only breathers along the JJ are observed. Otherwise, combinations of solitons, breathers, and plasma waves set along the JJ.

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Clusters of helicity and stochastic linking number generation in plasma

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Magnetic field lines in an ideal plasma preserve the topology, characterized by the Gauss linking number. However strong transversal gradients of current flowing approximately along the magnetic field lines favor magnetic reconnections and in the presence of a small resistivity the topology changes. Spatial distribution of the density of the linking number will also change showing concentration of current filaments and formation of magnetic islands. Current sheets in magnetically confined plasma exist in the poloidally rotating layer at the edge of a toroidal discharge (mode-H in tokamak) and the reconnections take the aspect of an extreme event (edge-localized modes, ELMs). We first describe the tearing mode that produces the breaking of the current-vorticity layer with formation of filaments. Then we examine this process in a framework in which the process of local concentration of magnetic helicity can be seen as a transition to spontaneous clusterization. The current layer between two Y points is then populated with travelling small magnetic islands.
The statistical process of helicity fluctuation and the generation of linking is examined as a field theoretical model where the topological transition (i.e. change of the topological degree given by a Gauss linking number) is mediated by random sphaleron transitions. Since this model (inspired from baryogenesis) produces finite increase of the topological content at every event of transition, we will estimate the rate of increase of the local concentration of linking number in the filaments in the ELM. Compared with the classical tearing-mode description, the generation and clusterization of linking number appears to be more detailed.
Finally we draw a parallel with the concentration of vorticity in the process of spontaneous formation of cyclonic events in the atmosphere. Here the process is reversed, with build up of large amplitude vortices from small scale helical atmospheric convections. The approximative two-dimensional geometry of the flow is the origin of the inverse cascade but the topological transitions correspond to the same clusterization of the helicity.

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Inferring monopartite projections of bipartite networks: an entropy-based approach

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Bipartite networks are currently regarded as providing a major insight into the organization of many real-world systems, unveiling the mechanisms driving the interactions which occur between distinct groups of nodes. One of the most important issues encountered when modeling bipartite networks is devising a way to obtain a (monopartite) projection on the

layer of interest, which preserves the information encoded into the original bipartite structure as much as possible.
In the present paper we propose an algorithm to obtain statistically-validated projections of bipartite networks, which implements a simple rule: in order for any two nodes to be linked, the number of shared neighbors must be statistically significant. Our assumption can be translated into requiring that the number of observed V motifs between the considered pair of nodes is significant.
Naturally, assessing the statistical significance of nodes similarity requires the definition of a proper statistical benchmark: here we consider a set of four null models, defined within the Exponential Random Graph framework. These benchmarks differ by the amount of information constrained (while the Bipartite Random Graph Model is only defined by the total number of links, the Bipartite Configuration Model constrains the whole degree sequence), thus providing benchmarks inducing projections characterized by a different level of detail. As a result, our algorithm outputs a matrix of link specific p-values, from which a validated projection can be straightforwardly obtained, upon running a multiple hypothesis test and retaining only the statistically-significant links.
Finally, we have tested our method on an economic network (i.e. the countries-products World Trade Web representation) and on a social network (i.e. the MovieLens dataset, collecting the users ratings of a list of movies): in both cases non trivial communities are detected.
In the first case, while projecting the World Trade Web on the countries layer reveals modules of similarly-industrialized nations, projecting it on the products layer allows communities characterized by an increasing level of complexity to be detected; in the second case, projecting MovieLens on the films layer allows clusters of movies whose affinity cannot be fully accounted for by genre similarity to be individuated.

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Maximum-entropy models for networks

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Entropy-maximization represents the unifying concept underlying the definition of a number of methods which are now part of the discipline known as "network theory". Examples of paramount importance are provided by null models, employed both for pattern detection and for for inferring the presence of unaccessible connections from partial information. Recently, a novel application of null models has been proposed, which consists in quantifying the information asymmetry of nodes. In other words, entropy can be fruitfully used to quantify the information content that nodes have access to, thus providing a novel indicator of their topological importance.
In this talk, a general method to define constrained maximum-entropy network ensembles will be illustrated and specific examples of the three aforementioned applications provided. In particular, 1) pattern detection techniques will be applied to reveal early-warning signals of the 2007-2008 worldwide crisis. Two real-world systems will be discussed: the Dutch Interbank Network and the World Trade Web; 2) a comparison between different reconstruction algorithms will be carried out, with particular emphasis on their application to economic and financial networks; 3) several, different, networks will be considered and the corresponding nodes will be ranked (according to different measures which will be, then, compared).
As a conclusion, different ways of enforcing constraints (i.e., either exactly or on average) will be proven not to lead to equivalent ensembles, as measured by the entropy functional. In physical terms, the latter statement can be rephrased by saying that the microcanonical and canonical recipes are, in several cases of interest, not equivalent. This difference, quantifiable upon comparing the values of Boltzmann and Gibbs-Shannon entropy, is found to be a function of the imposed constraints: more explicitly, an extensive number of constraints leads to non-equivalence.
The latter remark implies that the approach used to analyse networks indeed makes a difference and should not be underestimated whenever approaching the study of real-world systems.

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Climate prediction in model land: On the roles of initial condition uncertainty and natural variability

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Predicting the details of future climate on multi-decadal timescales is a significant challenge. Complicated atmosphere/ocean general circulation models (AOGCMs), and even more complicated Earth System Models (ESMs), are widely interpreted as tools for climate prediction. It remains, however, a subject of scientific debate how the task might best be approached to provide reliable, robust information, and what role GCMs should play. Furthermore, the societal relevance of the topic provides an unusual urgency for a conceptual scientific question of this nature.
Given the inevitable further increase in atmospheric greenhouse gas concentrations it is clear that the challenge is one of extrapolation. The 21st century will only be experienced once so there is no possibility of probabilistic verification. Future changes might be expected to depend on the large-scale features of the current state which limits the relevance of testing any prediction system on historic/palaeo data. A consequence of these characteristics of the problem is that climate prediction must rely heavily on physical understanding. However, we know that many aspects of the system exhibit nonlinear behaviour and scale interactions which raises questions over how complex or simple a model needs to be to be informative; are reductionist models likely to be most useful or should there be greater emphasis on emergent behaviour[1] or simply exploratory physically-based storylines[2]?
Progress on these issues can perhaps be made by considering what we mean by and how we go about climate prediction. Here I will illustrate some of these issues with a low-dimensional nonlinear system[3]. The limited scope of the concept of climate change as a changing attractor will be illustrated, along with the differences between natural variability and initial condition uncertainty; two concepts which are often used interchangeably in the climate modelling community. The differing roles of micro-initial condition uncertainty and macro-initial condition uncertainty[4] will be illustrated with ensembles of an AOGCM[5]. The consequences for the design of future AOGCM ensembles and the interpretation of todays cutting-edge ensembles will be discussed. Finally, questions regarding the required level of model complexity for real-world climate prediction and the relevance of stochastic parameterisations will be raised and left for open discussion.

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Lattice gases with a point source and a tourist walk in one dimension

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Exploration of surrounding territory from a point source is ubiquitous in nature, such as in foraging for food by a colony of social insects. In emerging applications of nanotechnology to health, we envisage large numbers of synthetic molecular walkers being released from an artificial capsid to explore their environment, e.g., the interior of a cell.
Random walks on a lattice are a common abstraction for processes involving particle diffusion. The symmetric exclusion process (SEP) is a random walk of multiple particles subject to the exclusion constraint: no two particles can simultaneously occupy the same site.
We studied [1] the symmetric exclusion process with an infinitely strong, unbounded source: whenever the origin is clear, a new particle is injected thereinto. We also studied the analogous process with the exclusion constraint removed. Using a combination of analytical results and extensive numerical simulations, we derived asymptotic expressions for the number of particles in the system for all dimensions d. Furthermore, we derived expressions for the number of distinct visited sites (the size of the explored territory) and the total visit activity, which are of interest in models of foraging and spreading. In many cases these quantities converge to their asymptotic behaviour exceedingly slowly, especially in experimentally relevant dimensions $d = 2, 3$, therefore simulations should be used to predict them in short-time applications.
We then turned to a more general process inspired by our interest in catalytic molecular walkers [2,3], a symmetric exclusion process with a localized source and with sites capable of catalytic slowdown once per particle. The hopping rate of a particle visiting a site for the first time is $r \leq 1$, and the hopping rate of a particle revisiting a site is 1. In 1D, the model describes the traffic flow of tourists in certain single-file scenarios, or foraging for an information resource. Using extensive numerical simulations, we found that macroscopic variables, viz., the number of walkers and the number of sites visited, exhibit distinct behaviors depending on r, including a superdiffusive phase. Moreover, average particle density exhibits phases with respect to r, and so does the density profile.

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Strong and weak-universal critical behaviour of a mixed-spin Ising model with a three-spin interaction on the Union Jack lattice

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The mixed spin-1/2 and spin-S Ising model on the Union Jack (centered square) lattice with four different three-spin (triplet) interactions and the uniaxial single-ion anisotropy is exactly solved by establishing a rigorous mapping equivalence with the corresponding zero-field (symmetric) eight-vertex model on a dual square lattice that is exactly soluble due to Baxter [1]. A rigorous proof of the aforementioned exact mapping equivalence is provided in two different independent ways: either by making use of the graph-theoretical formulation of the zero-field eight-vertex model [1] or by employing the spin representation of the zero-field eight-vertex model [2] together with the generalized star-square mapping transformation. The model under investigation generalizes the exactly tractable model originally suggested and examined by Urumov [3] when accounting for the additional uniaxial single-ion anisotropy acting on the spin-S atoms, which reside central sites of each elementary square face of the Union Jack lattice.
The influence of both the interaction anisotropy as well as the uniaxial single-ion anisotropy on phase transitions and critical phenomena is examined in particular. It is shown that the considered model exhibits a strong-universal critical behaviour with constant critical exponents when considering either the isotropic model with four equal triplet interactions or the anisotropic model with at most one different triplet interaction. On the other hand, we have found an exact evidence that the models with the four triplet interactions, which are pairwise equal to each other, exhibit a weak-universal critical behaviour characterized by continuously varying critical exponents. Under these circumstances, the relevant critical exponents are changing along the critical lines in dependence on a relative strength of the triplet interactions as well as the uniaxial single-ion anisotropy. Besides, it is demonstrated that the mixed-spin Ising models with the integer-valued spins S exhibit very different variations of the critical exponents in comparison with the analogous mixed-spin Ising models with the half-odd-integer spins S. The obtained rigorous results will be also confronted with the previously published exact results for the spin-1/2 Ising model with the triplet interaction on a triangular, kagome, decorated triangular and centered square lattice.

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Effects of kappa distributions on radiation belt dynamics

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Chorus waves play an important role in controlling electron radiation belt dynamics. Stochastic acceleration due to electron gyroresonance with whistler mode chorus can generate relativistic electrons in the Earths outer radiation belt. Gyroresonant interaction with whistler mode chorus can also cause electron losses from the inner magnetosphere via pitch angle scattering loss to the atmosphere.
The generation process of whistler mode chorus comprises a linear growth phase followed by a nonlinear growth phase. Linear wave growth is described by cyclotron resonance (Kennel-Petschek) theory whereby waves are excited by injected anisotropic electrons of tens-of-keV energy. A nonlinear cyclotron resonance theory has recently been developed to describe the nonlinear growth phase of whistler mode waves. Nonlinear phase trapping, the generation of an electromagnetic hole in phase space, and the associated nonlinear resonant current are found to be instrumental in the nonlinear wave growth process. Special forms of nonlinear phase trapping by coherent whistler mode waves provide the basis for efficient electron energization mechanisms known as relativistic turning acceleration and ultrarelativistic acceleration.
Here, we further examine the theory of linear and nonlinear growth of whistler mode chorus waves. We adopt the bi-Maxwellian, bi-Lorentzian (kappa), and Dory-Guest-Harris loss cone particle distributions. We generalize to an arbitrary energetic electron distribution the chorus equations, which are nonlinear ordinary differential equations that describe the generation of a whistler mode chorus element at the equator,

and we calculate the associated threshold wave amplitude for sustained nonlinear growth. We solve the chorus equations for the wave magnetic field amplitude and frequency, and hence obtain solutions for the nonlinear growth rates. For each distribution, we construct complete time profiles for the wave magnetic field amplitude that smoothly match at the interface of the linear and nonlinear growth phases. We investigate the role of kappa distributions in the nonlinear wave growth process.

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Chemical fluctuation theorem for vibrant reaction networks in living cells

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An intracellular reaction network is often constituted by complex stochastic processes interacting with cell environments. To understand stochastic and dynamic biological processes occurring in living cells, it is essential to construct a rigorous mathematical description of intracellular reaction networks interacting with the complex cell environment, which is often hidden and beyond direct observation. In this presentation, we introduce a novel concept, which we term the vibrant reaction process, whose rate coefficient is a stochastic variable that differs from cell to cell and fluctuates over time due to its coupling to cell state variables. Additionally, we present a stochastic kinetic theory for vibrant, intracellular networks interacting with hidden cell environments, utilizing a formal, implicit description of cell environmental dynamics and its coupling to the system network and an explicit modeling of the system part of the network. By applying our stochastic kinetic theory to a general model of the intracellular birth-death processes, we obtain the chemical fluctuation theorem, which relates microscopic dynamics of the birth and death processes to cell-to-cell variation in product number. The chemical fluctuation theorem provides a unified, quantitative explanation of cell-to-cell variation in mRNA and protein levels for various recently investigated gene expression systems. Our analysis of gene expression variability in *Escherichia coli* shows that the transcription of an active gene is a strongly non-Poisson process whose rate coefficient is a dynamic stochastic variable with either an oscillatory or monotonically decaying time correlation function. The time correlation function of the rate coefficient has an important consequence for cellular control over transcriptional noise. This work demonstrates a promising, new approach in quantitative biology, making the complex dynamics of chemical reactions in living cells and its biological consequences accessible to a rigorous mathematical description.

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The language of innovation

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Predicting innovation is a very peculiar problem in data science. Following its definition, an innovation is always a never-seen-before event and this makes the usual approach of learning patterns from the past a useless exercise. Here we propose a strategy to address the problem in the context of innovative patents, by defining an high dimensional space in which dynamics predict specific innovation events as well as global trends of technology popularity and abandon.
We define an innovation as a never-seen-before association of couples of technologies inside a patent (e.g. cameras and motorized steering wheels to build a self-parking car). Each patent is regarded as a collection of two or more technological codes. We define a distance among technological codes and we spot events of codes never occured together but with a small distance. To achieve such result we train a one-layer neural network to guess what technological code has been removed from a real patent (CBOW approach). The internal structure (the rows of a matrix) of such neural network provides an high dimensional embedding of each possible technological code, and distances (or angles) in this high dimensional space prove to be an excellent predictor of innovation. By looking at the distances among the embeddings of never co-occured codes we find 2 main results: 1) close codes have an extremely higher probability of being patented together in the future than randomly selected couples; 2) innovation events happening among close codes are persistent (i.e. patenting activity continues for years after the first innovation), while the rare event of innovation among far-apart codes tend to be a one-shot event.
By looking at the general distance vs. "number of co-occurences" relationship (even for couples that had been patented together in the past) we observe a very rich dynamics with clearly separated laminar flows going towards popularization or abandon of specific technological bonds. We therefore think that this approach provides a solid way of building a consistent euclidean "technological space", where distances and relative position are meaningful with respect to a technological semantic. This "technological space" opens to a vast set of possibile analytic strategies that can be implemented in real space, from clustering methods to dimensionality reduction approaches and any method that benefits from a continuous space embedding.

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The hidden structure of social brain: Analysis of multi-brain graphs

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We are our brains, the idea originating from Hippocrates, becomes increasingly recognized in the era of massive brain imaging and modern science of data analysis. Recent research considerably increased our knowledge about the fascinating brain functional capabilities, recognizing the brain areas responsible for different activities, information processing, emotions, a comprehension of languages, time, distance, numbers, as well as the origin of various diseases. Mapping the imaging data onto networks and the objective analysis by graphs theory has provided a significant leap in the contemporary science of the brain. Currently a consensus exists about the networks of anatomical relationships, which are a basis for more complex and dynamically variable graphs of the brain functional connections.The application of statistical physics to research brain functional stability, the onset of a disease or the memory has a long tradition. The problem of the social brain considers the social impact onto brain functions and the neuronal basis of the social conduct of humans. In contrast to the single brain imaging, the investigations of the social brain involve simultaneous recordings of a group of people during a particular communication. Besides, the complexity of the social brain is that it involves different brain areas that communicate, depending on the type of inputs and their precise contents (emotional, cognitive). Recently, we have introduced a new methodology [1] based on the use of the

algebraic topology of graphs to investigate the functional brain connections which underly the social brain of the particpating individuals and the inter-brain links in the aggregate multi-brain graphs. The simultaneously recorded EEG data [2] are mapped onto a correlation graph; we then apply the techniques of algebraic topology to detect the higher organized structures of the cliques of all order and their complexes. In this talk, we will demonstrate how different topology measures of such structures distinguish between the individual brain activity patterns and various inter-brain coordinations and how they agree with the participant's self-rating experience on the level of knowledge and understanding of the subject, and the speaker's narrative qualities and attractiveness. We also discuss the dynamical features of these connections and the capabilities of the methodology for other applications.

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Transition between Poisson and non-Poisson fluctuations in sales numbers

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Individual sales activities in convenience stores are analyzed based on detail point-of-sales data [1]. From theoretical viewpoint it is expected that sales numbers of each item follows a Poisson distribution, and we expect that the standard deviation of sales number fluctuation is equal to the square root of the mean value of the sales number. This law actually holds gener-ally for most of items but only for the cases that both time and space scales are small enough. In the case that the mean value of sales number is larger than a certain value there holds an-other fluctuation law, that is, the standard deviation is proportional to the mean value, imply-ing that the fluctuation is much larger than the case of Poisson process.
We introduce a simple model to understand this fluctuation law taking into account the fluctuation of number of customers. It is shown both theoretically and by data analysis that the above non-Poisson law holds generally for large mean values.
We also pay attention to some exceptional cases that the Poisson law breaks down even in small space and time, and we clarify the reason of deviation.

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Growth dynamics of complex business firms network

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In Japan there are about 1 million active business firms, and it is confirmed that the transac-tion relation network has a scale-free structure [1] and several non-trivial scaling relations are known to hold among quantities describing firm sizes such as annual sales, number of employ-ees and number of business partners [2]. In view of network growth we find that annihilation, creation and merger are the key processes with the clear tendency of preferential attachment with higher link nodes, and stochastic simulation of these processes produces a complex net-work structure which reproduces the basic properties of real business network for the link number distribution [3]. We also show our new approaches to tune the frequency of 3-body motifs by revising the growth model [4]. Percolation properties [5] and anatomical decomposi-tion [6] are applied to quantitative description of network structure in view of rigidity by re-moval of links wither randomly or intentionally.
Money flow on the whole network is approximated by a set of equations [7] that is based on the so-called the gravity law [8]. This set of equations is already implemented in RESAS (Regional Economy Society Analyzing System) [9], which is a big-data analysis platform pro-vided by the government of Japan.
Acknowledgement: The data of business firms is provided for academic use by Teikoku Databank, which is the largest corporate credit research company in Japan.

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Effect of crowding and confinement on first passage processes

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How does crowding affect the encounter rate of a particle with a target? The answer to this question has great significance, particularly in biophysics. An important example is the cell cytoplasm where crowding agents typically occupy 20-30% of the total volume and strongly influence the kinetics and thermodynamics of cellular reactions. We examine a model system consisting of hard disks confined in an annulus, as well as some complementary results for the corresponding 3D system, using molecular dynamics simulation, to investigate the effects of crowding and confinement on mean first passage times (MFPTs) and reaction rate. The steady state rate of a color reaction displays a maximum for a packing fraction between 0.2 and 0.3 depending on the system geometry. In the ballistic regime at low density the MFPTs and reaction rate are well described by a kinetic theory model. At higher densities we observe the onset of a diffusive regime that is only qualitatively described by a Smoluchowski-like theory with a constant coefficient of diffusion. The discrepancy is due, in part, to a layering phenomenon that becomes more and more pronounced with increasing density and confinement. We also study the angular distribution of the hitting point on the target sphere and compare with that obtained by solving the diffusion equation with mixed boundary conditions.

τ-Information geometry and entropy

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τ-Information geometry is an information geometry based on dually coupled affine spaces: one is an affine space $\overset{\tau=s}{\mathcal{P}}$ constructed by finite positive measures which are mutually absolutely continuous and defined on some measurable space, and the other is an affine space $\overset{\tau=1-s}{\mathcal{P}}$ given by taking "Hölder conjugate" with respect to a parameter τ which controls an affine property of the space of finite positive measures $\mathcal{P}$. τ-Information geometry with $\tau = 1$ yields the same results from Amari-style information geometry, but it gives the different results for $\tau \neq 1$. The most prominent feature of τ-Information geometry is that the magnitude of a measure is changed depending on a translation in the affine spaces $\overset{\tau=s}{\mathcal{P}}$ and $\overset{\tau=1-s}{\mathcal{P}}$, and conversely a scale transformation induces a translation in the affine spaces.
Here we pay attention to an entropy. In the context of τ-Information geometry, the entropy is given in the form of a non-extensive entropy. However, in general, an entropy is affected by a normalization/scale, so a conformal entropy is naturally defined and used. Considering the change of a normalization caused by a translation as the change of a conformal entropy, we can restore the non-extensive conformal entropy to being an extensive conformal entropy. This is quite important because an entropy should be extensive in any physical contexts. The principle that an entropy should be extensive leads to the AdS/CFT correspondence or the holography principle, which makes complex and difficult situations occurring to calculate physical quantities simple and easy situations by introducing an extra codimension. Then, we introduce a coordinate for a scale transformation as an extra codimension, and consider the $(2r+1)$-dimensional space of natural coordinates $\left(\theta^1, \ldots, \theta^r\right)$ for characterizing a distribution, their dual coordinates $(\eta_1, \ldots, \eta_r)$, and the scale coordinate $\left(\theta^0\right)$. Now, if all of the coordinates are independent of each other, a contact structure is naturally arising. Furthermore, the corresponding Heisenberg group is also available so that the group structure of the Heisenberg group gives a Legendre transformation for potential functions.

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Electrical conductivity of a monolayer of rod-like particles: A lattice approach

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The physical properties of inhomogeneous media attracts significant attention in the scientific community. The calculation of the electrical conductivity for a random mixture of insulating and conducting materials is one of the main problems in the theory of disordered systems. In particular, the singular behaviour of the electrical conductivity near a percolation threshold is of interest. Investigations of the physical properties of inhomogeneous media are significant for numerous applications such as the production and use of nanocomposites. Theoretical prediction of the effective properties for multiphase material systems is very important for the analyses of material performance and for the design of new materials.
In our study, the electrical conductivity of a monolayer produced by the random sequential adsorption (RSA) of linear k-mers, i.e., particles occupying k adjacent lattice sites, onto a square lattice was studied by means of computer simulation [1]. Both isotropic and anisotropic depositions were examined. To calculate the effective electrical conductivity, the monolayer was presented as a random resistor network. The Frank-Lobb algorithm was applied to calculate the electrical conductivity for different lengths ($k = 1 - 128$) and concentrations of the k-mers from $p = 0$ to the jamming limit, p_j. Two different models were examined, i.e., an insulating substrate and conducting k-mers and a conducting substrate and insulating k-mers. The "intrinsic electrical conductivity" and concentration dependence of the electrical conductivity were analysed.
The effect of impurities in the lattice and of defects in the k-mers on the behaviour of electrical conductivity has been studied [2]. The defects in the lattice are distributed randomly before deposition and these lattice sites are forbidden for the deposition of k-mers. The defects of the k-mers are distributed randomly on the deposited k-mers. The sites filled with k-mers have high electrical conductivity, whereas the empty sites, and the sites filled by either types of defect have a low electrical conductivity.
The effects of vertical drying [3] and diffusion-driven [4] self-organizations on behaviour of electrical conductivity has also been investigated.
The study was supported by the Ministry of Education and Science of the Russian Federation, Project No. 3.959.2017, and the National Academy of Sciences of Ukraine, Project No. 43/17-H.

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Self-similarity of critical phenomena and their dependence on the boundary conditions and shape of trapping potential for BEC in various mesoscopic traps

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We theoretically show that the thermodynamic parameters of the mesoscopic Bose systems in the critical region of Bose-Einstein condensation depend on the fine features of a trapping potential such as the boundary conditions and cuts of the trap. We suggest particular trap configurations which could be used to demonstrate the predicted effect experimentally [1].
The described effect cannot be accounted for by the macroscopic theories which consider the thermodynamic limit and operate only with the density of states. Such models exclude the analysis of the critical region where the statistics and thermodynamics is largely determined by a relatively small number of the lowest occupied energy states. The point is that these states could be strongly modified by changing the boundary conditions or cutting the trapping potential.
We employ the analytical mesoscopic theory of critical phenomena developed recently for an ideal gas [2,3]. In particular, we present the exact results for the specific heat of an ideal gas. We analytically show how the λ-curve describing the specific heat evolves noticeably with relatively small changes in the trapping potential which do not affect the macroscopic density of states. We also point out that the situation remains qualitative the same even in the presence of a weak interaction.

For an experimental verification of the predicted effect, we suggest to study the ring traps in which the azimuthal boundary conditions can be switched over from the periodic to zero ones as well as the box traps cut by the "laser knife" in which a whole layer of states could be excluded by controlling the light intensity of the cutting laser. In such traps, the predicted effect of variation in the thermodynamic parameters (like the heat capacity) and their λ-structure are well pronounced even for sufficiently large dimensions of a system and large, $10^3 - 10^5$, number of atoms.
A support from RFBR (project no. 16-32-00471) and the Dynasty Foundation is acknowledged.

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Technical, Legal and Business Challenges Faced by Blockchain Enabled Systems

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Over the past year interest around blockchain and distributed ledger technologies (DLT), more in general, has been increasing. The understanding of the technologies alongside investments in the field have been picking up and some use cases, besides digital currencies, are being explored. While several publications evaluate the disruptive power of blockchain-based systems, the literature on the challenges and hindrances to the successful development of blockchain-based systems is still limited.
¿ The aim of this paper is therefore to investigate the key challenges limiting the widespread adoption of DLT and to provide a comprehensive overview of the latest developments in this space. The paper is divided into three sections. The first part offers an overview of the main events occurred in the blockchain space until today by providing an analysis of alternative DLT applications: digital currencies, asset registries, application stacks and asset-centric technologies. The second part lists the current challenges faced by blockchain technologies dividing them into technical, business and legal challenges. For each group, ten challenges are identified and analysed. In the final part, to get more insights into the challenges, we design two surveys which received 295 responses from scholars and professionals with expertise on DLT. Initial observations point out to the fact that legal challenges have been perceived as the most important ones, while business challenges are the ones that have to be solved first according to the respondents to the survey. We conclude with the analysis of the data gathered from the surveys and a final discussion and suggestions for further research.

Thermal equilibrium states into superpositions of macroscopically distinct states

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We present a simple method for converting thermal equilibrium states into superpositions of macroscopically distinct states. Thermal equilibrium states, Gibbs states, are the most common states to human beings. By contrast, superpositions of macroscopically distinct states, hereafter generalized cat states, are recognized as the states not very accessible to humans, as the Schrödinger's paradox suggests. However, we find that the former can be converted into the latter through only two procedures: For N spin systems with $S = 1/2$, for example, prepare an equilibrium state in the presence of heat bath and magnetic field parallel to the x-axis. Then, measure the z-component of the magnetization. We show that the post-measurement state is a generalized cat state for the cases when spins do not interact with each other and when spins interact in the XYZ model manner. The mechanism of the conversion owes to the noncommutativity between M_z and the Hamiltonian in the presence of the magnetic field.
We find that the post-measurement state is a mixture of an exponentially large number of states. It is due to two factors: The pre-measurement state is a mixture of an exponentially large number of states, and the measurement operator projects onto an exponentially large subspace. This should be contrasted to the superposition states that were previously realized experimentally in systems at extremely low temperature, such as with SQUID [1], or with small degrees of freedom, such as with single-mode photons [2].
We note that there is a trade off between the resolution of the measurement and the probability of obtaining a generalized cat state. For the above calculation, we assumed that the measurement operator is a projection onto $M_- \leq M_z \leq M_+$ subspace. When $M_+ - M_-$, resolution, is $O(1)$, the post-measurement state is a generalized cat state with almost 100% probability. When $M_+ - M_-$ is larger, the success probability becomes exponentially small.
Lastly, we show that our method is feasible enough in experiments. With NV centers [3,4], that have a long coherence time, and SERF magnetometers [5], that have high sensitivity, we estimated that the obtained generalized cat state survives for about 7μs when $N = 100$. Expecting experimental realizations, we also discuss how to verify the success of the creation of generalized cat states.

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The quantum first detection problem: From the energy spectrum to the detection probabilities

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We consider the question of when a quantum system initially prepared in state A first arrives" in state B, i.e. the first arrival problem in quantum physics. To determine the arrival, the observer attempts to detect the system stroboscopically with fixed period via a projective measurement.The time of the first successful detection attempt is the first detection time. The corresponding probability of the event is the first detection probability. Formulated in amplitudes rather than in probabilities, the problem becomes very similar to the classical first passage theory of random walks.
It is possible to derive a renewal equation that connects the first detection amplitudes with the free evolution operator. The equation is solved via the classical technique of generating functions.
Due to its quantum nature, the problem exhibits many non-classical phenomena. E.g. due to the quantum Zeno effect, the dynamics of a quantum system becomes locked if it is observed to frequently. This prevents the system to ever be detected. Furthermore, interference effects lead to a non-monotonous decay of the first detection probabilities.
For systems with a continuous energy spectrum, e.g. a freely moving particle, the first detection probability can be expressed in terms of the spectral measure of the evolution operator (which is related to the density of energy states). This allows us to present an exact formula for the total probability of detection in terms of the spectral measures and their Hilbert transforms. The total probability of detection is

always less than unity, indicating that the quantum particle is highly likely to either silently pass the detector or to be reflected off the device.
Furthermore, we discuss long-time asymptotic behaviour of the first detection probabilities. It is shown that the latter decay like a power-law with superimposed oscillations. The exponent of the power law is determined by the spectral (or fracton) dimension of the spectral measures alone. The amplitude, phase, and frequency of the oscillation are determined by critical points of the energy-momentum surface and depend in general on the energy spectrum in its full detail.

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Philosophy of Information, some thoughts

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In [1] a theory which binds together basic concepts of information was developed. The theory may be conceived as an expansion of basic elements of what is nowadays referred to as Shannon Theory. Apart from applications to more mathematical disciplines, applications to areas within statistical physics, mainly related to maximum entropy analysis, were also presented. Technically, simple game theory (two-person zero-sum) was exploited. Philosophical considerations played a pronounced role as motivation. The modeling is abstract, and thus not based on probabilistic thinking. This follows thoughts of researchers such a Ingarden, Urbanik and also Kolmogorov who around 1970 stated that *"Information theory must precede probability theory and not be based on it"*.
Though abstract, the theory is quantitative. A brief indication: The key is a notion of *(description) effort*. This is a bivariate function which for each "truth instance" gives the effort an observer has to allocate in order to gain insight about the phenomenon, depending on the *control* the observer exercises over the system. This control is thought to depend on the *belief* the observer has about the system studied. Here we follow the mantra, due to Good, that *"belief is a tendency to act."* Minimal effort for a given fixed truth instance, one could call *necessity*, however, in view of standard probabilistic applications, we call this quantity *entropy*. The redundant effort is *redundancy* or *divergence*.
Emphasis in the presentation will be on philosophical considerations and their possible relevance for model building of physical systems. This may well be a bit risky as the author is neither a philosopher nor a physicist. Anyhow this is the plan. To give just one indication, we ask the question *"What can be known?"*. And the answer we suggest is that *"You can only know what you can describe."*. As description is tied to the effort function this is not an empty statement.

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Role of heterogeneity in stochastic agent-based models

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Most applications of Statistical Mechanics methods to agent-based models make assumptions that aim at a simplification of the mathematical treatment and which are reasonable, or well established, in other applications of the field. Amongst others, we can cite the assumption of the thermodynamic limit and the assumption that there is a high degree of homogeneity amongst the agents. This is certainly not true in most cases: the number of agents is never close to the Avogadro number and the dispersion in the individual features of agents is an unavoidable nature of the system. In this talk I will discuss some difficulties associated to the existence of such a heterogeneity and the mathematical tools that can be used to achieve analytical results. As an example, I will consider in detail both network and parametric heterogeneity in Kirmans model for herding behavior in financial markets. Stylized facts of financial markets (fat tails, volatility clustering) has been proposed as an emergent phenomenon of interactions among traders. One of the simplest agent-based models capable of reproducing these statistical properties is the one proposed by Kirman. The fundamental aspect of the model is that agents change opinion based on the proportion of neighbor agents holding it. The effect of network structure on the results of the model is also addressed with recent analytical tools known as heterogeneous mean field approximations. This approach suggests that the dynamics in an heterogeneous degree network is equivalent to the usual all-to-all approximation with an effective system size $N_{\rm eff} = N\mu_1^2/\mu_2$, where μ_k is the k-th moment of the degree distribution. This implies that highly heterogeneous degree networks are characterized by a low effective population number. Intuitively, only highly connected agents play an important role in the dynamics and the number of those agents is measured by this effective population number. Taking into account that most real networks are highly heterogeneous with power-law degree distributions, one concludes that the effect finite-size fluctuations is non-trivial and must be studied in detail for each specific type of network.

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Scaling of consensus times in the biased-voter model

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The voter model is arguably the simplest and one of the most widely studied out-of-equilibrium models with application to different scenarios of social interest. The rules are very simple: consider a network such that in each node lies an agent capable of holding one of the possible values of of a binary variable. Then, a node is randomly selected and the agent in that node copies the value of the variable held by another agent in another randomly selected connected node. Most of the literature assumes that both values of the binary variable are equivalent. In this work we focus in the situation where there is a bias towards of the two values. This situation has been considered previously as, for example, indicating the lack of asymmetry in the social preference for one or another language in a bilingual community. We introduce bias by letting a fraction of the agents to copy with a higher probability one the two options (the preferred option). We first assume that there is no correlation between the connections of the biased agents and revisit some of the results about the dependence of the time to reach consensus as a function of the bias parameter. We then ask the question of how the ratio of the density of connections between biased nodes (B) and unbiased nodes (U) influences the behavior of the system. To this end we use two different strategies to connect nodes and compare the results with the random network. Both strategies keep the same average degree and the total number of links as in a random network of the same size. Case I assumes that we cut links between unbiased nodes and draw additional links between biased nodes (i.e. a UU node becomes BB. The strategy in case II is to rewire links to increase the number of biased-biased connections (BU becomes BB) or to decrease the number of

unbiased-unbiased connections (UU becomes UB), keeping the degree of each node constant. It seems that a crucial role for reaching consensus are the degrees of biased and unbiased nodes, rather than the number of links between pairs of biased or unbiased nodes. Even if the majority of the nodes is biased but weakly connected, the probability to reach consensus in cases I and II cannot be larger than in a random network. On the other extreme case, when biased nodes form a well-organized minority, case I gives higher probability to order for the preferred state. In the thermodynamic limit any non-zero value of the bias leads to preferred consensus. In contrary, when the network is finite, there is always a chance to order in the not preferred state. For random network case we find that behavior of the system depends of the effective bias, which is the value of bias parameter multiplied by the number of biased nodes. When the topology is not random that scaling disappears. Our analytical results are supported by numerical simulations.

Robust chimera states in SQUID metamaterials

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Chimera states is a fascinating counter-intuitive phenomenon of partially coherent and partially incoherent behavior. This finding is a striking manifestation of symmetry breaking, since oscillators break synchrony even when they are identical and symmetrically coupled. This counterintuitive phenomenon was first observed in 2002 by Kuramoto and Battogtokh in systems of identical phase oscillators. During the last decade, chimera states have been theoretically investigated in a wide range of networks, where different kinds of coupling schemes varying from regular nonlocal to completely random topology have been considered.
The increasing number of studies on chimera states is impressive, ranging from physical and chemical, to biological and technological systems. Potential applications of chimera states in nature include the phenomenon of unihemispheric sleep in birds and dolphins, bump states in neural systems, power grids, and social systems.
Works on chimera states in superconducting systems, which is the focus of our study, are very scarce. We report on the emergence of robust multi-clustered chimera states in a dissipative-driven system of symmetrically and locally coupled identical SQUID (Superconducting QUantum Interference Device) oscillators. The snake-like resonance curve of the single SQUID is the key to the formation of the chimera states and is responsible for the extreme multistability exhibited by the coupled system that leads to attractor crowding at the geometrical resonance (inductive-capacitive) frequency. Until now, chimera states were mostly believed to exist for nonlocal coupling. Our findings provide theoretical evidence that nearest neighbor interactions are indeed capable of supporting such states in a wide parameter range in both one and two spatial dimensions.SQUID metamaterials are the subject of intense experimental investigations and we are highly confident that the complex dynamics demonstrated in this manuscript can be confirmed in the laboratory.

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Prewetting transition in electric field gradients

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We describe a class of phase transitions occurring in systems under spatially varying electric fields. In a mixture of liquids the coupling of the field to the dielectric constant can lead to a demixing transition if the external potential is large enough (and similar changes occur in the liquid-vapour coexistence curve of pure fluids). The demixing due to long-range electrostatic forces depends sensitively on the geometry of the system. A spinodal-like line governs the dynamical behaviour. Two main time scales characterize the non-equilibrium interface behavior: (1) the lag time t_L for forming an interface, and (2) the relaxation time to equilibrium. We nd that t_L increases as parameters (temperature, bulk composition, and surface charge) approach the electrostatic spinodal line in the phase diagram. Close to this line, t_L is proportional to a renormalized bulk concentration with an exponent of 1.16 ± 0.03.
In addition to the dielectric anisotropy, existence of a nite conductivity leads to appearance of large stresses when these systems are subject to external elds and usually to a reduction in the voltages required for the instabilities or phase transitions to occur. Predictions for thermodynamic equilibrium will be presented for polar liquids containing dissociated ions.
This electro-prewetting transition is believed to play an important role in inter-surface forces.
For example, colloidal stabilization in liquid mixtures without use of surfactants or polymers can be achieved. When a suitable salt is added to a solvent mixture, the coupling of the colloids surface chemistry and the preferential solvation of ions leads to a repulsive force between colloids that can overcome van der Waals attraction. This repulsive force is substantial in a large range of temperatures, mixture composition, and salt concentrations. The increased repulsion due to addition of salt occurs even for charged colloids. This mechanism may be useful in experimental situations where steric stabilization with surfactants or polymers is undesired.

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Can frequencies be predicted from mean flows?

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The von Karman vortex street is one of the most striking visual images in fluid dynamics. Immersed in a uniform flow of sufficient strength, a circular cylinder periodically sheds propagating vortices of alternating sign on either side of the "street". Although the von Karman vortex street can be simulated numerically with great accuracy, predicting its properties from general theoretical principles has proved elusive. It has been shown a linear stability analysis about the temporal mean yields an eigenvalue whose Real part is almost Zero and whose Imaginary part is very close to the vortex-shedding Frequency, a property which we call RZIF. However there has been no understanding of when and why the correct answer emerges from such an unorthodox procedure. Later work has shown that the mean flow and the frequency can be approximated without recourse to temporal simulation, by requiring that RZIF be satisfied, leading to a truncation called the Self Consistent Model (SCM). It has also been shown that this property can be generalized to flows

with a broad spectrum, namely that the response at each frequency can be calculated by linearizing about the mean flow.
We have carried out a similar analysis of thermosolutal convection, which is driven by opposing thermal and solutal gradients. In a spatially periodic domain, branches of traveling waves and standing waves are created simultaneously by a Hopf bifurcation. We find that linearization about the mean fields of the traveling waves yields an eigenvalue which, like the cylinder wake, satisfies the RZIF property. In marked contrast, linearization about the mean field of the standing waves yields neither zero growth nor the nonlinear frequency. We show that this difference can be attributed to the fact that the temporal power spectrum for the traveling waves is peaked, while that of the standing waves is broad. We give a general demonstration that the frequency of any quasi-monochromatic oscillation can be predicted from its temporal mean. We show that the traveling waves are a solution to the SCM, but only very near threshold, whereas the RZIF property is satisfied far above threshold.

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Stronger selection can slow down evolution on smooth fitness landscapes under recombination

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In population genetics, it is commonly expected that the rate of evolution is larger when selection is stronger. This is because stronger selection pressure ensures fitter genotypes created by mutation to survive. Indeed, in a weak mutation regime, it is well-known that the rate of evolution is described as $v = 4N\mu s$ on smooth landscape, where N is the population size, μ is the mutation rate, and s is the selection coefficient. This result clearly shows that the rate of evolution is monotonic with respect to s. This tendency is expected even in existence of clonal interference in large mutation rate, where beneficial mutations arising independently interfere with each other in asexual population. Therefore, in mutation-driven situation, the value of selection pressure maximizing the speed of evolution is infinity. However, source of genetic variation is not limited to mutation. In this paper, we show that this widely-believed story is not true for recombination-driven evolution, and evolution can slow down as selection pressure becomes stronger. Recombination is also a source of new genotypes besides mutation. Recombination between genomes mainly appears in sexual reproduction, and is beneficial in avoiding Muller's ratchet and clonal interference. Furthermore, horizontal gene transfer, which is a kind of recombination, is also considered to be main cause of evolution of prokaryotes. Here, we consider the situation where new genotypes are supplied only by recombination and migration instead of mutation, and fitness landscape is smooth. Existence of migration is necessary for constant evolution of the system, because evolution only by recombination finally homogenizes genotypes of the system. Specifically, we investigate two models. In the first model, population is divided into subpopulations, and migration occurs between subpopulations. This situation supposes that individuals of the same species with different genes are spatially distributed and migration between them starts to be allowed. In the second model, a system with a gene pool is considered, by regarding other subpopulations as a pool. This situation also models the individuals with subpopulations, but the subpopulations has adapted to their own niches and migration always decreases fitness. We numerically find that selection pressure maximizing the rate of evolution is finite in both situations.

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Picophytoplankton dynamics and chlorophyll distributions in a 2D spatial domain: stochastic model vs field data

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The spatio-temporal dynamics of four phytoplankton populations, responsible for about 80% of the total *chlorophyll a*, is modeled in a two-dimensional spatial domain by using initially a deterministic model based on advection-reaction-diffusion equations. Two limiting factors are considered, i.e. light intensity and nutrient concentration. Specifically, due to the characteristics of the marine ecosystem analyzed (South Mediterranean Sea), phosphorus is the nutrient component playing the role of limiting factor for the growth of the phytoplankton populations.
Phytoplankton abundances, obtained by solving numerically the deterministic model, are converted in *chlorophyll a* concentrations[1] and compared with field data collected in twelve marine sites along the Cape Passero (Sicily)-Misurata (Libya) transect[2,3].
Ecosystems however are open structures continuously subject not only to deterministic perturbations but also to random fluctuations coming from the environment. Deterministic models can not therefore account for the effects due to the intrinsic stochasticity present in a natural system. As a consequence, to take into account the environmental random fluctuations which affect the marine ecosystem considered, the deterministic advection-reaction-diffusion equations are modified by inserting terms of Gaussian noise[4]. The stochastic model allows to obtain distributions of chlorophyll concentration in a better agreement with the field data, in comparison with the deterministic approach, as confirmed by statistical checks based on χ^2 test.
A major issue of this work is that the phytoplankton dynamics is modeled by exploiting real values for physical and biological variables, i.e. hydrological and nutrients data acquired in situ, and including intraspecific competition for limiting factors, i.e. light intensity and phosphate concentration. In particular, the analysis permits to investigate the effect of the velocity field of marine currents and the two components of turbulent diffusivity on the spatial distributions of phytoplankton abundances in the Modified Atlantic Water, the upper layer of the water column of the Mediterranean Sea.
The analysis presented in this work can be considered as a case study and can be applied to different marine ecosystems within the Mediterranean basin, to predict the spatio-temporal behaviour of the primary production, and to prevent the consequent decline of some fish species in the Mediterranean Sea.

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Semiconductor laser Markov models in the micro-canonical, canonical and grand-canonical ensembles

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We are interested in semiconductor laser (SL) dynamics, namely its multimode stability. To that aim a microcanonical (MC) model was built and is very effective, but highly time-consuming to simulate [1]. We then question about the relevance of this statistical ensemble.
The model represents a SL by a Markov chain. It is composed of photon reservoirs figuring optical modes, and a finite number of electrons sharing a set of evenly-spaced energy levels. These states are split in two energy bands. Each energy level is occupied by zero or one electron, following the Pauli exclusion principle without spin consideration [2]. The system reaches its steady-state regime when pumping compensates exactly photon exits. Electron repartitions are directed by the Boltzmann thermalisation within each band. This photon flux is the main output of the model since it contains the laser noise. Photon absorption and emissions take place only at the laser energy level pair, one per mode. Their intensities are dictated by electron presence at each laser level. The way the latter occupation is coped with is determined by which statistical ensemble is favored.
The MC simulation takes into account the whole microstates, including electron thermalisation. It shows the laser multi-mode stability as expected and the possible occurrence of both the spectral hole burning and carrier heating [1]. Its main drawback is that one photonic event only occurs every 10^5 thermal ones.
To speed up calculations, we shift to a canonical (C) frame for electron thermalisation because the number of electrons in a band does not change except when photonics events occur. The C occupancies of the laser levels are obtained analytically [3], which allows to get rid of thermal events. As a main disadvantage, spectral hole burning and carrier-heating are now ignored. However a possible addition to the Markov framework may solve the question owing to an extension of the event set.
Finally, using the Fermi-Dirac distribution instead of the C ones is irrelevant for laser simulation purposes because carriers number fluctuations are ruled out. But it allows for a complete analytical description, which was shown to coincide with MC and C results for big systems.
The differences between the three ensembles will be discussed in this communication.

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Survival of a lazy evasive prey: modest effort, high success

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We study the survival of a prey which is hunted by N predators. The predators perform independent random walks on a regular lattice with V sites. When a predator jumps to the site occupied by the prey, the prey is caught. We analyze the efficacy of a lazy evasion strategy according to which the prey tries to avoid encounters with the predators by making a hop only when any of the predators appears within its sighting range. Otherwise the prey stays at its position. In this situation a prey exhibit diffusive-type motion. If the sighting range of such a lazy prey is equal to one lattice spacing, several predators are needed in order to catch the prey. Hence, when the density of the predators is low, the lazy evasion strategy leads to the spectacular increase of the survival probability. The model has been studied on different lattices: honeycomb, square and triangular in 2D, and simple cubic and diamond in 3D. The minimal number of predators needed to catch a prey, depends on the lattice type. The minimal number of predators is 2 for the triangular lattice, 3 for the square and honeycomb lattices and 4 for simple cubic and diamond lattices. The survival probability of an lazy evasive prey exponentially decreases with the time. For small predators density the rate of the survival probability is proportional to the predators density to the power Q, where Q is the minimal number of predators we need to catch a prey on the particular lattice. We also study the model with predators having large sighting range. Whenever the prey appears within predators sighting range, predators start a direct chase. In this case a pair of the predator and the evasive prey exhibit superdiffusive motion. The lazy evasion strategy leads to the spectacular increase of the survival probability when the density of the predators is low. The system with large sighting range of the predators exhibit an effective superdiffusive motion, whereas a far-sighting prey performs a diffusive-type motion.

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Quasi-coherent aspects in turbulent transport

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We present a statistical study of tracer transport in two-dimensional incompressible turbulence. It is well known that the turbulence has in these conditions a self-organizing character that consists of the generation of quasi-coherent structure (vortices). The tendency to self-organization appears at the basic level of tracer trajectories [1,2]. They can include both random and coherent aspects, which appear as random sequences of large jumps and trapping or eddying events. This complex behaviour is determined by the Hamiltonian structure of the equation of motion.
The aim of this study is to understand how the stochastic and quasi-coherent characteristics of the trajectories influence the transport. The paper is focused on determining the statistical properties of the distance between neighbour trajectories, which account for the degree of coherence of the motion.
The results are obtained with the decorrelation trajectory method [3] and the nested subensemble approach [4], which provide a semi-analytical mathematical description that goes beyond the quasi-linear regime that corresponds to quasi-Gaussian transport. They describe the statistical effects of trajectory trapping. The statistical characteristics of trapped and free trajectories are separately studied and the average, the dispersion, and the probability distribution for the trajectories and for the distance between two neighbour trajectories are determined.
The statistical characteristics of the trapped trajectories are completely different from those of the free trajectories. The trapped trajectories have a quasi-coherent behaviour. The average, dispersion, and probability distribution function for these trajectories and for the distance between two trajectories saturate. Neighbour trapped trajectories have clump lifetime much longer than the time of flight. This shows that trapped trajectories form structures similar to fluid vortices. The statistical parameters of these structures (size, build-up time, statistical weight) are determined. The large jumps between the trapping events are random. They have negligible clump lifetime. The small-time probability (at time of the order of the decorrelation time) is non-Gaussian for both types of trajectories.

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Suprathermal electrons in the solar corona and transition region

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Suprathermal tails are a common feature observed in solar wind electron velocity distributions (VDFs), and can be expected in the solar corona as well. Resonant interaction with whistler waves is one mechanism capable of producing suprathermal tails out of an initially Maxwellian VDF. This mechanism is presented here for the quiet solar corona, without any flare activity, in a closed magnetic loop (Vocks et al., 2008). The electron-whistler interaction is described by quasilinear theory. The kinetic model is based on a numerical solution of the Boltzmann-Vlasov equation for electrons, considering Coulomb collisions and wave-electron interaction. The waves enter the simulation box with a given power-law spectrum, that evolves inside the box due to wave propagation and absorption. The temporal change of the initially Maxwellian VDF is calculated until a final steady state is reached (Vocks et al., 2012). The results show that a population of suprathermal electrons develops, that can be approximated by a power-law in the energy range of 4 - 10 keV. The power-law index is in agreement with the solar wind kappa distribution observations. For lower energies, the electrons are quickly thermalized, and the efficiency of the acceleration mechanism decreases for higher energies.
These numerical studies show that the quiet solar corona is capable of producing suprathermal electron VDFs, with similar characteristics as observed in the solar wind. In the second part of this presentation, the propagation of suprathermal electrons from the loop through the steep temperature gradient of the transition region towards the chromosphere is studied. The coronal boundary condition of the simulation box is the electron VDF found at a loop footpoint in the previous simulation, while initial and chromospheric boundary conditions are Maxwellian VDFs with densities and temperatures based on a background fluid model. The model results (Vocks et al., 2016) show the presence of strong suprathermal tails in transition region electron VDFs, starting at energies of a few 10 eV. Above electron energies of 600 eV, electrons can traverse the transition region essentially collision-free. The presence of strong suprathermal tails in transition region electron VDFs shows that the assumption of local thermodynamic equilibrium is questionable there, with significant implications on EUV line formation and ionization dynamics.

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Time-autocorrelations for the slicer map and Levy walks in disordered media

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In a recent paper Salari et al (2015) introduced an analytically solvable model, the slicer map that reproduces the moments of the displacement for the motion of particles in quasi-one-dimensional quenched disordered media, as described in Burioni, et al (2010). Both dynamics exhibit a transition from subdiffusion, over normal diffusion to superdiffusion under parameter variation.
Here, we present the analytical solution of the time autocorrelation function of the slicer dynamics and compare it to numerical results on the motion in quenched disordered media. We establish scaling relations that allow us to elegantly perform this comparison. For a large range of parameters the two models show exactly the same behavior.

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Non-extensive approach to collisionless magnetic reconnection

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Magnetic reconnection and turbulence represent key plasma physical processes in which energy transfer and conversion processes lead to non-adiabatic particle acceleration, heating, energy dissipation and bulk plasma motions. Since these multi-scale dynamical processes pump energy towards kinetic scales faster than the energy-redistribution time scales, particle populations seldom relax to a Maxwell-Boltzmann distribution. In heliospheric plasmas kappa-distributed non-equilibrium particle velocity distribution functions (VDFs) are widely observed, typically exhibiting anisotropies because of the presence of the magnetic field. The possible theoretical justification for kappa-distributed electron and ion VDFs in space plasmas is provided by entropy generalization procedures appearing within the frame of non-extensive systems exhibiting long-range interactions. In an effort to link the in-situ heliospheric particle VDFs with the theoretical (bi-)kappa or Maxwell-Boltzmann distributions, the (an-)isotropic VDFs were fitted by global models describing the entire distribution, or by partial fits, corresponding to the core and the suprathermal halo separately. This contribution is focusing on the thorough examination and non-extensive description of electron and ion VDFs during crossings of the electron diffusion and separatrix regions of magnetic reconnection events observed at the Earths magnetopause from the Magnetospheric Multiscale mission (MMS). We will consider also the negative kappa signs near the reconnection regions which may arise from electric potentials. MMS 3D particle VDFs are available with unprecedented time resolution of 30 ms for electrons and 150 ms for ions. This allows us to study for the first time both the anisotropy effects and the spatial evolution of non-extensive features seen in particle VDFs across magnetic reconnection events. The MMS instrumentation was designed to understand electron scale physics crossing the electron diffusion region mainly at the Earths magnetopause and in the magnetotail . At the same time the data allow us to study turbulence generated structures which can also be associated with reconnection in the magnetosheath region. The non-extensive aspects of magnetic reconnection could help to understand more the kinetic plasma physical concepts, but contribute also to wider understanding of space weather.

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Information geometry on the thermal probability distributions for a weakly confining potential

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Information geometry is a useful framework for studying some families of probability distributions by identifying the space of probability distributions with a differentiable manifold endowed with a Riemannian metric and an affine connection which is not Levi-Civita connection. It is known that early developments of information geometry are mainly based on well-known exponential family of probability distributions. We studied some information geometric structures on the κ- and/or q-deformed-exponential families of probability distributions, which are non-Gaussians and with heavy-tails. On these deformed exponential families, we constructed the suitable statistical manifolds and showed some information geometric structures such as generalized Fisher metrics, dually-flat structures, generalized divergence functions, and so on. In this way we now know that information geometric structures exists for not only standard exponential families but also for deformed exponential families. However, if the information geometric structures for the standard exponential families and those for deformed exponential families exist separately and there had no relation each to other, one would have no special interest on them. In this contribution we consider the thermal probability distributions for a weakly confining potential in the basic framework of statistical physics. In contrast to the well-known standard case of Gaussian (or Boltzmann-Gibbs) distributions for strongly confining potential, e.g., a parabolic potential, the quasi-equilibrium thermal probability distributions for a special type of weakly confining potentials become non-Gaussian distributions and with heavy-tails, which describe anomalous diffusions and transports. We study the information geometric structures on the thermal probability distributions for a special type of weakly confining potential and show that the corresponding quasi-equilibrium distribution is indeed the κ-deformed exponential probability distribution, which is introduced by Kaniadakis and Scarfone. In addition we relate the Boltzmann-Gibbs distributions for this weakly confining potential and the κ-exponential distributions for the strongly confining potential, and discuss on the associated information geometric structures.

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Finite-power performance of heat engines in the linear response regime

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Topical Area: A
Workshop: 1 1

Within the framework of linear irreversible thermodynamics, Izumida recently introduced the thermodynamic description of local equilibrium to the endoreversible Carnot-like cycle consisting of two adiabatic and two isothermal processes, where the heat conduction is assumed to be phenomenological Fourier law. Nevertheless, the local equilibrium thermodynamic description to a quantum heat engine cycle (not restricted to Carnot-like one), and a unified framework for the study of finite-power quantum engines satisfying the endoreversible condition within linear irreversible thermodynamics, is still lacking. For this reason, we study the finite-power performance of a generalized quantum engine cycle based on the local equilibrium assumption, revealing the possibly universal bound of the efficiency at maximum power. Without loss of generality, the working substance of the heat engine is composed of harmonic oscillators and spin-1/2 particles, two types of particles in the universe: bosons and fermions.

We analyze a general model of quantum heat engine operating a cycle of two adiabatic and two thermal processes, where the working substance is composed of a harmonic or spin system. We apply the local equilibrium description to the heat engine cycle working in the linear response regime and derive the expressions of the efficiency and the power. By analyzing the entropy production rate along a single cycle, we identify the thermodynamic flux and force which a linear relation connects. From maximizing the power output, we find that such heat engines satisfy the tight-coupling condition and the efficiency at maximum power agrees with the CA efficiency known as the upper bound in the linear response regime.

Our approach is quite general because (except for use of local equilibrium assumption) it does not demand any particular system as its working substance obeys any one of the two typical quantum statistics (Fermi-Dirac and Bose-Einstein)and does not employ any specific law(s) of thermal conduction.

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Solar wind suprathermal electrons

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The solar wind electrons observed near 1 AU consist of three components: a thermal (∼10 eV) Maxwellian core, a much hotter (∼50 80 eV) haloo/strahl, and a power-law superhalo at energies above ∼2 keV. Solar wind surpathermal particles carry important information on the common particle acceleration/transport processes at the Sun and in the IPM. We present a statistical survey of solar wind suprathermal electrons measured at ∼0.1-200 keV by the WIND 3DP instrument at 1 AU during quiet times in solar cycles 23 and 24. All the strahl, halo and superhalo electron populations show no obvious correlation with the solar wind core population.
The halo electron population has an isotropic angular distribution, while the strahl population, predominantly observed in fast solar wind, is antisunward beaming along the interplanetary magnetic field. The observed energy spectrum of both strahl and halo electrons at ∼0.1-1.5 keV generally fits to a Kappa distribution function, with an index κ and effective temperature T_{eff}. We find a strong positive correlation between κ and T_{eff} for both strahl and halo electrons and a strong positive correlation between the strahl density and halo density, likely reflecting the nature of the generation of these electron populations. In both solar cycles, κ is larger at solar minimum than at solar maximum for both strahl and halo electrons, while the halo κ is generally smaller than the strahl κ.
For the superhalo electron population at quiet times, the observed pitch-angle distribution is generally isotropic, and the observed omnidirectional differential flux generally fits to a power-law function, $J \sim E^{-\beta}$. The spectral index β ranges from ∼1.6 to ∼3.7, with a broad maximum between 2.4 and 2.8 (2.0 and 2.4) in solar cycle 23 (24). Both β and

the integrated superhalo density show no obvious correlation with the sunspot number, solar flares, CMEs, etc.
These results suggest that solar wind suprathermal electrons have a different origin from the solar wind core: the strahl could originate from the Sun, e.g., due to the escaping electrons from the hot corona, to form a strong positive correlation between κ and T_{eff}; the halo may be due to some processes (including scattering and/or further acceleration) acting on the strahl in the IPM; the superhalo may originate from nonthermal processes related to the acceleration of the solar wind or could be formed in the IPM due to further acceleration and/or long-distance propagation effects.

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Long range dependence, fractional renewal models, and Bayesian inference

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This timely session is testimony to the fact that the importance of heavy tailed probability distributions, including the kappa distribution, is now well appreciated. A complementary problem is the effect of long range dependence (LRD) in time, and, since the 1960s, LRD as embodied by the fractional Gaussian noise and ARFIMA models has been a well-studied mechanism for the origin of 1/f noise and the Hurst effect. This talk will discuss two avenues of research, drawing on the authors' recent papers [Graves et al, Systematic inference of the long-range dependence and heavy-tail distribution parameters of ARFIMA models, Physica A, 2017; Watkins, "Mandelbrot's 1/f fractional renewal models of 1963-67: The non-ergodic missing link between change points and long range dependence", arXiv, 2016; Franzke et al, A Dynamical Systems Explanation of the Hurst Effect and Atmospheric Low-Frequency Variability, Scientific Reports, 2015; Graves et al, Efficient Bayesian inference for natural time series using ARFIMA processes, NPG, 2015; Graves et al, ""A brief history of long memory", arXiv, 2014].
The first avenue of research concerns breakpoints. These have long been known to be an alternative to the long-range dependent kernel in fGn as a source of the Hurst effect, but recent research by one of us has shown that Mandelbrot had proposed a model with a heavy tailed distribution of time intervals between the breaks as early as 1963. By 1965-67 he was showing how this was an alternative non-ergodic model for 1/f noise, with consequences for model choice and time series interpretation that are increasingly becoming topical in physics and elsewhere, and are still relevant to the topic of weak ergodicity breaking.
The second avenue concerns Bayesian inference when an LRD model is plausible. I will discuss our recent work on a novel systematic Bayesian approach for joint inference of the memory and tail parameters in an ARFIMA model with heavy-tailed innovations. I will also show its application to solar X-ray flare data.

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Generalised and fractional Langevin equations-implications for energy balance models

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Energy Balance Models (EBMs) have a long heritage in climate science for modelling global mean temperature anomalies. Many types of EBM have now been studied, including examination of spatiotemporal, and particularly latitudinal dependence, as well as possible low dimensional effects. Of particular interest to the statistical mechanics community is the stochastic EBM, which allows direct treatment of climate fluctuations and noise. Some recent stochastic EBMs (e.g. [1]) map on to the Langevin equation, with temperature anomaly replacing velocity, and other corresponding replacements being made. This raises the question as to how far the full technology of modern Langevin modelling could be applied to this aspect of the climate problem.
This talk will discuss this question, and give some preliminary answers. We first note that the most familiar Langevin equation is a limiting case of the generalised Langevin equation (GLE) which so far has seen little or no application in climate science, raising the question of whether a GLE-type EBM can be derived or motivated. This is particularly important because, as noted in [2], the EBM studied by Padilla et al [1] used a correlated red noise term but has a constant dissipation term. A fluctuation-dissipation theorem is thus precluded by its construction.
We then note that long memory simplifies the GLE to a fractional Langevin equation (FLE). The still controversial experimental evidence for long range memory in global temperature has already motivated investigation of a power law response model [3,4]. We go beyond this to ask whether an FLE-type EBM exists, and what its solutions would be.
See also these talks: Klages, Anomalous Fluctuation Relations, Newton Institute, October, 2013; Watkins, Generalised and Fractional Langevin Equations-Implications for Energy Balance Models, Norklima Meeting, Tromso, September, 2014 ; Klages, Anomalous Langevin Dynamics, Fluctuation Dissipation Relations and Fluctuation Relations, Climathnet meeting, Dartington Hall, January, 2015.

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Intraday correlation structure for high frequency financial data

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Correlation structure of the financial market is a subject that draws attention of both scientists and market practitioners. It is very important in understanding the way market works and may be applied in risk management among other financial issues. Recently, we developed a novel method of estimating correlations when dealing with high frequency data. It is based on the algorithm shown in [1], it does not require evenly spaced series and it can be used with different types of data (jump functions, step functions and other). This method also allows us to calculate correlation in different time-scales what makes it suitable to analyze Epps effect and compare it with other methods, like it was done in [2]. Along with this new estimator, we propose a new filtering method, which allows us

to create structured networks out off full correlation matrices. Using both mentioned tools we analyzed the intraday market structure at different time scales similarly to how it was done in [3]. We found some interesting features in recent data which are different from those found in older intraday quotations. These results support the statement that financial markets are getting more and more efficient, especially in high frequency domain. As a next step, we expand our research by analyzing spectral properties of data and we apply Complex Principal Component analysis, which was used before for daily data in [4]. With this methodology, adapted to our correlation algorithms, we were able to determine which forces drive the market most and at which time-scales. Moreover, complex correlations were used in order to find the lead lag relations among stocks and among principal components. Most of our findings seem to be in accordance with economical reasoning but there are some less intuitive results as well. Finally, we show how noise and data aggregation affect all methods used both in our work and in previous papers connected to the subject of financial correlation. As a result, we are able to distinguish between meaningful, robust results and effects which are mainly consequences of increasing noise.

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Oscillation phenomena in multiparticle production processes

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There is good evidence for the presence of quasi-power law distributions decorated with log-periodic oscillation in many different, apparently very disparate branches of science. We can therefore expect that oscillations of certain variables in fact constitute a universal phenomenon which is to be expected in a large class of stochastic processes, independently of the microscopic details. In this presentation we concentrate on oscillation phenomena seen at LHC energies in transverse momentum distributions and multiplicity distributions. Large transverse momentum distributions apparently exhibit power-like behavior. However, under closer inspection, this behavior is in fact decorated with some log-periodic oscillations. It suggests that either the exponent of the power-like behavior is in reality complex, or that there is a scale parameter which exhibits specific log-periodic oscillations. This problem is discussed using Tsallis distribution with scale parameter T and with complex nonextensivity parameter q [1-3]. Fourier transforms of oscillations of the temperature $T(pT)$ deduced from the experimental data on multiparticle production, we have used to investigate oscillations in $T(r)$. We have found that the log-periodically oscillating $T(r)$ represents some log-periodic sound wave forming in the source [4]. The observed oscillations have been attributed to a discrete scale invariance. However, it turns out that such scale invariant functions also satisfy wave equations showing a self-similarity property. In both cases these functions exhibit log-periodic behavior. In what concerns multiplicity distributions $P(N)$, they are most frequently described by the Negative Binomial Distribution. However, with increasing collision energy some systematic discrepancies become more and more apparent. Presence of oscillation in counting statistics is well establish. We propose a novel phenomenological description of the observed multiplicity distributions which allows for a more detailed quantitative description of the complex structure of the experimental data on $P(N)$ [5]. It is provided by coefficients C_j (connected with combinants, but not identical to them) defined by the recurrence relation $(N+1)P(N+1) = \sum_j C_j P(N-j)$. We observe strong oscillations of coefficients C_j at LHC energies [5]. These oscillations will await their physical justification, i.e., indication of some physical process which would result in such a phenomenon.

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Fractality of complex networks emerging from self-organized critical dynamics

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Structures of real-world networks are classified into two types from a viewpoint of the relation between the number of nodes and the shortest path length, namely small-world structures [1] where the average path length $\langle l \rangle$ increases at most logarithmically with the network size N and fractal structures [2] where $\langle l \rangle$ scales with N in a power-law manner. Although the small-world property arises from the existence of short-cut edges, the origin of fractality in complex networks still remains unclear. It is thus also not understood why there exist small-world and fractal networks in the real world.
We propose a model of self-organized critical (SOC) dynamics of complex networks and present a possible explanation of the emergence of fractal and small-world networks. A network in our model experiences a continued growth and its occasional decay due to the instability of large grown networks against cascading overload failures. In this work, the description of cascading overload failures is based on the model proposed by Ref. [3] in which temporally fluctuating loads are described by random walkers. We show that cascading failures occur intermittently and prevent networks from growing infinitely. The distribution of the time interval between successive cascades obeys a power-law form. Power-law distributions are also found in both the avalanche size that is the number of eliminated nodes in a single cascade and the cluster size defined as the number of nodes in a connected component. These facts indicate that the network dynamics possesses SOC characteristics. In our model, the load reduction parameter r is set to vary with the network size during the SOC dynamics. When r of the network coincides with its critical value r_c, a cascade of overload failures (critical cascade) decays the network into a critical one. Our result shows that giant components just after critical cascades have fractal structures. The fractal dimension d_B is close to that for the giant component after a critical cascade starting with an Erdős-Rényi random graph. In contrast, networks far from criticality display the small-world property. In particular, we demonstrate the crossover behavior from fractal to small-world structure in a growing process from a critical network, which is caused by short-cut edges introduced by newly added nodes. We have also discussed suitable parameter values to realize SOC dynamics.

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Dynamics of words popularity observed from large scale social data

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space written by humans such as blog and tweet is especially interesting database because the data directly reflects trends and topics in human society. For example, the number of blog entries including earthquake have a clear peak when a large earthquake occurs. By using a huge Japanese blog data base with the author ID, we can observe not only the number of entries per day for any words, but also personal dynamics of blog entries. In this presentation, we report statistical properties and modeling for four major categories of words.
The first is ordinary words which is used in our daily life, for example soon. The number of entries of soon has a steady fluctuation. The second is Trending words, for example Twitter. The number of entries of Twitter was increasing exponential from Oct. 2008 to Jun 2010. The third is News words, for example Michael Jackson. We can observe clear jump and power law decaying in the number of entries of Michael Jackson after the news of which Michel Jackson died[3].
The fourth is "event words" which has growth and relaxation characterized by a power function around the peak day such as national holidays. We reproduced these dynamics by an agent-based model based on the SIR (Susceptible-Infected-Recovered) model which is well known in mathematical epidemiology to clarify the origin of these dynamics from the view point of bloggers interactions.
In order to reproduce not only an exponential but also a power law growth and relaxation behaviors observed in trending words, we developed the base model by adding some effects to our model, for example an external shock effect, a deadline effect and an amorphous effect. The amorphous effect, inspired by solid physics studies, gives bloggers individual characteristics, in other words individual duration of interest for the specific word. As a result of adding these essential effects, our model reasonably reproduces the dynamics observed from our data. In addition we give master equation of our stochastic agent-based model and introduce the equation of lifecycle of popularity as seen in the trending words.
Our model can be applied to a prediction and control for spreading false rumors as seen in after the huge 2011 earthquake in Japan[4].

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Quantum critical behavior of the quantum Ising model on fractal lattices

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In this research work, I study the properties of the quantum critical point of the transverse-field quantum Ising model on various fractal lattices such as the Sierpinski carpet, Sierpinski gasket, and Sierpinski tetrahedron. When a magnetic field is applied perpendicular to the Ising spin direction, quantum fluctuations affect the transition between the ferromagnetic and the paramagnetic phases. Using a recently developed continuous-time quantum Monte Carlo simulation method and finite-size scaling analysis, I investigated the interplay between the quantum fluctuations and the exotic dimensionality of the fractal structure and its effect on the critical behavior. As a result, I could identify the quantum critical point and investigate its scaling properties. Among others, I calculated the dynamic critical exponent and found that it is greater than one for all three structures studied in this work. The fact that it deviates from one is a direct consequence of the fact that the spatial dimensions have a fundamentally different structure that the time dimension because fractal lattices are not integer-dimensional regular lattices. Other critical exponents were also calculated. All evaluated exponents are different from those of the classical critical point and satisfy the quantum scaling relation, thus confirming that I have indeed found the quantum critical point. I found that the Sierpinski tetrahedron, of which the dimension is exactly 2, belongs to a different universality class than that of the two-dimensional square lattice. I therefore confirm that the critical exponents depend on more details of the structure than just the dimension and the symmetry.

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Nonlinear wave-particle interaction and electron kappa distribution

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In this presentation, I will discuss the physics of nonlinear wave-particle interactions that lead to the electron kappa velocity distribution function as a stationary asymptotic state. The theoretical framework is based upon the plasma weak turbulence theory, which does not invoke non-extensive thermodynamics, but the final time-asymptotic solution shows that the kappa distribution is the only allowable state in weakly turbulent plasma, the other exact solution being the Maxwell-Boltzmann distribution for quiescent plasma. I will also discuss the transition from initial Vlasov equilibrium, which can be viewed as a system far from equilibrium, followed by the collective relaxation via beam-plasma instability excitation. The beam-plasma instability is a well-known and textbook problem that involves the emission of Langmuir waves by a streaming electron beam in the background of stationary plasma. The linear instability theory predicts exponential wave growth, but quasilinear relaxation saturates the linear instability. However, the quasilinear saturation is not a true time-asymptotic steady state since nonlinear mode coupling stage follows the quasilinear saturation. The nonlinear mode coupling processes(s) eventually bring(s) the system to the so-called turbulent quasi equilibrium state [Treumann, 1999], which is characterized by the kappa distribution. The final turbulent quasi-equilibrium state can be rigorously studied by employing the steady-state assumption of kinetic weak plasma turbulence theory. Analytical solution shows that one possible steady-state solution is the thermodynamic equilibrium solution (Maxwell-Boltzmann state). On the other hand, if the steady state includes a finite level of turbulent fluctuations, then the only allowable solution is the kappa solution (the non-extensive state) with a specific value of kappa index [Yoon, 2012, 2014]. Thus, this seems to show that nature allows either a thermodynamic equilibrium state or kappa equilibrium state. This finding implicates a profound inter-relationship between the turbulent equilibrium state in plasmas and the non-extensive thermodynamic description.

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Following the product progression network to escape from the poverty trap

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Is there a common path of development for different countries, or each one must follow its own way? In order to produce cars, one has to learn how to produce wheels before? Let us represent countries as walkers in a network made of goods[1], defined such that if a country steps on one product, it exports it. Which are the best paths in the product network?
We build a network of products using the UN-Comtrade data about the international trade flows. A possible approach is to connect two products if many countries produce both of them[2]. Wanting to study the countries' dynamics, our links should be directed: a country usually goes from one product to another, but not vice versa, indicating a natural progression. In particular, we project the empirical country-product bipartite network in a filtered monopartite one in which a suitable normalization takes into account the nested structure of the system.
We study the temporal evolution of countries, finding that they follow the direction of the links during industrialization, and spotting which products are helpful to export new products. These results suggest paths in the product progression network which can drive countries' policies in the industrialization process and to exit from the poverty trap.
In the standard view of the industrialization of countries, these have to face a barrier to escape from the poverty trap, which is a monetary threshold defined in terms of average wage or physical capital. When such a threshold is reached, a self-feeding process quickly brings the country from the poverty trap to the "catching up" with the fully developed countries.
We use a non-monetary measure of the economic complexity of a country, called Fitness[3], to show that complex economies start the industrialization process with a lower threshold[4]. On the contrary, if the Fitness is low, a sustainable growth can be reached only if a higher standard, monetary threshold is reached. As a consequence, we can introduce the concept of a two-dimensional poverty trap: a country will start the industrialization process if it is not complex but rich, or if it is poor but very complex (exploiting this new dimension to escape from the poverty trap), or a linear combination of the two.
Finally, we show that following the recommendations given by the previously introduced product network is correlated with a systematic increase of Fitness, showing that such a strategy can lower the barrier to exit from the poverty trap.

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Liquidity crises in the limit order book: a tale of two time scales

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We present an empirical analysis of the microstructure of financial markets and, in particular, of the static and dynamic properties of liquidity. We tracked the limit order book dynamics of four highly traded stocks for one year, finding that price movements can be explained in terms of liquidity crises and that, more importantly, the quantitative definition of liquidity should depend on the considered time scale. Indeed, we find that on relatively large time scales (15 min) large price fluctuations are connected with the failure of the subtle mechanism of compensation between the flows of market and limit orders. In other words, the missed revelation of the latent order book breaks the dynamical equilibrium between the flows, triggering the large price jumps. This behavior naturally leads to a dynamical definition of liquidity. On smaller time scales (30 s), instead, the static depletion of the limit order book is a useful indicator of a possible intrinsic fragility of the system which, when present, leads to a strongly nonlinear enhancement of the response, in terms of price impact, to incoming orders, even if their volume is small. In order to quantify this phenomenon, we introduce a static measure of the liquidity imbalance present in the book and we show that this quantity is correlated to both the sign and the magnitude of the next price movement. For instance, when the liquidity imbalance is equal to 0.8 (in a scale from 0 to 1) one finds a number of positive returns which is roughly double than the number of the negative ones. We point out that the imbalance is calculated at the beginning of the time window which defines the price movement.
These empirical findings prove that large price fluctuations are due to different mechanisms that act at different time scales. In both cases, the volumes of the incoming orders play a minor role with respect to the fragility of the system and, in particular, to the possible typologies of liquidity crises we discuss. In conclusion, the effective liquidity should be defined in relation to the time interval one wants to consider.

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Weak turbulence analysis of wave spectra in plasmas containing a population of particles with power-law velocity distributions

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Observations have shown that plasma particles in the solar wind frequently display power-law velocity distributions, which can be isotropic or anisotropic. Particularly, the velocity distribution functions of solar wind electrons are frequently modeled as combination of a background Maxwellian distribution and a non-thermal distribution which is known as the "halo" distribution, eventually added of a smaller population of energetic particles with field-aligned velocities, which is known as the "strahl" distribution. Motivated by these observations, we consider a tenuous plasma with Maxwellian ions and with electrons described by a summation of an isotropic Maxwellian distribution and an isotropic kappa distribution, and utilize the formalism of weak turbulence theory to discuss the spectra of electrostatic waves which must be present in such a plasma, satisfying conditions of quasi-equilibrium between processes of spontaneous fluctuations and of induced emission. The analysis is made considering different values of the kappa index of the electron distribution, and different values of the relative number density of the electrons associated to the kappa distributions. By taking into account effects due to electromagnetic waves into the weak turbulence formalism, we investigate the electromagnetic spectra which satisfy conditions of "turbulent equilibrium", in the presence of a fraction of electrons described by kappa distributions, and also the time evolution of the wave spectra and of the electron velocity distribution, which occurs in the case of the presence of an electron beam in the electron distribution. The numerical analysis made using the equations

of weak turbulence theory allows for separate analysis of the effect of different mechanisms on the evolution of the system, namely the analysis of spontaneous fluctuation, induced mechanisms, three-wave decay, and scattering. For the numerical analysis, we also consider the influence of different values of parameters like the "plasma parameter" and the ratio of electron and ion temperatures, on the initial spectrum of electrostatic waves and on the evolution of the system.

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Evolution of kappa-distributed protons downstream of the heliospheric termination shock in the presence of charge-exchange

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Kappa functions have long been used in the analysis and modeling of suprathermal particles in various space plasmas. In situ observations of the supersonic solar wind show its distribution contains a cold ion core and power-law tail, which is well-represented by a kappa function. In situ plasma observations by Voyager, as well as observations of energetic neutral atom (ENA) spectra by the Interstellar Boundary Explorer (IBEX), showed that the compressed and heated inner heliosheath (IHS) plasma beyond the termination shock can also be represented by a kappa function. IBEX exposes the IHS plasma properties through the detection of keV ENAs generated by charge-exchange in the IHS. However, charge-exchange modifies the plasma as it flows through the IHS, making it more difficult to ascertain the parent proton distribution.
In this talk, we first investigate the evolution of the IHS proton distributions, initially represented by a kappa distribution immediately downstream of the termination shock, that experience losses due to energy-dependent charge-exchange with neutral hydrogen atoms. We discuss the effects of fitting a kappa function to the IHS proton distribution over limited energy ranges as a function of distance from the termination shock, its dependence on the initial proton distribution properties at the termination shock, and implications for understanding the observations.
Next, we look at recent IBEX observations of the hydrogen ENA spectrum from the heliotail, which suggest the existence of a roll-over in the ENA spectrum at energies below 0.1 keV. We seek to understand the origin of these ENAs based on a model of the proton distribution function propagating down the heliotail by including the gain and loss of pickup ions by charge-exchange with neutral hydrogen atoms from a 3D kinetic-Monte Carlo simulation of neutral atoms in the heliosphere. We find that most ENAs observed above 0.1 keV come from termination shock-processed pickup ions, initially kappa-distributed with index 2, that propagate down the heliotail. Very low energy ENAs originate from pickup ions injected into the IHS plasma via charge-exchange with neutral hydrogen from the very local interstellar medium and the outer heliosheath. We will discuss the implications of the initial proton distribution at the termination shock, and the source of ENAs that IBEX can see from the heliotail.

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DNA flexibility at short length scales

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Bending and twisting flexibility of the helix are essential to the DNA packaging in chromosomes, to the DNA-protein binding and to the formation of those transient local base pair openings along the chain which regulate DNA replication and transcription. Experimental advances in single molecule micro-manipulation techniques over the last decades have permitted achieving substantial knowledge of the DNA flexibility properties mostly by sampling the molecule response to applied mechanical deformations. Studies of DNA cyclization properties have also indicated that DNA maintains an intrinsic flexibility at length scales which are smaller than the typical persistence length thus questioning, at such scales, the applicability of traditional worm-like-chain models.
For short DNA molecules, all-atomistic simulations and mesoscopic models provide useful analytical tools as they can treat the helix at the level of the base pair and include those large fluctuational effects which shape the helix flexibility properties. We address these issues by reviewing a computational method, based on the path integral formalism, developed in the last years both for linear and circular helicoidal molecules [1-3]. The method is applied to a mesoscopic Hamiltonian which incorporates, for a helical molecule in a solvent potential, both the inter-strand hydrogen bond interactions and the intra-strand stacking interactions. The model also accounts for the bending and twisting fluctuations between adjacent base pairs along the molecules stack. The base pair separations are considered as trajectories in the path configuration space and the total partition function is computed by summing in the path space over a broad ensemble of base pair configurations consistent with the physical requirements of the model potential. Some recent results regarding the cyclization probabilities of molecules with about 100 base pairs [4] and the elastic response of short chains to external loads [5] are presented.

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Modified planar rotator model for efficient gap filling in spatial data

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An ever increasing amount of data collected by various remote sensing technologies as well as the need for their efficient (such as near real time) processing calls for development of new techniques. For example, geostatistical methods [1], that are traditionally used to predict missing values in spatial data, suffer from computational inefficiency, restriction to Gaussian data, as well as various subjective choices in variogram modeling [2]. Therefore, they are impractical if not useless in case of massive data sets. Novel techniques are often developed based on an interdisciplinary approach, which was also behind the idea of alleviating the above limitations via modeling spatial correlations by means of interaction-based Gibbs random fields [3] and spin [4] models from statistical physics.
In the same spirit, in the present study we introduce a spatial prediction method inspired from statistical physics for the efficient estimation of missing data on partially sampled Cartesian grids. The prediction model is based on a classical

planar rotator (or XY) spin model, which is modified in order to display relevant short-range correlations and to allow an appropriate one-to-one mapping between the data and spin values. Spatial correlations present in the data are captured in terms of nearest-neighbor interactions between the spin variables. The only parameter of the model is the thermodynamic temperature, which is estimated from the sample-based nearest-neighbor correlations (which are included in the energy function).
Conditional Monte Carlo simulations honoring the sample values are performed at the inferred temperature on the entire grid to bring the system into thermal equilibrium and subsequently collect prediction statistics. Since the model does not show undesirable critical slowing down, the relaxation process is rather fast.In addition, the short-range nature of the interactions allows vectorization of the algorithm. Consequently, the proposed method achieves roughly linear scaling with the system size. This scaling implies that it is significantly more efficient than the conventional geostatistical approaches and also applicable to huge spatial data sets, such as satellite and radar images. We also discuss the potential of its implementation on GPU processors.

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STATISTICAL PHYSICS

2017

ISBN 13 9788890529696