128th STATISTICAL MECHANICS CONFERENCE

Abstracts of Invited Talks

Michael Aizenman, Princeton University
Quantum stoquastic tensor networks from a stat mech perspective
Tensor networks form platforms for quantum computations, and appear naturally also in the representation of thermal and ground states of many body quantum systems. The talk will focus on correlations and entanglement in a class of such networks through methods that emerge from analogies with systems of classical statistical mechanics. (Work in progress with Simone Warzel).

Giada Basile, Universit`a di Roma 'La Sapienza'
Large deviations for binary collision models
I will present some recent results on large deviations for binary collision stochastic models. The paradigmatic model is the Kac's walk, described, in the kinetic limit, by the homogeneous Boltzmann equation. Although the dynamics preserves the energy, atypical paths that violate energy conservation may occur with exponentially small probability in the number of particles. I will exhibit a few examples of atypical paths with increasing/decreasing energy, and I will show that a dynamical phase transition may occur for the asymptotics of the total number of collisions.
This is a joint work with L. Bertini, D. Benedetto, E. Caglioti and D. Heydecker. Founded by the European Union - Next Generation EU.

Arup Chakraborty, MIT
How the humoral immune system learns
The humoral immune system, comprised of B cells and their products (antibodies), generates protective responses against a vast and evolving world of infectious disease-causing microbial pathogens. Despite the great diversity of pathogens, a bespoke response tailored for the specific infecting pathogen is generated. Humoral immunity learns how to generate such a response by a Darwinian evolutionary process that ensues upon exposure to a pathogen. A memory of this "training" is imprinted, which can be recalled upon re-exposure to that pathogen by similar processes. These processes underlying humoral immunity and learning are stochastic, dynamic, and driven far from equilibrium. Based on statistical physics-based models of these processes along with experiments and clinical data (with collaborators) we find that the humoral immune system learns to generalize and become able to respond to previously unseen variants of a pathogen upon repeated exposure to one (or very few) variant (s). The mechanisms underlying this remarkable ability will be described. Finally, I will note how we are exploring and exploiting analogies between how the humoral immune system learns and how machines learn to potentially make fundamental advances of pragmatic value.

Dmitri Chklovskii, Flatiron Institute
Do Your Neurons Understand Physics Better Than You Do?
The Rectified Linear Unit (ReLU), a fundamental building block in contemporary artificial intelligence, critically oversimplifies the intricate temporal dynamics observed in biological neurons. In this talk, we introduce a novel conceptual framework for neuronal functionality based on the clustering of coherent sets—collections of dynamical states evolving cohesively over finite time intervals. Leveraging spectral clustering techniques borrowed from dynamical systems, we present an algorithmic neuron model that accurately captures these temporal dynamics. Our approach holds significant potential to advance neuroscience research and the development of biologically inspired artificial intelligence systems.

SueYeon Chung, NYU/Flatiron Institute
Computing with Neural Manifolds: Towards a Multi-Scale Understanding of Biological and Artificial Neural Networks
Recent breakthroughs in experimental neuroscience and machine learning have opened new frontiers in understanding the computational principles governing neural circuits and artificial neural networks (ANNs). Both biological and artificial systems exhibit an astonishing degree of orchestrated information processing capabilities across multiple scales - from the microscopic responses of individual neurons to the emergent macroscopic phenomena of cognition and task functions. At the mesoscopic scale, the structures of neuron population activities manifest themselves as neural representations. Neural computation can be viewed as a series of transformations of these representations through various processing stages of the brain. The primary focus of my lab's research is to develop theories of neural representations that describe the principles of neural coding and, importantly, capture the complex structure of real data from both biological and artificial systems.

In this talk, I will present three related approaches that leverage techniques from statistical physics, machine learning, and geometry to study the multi-scale nature of neural computation. First, I will introduce new statistical mechanical theories that connect geometric structures that arise from neural responses (i.e., neural manifolds) to the efficiency of neural representations in implementing a task. Second, I will employ these theories to analyze how these representations evolve across scales, shaped by the properties of single neurons and the transformations across distinct brain regions. Finally, I will demonstrate how insights from the theories of neural representations can elucidate why certain ANN models better predict neural data, facilitating model comparison and selection.

Predrag Cvitanowic, Georgia Tech
Field theory description of spatiotemporal chaos
Description of fluid turbulence by unstable invariant solutions of Navier-Stokes equations, with no statistical assumptions, leads us to a formulation of a new, deterministic field theory of both (low-dimension) chaotic dynamical systems, and (infinite-dimension) spatiotemporally turbulent flows.
The main novelty in our formulation is that we treat space and time democratically, and work in infinite spacetime, with the partition sum given by a sum over all spatiotemporal Bravais lattices, each contributing a sum over multi-periodic solutions of the defining equations. Here the "thermodynamic parameter" is neither the time T (as is the custom in the dynamical systems literature) nor the spatial extent L, but the spacetime Bravais lattice volume V=LT.
This partition sum leads to a new kind of a zeta function, our exact spatiotemporal zeta function, which in one time and one space dimension takes form of an infinite product of Dedekind eta functions, one for each prime multi-periodic solution, with a stability weight given by its Hill-Poincare functional determinant.
This is a combined work with Han Liang

Tatiana Engel, Princeton University
Universal scaling of intrinsic timescales across the whole mouse brain
Ongoing neural activity unfolds over diverse intrinsic timescales, which increase along the cortical hierarchy and vary across neurons within each area, reflecting their functional specialization. Yet, the mechanisms underlying the variation of timescales within and across brain regions remain largely unknown. Using a brain-wide dataset of single-neuron activity, we found that timescales varied widely across regions, with the midbrain and hindbrain exhibiting five-fold slower timescales than the forebrain. Despite this variation, timescales within each area followed a universal power law with a consistent scaling exponent of –2, spanning the range from tens of milliseconds to several seconds. To investigate the mechanisms behind this scaling, we studied recurrent neural network models with random connectivity. We found that power-law timescale distributions emerge in networks with heavy-tailed connectivity operating in a chaotic regime, occurring when synaptic gain parameter is sufficiently large. In this regime, the timescale exponent follows that of the connectivity distribution, independent of synaptic gain, while the median timescale depends on both parameters. The scaling exponent of –2 aligns with previously reported connectome data, reinforcing the link between connectivity and timescale distributions. Our findings reveal the organizing principles of timescale

variation across the whole mouse brain and propose a unifying network mechanism for their emergence and universal scaling.

Pablo Ferrari, Universidad de Buenos Aires and Conicet
Hard rod hydrodynamics and the Lévy Chentsov field
A Poisson line process is a random set of straight lines contained in the plane, as the image of the map $(x,v)\mapsto (x+vt)_{t\in\mathbb{R}}$, for each point (x,v) of a Poisson process in the space-velocity plane. By associating a step with each line of the process, a random surface is obtained. The diffusive rescaling of the surface converges to the Lévy-Chentsov field, a classical Gaussian field. The process is also called Brownian motion with several parameters because a cut of the surface with a perpendicular plane, reveals Brownian motion.

A hard rod is an interval contained in $\mathbb{R}$ that travels ballistically until it collides with another hard rod, at which point they interchange positions. By associating each line with the ballistic displacement of a hard rod and associating surface steps with hard rod jumps, we obtain the hydrodynamic limits of the hard rods in the Euler and diffusive scalings, in function of Chentsov type surfaces.

James Fitzgerald, Northwestern University
Stability through plasticity: Finding robust memories through representational drift
Memories are believed to be stored in synapses and retrieved through the reactivation of neural ensembles. Learning alters synaptic weights, which can interfere with previously stored memories that share the same synapses, creating a tradeoff between plasticity and stability. Interestingly, neural representations exhibit significant dynamics, even in stable environments, without apparent learning or forgetting—a phenomenon known as representational drift. Theoretical studies have suggested that multiple neural representations can correspond to a memory, with post-learning exploration of these representation solutions driving drift. However, it remains unclear whether representations explored through drift differ from those learned or offer unique advantages. Here we show that representational drift uncovers noise-robust representations that are otherwise difficult to learn. We first define the non-linear solution space manifold of synaptic weights for a fixed input-output mapping, which allows us to disentangle drift from learning and forgetting and simulate representational drift as diffusion within this manifold. Solutions explored by drift have many inactive and saturated neurons, making them robust to weight perturbations due to noise or continual learning. Such solutions are prevalent and entropically favored by drift, but their lack of gradients makes them difficult to learn and non-conducive to further learning. To overcome this, we introduce an allocation procedure that selectively shifts representations for new information into a learning-conducive regime. By combining allocation with drift, we resolve the tradeoff between learnability and robustness.

Erwin Frey, LMU Munich
Turing Foams and Active Foams
Non-equilibrium protein pattern formation and the self-organization of motor-filament mixtures, driven by NTPase cycles, are crucial mechanisms for cellular processes like division and polarization. Despite their distinct physical origins, both systems can form remarkably similar structures. Protein diffusion-reaction dynamics lead to foam-like patterns, which we termed ``Turing foams," that follow non-equilibrium interface laws similar to equilibrium foams [1]. Motor-filament mixtures similarly self-organize into supramolecular structures, including micelles, bilayers, and foams, driven by instabilities [2]. This talk will discuss the shared non-equilibrium principles governing these systems, focusing on interface laws linked to thermodynamic-like relations.
[1] Deciphering the Interface Laws of Turing Mixtures and Foams, Henrik Weyer, Tobias A. Roth, and Erwin Frey, [arXiv:2409.20070].
[2] Supramolecular assemblies in active motor-filament systems: micelles, bilayers, and foams, Filippo De Luca, Ivan Maryshev, and Erwin Frey, Physical Review X 14, 031031 (2024).

Stefano Fusi, Columbia University
Rarely categorical, always high-dimensional: how the neural code changes along the cortical hierarchy

A long-standing debate in neuroscience concerns whether individual neurons are organized into functionally distinct populations that encode information differently (“categorical” representations) and the implications for neural computation. Here, we systematically analyzed how cortical neurons encode cognitive, sensory, and movement variables across 43 cortical regions during a complex task (14,000+ units from the International Brain Laboratory public Brain-wide Map data set) and studied how these properties change across the sensory-cognitive cortical hierarchy. We found that the structure of the neural code was scale-dependent: on a whole-cortex scale, neural selectivity was categorical and organized across regions in a way that reflected their anatomical connectivity. However, within individual regions, categorical representations were rare and limited to primary sensory areas. Remarkably, the degree of categorical clustering of neural selectivity was inversely correlated to the dimensionality of neural representations, suggesting a link between single-neuron selectivity and computational properties of population codes that we explained in a mathematical model. Finally, we found that the fraction of linearly separable combinations of experimental conditions (“Shattering Dimensionality”) was near maximal across all areas, indicating a robust and uniform ability for flexible information encoding throughout the cortex. In conclusion, our results provide systematic evidence for a non-categorical, high-dimensional neural code in all but the lower levels of the cortical hierarchy.

Pedro Garrido, University of Granada
Anharmonic lattices with periodic forcing: Some results
We have rigorously demonstrated the existence of a well-defined perturbation scheme around the harmonic solution when the anharmonic potential has bounded second derivatives and when the frequency of the forcing and its harmonics lies outside the range of harmonic frequencies.
Additionally, we describe the system's general behavior when the forcing is in resonance with some of the harmonic frequencies and/or when the anharmonicity is strong.

Mark Goldman, UC Davis
STDP^2: a metaplasticity mechanism for learning synaptic plasticity rules
Synaptic plasticity rules govern how the strengths of connections between neurons evolve over time to mediate learning. Classically, such plasticity rules are assumed to be hardwired into neural circuits. Here, we suggest that plasticity rules themselves may be highly plastic, enabling neural circuits to optimize their learning rules based on the statistics of their spiking inputs. We focus our study on spike-timing-dependent plasticity (STDP), in which the strength of synaptic weight changes is governed by the timing between the presynaptic and postsynaptic spikes a neuron experiences. We show that the plasticity kernels that define the changes in synaptic weight resulting from pre-post spike pairs at different temporal intervals can themselves be learned from the long-timescale statistics of the spike pair correlations. We refer to this form of metaplasticity as STDP2: spike-timing dependent plasticity of spike-timing dependent plasticity. We demonstrate with both phenomenological and biochemical models how STDP2 can explain the recent finding that plasticity rules in the region of the brain known as the cerebellum are precisely tuned to behaviorally relevant time delays. Depending on the form and kinetics of the biochemical network, STDP2 can tune the STDP plasticity kernel to different statistical features of a neuron’s pre-post spike interval distribution. Altogether, this work suggests that the fundamental rules governing synaptic plasticity are themselves plastic and demonstrates how this metaplasticity can be mechanistically implemented to enhance the learning capability of neural circuits.

Oskar Hallatschek, UC Berkeley
Microfluidic Island Biogeography
Microbial communities often thrive in spatially confined environments, such skin pores or intestinal crypts. These microhabitats foster stable populations that contribute to the diversity and functionality of microbiomes. However, the impact of spatial constraints on microbial community assembly and evolution remains poorly understood. By monitoring and modeling microbial populations under controlled microfluidic confinement, we uncover a rich spectrum of dynamical patterns that are controlled by the competition between density-dependent outflow and population growth. Our findings reveal that passive diffusion, regulated by population density, can push a reproducing community to a jamming threshold—leading to a complete loss of mixing and intra-species competition. The emerging sensitivity to scale may be viewed as a rigorously quantifiable in vitro version of similar effects reported in the field of island biogeography, and underscores the need to control for

scale in microbial ecology experiments. Systematic, flow-adjustable length scale variations may serve as a promising strategy to elucidate further scale-dependent tipping points and to rationally modulate the stability and resilience of microbial colonizers.

Naomichi Hatano, University of Tokyo
Non-Hermiticity and non-Markovianity of open quantum systems
The open quantum system is a part of a bigger closed system; it is typically a small but complex system (often called the system) surrounded by a large but simple system (often called the environment).
I here report our new findings about the non-Hermiticity and non-Markovianity of open quantum systems.
Since the system exchanges energy and probability with the environment, the effective Hamiltonian of the system is generally non-Hermitian.
Complex eigenvalues of all resonant states are given by the non-Hermitian Hamiltonian. For one-body scattering problem, I report our new resolution of unity that comprises all point spectra including all complex eigenvalues.
Another interesting feature of open quantum systems is their dynamics.
Since the environemnt functions as a memory, the dynamics of the system is generally non-Markovian with the memory kernel coming from the Green's function of the environment. Again for one-body problem, I report our new findings about the power-law decay in the short- and long-term regimes of the dynamics of the system.

David Huse, Princeton University
A low-density parity check (LDPC) code as a nonrandom spin glass
We explore the phase diagram and the "landscape" of a classical LDPC code model as a nonrandom Ising spin-glass model on regular random graphs and on trees (expander graphs). The model we consider has extensive ground state entropy, having an extensive number of Z_2 Ising symmetries. The ground states are generalized ferromagnetic states which are at the bottom of "smooth valleys", so relaxational dynamics at zero temperature in these ferromagnetic valleys converges quickly to the ground state without errors (good performance as a "passively error correcting" code). But at low nonzero temperature the system at thermal equilibrium is instead in a spin glass phase, with a first-order-like transition to the paramagnet at the spin glass critical temperature. This thermal equilibrium spin glass transition is thermodynamically invisible; it is seen in the dynamics and in "point-to-set" long-range correlations (Mezard and Montanari).
Work with Grace Sommers (Princeton), Benedikt Placke (Oxford), Vedika Khemani (Stanford).

Yariv Kafri, Technion
Stability of Discrete and Continuous-Symmetry Flocks
The talk will discuss the stability of flocking phases which exhibit symmetry breaking. For models which break a discrete symmetry, both an active Ising model and a hydrodynamic description will be used to show that droplets of particles moving in a direction opposite to that of the ordered phase nucleate and grow ballistically in all directions. The results imply that, in the thermodynamic limit, discrete-symmetry flocks are metastable in all dimensions. Following this the ordered phase of a flocking model which breaks a continuous symmetry will be considered and argued to be stable in parts of the phase diagram. This implies that in flocking models, in contrast to equilibrium systems, breaking a continuous symmetry is easier than a discrete one.

Randall Kamien, University of Pennsylvania
Knitogami
We explore the relationship between a knitted yarn network and its "scaffold surface" to address topological, geometric, and mechanical questions about knit textile behavior. The scaffold structure allows for a mean-field understanding of yarn mechanics, reducing the need to simulate direct yarn-to-yarn contacts by focusing on the geometry of the scaffold surface as an intermediary object. The scaffold structure as part of the Schwarz

diamond minimal surface further offers insight into the geometric tendencies of knit and purl stitches, as well as their interfaces.

Mehran Kardar, MIT
Competition at the front of expanding populations
When competing species grow into new territory, the population is dominated by descendants of successful ancestors at the expansion front. Successful ancestry depends on the reproductive advantage (fitness), as well as ability and opportunity to colonize new domains. We present a model that integrates both elements by coupling the classic description of one-dimensional competition (Fisher equation) to the minimal model of front shape (KPZ equation). Macroscopic manifestations of these equations are distinct growth morphologies controlled by expansion rates, competitive abilities, or spatial anisotropy, In some cases the ability to expand in space may overcome reproductive advantage in colonizing new territory. When new traits appear with accumulating mutations, we find that variations in fitness, as well as fixation time, belong to distinct universality classes depending on limits to gain of fitness.

Kirill Korolev, Boston University
KPZ and Fisher equations describe competition in microbial colonies
In growing populations, the fate of mutations depends on their competitive ability against the ancestor and their ability to colonize new territory. I will discuss a theory that integrates both aspects fitness via a coupling between two classic reaction-diffusion equations: the KPZ equation, which describes surface growth, and the Fisher equation, which describes the spatial spread of a beneficial allele. The coupled equations exhibit distinct dynamical regimes and colony morphologies depending on whether the Fisher equation admits pulled (linear) or pushed (nonlinear) solutions. This theory explains recent experimental observation of slow expanders taking over the expansion front and predicts novel morphologies of mutant sectors within microbial colonies.

Andrej Kosmrlj, Princeton University
Designing the Morphology of Separated Phases in Multicomponent Liquid Mixtures
Phase separation of multicomponent liquid mixtures plays an integral part in many processes ranging from industry to cellular biology. While the physics of binary and ternary liquid mixtures is well-understood, the thermodynamic properties of N-component mixtures with $N>3$ have remained relatively unexplored. This makes it challenging to understand how cells control concentrations of molecules and their interactions to navigate phase diagrams to achieve target structures. To address this issue, we developed novel algorithms for constructing phase diagrams and for predicting the morphology of separated phases. To determine the number of coexisting phases and their compositions, we developed a new algorithm for constructing complete phase diagrams, based on numerical convexification of the discretized free energy landscape. Furthermore, we developed a graph theory approach to predict the topology of coexisting phases from a given set of surface energies (forward problem), enumerate all topologically distinct morphologies, and reverse engineer conditions for surface energies that produce the target morphology (inverse problem).

Konstantin Mischaikow, Rutgers University
Identifying Nonlinear Dynamics from Sparse Data
I will discuss a novel method, combining Conley theory and Gaussian Process surrogate modeling with uncertainty quantification, through which it is possible to characterize local and global dynamics, e.g., existence of fixed points, periodic orbits, connecting orbits, bistability, and chaotic dynamics, and to provide lower bounds on the confidence that this characterization of the dynamics is correct. Furthermore, numerical experiments indicate that it is possible to identify nontrivial dynamics with high confidence with surprisingly small data sets.

Partha Mitra, Cold Spring Harbor Laboratory
AI Without Networks
Machine Learning (ML) stands on two legs: large training data corpora and many-parameter artificial neural networks (ANNs). The data corpora are needed to represent the complexity of the world. The role of the networks is less transparent due to the obscure dependence of the network parameters and outputs on the

training data and inputs. This raises problems, ranging from technical-scientific to legal-ethical. We hypothesize that a transparent approach to machine learning is possible without using networks or parameters at all. By generalizing a parameter-free, statistically consistent data interpolation method, which we analyze theoretically in detail, we develop a network-free framework for ML incorporating generative modeling. We derive exact results for the convergence rates of errors to the theoretical Bayes limits. Interestingly the convergence rate is dimension-independent, and relevant quantities show scale-free distributions which we derive. We demonstrate the framework with examples from three different disciplines - ethology, control theory, and mathematics. The framework is deterministic and does not require any training or parameter or model selection, and is easily reproduced and ported, desirable qualities for scientific applications.

Alexandre Morozov, Rutgers University
Emergence of cooperativity in the game of Prisoner's Dilemma
Complex life would be impossible without cooperation at all levels of biological organization: genes cooperate to create regulatory networks and signaling pathways, cells become parts of multicellular organisms, animals enter into complex cooperative arrangements both within and between species. Cooperation is ubiquitous in modern human societies and is credited with the development of civilization. However, Darwinian evolution is believed to promote selfish behavior - societies of cooperators are vulnerable to cheaters that ultimately take over, destroying cooperation in biological populations. This apparent paradox has puzzled evolutionary biologists for more than half a century. A well-known model of the paradox is provided by the celebrated Prisoner's Dilemma, an elegant mathematical framework which favors cheaters, even though being a part of a cooperative society brings about greater overall rewards. Here we demonstrate that it is possible to achieve high levels of cooperativity in the game of Prisoner's Dilemma without developing any game strategies or introducing additional assumptions about genetic relatedness and population structure. The only requirement is that the probability of cooperation has to vary depending on the opponent, instead of being blind to the opponent's physical appearance and patterns of behavior. Opponent-specific responses drive the population through a sequence of persistent cooperative states - a plausible starting point for more stable modes of cooperation observed in animal and human societies.

Ilya Nemenman, Emory University
A second look at low-dimensional neural computation
Low-dimensional manifolds are widely believed to underlie neural population activity, guiding our understanding of brain computation. But is this belief empirically justified? In this talk, I will draw on tools from random matrix theory and modern machine learning to revisit the evidence for low-dimensional neural dynamics and to explore whether current interpretations may be misleading. I will then address how such manifolds might emerge from the dynamics of large neural networks, and why low-dimensional computation could offer functional advantages.

Jed Pixley, Rutgers University
Controlling chaos on classical and quantum computers
Chaotic evolution, the exponential sensitivity to initial conditions, underpins a great deal of everyday phenomena. In certain settings, it is possible to control the chaotic evolution by pushing the system towards an unstable fixed point of the dynamics, which drives the system through an absorbing state transition. Recent efforts have shown how to embed this kind of dynamics into a quantum many-body system, which requires using measurements and feedback to design the control operation. In the quantum setting this drives a measurement induced phase transition that may or may not coincide with the absorbing state transition depending on the structure of the feedback operation. We will discuss the current theoretical understanding of feedback driven transitions in quantum many-body systems and will present data on realizing this system on IBM’s superconducting quantum processor with over 100 qubits.

Abigail Plummer, Boston University
Statistical mechanics of the flexural Ising model

Inspired by both nanoscale and macroscale metamaterials, we study thermalized membranes with embedded arrays of buckled bistable nodes with simulations and theory. Buckled nodes interact with their neighbors via the elastic energy of the host membrane such that they prefer to be antialigned at zero temperature, similar to an Ising antiferromagnet. Molecular dynamics simulations of this system reveal a phase transition in the ordering of buckled nodes for which critical exponents can be measured. Many, but not all, of these critical exponents are consistent with the Ising universality class. We explore this result using renormalization group methods. We also establish a mapping between extrinsic curvature (i.e., wrapping the thermalized membrane into a cylinder) and an effective external magnetic field.

Subir Sachdev, Harvard University
Spin liquids and the cuprate superconductors
I will survey recent theoretical advances on the spin liquid states of square lattice antiferromagnets, and on two-dimensional strange metal states inspired by the zero-dimensional SYK model.
I will then connect these advances to key features of the phase diagram of the cuprates.

Sebastian Seung, Princeton University
The Mind of a Fly
Neuroscientists now have a map of connections between the 140,000 neurons in a fruit fly brain. This "fly connectome" was hailed by the media as a revolutionary achievement. But can a digital map of a dead brain, no matter how detailed, really tell us about the mind of a fly? I will show you the dazzling sights of fly neurons, and then I will help you decipher their meaning. Just by looking and thinking, you will understand some of the workings of a fly's mind.

Gigliola Staffilani, MIT
A curious phenomenon in wave turbulence theory
In this talk we will use the periodic cubic nonlinear Schrödinger equation to present some estimates of the long time dynamics of the energy spectrum, a fundamental object in the study of wave turbulence theory. Going back to Bourgain, one possible way to conduct the analysis is to look at the growth of high Sobolev norms. It turns out that this growth is sensitive to the nature of the space periodicity of the system. I will present a combination of old and very recent results in this direction.

Paul Steinhardt, Princeton University
The search for quasicrystals: here, there, and everywhere
The talk will first briefly discuss the subtle relation between quasicrystals and hyperuniformity. Then it will describe current progress in searching for quasicrystals in unexpected places outside the laboratory.

Vincenzo Vitelli, University of Chicago
Odd Turbulence
Fully developed turbulence is a universal and scale-invariant chaotic state characterized by an energy cascade from large to small scales at which it is eventually arrested by dissipation. In this talk, we show how to harness turbulent cascades to generate patterns. Pattern formation entails a process of wavelength selection, which can usually be traced to the linear instability of a homogeneous state. By contrast, our fully nonlinear mechanism is triggered by the non-dissipative arrest of turbulent cascades: energy piles up at an intermediate scale, which is neither the system size nor the smallest scales at which it is usually dissipated. The tunable wavelength of these cascade-induced patterns can be set by a non-dissipative transport coefficient called odd viscosity, ubiquitous in chiral fluids ranging from bioactive to quantum systems. Odd viscosity acts as a scale-dependent Coriolis-like force and leads to two-dimensionalization of the flow and suppression of intermittency. These effects are caused by parity-breaking waves that give rise to a regime of (odd) wave turbulence at small scales. Apart from odd viscosity fluids, we discuss how cascade-induced patterns can arise in natural systems, including atmospheric flows, stellar plasma such as the solar wind, or the pulverization and coagulation of objects or droplets in which mass rather than energy cascades.

Jane Wang, Cornell University
Physics and Evolution of Insect Flight
I will discuss computational models for insect flight, mathematical analyses of flight stability, and control algorithms for insects' equilibrium reflexes. These works are motivated to understand the connection between the physical principles of flight and insects' evolved behavior.

Ned Wingreen, Princeton University
The Benefits of a Fitness-Dependent Mutation Rate: Insights from B Cell Affinity Maturation
B cells expressing high-affinity antibodies are generated through an evolutionary process called B cell affinity maturation, which involves iterative cycles of selection and division coupled with somatic hypermutation. However, because mutations are random, they rarely enhance antibody affinity. Recently, it was discovered that the counterproductive effects of mutagenesis are mitigated during B cell affinity maturation by modulating somatic hypermutation rates based on the affinity of antibodies expressed by individual B cells. Motivated by these observations linking mutation rates to individual fitness, we analyze an evolutionary hill-climbing model with fitness-dependent mutation rates. Our results reveal a sharp transition and a sign change in the optimal slope of mutation rate vs. fitness that maximizes the speed of adaptation. In the biologically relevant regime where favorable mutations are rare, mutation rates that decrease with increasing relative fitness significantly accelerate the accumulation of beneficial mutations. Furthermore, we find that lowering mutation rates for fitter individuals can prevent "mutational meltdown" in asexual populations by reducing the likelihood of fixation of deleterious mutations. These findings suggest potential strategies to enhance population adaptation to environmental changes and to improve the efficiency of evolutionary algorithms and directed evolution.