Abstracts of Invited Talks

Larry Abbott – Columbia University
Could a Fly Pass Physics 1?

Michael Aizenman – Princeton University

Jean Bricmont – UC Louvain
Proofs on non-locality almost without experiments
We will give a direct proof on non-locality, without using Bell's inequalities, and using only the perfect correlations between measurements made on distant particles.

Ivan Corwin – Columbia University
Stationary measures for open boundary systems
The Matrix Product Ansatz (as in work of Derrida, Evans, Hakim and Pasquier) is a powerful approach to describe stationary measures for various open boundary systems like ASEP. Finding good representations (as in work of Enaud and Derrida, or Uchiyama, Sasamoto and Wadati) for the quadratic algebra involved here and taking large N asymptotics is considerable work, though the limits of the stationary measures have rather nice descriptions in terms of Brownian excursions, meanders or related objects (see, for example, work of Derrida, Enaud and Lebowitz or Bryc and Wang). I will explain a new approach to describe stationary measures for open boundary systems found in the study of integrable probability. At the finite N level the stationary measures already resemble their limits in that they are described in terms of two random walks interacting in a certain potential. This method builds on ideas from the theory of Macdonald processes and readily yields asymptotic results. I will specifically focus on the log-gamma polymer with open boundaries for which there is not a clear version of the matrix product ansatz. This is based on joint work with Guillaume Barraquand and Zongrui Yang.

Leticia Cugliandolo – LPTHE
Dynamics of Motility-Induced clusters: coarsening beyond Ostwald ripening
Active Brownian Particles undergo Motility Induced Phase Separation, a mechanism whereby they form dense clusters under sufficiently strong energy injection, clusters which grow until the compact phase occupies a finite portion of the sample. I will describe this process and show that standard Oswald ripening combines with aggregation/fragmentation. This entails a rather complex dynamics with clusters undergoing enhanced diffusion, leading to a non-trivial distribution and geometry of clusters during growth, and some other peculiar properties which I will discuss.

Ivana Cvijovic – Stanford University
Mapping the statistics of tissue residence and migration in the human antibody-mediated immunity
Antibodies are crucial in defending against pathogens, but unlike most proteins, they aren't genetically encoded at birth. Instead, they arise in a stochastic evolutionary process in specialized immune cells called B cells. Studying this process is essential for understanding how antibody-mediated immunity develops, is maintained, and evolves throughout life. Recent advances in sequencing technologies allow us to study this at scale by sequencing the genes that encode antibodies. Although most samples used for studying B cell repertoires are collected from peripheral blood, B cells migrate between lymphatic tissues as they proliferate and differentiate. Thus, it is not clear whether the population of circulating B cells in the peripheral blood is representative of the B cell system as a whole. This gap is particularly important because it is know that the majority of circulating

antibody proteins come from cells that reside in the bone marrow, and unclear how these cells are related to those residing in other lymphatic organs. Our study addresses this gap by examining human antibody cells from various lymphatic tissues in the same individual. Our findings reveal extensive exchange between these tissues, but also significant differences among B cells residing in different locations. These insights help us better understand the process by which B cells commit to long-term memory and the statistics governing this active process. Specifically, our results shed light on the tempo and pace at which B cells make decisions about committing to long-term memory.

Michael DeWeese – UC Berkeley

Gregory Eyink – Johns Hokins University
Statistical Physics and Fluid Turbulence in Collision: Spontaneous Stochasticity
The 1998 work of Bernard, Gawędzki and Kupiainen discovered that anomalous dissipation of a scalar advected by turbulence requires a breakdown in the uniqueness of Lagrangian particle trajectories, with molecular Brownian motion amplified to macroscopic scales by turbulent Richardson dispersion. This intrinsic randomness is now called Lagrangian spontaneous stochasticity and has been rigorously demonstrated in models (Kraichnan passive scalar, Burgers) and observed in numerical simulations. More recently, Eulerian spontaneous stochasticity of the full velocity field, due to non-unique dissipative solutions of the Euler fluid equations in the infinite Reynolds limit, has been proved in toy models and observed numerically.
Here small-scale noise is amplified by the ``inverse error cascade" of Lorenz. However, these results challenge the standard belief in the fluid mechanics community that turbulence can be described by deterministic Navier-Stokes equations, ignoring effects of thermal noise. Moreover, they challenge the paradigm in statistical physics that fluid equations arise generally as a ``law of large numbers'' in a ``hydrodynamic scaling limit". Fresh perspectives and new opportunities are thus opened for both fields.
In statistical physics, non-equilibrium thermal fluctuations may be strongly non-Gaussian even in laminar flows and can be investigated by methods of Gawędzki and Kupiainen for the Kraichnan model. In fluid turbulence the spontaneously stochastic limit at infinite Reynolds number has strong analogies to disordered spin systems with infinitely-many ground states and can be tackled with methods from statistical physics such as renormalization group and replica symmetry-breaking.
The work reported here was carried out with colleagues D. Bandak, N. Goldenfeld, A. Jafari, and A. Mailybaev in a collaboration "Revisiting the Turbulence Problem Using Statistical Mechanics" funded by the Simons Foundation through Targeted Grants Nos. 663054 (G.E.) and 662985(N.G.)

Laura Foini – CNRS IPhT Saclay
The eigenstate thermalization hypothesis
The eigenstate thermalization hypothesis (ETH) was developed to explain the mechanism by which "chaotic" systems reach thermal equilibrium from a generic state.
ETH is an ansatz for the matrix elements of physical operators in the basis of the Hamiltonian, and since its postulation, numerous studies have characterized these quantities in increasingly fine detail, providing a solid framework for understanding the (thermo) dynamics of quantum many-body systems.
ETH can be viewed as a generalisation of random matrix theory and, in fact, within this ansatz matrix elements are modeled as random variables.
In our work, we have generalized the ETH ansatz in order to take into account correlations between matrix elements which are essential to describe high-order correlation functions.
By analogy with the theory of random matrices, one can assume a certain hierarchy between these correlations and show how this generalized ansatz underlies a relationship between ETH and free probability, a branch of mathematics that studies non-commutative random variables. This relationship allowed us to unveil a particular structure of the time-dependent correlation functions in thermal equilibrium.

Mark Freidlin – University of Maryland
Long-Time Influence of Small Perturbations
Long-time influence of small deterministic and stochastic perturbations can be described as a motion on the simplex of invariant probability measures of the non-perturbed system. I will demonstrate this general

approach in the case of perturbations of a stochastic system with multiple stationary regimes. If the system has a first integral, the long-time behavior of the perturbed system, in an appropriate time scale, can be described by a motion on the Reeb graph of the first integral. This is a modified (because of the intrinsic vertices of the Reeb graph) averaging-principle-type result. If the non-perturbed stochastic system has just a finite number of ergodic invariant probability measures, the long-time behavior is defined by limit theorems for large deviations.

Cristian Giardina – University of Modena and Reggio Emilia
SOLVABLE MODELS OF ENERGY TRANSPORT
In this talk we will discuss a geometrical approach to the problem of the KPZ Universality. Instead of looking at the height (interface) function and Airy processes, we will focus on the statistics of shocks and points of concentration of mass. We will also discuss the connection with the problem of the coalescing Brownian motions and coalescing fractional Brownian motions.

Shlomo Havlin – Bar Ilan University
Interdependent networks yield novel physical phase transitions
A theoretical framework for studying the percolation theory of interdependent networks will be presented. In interdependent networks, such as infrastructures, when nodes in one network fail, they cause dependent nodes in other networks to also fail. This may happen recursively and can lead to a cascade of failures and to a sudden fragmentation of the system. This is in contrast to a single network where the percolation transition due to failures is continuous. I will present analytical solutions based on percolation theory, for the order parameter (functional network) and cascading failures, for a network of n interdependent networks. Our analytical results show that the percolation theory of a single network studied for 80 years is just a limited case, n=1, of the general and a significantly richer case of n>1. I will also show that interdependent networks embedded in space are significantly more vulnerable and have significantly richer behavior compared to non-embedded networks. In particular, small localized attacks of zero fraction but above a microscopic critical size lead to cascading failures that dynamically propagate like nucleation and yield an abrupt phase transition. I will finally show that the abstract interdependent percolation theory and its novel behavior in networks of networks can be realized and proved in controlled experiments performed on real physical systems. I will discuss the consequences of phase transitions in real physical interdependent systems. I will present very recent experiments that support the interdependent network theory on interdependent superconducting networks where we identified a novel abrupt transition due to cascading failures between the systems although each isolated system shows a continuous transition.
References:
[1] S. Buldyrev, G. Paul, H.E. Stanley, S. Havlin, Nature, 464, 08932 (2010).
[2] J. Gao, S. Buldyrev, H. E. Stanley, S. Havlin, Nature Physics, 8, 40 (2012).
[3] A. Bashan et al, Nature Physics, 9, 667 (2013)
[4] A Majdandzic et al, Nature Physics 10 (1), 34 (2014); Nature Comm. 7, 10850 (2016)
[5] M. Danziger et al, Nature Physics 15(2), 178 (2019)
[6] B. Gross, I Bonamassa and S. Havlin, Fractal fluctuations at mixed-order transitions in interdependent networks, 129 (26), 268301 (2022)
[7] I Bonamassa, Interdependent superconducting networks, preprint arXiv:2207.01669 (2022), Nature Physics (in press, 2023)

Kostya Khanin – University of Toronto
On KPZ problem and statistics of stochastic flows

Leonid Koralov – University of Maryland
Perturbations of Parabolic Equations and Diffusion Processes with Degeneration: Boundary Problems and Metastability
We study diffusion processes in a bounded domain with absorbing or reflecting boundary. The generator of the process is assumed to contain two terms: the main term that degenerates on the boundary in a direction orthogonal to the boundary and a small non-degenerate perturbation. Understanding the behavior of such

processes allows us to study the stabilization of solutions to the corresponding parabolic equations with a small parameter. Metastability effects arise in this case: the asymptotics of solutions, as the size of the perturbation tends to zero, depends on the time scale. Initial-boundary value problems with both the Dirichet and the Neumann boundary conditions will be considered. The talk is based on joint work with M. Freidlin.

Dov Levine – Technion

Jani Lukkarinen – University of Helsinki
Generation and propagation of chaos in the stochastic Kac model
Propagation and generation of "chaos" is an important ingredient for rigorous control of applicability of kinetic theory. Chaos can here be understood as sufficient statistical independence of random variables related to the "kinetic" observables of the system. In this talk based on a joint work with Aleksis Vuoksenmaa, we consider the stochastic Kac model with random velocity exchange. In earlier pioneering works by Janvresse; Carlen, Carvalho and Loss; Mischler and Mouhot, properties such as spectral gap and propagation of chaos starting from certain permutation invariant states have been determined. Here, we focus on generation of chaos, in the sense of approach to a permutation invariant state in this system. We set up suitable random variables and propose methods to control the evolution of their cumulants.

Ben Machta – Yale University

Marcelo Magnasco – Rockefeller University

Leenoy Meshulam – University of Washington
From 100k pigment cells to skillful camouflage: emerging simplicity in sleeping octopuses
For an animal to perform any function, millions of cells furiously interact with each other. Be it a simple computation or a complex behavior, all biological functions involve the concerted activity of many individual units. We seek theoretical approaches that can simplify the rich dynamics of the coordinated activity of thousands of individual cells. In this talk, I shall focus on camouflage behavior in the octopus during wake and sleep. Octopuses possess the remarkable ability to rapidly modify pigment cells on their skin to match their highly visually complex environment. As such, it is a perfect system to study how a macroscale property – camouflage, emerges from microscale level activity of individual cells. We draw on concepts from statistical physics to capture the collective nature of its skin patterns. We find that camouflage skin pattern activity during sleep is reliably confined to a (quasi-) defined dynamical space. Our approach uncovers simplicity despite the apparent complexity of the system.

Alexandre Morozov – Rutgers University
SmartRunner: an adaptive approach to global optimization in discrete systems
Numerous fields in science and technology require global optimization **-** the determination of a global minimum or maximum of a function of a large number of independent variables. Such functions are typically represented as fitness or energy landscapes that are too high-dimensional to be visualized directly. Global optimization problems are challenging because of the predominance of local optima, whose number tends to grow rapidly with the size of the system. In addition, function evaluations can be very costly, imposing a strict constraint on the total number of evaluations available to the algorithm before the final solution must be produced. Many heuristic global optimization algorithms have been proposed over the years, including Simulated Annealing (SA), Stochastic Hill Climbing (SHC), Genetic Algorithm (GA), and Taboo Search (TS). These algorithms often employ an analogy with physical (the behavior of systems with many degrees of freedom in thermal equilibrium at a finite temperature: SA) or biological systems (evolution of a population under mutation and recombination: GA). However, these computational techniques do not explicitly adapt to the nature of the function being optimized, except in a very limited sense of gradually lowering the temperature in SA or keeping a "taboo list" of recently visited states in TS. Here, we present an explicitly adaptive approach to global optimization based on ideas borrowed from reinforcement learning **-** an area of machine learning in which an intelligent agent is able to move on the landscape and learn the best strategy in real time through trial and error. We will demonstrate the performance of our optimization algorithm, called

SmartRunner, on a challenging set of test functions, including the Sherrington-Kirkpatrick spin glass model and the Kauffman's NK fitness landscape model. We will also show that adding a simple adaptive term to the original fitness or energy function can rescue other algorithms, such as SA or GA, from being stuck in local optima.

Ilya Nemenman – Emory University

Chuck Newman – NYU
Thermodynamic Limit of the first Lee-Yang Zero
In a recent paper (arXiv:2210.03602, to appear in C.P.A.M.), Jianping Jiang and I completed (for the standard Ising ferromagnet in d dimensions) the rigorous
verification of the celebrated Yang-Lee (1952) and Lee-Yang (1952) proposal that thermodynamic singularities are exactly the limits in the real physical parameter space (say, the real line for the external magnetic field) of finite-volume singularities in the complex plane. The missing ingredient was to prove that for *all* $T > T_c$, there is a zero-free disc of the partition function about the origin; this extends the 1971-73 high-temperature results of Ruelle. A key ingredient in the proof is the result by Federico Camia, Jianping Jiang and me (arXiv:2207.12247, to appear in Commun. Math. Phys.) that in zero field, the even (multi-site) Ursell functions u_{2k} satisfy:
$(-1)^k u_{2k}$ is increasing in each (ferromagnetic) coupling. The positivity of $(-1)^k u_{2k}$ for all k was derived by Shlosman in 1986.

Stephanie Palmer – University of Chicago

Ron Peled – Tel Aviv University, Princeton University and IAS

Will Perkins – Georgia Tech
Tree contractions, correlation decay, and uniqueness for hard spheres
I will describe the method of correlation decay on the computational tree from the algorithmic study of approximate counting and sampling and then show how it can be used to prove Gibbs uniqueness and analyticity results for classical gases like the hard sphere model.

Joshua Shaevitz – Princeton University
Polar and nematic states drive 3D pattern formation in the bacterium Myxococcus xanthus.
The soil dwelling bacterium Myxococcus xanthus is an amazing organism that uses collective motility to hunt in giant packs when near prey and to form beautiful and protective macroscopic structures comprising millions of cells when food is scarce. I will present an overview of how these cells move and how they regulate that motion to produce different phases of collective behavior. Inspired by recent work on active matter and the physics liquid crystals, I will discuss experiments that reveal how these cells generate nematic order, how defect structure can dictate global behavior, how transient polar states govern the ultimate dynamics, and how cells actively tune the Péclet number of the population to drive a phase transition from a gas-like flocking state to an aggregated liquid-droplet state during starvation.

Avy Soffer – Rutgers University
A new approach to Scattering: On the Asymptotic states of Nonlinear Dispersive and Hyperbolic equations with General Data
I will present a new approach to finding the asymptotic states of Nonlinear Wave Equations with general initial data.
In particular we find for a large class of equations that all asymptotic states are linear combinations of free wave, localized part (solitons, breathers..) and a possibility of self-similar solutions as well in some cases. These results hold for initial data for which the H^1 Sobolev norm (the energy norm) is uniformly bounded in time.

This answers the question of Asymptotic Completeness to a large class of equations, including for the first time, equations with time dependent potentials.
These are joint works with Baoping Liu (Peking Univ) and Xiaoxu Wu (Rutgers).

Tom Spencer – Institute for Advanced Study

Uwe Tauber –Virginia Tech
Spatially Inhomogeneous Stochastic Cyclic Competition Models: Stabilizing Vulnerable Ecologies Through Immigration Waves
We study the induction and stabilization of spiral structures for the cyclic three-species stochastic May–Leonard model with asymmetric predation rates on a spatially inhomogeneous two-dimensional toroidal lattice using Monte Carlo simulations. In an isolated setting, strongly asymmetric predation rates lead to rapid extinction from coexistence of all three species to a single surviving population. However, when the asymmetric competing system is coupled via diffusive proliferation to a fully symmetric May–Leonard patch, the stable spiral patterns from this region induce transient plane-wave fronts and ultimately quasi-stationary spiral patterns in the vulnerable asymmetric region. Thus, the endangered ecological subsystem may effectively become stabilized through immigration from a smaller stable region. To describe the stabilization of spiral population structures in the asymmetric region, we compare the increase in the robustness of these topological defects at extreme values of the asymmetric predation rates in the spatially coupled system with the corresponding asymmetric May–Leonard model in isolation. We delineate the quasi-stationary nature of coexistence induced in the asymmetric subsystem by its diffusive coupling to a symmetric May–Leonard patch, and propose a (semi-) quantitative criterion for the spiral oscillations to be sustained in the asymmetric region.
Reference: S.R. Serrao and U.C.T., Eur. Phys. J. B 94, 175 (2021) [arXiv:2105.08126]

Ramon Van Handel – Princeton University
Phase transitions and nonasymptotic random matrix theory
Classical random matrix theory is almost exclusively concerned with the asymptotic properties very special random matrix models, such as matrices with i.i.d. entries, invariant ensembles, or small perturbations thereof. However, recent breakthroughs in nonasymptotic random matrix theory make it possibe to obtain remarkably precise information about nearly arbitrarily structured random matrices (that may be highly nonohomgeneous, sparse, have dependent entries, and be far outside mean-field situations). For example, it is possible, under mild assumptions, to compute the extreme eigenvalues of an arbitrarily structured random matrix to leading order in terms of a deterministic variational principle. This opens the door to studying various phenomena that were not accessible, or would have required a delicate case-by-case analysis, by classical methods. As an illustration, I will show how this theory gives rise to phase transitions for the extreme eigenvalues of structured random matrices.

Massimo Vergassola – UC San Diego
Fluid dynamics of embryonic development
Early embryogenesis of most metazoans is characterized by rapid and synchronous cleavage divisions. After fertilization, Drosophila embryos undergo 13 swift rounds of DNA replication and mitosis, leading to about 6,000 nuclei distributed along the anteroposterior axis of the embryo. The very first cycles involve substantial flows, both in the bulk and at the cortex of the embryo, while waves of nuclear divisions are observed in late cycles. I shall discuss the experimental data and theoretical models for the fluid dynamics of the cytoplasmic flows that are responsible for the transport of the nuclei and the early patterning of the embryo.

Jan Wehr – University of Arizona
Quantum trajectories of stimulated emission

Ned Wingreen – Princeton University
Exclusion of unwanted components from biomolecular condensates
It has recently become clear that the interiors of cells are organized in both space and time by non-membrane bound compartments, many of which form via liquid-liquid phase separation. These phase-separated condensates play key roles in processes ranging from transcription to translation, signaling, and more. A notable feature of many of the proteins that drive phase separation, i.e., the scaffold molecules, is that they contain large blocks of intrinsically disordered regions (IDRs). These IDRs are believed to play many roles, including modulating the condensates' stability, modifying condensate physical properties such as density and internal diffusivity, and providing binding sites for the rest of the condensate's components, i.e., the client molecules. I will discuss an additional important role of IDRs, namely to exclude large undesired macromolecules from condensates. This exclusion effect arises from the large conformational entropy of IDRs, i.e., there is a large free-energy cost to occupying volume that would otherwise be available to the IDRs. We find that at realistic IDR densities, particles as small as the size of a typical protein (5 nm in diameter) can be more than 90% excluded from condensates. Comparison to data on partitioning of particles into natural and engineered condensates suggests that condensate IDRs may play a generic exclusionary role across organisms and types of condensates.

Horng-Tzer Yau – Harvard University

Emil Yuzbashyan – Rutgers University
Is nonequilibrium superconductivity a quantum or a classical phenomenon?
I will show that the classical (mean-field) description of nonequilibrium superconductivity is exact in the thermodynamic limit for local observables but breaks down for global quantities, such as the entanglement entropy or Loschmidt echo. I will do this by solving for and comparing exact quantum and exact classical long-time dynamics of a BCS superconductor with interaction strength inversely proportional to time and evaluating local observables explicitly.
The long-time steady state of the system is a gapless superconductor whose superfluid properties are only accessible through energy resolved measurements. This state is nonthermal but conforms to an emergent generalized Gibbs ensemble.

Francesco Zamponi – CNRS and Ecole Normale Superieure
Exact solution of liquid dynamics in infinite dimensions
I will describe the exact solution of the dynamics of liquids in the limit of infinite spatial dimensions.
The solution is formulated in terms of an effective two-body dynamics, coupled to a thermal bath due to the other particles, as in any dynamical mean-field theory. The thermal bath is described by a self-consistently determined memory function.
The solution predicts a non-trivial dynamics in the dense liquid regime, and a glass transition at even higher densities.