BP 3: Cell Mechanics 1

Time: Monday 9:30–12:30 Location: H15

Prize Talk BP 3.1 Mon 9:30 H15

Basal tension in the wing disc epithelium - what's collagen got to do with it — Karla Yanin Guerra Santiallan[1,3], Christian Dahmann[2], and •Elisabeth Fischer-Friedrich[1,3,4,5] — [1]Cluster of Excellence Physics of Life, Technische Universität Dresden, Dresden, Germany — [2]Institute of Genetics, Technische Universität Dresdenn, Dresden, Germany — [3]Biotechnology Center, Technische Universität Dresden, Dresden, Germany — [4]Faculty of Physics, Technische Universität Dresden, Dresden, Germany — [5]Laureate of the Hertha-Sponer-Prize 2022

Healthy tissue morphogenesis is an important prerequisite for organ function. During development, epithelial folding is a major element of tissue morphogenesis. It has been shown that epithelial folding can be driven through a reduction of basal cell tension. However, a comprehensive analysis of the regulating factors of basal tension is still lacking. In this study, we use indentation with the cantilever of an atomic force microscope to estimate mechanical tension at the basal cell boundary in the wing disc epithelium of the 3rd instar larva of *Drosophila melanogaster*. We find that basal tension is not only affected by contractility of the actin cytoskeleton but is strongly influenced by the presence of the basement membrane as well as osmotic pressure. Our data suggest that elastic stresses in the basement membrane induced by basement membrane stretch, e.g. via osmotic swelling, may be a key factor in the adjustment of basal tension.

BP 3.2 Mon 10:00 H15

Viscoelasticity of spherical cellular aggregates — •Antoine Girot[1,2], Marcin Makowski[1], Marco Rivetti[1], Christian Kreis[1,3], Alexandros Fragkopoulos[1,2], and Oliver Bäumchen[1,2] — [1]Max Planck Institute for Dynamics and Self-Organization (MPIDS), 37077 Göttingen, Germany — [2]University of Bayreuth, Experimental Physics V, 95447 Bayreuth, Germany — [3]Department of Physical and Environmental Sciences, University of Toronto, ON Toronto, Canada

Understanding the complexity of many biophysical processes such as the dynamics of biological tissues requires a proper mechanical characterization of multicellular aggregates. Current experimental techniques, however, are typically limited to systems that are not larger than an individual cell. We employ *in vivo* micropipette force measurements combined with optical detection to precisely measure the force response and the deformation of living organisms simultaneously. In this presentation, we use this approach to investigate the mechanical behaviour of *Volvox globator*, a multicellular aggregate composed of thousands bi-flagellated cells forming a spherical monolayer filled with mucilage. *Volvox* is considered a model system, *e.g.* to study the evolution from single cells to multicellular life. We show that a model that couples elastic and viscous components is in excellent agreement with the mechanical response of *Volvox* and therefore can be used to extract the viscoelastic properties. We find that the viscous component is rate-dependent and exhibits a shear-thinning behaviour, while the elasticity of the cellular monolayer depends on the size of the colony.

BP 3.3 Mon 10:15 H15

Phase field model for the mechanics and migration of nucleated cells — •Robert Chojowski, Ulrich S. Schwarz, and Falko Ziebert — Institute for Theoretical Physics and BioQuant, Heidelberg University, Germany

Eukaryotic cells are built from many different constituents of varying sizes and properties. Of these organelles, the nucleus is by far the largest one. During recent years, it has become clear that many cellular functions are modulated by the nucleus, including mechanosensing of the environment and cell migration in complex environments. Its stiffness has been determined by AFM and micropipette experiments to be up to 10-fold higher than the stiffness of the surrounding cytoplasm. Despite its physical and biological importance, the nucleus is often neglected in models for cell mechanics and migration. Here we extend our reversible elastic phase field method [1] by a compartment with nuclear elasticity. We validate our numerical implementation by comparing to the analytical solution of a homogeneously adhered disk-like cell. We then simulate the effect of the nucleus for several interesting experimental setups, in particular for cell migration through a narrow channel.

[1] R. Chojowski, U.S. Schwarz, F. Ziebert, Reversible elastic phase field approach and application to cell monolayers, Eur. Phys. J. E 43, 63 (2020)

BP 3.4 Mon 10:30 H15

Mechanical Properties of the Premature Lung — •Jonas Naumann[1], Nicklas Koppe[1], Ulrich Herbert Thome[2], Mandy Laube[2], and Mareike Zink[1] — [1]Research Group Biotechnology and Biomedicine, Peter-Debye-Institute for Soft Matter Physics, Leipzig University, 04103 Leipzig, Germany — [2]Center for Pediatric Research Leipzig, Department of Pediatrics, Division of Neonatology, Leipzig University, 04103 Leipzig, Germany

Even though mechanical ventilation is a life-saving therapy for premature infants suffering from respiratory distress syndrome, prolonged ventilation and related mechanical load may cause subsequent pulmonary diseases such as bronchopulmonary dysplasia. To study the effect of mechanical stress on the immature lung, premature rat lungs were subjected to rheology experiments in compression and tension at different velocities. Here, fetal lungs behaved significantly stiffer with increasing deformation velocities as also used during high-frequency ventilation. A higher Young's modulus of fetal rat lungs compared to adult controls clearly pointed towards altered tissue characteristics. Furthermore, influences of hydrostatic pressure differences on the electrophysiology of lung epithelial cells were studied with a pressure-adjustable Ussing chamber. We observed a strong impact of hydrostatic pressure on vectorial sodium transport, important for alveolar fluid clearance. These pressure-dependent cellular alterations might explain clinical observations of ventilation-induced side effects.

15 min. break

BP 3.5 Mon 11:00 H15

Novel Optofluidic Particle Trap Enables FemtoNewton Force Sensing — •Iliya Stoev[1,2], Benjamin Seelbinder[1,2], Elena Erben[1,2], Nicola Maghelli[1,2], and Moritz Kreysing[1,2,3] — [1]Max Planck Institute of Molecular Cell Biology and Genetics, Pfotenhauerstraße 108, 01307, Dresden, Germany — [2]Centre for Systems Biology, Pfotenhauerstraße 108, 01307, Dresden, Germany — [3]Cluster of Excellence Physics of Life, TU Dresden, Arnoldstraße 18, 01307, Dresden, Germany

Here we show how thermoviscous expansion phenomena can be used to generate a new contactless particle trap that is characterised by a linear force-extension relationship and can therefore be employed in non-invasively measuring femtoNewton forces with thermally limited sensitivity. Our new method combines optics with microfluidics, lifting prerequisites related to the probe material and resulting in only moderate heating at the position of the micromanipulated object. This offers an appealing alternative to the use of optical tweezers in highly delicate samples and living systems. As a follow-up work, we aim to explore the opportunity of using these thermoviscous flows in a novel phase-sensitive microrheology approach by building on the formalism established in classic bulk rheology. We anticipate that our new method would be of interest to material scientists and mechanobiologists alike as it provides a route towards measuring the mechanics of highly viscous media, tenuous gels and likely even cellular cytoplasm or embryonic ooplasm. Further refinements of the method aim at removing the need for using fluorescent tags and/or external probes.

BP 3.6 Mon 11:15 H15

Theoretical model reveals significance of microtubules poleward flux in chromosome congression — •Ivan Sigmund, Domagoj Božan, and Nenad Pavin — University of Zagreb, Faculty of Science

At the onset of mitosis, a living cell forms mitotic spindle to ensure proper division of duplicated chromosomes between two daughter cells, whereas malfunctioning spindles can lead to chromosome missegregation. During prometaphase chromosomes are initially randomly distributed and in interaction with microtubules experience forces that congress them in spindle equator. Here we investigate what are the dominant forces that drive chromosome congression. By introducing a theoretical model, we show that length dependent poleward flux generates a net force towards the spindle equator. This poleward flux

is generated by motor proteins which accumulate along the region of antiparallel microtubule overlaps. On the other hand, forces exerted by passive crosslinkers, that accumulate within the region of parallel microtubule overlaps, are off-centering, and can impair chromosome congression. Thus, our model reveals the significance of microtubule poleward flux in chromosome congression.

BP 3.7 Mon 11:30 H15

Red blood cell shape transitions and dynamics in time-dependent capillary flow — •Katharina Graessel[1], Steffen M. Recktenwald[2], Felix M. Maurer[2], Thomas John[2], Christian Wagner[2,3], and Stephan Gekle[1] — [1]Biofluid Simulation and Modeling, Theoretische Physik VI, University of Bayreuth — [2]Dynamics of Fluids, Experimental Physics, Saarland University — [3]Physics and Materials Science Research Unit, University of Luxembourg

Red blood cells in small microchannels flow in characteristic shapes, mainly symmetric croissants at the channel center and non-symmetric off-centered slippers. While these shapes have been studied for some time, not much is known about the transition dynamics between different states. Here, we use boundary-integral simulations together with microfluidic experiments in time-dependent flows to observe and understand red blood cell shape transitions. The transition from the croissant to the slipper shape happens much faster than the opposite transition. We find that the center of mass of slipper cells shows lateral oscillations due to the tank-treading movement of the RBC membrane. The oscillation frequency increases with the cell velocity and the viscosity of the surrounding fluid.

BP 3.8 Mon 11:45 H15

Elastic modulus of lipid-loaded platelets investigated with scanning ion conductance microscopy (SICM) — •Hendrik von Eysmondt[1], Johannes Rheinlaender[1], Madhumita Chatterjee[2], and Tilman E. Schäffer[1] — [1]Institute of Applied Physics, Eberhard-Karls-University Tübingen, Germany — [2]Department of Cardiology and Angiology, University Hospital Tübingen, Germany

Platelets are small, anucleate blood cells involved in blood hemostasis, wound healing, and immune response as well as in diseases like atherosclerosis and coronary artery disease. Both low-density lipoprotein (LDL) and its oxidized form (OxLDL) increase the prothrombotic potential of platelets. Recently, it was shown that a chemokine receptor ACKR3/CXCR7 agonist inhibits platelet activation and thrombus formation, offering a new therapeutic choice for hyperlipidemic patients. However, the impacts of LDL, OxLDL, and CXCR7-agonist on platelet morphology and mechanics have not yet been identified.

We therefore investigated the influence of LDL, OxLDL, and CXCR7-agonist on platelet morphology and mechanics using SICM. We showed that CXCR7-agonist pre-treatment reduced the initial spreading rate on collagen, the final spreading area on both collagen and fibrinogen, and the elastic modulus on fibrinogen. We also showed that OxLDL, but not LDL, significantly alters the morphology and elastic modulus of lipid-loaded platelets and that CXCR7-agonist pretreatment can reverse some of the effects of OxLDL.

BP 3.9 Mon 12:00 H15

Measuring the Tension of Droplets and Living Cells with the Scanning Ion Conductance Microscope — •Johannes Rheinlaender and Tilman E. Schäffer — Institute of Applied Physics, University Tübingen, Germany

It is well known that surface tension can dominate the mechanics of micro- and nanoscale systems. However, probing the mechanics of elastic interfaces at the micrometer scale can be difficult because of the complex probe-sample interactions or the unknown underlying geometry. Here, were introduce a method to measure the surface tension of interfaces at the micrometer scale in a contact-free manner using the scanning ion conductance microscope (SICM). The SICM is based on recording the ion current through a nanopipette and was recently extended to also measure the mechanical stiffness of soft samples utilizing a microfluidic flow through the nanopipette opening. By measuring the three-dimensional shape and mechanical stiffness of oil droplets on various surfaces, we show that we can quantitatively measure their surface tension independently of their shape over more than three orders of magnitude. Applying this concept to living cells, we show that we can quantitatively measure their local stiffness and average (cortical) tension in a contact-free way. Living cells exhibit cortical tensions on the order of few mN/m, which we found to strongly vary with cell type and external conditions. For example, we show that normal and cancer cells strongly differ in their cortical tension, which demonstrates that the SICM is a versatile tool to measure the mechanical properties of living cells.

BP 3.10 Mon 12:15 H15

The secret life of sarcomeres: stochastic heterogeneity of sarcomeres in beating stem-cell-derived cardiomyocytes — •Daniel Härtter[1,2], Lara Hauke[1], Wolfram-Hubertus Zimmermann[1], and Christoph F. Schmidt[2] — [1]Institute of Pharmacology and Toxicology, Göttingen University Medical Center, Germany — [2]Department of Physics and Soft Matter Center, Duke University, Durham, NC, USA

Sarcomeres are the basic contractile units of cardiac muscles. We tracked single sarcomere motion in individual hiPSC-derived cardiomyocytes at high resolution, using a novel set of experimental and computational tools. While the emergent cell-level motion is smooth, individual sarcomeres are highly motile and behave heterogeneously during beating cycles. In response to rigid mechanical constraints, sarcomeres are forced into a tug-of-war-like competition. Automated, machine-learning-supported analysis of a large data set (>1200 cells) indicates that sarcomere heterogeneity is not caused by static non-uniformity between sarcomeres (e.g., strong/weak), but can be primarily attributed to the stochastic and non-linear nature of sarcomere dynamics and thus occurs intrinsically during cardiomyocyte beating. We show that a simple dynamic model reproduces crucial experimental findings by assuming a non-monotonic force-velocity relation for single sarcomeres, as previously predicted for ensembles of motor proteins. This led us to a novel, active matter perspective on sarcomere motion, with sarcomeres as interacting, non-linear and stochastic agents, in contrast to the prevailing mechanistic view on muscle contraction.