Abstracts of Invited Talks

Vijay Balasubramanian  
University of Pennsylvania

Carl M. Bender  
Washington University in St. Louis

"PT symmetry in quantum mechanics and quantum field theory"
PT-symmetric quantum theory began with an analysis of the strange-looking non-Hermitian Hamiltonian $H=p^2+x^2(ix)^\epsilon$. This Hamiltonian is PT symmetric and the eigenvalues of this Hamiltonian are discrete, real, and positive when $\epsilon \geq 0$. In this talk we discuss the corresponding quantum-field-theoretic Hamiltonian $$H=\frac{1}{2} (\nabla \phi)^2 + \frac{1}{2} \phi^2 (i \phi)^\epsilon$$ in $D$-dimensional spacetime, where $\phi$ is a pseudoscalar field. We show how to calculate the Green's functions as series in powers of $\epsilon$ directly from the Euclidean partition function. We derive exact finite expressions for the vacuum energy density, the renormalized mass, and the connected $n$-point Green's functions for all $n$ and for $0 \leq D < 2$. For $D \geq 2$ the one-point Green's function and the renormalized mass become infinite, but perturbative renormalization can be performed. The beautiful spectral properties of PT-symmetric quantum mechanics appear to persist in PT-symmetric quantum field theory.

Bill Bialek  
Princeton University

Tommaso Biancalani  
Broad Institute of MIT and Harvard

“Disentangling bacterial invasiveness from lethality in an experimental host-pathogen system”
Understanding virulence remains a central problem in human health, pest control, disease ecology and evolutionary biology. Bacterial virulence is typically quantified by phenomenological indicators such as the LT50 (i.e. the time taken to kill 50% of an infected population). However, virulence emerges as a result of complex processes that occur at different stages: the pathogen needs to breach the primary host defenses, find a suitable environment to replicate, and finally express the virulence factors that cause lethality. It is well-known that pathogens exhibit a very broad spectrum of strategies to accomplish these three tasks, yet, phenomenological indicators such as the LT50 cannot distinguish the ability of the pathogen to invade the host from its ability to kill the host. Here, we propose a physical host-pathogen theory that shows how to disentangle colonization, growth, and pathogen lethality from the survival kinetics of a host population. Preliminary experimental data from C. elegans nematodes exposed to various pathogens shows that host mortality becomes severe only once the pathogen population has reached its carrying capacity within the host. In the talk, I will discuss various model predictions and compare them against experimental data.

Paul Bourgade  
New York University

“Overlaps between eigenvectors of Ginibre matrices”
Eigenvectors of non-hermitian matrices are non-orthogonal, and their distance to a unitary basis can be quantified through the matrix of overlaps. These variables quantify the stability of the spectrum, and characterize the joint eigenvalues increments under Dyson-type dynamics. They first appeared in the physics literature; well known work by Chalker and Mehlig calculated the expectation of these overlaps for complex Ginibre matrices. For the same model, we extend their results by deriving the distribution of the overlaps and their correlations. As a corollary, at equilibrium, eigenvalues move with diffusive scaling under the Dyson-dynamics. (Joint work with G. Dubach).

Christian Brennecke  
Harvard University

“Bogoliubov Theory in the Gross-Pitaevskii Limit”
We consider Bose gases consisting of $N$ particles trapped in a box with volume one and interacting through a repulsive potential with scattering length of the order $N^{-1}$ (Gross-Pitaevskii regime). We determine the ground state energy and the low-energy excitation spectrum, up to errors vanishing as $N \to \infty$. Our results confirm Bogoliubov’s predictions. This is joint work with C. Boccato, S. Cenatiempo and B. Schlein.

Edouard Brezin
Ecole Normale Supérieure
"Random matrices and geometry of surfaces, an historical survey"

Tom Butler
Amazon

David Campbell
Boston University
“The Subtle Road to Equilibrium in the FPUT Model”
The interpretation and consequences of the celebrated Fermi, Pasta, Ulam, Tsingou (FPUT) numerical experiment have challenged scientists for more than six decades. The history of how the original FPUT discovery led to the theory of “solitons,” was key in the understanding of Hamiltonian chaos, and led to the birth of “nonlinear science” is well documented, but there are many fascinating details which are only now being explored and understood. In this presentation, I will discuss two recently studied examples: namely, the details of the existence and breakdown of recurrences and super-recurrences in both the alpha- and beta- versions of the FPUT system, and the remarkable intermittent dynamics, involving long-time, large deviations, that occur once the systems has nominally reached equilibrium.

In the first study1, we find higher-order recurrences (HoR)s—which amount to “super-super-recurrences” in both the alpha and beta models. The periods of these HoR scale non-trivially with energy due to apparent singularities caused by nonlinear resonances, which differ in the two models. Further, the mechanisms by which the HoR breakdown differ strikingly in the two models.

In the second study2, we find that the dynamics at equilibrium is characterized by a power-law distribution of excursion times far off equilibrium, with diverging variance. Long excursions arise from sticky dynamics close to localized excitations in normal mode space ($q$-breathers). Measuring the exponent allows to predict the transition into nonergodic dynamics.

*Work in collaboration with Carlo Danieli, Sergej Flach, and Salvatore Pace,

Eric Carlen
Rutgers University

Arup Chakraborty
MIT
“Inducing cross-reactive antibody responses by vaccination: a crossroad of statistical mechanics”
Vaccination has saved more lives than any other medical procedure. But, today some pathogens have evolved that defy successful vaccination using the empirical paradigms pioneered by Pasteur and Jenner over two centuries ago. HIV is a prominent example. A major barrier to the development of a vaccine against HIV is the high mutability of the virus, which enables HIV to mutate to evade vaccine-induced antibodies and T cells that lie ready and waiting for certain strains. Antibodies are produced by a non-equilibrium Darwinian evolutionary process called affinity maturation. A question of great interest is
how vaccination protocols can be designed to elicit antibodies that are cross-reactive to diverse HIV strains. I will describe work that shows how vaccination with multiple variant strains to induce cross-reactive antibodies results in conflicting selection forces that “frustrate” affinity maturation. I will then discuss how optimal temporal patterns of frustration can promote the evolution of broadly neutralizing antibodies.

**Rodica Costin**
Ohio State University

**Ayse Erzan**
Istanbul Technical University

"Field theory and renormalization group on non-metric spaces"

We implement the analogue of the "momentum space" renormalization group à la Wilson for a scalar ψ4 field theory on deterministic networks, which are not translationally invariant and not necessarily embedded in metric spaces. For these non-metric spaces the correlation length is not well defined and hyperscaling relations cannot be used. Our method relies on a generalized Fourier analysis using the eigenvectors of the graph Laplacian, which may be explicitly calculated using the symmetries of the networks. On the hierarchical lattice, the critical exponents depend on the spectral dimension ds, which can be varied using Itzykson's scheme. At the lower critical dimension for the Ising universality class, up to second order the Gaussian fixed point is stable with respect to quartic perturbations, as previously observed by Wilson. Non-Gaussian fixed points arise for 2<ds < 4.


**Paul Goldbart**
University of Texas at Austin

**Jeffrey Harvey**
University of Chicago

**Björn Hof**
IST Austria

**Ian Jauslin**
Princeton University

**Mehran Kardar**
MIT

“Bacterial range expansions on a growing front: Roughness, Fixation, and Directed Percolation”

Directed Percolation (DP) is a classic model for nonequilibrium phase transitions into a single absorbing state (fixation). It has been extensively studied by analytical and numerical techniques in diverse contexts. Recently, DP has appeared as a generic model for the evolutionary/ecological dynamics of competing bacterial populations. Range expansion - the stochastic reproduction of bacteria competing for space to be occupied by their progeny - leads to a fluctuating and rough growth front, which is known from experiment and simulation to affect the underlying critical behavior of the DP transition. We employ symmetry arguments to construct a pair of non-linear stochastic partial differential equations describing the co-evolution of surface roughness with the composition field of DP. Macroscopic manifestations (phenomenology) of these equations on growth patterns and genealogical tracks of range expansion will be presented. Jordan M. Horowitz, Mehran Kardar

**Igor Klebanov**
Princeton University
Christian Maes  
KU Leuven  
“Cosmic acceleration from quantum Friedmann equations”

We consider a simplified model of quantum gravity using a mini-superspace description of an isotropic and homogeneous universe with dust. We derive the corresponding Friedmann equations for the scale factor, which now contain a dependence on the wave function. We identify wave functions for which the quantum effects lead to a period of accelerated expansion that is in agreement with the apparent evolution of our universe, without introducing a cosmological constant. Authors: Thibaut Demaerel, Christian Maes and Ward Struyve (Instituut voor Theoretische Fysica, KU Leuven)

Juan Maldacena  
Institute for Advanced Study

"Entanglement and the geometry of spacetime"

We will discuss how the quantum mechanical property of entanglement is related to the geometry of spacetime.

Vieri Mastropietro  
University of Milan

Thierry Mora  
Ecole Normale Supérieure

“Diversity and specificity of immune repertoires”

The diversity of repertoires of B-cell and T-cell receptors is generated by a stochastic process of gene rearrangement called VDJ recombination, and is later sculpted by selection, clonal proliferation, and somatic hypermutations. I will show how these processes can be learned quantitatively from high-throughput repertoire sequencing data. The resulting models can then be used to estimate the diversity of repertoires and their overlap between individuals, to identify condition-specific immune receptors from patient cohort data, and to detect signatures of immune responses in single patients.

Narayanan Bhargav Peruvemba  
Rutgers University

“Diffusion on graphs”

Diffusion on a graph is a cellular automaton describing how integer labels on the vertices evolve. The label of a vertex is just the number of particles at that vertex, and at each step, each vertex simultaneously sends one particle to each of its neighbours with fewer particles, mimicking flow towards lower concentrations. What can we say about the trajectories of various initial configurations in this process? Here’s an amuse bouche: this firing rule may generate negative labels when started from a completely positive initial configuration, so it is not clear, a priori, if one must even have a stable final state, or even periodic behaviour necessarily!

Phil Nelson  
University of Pennsylvania

Stefano Olla  
Université Paris Dauphine-PSL

Jeremy Quastel  
University of Toronto

“The strong coupling fixed point of the KPZ universality class”

We describe the scaling invariant, completely integrable Markov process which governs long time large scale fluctuations of 1d random interface growth. It was discovered through a complete solution of TASEP, the most popular discretization of the Kardar-Parisi-Zhang equation. Joint work with Konstantin Matetski and Daniel Remenik
“Quantum graphs and convex geometry”
Quantum graphs—that is, Laplacians on metric graphs with Kirchoff boundary conditions—have been used in mathematical physics to model a range of phenomena, from wave guides and photonic crystals to quantum chaos and localization. In this talk, I will aim to explain how we recently encountered these objects unexpectedly in a very different area of mathematics, namely convex geometry. Exploiting the structure of these models yields a key part of the solution of a 120 year old problem of H. Minkowski. (This is joint work with Yair Shenfeld.)

“Emergent eco-evolutionary phenomena in microbial communities”
The complexity of microbial community dynamics stems not only from the diversity of these communities and the richness of their microbial interactions but also from the fact that many of these interactions can readily evolve. As mutant strains with altered interactions increase in frequency they reshape the ecological dynamics and the selection pressures on existing strains. The spectrum of possible consequences of such an interplay between ecology and evolution are poorly understood. To start filling this gap, we investigated the eco-evolutionary dynamics in communities dominated by toxin-mediated interactions. Such interactions are ubiquitous among soil microbes, and whether and how they contribute to diversity has been a long-standing puzzle. We identified several emergent eco-evolutionary phenomena. First, the dynamics could robustly discover complex evolutionary stable states in which multiple strains coexist (Nash equilibria) despite the fact that such states are unreachable through a step-by-step community assembly. Rather, the system as a whole tunnels between collective states via a fundamentally eco-evolutionary process. Second, communities of particular strains can emerge and persist even if these communities are not ecologically stable. Finally, the dynamics can exhibit intermittency in which prolonged periods of apparent community stability are interrupted by periods of fast strain turnover. In spatially structured communities, this intermittency leads to mosaics in which different spatial regions are in different eco-evolutionary regimes in a phenomenon reminiscent of phase coexistence in material science. These findings demonstrate that toxin-mediated interactions are a viable mechanism for explaining diversity, provide a qualitatively new mechanism for adaptive diversification, and expand our understanding of the different possible modes of eco-evolutionary dynamics in microbial communities.

“Odd Elasticity”
Hooke's law states that the deformations or strains experienced by an elastic object are proportional to the applied forces or stresses. The number of coefficients of proportionality between stress and strain, i.e. the elastic moduli, is constrained by energy conservation. In this Letter, we generalize continuum elasticity to media in which energy is not conserved, such as solids with microscopic activity. This generalization, which we dub odd elasticity, reveals that two additional elastic moduli exist in an isotropic solid with non-conservative interactions. Such an odd-elastic solid can be regarded as a distributed engine: work is locally extracted, or injected, during quasi-static cycles of deformation. By coarse graining illustrative microscopic
models, we show how odd elasticity emerges in active metamaterials composed of non-reciprocal springs that actuate internal torques in response to strain. Our predictions, corroborated by simulations, uncover phenomena ranging from activity-induced auxetic behavior and buckling to wave propagation powered by self-sustained active elastic cycles.

**Aleksandra Walczak**
**CNRS and Ecole Normale Supérieure**
**“Prediction in immune repertoires”**
Predicting the future state of a complex environment requires weighing the trust in new observations against prior experiences. In this light, I will present a view of the adaptive immune system as a dynamic Bayesian machinery that updates its memory repertoire by balancing evidence from new pathogen encounters against past experience of infection to predict and prepare for future threats. The results suggest that pathogenic environments are sparse and that memory repertoires significantly decrease infection costs even with moderate sampling.

**Shenshen Wang**
**University of California, Los Angeles**
**“Evolving generalists in changing landscapes”**
Evolving systems, be it an antibody repertoire in the face of mutating pathogens or a microbial population exposed to varied antibiotics, respond to ever changing environments through a constant search for adaptive solutions in high-dimensional fitness landscapes. Generalists are robust performers that remain fit under varied environmental conditions. For better (induction of broad antibody response) or worse (emergence of multi-drug resistance), it is important for evolution to discover these adaptive solutions efficiently. Yet, whether and when environmental changes can offer them evolutionary advantage over specialists remains an open question. We use a generative model within a generic landscape framework to study evolutionary discovery of generalists in slowly changing environments. We show that switching rugged fitness landscapes can enhance the propensity to evolve high performers, if the landscapes’ topography is related in a way that balances the trade-offs between diversity, quality and accessibility of such solutions, thus demonstrating a general route toward favoring or avoiding generalists via a proper choice of cycling environments.

**Jean Zinn-Justin**
**IRFU/CEA, Paris-Saclay**
**“From Callan-Symanzik equations to numerical values of critical exponents”**
I will briefly recall how, in the spirit of Wilson's RG theory of critical phenomena, Callan-Symanzik’s equations have provided a convenient framework to calculate numerical values of various critical quantities at fixed dimensions, alternative to the famous Wilson-Fisher epsilon-expansion.