SYQS 1: Nonequilibrium Collective Behavior in Open Classical and Quantum Systems

Time: Thursday 15:00–17:45 Location: H1

Invited Talk SYQS 1.1 Thu 15:00 H1

Active quantum flocks — Reyhaneh Khasseh[1,2], Sascha Wald[3], Roderich Moessner[2], Christoph Weber[1,2], and •Markus Heyl[1,2] — [1]Theoretical Physics III, Center for Electronic Correlations and Magnetism, Institute of Physics, University of Augsburg, D-86135 Augsburg, Germany — [2]Max-Planck-Institut für Physik komplexer Systeme, 01187 Dresden, Germany — [3]Statistical Physics Group, Centre for Fluid and Complex Systems, Coventry University, Coventry, England

Flocks of animals represent a fascinating archetype of collective behavior in the macroscopic classical world, where the constituents, such as birds, concertedly perform motions and actions as if being one single entity. Here, we address the outstanding question of whether flocks can also form in the microscopic world at the quantum level. For that purpose, we introduce the concept of active quantum matter by formulating a class of models of active quantum particles on a one-dimensional lattice. We provide both analytical and large-scale numerical evidence that these systems can give rise to quantum flocks. A key finding is that these flocks, unlike classical ones, exhibit distinct quantum properties by developing strong quantum coherence over long distances. We propose that quantum flocks could be experimentally observed in Rydberg atom arrays. Our work paves the way towards realizing the intriguing collective behaviors of biological active particles in quantum matter systems. We expect that this opens up a path towards a yet totally unexplored class of nonequilibrium quantum many-body systems with unique properties.

Invited Talk SYQS 1.2 Thu 15:30 H1

Robust dynamics and function in stochastic topological systems — •Evelyn Tang — Rice University, Houston, TX

Living systems exhibit various robust dynamics and cycles during system regulation, growth, and motility. However, how robustness emerges from stochastic components remains unclear. Towards understanding this, I develop topological theories that support robust edge currents and localization, effectively reducing the system function to a lower-dimensional subspace. I will introduce stochastic networks in molecular reaction space that model long and stable time scales, such as the circadian rhythm. More generally, we prove that unlike their quantum counterparts, stochastic topological systems require driving or non-equilibrium for edge states and strong localization. I will close by discussing experimental platforms for the detection and use of edge currents for self-assembly and replication in living systems.

Invited Talk SYQS 1.3 Thu 16:00 H1

Nonequilibrium Dynamics of Disorder-Driven Ultracold Fermi Gases — •Artur Widera — University of Kaiserslautern-Landau, Department of Physics and state-research center OPTIMAS, 67663 Kaiserslautern, Germany

Ultracold quantum gases provide a unique platform to experimentally study many-body dynamics under precisely controlled external potentials and driving forces. In this talk, I will present recent results on the dynamics of an ultracold gas of spin-polarized fermionic lithium atoms subjected to a time-dependent disorder potential. For static disorder, we observe signatures of the well-known Anderson localization. In contrast, time-varying disorder with finite correlation time is expected to disrupt localization. Specifically, for weak disorder, we find that time-dependent disorder induces a transition in the transport behavior of the gas from normal diffusion to superdiffusion and eventually ballistic motion as the correlation time of the disorder decreases. This enhanced diffusion is well described by a stochastic Fermi acceleration model, where randomly fluctuating force fields drive the system. Interestingly, for strong disorder, normal diffusion persists over a broad range of disorder correlation times despite the time-varying potential. We attribute this resilience to the continued presence of destructive interference as quantified by the localized fraction of atoms, which remains intact even under the influence of time-dependent disorder. These results point toward a nonequilibrium phase transition between localized and diffusive regimes in this driven system.

15 min. break

Invited Talk SYQS 1.4 Thu 16:45 H1

Topological classification of driven-dissipative nonlinear systems — •Oded Zilberberg[1], Greta Villa[1], Kilian Seibold[1], Vincent Dumont[2], Gianluca Rastelli[3], Mateusz Michałek[4], Alexander Eichler[2], and Javier del Pino[1] — [1]Department of Physics, University of Konstanz, Universitätsstraße 10, 78464 Konstanz, Germany — [2]Laboratory for Solid State Physics, ETH Zurich, CH-8093 Zürich, Switzerland — [3]Pitaevskii BEC Center, CNR-INO and Dipartimento di Fisica, Università di Trento, I-38123, Trento, Italy — [4]Dept. of Mathematics and Statistics, University of Konstanz, Universitätsstraße 10, 78464 Konstanz, Germany

Topological classification of matter has become crucial for understanding the linear response of (meta-)materials, with associated quantized bulk phenomena and robust topological boundary effects. Moving to nonlinear systems, we develop an approach that harnesses the topology of structurally stable vector flows, and thus propose a new topological graph invariant to characterize out-of-equilibrium dynamical systems. We exemplify our approach on the ubiquitous model of a dissipative bosonic Kerr cavity, subject both to one- and two-photon drives. Using our classification, we can identify the topological origin of phase transitions in the system, as well as explain the robustness of a multicritical point in the phase diagram. We, furthermore, identify that the invariant distinguishes population inversion transitions in the system in similitude to a Z2 index. Our approach spans across the classical-to-quantum regimes, and extensions to coupled nonlinear cavities are postulated.

Invited Talk SYQS 1.5 Thu 17:15 H1

Learning dynamical behaviors in physical systems — •Vincenzo Vitelli — University of Chicago, Chicago, USA

Physical learning is an emerging paradigm in science and engineering whereby (meta)materials acquire desired macroscopic behaviors by exposure to examples. So far, it has been applied to static properties such as elastic moduli and self-assembled structures encoded in minima of an energy landscape. Here, we extend this paradigm to dynamic functionalities, such as motion and shape change, that are instead encoded in limit cycles or pathways of a dynamical system. We identify the two ingredients needed to learn time-dependent behaviors irrespective of experimental platforms: (i) learning rules with time delays and (ii) exposure to examples that break time-reversal symmetry during training. After providing a hands-on demonstration of these requirements using programmable LEGO toys, we elucidate how they emerge from physico-chemical processes involving the causal propagation of fields. Our trainable particles can self-assemble into structures that move or change shape on demand, either by retrieving the dynamic behavior previously seen during training. This phenomenology is captured by a non-reciprocal Hopfield spin model amenable to analytical treatment. The principles illustrated here provide a step towards von Neumann's dream of engineering synthetic living systems that adapt to the environment.