

## Abstracts of Invited Talks

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**Natan Andrei**

Rutgers University

**“Quench dynamics in the Sine-Gordon model - Loschmidt Echo and work distribution”**

The Sine-Gordon Hamiltonian is ubiquitous in low-dimensional physics, with applications that range from cold atom systems and strongly correlated systems to quantum impurity systems. We study here its non-equilibrium dynamics using the quantum quench protocol, following the system as it evolves under the Sine-Gordon Hamiltonian from initial Mott type states with large potential barriers. By means of the Bethe Ansatz we calculate exactly the Loschmidt amplitude, the fidelity and work distribution characterizing these quenches for different values of the interaction strength. Some universal features are noted as well as an interesting duality relating quenches in different parameter regimes of the model.

**John Barton**

University of California Riverside

**“Path integral inference of selection in evolving populations”**

Understanding the forces that shape genetic evolution is a subject of fundamental importance in biology and one with numerous practical applications. Modern experimental techniques give insight into these questions, but inferring evolutionary parameters from sequence data, such as how an organism's genotype affects its fitness, remains challenging. Here I will present a method to infer selection from genetic time-series data using a path integral approach based in statistical physics. This approach is shown to be both exceptionally fast and accurate in comparison with other established methods. I will also show how our method can be successfully applied to study how HIV evolves to escape from human immune responses.

**Nihat Berker**

Kadir Has University and MIT

**“All-Temperature Ordering in Maximally Random Systems, Lower Lower-Critical Spin-Glass Dimension, and Continuously Variable Physical Dimension”**

Discrete-spin systems with maximally random nearest-neighbor interactions that can be symmetric or asymmetric, ferromagnetic or antiferromagnetic, including off-diagonal disorder, are studied, for the number of states  $q = 3, 4$  in  $d$  dimensions.[1] We use renormalization-group theory that is exact for hierarchical lattices and approximate (Migdal-Kadanoff) for hypercubic lattices. For all  $d > 1$  and all noninfinite temperatures, the system eventually renormalizes to a random single state, thus signaling  $q \times q$  degenerate ordering. Note that this is the maximally degenerate ordering. For high temperature initial conditions, the system crosses over to this highly degenerate ordering only after spending many renormalization-group iterations near the disordered (infinite-temperature) fixed point. Thus, a temperature range of short-range disorder in the presence of long-range order is identified, as previously seen [2] in underfrustrated Ising spin-glass systems. The entropy is calculated for all temperatures, behaves similarly for ferromagnetic and antiferromagnetic interactions, and shows a derivative maximum at the short-range disordering temperature. With a sharp immediate contrast of infinitesimally higher dimension  $1 + \epsilon$ , the system is as expected disordered at all temperatures for  $d = 1$ . Using the same method, by quenched-randomly mixing local units of different spatial dimensionalities, we have also studied [3] Ising spin-glass systems on hierarchical lattices continuously in dimensionalities  $1 < d < 3$ . The global phase diagram in temperature, antiferromagnetic bond concentration, and spatial dimensionality is calculated. We find that, as dimension is lowered, the spin-glass phase disappears to zero temperature at the lower critical dimension  $d_c = 2.431$ . Our system being a physically realizable system, this sets an upper limit to the lower-critical dimension in general for the Ising spin-glass phase. As dimension is lowered towards  $d_c$ , the spin-glass critical temperature continuously goes to zero, but the

spin-glass chaos fully sustains to the brink of the disappearance of the spin-glass phase. The Lyapunov exponent, measuring the strength of chaos, is thus largely unaffected by the approach to dc and shows a discontinuity to zero at dc.

[1] B. Atalay and A. N. Berker, Phys. Rev. E 97, 052102 (2018).

[2] E. Ilker and A. N. Berker, Phys. Rev. E 89, 042139 (2014).

[3] B. Atalay and A. N. Berker, Phys. Rev. E, in press (2018).

**Michael Brenner**

Harvard University

**“The quest to find a singularity of the Euler Equations: Theory, Simulations and Experiments”**

**Paul Chaikin**

NYU

**“Quantifying hidden order out of equilibrium”**

While the equilibrium properties, states, and phase transitions of interacting systems are well described by statistical mechanics, the lack of suitable state parameters has hindered the understanding of non-equilibrium phenomena in diverse settings, from glasses to driven systems to biology. Here we introduce a simple idea enabling the quantification of organization in non-equilibrium and equilibrium systems, even when the form of order is unknown. The length of a losslessly compressed data file is a direct measure of its information content. Here we use lossless data compression to study several out-of-equilibrium systems, and show that it both identifies ordering and reveals critical behavior and even some critical exponents in dynamical phase transitions. Our technique should provide a quantitative measure of organization in systems ranging from condensed matter systems in and out of equilibrium, to cosmology, biology and possibly economic and social systems.

**Lucy Colwell**

University of Cambridge

**“Using evolutionary sequence variation to build predictive models of protein structure and function”**

The evolutionary trajectory of a protein through sequence space is constrained by its function. Collections of sequence homologs record the outcomes of millions of evolutionary experiments in which the protein evolves according to these constraints. The explosive growth in the number of available protein sequences raises the possibility of using the natural variation present in homologous protein sequences to infer these constraints and thus identify residues that control different protein phenotypes. Because in many cases phenotypic changes are controlled by more than one amino acid, the mutations that separate one phenotype from another may not be independent, requiring us to understand the correlation structure of the data. Models constrained by this structure are capable of (i) inference of residue pair interactions accurate enough to predict all atom 3D structural models; and predictions of (ii) binding interactions between different proteins and (iii) binding between protein receptors and their target ligands.

The challenge is to distinguish true interactions from the noisy and under-sampled set of observed correlations in a large multiple sequence alignment. Current methods ignore the phylogenetic relationships between sequences, potentially corrupting the identification of covarying positions. Here, we use random matrix theory to demonstrate the existence of a power law tail that distinguishes the spectrum of covariance caused by phylogeny from that caused by phenotypic interactions. The power law is essentially independent of the phylogenetic tree topology, depending on just two parameters - the sequence length, and the average branch length of the tree. We demonstrate that these power law tails are ubiquitous in the large protein sequence alignments used to predict contacts in 3D structure, as predicted by our theory, and confirm that truncating the corresponding eigenvectors improves contact prediction.

**Rava Azeredo da Silveira**  
"Neuroscience/Cognition"

Ecole Normale Supérieure

**Michael Desai**

Harvard University

"Observing evolutionary dynamics with lineage tracking"

In large microbial populations, the fates of mutations are often determined over long timescales by competition and hitchhiking among rare high-fitness lineages. I will describe a renewable high-efficiency barcoding approach which makes it possible to periodically add barcodes to an evolving yeast population. New barcodes are integrated immediately downstream of existing barcodes, so that each cell contains a string of barcodes that encodes its ancestry. By sequencing the barcode locus, we can then track the frequencies of all the lineages and sub lineages in the population for an indefinite period of time and trace the ancestry of all the individuals in the population. I will explain what we saw when we used this system to observe evolutionary dynamics at high resolution in two laboratory yeast populations.

**Abhishek Dhar**

International Centre for Theoretical Sciences

"Light-cone spreading of perturbations and the butterfly effect in classical spin chains."

The talk will discuss the chaotic growth and spread of perturbations in many body classical systems with Hamiltonian dynamics. In particular, we will consider the example of the Heisenberg spin chain and show that chaos propagation can be characterised by a velocity dependent Lyapunov exponent. The perturbation spreads ballistically and we comment on some interesting properties of the propagation front.

**Thorsten Emig**

CNRS & Massachusetts Institute of Technology

"Modified Szegő–Widom Theorem for Block Toeplitz Matrices with Zero Modes & some Applications"

The Szegő–Widom theorem provides an expression for the determinant of block Toeplitz matrices in the asymptotic limit of large matrix dimension  $n$ . In my talk, I shall demonstrate that the presence of zero modes, i.e, eigenvalues that vanish as  $\alpha^n$ ,  $|\alpha| < 1$ , when  $n \rightarrow \infty$ , requires a modification of the Szegő–Widom theorem. A new asymptotic expression for the determinant of a certain class of block Toeplitz matrices with one pair of zero modes is derived. The result is inspired by critical Casimir forces in two dimensions and one-dimensional topological superconductors, and the relation with these systems is discussed.

**Biroli Giulio**

Institut de Physique Théorique

"Collective phenomena in large interacting ecosystems"

I will first start with a general introduction on theoretical ecology, stressing the reasons that make connections with statistical physics interesting and timely. I will then focus on Lotka-Volterra equations, which provide a general model to study large assemblies of strongly interacting degrees of freedom in many different fields: biology, economy and in particular ecology. I will present our analysis of Lotka-Volterra equations as model of ecosystems formed by a large number of species and show the different phases that emerge. Two of them are particularly interesting: when interactions are symmetric we find a regime characterised by an exponential number of multiple equilibria, all poised at the edge of stability for a large number of species. For non symmetric interactions, this phase is replaced by a chaotic one. I will then conclude discussing relationships with experiments and general consequences of our works.

**Ramin Golestanian**

Organization (MPIDS) and Oxford University

Max Planck Institute for Dynamics and Self-

**“Condensation transition in a simple model of colloids with diffusivity edge”**

I introduce a simple mean-field model in which an effective description of a colloidal system is presented when it is driven away from equilibrium.

**Sarang Gopalakrishnan**

CUNY

**“Quantum phase transitions in spin chains with hyperuniform couplings”**

We explore quantum phase transitions in spin chains with couplings that are aperiodic but "hyperuniform" in the sense that their long-wavelength fluctuations are suppressed. We focus on the case of random hyperuniform couplings, but if time permits, the case of quasiperiodic couplings will also be discussed. We construct a one-parameter family of disorder models, controlled by a parameter  $\alpha$ , such that  $\alpha = 0$  corresponds to uncorrelated randomness, while for increasing  $\alpha$  long-wavelength fluctuations are increasingly suppressed. We find two regimes of behavior: when  $\alpha$  is small, the transitions we find are of the infinite-randomness type; for large  $\alpha$ , by contrast, the randomness is RG-irrelevant for static properties, but nevertheless completely restructures the dynamics at the critical point.

**Michael Gullans**

Princeton University

**“Entanglement structure of current-driven diffusive fermion systems”**

Applying a chemical potential bias to a conductor drives the system out of equilibrium into a current carrying non-equilibrium state. This current flow is associated with entropy production in the leads, but it remains poorly understood under what conditions the system is driven to local equilibrium by this process. We investigate this problem using two toy models for coherent quantum transport of diffusive fermions: Anderson models in the conducting phase and a class of random quantum circuits acting on a chain of qubits, which exactly maps to an interacting fermion problem. Under certain conditions, we find that the long-time states in both models exhibit volume-law mutual information and entanglement, in striking violation of local equilibrium. Extending this analysis to Anderson metal-insulator transitions, we find that the volume-law entanglement scaling persists at the critical point up to mobility edge effects. This work points towards a broad class of examples of physical systems where volume-law entanglement can be sustained, and potentially harnessed, despite strong coupling of the system to its surrounding environment.

**Timothy Halpin-Healy**

Barnard College

**“Feynman’s Gold”**

2018 is the centenary year of Dick Feynman’s birth; thirty years since his passing. Many of his prized possessions & personal papers were sold recently at Sotheby’s, New York City. This talk will relate some of the impressions of the speaker, who revered Feynman in his youth, but accidentally came to consult on this special auction sale, suddenly finding himself backstage, sitting quietly with the great magician.

**Terence Hwa**

UCSD

**“Growth and Expansion of Chemotactic Bacterial Populations in Open Environment”**

**Hans Jauslin**

Université de Bourgogne

**“Quantization of the electromagnetic field in interaction with a dissipative and dispersive medium; applications to quantum plasmonics”**

The quantization of plasmons has been analyzed mostly under the assumption of an infinite-sized bulk medium interacting with the electromagnetic field. We reformulate it for finite-size media, such as metallic or dielectric nano-structures, highlighting sharp differences. By diagonalizing the Hamiltonian by means of a Lippmann-Schwinger equation, we show the contribution of two sets of bosonic operators, one stemming from medium fluctuations, and one from the electromagnetic field. The results apply to general models including dissipative and dispersive responses.

This is joint work with V. Dorier, J. Lampart and S. Guérin.

**Yariv Kafri**

Technion

**“Long-range forces between bodies in active matter”**

A single non-spherical body placed in an active fluid generates currents. When two or more passive bodies are placed in an active fluid these currents lead to long-range interactions. Using a multipole expansion their leading-order behaviors will be characterized in terms of single-body properties. The interactions are showed to decay as a power law with the distance between the bodies, be anisotropic, and not obey an action-reaction principle. The interactions lead to rich dynamics of the bodies, illustrated by the spontaneous synchronized rotation of pinned non-chiral bodies and the formation of traveling bound pairs. The occurrence of these phenomena depends on tunable properties of the bodies, thus opening new possibilities for self-assembly mediated by active fluids.

**Aharon Kapitulnik**

Stanford University

**“Emerging Phenomena at a Quantum Phase Transition: the Magnetic Field-Tuned Superconductor to Insulator Transition”**

The magnetic-field tuned superconductor-to-insulator transition (H-SIT), along with the quantum-Hall liquid-to-insulator transitions (QHIT) are paradigmatic quantum phase transitions and among the best experimentally studied ones. While evidence continues to mount to the fact that these two phenomena are in the same universality class, key results in the QHIT were not previously identified in the case of H-SIT. Tuning the disorder of two-dimensional superconducting films, and studying the full resistivity tensor, our results show a stark difference between films exhibiting weak vs. strong disorder. In weakly disordered films, the superconducting state gives way to an "anomalous metallic phase" with a resistivity that extrapolates to a non-zero value, but with a vanishing Hall resistance. In the strong disorder limit a "true" H-SIT is observed, characterized by an emerging self-duality at the H-SIT, and the proximate insulating phase is fundamentally distinct from a conventional "Anderson insulator" in that the Hall resistance, rather than diverging, tends to a finite value as the temperature approaches zero. That these features are analogous to behaviors previously documented near the QHIT supports the existence of the correspondence between the two problems implied by the composite boson theory.

**Vedika Khemani**

Harvard University

**“Quantum chaos and the emergence of dissipative hydrodynamics under unitary dynamics”**

**Eugene Kolomeisky**

University of Virginia

**“Kelvin-Froude wake patterns of a traveling pressure disturbance”**

According to Kelvin, a point pressure source uniformly traveling over the surface of deep calm water leaves behind a peculiar wake pattern confined within  $39^\circ$  sector and consisting of the so-called transverse and diverging wavefronts. Actual ship wakes are somewhat different in their appearance both from each other and from Kelvin's prediction. The difference can be attributed to a deviation from the point source limit and quantified by the Froude number  $F$ . We show how the Kelvin argument can be modified to include finite-size effects and classify resulting wake patterns. For smooth pressure sources there exist two characteristic Froude numbers,  $F_1$  and  $F_2 > F_1$ , such as the wake is only present if  $F \gtrsim F_1$ . For  $F_1 \lesssim F \lesssim F_2$  the wake consists of only transverse wavefronts confined within a sector of an angle smaller than Kelvin's. An additional  $39^\circ$  wake made of both transverse and diverging wavefronts is formed outside the "transverse" sector for  $F > F_2$ . If the pressure source has sharp boundary, additional interference effects are present in the small Froude number limit.

**Leonid Koralov**

University of Maryland

**“Large Time Behavior of Randomly Perturbed Dynamical Systems and a New Class of Boundary Value Problems”**

We will discuss several asymptotic problems for randomly perturbed flows. One class of flows (with regions where a strong flow creates a trapping mechanism) leads to a new class of boundary value problems with non-standard boundary conditions. The same problems appear as a limiting object when studying the asymptotic behavior of diffusion processes with pockets of large diffusivity.

We will also discuss how large-deviation techniques can be used to study the asymptotic behavior of solutions to quasi-linear parabolic equations with a small parameter at the second order term and the long time behavior of the corresponding diffusion processes.

**Andrej Kosmrlj**

Princeton University

**“Phase separation in multicomponent liquid mixtures”**

Multicomponent systems are ubiquitous in nature and display complex phase behavior. For example, recent evidence shows that cellular compartmentalization of several cellular bodies occurs by the formation of membrane-less liquid-like droplets via classical phase separation processes. Furthermore, these droplets can self-organize into hierarchical structures with functional implications for cells and their formation can even be manipulated via optical means. Motivated by these observations we investigate phase separation in systems with  $N$  components by using the Flory-Huggins theory of regular solutions. I will discuss how phase diagrams can be obtained via the convex hull construction of free energy landscapes. In order to investigate how different coexisting domains pack in space and how do they grow and coarsen over time, we used the Cahn-Hilliard formalism. We observe that phase separation sometimes occurs in multiple stages. I will discuss how we can estimate interfacial tensions and volume fractions of the coexisting phases, which determine the equilibrium morphology of system. Finally, I will comment on the coarsening of coexisting domains, which can exhibit cross-overs between different scaling regimes.

**Leonid Mirny**

Massachusetts Institute of Technology

**“Physics of Chromosomes”**



**Adam Nahum**

Oxford University

“Simple models for nonintegrable quantum dynamics, and connections to classical statistical mechanics”

**Thomas Nattermann**

University of Cologne

“Vector Chiral phases in frustrated 2D classical XY-model and quantum spin chain”

The phase diagram of frustrated 2D classical and 1D quantum XY models is calculated analytically. Three phases are found: a helical magnetic phase with quasi-long range order, a helical spin liquid phases, and a paramagnetic phase. Vortex interaction is short range on small and logarithmic on large scales. The chiral transition is Ising-like by symmetry, but has non-Onsager exponents due to nonlocal interaction. Exponents are calculated in an expansion around 2.5 dimensions. Applications to anti-ferromagnetic quantum spin chains are discussed.

Co-authors are Valery Pokrovsky and Hannes Schenck

**Vadim Oganesyan**

CUNY

“Scaling description of the many-body localized phase and its spectral signatures”

We experiment with definitions of the decay (localization) length in the many-body localized (MBL) phase as extracted numerically from different correlation functions. We find that all correlation functions in MBL systems exhibit log-normal statistics with mean and variance growing linearly in separation, thereby implying sharply defined (inverse) decay lengths with values differing one observable to another. Importantly, all these values remain quite short over a broad range of parameter space, implying stability of the MBL phase against isolated ergodic inclusions. We also show how these broad distributions may be extracted using interferometric probes such as double electron-electron resonance (DEER) and the statistics of local spin precession frequencies.

Coauthors: V. Varma, S. Gopalakrishnan, V. Oganesyan, D. Pekker, A. Raj

**Dan Pirjol**

IFIN - Bucharest

“Large deviations for time-averaged diffusions in the small time limit”

Time integrals of one-dimensional diffusions appear in the statistical mechanics of disordered systems, actuarial science and mathematical finance. The talk presents large deviations asymptotics for the time-average of a diffusion in the small time limit. The result follows from the classical pathwise large deviations result for diffusions obtained by Varadhan in 1967, and the contraction principle. The rate function is expressed as a variational problem, which is solved explicitly.

Applications are presented to the short maturity asymptotics of Asian options in mathematical finance.

[Based on work with Lingjiong Zhu, Florida State University]

**Jed Pixley**

Rutgers University

“‘Magic-Angle’ Semimetals”

We will discuss the effects of quasiperiodicity on semimetals with Dirac points in two and three dimensions. We will show that a quasiperiodic potential gives rise to a sharp quantum phase transition from a Weyl semimetal into a diffusive metal phase, with a clear non-analyticity in the density of states. This transition can be described by a delocalization transition in momentum space: the quasiperiodic potential destabilizes the ballistic plane wave eigenstates. Due to the weakness of quasiperiodicity, we are able to generalize this transition to two and even one dimension. By tracking the velocity of the Dirac cone we show that at the semimetal to metal phase transition, the velocity goes to zero and the effective

bands become flat. We will discuss how this is the same phenomena that happens at the band structure level in twisted bilayer graphene at the “magic-angle”. Lastly, we will determine the effects of interactions by constructing effective Hubbard models with dramatically enhanced interactions due to this novel semimetal-to-metal phase transition. Our results open the possibility of realizing magic-angle physics in ultra-cold atomic gases and trapped ion experiments.

**Leo Radzihovsky**

University of Colorado

“Fracton-Elasticity Duality”

**Sidney Redner**

Santa Fe Institute

“The Dynamics of Dumb and Less Dumb Foraging”

**Shivaji Sondhi**

Princeton University

“ETH without Thermalization”

The eigenstate thermalization hypothesis (ETH) asserts that single eigenstates of chaotic many body Hamiltonians reproduce the predictions of statistical mechanics. One can restate this as the statement that the equilibrium density matrix can be replaced by one of its representative eigenstates. I will describe two other settings where such a replacement for density matrices appears to be possible. Specifically, these are reduced density matrices on subsystems - in equilibrium and in non-equilibrium steady states in boundary driven GKLS equations.

**Dan Stein**

NYU

“Nature vs. Nurture in Complex (and Not-So-Complex) Systems”

Understanding the dynamical behavior of many-particle systems following a deep quench is a central issue in both statistical mechanics and complex systems theory. One of the basic questions centers on the issue of predictability: given a system with a random initial state evolving through a well-defined stochastic dynamics, how much of the information contained in the state at future times depends on the initial condition (“nature”) and how much on the dynamical realization (“nurture”)? We discuss this question and present both old and new results for both homogeneous and random systems in low and high dimension.

**Brian Swingle**

University of Maryland

“Quantum Lyapunov Spectrum”

We propose a definition of a spectrum of Lyapunov exponents for quantum many-body systems and study it in the context of the Sachdev-Ye-Kitaev model and the disordered Heisenberg spin chain. We find that for quantum chaotic systems the spectrum so defined exhibits random matrix statistics. We also exhibit a possible relation to entanglement entropy growth via one notion of quantum Kolmogorov-Sinai entropy. The discussion will be set in the broader context of many-body quantum chaos and black hole dynamics.

**Romain Vasseur**

University of Massachusetts

“Hydrodynamics of quantum integrable systems: transport, diffusion and operator spreading”



In this talk, I will discuss the recently introduced generalized hydrodynamics framework to describe the non-equilibrium dynamics of integrable systems. I will explain how it can be used to capture transport properties, entanglement and operator spreading in such systems. Using simple kinetic theory arguments, I will show how diffusion can arise from ballistically spreading quasiparticles.