# 129th STATISTICAL MECHANICS CONFERENCE
# SHORT TALK SCHEDULE

## SESSION A: Monday December 15, 2025 9:00 am - 10:00 am

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**A1: Benjamin Sorkin, Princeton University**
**Title**: **Accelerated Ostwald ripening by chemical activity**
**Coauthors: Ned Wingreen**
**Abstract:** Living systems often harness energy to accelerate desired biological processes. One ubiquitous process is phase separation of biomolecular condensates, which promote enzyme-substrate colocalization and enable membrane-free compartmentalization in living cells. We are thus motivated to devise a theory pinpointing how active chemical reactions, interconverting molecules between phase-separating and inert forms, can drive faster condensate coarsening. We find that mass conservation limits droplet volume growth to being linear in time regardless of activity, resembling the passive Lifshitz–Slyozov law. However, if reactions are restricted to occur only outside droplets, the rate of Ostwald ripening can be increased by an arbitrarily large factor. We posit that the ability to induce rapid biocondensate coarsening can be advantageous in synthetic biology, e.g., as a regulator of metabolic channeling.

**A2: Hari Rajesh, Rutgers University**
**Title: Topological Phases in Solute-Frustrated Clock Models**
**Coauthors: Rick Remsing**
**Abstract:** Nanoconfinement can lead to new and exciting behavior in aqueous chemical systems. Of particular interest are the unique phase behavior and enhancement of reaction rates when aqueous electrolyte solutions are confined within the interlayer of layered materials. These systems can be modeled by solute-frustrated q-clock (SFqC) models, where solutes are added to the q-clock model. We perform Monte Carlo simulations of these SFqC models to understand their phase behavior. We find that these systems each exhibit a variety of topological phases at low temperatures; for instance, we find that topological defects can drive crystallization. Additionally, we develop some theoretical understanding of these models which predicts many of the interesting phenomena observed. We anticipate these results to guide the development of materials that take advantage of frustration and topology to tune nanoconfined aqueous chemical dynamics.

**A3: Ben Vollmayr-Lee, Bucknell University**
**Title: Lifshitz-Slyozov Theory with an Anisotropic Surface Tension**
**Coauthors: Arjun Anand, Melinda Andrews**
**Abstract:** We investigate the impact of an anisotropic surface tension on late-stage dilute phase separation dynamics, revisiting the seminal Lifshitz-Slyozov (LS) theory which traditionally relies

on the assumption of isotropy. Using a perturbative treatment for weak anisotropy, we demonstrate that although the characteristic drop growth law remains unchanged, the anisotropy causes a significant breakdown of morphological universality. Specifically, we find a one-parameter family of nonequilibrium drop shapes that depend on the scaled drop size, where smaller drops are more spherical and larger drops exhibit enhanced anisotropy in comparison to the equilibrium Wulff shape. Furthermore, the analysis confirms that the drop size distribution is modified from the isotropic LS distribution, occurring at second order in anisotropy strength.

**A4: Istvan Kovacs, Northwestern University**
**Title: Structural brain criticality**
**Coauthors: Helen S. Ansell**
**Abstract:** Recent cellular-level volumetric brain reconstructions have revealed high levels of anatomic complexity. Determining which structural aspects of the brain to focus on, especially when comparing with computational models and other organisms, remains a major challenge. Here we quantify aspects of this complexity and show evidence that brain anatomy satisfies universal scaling laws, establishing the notion of structural criticality in the cellular structure of the brain. Our framework builds upon understanding of critical systems to provide clear guidance in selecting informative structural properties of cellular brain anatomy. As an illustration, we obtain estimates for critical exponents in the human, mouse and fruit fly brains and show that they are consistent between organisms, to the extent that data limitations allow. Such universal quantities are robust to many of the microscopic details of the cellular structures of individual brains, providing a key step towards generative computational models of the cellular structure of the brain, and also clarifying in which sense one animal may be a suitable anatomic model for another.

**A5: Sean Fancher, University of Michigan**
**Title**: **Sensitivity Limits from the Geometry of Nonequilibrium Response**
**Coauthors: Jordan Horowitz**
**Abstract**: Many biophysical processes can be accurately modeled as a system stochastically exploring a discrete and connected network of possible states. Probability distributions over this space are not only subject to the system's intrinsic noisy dynamics, but may also be influenced by externally imposed perturbations. While results such as the Fluctuation-Dissipation Theorem allow for a precise understanding of how such perturbations may affect observable quantities on the system, these only properly function at equilibrium. Here, we explore the case of perturbations on nonequilibrium stochastic systems and derive a new response formula based on the Matrix-Tree Theorem approach. In particular, we derive the tightest possible linear bounds to sensitivity in arbitrary observables based on only the topology of the state network. These bounds stem from achetypical primitive models we call "uniquely constructable sets" that dictate the system properties under extreme conditions. As an exploratory example, we investigate a model of a macromolecule with three ligand binding sites to showcase how the

uniquely constructable sets can be used to find all possible variations that are capable of maximizing the sensitivity of the number of bound sites relative to the external ligand concentration.

**A6: Celia Reina, University of Pennsylvania**
**Title: A statistical mechanics framework for deriving continuum models far from equilibrium and its application to phase transforming systems**
**Coauthors: Travis Leadbetter, Prashant K. Purohit**
**Abstract :** We present a statistical mechanics framework for constructing predictive non-equilibrium thermodynamics models from particle systems obeying Langevin dynamics, that does not rely on fitting to experiments or lower scale simulations. The framework, called Stochastic Thermodynamics with Internal Variables (STIV) [1] only relies on the following ingredients: (i) a functional form for the microscopic probability distribution, parameterized by the state variables (these will include the classical state variables in equilibrium thermodynamics, such as strain and temperature, and internal variables needed to prescribe the non-equilibrium state), (ii) the definition of thermodynamic quantities as in stochastic thermodynamics [2], and (iii) a variational statement of the Fokker-Planck equation, proposed by Eyink [3], from which the evolution equation of the state variables can be derived. We show how this framework can be used to construct what we believe is the first statistical mechanics derivation of a non-conservative phase field model in a one-dimensional elastic medium [4]. We remark that phase field methods are a highly popular and versatile approach for modeling interface material behavior. However, their formulation is primarily phenomenological, and the connection to lower scale physics often proceeds through parameter fitting. In contrast, the model derived via STIV is free of phenomenology, and comparisons to Langevin dynamic simulations indicate that it is highly predictive of the macroscopic response. References: [1] Leadbetter, T., Purohit, P. K., & Reina, C. (2023). A statistical mechanics framework for constructing nonequilibrium thermodynamic models. PNAS Nexus, 2(12), pgad417. [2] U. Seifert, Stochastic thermodynamics, fluctuation theorems and molecular machines, Reports on Progress in Physics 75 (2012) 504 126001. [3] G. L. Eyink, Action principle in nonequilibrium statistical dynamics, Physical Review E 54 (1996) 3419. [4] Leadbetter, T., Purohit, P. K., & Reina, C. (2025). A statistical mechanics derivation and implementation of non-conservative phase field models for front propagation in elastic media. Journal of the Mechanics and Physics of Solids, 204, 106240.

**A7: Matthew Marko, Marko Motors LLC**
**Title: Numerical studies of the impact of the intermolecular Van der Waals forces on entropy**
**Abstract :** A numerical model is built, simulating the principles of kinetic gas theory, to predict pressures of molecules in a spherical pressure vessel; the model tracks a single particle and multiplies the force on the spherical walls by a mole of molecules to predict the net pressure. An intermolecular attractive force is added for high-density simulations, to replicate a real fluid; the force is chosen to ensure the fluid matches the Peng-Robinson equation of state as it is compressed to a near supercritical density. The standard deviations of the molecule velocity with

respect to temperature and density is studied to define the entropy. A clear correlation between the calculated entropy and the measured standard deviation of the velocity was obtained for ideal-gas simulations. When analyzing the simulated molecules of real argon, a clear correlation was observed from the strength of the intermolecular Van der Waals forces, and the reduction in this equivalent entropy, as defined by the of molecule velocities was obtained. This effort served to numerically replicate the observed impact of the intermolecular Van der Waals forces on the entropy of real fluids, as studied experimentally in an earlier effort (http://doi.org/10.1038/s41598-022-11093-z).

**A8: Qidong He, Rutgers University (Monday after 9:30)**
**Title**: **Extended regime of nematic order in an interacting monomer-dimer model of Heilmann and Lieb**
**Abstract:** We revisit a two-dimensional model of liquid crystals introduced by Heilmann and Lieb (1979), which consists of a system of dimers on the square lattice at chemical potential mu, interacting via a hard-core repulsion and an attractive interaction of strength -a0. We prove this conjecture under the additional condition that 3a>mu by adapting the strategy of Hadas and Peled (2025) for proving the existence of a columnar phase in the hard-square model. The proof uses a version of the disagreement percolation method developed by van den Berg and **Maes** (1994). [arXiv:2511.23437]

**A9: Stephen Thornton, UCLA**
**Title : Scaling functions for rigidity transitions in disordered systems near 2 dimensions**
**Coauthors : Danilo B. Liarte, Itai Cohen, James P. Sethna**
**Abstract:** Rigidity percolation and jamming are two examples of zero-temperature phase transitions where materials continuously lose their shear modulus. A dynamical mean field theory (DMFT), the coherent potential approximation (CPA), gives predictions for all linear response quantities of disordered elastic media near these transitions. We compute all critical exponents and scaling functions within the CPA and show that the scaling of this DMFT is rich, with logarithmic corrections appearing in 2D. We quantitatively describe these logarithmic corrections and find modified critical exponents below 2D using normal form theory, which gives a scaling structure similar to a full RG, where a variable controlling the amplitude of low-frequency dissipation becomes marginal in 2D.

**A10: Leone Luzzatto, Northwestern University**
**Title: A cluster-based approach to phase transitions in active system**
**Coauthors: Leone V. Luzzatto, Mathias Casiulis, Stefano Martiniani, István A. Kovács**
**Abstract**: Phase transitions in active and other non-equilibrium systems can be challenging to study using the standard tools of statistical physics. However, phase transitions can often be described in terms of the percolation properties of appropriate geometric clusters, and cluster

formation is a common feature of many active systems. We show how to efficiently locate and characterize first- and second-order phase transitions in active systems by studying one-dimensional cross-sections of emerging clusters, using motility-induced phase separation as a paradigmatic example. This approach—known as cluster tomography—enables us to measure some critical exponents without explicitly introducing system-specific order parameters or mapping to an equilibrium system. Cluster tomography is an easy-to-implement yet powerful approach for studying higher-order correlations in far-from-equilibrium systems, making it a useful addition to the standard toolbox of statistical physics.

**A11: Anirban Mukherjee, Princeton University**
**Title: Generic power laws in higher-dimensional lattice models with multidirectional hopping**
**Coauthors: Animesh Hazra, Tanmoy Chakraborty, Punyabrata Pradhan**
**Abstract:** We show that, on a $d-$dimensional hypercubic lattice with $d>1$, conserved-mass transport processes, with {\it multidirectional} hopping that respect all symmetries of the lattice, exhibit power-law correlations for generic parameter values $-$ even {\it far} from phase transition point, if any. The key idea for generating the algebraic decay is the notion of {\it multidirectional} hopping, which means that several chunks of masses, or several particles, can hop out simultaneously from a lattice site in multiple directions, consequently breaking detailed balance. Notably, the systems we consider are described by a continuous-time Markov process, are diffusive, {\it lattice-rotation symmetric}, spatially homogeneous and thus have {\it no} net mass current. Using hydrodynamic and exact microscopic theory, we show that, for spatial dimensions $d > 1$, the steady-state static density-density and ``activity''-density correlation functions in the thermodynamic limit typically decay as $\sim 1/r^{(d+2)}$ at large distance $r=|{\bf r}|$; the strength of the power law is exactly calculated for several models and expressed in terms of the density-dependent bulk-diffusion coefficient and Onsager matrix (or, mobility tensor). In particular, our theory explains why center-of-mass-conserving dynamics, used to model novel disordered {\it hyperuniform} state of matter, result in generic long-ranged correlations. However, in a restricted parameter regime, the correlations can also be short ranged and are characterized through the Onsager matrix. Ref.- Animesh Hazra, Tanmoy Chakraborty, \underline{\textbf{Anirban Mukherjee}}, and Punyabrata Pradhan, \textit{Generic power laws in higher-dimensional lattice models with multidirectional hopping}, \textit{Phys. Rev. E} (accepted 3 September 2025), \href{https://arxiv.org/abs/2503.18365}{arXiv:2503.18365}.

**A12: Aaron Beyen, KU Leuven**
**Title**: **Coupling an elastic string to an active bath: the emergence of inverse damping**
**Coauthors: Christian Maes and Ji-Hui Pei**
**Abstract:** We consider a slow elastic string with Klein-Gordon dynamics coupled to a bath of

run-and-tumble particles. We derive and solve the induced Langevin-Klein-Gordon string dynamics with explicit expressions for the streaming term, friction coefficient, and noise variance. These parameters are computed exactly in a weak coupling expansion. The induced friction is a sum of two terms: one entropic, proportional to the noise variance as in the Einstein relation for a thermal equilibrium bath, and a frenetic contribution that can take both signs. The frenetic part wins for higher bath persistence, making the total friction negative, and hence creating a wave instability akin to inverse Landau damping. However, this acceleration decreases and eventually disappears when the propulsion speed of the active particles becomes much higher. Detailed simulations confirm the initial growth driven by this anti-damping.

**SESSION B: Tuesday, December 16, 2025 9:00 am- 9:30 am**

**B1: Peter Morse, Seton Hall University**
**Title: Packing spheres with no translational degrees of freedom**
**Coauthors: Eric Corwin, R. Cameron Dennis, Milo Tiemann**
**Abstract:** The standard sphere packing problem is concerned with the most efficient packing in each dimension d. This problem has a long and rich history in mathematics, and yet solutions are only known in d=1, 2, 3, 8, and 24. While strong conjectures for best packings exist in many other dimensions, proof in each dimension is notoriously difficult. Constraints, however, reduce the complexity of the solution space, and thus in this work, we apply the greatest number of constraints that retain non-triviality. Given a point pattern, we ask what is the most efficient packing of polydispsere spheres that can decorate it. This problem has a rank-d programming solution, yet the greediest algorithm does quite well and becomes exact in the limit of large dimension. Here, I will discuss the relation of this problem to associated glass and jamming problems and make a connection to the landscape of the random Lorentz gas.

**B2: Lawrence Frolov, Rutgers University**
**Title: Idealized detecting screens and the arrival time problem**
**Abstract:** Consider a particle prepared in some bounded region of physical space, and suppose a detecting screen has been placed along the boundary of this region. How does the presence of this screen influence the dynamics of the particle's wave function? Under some simple idealizations, effectively irreversibility of detection process and strong sensitivity to interaction, I will show the wave function conditioned on non-detection must satisfy a linear absorbing boundary condition along the detecting screen as it obeys the standard Schrödinger equation away from the screen. I will then show that a Born rule for the time of detection naturally emerges for each of these idealized detecting screen models.

**B3: Carlo Vanoni, Princeton University**
**Title: Effective delocalization in the one-dimensional Anderson model with stealthy disorder**
**Coauthors: Boris L. Altshuler, Paul J. Steinhardt, Salvatore Torquato**
**Abstract:** We investigate analytically and numerically the one-dimensional Anderson model with stealthy disorder, characterized by a power spectrum that vanishes over a continuous range of wave numbers. Motivated by recent studies on the optical transparency of stealthy hyperuniform layered media, we calculate the localization length using a perturbative expansion of the self-energy. For fixed energy and small but finite disorder strength $W$, we show that there exists, for any finite system size, a range of stealthiness $\chi$ where the localization length exceeds the system length, leading to an “effective delocalization." This phenomenon arises from the long-range correlations inherent to stealthy disorder, which suppress contributions across a

continuous range of length scales. Unlike uncorrelated disorder, where the localization length $\xi \sim W^{-2}$ at leading order, in stealthy systems the first several terms of the perturbation expansion vanish as $\chi$ increases, yielding scaling of the form $\xi \sim W^{-2n}$ with arbitrarily large $n$. These analytical predictions are supported by numerical simulations. Our findings highlight the distinctive localization properties of stealthy disorder and provide a framework for exploring its implications in quantum systems of both theoretical and experimental interest.

**B4: Sergio Eraso, MIT**
**Title : Length Distributions of a Model of Filament Growth with Side-Branching**
**Coauthors : Mehran Kardar**
**Abstract:** Branching structures are ubiquitous in biological systems at a variety of scales, from cytoskeletal networks to plant roots. Here, we present an analytical study of deterministically elongating filaments that undergo stochastic branching in the absence of interactions. We calculate the length distributions of subpopulations of fixed and actively growing segments for tip bifurcations and side-branching processes. In the absence of side-branching, these subpopulations exhibit identical distributions. However, the inclusion of side-branching breaks this symmetry, producing distinct universality classes (functional forms) of length distributions depending on whether branching occurs on fixed and/or growing filaments. Furthermore, we find that the ratio of typical branch lengths of fixed and active filaments is confined to a finite interval when side branching acts on growing filaments. Thus, experimental measurements deviating from the predicted finite interval would suggest the involvement of branching mechanisms beyond those included in this model.