BP 16: Membranes, Vesicles and Synthetic Life-like Systems II

Time: Wednesday 9:30–12:45 Location: BAR/0205

Invited Talk BP 16.1 Wed 9:30 BAR/0205

Illuminating mitochondrial permeabilisation in apoptosis — •Ana J. Garcia Saez — Max Planck Institute of Biophysics, Frankfurt am Main, Germany

Mitochondrial permeabilization is a key step in the signaling pathway of apoptosis and in the cell*s commitment to death. It affects the outer and subsequently the inner mitochondrial membranes through the opening of membrane pores via mechanisms that are not fully clear. This releases cytochrome c and SMAC into the cytosol, leading to the activation of caspases, a set of proteases that accelerate cell death and that block inflammation by inactivating intracellular innate immunity effectors. Mitochondrial inner membrane permeabilization additionally releases mtDNA into the cytosol, which in turn activates intracellular innate immunity pathways unless counterbalanced by caspases. Here, I will discuss our work using advanced microscopy methods to advance our understanding of the molecular mechanisms of mitochondrial pores in apoptosis and how they function in the regulation of cell death and of inflammatory signaling outcomes.

BP 16.2 Wed 10:00 BAR/0205

Phase separation driven by membrane binding of receptor proteins of different size — •Samuel S. Gomez[1], Lennart Kleinschmidt[2], Daxiao Sun[2], Alf Honigmann[2], and Christoph Weber[1] — [1]Faculty of Mathematics, Natural Sciences, and Materials Engineering, Institute of Physics, University of Augsburg, Augsburg, Germany — [2]Technische Universität Dresden, Biotechnologisches Zentrum, Center for Molecular and Cellular Bioengineering (CMCB), Dresden, Germany

We aim to understand the physical mechanisms governing the spatial organisation and assembly of adherens junctions (AJs). A key open question is how size differences in the extracellular domains of AJ receptor proteins contribute to their segregation during junction formation. To address this, we develop a theoretical model of receptor-mediated adhesion between a GUV and a SLB, using both simulations and an experimental in-vitro setup to test and refine our model. Our model suggests that differences in receptor length are sufficient to drive spatial segregation, even in the absence of cis-interactions with similar adhesion affinities. We extend our model to understand the link between spatial organisation at the mesoscopic level of receptor segregation at membrane adhesion contact sites to the macroscopic heterogenous organisation of receptor proteins on the GUV. Our model aims to provide new insights into the physical principles underlying AJ assembly, in particular spatial organisation of receptor proteins on the mesoscopic and macroscopic level of the membrane within the AJ complex.

BP 16.3 Wed 10:15 BAR/0205

Selective information processing by particle distributions at living interfaces — •Jenna Elliott[1,2] and Anna Erzberger[1,2] — [1]European Molecular Biology Laboratory (EMBL), Heidelberg, Germany — [2]University of Heidelberg, Heidelberg, Germany

Living cells are capable of responding to environmental cues under noisy conditions, even in the absence of a centralised control unit or brain. Such systems therefore provide an ideal platform for uncovering the physical principles behind robust, decentralised information processing in soft materials. Motivated by the role interfaces play in relaying signals across cell boundaries, we investigate how spatially-varying particle distributions on interfaces facilitate information transmission in living cells. Starting from a statistical description of particle dynamics, we show that these distributions act as signal filters that nonlinearly amplify heterogeneities in their environment. This mechanism permits a form of pattern recognition, with inter-particle interactions tuning the response function of the filter. We explicitly identify both thresholding and edge-detecting regimes and, accounting for thermal noise in the filters, quantify the flow of information across the interface. We find that, when suitably tuned, the noisy filters selectively compress input signals, resulting in the efficient encoding of information relevant to downstream tasks. Overall, our results indicate that the noisy patterning of membranes may be used to selectively sense environmental cues in biologically inspired systems, suggesting exciting implications for how physical interactions may encode computational logic in soft materials.

BP 16.4 Wed 10:30 BAR/0205

Synthetic cell-based artificial tissues to study T cell activation — Anna Burgstaller[1] and •Oskar Staufer[1,2,3] — [1]INM - Leibniz Institute for New Materials, Saarbrücken, Germany — [2]Campus D2 2 — [3]Max Planck Bristol Center for Minimal Biology, Bristol, United Kingdom

T cells integrate biochemical and biophysical cues within lymph nodes, collectively determining activation of adaptive immunity. Quantitatively understanding how mechanical and biochemical signals converge at the single-cell and tissue level requires new model systems. To address this, we developed millimeter-sized artificial lymph nodes assembled from synthetic cells. The mechanical properties of the synthetic cells, specifically their Young*s modulus, can be precisely tuned, while their surfaces can be functionalized with biochemical stimuli. This allows to independently tune their biomechanics and biochemistry. The resulting tissue architecture, including its anisotropy and stiffness, can be engineered to probe emergent, tissue-scale phenomena. Performing live cell microscopy of migrating T-cells within synthetic lymph nodes, we validate that they reproduce in vivo T-cell motility. Statistical modeling of migration trajectories reveals that tissues must support search strategies for effective signal integration and that confinement degree promotes regulatory phenotypes of the T cells. Our synthetic cell-based tissues recapitulate architectural features of lymphatic organs, providing a platform to dissect how mechano-signaling interacts with biochemical cues to shape T-cell immunity

BP 16.5 Wed 10:45 BAR/0205

Excitable lipid nanotubes as a model system of neuron signaling and for neuromorphic systems — •Jan Steinkühler — CAU Kiel University, Germany

Voltage-sensitive ion channels stand at the centre in the study of cellular excitability in neuronal networks. However, the spatial propagation of electrical waves along nerve fibres is not a property inherent to an individual ion channel but rather emerges from the arrangement of ion channels along a tubular lipid membrane. While the *in vitro* study of functional ion channels in model membranes is well established, the propagation of an action potential along a lipid-bilayer nanotube has not yet been investigated. Here we present our experimental work examining these phenomena with electro-optical measurements on force-induced lipid nanotubes and demonstrate the cable-like properties of such nanotubes. Furthermore, we study memory effects arising from the interplay between electrical-field-induced lipid migration and ionic nanofluidic conductance. Finally, we show our lab's efforts toward automated cell-free expression of ion channels and data-driven modeling of membrane excitability. More broadly, our results help establish the interplay between membrane phase, shape, and electrical properties in a controlled experimental setup.

15 min. break

BP 16.6 Wed 11:15 BAR/0205

Membrane reshaping across the tree of life — •Felix Frey — Institute of Science and Technology Austria, Klosterneuburg, Austria — Eindhoven University of Technology, Eindhoven, The Netherlands

Across the tree of life, different designs of cellular membranes have evolved that are both stable and flexible. In bacteria and eukaryotes single-headed lipids self-assemble into flexible bilayer membranes. By contrast, archaea have distinct membranes that typically contain mixtures of single-headed bilayer lipids and double-headed bolalipids. While this composition is believed to enable extremophile archaea to survive harsh environments, the physical mechanisms underlying the reshaping of archaeal membranes are often unknown. Here, through the development of coarse-grained molecular dynamics simulations, we systematically compare the different membrane designs [1]. We explore the physical properties of archaeal membranes and explain how their stability and response to reshaping depends on the flexibility of single bolalipids and the amount of bilayer lipids they contain.

[1] M. Amaral*, F. Frey*, X. Jiang, B. Baum, A. Šarić (2025) Balancing stability and flexibility when reshaping archaeal membranes, eLife 14:RP105432, *Equal contributions.

BP 16.7 Wed 11:30 BAR/0205

Fluctuating triply periodic membranes: a phase-field study of diffusion in dynamic, confining environments — •Jakob Mihatsch and Andreas M. Menzel — Institut für Physik, Otto-von-Guericke-Universität Magdeburg, Universitätsplatz 2, 39106 Magdeburg, Germany

Understanding how individual entities move through interconnected structures is crucial for applications in biology and technology. A key example is the diffusive motion of molecules in porous networks. This porous environment is usually not static, but subject to thermal fluctuations and interactions with the object that is transported through it. Focusing on the situation of a spherical diffusive particle confined by fluctuating triply periodic membrane structures, we investigate numerically the effect of such a dynamic environment on the motion of a confined object [1]. We employ a phase-field approach to model the membrane surface, which allows us to apply dynamic perturbations to the shape of the membrane, without having to track its location explicitly. Triply periodic membranes can form channels with narrow pores, which lead to transient trapping. We find that thermal fluctuations can widen these pores, which speeds up diffusive transport and allows larger particles to pass through the pores than one would expect for an unperturbed membrane. Our work also shows that deformation of the membrane induced by the particle plays an important role in enhancing diffusion. Our results should be directly observable, for example, during protein diffusion through biological environments.
[1] J. Mihatsch, A. M. Menzel, arXiv:2511.23192 (2025).

BP 16.8 Wed 11:45 BAR/0205

Optimizing Dynamin for Membrane Fission — •Russell Spencer and Marcus Muller — Georg-August University Göttingen, Göttingen, Germany

Membrane tube fission is a fundamental cellular process, facilitated by the dynamin protein family. The primary energetic barrier to fission arises from the (constriction-catalyzed) collapse of the tube into a hemifused intermediate. We previously developed a self-consistent field theory (SCFT) framework to systematically study this process, and validated it against experiments. The precise mechanisms by which dynamin promotes this transition, however, remain unclear. We now model membrane tubes in the presence of dynamin-like proteins, incorporating both steric constriction and surface interactions. We explore the effect of different protein-membrane coupling mechanisms on the fission barrier, including excluded volume, head-group adhesion, and leaflet splay. While membrane attraction is necessary for protein assembly and induces curvature, it also opposes local constriction, inhibiting tube collapse. In contrast, insertion of the PH domain into the head groups leads to their splaying and produces a localized chevron-shaped membrane deformation. This facilitates tube collapse without opposing local constriction, thus promoting fission.

BP 16.9 Wed 12:00 BAR/0205

Interferometric and Fluorescence Nanoparticle Tracking for Analysis of Extracellular Vesicles — •Shuhan Jiang[1,2], Anna Kashkanova[4], Morgan Miller[1,2], Hannarae Lee[1,2,3], Hamed Qazvini[1,2], and Vahid Sandoghdar[1,2,3] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Max-Planck-Zentrum für Physik und Medizin, Erlangen, Germany — [3]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany — [4]AE Eindhoven, Groene Loper 19, Flux, Netherlands

Extracellular vesicles (EVs) are considered to be important disease markers. However, their inherent heterogeneity poses a major challenge for the characterization of their physical properties and biochemical content. We combine interferometric nanoparticle tracking analysis (iNTA) with fluorescence detection to measure particle size, refractive index, and fluorescence intensity with single-molecule sensitivity. We verify that the fluorescence signal increases with particle size for dye-labeled liposomes, and that count rates shift as one changes the labeling density. In an exemplary case study applied to HEK293-derived EVs, we show that the method resolves CD9/CD81-positive subpopulations, while marker-negative particles appear more heterogeneous, suggesting contaminants or altered composition. We discuss the potential of this multimodal approach for precise differentiation of heterogeneous nanoparticles and quantitative biomarker analysis.

BP 16.10 Wed 12:15 BAR/0205

Active and Brownian Colloids interacting with Lipid Vesicles — •Antonio Stocco, Clément Marque, and Florent Fessler — Institut Charles Sadron, CNRS, Strasbourg, France

Motion of active and passive Brownian particles is strongly affected by confinement effects, which impact the persistence of the ballistic dynamics and can guide transitions and instabilities when dealing with deformable interfaces. Here, I will present some experimental results describing the dynamics of active and passive colloids interacting with soft fluctuating membranes. Our experimental systems are composed of Giant unilamellar vesicles (GUVs) with tunable membrane tension and bare or Janus self-propelled colloids showing different hydrodynamic and particle-membrane interactions. We were able to observe emerging dynamics such as autonomous particle engulfment by the vesicle membrane, hysteresis of the particle wrapping dynamics and membrane tension dependent particle drag [1,2,3]. References: [1] F Fessler, M Wittmann, J Simmchen, A Stocco. Dynamics of Active Colloid Engulfment by Giant Lipid Vesicles, Soft Matter 2024, 20, 5904. [2] F Fessler, P Muller, A Stocco, Energetics and dynamics of membrane necks in particle wrapping, Journal of Colloid and Interface Science 2025, 700, 138524 [3] C Marque, G d'Avino, D Larobina, A Michel, A Abou-Hassan, A Stocco Diffusion of a single colloid on the surface of a giant vesicle and a droplet Physical Review E2025, 111 (2), 025411

BP 16.11 Wed 12:30 BAR/0205

pH Dependence of the Structure of Drug-Free Lipid Nanoparticle Dispersions — •Marta Gallo[1], Klaus Götz[1], Bishoy Hakim[1], Carola Vogel[1], Christian Bär[1], Lionel Porcar[2], and Tobias Unruh[1] — [1]Institute for Crystallography and Structural Physics, Friedrich Alexander University Erlangen Nürnberg — [2]Institut Laue-Langevin, 71 Avenue des Martyrs, Grenoble 38042, France

Lipid nanoparticle (LNP) dispersions are promising drug-delivery systems due to their ability to encapsulate diverse therapeutics and release them in controlled ways. A key advantage of many LNPs is their sensitivity to environmental pH, enabling drug release in acidic endosomal conditions through lipid conformational changes that destabilize the particles. To clarify these mechanisms, we synthesized drug-free LNPs mimicking the Comirnaty formulation and examined how pH affects their structure. Using simultaneous small angle X-ray and neutron scattering (SAXS/SANS) at the ILL D22 instrument, we monitored particle swelling and ordered-structure formation across different pH levels. Dialysis experiments, transitioning samples between pH 3.3 and 7, demonstrated fully reversible structural changes, as confirmed by cryo-TEM. Coupling SAXS/SANS with photon correlation spectroscopy (PCS) revealed a complex particle size distribution and deeper insight into LNP dynamics under different contrasts and pH conditions. The results clarify how pH-triggered structural transitions govern LNP behavior, supporting the design of next-generation delivery systems with enhanced release control and targeting.