Symposium Active nematics: From 2D to 3D (SYAN)

jointly organised by
the Biological Physics Division (BP),
the Chemical and Polymer Physics Division (CPP), and
the Dynamics and Statistical Physics Division (DY)

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Active nematics are one of the most studied manifestations of active matter with main examples being mixtures of cytoskeletal filaments and motor proteins, but also force-generating, deforming and reorienting cells in living tissue. While the vast majority of active nematics have been studied in 2D systems, recently several advances towards 3D active nematics were made. Examples are systems that undergo multiple transitions from 3D space-filling to a compressed sheet, active filaments embedded in a passive liquid crystal and organoids in the case of tissue. The symposium will feature the experimental and theoretical challenges in the transition from 2D to 3D active nematic systems and its implications.

Overview of Invited Talks and Sessions

(Lecture hall Audimax 1)

Invited Talks

SYAN 1.1	Fri	10:00–10:30	Audimax 1	**Corrugated patterns made from an active nematic sheet** — •Anis Senoussi, Shunichi Kashida, Raphaël Voituriez, Jean-Christophe Galas, Ananyo Maitra, Estevez-Torres André
SYAN 1.2	Fri	10:30–11:00	Audimax 1	**Wrinkling instability in 3D active nematics** — •Isabella Guido
SYAN 1.3	Fri	11:15–11:45	Audimax 1	**Three-dimensional active nematic defects and their energetics** — •Miha Ravnik
SYAN 1.4	Fri	11:45–12:15	Audimax 1	**Liquid-crystal organization of liver tissue** — •Benjamin M Friedrich, Hernan Morales-Navarrete, Andre Scholich, Hidenori Nonaka, Fabian Segovia Miranda, Steffen Lange, Jens Karschau, Yannis Kalaidzidis, Frank Jülicher, Marino Zerial
SYAN 1.5	Fri	12:15–12:45	Audimax 1	**Machine learning active nematic hydrodynamics** — •Vincenzo Vitelli

Sessions

SYAN 1.1–1.5	Fri	10:00–12:45	Audimax 1	**Active nematics: From 2D to 3D**

SYAN 1: Active nematics: From 2D to 3D

Time: Friday 10:00–12:45 Location: Audimax 1

Invited Talk SYAN 1.1 Fri 10:00 Audimax 1

Corrugated patterns made from an active nematic sheet — •Anis Senoussi[1], Shunichi Kashida[3], Raphaël Voituriez[2], Jean-Christophe Galas[2], Ananyo Maitra[2], and Estevez-Torres André[2] — [1]ESPCI, Paris, France — [2]Sorbonne Université, Paris, France — [3]xFOREST Therapeutics, Kyoto, Japan

To what extent can we engineer matter that shapes itself? To investigate this question, we study a 3D solution of multimeric kinesin motors and microtubule filaments. In addition to previously described patterns such as asters and chaotic flows, we report that such a solution can spontaneously form a 2D free-standing nematic active sheet that actively buckles out of plane into a centimeter-sized periodic corrugated sheet in the presence of a depletant. This pattern is stable at low activity and is transient - ultimately breaking into chaotic flows - at higher activities. We demonstrate that the wavelength and dynamics of the corrugations are controlled by the motor concentration and the depletant concentration, in good agreement with a hydrodynamic theory of active fluids. Our results underline the importance of both passive and active forces in shaping active matter and provide some insights on how active fluids can be sculpted into a static material through an active mechanism.

Invited Talk SYAN 1.2 Fri 10:30 Audimax 1

Wrinkling instability in 3D active nematics — •Isabella Guido — Max Planck Institute for Dynamics and Self-organization

Networks of biopolymers and motor proteins are useful model systems for the understanding of emergent behaviours of active matter. In this study we investigate how this active filamentous structures promote nonequilibrium processes induced by active stress at the microscale. By combining passive processes that produce entropic forces and extensile and contractile forces exerted by motors we show that the system exhibits a nematic organization characterised by long-range orientational order. The evolution of the system over time is particularly interesting and unique. We observe 3D to 2D transition by contracting into a sheet, expansion in the direction perpendicular to the contraction, 3D wrinkling pattern formation, and finally, explosion into a spatio-temporal disordered state. Finally, we examine the influence of external stimuli such as confinement, crowding agent and filament length on the properties of the different development phases of the system.

15. min break

Invited Talk SYAN 1.3 Fri 11:15 Audimax 1

Three-dimensional active nematic defects and their energetics — •Miha Ravnik — Faculty of Mathematics and Physics, University of Ljubljana, Ljubljana, Slovenia — Josef Stefan Institute, Ljubljana, Slovenia

Active nematic fluids regularly exhibit topological defects, undergoing distinct dynamics which is determined by the coupling between the orientational order and the material flow. The type of defects and their role naturally depend on the dimensionality of the system, but importantly also on the geometry, confinement, flow, driving, and activity. Here, we present structures of topological defects in active nematic complex fluids, forming umbilic defects, singular loops, point defects, and disclinations. Specifically, we show defect profiles and dynamics in a three-dimensional active nematic droplet, also highlighting the role of different surface coupling regimes. Further, we demonstrate the dynamics of general singular defect loops in three-dimensional active nematics, which we show is strongly affected by the local twisting of the nematic director close to the singular defect cores. Finally, we discuss the energetics *energy dissipation and production- in active nematics as affected by topological defects.

Invited Talk SYAN 1.4 Fri 11:45 Audimax 1

Liquid-crystal organization of liver tissue — •Benjamin M Friedrich[1,2], Hernan Morales-Navarrete[3], Andre Scholich[4], Hidenori Nonaka[3], Fabian Segovia Miranda[3], Steffen Lange[2,5], Jens Karschau[2], Yannis Kalaidzidis[3], Frank Jülicher[4], and Marino Zerial[3] — [1]Physics of Life, TU Dresden, Germany — [2]cfaed, TU Dresden, Germany — [3]MPI CBG, Dresden, Germany — [4]MPI PKS, Dresden, Germany — [5]HTW, Dresden, Germany

Tissue function requires specific spatial organization of different cell types, yet should be flexible to allow for cell division and growth. Liquid-crystal order can serve this purpose. We present a general framework to quantify liquid-crystal order in 3D tissues and apply it to high-resolution imaging of mouse liver. We show that nematic cell polarity axes of hepatocytes (the main cell type in the liver) follow long-range liquid-crystal order. These tissue-level patterns of cell polarity are co-aligned with a structural anisotropy of two transport networks, blood-transporting sinusoids and bile-transporting canaliculi that intertwine the tissue. Silencing communication from hepatocytes to sinusoids via Integrin-β1 knockdown disrupted both liquid-crystal order of hepatocytes and organization of the sinusoidal network, suggesting that bi-directional communication between hepatocytes and sinusoids orchestrates tissue architecture. Using a network generation algorithm, we computationally explore the resilience of anisotropic sinusoidal networks to local damage, thus addressing the link between form and function in a complex tissue with biaxial liquid-crystal order.

Invited Talk SYAN 1.5 Fri 12:15 Audimax 1

Machine learning active nematic hydrodynamics — •Vincenzo Vitelli — James Franck Institute and Department of physics, University of Chicago

Hydrodynamic theories effectively describe many-body systems out of equilibrium in terms of a few macroscopic parameters. However, such parameters are difficult to determine from microscopic information. Seldom is this challenge more apparent than in active matter, where the hydrodynamic parameters are in fact fields that encode the distribution of energy-injecting microscopic components. In this talk, I will use active nematics to demonstrate that neural networks can map out the spatiotemporal variation of multiple hydrodynamic parameters and forecast the chaotic dynamics of these systems. We analyze biofilament/molecular-motor experiments with microtubule/kinesin and actin/myosin complexes as computer vision problems. Our algorithms can determine how activity and elastic moduli change as a function of space and time, as well as adenosine triphosphate (ATP) or motor concentration both in 2D and 3D. The only input needed is the orientation of the biofilaments and not the coupled velocity field which is harder to access in experiments. We can also forecast the evolution of these chaotic many-body systems solely from image sequences of their past using a combination of autoencoders and recurrent neural networks with residual architecture. In realistic experimental setups for which the initial conditions are not perfectly known, our physics-inspired machine-learning algorithms can surpass deterministic simulations.