BP 19: Cell Mechanics 2

Time: Wednesday 15:00–17:15 Location: H16

BP 19.1 Wed 15:00 H16

Light, proteins, and shape: exploiting protein pattern formation for light-controlled oocyte deformations — Jinghui Liu[2], •Tom Burkart[1], Alexander Ziepke[1], Erwin Frey[1], and Nikta Fakhri[2] — [1]Arnold Sommerfeld Center for Theoretical Physics (ASC) and Center for NanoScience (CeNS), Department of Physics, Ludwig-Maximilians-Universität München, Munich, Germany — [2]Department of Physics, Massachusetts Institute of Technology, Cambridge, MA 02139

To coordinate shape deformations, in particular cell division, cells rely on chemical reaction networks that process spatial and temporal cues, such as cell cycle signals, and control the mechanical activity that generates the required deformation. In starfish oocytes, a Rho-GTP protein pattern on the cell membrane regulates actomyosin contractility which induces large-scale cell deformations during meiotic anaphase. By engineering optogenetic activators of Rho-GTP, the native control mechanism can be hijacked to manually trigger the actomyosin contractility and thereby deform the oocyte even before entering meiotic anaphase. We study how such an artificial guiding cue is processed by the mechanochemical machinery in starfish oocytes. We combine simulations of the protein reaction-diffusion dynamics with the dynamic shape deformation of the oocyte to predict spatio-temporal light activation patterns that produce custom cell deformations. Our results contribute to the development of an overarching theoretical framework that allows to study and design minimal artificial cells capable of self-regulated and externally controlled shape changes.

BP 19.2 Wed 15:15 H16

Modeling Cell Shape and Forces on Structured Environments in Three Dimensions — •Rabea Link and Ulrich Sebastian Schwarz — Institute for Theoretical Physics, University Heidelberg, Germany

Micropatterns are a widely used tool to standardize the mechanical environment single cells or cell collectives experience in experiments. In recent years, microstructures manufactured with direct laser writing have tremendously increased the design possibilities of structured environments for cells. We model the shape, spreading dynamics and forces of a single cell with external adhesive cues using a three-dimensional compartmentalized Cellular Potts Model on 2D micropatterns and in 3D structured environments. This allows us to investigate the influence of the nucleus on the cell shape and spreading dynamics. In addition, we compare the cell shapes obtained by the Cellular Potts Model with the minimal energy shape of a surface under tension in the same mechanical environment and with experimental results.

BP 19.3 Wed 15:30 H16

Exploiting nonlinear elasticity for robust mechanosensation in disordered fiber networks — Estelle Berthier[1], •Pierre Ronceray[2], and Chase Broedersz[1,3] — [1]Arnold-Sommerfeld-Center for Theoretical Physics and Center for NanoScience, Ludwig-Maximilians-Universität München, Germany — [2]Centre Turing and Centre de Physique Théorique, Université Aix-Marseille, France — [3]Department of Physics and Astronomy, Vrije Universiteit Amsterdam, Netherlands

Cell behavior is steered by guiding cues from their surrounding extracellular environment. Cells anchor to the extracellular matrix (ECM) and perform mechanosensation: they probe their surrounding's mechanical response and regulate their behavior according to the stiffness they sense. Yet, the robustness of cellular mechanosensing is physically limited by the ECM intrinsic disorder and complex mechanical response of both the network and its constituents. Thus, it remains what strategies cells employ to accurately interpret mechanical guiding cues of such a heterogeneous environment.

Using a theoretical framework for disordered fiber networks, we evaluate the mechanical information cell can obtain by performing local measurements. We show that the signal-to-noise ratio of stiffness measurements increases dramatically in the nonlinear regime: the measurements become insensitive to local structural fluctuations of the network. We provide a scaling argument supporting that the local measurement effectively behaves as a sensory device of larger size.

BP 19.4 Wed 15:45 H16

Competition between cell deformation and depletion force: Quantified by 3D image analysis of red blood cell doublets — •Mehrnaz Babaki[1,2], Minne Paul Lettinga[1,2], and Dmitry Fedosov[3] — [1]Biomacromolecular Systems and Processes (IBI-4), Forschungszentrum Jülich GmbH, Jülich, Germany — [2]Laboratory for Soft Matter and Biophysics, KU Leuven, Leuven, Belgium — [3]Theoretical Physics of Living Matter (IBI-5/IAS-2), Forschungszentrum Jülich GmbH, Jülich, Germany

Understanding cell deformation associated with an external force is the key to a full comprehension of the behaviour of cells under mechanical loading. Red Blood Cells (RBCs) are an extreme example of deformable cells. The high deformability of RBCs influences the blood flow and blood circulation in both physiological and pathophysiological conditions as well as RBC aggregation

We investigated the deformation of RBCs using analysis of the 3D reconstructed confocal images of the RBCs in aggregated doublets. Here we use non-absorbing rod-like particles, causing depletion attraction. Our analysis yields the change in the bending energy of RBCs in a doublet, as well as the change in the depletion energy.

We identified a sequence of configurational transitions of RBC doublets upon increasing rod-like particles concentration, thus maximizing the free volume available for the depletants at the cost of deformation energy. We compared the experimental results with simulations, where we explored the different energy contributions to deformation, as well as the stability of RBC doublets at low depletion force.

15 min. break

BP 19.5 Wed 16:15 H16

Butterfly scale morphogenesis: Wrinkling on the micron scale — •Jan Totz[1], Anthony McDougal[2], and Mathias Kolle[2] — [1]Departments of Mathematics and Mechanical Engineering, Massachusetts Institute of Technology, Cambridge MA 02139, USA — [2]Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge MA 02139, USA

Micron-scale surface modulations such as wrinkles or folds underly a number of modern engineering applications, such as photonic structures in photovoltaics and flexible metasurfaces. Controlled and precise fabrication of these modulations is a challenge for human manufacturing techniques. In stark contrast, biological systems robustly utilize morphological changes in their developmental program to create multigerm bodies, hairs and scales on spatial scales which would be costly to replicate with human manufacturing. In this talk I will present recent measurements of in-vivo butterfly scale development exhibiting wrinkling. The observations are rationalized with a numerical finite element simulation and a parsimonious continuum mechanics model.

BP 19.6 Wed 16:30 H16

Active morphogenesis of patterned epithelial shells — •Diana Khoromskaia[1] and Guillaume Salbreux[1,2] — [1]The Francis Crick Institute, 1 Midland Road, NW1 1AT, United Kingdom — [2]University of Geneva, Quai Ernest Ansermet 30, 1205 Genève, Switzerland

Shape transformations of epithelial tissues in three dimensions, which are crucial for embryonic development or in vitro organoid growth, can result from active forces generated within the cytoskeleton of the epithelial cells. How the interplay of local differential tensions with tissue geometry and with external forces results in tissue-scale morphogenesis remains an open question. Here, we describe epithelial sheets as active viscoelastic surfaces and study their deformation under patterned internal tensions and bending moments. In addition to isotropic effects, we take into account nematic alignment in the plane of the tissue, which gives rise to shape-dependent, anisotropic active tensions and bending moments. We present phase diagrams of the mechanical equilibrium shapes of pre-patterned closed shells and explore their dynamical deformations. Our results show that a combination of nematic alignment and gradients in internal tensions and bending moments is sufficient to reproduce basic building blocks of epithelial morphogenesis, including fold formation, budding, neck formation, flattening, and tubulation.

BP 19.7 Wed 16:45 H16

Condensed topological defects in compressible active nemat-

ics — •Ivan Maryshev[1], Timo Krüger[1], and Erwin Frey[1,2] — [1]LMU, München, Germany — [2]Max Planck School Matter to Life, München, Germany

So far, topological defects with plus/minus 1/2 charges have been considered to be characteristic features of homogeneous active nematics. Phase-separated systems, in turn, have been known for the formation of dense nematic bands. Here, we use the agent-based model for weakly-aligning self-propelled filaments and, for the first time, demonstrate that phase-separated active nematics form -1/2 defects of a new kind. In contrast to the homogeneous case, these new defects correspond to high-density regions and coexist with bending bands. We also observe filamentous arc ejections - formations of lateral arcuate structures that separate from the band's bulk and move in a transverse direction. We show that the key control parameters defining the transition from the topologically charged structures to stable bands are the initial density of particles and their path persistence length. Finally, we develop hydrodynamic theory recapitulating observed phenomena.

BP 19.8 Wed 17:00 H16

Spherical harmonics analysis of in vivo force probes for tissue stress quantification — •Alejandro Jurado[1], Bernhard Wallmeyer[2], Christoph Engwer[2], and Timo Betz[1] — [1]Third Institute of Physics - Biophysics, Friedrich-Hund-Platz 1, University of Göttingen — [2]Institute of Cell Biology, ZMBE, Von-Esmarch-Str. 56, University of Münster

The mechanical analysis of tissue motion offers a new insight in key biological processes such as embryogenesis, cancer cell invasion and wound healing. Force quantification at this scale has been drastically improved with the emergence of in vivo sensors such as oil droplets or hydrogel beads which open up the possibility of non-invasive studies. Many approaches in recent literature rely on numerical processes to iteratively reconstruct the surface of measured beads, which can be computationally expensive and rendering results that are difficult to interpret. In this work we present the analysis of arbitrarily deformed beads based on the expansion in Spherical Harmonics in a Python custom software. We exploit the fast converging algorithms offered by SHTools [1] to reduce the great complexity of three-dimensional radial deformations to an affordable harmonic coefficient table which is directly fed into an analytical solution of the Navier-Cauchy equation. As a first proof-of-concept we show the performance of the software with polyacrylamide beads injected into zebrafish embryo at early developmental stages, in which the stress field could help understanding the processes of epiboly and shield formation. [1] Wieczorek M.A., Meschede M., 2018. Geochem. Geophys. Geosyst. 19(8), 2574-2592