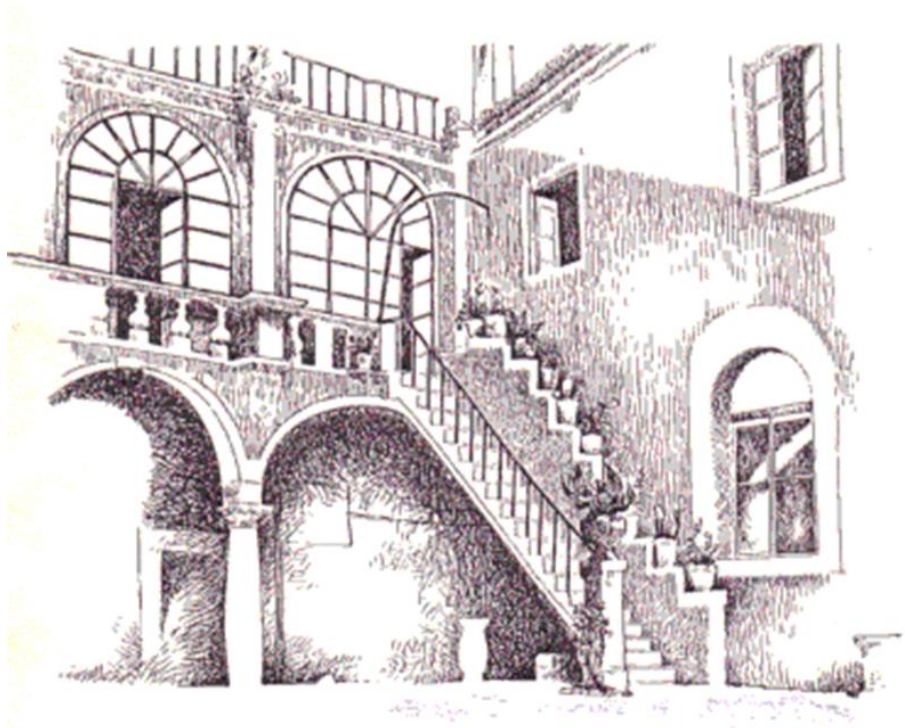
WE Heraeus Stiftung Workshop on:

Self-organized hyperuniformity in and out of equilibrium



Ettore Majorana Foundation and Centre for Scientific Culture

INTERNATIONAL SCHOOL OF STATISTICAL PHYSICS
Peter Hänggi and Fabio Marchesoni, Directors

Course XXIX: Self-organized hyperuniformity in and out of equilibrium

(Peter Hänggi, Yunyun Li, and Ran Ni, Directors)

1 – 6 July 2026, Erice, Italy

Sponsors

WILHELM UND ELSE
HERAEUS-STIFTUNG

Time	Day 1 (Thu - 2 Jul)	Day 2 (Fri - 3 Jul)	Day 3 (Sat - 4 Jul)	Day 4 (Sun - 5 Jul)
08:50-09:00	**Welcome and Opening Remarks**			
09:00-09:45	Ran Ni (Online)	Hartmut Löwen	Naomi Oppenheimer	Ludovic Berthier
09:45-10:05	Mike Cates	Yuta Kuroda	Mengjie Zu	Nadia Bihari Padhan
10:05-10:25		Yonglun Jiang	Vinodkumar Saranathan	Sebenzile Tsabedze
10:25-10:30		Coffee break	Coffee break	Coffee break
10:30-10:50	Coffee break			
10:50-10:55		Alexey Snezhko	Arjun Yodh	Erdal C. Oğuz
10:55-11:35	Limei Xu (Online)			
11:35-11:40		Zhen Zhang	Mikko Alava	Qunli Lei
11:40-11:55	Mathias Casiulis			
11:55-12:05		Mehmet Can Ucar		
12:05-12:10			**Lunch break**	William D. Pineros
12:10-12:15	Shang Gao			
12:15-12:25		**Lunch break**		
12:25-12:30				**Lunch break**
12:30-12:35	**Lunch break**			
12:35-13:15				
13:15-14:30			**Afternoon excursion**	
14:30-15:15	Serim Ilday	Takeshi Kawasaki		Alberto Fernandez-Nieves
15:15-15:35	Salvatore Torquato (Online)	Raphaël Maire		David Pine
15:35-15:55		Sam Wilken		
15:55-16:00		Coffee break		
16:00-16:20	Coffee break			Coffee break
16:20-16:25		Ning Xu		
16:25-16:40	Stefan Jorda			Kay Wiese
16:40-17:05	Marjolein Dijkstra			
17:05-17:10		Tero Mäkinen		
17:10-17:25				**Closing remarks & Dinner**
17:25-17:45	Tal Agranov	Fabio Marchesoni		
17:45-18:30	**Poster / free discussion**			
18:30-18:45	Dinner	Dinner	Dinner	

Program

Wednesday, 1 July 2026

Arrival

Thursday, 2 July 2026

Session chair: Peter Hänggi

8:50 – 9:00, Welcome & Opening Remarks

9:00 – 9:45, **Ran Ni**, “Stable and metastable non-equilibrium dynamic hyperuniform states” (online)

9:45 – 10:30, **Mike Cates**, “Role of Centre-of-Mass Conservation in Hyperuniform Dynamics”

10:30 – 10:55, *** Coffee Break ***

Session chair: Mike Cates

10:55 – 11:40, **Limei Xu**, “Order behind disorder” (online).

11:40 – 12:10, Mathias Casiulis, “Hyperuniform systems are maximally irreversible”

12:10 – 12:30, Shang Gao, “Cooperation-Competition Induced Self-Organized Criticality in Animal Collectives”

12:30 – 14:30, *** Lunch Break ***

Session chair: Ning XU

14:30 – 15:15, **Serim Ilday**, “Emergence of Disordered Hyperuniformity through Driven Dissipative Dynamics”

15:15 – 16:00, **Salvatore Torquato**, “Hyperuniformity of Weighted Particle Systems” (online)
16:00 – 16:25, *** Coffee Break ***

Session chair: Serim Ilday

16:25 – 16:40, Stefan Jorda, “Introduction to the Heraeus Foundation”

16:40 – 17:25, **Marjolein Dijkstra**, “Geometric origin of particle and dislocation dynamics during grain boundary migration”.

17:25 – 17:45, Tal Agranov, “Self-organized hyperuniformity in a minimal model of population dynamics”

17:45 – 18:30, *** Poster & free discussion ***

Friday, 3 July 2026

Session chair: Kay Wiese

9:00 – 9:45, **Hartmut Löwen**, “Hyperuniformity in active matter”.

9:45 – 10:05, Yuta Kuroda, “Hyperuniformity in chiral active particles”.

10:05 – 10:25, Yonglun Jiang, “Vortex formation and collective flow in dense active granular matter with tunable activity”.

10:25 – 10:50, *** Coffee Break ***

Session chair: Hartmut Löwen

10:50 – 11:35, **Alexey Snezhko**, “Hyperuniform active chiral fluids ”.

11:35 – 11:55, Zhen Zhang, “Emergent Platonic symmetry in disordered materials at extended length scales”.

11:55 – 12:15, Mehmet Can Ucar, “Emergence of hyperuniform tiling in the developing retina”.

12:15 – 14:30, *** Lunch Break ***

Session chair: Alexey Snezhko

14:30 – 15:15, **Takeshi Kawasaki**, “Protocol Dependence and Universality in Jammed Particle Systems: Structure and Rheology”.

15:15 – 15:35, Raphaël Maire, “Hyperuniformity suppresses nucleation and capillary waves in fluids”.

15:35– 15:55, Sam Wilken, “Coalescence-driven unjamming of multicomponent DNA liquid layers”.

15:55 – 16:20, *** Coffee Break ***

Session chair: Takeshi Kawasaki

16:20 – 17:05, **Ning Xu**, “Making quasicrystal formation simple”.

17:05– 17:25, Tero Mäkinen, “Avalanche dynamics in atom probe tomography of multicomponent materials”.

17:25 – 17:45, Fabio Marchesoni, “Hyperuniform in Non-reciprocal Suspensions”.

17:45 - *** Dinner ***

Saturday, 4 July 2026

Session chair: Erdal C. Oğuz

9:00 – 9:45, **Naomi Oppenheimer**, “Hyperuniformity in vortex and rotor assemblies”.

9:45 – 10:05, Mengjie Zu, “Learning, Memory, and Independent Response in Disordered Solids”.

10:05 – 10:25, Vinodkumar Saranathan, “Hyperuniformity in non-iridescent, avian photonic glasses”.

10:25 – 10:50, *** Coffee Break ***

Session chair: Naomi Oppenheimer

10:50 – 11:35, **Arjun Yodh**, “Structure, Dynamics, and Defects in disordered and partially ordered Complex Fluids”.

11:35 – 12:05, Mikko Alava, “Exploring the impact of structure on the mechanical properties of metallic glasses”.

12:05 – 13:15, *** Lunch Break***

13:15 *** Afternoon Excursion ***

Sunday, 5 July 2026

Session chair: David Pine

9:00 – 9:45, **Ludovic Berthier**, “Hyperuniformity in dense particle systems”.

9:45 – 10:05, Nadia Bihari Padhan, “Hyperuniformity in Multiphase Fluids: How Hydrodynamics, Activity, and Wetting Control Large-Scale Order”.

10:05 – 10:25, Sebenzile Tsabedze, “Regularity and resilience of short-range order in randomly perturbed lattices”.

10:25 – 10:50, *** Coffee Break ***

Session chair: Ludovic Berthier

10:50 – 11:35, **Erdal C. Oğuz**, “Statistical unit cells and geometric criticality in high-symmetry quasicrystals”.

11:35 – 12:05, **Qunli Lei,** “Liquid-gas criticality of non-equilibrium hyperuniform fluids”.

12:05 – 12:25, William D. Pineros, “Emergent synchronization in dense assemblies with embedded active particles”.

12:25 – 14:30, *** Lunch Break ***

Session chair: Arjun Yodh

14:30 – 15:15, **Alberto Fernandez-Nieves**, “Correlations in active nematic defects”.

15:15 – 16:00, **David Pine**, “Hyperuniform Structures Formed by Shearing Colloidal Suspensions”.

16:00 – 16:25, *** Coffee Break ***

Session chair: Yunyun Li

16:25 – 17:10, **Kay Wiese**, “Hyperuniformity in Conserved Directed Percolation, and its limits in Random Organization”.

17:10, Final Remarks & End

Monday, 6 July 2026

Departure

ABSTRACTS

Title: Stable and Metastable Non-equilibrium Dynamic Hyperuniform States

Authors: Ran Ni[1]

Affiliations: [1] School of Chemistry, Chemical Engineering and Biotechnology, Nanyang Technological University, Singapore)

Presenting Author: Ran Ni, r.ni@ntu.edu.sg

Abstract: In this talk, I will first introduce the new state of matter of non-equilibrium hyperuniform fluid that we found in systems of active colloids [1], and its hydrodynamic theory [2]. Afterwards, I will talk about the generalized hyperuniform fluid of reactive particles and the related continuous and discontinuous absorbing phase transitions. We found that the discontinuous absorbing transition of hyperuniform fluid cannot occur through the kinetic pathway of nucleation and growth, and the phase transition rate decreases with increasing the system size [3]. This implies that the metastable non-equilibrium hyperuniform fluid is 'kinetically stable' in the thermodynamic limit, which challenges the common understanding of metastability in discontinuous phase transitions. This 'metastable yet kinetically stable' hyperuniform fluid features a new hyperuniform scaling $S(k \to 0) \sim k^{1.2}$, which also exists in discontinuous absorbing transitions without center-of-mass conservation. We find that this new metastable hyperuniform state originates from the interplay of nonlinear activation, multiplicative demographic noise, and conserved diffusive fluctuations [4].

Keywords: hyperuniformity, active matter, hydrodynamics, discontinuous absorbing transitions

References

[1] Q. Lei, M. P. Ciamarra, and R. Ni, Sci. Adv. 5, eaau7423 (2019)

[2] Q. Lei, and R. Ni, Proc. Natl Acad. Sci. USA 116, 22983 (2019)

[3] Y. Lei, and R. Ni, Proc. Natl Acad. Sci. USA 120, e2312866120 (2023)

[4] Y. Lei, and R. Ni, arXiv:2605.13561 (2026)

Title: Role of Centre-of-Mass Conservation in Hyperuniform Dynamics

Authors: Mike Cates
Affiliations: DAMTP, University of Cambridge, Cambridge CB3 0WA, United Kingdom
Presenting Author: Mike Cates m.e.cates@damtp.cam.ac.uk

Abstract: I will review recent collaborative work on the emergence of hyperuniformity during phase ordering and in random organization, emphasizing the importance of a conservation law on the centre of mass of the density field. First, in phase ordering, the role of the conservation law in causing hyperuniformity was first identified by Tomita a decade before that word was invented [1]. However his arguments were hard to follow and, in places, flawed. A careful reworking of those arguments allows them to be confirmed and extended to address phase separation in systems with density-dependent mobility as well as activity, clarifying the general mechanisms whereby hyperuniformity emerges in phase ordering problems [2]. Second, as realized by Hexner and Levine [3], centre-of-mass conservation can impart hyperuniformity throughout the active phase in the random organization (RO) problem -- creating a radical departure from the standard RO case which is hyperuniform only at criticality. Based on a careful analysis of a Doi-Peliti field theory for RO, we argue that omission of diffusive noise, by creating centre-of-mass conservation, can likewise change the hyperuniformity exponent at the RO critical point, leaving other exponents unchanged [4]. Indeed the diffusive noise shows all the hallmarks of dangerous irrelevance in the renormalization group sense.

Keywords: Hyperuniformity, Phase Separation, Random Organization, Renormalization Group.

References:

[1] H. Tomita. Preservation of isotropy at the mesoscopic stage of phase separation processes. Prog. Theor. Phys., 85: 47–56, 1991.
[2] F. de Luca, X. Ma, C. Nardini, M.E. Cates. Hyperuniformity in phase ordering: the roles of activity, noise and non-constant mobility, J. Phys. Cond. Matt. 36: 405101, 2024.
[3] D. Hexner, D. Levine. Noise, diffusion and hyperuniformity, Phys. Rev. Lett. 118:020601, 2017.
[4] X. Ma, J, Pausch, M.E. Cates, Theory of hyperuniformity at the absorbing state transition, arXiv:2310.17391; X. Ma, J. Pausch, G. Pruessner, M. E. Cates. Hyperuniformity at the absorbing state transition: Perturbative RG for random organization, arXiv:2507.07793.

Title: Order behind disorder

Authors: Limei XU

Affiliations: Peking University

Abstract:

TBA

Title: Hyperuniform systems are maximally irreversible

Authors: Mathias Casiulis [1,2], Satyam Anand [1,3], Stefano Martiniani [1,2,3,4]

Affiliations:

[1] Center for Soft Matter Research, Department of Physics, New York University, New York, USA

[2] Simons Center for Computational Physical Chemistry, Department of Chemistry, New York University, New York, USA

[3] Courant Institute of Mathematical Sciences, New York University, New York, USA

[4] Center for Neural Science, New York University, New York, USA

Presenting Author: Mathias Casiulis, mc9287@nyu.edu

Abstract: Hyperuniform systems, defined by the anomalous suppression of large-scale density fluctuations, are a paradigm of non-equilibrium self-assembly. While mechanisms underlying the self-assembly of hyperuniform states have been widely studied, the energetics of this process remain unexplored. This raises a fundamental question: what is the energetic cost of self-assembling a hyperuniform system? Here, we address this question across several noisy particle systems drawn from soft matter and machine learning, in which hyperuniformity can be induced by tuning noise correlations.

Despite their distinct microscopic dynamics, we uncover a universal behavior across all systems: hyperuniform states are maximally irreversible, as quantified by the entropy production rate. Further, we develop a path integral formulation of the entropy production rate directly from the microscopic dynamics, which explains our observations. Our work establishes a direct link between emergent long-range structure and time irreversibility and opens a new avenue of probing the energetic cost of hyperuniform self-assembly, ubiquitous across physics, biology, and materials science.

Keywords: Hyperuniformity, Stochastic Dynamics, Entropy Production Rate, Self-Assembly

Funding Acknowledgment: M.C. and S.M. acknowledge the Simons Center for Computational Physical Chemistry for financial support. This work was supported in part through the NYU IT High Performance Computing resources, services, and staff expertise.

Title: Cooperation-Competition Induced Self-Organized Criticality in Animal Collectives

Authors: Hao Shang[1], Shang Gao[1], Qun-Li Lei[1]

Affiliations: [1] School of Physics, Nanjing University, China;

Presenting Author: Shang Gao；602024220061@smail.nju.edu.cn

Abstract: Collective organization in biological and active matter systems often emerges from the interplay between cooperation benefits and local competition. Motivated by quorum-sensing mechanisms, we extend the random organization model by introducing a threshold-based motility rule: particles become stationary only when they are non-overlapping and surrounded by at least k neighbors within a sensing range. The model exhibits absorbing, active, and liquid–gas phase separation state. Finite-size scaling analysis shows that the absorbing phase transition in this model belongs to the Manna universality class, and the spatial structure displays disordered hyperuniformity. Meanwhile, the liquid–gas critical point belongs to Ising universality class despite the irreversible dynamics. In the dilute regime, the system self-organizes into a critical state characterized by avalanche dynamics with power-law statistics; this self-organized critical state likewise forms a disordered hyperuniform structure. Remarkably, the measured avalanche exponents are consistent with mean-field Manna universality rather than the expected two-dimensional Manna class. These results demonstrate that the density-threshold-based, quorum-sensing-mediated cooperation–competition interplay can generically induce both nonequilibrium phase separation and self-organized criticality without parameter fine-tuning.

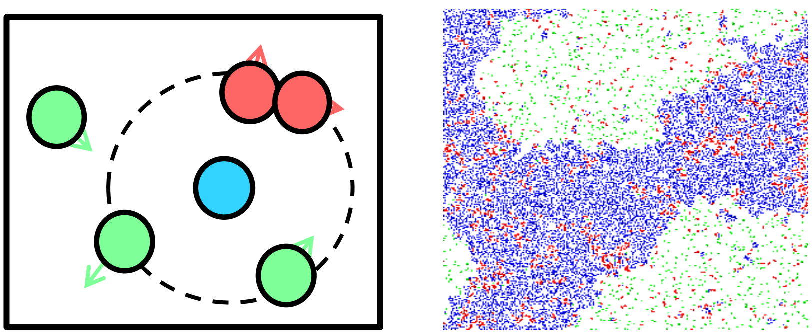


Figure Caption: Model description and simulation snapshot

Keywords: quorum sensing, absorbing phase transition, self-organized criticality, disordered hyperuniformity

Title: Emergence of Disordered Hyperuniformity through Driven Dissipative Dynamics

Authors: Serim Ilday[1,2,3]

Affiliations:

[1] Faculty of Electrical Engineering and Information Technologies (ETIT), Ruhr University Bochum (RUB), Germany

[2] Faculty of Physics and Astronomy, Ruhr University Bochum (RUB), Germany

[3] Center for Complex Interactions (CCI), Ruhr University Bochum (RUB), Germany

Presenting Author: Serim Ilday (serim.ilday@rub.de)

Abstract: In 2021, we reported the dynamical emergence and evolution of disordered hyperuniform states [1] in a driven dissipative colloidal system [2,3] during relaxation toward equilibrium. In this talk, I will conceptually discuss the origin and persistence of this behaviour within driven dissipative dynamics, with the aim of linking the characteristic time, length, and energy scales to underlying gradients, fluxes, and flows.

Keywords: driven dissipative dynamics, colloids, disordered hyperuniformity.

Funding Acknowledgment: We acknowledge funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (Grant No. 853387) and Marie Skłodowska-Curie Actions (Grant No. 120C074).

References

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Title: Hyperuniformity of Weighted Particle Systems

Authors: Salvatore Torquato

Affiliations: Dept. of Chemistry, Dept. of Physics, Princeton Institute of Materials and Applied & Computational Mathematics, Princeton University, Princeton, NJ 08544, USA

Presenting Author: Salvatore Torquato (torquato@princeton.edu)

Abstract: I will begin my talk with a brief overview of the hyperuniformity concept for unweighted particle configurations [1]. The rest of the talk will be focused on a very recent generalization of hyperuniformity to many-particle systems in which the particles carry weights: internal degrees of freedom such as scalars (charges and masses), vectors (electric dipole moments, velocities, and torques), pseudovectors (spins and angular momenta), directors (bond orientations), tensors (quadrupole moments), or extrinsic local attributes (Voronoi-cell characteristics) [2]. Our generalization extends hyperuniformity from fluctuations in particle positions to fluctuations in the spatial distribution of weights and examines how weighted fluctuations compare to their unweighted counterparts. We derive generalized weighted pair correlation functions, autocovariance functions, and spectral functions and show their relation to formulas for the local variance in weighted many-particle systems. Then, we apply our formalism to determine the hyperuniformity or nonhyperuniformity of bond-orientational ordered phases, dipolar liquid water, Voronoi-cell volumes, and certain ionic liquids in various Euclidean space dimensions. We demonstrate that hyperuniformity in the particle system does not necessarily translate to hyperuniformity of the weighted system. In fact, cases exist where a hyperuniform particle system becomes antihyperuniform when weighted and others where nonhyperuniform or antihyperuniform particle systems yield hyperuniform weighted systems. This theoretical framework provides a road map for quantifying large-scale fluctuations in weighted many-particle systems, offering a powerful tool for identifying systems with novel physical properties.

Keywords: (e.g., hyperuniformity, antihyperuniformity, disordered systems, jamming, weighted particle configurations, fluctuations, Voronoi-cell statistics)

Funding Acknowledgment: Supported by the Army Research Office under
Cooperative Agreement No. W911NF-22-2-0103.

References

[1] S. Torquato, "Hyperuniform States of Matter, **Physics Reports, 745**, 1-95 (2018).

[2] S. Torquato, J. Kim, M. A. Klatt, R. Car, and P. J. Steinhardt, "Hyperuniformity of Weighted Particle Systems," **Physical Review X, 16** ,011042 (2026).

Geometric origin of particle and dislocation dynamics during grain boundary migration

Author: Marjolein Dijkstra
Affiliations: Utrecht University

Grain boundaries are complex defects in polycrystalline systems and their migration has a key role in determining the properties of such solids. Understanding grain boundary motion in terms of both particle and dislocation dynamics remains a central problem. Here we establish a fundamental geometric principle governing grain boundary migration at the microscopic level: particles preferentially transition between grains at specific lattice equivalence points identified through a refined O-lattice construction. We validate this principle using loop-shaped grain boundaries in two-dimensional colloidal crystals created with holographic optical tweezers and computer simulations. Building on this principle, we develop a geometric framework that accurately predicts the microscopic dynamics of both particles and dislocations during grain boundary migration. Our results shed light on the microscopic mechanism of grain boundary migration and reveal the intrinsic connection between the dynamics of particles and dislocations.

Title: **Self-organized hyperuniformity in a minimal model of population dynamics**

Authors: Tal Agranov,(1, 2) Natan Wiegenfeld,(1, 3) Omer Karin,(4) and Benjamin D. Simons(1, 2)
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2) Gurdon Institute, University of Cambridge, Cambridge CB2 1QN, UK
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4)Department of Mathematics, Imperial College London, London, SW7 2AZ, UK
Presenting Author: Tal Agranov
ta487@cam.ac.uk

Abstract: In this talk, I will present our recent work, in which we uncover self-organized hyperuniformity in a generic model of population dynamics. The model generalizes a class of models recently introduced to account for protracted transients in biological systems. In these models, competition among individuals for a shared resource generates an effective feedback mechanism that asymptotically guides the population towards a critical steady state with divergent individual lifetimes.

Remarkably, we find that in its spatially extended form, the model exhibits hyperuniform density correlations. Through explicit coarse-graining, we derive a hydrodynamic theory that clarifies the underlying mechanism for this striking statistical behaviour. Unlike previous models for non-equilibrium hyperuniform states, our model does not exhibit conservation laws, even in the asymptotic regime.

These results suggest potential applications to cellular population dynamics and ecological systems. More broadly, our framework highlights how resource-mediated interactions can regulate collective behaviour in living systems, and opens new directions for exploring self-organization in non-equilibrium biological contexts.

Keywords: hyperuniformity, self-organization, population dynamics

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Title: Hyperuniformity in Active Matter

Author: Hartmut Löwen
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Presenting Author: Hartmut Löwen, email: hlowen@hhu.de

Abstract: Hyperuniformity was discovered in dense chiral active matter based on particle-resolved studies [1], field theory [2] and experiments on circling algae [3]. The talk will be devoted to highlight more connections between hyperuniformity and active matter: First of all, we demonstrate that hyperuniformity is generically present in a broad class of active field theories [4]. Second, we study the one-component plasma (OCP) of charged particles in a neutralizing background, a standard model for charged liquids, electrolytes and plasmas. In equilibrium, the OCP is hyperuniform due to global charge neutrality with an exponent 2 for the scaling of the fluid structure factor S(q) as a function of wave vector q such that it falls in class 1 of hyperuniformity. We then generalize the OCP to active Brownian and Langevin motion to an active OCP model corresponding to self-propelled charges which can be experimentally realized in a complex plasma. We find that the exponent does not change but the prefactor is enhanced by activity [5]. Hence the active OCP constitutes another hyperuniform active model system in nonequilibrium.

Keywords: hyperuniformity, active matter, chirality, plasmas

References

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Title: Hyperuniformity in chiral active particles

Authors: Yuta Kuroda[1], Takeshi Kawasaki[2], and Kunimasa Miyazaki[3]
Affiliations: [1] University of Stuttgart, Germany, [2] University of Osaka, [3] Nagoya University
Presenting Author: Yuta Kuroda (yuta.kuroda@itp4.uni-stuttgart.de)

Abstract:
Active matter has become an established class of nonequilibrium systems that exhibits a variety of phenomena absent in equilibrium systems. Among the many classes of active matter, chiral active particles, which undergo self-propelled motion with a left- or right-handed bias, have recently attracted much attention. One of the most striking features of such chiral particle systems is hyperuniformity, namely the suppression of density fluctuations, which has been observed in numerical simulations [1] and experiments [2]. This behavior is in stark contrast to that of non-chiral active particle systems, in which giant density fluctuations are commonly observed.
In this talk, I first present a theoretical framework for hyperuniformity in two-dimensional systems of chiral active particles [3]. Starting from a particle-based model, I derive a simple fluctuating hydrodynamic equation, and a linear analysis of this equation reproduces the hyperuniform scaling observed numerically. I then extend the theory to three-dimensional systems, in which each particle undergoes helical motion. Linear analysis and numerical simulations reveal that, in three dimensions, the density correlation function becomes singular at the origin in Fourier space [4].

Keywords: hyperuniformity, chiral active matter

References

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[3] Y. Kuroda and K. Miyazaki, Journal of Statistical Mechanics: Theory and Experiment, 103203 (2023)
[4] Y. Kuroda, T. Kawasaki, and K. Miyazaki, Physical Review E **112**, 045426 (2025)

Title: Vortex formation and collective flow in dense active granular matter with tunable activity

Authors: Xinzhu Xie[1], Yujie Wang[1], Yonglun Jiang[1]
Affiliations: [1] Department of Physics, Chengdu University of Technology, China
Presenting Author: Yonglun Jiang, yonglun.jiang@cdut.edu.cn

Abstract: Driven and active many-body systems often develop striking collective flow patterns, but directly identifying the dynamical structures that control these states remains a central challenge in nonequilibrium physics. Understanding how activity shapes collective motion is therefore an important problem across active matter, soft condensed matter, and granular physics. Here we study a dense two-dimensional vibrated granular system composed of self-propelled polar disks whose activity can be tuned in a controlled way through particle design, providing an experimental route to directly test the role of activity in emergent flow. In the dense regime, we observe robust mesoscale vortex structures in the coarse-grained flow field, and preliminary measurements show that vortex size, lifetime, and spatial statistics evolve systematically with activity. These results suggest that vortex statistics provide a useful framework for describing the collective behavior of the system. To test this idea, we adapt the vortex-gas mean-field model of Giomi by replacing the top-hat approximation for the single-vortex vorticity profile with the experimentally measured profile[1], which brings the theoretical prediction for energy spectra into closer agreement with our measurements. Ongoing work aims to clarify the physical mechanism of vortex emergence. More broadly, our results establish dense active granular matter as a controllable platform for studying pattern formation and self-organization in nonequilibrium many-body systems.

Keywords: Disordered systems, active matter, self-organization, pattern formation
Funding Acknowledgment: Supported by National Natural Science Foundation of China grants 12534008 (YW), and National Natural Science Foundation of China grants 12274292 (YW)

References

[1] Giomi, L. Geometry and Topology of Turbulence in Active Nematics. Phys. Rev. X 5, 031003 (2015).

Title: Hyperuniform active chiral fluids

Authors: Bo Zhang, Alexey Snezhko

Affiliations: Materials Science Division, Argonne National Laboratory, USA

Presenting Author: Alexey Snezhko

Abstract: Active matter demonstrates complex spatiotemporal self-organization and the emergence of collective behavior. We use shape anisotropy of colloidal particles and Quincke electro-hydrodynamic phenomenon to achieve spontaneous motion of particles at circular trajectories with radii controlled by the strength of the external electric field, and handedness spontaneously selected by each particle upon application of the field. By controlling the activity of the Quincke rollers through variations of the energizing electric field, we reveal the emergent of novel dynamic phases, ranging from a gas of spinners to aster-like vortices and synchronized rotating flocks. Those novel dynamic states are robust and fully reversible by the activity.

We further demonstrate that dynamic self-organization in such active ensembles leads to the formation of a hyperuniform fluid phase with significantly suppressed long-wavelength density fluctuations approaching those in crystal structures. We show that the global hyperuniformity in our system often coexists with large local density fluctuations at intermediate length scales associated with the formation of dynamic clusters, such as localized vortices or flocks. We demonstrate that hyperuniformity disappears in those ensembles as the curvature of particles' motion increases and circular motion transforms into localized spinning, reducing the interactions between the particles and preventing the formation of collective states.

The results experimentally demonstrate hyperuniform active roller fluid and provide insights into an interplay between chirality, activity and hyperuniformity.

Keywords: chiral active fluids, emergent dynamics, hyperuniformity

Funding Acknowledgment: The research was supported by the U.S. Department of Energy, Office of Science, Materials Sciences and Engineering Division

References

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[2] Bo Zhang, Alexey Snezhko, Phys. Rev. Lett. 128, 218002 (2022)

Title: Autonomous Structural Hyperuniformity in Viral Complexes: Isolating Long-Range Signaling from Stochastic Noise through Physics-Informed ML

Authors: Lionell E. Nava Ramos[1]
Affiliations: [1] Independent Researcher, Proyecto VALLY. Centro de Investigación en Informática (CII), Universidad Politécnica Territorial de Maracaibo (UPTMA), Zulia, Venezuela
Presenting Author: Lionell E. Nava Ramos (lionnava@gmail.com)

Abstract: The dynamic regulation and structural integrity of biological soft matter—such as multimeric protein assemblies and collagen networks—are governed by complex mechanical correlations. Traditional Elastic Network Models (ENMs), relying on the harmonic approximation, frequently fail to disentangle functional mechanical order from thermal noise, often over-predicting the mobility of solvent-exposed boundaries (the "whip effect"). Here, we present VALLY-Scan v4.0.0, a Physics-Informed Machine Learning (PIML) framework designed to uncover hidden topological order and suppress fluctuation artifacts in soft matter networks. VALLY-Scan extracts a 10-dimensional multiscale tensor from 3D spatial topologies, comprising statistical mechanics matrices (Hessian and Kirchhoff), Perturbation Response Scanning (PRS) profiles, and localized steric constraints (Van der Waals volumetric hindrance and dihedral conformational entropy).

By integrating these steric penalties, the Random Forest orchestrator acts as a spatial filter, successfully suppressing peripheral noise and isolating mechanically coupled internal domains. Applied to a collagen-like triple helix network (PDB: 1BKV), the 10D PIML model achieved an exceptional correlation of r=0.928 with empirical flexibility data. Furthermore, by decoupling physical topology from chemical identity, we simulated the introduction of a localized structural defect (61-Proline →Glycine mutation). The model successfully isolated the "allosteric signaling delta," revealing exactly how the topological matrix redistributes mechanical stress and long-range disorder across the soft matter fiber. This work demonstrates that integrating localized steric constraints with global statistical mechanics provides a robust computational methodology for decoding fluctuation phenomena and material failure in complex biological systems.

Figure:

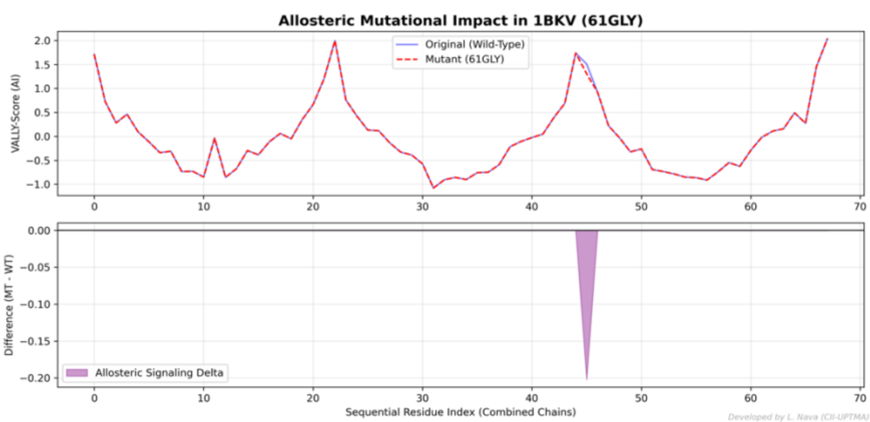

Figure C Figure 1. Mechanical stress propagation in a collagen network (1BKV) following a 61PRO→ GLY simulated defect. The Allosteric Signaling Delta (bottom panel) isolates the exact long-range mechanical disruption triggered by the point mutation, successfully filtering out global thermal noise.

Keywords: Soft matter, fluctuation phenomena, physics-informed machine learning, elastic network models, topological mechanics.
Funding Acknowledgment: Supported by the Centro de Investigación en Informática (CII), UPTMA.

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Emergence of hyperuniform tiling in the developing retina

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Efficient tiling of space is a fundamental design principle of living systems: from neurons to vascular networks, branched structures must optimize spatial coverage for proper function. Yet, how cells decode local spatial information to collectively tile territories without a global blueprint remains a key open question. Here, we develop a biophysical theory of interacting branched cells, and show that local repulsion coupled with density-dependent feedback on growth drives efficient tiling with minimal territorial overlap. Our model predicts that the same local interactions simultaneously suppress long-range density fluctuations, driving the cellular collective toward hyperuniformity. We confirm these theoretical predictions with experiments on microglial patterning in the developing retina, and show that genetic perturbations resulting in limited arbor growth disrupt both tiling and fluctuation suppression. Our results reveal that two seemingly distinct optimization principles of biological patterning, large-scale regularity and efficient tiling, are intimately linked and arise from a single growth-repulsion feedback, suggesting a general principle for self-organized tissue patterning.

Title: Emergent Platonic symmetry in disordered materials at extended length scales

Authors: Zhen Zhang[1], Walter Kob[2]
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Abstract: Disordered materials, ranging from dense hard-sphere packings to directionally bonded networks, are typically regarded as locally ordered but structurally random at larger length scales, with no expectation of symmetry beyond local motifs. Here, using a novel four-point structural correlation method, we uncover a complete set of Platonic symmetries organized across extended length scales in amorphous systems. In hard-sphere-like systems, such as Lennard-Jones and granular packings, we identify alternating icosahedral and dodecahedral symmetries. In network-forming systems like silica, we find that cubic and octahedral symmetries emerge beyond the initial tetrahedral order, which can be systematically enhanced under pressure. These findings demonstrate the power of higher-order correlation functions in uncovering hidden structural hierarchies, providing a new framework for understanding glass physics and engineering functional disordered materials through structural tuning.

Keywords: Amorphous materials, hidden order, Platonic symmetries, higher-order structural correlations, structural hierarchy

Funding Acknowledgment: The work was supported by the National Natural Science Foundation of China (Grant No. 12474185)

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Title: Protocol Dependence and Universality in Jammed Particle Systems: Structure and Rheology

Authors: Takeshi Kawasaki[1,2,3], Duc T. Dam[3], Kunimasa Miyazaki [3]
Affiliations: [1] Department of Physics, The University of Osaka, [2] D3 center, The University of Osaka, [3] Department of Physics, Nagoya University
Presenting Author: Takeshi Kawasaki

Abstract:
In athermal particulate systems, where thermal fluctuations are negligible, increasing density induces a transition from a flowing state to a rigid state, known as the jamming transition. This transition is strongly dependent on the preparation history (protocol) of particle configurations, leading to significant variations not only in the transition density but also in the nonlinear rheological response under external driving. At the jamming point, the system exhibits marginally stable structures, accompanied by suppressed long-wavelength density fluctuations, i.e., hyperuniformity. However, the relationship between such protocol dependence and universal features remains insufficiently understood and lacks a systematic framework.

In this talk, we focus on nonlinear rheology near the jamming transition and present a systematic classification that distinguishes protocol-dependent quantities from protocol-independent, universal features [1]. Furthermore, we discuss how the structural signature of hyperuniformity is influenced by preparation history and to what extent it exhibits universality [2, 3].

Keywords: hyperuniformity, disordered systems, jamming, non-linear rheology

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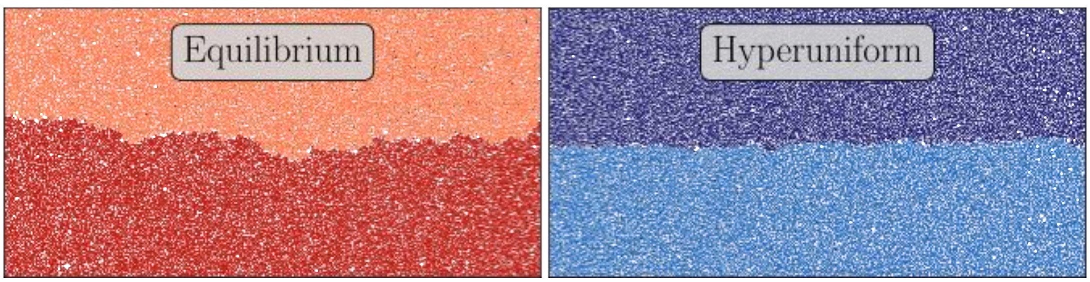
[3] D. T. Dam et al., arXiv:2507.12738.

Title: Hyperuniformity suppresses nucleation and capillary waves in fluids

Authors: Raphaël Maire[1], Leonardo Galliano[2], Andrea Plati[3], Ludovic Berthier[4]
Affiliations: [1]University of Barcelona, 08028 Barcelona, Spain, [2]École Normale Supérieure, 75005 Paris, France [3]Laboratoire de Physique des Solides, Orsay 91405, France, [4]Laboratoire Gulliver ESPCI, 75005 Paris, France
Presenting Author: Raphaël Maire, maire@ub.edu

Abstract: We recall how hyperuniformity generically emerges in non-equilibrium fluids via conservation laws [1]. We then show that the resulting suppression of density fluctuations also inhibits nucleation in fluids undergoing liquid–gas phase separation [2]. Capillary waves at the interface between the two phases are likewise suppressed (see Figure) and fall into a new universality class [3]. These results arise from a field-theoretic description of the density field and are linked to other hyperuniform-fluid phenomena, including the absence of diverging fluctuations at the liquid–gas critical point [4] and violations of the Hohenberg–Mermin–Wagner theorem in crystals [5].

Figure:



Roughness comparison between an interface in an equilibrium and hyperuniform fluid.

Keywords: hyperuniformity, interface, phase-separation, nucleation, universality-class

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Title: Coalescence-driven unjamming of multicomponent DNA liquid layers

Authors: Abhishek Ghadai[1], Aria Chaderjian[2], Omar Saleh[2,3], Sam Wilken[1]
Affiliations: [1]Chemistry Department, Johannes Gutenberg University – Mainz, Germany, [2]Physics Department, University of California, Santa Barbara, USA, [3]Materials Department, University of California, Santa Barbara, USA
Presenting Author: Sam Wilken – swilken@uni-mainz.de

Abstract: A notable multicomponent tissue is the avian retina, composed of five types of cone photoreceptors that organize into aperiodic structures with hidden order, where both individual components and all cone types together display long-range density fluctuations that are strongly suppressed, known as 'hyperuniformity'. Furthermore, to model living tissues without the complexity of in vivo systems, phase-field models of cells as multiphase liquid droplets have been developed, mimicking many physical characteristics of living tissues such as mechanical liquid-to-solid and orientational order-disorder phase transitions, as well as topological structure-function relationships. To systematically examine organizational mechanisms in multicomponent tissues, we have created a precise multi-phase experimental model system called 'DNA nanostars'. We employ DNA nanotechnology design methods to construct nine orthogonal DNA-based liquids with well-defined properties and tunable phase diagrams [1]. At high densities, these multicomponent droplet systems form a jammed quasi-2D layer with strong dynamic heterogeneity that then undergoes an unjamming phase transition driven by droplet coalescence. To support experimental findings, we develop Brownian dynamics simulations that quantitatively replicate experimental coarsening dynamics in the single-component case. Sufficiently diverse multicomponent packings display jammed configurations similar to those observed in experiments, with strongly suppressed coarsening dynamics. Just before unjamming, these packings contain composite structures that reflect mechanisms by which each component and the overall system organize. Multicomponent jammed liquid packings offer a minimal route to hyperuniform-like organization, providing a framework for understanding how living tissues attain robust, collective spatial order without external patterning cues.

Keywords: Tissue organization, hyperuniformity, jamming, disordered systems, self-organization
Funding Acknowledgment: Supported by the Carl Zeiss Foundation Center for Synthetic Genomics.

References

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Title: Making quasicrystal formation simple

Authors: Zhehua Jiang[1], Mengjie Zu[1], Peng Tan[2], Hua Tong[1], Ning Xu[1]
Affiliations: [1]Department of Physics, University of Science and Technology of China, China;
[2]Department of Physics, Fudan University, China
Presenting Author: Ning Xu, ningxu@ustc.edu.cn

Abstract: Due to special rotational symmetries, the conditions for preparing quasicrystals are often demanding, typically requiring multiple length scales to stabilize them. Our study breaks this traditional understanding by achieving self-assembled quasicrystals in high-density soft-core particle systems with a single length scale, and even obtaining octagonal quasicrystals, which have rarely been reported in soft matter systems. More surprisingly, by exploiting the instability of the square lattice, we obtained dodecagonal quasicrystal approximants and quasicrystalline building blocks in the simplest monodisperse hard-sphere system. Furthermore, we developed a purely mechanical method that enables rapid and efficient formation of nearly perfect quasicrystals in systems where constant-temperature self-assembly typically leads only to random tiling and struggles to form structurally near-perfect quasicrystals. Our research provides a new, minimalistic route to quasicrystal formation.

Keywords: quasicrystals, hard sphere, instability, square lattice, self-assembly
Funding Acknowledgment: Supported by National Natural Science Foundation of China

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Title: Avalanche dynamics in atom probe tomography of multicomponent materials

Authors: Tero Mäkinen[1], Aslam Shaikh[1], Marouane Mejres[2], Allisson Saiter-Fourcin[2], Nicolas Delpouve[2], François Vurpillot[2], Mikko Alava[1], Ivan Lomakin[1]

Affiliations: [1] Aalto University, Department of Applied Physics, Espoo, Finland [2] Univ. Rouen Normandie, INSA Rouen Normandie, CNRS, Normandie Univ., GPM Rouen, France

Presenting Author: Tero Mäkinen tero.j.makinen@aalto.fi

Abstract: Metallic glasses and multicomponent alloys exhibit structural or compositional disorder alongside subtler features, such as short-range order and signatures of hyperuniformity. Atom probe tomography (APT) is widely used to experimentally probe material microstructure, but its interpretation assumes that detected ions reflect an unbiased sampling of the underlying structure. We show that this assumption breaks down [1]. Combining experimental APT data on multicomponent alloys (metallic glasses and medium entropy alloys) with simulations [2], we demonstrate that field evaporation proceeds via avalanche-like cascades with strong spatiotemporal correlations. The temporal correlations can span up to 1000 evaporated atoms. These correlations arise from local heterogeneities in evaporation fields and follow branching-process dynamics analogous to Hawkes processes. The evaporation front (the atoms on the surface) thus behaves like a driven disordered interface and roughens as atoms are evaporated from the surface.

These correlations can introduce systematic biases in reconstructed atomic positions [3], which can mimic or obscure e.g. short-range order. More broadly, they raise the question of whether apparent signatures of e.g. suppressed density fluctuations, relevant to hyperuniformity, may partly reflect measurement-induced correlations.

We also present an improved reconstruction approach that accounts for these effects, enabling more reliable characterization of multicomponent systems. Our results highlight the need to improve the experimental methodology to disentangle intrinsic structural order from correlations generated by the measurement process itself.

Keywords: atom probe tomography, multicomponent alloys, avalanches, short range order

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Title: Hyperuniform in Non-Reciprocal Suspensions

Authors: Feifei Liu, Fabio Marchesoni, Yunyun Li

Affiliations: Tongji University

Abstract:
Collective dynamics often yield novel forms of order. We investigate the collective dynamics of a suspension system comprised of agents --- biological or synthetic --- characterized by limited visual sensing and dynamical response capabilities. These agents can switch their chirality on or off in response to local density thresholds of neighboring agents within their visual cone, a nonreciprocal interaction we term “visual quorum sensing” (QS). Our analysis reveals that, under suitable sensing conditions, the system spontaneously self-organizes into extended honeycomb-like crystals and hyperuniform structures. Notably, this self-organization emerges without global information of the system’s configuration, centralized coordination or pre-defined structural templates, relying solely on localized and limited interactions among nearby agents. Furthermore, this ordering can span systems of arbitrary size. Our study bridges the principles of biological self-assembly principles with synthetic active matter, suggesting new strategies for scalable synthesis of honeycomb materials and programmable autonomous micro-robotics.

[1] Yuxin Zhou, Qingqing Yin, S. Nayak, P. Bag, P. K. Ghosh, Y. Li* and F. Marchesoni, Visual quorum sensing in chiral suspensions: Hyperuniformity and edge currents, PNAS nexus 4, pgaf373 (2025)

Hyperuniformity in vortex and rotor assemblies

Author: Naomi Oppenheimer

Affiliation: Tel Aviv University

Ensembles of particles rotating in a two-dimensional fluid can exhibit chaotic dynamics yet develop signatures of hidden order. Such rotors are found in the natural world spanning vastly disparate length scales — from the rotor proteins in cellular membranes to models of atmospheric dynamics. In this talk, I will show that an initially random distribution of either driven rotors in a viscous membrane or ideal vortices with minute perturbations spontaneously self-assembles into a distinct arrangement. Despite arising from drastically different physics, these systems share a Hamiltonian structure that sets geometrical conservation laws, resulting in prominent structural states. We find that the rotationally invariant interactions isotropically suppress long-wavelength fluctuations — a hallmark of a disordered hyperuniform material. With increasing area fraction, the system orders into a hexagonal lattice. In mixtures of two co-rotating populations, the stronger population will gain order from the other, and both will become phase-enriched.

Title: *Learning, Memory, and Independent Response in Disordered Solids*

Authors: Mengjie Zu[1], Carl P. Goodrich[1]

Affiliations: [1] Institute of Science and Technology Austria, Austria

Presenting Author: Mengjie Zu, mengjie.zu@ist.ac.at

Abstract: Disordered materials, such as glasses and amorphous solids, lack the regular structure of crystals, making their properties difficult to predict and control. Nevertheless, they exhibit remarkable tunability. Here, we present a framework that combines statistical physics and differentiable programming to understand and exploit this behavior.

Using automatic differentiation, we directly link microscopic interaction parameters to macroscopic observables such as elasticity and pressure, enabling efficient optimization of material properties[1] . This approach allows disordered systems to be "trained" through iterative updates, revealing how their energy landscapes reorganize under perturbations.

A central result is that disordered solids exhibit independent response, meaning that different properties can be tuned separately. In many cases, this independence is complete: all targeted properties can be controlled simultaneously given sufficient parameters[2] . The tunability is governed by susceptibilities, which determine how strongly properties respond and how easily they can be optimized.

Optimization also induces localized rearrangements and history-dependent effects, leading to memory formation in the material[3]. These findings connect disordered systems to broader concepts of self-organization, critical response, and learning.

Overall, disorder enables flexible, high-dimensional control, providing a pathway toward adaptive and multifunctional materials.

Keywords: disordered systems, self-organization, memory, tunability, optimization, automatic differentiation

References

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Title: Hyperuniformity in non-iridescent, avian photonic glasses

Authors: Haysun H. Choi[1], Richard O. Prum[1], Vinodkumar Saranathan[2]

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Presenting Author: Vinodkumar Saranathan, saranathan@univ-tours.fr

Abstract: Hyperuniformity (*sensu* Torquato and Steinhardt) quantifies the suppression of long-wavelength density fluctuations in material composition and provides a unified framework for characterizing relative order vs. disorder in isotropic, amorphous structures [1]. While hyperuniformity has been extensively studied theoretically and recently documented in synthetic 2D materials [1], it has seen very few applications in biology despite offering convenient quantitative measures of disorder/order to enable comparative studies of trait evolution. Non-iridescent structural colors in bird feather barbs arise via phase separation of β-keratin from cytosol into two stereotypical isotropic morphologies with short-range correlated disorder (or quasi-periodic order) [2]. These morphologies include quasi-ordered, bicontinuous channels to nucleation and growth-like phases. 3D photonic crystals (inverse RHCP, inverse BCC and single gyroid) have also evolved in a few bird families from ancestral quasi-ordered morphologies [2]. Phylogenetic analyses show that these derived ordered morphologies exhibit greater structural coherence and produce purer reflectance hues, which explain their likely evolution via female preferences for saturated colors [2]. Here, we develop empirical metrics to quantify the degree of hyperuniformity directly from the bulk SAXS data obtained from hundreds of photonic feathers across birds to establish a biologically relevant framework of hyperuniformity to understand these intriguing biological disorder-to-order transitions that offer great biomimetic promise for inspiring next-generation designer materials for photonics and photovoltaics.

Keywords: hyperuniformity, correlated disorder, phase separation, animal structural colors, biological phase transitions

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Structure, Dynamics, and Defects in disordered and partially ordered Complex Fluids

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Abstract

I will describe work from my lab with colloids and liquid crystals. Experiments with particles explore the nature and influence of "defects" in a range of disordered, partially ordered, and crystalline thin colloidal films. Experiments with liquid crystals in confined geometries explore responses of topological defects to applied magnetic fields and across the nematic-smectic phase transitions. The work reveals novel behaviors of dislocations in ultrathin colloidal films, defects in particle-based amorphous solids, and disclinations and defect walls in oriented and layered liquid crystals.

Keywords: disordered systems, partially ordered systems, colloids, liquid crystals, topological defects, self-assembly

Funding Acknowledgment: Supported by NSF Grants DMR20-03659, DMR-2309043.

Title: Exploring the impact of structure on the mechanical properties of metallic glasses

Authors: Mikko Alava and Tero J. Mäkinen

Affiliations: Aalto University, Finland

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Abstract: Metallic glasses exhibit elasticity and yielding that depend sensitively on composition and cooling history, reflecting the underlying structural disorder. In shear, they deform through intermittent stress-drop avalanches. We consider Cu–Zr–(Al) systems and connect deformation statistics with Bayesian, small-data approaches.

Under athermal quasistatic shear, variations in composition and cooling history reveal how disorder controls the transition from an initial regime with a pseudogap to critical avalanching near yielding. While post-yield dynamics display universal, scale-free behavior, the elastic response and yielding point retain a strong imprint of preparation, demonstrating how disorder encoded by cooling and composition governs mechanical behavior [1].

Bayesian optimization combined with molecular dynamics provides a systematic way to explore the high-dimensional space of compositions and processing conditions [2]. This approach uncovers how different combinations of composition and cooling generate distinct disorder states, which in turn control elasticity and yielding. Bayesian exploration acts as a probe of the structure–property landscape, revealing how cooling-induced disorder organizes mechanical response.

A physics-informed Bayesian model leverages early plastic-strain accumulation to predict yielding from the nominally elastic regime. Distinct plasticity growth behaviors linked to thermal history (“good” and “bad” glasses) are captured within a unified framework, and Bayesian inference enables early, uncertainty-aware predictions of stress–strain curves and yield [3].

Keywords: disordered systems, glasses, avalanches, plasticity, Bayesian machine learning

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.

Title: Hyperuniformity in dense particle systems

Authors: Ludovic Berthier[1]

Affiliations: [1] Gulliver, CNRS & ESPCI-PSL, Paris, France

Presenting Author: Ludovic Berthier

Abstract: We discuss the interplay between suppressed density fluctuations (hyperuniformity) in very dense particle systems and the physics of glass and jamming transitions. Hyperuniformity has been separately invoked for particle packings exactly at the jamming transition and in the context of ultrastable glasses. By selecting models and non-equilibrium algorithms, we revisit these connections and disentangle the role of non-equilibrium effects, arrested dynamics, thermal and non-thermal vibrations, and preparation protocols in the observation of hyperuniform structures. We also investigate the putative connection between glass stability and hyperuniformity.

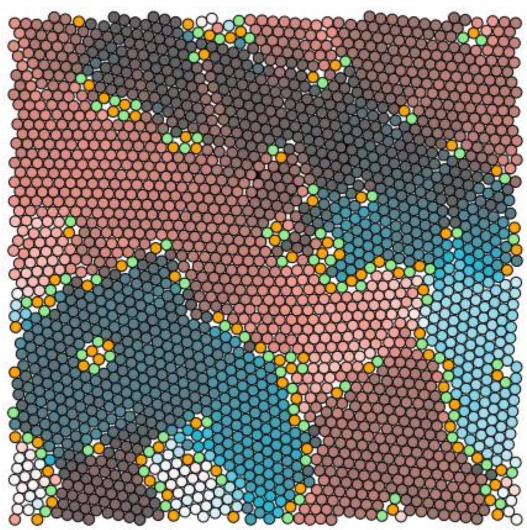

Figure Caption: Example of a non-equilibrium disordered structure with suppressed density fluctuations at large length scales.

Keywords: Hyperuniformity, disordered systems, jamming, glass transition

Title: Hyperuniformity in Multiphase Fluids: How Hydrodynamics, Activity, and Wetting Control Large-Scale Order

Authors: Nadia Bihari Padhan[1] and Axel Voigt[1]

Affiliations: [1]Institute of Scientific Computing, Technical University, Dresden, Germany

Presenting Author: Nadia Bihari Padhan [nadia_bihari.padhan@tu-dresden.de]

Abstract: Hyperuniformity has emerged as a unifying concept to characterize hidden order in disordered systems, with phase-separating fluids providing a natural setting where such order can arise dynamically. The late-time coarsening dynamics in phase-separating systems are known to produce hyperuniform patterns, a feature well established for scalar field theories such as the Cahn–Hilliard equation and also observed in dry active scalar systems. In the first part of this talk, I will demonstrate how hydrodynamic interactions modify this picture in a wet active system governed by Active Model H. Direct numerical simulations show that while passive model H retains hyperuniformity during coarsening, the combination of activity and fluid flow suppresses it, particularly in the presence of contractile stresses [1]. This suppression can be traced to a fundamental shift in spectral energy transfer—from an inverse cascade that sustains large-scale order to a forward cascade that breaks down emerging structures. In the second part, I will turn to multicomponent fluids and examine hyperuniformity in ternary mixtures described by the Cahn–Hilliard–Navier–Stokes equations. Large-scale simulations reveal that hydrodynamics again weakens hyperuniformity, while interfacial topology introduces an additional level of control. The system exhibits diverse morphologies, including interconnected domains and double emulsions reminiscent of biological phase separation (see Fig. 1). In partial wetting regimes, all components display comparable hyperuniformity, whereas in complete wetting conditions, the wetting phase shows a pronounced reduction due to additional geometric fluctuation modes associated with encapsulation [2]. Taken together, these results show that hyperuniformity in multiphase fluids is not universal but is strongly shaped by transport mechanisms and interfacial structure. This perspective opens new avenues for controlling large-scale spatial order in complex fluids, with potential implications across soft matter, materials science, and biological organization.

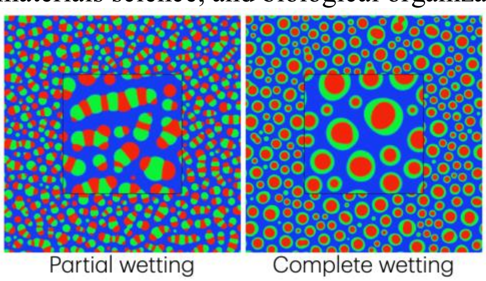

Figure-1: Pseudocolor plots of the order parameters (c1, c2, c3) illustrating phase separation into three distinct components (green, red, blue), shown for partial and complete wetting regimes.

Keywords: hyperuniformity, phase separation, multiphase fluids, active fluids, wetting

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Title: Regularity and resilience of short-range order in randomly perturbed lattices

Authors: Sebenzile Tsabedze[1,2], Simiso Mkhonta[2]

Affiliations: [1] Department of Physics, Johannes Gutenberg-Universitat Mainz, Germany

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Presenting Author: (Sebenzile Tsabedze, stsabedz@uni-mainz.de)

Abstract: Randomly perturbed lattice models play a vital role in exploring novel quasi-disordered structures, such as disordered photonic crystals that combine the coherent optical effects of periodic crystals with the broadband, isotropic power spectra characteristic of disordered media. Studies have demonstrated that Bragg scattering peaks in uniformly randomized lattices can be switched on and off by varying the perturbation strength while preserving the long-range order of the underlying lattice structure. We investigated the pair correlation statistics and number variance of randomly perturbed lattices, focusing on how perturbations affect the system's short-range order. We find that locally isotropic perturbations generate disordered structures exhibiting resilient hyperuniformity and robust short-range order. Our results demonstrate that such systems maintain structural regularity despite random perturbations. This offers insight on an alternative approach for designing partially disordered hyperuniform structures.

Keywords: (Hyperuniformity, Random perturbation, Disordered systems, Quasi-crystals, Short-range order, Number variance)

References (optional)

Tsabedze, S., Dlamini, N., Mkhonta, S. K. (2022). Regularity and resilience of short-range order in uniformly randomized lattices. *J. Phys. Commun*, **6**(10), 105008

Title: Statistical unit cells and geometric criticality in high-symmetry quasicrystals

Authors: Alan Rodrigo Mendoza Sosa[1], Atahualpa S. Kraemer[2], Michael Schmiedeberg[3], Erdal C. Oğuz[1]

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Presenting Author: Erdal C. Oğuz, ecoguz@iphy.ac.cn

Abstract: Quasicrystals can exhibit arbitrarily high rotational symmetry N, yet increasing N makes their local structure appear progressively more disordered, resembling random tilings while remaining perfectly quasiperiodic. This raises a fundamental question: on what length scales is long-range quasiperiodic order statistically detectable?

In this talk, I will show that high-symmetry quasicrystals exhibit a symmetry-controlled structural crossover. At short length scales, density fluctuations are only weakly suppressed, consistent with Class III hyperuniformity. Beyond a crossover length, long-range quasiperiodic order manifests through strongly suppressed fluctuations together with pronounced oscillations in correlation functions, whose wavelength defines an emergent length scale that we identify as *statistical unit cells*—finite regions over which statistical properties effectively repeat.

I then consider the infinite-symmetry limit ($N \to \infty$). In this limit, the crossover length diverges, and density fluctuations over all accessible scales approach those of random systems. This suggests that the infinite-symmetry limit can be understood as a form of geometric critical point at which distinctions between quasiperiodic order and randomness vanish. Within this framework, statistical unit cells bridge the conceptual gap between crystals, quasicrystals, and amorphous matter, providing a unified way to understand the emergence and organization of order in aperiodic materials.

Keywords: hyperuniformity, quasicrystals, disordered systems

Title: Liquid-gas criticality of non-equilibrium hyperuniform fluids

Authors: Shang Gao[1], Hao Shang[1], Hao Hu, Yu-Qiang Ma[1], Qun-Li Lei[1]

Affiliations: [1] School of Physics, Nanjing University, China;

Presenting Author: Qun-Li Lei；lql@nju.edu.cn

Abstract: In statistical physics, it is well established that the liquid-gas (LG) phase transition with divergent critical fluctuations belongs to the Ising universality class. Whether non-equilibrium effects can alter this universal behavior remains a fundamental open question. In this work, we theoretically prove that non-equilibrium hyperuniform (HU) fluids with additional center-of-mass conservation exhibit LG criticality different from the Ising universality class. As a specific case, we investigate a 2D HU fluid composed of active spinners, where phase separation is driven by dissipative collisions. Strikingly, the critical point is calm yet highly susceptible, in fundamental violation of the conventional fluctuation-dissipation relation. Consistently, we observe short-range pairwise correlation functions coexisting with quasi-long-range response functions at the critical point. Based on a generalized Model B and renormalization-group analysis, we prove that hyperuniformity reduces the upper critical dimension d_c from 4 to 2 and the critical point exhibits Gaussian density fluctuations. Furthermore, the HU fluid undergoes non-conventional spinodal decomposition, where the decomposition time diverges but the characteristic length scale remains finite as the critical point is approached. The origin of the above anomalies lies in the non-equilibrium nature of the system which obeys a generalized fluctuation-dissipation relation $2\mathrm{Im}\,\chi(q,\omega) = \omega C(q,\omega)/k_B T_{\mathrm{eff}}(q)$ with a scale-dependent effective temperature $T_{\mathrm{eff}}(q) \propto q^2$.

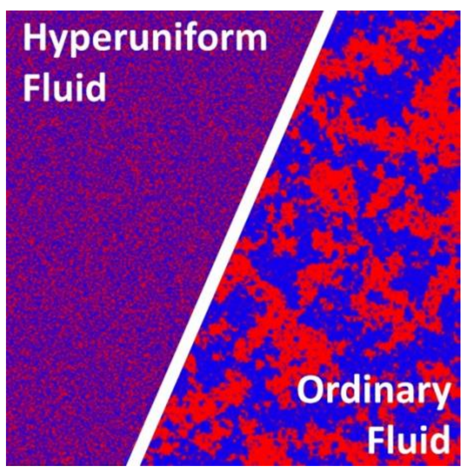

Figure Caption: Hyperuniform and ordinary fluids at liquid-gas critical point.

Keywords: hyperuniformity, active matter, liquid-gas phase transition, critical phenomena

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Title: Emergent synchronization in dense assemblies with embedded active particles

Authors: William D. Pineros

Affiliations: University of Caen, Normandy France

Presenting Author: William. D. Pineros, William.pineros@unicaen.fr

Abstract: Assemblies of particles in dense conditions and with dispersed energy fluctuations represent a broad, and important class of materials such as those in confluent and contractile tissues. In this work, we consider dense assemblies of particles with adjustable particle size subject only to steric interactions, and a small fraction of which are active via continuous pulsation. We show that varying mixtures of such size-dependent particles can result in emergent synchronization (either aligining or anti-alignining) as a function of the particle stiffness. Key to this process is the arrangement of activity within the assembly matrix so as to activate distinct vibration modes, and which at constant energy flux and stiffness, correspondingly define the emerging form of dynamics. Such result brings to light that emergent dynamics in dense materials require an additional form of precise architectural control in addition to the underlying interactions and activity form.

Title: Correlations in active nematic defects

Author: Alberto Fernandez-NIeves

Affiliation: Department of Condensed Matter Physics, University of Barcelona, Spain

Presenting Author: Alberto Fernandez-Nieves

Abstract: Defects in nematics frustrate the orientational order of this liquid crystalline phase. When driven out-of-equilibrium, these defects self-propel, interact, and create and annihilate by pairs, resulting in an apparently disordered state. Here, we show that this state possesses a hidden order characterized by the suppression of number fluctuations below a length scale that can be as large as the system size. This apparent hyperuniformity is most pronounced when considering the subpopulation of either the positive or the negative defects, illustrating lack of multi-hyperuniformity. Our experimental findings are supported by hydrodynamic theory and agent-based simulations, which further allow elucidating the role of both creation/annihilation of defect pairs and of their mutual correlations in achieving this apparent hyperuniformity.

Keywords: Active nematic defects, correlations, creation/annihilation, hyperuniformity

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Title: Hyperuniform Structures Formed by Shearing Colloidal Suspensions

Authors: David J. Pine

Affiliations: (Department of Physics, New Yoek University, USA)

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Abstract: We investigate the dynamical phase transition in periodically sheared colloidal suspensions, characterized by a critical strain amplitude γ_c separating an absorbing state of reversible particle trajectories from an active state of chaotic, diffusive motion. We introduce a model—random organization—in which irreversible collisions between particles, rather than simply producing diffusive chaos, instead drive the system to self-organize so as to avoid future collisions. This mechanism gives rise to a self-organized, non-fluctuating quiescent state, with a sharp dynamical phase transition separating it from fluctuating, diffusive states. At criticality, random organization and related absorbing-state models predict hyperuniformity: an anomalously strong suppression of long-wavelength density fluctuations characterized by a structure factor $S(q \rightarrow 0) \sim q^{\alpha}$ with $\alpha > 0$. New experiments on periodically sheared suspensions confirm this picture with remarkable quantitative agreement, revealing that particles self-organize into structures with anisotropic short-range order but isotropic, long-range hyperuniform order as the oscillatory shear amplitude approaches γ_c. Together, the model and experiments provide new insight into how driven non-equilibrium systems can self-organize, with implications for controlling and manipulating material structure at the micro- and nanoscale

Keywords: (hyperuniformity, self-organization, colloids)

Title: Hyperuniformity in Conserved Directed Percolation, and its limits in Random Organization

Author: Kay Jörg Wiese

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Presenting Author: Kay Wiese (wiese@lpt.ens.fr)

Abstract: We use an exact mapping of conserved directed percolation (CDP) onto disordered elastic manifolds at depinning, to show that density fluctuations are hyperuniform. The hyperuniformity exponent α is given by $\alpha = 4-d-2\zeta$, where ζ is the roughness at depinning, which can be calculated via RG (see figure). This is relevant for the random organization model (ROM), and its biased cousin (BROM). When approaching the glassy phase at vanishing shear rate, time scales diverge suggesting that the equivalence breaks down.

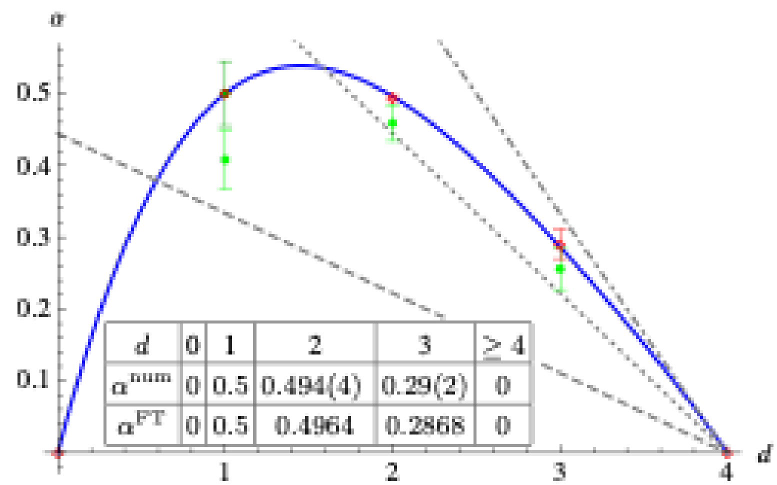

Figure Caption: The exponent α as a function of dimension *d*, and results from renormalization.

Keywords: hyperuniformity, disordered systems, field theory, renormalization

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Posters

(A) Mathias Casiulis, “Fast Spherical Harmonics Implementation of Non-uniform Point-pattern Optimization”.

(B) Vahideh Sardari, “Surface Growth Dynamics and Interface Fluctuations during Granular Sedimentation in a Hele-Shaw Cell”.

(C) Alon Kaufman, “Hyperuniformity in Microphase-Separated Fluids with Power-Law Repulsion”.

(D) Shang Gao, “Interaction-Controlled Self-Organized Criticality in Active Spinner Systems”.

(E) Feifei Liu, “Hyperuniform in Quorum Sensing Suspensions”.

Title: Fast Spherical Harmonics Implementation of Non-uniform Point-pattern Optimization

Authors: Mathias Casiulis [1,2], Stefano Martiniani [1,2,3,4]

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Abstract: Producing hyperuniform systems at scale has been a challenging numerical task since the introduction of hyperuniformity. The most common route has been optimization of a loss through the collective variable approach [1]. Recently, an optimal algorithm for such loss-based techniques through the use of non-uniform fast Fourier transforms [2].

However, this technique is limited to flat Euclidean space, limiting applications to curved manifolds, e.g. for coatings or sampling.

In this poster, I present an optimally fast algorithm for spectral optimization of point patterns on the sphere, that relies on non-uniform fast spherical harmonics. I demonstrate its performance on simple examples, e.g. stealthy hyperuniform point patterns, and give evidence of optimal scaling. I then showcase other applications, from optimal signal sampling on the sphere to material design.

This work paves the way for optimization on generic curved manifold through manifold harmonic transforms.

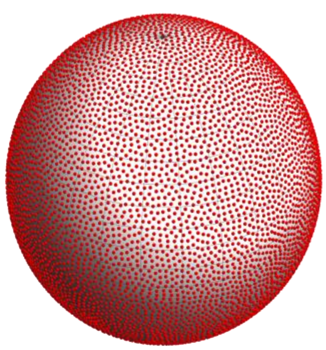

Figure Caption: Stealthy hyperuniform point pattern on the sphere with 10000 points.

Keywords: Hyperuniformity, Optimization, Numerical methods, Sampling, Curved space, Materials.

Funding Acknowledgment: M.C. and S.M. acknowledge the Simons Center for Computational Physical Chemistry for financial support.This work was supported in part through the NYU IT High Performance Computing resources, services, and staff expertise.

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[1] O. U. Uche et al., Constraints on collective density variables: Two dimensions, PHYSICAL REVIEW E 70, 046122 (2004)

[2] A. H. Shih et al., Fast Generation of Spectrally-Shaped Disorder, PHYSICAL REVIEW E 110, 034122 (2024)

Title: Surface Growth Dynamics and Interface Fluctuations during Granular Sedimentation in a Hele-Shaw Cell

Authors: Vahideh Sardari[1,2], Maniya Maleki[2,3]

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[1] Simply Complex Lab, Department of Electrical Engineering and Information Technology, Ruhr University Bochum, Bochum, Germany.

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Presenting Author: Vahideh Sardari (v.sardari.k@gmail.com)

Abstract: Understanding how collective behavior and interfacial fluctuations emerge from microscopic particle interactions remains a central challenge in nonequilibrium statistical physics. We investigate surface growth during the sedimentation of spherical granular particles in a low-viscosity fluid confined within a vertical Hele–Shaw cell through a combination of controlled experiments and discrete element method (DEM) simulations. As particles settle and accumulate at the bottom of the cell, a growing one-dimensional rough interface develops. The evolving morphology is characterized using measurements of interface width, growth and roughness exponents, spatial correlation functions, and structure-factor S(k) analysis. Numerical simulations reproduce the experimental observations with good quantitative agreement while explicitly accounting for particle interactions during deposition. The results reveal nontrivial scaling behavior associated with nonequilibrium surface growth. Different analysis methods yield distinct roughness exponents, suggesting multi-affine characteristics of the interface and deviations from simple Family–Vicsek scaling. Structure-factor S(k) analysis exhibits a robust power-law behavior over a broad range of length scales and indicates the absence of strong anomalous scaling despite the presence of complex interfacial dynamics. These findings provide insight into how microscopic interactions and particle rearrangements influence fluctuation spectra, roughening processes, and emergent collective behavior in driven granular systems. They also motivate future investigations into possible links between interfacial fluctuation suppression, hidden long-range correlations, and hyperuniformity in nonequilibrium particulate matter.

Keywords: granular sedimentation; interface fluctuations; kinetic roughening; structure factor; nonequilibrium systems; disordered matter.

Funding Acknowledgment: No specific funding was received for this work.

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Title: Hyperuniformity in Microphase-Separated Fluids with Power-Law Repulsion
Authors: Alon Kaufman[1], Erdal C. Oğuz[2], Haim Diamant[1]

Affiliations: [1] School of Chemistry, Tel Aviv University, Israel.
[2] Laboratory of Physics, Chinese Academy of Sciences, China.

Presenting Author: Alon Kaufman, alonkaufman@mail.tau.ac.il

Abstract: Competing short-range attraction and long-range repulsion drive fluids toward microphase separation, leading to stable finite-size domains. At the same time, strongly long-range power-law repulsion leads to hyperuniformity. We study a fluid that combines these two effects using a Ginzburg–Landau framework and Monte Carlo simulations. We derive a self-consistent description of the equilibrium structure factor, which shows a power-law decay at small wavevectors, signaling disordered hyperuniformity. The theory further predicts an emergent characteristic length scale for the disordered domain pattern and a modified critical temperature. Monte Carlo simulations support these predictions, reproducing the predicted structure factor and the scaling behavior of its peak. We further analyze the domain size distribution.

Keywords: hyperuniformity, microphase separation, long-range interactions

Funding Acknowledgment: Supported by Israel Science Foundation and the National Natural Science Foundation of China (ISF-NSFC Grant No. 3159/23).

Title: Interaction-Controlled Self-Organized Criticality in Active Spinner Systems

Authors: Shang Gao[1], Qun-Li Lei[1]

Affiliations: [1]School of Physics, Nanjing University, China;

Presenting Author: Shang Gao；602024220020@smail.nju.edu.cn

Abstract: Self-organized criticality provides an important mechanism for reaching critical states without fine-tuning. Whether its universality is affected by the form of microscopic interactions is a key question for understanding critical behavior in nonequilibrium active systems. In this work, we use active spinner systems as models to investigate the effects of different forms of attractive interactions on self-organized critical dynamics and the formation of hyperuniform structures. The results show that the system can generate intermittent avalanche events during slow relaxation and, under certain conditions, form self-organized critical hyperuniform states. Further comparisons of different interaction potentials reveal that long-range attractive interactions help the system approach the Manna self-organized critical behavior, with the avalanche distributions and finite-size scaling displaying robust universality. In contrast, short-range attractive or truncated interactions significantly alter the avalanche statistics, drive the system toward a subcritical state, leading to interaction-controlled nonuniversal self-organized-criticality-like behavior. This study shows that self-organized critical behavior in active matter is not entirely determined by the mechanism of conserved directed percolation. The interaction range also affects self-organized criticality and the emergence of hyperuniformity, providing new insights into the understanding and design of self-organized critical hyperuniform states.

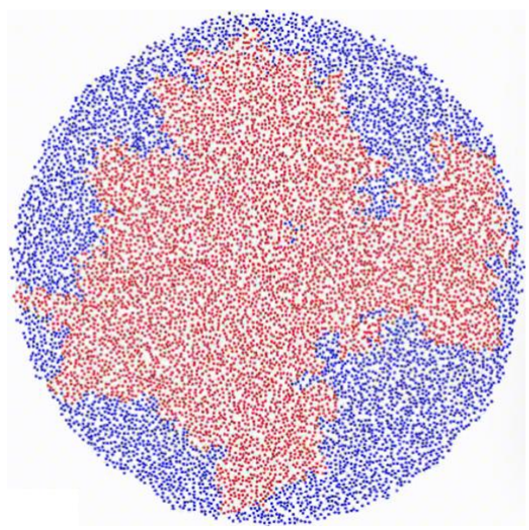

Figure Caption: Avalanche in self-organized critical hyperuniform droplet.

Keywords: self-organizing criticality, active matter, hyperuniformity

Title, "Hyperuniform in Quorum Sensing Suspensions"

Authors: Feifei Liu[1], Fabio Marchesoni[1], Yunyun Li[1]

Affiliations: [1] Tongji University, China;

We investigate quorum sensing induced hyperuniformity in two-dimensional suspensions. The system consists of passive disks with repulsive interactions. Each particle adjusts its diffusivity according to a quorum sensing signal p_i measured within a sensing radius d_c : when $P_i > P_{th}$, the particle switches to a high-diffusivity state; otherwise, it remains in a low-diffusivity state. Our simulations show that, at an appropriate sensing distance, the system can effectively suppress large-scale density fluctuations and form a hyperuniform distribution. The static structure factor follows $S(q) \propto q^{\alpha}$in the small-q regime, with α ≈1 under optimal conditions, corresponding to a critical hyperuniform system. Further analysis reveals that the optimal hyperuniform condition approximately satisfies $d_c = L_p + \sigma$, indicating a matching relationship among the QS sensing length, particle size, and switching threshold.

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