126th STATISTICAL MECHANICS CONFERENCE

SHORT TALK SCHEDULE

SESSION A

A1: Giovanni Battista Carollo, University of Bari
Title: Modeling quenched disorder with a multibath
Coauthors: Giuseppe Gonnella, Federico Corberi
Abstract : We discuss the behavior of disordered systems in contact with a multibath, meaning that different groups of variables are in contact with a specific thermal bath characterized by a specific value of temperature and timescale. More specifically, we highlight the relation between a system with quenched disorder in contact with a thermal bath and a companion one where the originally frozen disorder is annealed by thermalisation with a second thermal reservoir at a different temperature. In the limit in which the disorder variables become extremely slow and hot the two systems are expected to share the same static properties. We discuss the non-equilibrium fluctuation-dissipation relation in the annealed system and the associated concept of effective temperature in different models. We show that such effective temperature not only may bear a signature of the temperatures of the two reservoirs, but also reveals the fluctuation-dissipation relation of the corresponding quenched model in the aging state after a temperature quench.

A2: Jaeuk Kim, Princeton
Title: Perfect transparency intervals of disordered stealthy hyperuniform two-phase media
Coauthors: Salvatore Torquato
Abstract: Disordered stealthy hyperuniform (SHU) two-phase dielectric composites exhibit novel electromagnetic wave transport properties. One salient property is perfect transparency up to a finite wavenumber. This property implies that within a finite range of wavenumbers, electromagnetic waves can propagate without any loss, and the effective dynamic dielectric constant has a zero imaginary part. We derive the theoretical predictions on these intervals for perfect transparency of SHU composites. To achieve our goal, we use exact nonlocal strong-contrast expansions of the effective dynamic dielectric constant tensor, which has been demonstrated to be very accurate even beyond the long-wavelength regime via the full-waveform simulations. Using the second-order approximations of this series, we obtain the formulas of perfect transparency intervals for three-dimensional SHU media with various structural symmetries: layered, transversely isotropic, and fully isotropic. We prove that these intervals are valid up to the third order, especially for layered media and transversely isotropic media with transverse magnetic (TM) polarization. We discuss physical implications of these predictions. [1] J. Kim and S. Torquato, Optica, 10 965972 (2023) [2] J. Kim and S. Torquato, Opt. Mater. Express, 14 194-215 (2024)

A3: Peter Morse, Princeton University
Title: Decorrelation in disordered stealthy hyperuniform systems as a function of dimension
Coauthors: Paul Steinhardt, Sal Torquato
Abstract: Stealthy hyperuniform point patterns have a structure factor that is precisely zero over a range of wavenumbers which includes zero. Given that the structure factor is related to the two point correlation function through a Fourier transform, stealthy hyperuniform point patterns can thus be considered hard spheres in Fourier space up to the two point level. This relationship allows us to make several claims and predictions about stealthy hyperuniform systems, particularly in high dimensions, where all higher order correlation functions become trivially related to two-point correlations. For disordered systems, we predict the structure of equilibrium stealthy systems given the requirement that their structure factor should reduce to a simple step function in high dimensions. We compare these predictions to the structure of non-equilibrium disordered stealthy hyperuniform systems created from minimizations in dimensions d=2-8. We find that the structure of the non-equilibrium disordered stealthy hyperuniform systems better match the equilibrium predictions as dimension increases.

A4: Ian Jauslin, Rutgers University
Title: **A simple, reflection positive model with a liquid-vapor phase transition**
Coauthors: Qidong He, Joel L. Lebowitz, Ron Peled
Abstract: At 100 degrees Celsius, liquid water boils and transitions to a gas state. This transition is a first-order phase transition, between a phase where particles interact a lot, to one in which they interact little. Because strongly interacting particle systems are difficult to study, this phase transition is not so easy to understand. In the XIXth century, Maxwell introduced a procedure that reproduces the theormodynamic properties that were measured experimentally. However, the theoretical justification of Maxwell's construction from first principles is notoriously difficult. In a breakthrough paper that appeared in 1966, J.L. Lebowitz and O. Penrose derived the Maxwell construction starting from a microscopic model, in which particles interact via a so-called Kac potential, which is infinitely weak and infinitely long-range (in this sense, their result is a mean-field one). Since then, there has been much work in attempting to extend this result to systems of particles with weak (but finite) interactions over large (but finite) range. Lebowitz, Mazel, and Presutti managed to do just that in 1998-99 for a model of particles with a Kac-type attraction, but also a long range four-body repulsion. It is still an open problem to extend the Lebowitz-Penrose result to models with a pair interaction, which is more natural than the four-body potential of Lebowitz, Mazel, and Presutti. In this talk, I will present work in progress in which we define a simplified interacting particle model, with a pair interaction. This model is a coarse-grained version of one in which particles interact via an attractive Kac potential, as well as a (repulsive) hard-core interaction. We prove that this model is reflection-positive, which allows us to easily prove the existence of a phase transition that has all of the hallmarks of the liquid-vapor transition. This model is thus one in which the liquid-vapor phase transition can be

understood with minimal effort, while being somewhat realistic, by virtue of having only pairwise interactions between particles.

A5: Qidong He, Rutgers University
Title: **Analyticity for classical hard-core gases via recursion**
Abstract: Using an extension of the recursion method developed by Michelen-Perkins (2023), I improve the known lower bound on the activity up to which the (infinite-volume) pressure of a continuum system of hard spheres with possibly attractive pair interactions is analytic. In the high-temperature regime, the improved bound surpasses the classical Penrose-Ruelle bound by a factor of e^2. [arXiv:2405.04451]

SESSION B

B1: Nikolai Bogolyubov, Russian Academy of Sciences
Title: Fluorescence by a polar quantum system in a polychromatic field
Coauthors : Andrey V. Soldatov
Abstract : The fluorescent radiative properties of a trichromatically driven quantum polar system with broken spatial inversion symmetry represented by a model of a single-electron two-level asymmetric quantum dot with permanent electric dipole moment, so that its electric dipole operator diagonal matrix elements are not equal to each other, were examined. It was shown that the high-frequency spectral properties of the fluorescent radiation can be alterated with equal efficiency either by controlling the intensity or polarization of the low-frequency component of the trichromatic driving field, or else by changing the degree of the quantum dot asymmetry. Possible options to apply this useful effect for practical purposes in the field of optoelectronics are also discussed. 1. N. N. Bogolyubov, Jr., A. V. Soldatov, “Resonance fluorescence of polar quantum systems in a bichromatic field”, Theor. and Math. Phys., 217:3 (2023), p. 1827–1841 2. N. N. Bogolyubov (Jr.), A. V. Soldatov, “Optoelectronic transistor effect in a polar quantum system driven by a trichromatic field”, Phys. Part. Nucl., 54:6 (2023), p. 1132–1141

B2: Justus Wilhelm Fink, Rutgers
Title: How to quantify fitness in biological systems
Coauthors: Michael Manhart
Abstract: Fitness is a key concept of evolutionary theory and perhaps one the most ambiguous terms in the biological literature. This is unfortunate, because even in highly controlled microbial systems, different research groups track evolutionary progress using different fitness metrics. Where do they all these fitness metrics come from and can we say which ones are natural? I will briefly outline a framework that allows to conceptualize relative and absolute fitness metrics, starting from the single axiom that 'fitness is any number that is sufficient to predict the future abundance'.

B3: Haina Wang, Princeton University
Title: Designer Pair Statistics of Disordered Many-Particle Systems with Novel Properties
Coauthors: Salvatore Torquato
Abstract: : Knowledge of exact analytical functional forms for the pair correlation function $g_2(r)$ and its corresponding structure factor $S(k)$ of disordered many-particle systems is limited. For fundamental and practical reasons, it is highly desirable to add to the existing data base of analytical functional forms for such pair statistics. Here, we design a plethora of such pair

functions in direct and Fourier spaces across the first three Euclidean space dimensions that are realizable by diverse many-particle systems with varying degrees of correlated disorder across length scales, spanning a wide spectrum of hyperuniform, typical nonhyperuniform and antihyperuniform ones. This is accomplished by utilizing an efficient inverse algorithm that determines equilibrium states with up to pair interactions at positive temperature that precisely match targeted forms for both $g_2(r)$ and $S(k)$. Among other results, we realize an example with the strongest hyperuniform property among known positive-temperature equilibrium states, critical-point systems (implying unusual 1D systems with phase transitions) that are not in the Ising universality class, systems that attain self-similar pair statistics under Fourier transformation, and an experimentally feasible polymer model. We show that our pair functions enable one to achieve systems with a wide range of translational order and self-diffusion coefficients $\cal D$, which are inversely related to one another. One can design other realizable pair statistics via linear combinations of our functions or by applying our inverse procedure to other desirable functional forms. Our approach facilitates the inverse design of materials with desirable physical and chemical properties by tuning their pair statistics.

B4: Charles Maher, Princeton University
Title: Hyperuniformity Classes of Quasiperiodic Tilings via Diffusion Spreadability
Coauthors: Adam Hitin-Bialus, Charles Emmett Maher, Paul J. Steinhardt, and Salvatore Torquato
Abstract: Hyperuniform point patterns can be classified by the hyperuniformity scaling exponent $\alpha > 0$, that characterizes the power-law scaling behavior of the structure factor S(k) as a function of wavenumber $k \equiv |\mathbf{k}|$ in the vicinity of the origin, e.g., $S(k) \sim |k|^\alpha$ in cases where S(k) varies continuously with k as $k \to 0$. In this paper, we show that the spreadability is an effective method for determining α for quasiperiodic systems where S(k) is discontinuous and consists of a dense set of Bragg peaks. It has been shown in [Torquato, Phys. Rev. E 104, 054102 (2021)] that, for media with finite α, the long-time behavior of the excess spreadability $S(\infty) - S(t)$ can be fit to a power law of the form $\sim t^{(-(d-\alpha)/2)}$, where d is the space dimension, to accurately extract α for the continuous case. We first transform quasiperiodic and limit-periodic point patterns into two-phase media by mapping them onto packings of identical nonoverlapping disks, where space interior to the disks represents one phase and the space in exterior to them represents the second phase. We then compute the spectral density spectral density of the packings, and finally compute and fit the long-time behavior of their excess spreadabilities. Specifically, we show that the excess spreadability can be used to accurately extract α for the 1D limit-periodic period doubling chain ($\alpha = 1$) and the 1D quasicrystalline Fibonacci chain ($\alpha = 3$) to within 0.02% of analytically known results. Moreover, we obtain a value of $\alpha = 5.97 \pm 0.06$ for the 2D Penrose tiling, which had not been known previously. We also show that, due to the self-similarity of the structures examined here, one can truncate the small-k region of the scattering information used to compute the spreadability and obtain an accurate value of α, with a small deviation from the untruncated case that decreases as the

system size increases. This strongly suggests that one can obtain a good estimate of α for an infinite self-similar quasicrystal from a modestly-sized finite sample. The methods described here offer a simple way to characterize the large-scale translational order present in quasicrystalline and limit-periodic media in any space dimension that are self-similar. Moreover, the scattering information extracted from these two-phase media encoded in spectral density, can be used to estimate their physical properties, such as their dynamic dielectric constants, dynamic elastic constants, and fluid permeabilities.

B5: Murray Skolnick, Princeton University
Title: A hard particle packing algorithm for modeling layered mosaic perovskite alloy microstructures across length scales
Coauthors: Salvatore Torquato
Abstract: Layered metal-halide perovskite materials display a wide-variety of microstructures that span the order-disorder spectrum and can be tuned via the composition of the constituent B-site octahedral species. To better understand the formation and physical properties of these complex alloys, we develop a computationally efficient hard-particle packing algorithm that models accurately their geometrical and topological properties across length scales. Our algorithm can accurately predict the miscibility of a prescribed composition of different B-site octahedra. Additionally, by identifying the percolating networks of paramagnetic B-sites at various compositions, the simulated structures provide insight into the long-range magnetic order of certain alloys.