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List of Oral Presentations

Matteo Paris - *Università degli Studi di Milano*

An all-optical quantum simulator for the dynamics of open quantum systems

We address the dynamics of a quantum system coupled to a quantum environment and discuss the conditions under which the dynamics may be described in terms of the effective interaction with a classical fluctuating field.

Paolo Giorda - *Università di Pavia*

Coherence and quantum estimation

The geometry of quantum states provides a unifying framework for estimation processes based on quantum probes, and it allows to derive the ultimate bounds of the achievable precision. We show a relation between the statistical distance between infinitesimally close quantum states and the second order variation of the coherence of the optimal measurement basis with respect to the state of the probe. In Quantum Phase Estimation protocols, this leads to identify coherence as the relevant resource that one has to engineer and control to optimize the estimation precision. Furthermore, the main object of the theory i.e., the Symmetric Logarithmic Derivative, in many cases allows to identify a proper factorization of the whole Hilbert space in two subsystems. The factorization allows: to discuss the role of coherence vs correlations in estimation protocols; to show how certain estimation processes can be completely or effectively described within a single-qubit subsystem; and to derive lower bounds for the scaling of the estimation precision with the number of probes used. We illustrate how the framework works for both noiseless and noisy estimation procedures, in particular those based on multi-qubit GHZ-states. Finally we succinctly analyze estimation protocols based on zero-temperature critical behavior. We identify the coherence that is at the heart of their efficiency, and we show how it exhibits the non-analyticities and scaling behavior proper of a large class of quantum phase transitions.

Alessandro Codello - *SISSA, Trieste*

Universality in the epsilon-expansion

I'll describe the family of renormalizable scalar QFTs with self-interacting potentials of highest monomial ϕ^m below their upper critical dimensions $d_c = 2m/(m-2)$, and study them using a combination of CFT constraints, Schwinger-Dyson equation and the free theory behavior at the upper critical dimension. For even integers, $m \geq 4$ these theories coincide with the Landau-Ginzburg description of multi-critical phenomena and interpolate with the unitary minimal models in $d = 2$, while for odd m the theories are non-unitary and start at $m = 3$ with the Lee-Yang universality class. For all the even potentials and for the Lee-Yang universality class, I show how the assumption of conformal invariance is enough to compute the scaling dimensions of the local operators ϕ^k and of some families of structure constants at leading order.

Matteo Polettini - *University of Luxembourg*

Effective thermodynamics for a marginal observer

Effective thermodynamics for a marginal observer Abstract: Thermodynamic modelling often presumes that the observer has complete information about the system she or he deals with: no parasitic current, exact evaluation of the forces needed to drive the system out of equilibrium. However, most often the observer only measures partial, or marginal information. How is she or he to make consistent thermodynamic claims? Disregarding sources of dissipation might lead

to untenable claims, such as the possibility of perpetuum mobile. Basing on the tenets of Stochastic Thermodynamics, we show that for such an observer it is nevertheless possible to produce an effective description that does not dispense with the fundamentals of thermodynamics: the 2nd Law, the Fluctuation-Dissipation paradigm, and the more recent and encompassing Fluctuation Theorem.

Matteo Osella - *Università di Torino*

Statistics of shared components in complex component systems

Many complex systems are modular. Such systems can be represented as "component systems", i.e., sets of elementary components, such as LEGO bricks in LEGO sets. The bricks found in a LEGO set reflect a target architecture, which can be built following a set-specific list of instructions. In other component systems, instead, the underlying functional design and constraints are not obvious a priori, and their detection is often a challenge of both scientific and practical importance, requiring a clear understanding of component statistics. Importantly, some quantitative invariants appear to be common to many component systems, most notably a common broad distribution of component abundances, which often resembles the well-known Zipf's law. Such "laws" affect in a general and nontrivial way the component statistics, potentially hindering the identification of system-specific functional constraints or generative processes. Here, we specifically focus on the statistics of shared components, i.e., the distribution of the number of components shared by different system realizations, such as the common bricks found in different LEGO sets. To account for the effects of component heterogeneity, we consider a simple null model, which builds system realizations by random draws from a universe of possible components. Under general assumptions on abundance heterogeneity, we provide analytical estimates of component occurrence, which quantify exhaustively the statistics of shared components. Surprisingly, this simple null model can positively explain important features of empirical component-occurrence distributions obtained from large-scale data on bacterial genomes, LEGO sets, and book chapters. Specific architectural features and functional constraints can be detected from occurrence patterns as deviations from these null predictions, as we show for the illustrative case of the "core" genome in bacteria.

Reference: https://doi.org/10.1103/PhysRevX.8.021023

Marco Budinich - *Università di Trieste & INFN*

The SATisfiability problem in spinorial form

The Boolean SATisfiability Problem (SAT) is the archetypical combinatorial problem and more than 20 years ago the problem was formulated in the language of statistical mechanics. This brought both theoretical insights and competitive solution algorithms in some instances.

In this work we present a completely different SAT formulation in the language of spinors - Clifford algebra - that yields a purely geometrical necessary and sufficient condition for unsatisfiability. With this result we outline an algorithm to test for unsatisfiability with possibly interesting theoretical properties.

In this form the problem has some similarity with the Onsager solution of the two dimensional Ising model and we discuss possible interchanges.

Giacomo Gradenigo - *CNR-NANOTEC, Roma*

Glassy behaviour of light: insights from numerical simulations on realistic complex networks

It has been recently proposed that the fluctuations in the emission spectra of random lasers can be understood in terms of a thermodynamic phase transition to a glassy phase: this is a regime where the amplitudes and phases of light normal modes are frozen in the same disordered configuration for the whole duration of the pulse. So far the only analytical predictions on the thermodynamics of this phase have been obtained in the so-called narrow band approximation, that is by assuming a light-modes interaction network that is fully connected and in whose constitution the mode frequencies play no role at all.
We present the first numerical results, obtained from highly optimized GPU-codes, showing that the thermodynamic glass transition with the features predicted by the mean field models is, indeed, present even when the light modes are put on

the less dense and correlated network, termed mode-locking graph, best reproducing the true interaction network. We are therefore able to interpolate between the state of the art of experimental results on glassy random lasers and the recent analytic results on the related statistical mechanical models with frustrated mode couplings.

Andrea Gabrielli - *CNR-ISC, Roma*

Statistical physics approach to unfold the innovation system for the development of countries: co-evolution of Science, Technology and Production

In this talk we show that the space in which scientific, technological and economic developments interplay with each other can be mathematically shaped using pioneering multilayer network and complexity techniques [1].

We build the tri-layered network of human activities (scientific production, patenting, and industrial production) and study the interactions among them, also taking into account the possible time delays. Within this construction we can identify which capabilities and prerequisites are needed to be competitive in a given activity, and even measure how much time is needed to transform, for instance, the technological know-how into economic wealth and scientific innovation, being able to make predictions with a very long time horizon. Quite unexpectedly, we find empirical evidence that the naive knowledge flow from science, to patents, to products is not supported by data, being instead technology the best predictor for industrial and scientific production for the next decades.

[1] E. Pugliese, G. Cimini, A. Patelli, A. Zaccaria, L. Pietronero, A. Gabrielli, "Unfolding the innovation system for the development of countries: co-evolution of Science, Technology and Production", https://arxiv.org/abs/1707.05146

Marco Zamparo - *Politecnico di Torino*

On the Mean Residence Time in Stochastic Lattice-Gas Models

A heuristic law widely used in fluid dynamics for steady flows states that the amount of a fluid in a control volume is the product of the fluid influx and the mean time that the particles of the fluid spend in the volume, or mean residence time. I will show that if the mean residence time is introduced in terms of sample-path averages, then stochastic lattice-gas models with general injection, diffusion, and extraction dynamics verify this law. Only mild assumptions are needed in order to make the particles distinguishable so that their residence time can be unambiguously defined. I will use this general result to obtain explicit expressions of the mean residence time for the Ising model on a ring with Glauber + Kawasaki dynamics and for the totally asymmetric simple exclusion process with open boundaries.

Alessandra Bianchi - *Università di Padova*

Random walk in a non-integrable random scenery time

In this talk we consider a one-dimensional process in random environment, also known in the physical literature as Levy-Lorentz gas. The environment is provided by a renewal point process that can be seen as a set of randomly arranged scatterers, while the process roughly describes the displacement of a particle moving on the line at constant velocity, and changing direction at the scatterers position with probability 1/2.
We investigate the annealed behavior of this process in the case of inter-distances between scatterers having infinite mean, and establish, under suitable scaling, a functional limit theorem for the process. In particular we show that, contrary to the finite mean case, the behavior of the motion is super-diffusive with explicit scaling limit related to the Kesten-Spitzer process. The key element of the proof is indeed a representation of the consecutive "hitting times on the set of targets" as a suitable random walk in random scenery.

Miguel Angel Muñoz - *Universidad de Granada*

Landau-Ginzburg theory of cortex dynamics

Understanding the origin, nature, and functional significance of complex patterns of neural activity, as recorded by diverse

electrophysiological and neuroimaging techniques, is a central challenge in neuroscience. Such patterns include collective oscillations emerging out of neural synchronization as well as highly hetero- geneous outbursts of activity interspersed by periods of quiescence, called "neuronal avalanches". Much debate has been generated about the possible scale invariance or criticality of such avalanches and its relevance for brain function. Aimed at shedding light onto this, in this TALK we analyze the large-scale collective properties of the cortex by using a mesoscopic approach following the principle of parsimony of Landau-Ginzburg. The proposed model is similar to that of Wilson–Cowan for neural dynamics but crucially, includes stochasticity and space; synaptic plasticity and inhibition are considered as possible regulatory mechanisms. Detailed analyses uncover a phase diagram including down-state, synchronous, asynchronous, and up-state phases and reveal that empirical findings for neuronal avalanches are consistently reproduced by tuning our model to the edge of synchronization. This reveals that the putative criticality of cortical dynamics does not correspond to a quiescent-to-active phase transition as usually assumed in theoretical approaches but to a synchronization phase transition, at which incipient oscillations and scale-free avalanches coexist. This approach constitutes a framework to rationalize the possible collective phases and phase transitions of cortical networks in simple terms, thus helping to shed light on basic aspects of brain functioning from a very broad perspective.

Trang-Anh Nghiem - *European Institute of Theoretical Neuroscience, Paris*

Spectral structure of human brain activity: an analogy with thermodynamics

Neural electromagnetic (EM) signals recorded non-invasively from individual human subjects vary in complexity and magnitude between brain states. Accordingly, variations in neural activity across different brain functions have been difficult to quantify and interpret, due to their complex, broad-band features in the frequency domain. Studying signals recorded with magnetoencephalography (MEG) from healthy young adult subjects while resting and performing cognitively demanding tasks, a systematic framework inspired by thermodynamics is applied to neural EM signals. Despite considerable inter-subject variation, data support the existence of a robust and linear relationship that defines an effective state equation conserved across brain states examined here. Physical relationships between state variables are further investigated using a Kuramoto network model, revealing that an interplay between noise and coupling strength can reproduce similar coherent variation of empirically observed state variables as in experimental data. We discuss the possible physical meaning of variables such as the analogs of energy, entropy and temperature, as derived from MEG recordings.

Elif Köksal Ersöz - *INRIA Sophia Antipolis - Méditerranée*

Anticipation via canards in excitable systems

Anticipated synchronisation appears as a counter-intuitive observation of synchronisation in a wide range of dynamical systems from biology to engineering applications. It can occur in unidirectionally interacting systems where the receiver is subject to a self-delayed feedback in addition to a signal coming from the sender. This particular interaction permits the receiver to predict the future trajectory of the sender. In this study, we focused on the anticipated behaviour in excitable systems, in particular type-II neuron models, and linked it with another counter-intuitive phenomenon, namely canards. Canard trajectories structure the excitability and synchronisation properties of multiple timescale systems exhibiting excitable dynamics. By developing a theoretical framework enhanced by numerical continuation, we showed that the underlying canard structure in excitable systems can responsible for delaying sub-threshold solutions, but anticipating the spiking ones.

Matteo di Volo - *UNIC CNRS France*

Collective dynamics in cortical networks: from asynchronous irregular to oscillations

We discuss the collective dynamics emerging in cortical neuronal networks where the microscopic dynamics is irregular due to the balance between excitation and inhibition, in accordance with experimental findings. Thanks to mean field techniques we investigate the transitions from asynchronous to oscillatory dynamics in excitatory and inhibitory neural networks.

Hongjie Bi - *Université de Cergy-Pontoise, France*

Coexistence of oscillatory states in balanced spiking inhibitory networks

We consider balanced sparse inhibitory networks of quadratic integrate-and-fire (QIF) neurons. The QIF model representing the canonical model for class I neurons near the spiking threshold. We derive a mean-field version of the corresponding sparse network for finite synaptic ecay (namely, exponential) by following a recently developed reduction technique developed for QIF networks [1]. For random sparse networks we consider an equivalent network with quenched disorder. In the mean-field model we observe a region of coexistence of a stable focus with periodic oscillations. In direct simulations of the corresponding spiking network, the microscopic irregular dynamics, due to the balanced state, turns the stable focus in an state with collective oscillations [2]. Therefore we observe the coexistence of two oscillatory states corresponding to slow and fast Gamma oscillations generated by the same neuronal population. These results can have relevance for the study of information flow in the brain [3].

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[2] Transition from asynchronous to oscillatory dynamics in balanced spiking networks with istantaneous synapses, M. d Volo and A. Torcini, preprint (2018)
[3] Colgin, Laura Lee, et al. "Frequency of gamma oscillations routes flow of information in the hippocampus." Nature 462.7271 (2009): 353.

Wesley Clawson - *INS, Aix-Marseille University*

Switching States of Neuronal Networks in the Brain

Oscillations are believed to play a role in flexible information routing between regions but their impact on the way in which information is processed locally within region is still unclear. Here we use an information theory approach to quantify the involvement of individual neurons in the primitive information processing operations of storage and sharing that can be viewed as generic building blocks of local circuit computations. We introduce the concept of a computing microstate, an epoch in which neurons are assigned to a consistent information processing role. Each microstate has associated state-specific computing hubs, neurons most strongly involved in sharing and storage operations. We find that there is a multiplicity of different computing microstates, and that discrete transitions between them cause neurons and computing hubs to switch their functional roles. Importantly, global oscillatory states (slow and theta oscillations during anesthesia or sleep) affect both the repertoire of available computing microstates and the complexity of their observed temporal sequences. This enables a democratic role sharing in which nearly half of the recorded neurons can act as a computing hub in at least some of the microstates. Together, this suggests that the roles played by neurons in local computations are not firmly hard-wired but rather emerge as the effect of rich collective dynamics, modulated by global oscillatory states.

Rossana Mastrandrea - *Scuola IMT Alti Studi Lucca*

The basal scaffold of the brain functional architecture

The analysis of brain functional architecture is a paradigmatic example of complex system, since brain functionality emerges as a global property of local interactions. A complete description of multi-scale and multi-level segregation and integration of brain regions represents a challenging issue to address and unearths the complexity of its whole functional organization. Here we analysed functional magnetic resonance imaging data from forty human healthy subjects during resting condition. Network theory is able to visualise the skeleton of functional correlations (weights) between different regions (nodes) of the brain and to extract information, by selecting only the most important features out of the noise. On the resulting human functional brain network, we performed a modified version of the percolation analysis and compared the results with a null model: a not-trivial hierarchical organization in modules emerges. A zoom in the modular structure through a maximum spanning forest (MSF) approach unveiled a chain-like organization of the brain regions, never observed before. Intuitively, nodes tend to link with nodes in the same anatomical area, except for regions in the Temporal Lobe. Passing from the MSF to the maximum spanning tree, the network preserved the chain-like structure, confirming some outcomes and revealing the centrality of the Occipital Lobe and some regions from the Temporal Lobe and the Cerebellum. In the last part, we showed preliminary but promising results for 44 Schizophrenic subjects. We applied the same procedure described before finding interesting similarities and differences with the sample of healthy individuals.

Tiziano Squartini - *Scuola IMT Alti Studi Lucca*

Entropy-based approach to missing-links prediction

Link-prediction is an active research field within network theory, aiming at uncovering missing connections or predicting the emergence of future relationships from the observed network structure. This paper represents our contribution to the stream of research concerning missing links prediction. Here, we propose an entropy-based method to predict a given percentage of missing links, by identifying them with the most probable non-observed ones. The probability coefficients are computed by solving opportunely defined null-models over the accessible network structure. Upon comparing our likelihood-based, local method with the most popular algorithms over a set of economic, financial and food networks, we find ours to perform best, as pointed out by a number of statistical indicators (e.g. the precision, the area under the ROC curve, etc.). Moreover, the entropy-based formalism adopted in the present paper allows us to straightforwardly extend the link-prediction exercise to directed networks as well, thus overcoming one of the main limitations of current algorithms. The higher accuracy achievable by employing these methods - together with their larger flexibility - makes them strong competitors of available link-prediction algorithms.

https://arxiv.org/pdf/1802.02064.pdf

Pierfrancesco Di Cintio - *CNR-IFAC & INFN, Firenze*

N-body chaos and the continuum limit in numerical simulations, revisited

In this talk I will question the validity of the continuum limit and the use of frozen N- body realizations to obtain qualitative information on particle orbits in large N gravitational system in stellar dynamics. With the aid of detailed numerical simulations with refined symplectic integrators developed in the context of numerical celestial mechanics, I will compare orbits in frozen potentials with orbits in self consistent equilibrium models. In addition, I will show some results that could be relevant for the physics of charged particle beams.

Alberto Petri - *CNR-ISC, Roma*

Hydro vs micro-dynamics of a column shaken beads

It is well known that energy dissipation and non linear interactions can deeply affect the dynamics of granular matter, often making usual hydrodynamic approaches problematic. Here we report on the experimental investigation of a model system, made of some beads constrained into a 1-d geometry by a narrow vertical pipe and shaken at the base by a piston exited by a periodic wave. Although similar systems have been the subject of several studies from the theoretical and numerical point of view, very few experimental instances exist. Recording the beads motion with high frame rate camera allows to investigate in detail the microscopic dynamics, yielding useful information to improve the hydrodynamic description.

Andrea Mazzolini - *ICTP, Trieste*

Zipf and Heaps laws from dependency structures in component systems

Complex natural and technological systems can be considered, on a coarse-grained level, as assemblies of elementary components: for example, genomes as sets of genes, or texts as sets of words. On one hand, the joint occurrence of components emerges from architectural and specific constraints in such systems. On the other hand, general regularities may unify different systems, such as the broadly studied Zipf and Heaps laws, respectively concerning the distribution of component frequencies and their number as a function of system size. Dependency structures (i.e., directed networks encoding the dependency relations between the components in a system) were proposed recently as a possible organizing principles underlying some of the regularities observed. However, the consequences of this assumption were explored only in binary component systems, where solely the presence or absence of components is considered, and multiple copies of the same component are not allowed. Here, we consider a simple model that generates, from a given ensemble of dependency structures, a statistical ensemble of sets of components, allowing for components to appear with any multiplicity. Our model is a minimal extension that is memoryless, and therefore accessible to analytical calculations. A

mean-field analytical approach (analogous to the "Zipfian ensemble" in the linguistics literature) captures the relevant laws describing the component statistics as we show by comparison with numerical computations. In particular, we recover a power-law Zipf rank plot, with a set of core components, and a Heaps law displaying three consecutive regimes (linear, sub-linear and saturating) that we characterize quantitatively.

Marco Baldovin - *Sapienza Università di Roma*

Langevin equation in systems with also negative temperatures

We discuss how to derive a Langevin equation (LE) in non standard systems, i.e. when the kinetic part of the Hamiltonian is not the usual quadratic function. This generalization allows to consider also cases with negative absolute temperature. We first give some phenomenological arguments suggesting the shape of the viscous drift, replacing the usual linear viscous damping, and its relation with the diffusion coefficient modulating the white noise term. As a second step, we implement a procedure to reconstruct the drift and the diffusion term of the LE from the time-series of the momentum of a heavy particle embedded in a large Hamiltonian system. Applying the method to systems with negative temperature, we can observe that also in this case there is a suitable LE, obtained with a precise protocol, able to reproduce in a proper way the statistical features of the slow variables. In other words, even in this context, systems with negative temperature do not show any pathology.

Mattia Radice - *Università dell'Insubria*

A persistent random walk on an averaged environment for the Lévy-Lorentz gas

Persistent random walks represent a class of stochastic models where, in their simplest version, a particle jumps to a nearest-neighbour site where there is a probability T of being transmitted and R of being reflected. Such nontrivial, correlated random walks have been recognized as a natural model for a number of relevant settings, from long-chain polymers, to chemotaxis, to active matter, but many of the associated statistical properties still remain unexplored. We introduce a non-homogeneous, persistent random walk that may be viewed as a mean-field version of the Lévy-Lorentz gas, which consists of an array of scatterers whose distances are distributed according to a Lévy distribution with parameter $0 < \alpha < 2$, i.e. a distribution whose second moment is not defined. Depending on the values of α, the model shows a transition from normal transport ($1 < \alpha < 2$) to superdiffusion ($0 < \alpha < 1$), with an exponent $\nu(\alpha) = 2/(1+\alpha)$, which is analytically derived by an appropriate continuum limit.

Joint work with Roberto Artuso, Giampaolo Cristadoro and Manuele Onofri

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Alessandro Colombo - *Università degli Studi di Milano*

Miming the Memes for Imaging the Unimagined

Coherent Diffractive Imaging (CDI) is a technique for imaging matter hit by coherent radiation. The experimentally recorded diffraction pattern $I_{i,j}$ is the square modulus of the Fourier Transform (FT) of the sample density distribution $\rho_{i,j}$, while any information about its phases is lost. Therefore, the inverse FT to get the real-space image of the sample can be accomplished only after the retrieval of the phase information by means of suitable algorithms. These algorithms treats each entry of $\rho_{i,j}$ as a free parameter, trying to optimize the discrepancy with the experimental measurement $I_{i,j}$. The number of unknowns involved in the optimization, which merely are the pixels of the image $\rho_{i,j}$, runs from 10^5 for 2D CDI up to 10^7 for the 3D case. This means that the solution is a point in a $10^{5\sim7}$-dimensional space. Standard deterministic algorithms for phase retrieval are iterative gradient-based approaches, which suffer from many limitations, among which stagnation in local optima. On the other side, purely stochastic approaches are doomed to fail, due to the high dimensionality of the optimization problem and the involvement of the Fourier Transform in the evaluation of the cost function.
Our hybrid stochastic method, called Memetic Phase Retrieval (MPR) [1], mixes a genetic algorithm with gradient-based procedures, giving rise to a memetic algorithm, a class of stochastic optimization methods representing one of the recent growing areas of research in evolutionary computation. In particular, MPR treats a population of candidate solutions to the problem, which are able to self-improve via standard iterative approaches, and combines, step by step, their information by the use of computational intelligence. The complex dynamic of MPR is capable to approach and identify the

solution much better than the standard procedures. Imaging results on 2D and 3D imaging will be presented, along with a description of the method, showing how much computational intelligence is effective in facing such a complex optimization problem.

[1] Colombo, Alessandro, et al. "Facing the phase problem in coherent diffractive imaging via memetic algorithms." Scientific Reports 7 (2017): 42236.

Marco Faccioli - *Università di Padova*

Gaussian fluctuations in quantum phase transitions

We discuss the effect of Gaussian quantum fluctuations close to the critical point of a quantum phase transition [1]. In particular, we analyze the effective action of the Bose-Hubbard Hamiltonian close to the Mott-superfluid phase transition [2]. This effective action contains the familiar Ginzburg-Landau-Wilson terms [3] but also first order and second order time derivatives of the complex order parameter. We investigate the elementary excitations of this effective action finding that they are in good agreement with experimental data [4]. From the elementary excitations and using dimensional regularization [5], we determine beyond-mean-field Gaussian corrections to the zero-temperature equation of state of the system. We show that these Gaussian corrections crucially depend on the dimensionality of the system.

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Francesco Mambretti - *Università degli Studi di Milano*

Energy-landscape driven crystallization slowdown in supercooled liquid mixtures

Crystallization is a process of fundamental importance in a variety of fields ranging from materials to climate science. At the microscopic level, crystallization in supercooled liquids is described qualitatively by the classical crystal nucleation and growth theories. In general, however, solid formation is a far more complex process and even the rich behavior observed in simple binary mixtures greatly challenges our current understanding of crystallization. Recently, I joined the group of R. Grisenti in an experimental campaign at DESY, Germany, based on innovative x-ray scattering measurements on liquid microjets [1]. The results have revealed a non-trivial dependence of the crystallization rate on the mixing ratio of supercooled Argon-Krypton liquid mixtures. Our Molecular Dynamics simulations show that this dependence is mainly related to an increased probability for fluctuations between crystal-like and liquid-like states at the crystal/liquid interface driven by the change in the potential energy landscape with composition. The emerging picture might be valid in general, providing a major step towards a more sophisticated theory of crystal growth in out-of-equilibrium supercooled liquids. Moreover, these results support the hypothesis[2] that the energy-landscape complexity may play a leading role also in systems characterized by a higher supercooling degree and by the competition between the crystal formation and the onset of a glassy phase.

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2) P.G. Debenedetti et al., Nature 410, 259 (2001)

Chahan Kropf - *INFN, Pavia*

Optimal exciton current in one-dimensional chains

Finding optimal parameters for exciton transport in small quantum systems is an important step to guide the building of novel and efficient light-harvesting devices. In one-dimensional models of finite size attached to a lead (modeled to study exciton transport) coherence-enhanced transport is achieved when the coupling to the lead is close to the superradiant transition [1]. Using these results we show that such coherence-enhanced transport is compatible with the parameters of transition metal oxides thin films, and thus the latter can potentially be used for experimental verification. In addition, we benchmark our model with more realistic dynamical mean-field theory (DMFT) calculations of a Hubbard model in the

Mott insulating phase in a parameter range close to the optimum. Our work suggests that coherence-enhanced transport is achievable in nano-scale solid state devices which would provide an experimental platform for research on light-harvesting devices with substantial advantages over their bio-molecule based counterparts.

1. G.L. Celardo, F. Borgonovi, M. Merkli, V.I. Tsifrinovich, and G.P. Berman, J. Phys. Chem. C, 116, 22105 (2012)

Rosa Giuliano - *Università della Calabria*

Persistent current and zero-energy Majorana modes in a p-wave disordered superconducting ring

In this talk will be discussed the emergence of zero-energy Majorana modes in a disordered finite-length p-wave one-dimensional superconducting ring, pierced by a magnetic flux ϕ when it is tuned at an appropriate value $\phi = \phi^\star$. In the absence of fermion parity conservation, will be evidenced the emergence of the Majorana modes by looking at the discontinuities in the persistent current $I[\phi]$ at $\phi = \phi^\star$. By monitoring the discontinuities in $I[\phi]$, will be shown how to map out the region in parameter space characterized by the emergence of Majorana modes in the disordered ring.

Andrea Colcelli - *SISSA, Trieste*

Deviations from Off-Diagonal Long-Range Order and Mesoscopic Condensation in One-Dimensional Quantum Systems

A quantum system exhibits off-diagonal long-range order (ODLRO) when the largest eigenvalue λ_0 of the one-body-density matrix scales as $\lambda_0 \sim N$, where N is the total number of particles. Putting $\lambda_0 \sim N^{\mathcal{C}}$ to define the scaling exponent $\mathcal{C}$, then $\mathcal{C} = 1$ corresponds to ODLRO and $\mathcal{C} = 0$ to the single-particle occupation of the density matrix orbitals. When $0 < \mathcal{C} < 1$, $\mathcal{C}$ can be used to quantify deviations from ODLRO. In this talk I will present the study of the exponent $\mathcal{C}$ in a variety of one-dimensional bosonic and anyonic systems.

Zeno Filiberti - *Università dell'Insubria*

A statistical approach to thermo-osmosis

Fluids in temperature gradients are among the simplest systems out of equilibrium and serve as testing ground for our understanding of stationary, non equilibrium states. A temperature gradient in the bulk drives a heat flux, while the local density changes and the pressure remain uniform, granting mechanical equilibrium. However, near a surface, the pressure balance cannot be realized and the fluid is set into motion. This phenomenon is known as thermo-osmosis and has been studied in rarefied gases since many years [1,2]. The same effect is also expected in liquids, although the lengthscales involved are much shorter. Arguments based on non equilibrium thermodynamics led Derjaguin to conclude that the phenomenon originates at the wall-fluid interface and an approximate expression for the thermo-osmotic velocity in liquids was proposed [3]. Only recently numerical simulations attempted a quantitative investigation of this effect, while a direct experimental evidence is still missing. Here, starting from a microscopic model of molecular fluid and taking advantage of the Kubo-Mori linear response theory, we provide a first principle description of the phenomenon. By specializing the resulting expressions to the liquid and to the gas regimes we show that two quite different physical mechanisms are at work: while in dense fluids the phenomenon originates from the anisotropies of the pressure tensor near the wall, in agreement with Derjaguin approach, in the rarefied limit the mechanism has a purely kinetic nature and the linear response formalism confirms the understanding based on kinetic theories.

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Lorenzo Caprini - *Gran Sasso Science Institute (GSSI)*

Activity induced delocalization and freezing in self-propelled systems

We study a system of interacting active particles, propelled by colored noises, characterized by an activity time τ, and

confined by a single-well anharmonic potential. We observe that - already with negligible interactions - increasing τ pushes the particles far from the potential minimum, until a saturation distance is reached. We compute the phase diagram (activity vs interaction length), showing that interaction does not spoil this delocalisation phenomenon but induces a liquid- or solid-like structure in the densest regions. An approximate analytical scheme gives fair predictions for the density profiles in the weakly interacting case. The analysis of non-equilibrium heat fluxes of the system reveals that in the region of largest concentration of particles equilibrium is restored in several aspects.

Francesco De Santis - *Sapienza Università di Roma*

Computation of the Zero Temperature RSB order parameter in Bethe Lattice Spin Glasses

Bethe Lattice Spin Glasses are models with finite connectivity which undergo a Replica Symmetry Breaking (RSB) phase transition in field, at zero temperature. We compute numerically the RSB order parameter of the model near the transition, in the case of minimum connectivity (z=3) and bimodal distribution of the couplings ($J = \pm 1$). The method is based on a universal formula which relates the order parameter to the joint probability distribution of the energy difference and overlap of excitations induced by a convenient perturbation to the Hamiltonian.

Giacomo Rapisardi - *Scuola IMT Alti Studi Lucca*

Multiple structural transitions in interacting networks

Many real-world systems can be modeled as interconnected multilayer networks, namely a set of networks interacting with each other. Here we present a perturbative approach to study the properties of a general class of interconnected networks as inter-network interactions are established. We reveal multiple structural transitions for the algebraic connectivity of such systems, between regimes in which each network layer keeps its independent identity or drives diffusive processes over the whole system, thus generalizing previous results reporting a single transition point. Furthermore we show that, at first order in perturbation theory, the growth of the algebraic connectivity of each layer depends only on the degree configuration of the interaction network (projected on the respective Fiedler vector), and not on the actual interaction topology. Our findings can have important implications in the design of robust interconnected networked system, particularly in the presence of network layers whose integrity is more crucial for the functioning of the entire system. We finally show results of perturbation theory applied to the adjacency matrix of the interconnected network, which can be useful to characterize percolation processes on such systems.

Jonathan Fiorentino - *Sapienza Università di Roma*

Statistics of optimal information flow in ensembles of regulatory motifs

Genetic regulatory circuits universally cope with different sources of noise that limit their ability to coordinate input and output signals. In many cases, optimal regulatory performance can be thought to correspond to configurations of variables and parameters that maximize the mutual information between inputs and outputs. Since the mid-2000s, such optima have been well characterized in several biologically relevant cases. Here we use methods of statistical field theory to calculate the statistics of the maximal mutual information (the "capacity") achievable by tuning the input variable only in an ensemble of regulatory motifs, such that a single controller regulates N targets. Assuming (i) sufficiently large N, (ii) quenched random kinetic parameters, and (iii) small noise affecting the input-output channels, we can accurately reproduce numerical simulations both for the mean capacity and for the whole distribution. Our results provide insight into the inherent variability in effectiveness occurring in regulatory systems with heterogeneous kinetic parameters.

List of Poster Presentations

Giulio Amato - *Freiburg University*

Quantum transport with cold atoms

The classical theory of transport is of paramount importance, being at the basis of electronics. Nonetheless, in recent years, the quantum theroy of transport has become more and more relevant. In fact, due to the novel experimental capabilities, it is possible to perform studies on the transport of ultracold atoms, which, under appropriate conditions (e.g. low temperatures), behave quantum mechanically. In particular, the chance to witness novel quantum effects and the possibility to change the nature of the ultracold atoms filling the lattice, from fermionic to bosonic, gives a wide variety of interesting research topics. We present here some preliminary result.

Marco Baiesi - *Università di Padova*

Response to noise variations in stochastic systems

Recently there has been a considerable interest in fluctuation-response relations for nonequilibrium regimes. An example of such relations characterizes the thermal response to a variation of one temperature of a reservoir in contact with the system. For inertial systems, we show that Andersen thermostats are a natural tool for studying this kind of thermal response. For nonequilibrium overdamped systems it is also possible to derive fluctuation-response relations. We discuss the common theme characterizing these formulas.

Victor Buendia Ruiz-Azuaga - *Università di Parma e Universidad de Granada*

Limited role of spatial self-structuring in emergent trade-offs during pathogen evolution

Pathogen transmission and virulence are main evolutionary variables broadly assumedto be linked through trade-offs. In well-mixed populations, these trade-offs are often ascribed to physiological restrictions, while populations with spatial self-structuring might evolve emergent trade-offs. Here, we reexamine a model of the latter kind proposed by Ballegooijen and Boerlijst with the aim of characterising the mechanisms causing the emergence of the trade-off and its structural robustness. Using invadability criteria, we establish the conditions under which an evolutionary feedback between transmission and virulence mediated by pattern formation can poise the system to a critical boundary separating a disordered state (without emergent trade-off) from a self-structured phase (where the trade-off emerges), and analytically calculate the functional shape of the boundary in a certain approximation. Beyond evolutionary parameters, the success of an invasion depends on the size and spatial structure of the invading and invaded populations. Spatial self-structuring is often destroyed when hosts are mobile, changing the evolutionary dynamics to those of a well-mixed population. In a metapopulation scenario, the systematic extinction of the pathogen in the disordered phase may counteract the disruptive effect of host mobility, favour pattern formation and therefore recover the emergent trade-off.

Davide Emilio Galli - *Università degli Studi di Milano*

Quantum Critical Behavior of One-Dimensional Soft Bosons in the Continuum

We have investigated [1] a 1D system of bosons interacting via a soft-shoulder potential in the continuum, typical of dressed Rydberg gases. The flatness of the potential at short distances introduces a typical length, such that, at relatively high densities and sufficiently strong interactions, clusters are formed, even in the presence of a completely repulsive potential.

We employ quantum Monte Carlo simulations, which allow for the exact calculation of imaginary-time correlations, and a stochastic analytic continuation method, to extract the dynamical structure factor. At finite densities, in the weakly interacting homogeneous regime, a rotonic spectrum marks the tendency to clustering. With strong interactions, we indeed observe cluster liquid phases emerging, characterized by the spectrum of a composite harmonic chain. Luttinger theory has to be adapted by changing the reference lattice density field. In both the liquid and cluster liquid phases, for two-particle clusters we find convincing evidence of a secondary mode, which becomes gapless only at the transition. In that region, we also measure the central charge and observe its increase towards c=3/2, and we note a fast reduction of the Luttinger parameter. We interpret such observations in terms of the compresence of a Luttinger liquid and a critical transverse Ising model, related to the instability of the reference lattice density field towards coalescence of couples of particles. Even in the absence of a true lattice, we are able to evaluate the spatial correlation function of a suitable pseudospin operator, which manifests ferromagnetic order in the cluster liquid phase, exponential decay in the liquid phase, and algebraic order at criticality.

[1] S. Rossotti, M. Teruzzi, D. Pini, D.E. Galli, and G. Bertaina Phys. Rev. Lett. 119, 215301 (2017).

Manuele Onofri - *Università dell'Insubria*

Simulations on a persistent random walk on an averaged environment for the Lévy-Lorentz gas

We present results of simulations concerning the averaged Lévy-Lorentz gas. Both from analytical and numerical results we notice, depending on α, two different regimes, one described by normal diffusion ($\alpha > 1$) and the other by superdiffusion ($\alpha < 1$). For the normal regime we obtain a good agreement between simulations and analytical results over the entire range $1 < \alpha < 2$, while in the anomalous case we discuss how finite time simulations can hardly reproduce correctly the asymptotic results.

Joint work with R. Artuso, G. Cristadoro and M. Radice

Francesco Petiziol - *Università di Parma*

Structure of counterdiabatic fields and approximate counterdiabatic driving

Adiabatic processes are ubiquitous in quantum science, and they are a crucial resource in the field of time-dependent quantum control. However, the limitations imposed by coherence times are typically in sharp contrast with the necessity of slow evolutions. In recent years, various methods have been proposed for speeding up adiabatic processes. A most promising one, known as method of the couterdiabatic fields or transitionless quantum driving, suggests to add a control field which compensates exactly for non-adiabatic transitions at all times. Unfortunately, in most cases of interest the correcting field turns out to involve interactions not included among the initial control possibilities. We investigate more in detail how the matrix structure of the correcting field is related to the initial set of controllable Hamiltonians. Building on such results, we discuss the possibility of realizing it in an approximate manner, by means of the available control resources. We then propose an explicit method for realizing an approximate counterdiabatic driving.

Marco Pretti - *ISC-CNR, Torino*

Dynamical transition in the TASEP with Langmuir kinetics: mean-field theory

We study the dynamical transition in the Totally Asymmetric Simple Exclusion Process with open boundaries. Such a phenomenon is characterized by a singularity in the relaxation rate of the system to its non-equilibrium steady state. In the high-density (low-density) phase, the relaxation rate becomes independent of the injection (extraction) rate, at a certain critical value of the parameter. This transition is not accompanied by any change in the steady state. We provide rigorous bounds for the relaxation rate that become tight in the infinite size limit. We generalize these results to the TASEP with Langmuir kinetics, where particles can also bind to an empty site and unbind from an occupied one, at given rates. We restrict the analysis to the symmetric case of equal binding/unbinding rates and show that a dynamical transition occurs in this case as well.

Anjan Roy - *Università dell'Insubria*

Bacterial populations with growth heterogeneity

We numerically studied gene regulation models in bacterial systems which show growth bi-stability, at the level of a single cell and extended it to two types of population set-ups popular with experimentalists, namely, the Chemostat (or continuous culture) and a microfluidic device called the Mother Machine. We find that typically measured quantities such as growth rates, switching rates, distribution of proteins and hysteresis curves, have distinctive signatures at the single cell and population levels. In the process we also developed a highly efficient version of Gillespie's Stochastic Simulation Algorithm, which makes simulating large population of cells possible.

Michele Tizzani - *Università di Parma*

Epidemics Spreading on temporal networks with memory effects

Activity Driven models are an interesting class of temporal networks. They are characterized by assigning to each node an activity, easily measured from extensive datasets, that represents the number of activation per time of a node [1]. Strong ties and rules for links formations in activity driven networks can be encoded in a memory function that represent the probability for a node, that has already been in contact with a certain number of different nodes, to establish a new link. The memory function has been extensively measured from real datasets and it has been shown to reproduce well the asymptotic evolution of several real temporal networks [2].

In activity driven networks without memory effects, epidemic models can be analytically studied due to the fully mean field nature of the model [1]. Here, we perform a detailed analysis of the SIR and SIS models on activity driven networks with memory. We show that, in general, memory effects lower the epidemic threshold, promoting infection spreading, as already shown in [3] for a single value of the memory parameters. Interestingly, we also show that memory induces non ergodic effects in the dynamics: the value of the epidemic threshold strongly depends on the starting time of the epidemic spreading. Despite this complex dynamical behavior, we are able to provide an analytic description of the epidemic thresholds when the epidemics starts at a very large value of the average degree of the time integrated network. In this case, the creation of new connections becomes very unlikely so that the epidemics evolve on an effective static network. The static network is characterized by a large connectivity so that a suitable site dependent mean field approach can be applied as well and we can formulate the activity based mean field model (ABMF). In this framework the epidemic process can be seen as an activity driven process evolving on the effective static network.

We compare numerical simulations with analytical predictions showing a quite good agreement in the ABMF regime. Surprisingly for strong memory, the value of the threshold tends to the memoryless system. This is due to the fact that, in the effective static networks, large activity nodes are also the most connected and this amplifies the effects of the activity fluctuations. In this framework, degree fluctuations vanishes increasing the memory parameter. On the other hand, for small values of the memory the static networks is maximally heterogeneous in the degree, providing a maximal difference between the analytic prediction and the threshold of the memoryless case.

[1] Perra N, Gonçalves B, Pastor-Satorras R, Vespignani A. Activity driven modeling of time varying networks. Scientific Reports. 2012;2:469. doi:10.1038/srep00469.
2] Ubaldi E, Perra N, Karsai M, Vezzani A, Burioni R, Vespignani A. Asymptotic theory of time-varying social networks with heterogeneous activity and tie allocation. Scientific Reports. 2016;6:35724. doi:10.1038/srep35724.
[3] Kaiyuan Sun, Andrea Baronchelli, and Nicola Perra, Contrasting eects of strong ties on sir and sis processes in temporal networks, The European Physical Journal B 88 (2015), no. 12, 326.

Pablo Villegas - *Universidad de Granada*

Landau Ginzburg theory of cortex dynamics: Scale-free avalanches emerge at the edge of synchronization

The human cortex operates in a state of restless activity, the meaning and functionality of which are still not understood. A fascinating, though controversial, hypothesis, partially backed by empirical evidence, suggests that the cortex might work at the edge of a phase transition, from which important functional advantages stem. However, the nature of such a transition remains elusive. Here, we adopt ideas from the physics of phase transitions to construct a general (Landau Ginzburg) theory of cortical networks, allowing us to analyze their possible collective phases and phase transitions. We conclude that the empirically reported scale-invariant avalanches can possibly come about if the cortex operated at the

edge of a synchronization phase transition, at which neuronal avalanches and incipient oscillations coexist.

Alexander Wagner - *Ruprecht-Karls-Universität, Heidelberg*

Topological effects in quantum walks of a BEC
