15th Easter Biophysics Workshop (EBW2022)

April 20/21 2022
Tainach, Austria

Book of Abstracts

Organizers:

- Douwe Bonthuis (Co-Chair)
- James Jennings
- Enrico F. Semeraro
- Georg Pabst (Chair)

Workshop Homepage: https://xmas-biophysics-workshop2021.uni-graz.at/en/

Program

Wednesday, April 20th

09:00-10:00 **Check-In**
10:00-10:20 **Opening word**

Section I: Lipid Bilayers

Chair: Primož Ziherl

10:20-10:40	*James Jennings*	**Cationic Lipidoids: Protonation-Driven Self-Assembly and Membrane-Targeting Antimicrobial Activity**
10:40-11:00	*Michael Kaltenegger*	**Intrinsic Lipid Curvatures of Mammalian Plasma Membrane Outer Leaflet Lipids and Ceramides**
11:00-11:20	*Marin Šako*	**Lipid Bilayer Cavitation and Adhesion Energy Using Molecular Dynamics Simulations**
11:20-11:40	*Moritz P. K. Frewein*	**Interleaflet Coupling in Asymmetric Liposomes**
11:40-12:00	*Paulina Piller*	**Membrane Asymmetry Affects Activity of an Integral Membrane Enzyme**

12:00-14:00 **Lunch**

Section II: Polymers and Self-Assembly (A)

Chair: Cristian Micheletti

14:00-14:20	*Matej Kanduč*	**Nanochannels and Nanodroplets in Polymer Membranes Controlling Ionic Transport**
14:20-14:40	*Mattia A. Ubertini*	**Computer Simulations of Melts of Ring Polymers with Non-Conserved Topology: A Dynamic Monte Carlo Lattice Model**
14:40-15:00	*Pietro Chiarantoni*	**Effect of Ring Rigidity on the Statics and Dynamics of Linear Catenane**
15:00-15:20	*Douwe J. Bonthuis*	**Current Fluctuations in Nanopores Reveal the Polymer-Wall Adsorption Potential**

15:20-16:00 **Coffee break**

Section III: Polymers and Self-Assembly (B)

Chair: Douwe J. Bonthuis

16:00-16:20	*Ida Delač M.*	**On the Road to Functionalized Two-Dimensional Materials**
16:20-16:40	*Horacio V. Guzman*	**Nanomechanical Crowding at the Interface between RNA and Soft Surfaces**

16:40-17:00	*Matteo Becchi*	**Complexity Emerging from Crowding in a Self-Limited Self-Assembling System**
17:00-17:20	*Fabio Staniscia*	**Tuning Contact Angles of Aqueous Droplets on Hydrophilic and Hydrophobic Surfaces by Surfactants**
17:20-17:40	*Tomislav Vuletić*	**Distinguishing Algal Cell Species by Quartz Crystal Microbalance**

18:00-19:30 **Dinner**

Thursday, April 21st

08:00-09:00 **Breakfast & Checkout**

Section IV: Cells and Colloids

Chair: Gerhard Kahl

09:00-09:20	*Antonio Šiber*	**Mechanics of Inactive Swelling and Bursting of Porate Pollen Grains**
09:20-09:40	*Anže L. Božič*	**Mechanical Design of Apertures and Their Role in Infolding of Pollen Grains**
09:40-10:00	*Blaž Ivšić*	**Influence of Cell Shape on Dynamics of Rac1**
10:00-10:20	Šimun Mandić	**Functionalization of 2D Materials Using Solute Droplet Deposition**
10:20-10:40	*Maximilian Hübl*	**Microswimmers Learning Chemotaxis with Genetic Algorithms**

10:40-11:00 **Coffee break**

Section V: Morphology

Chair: Antonio Šiber

11:00-11:20	*Saša Svetina*	**Red Blood Cell Discocyte Shape and Lateral Distribution of Piezo1 over its Membrane**
11:20-11:40	*Matej Krajnc*	**Mechanics of a Multilayer Epithelium Instruct Tumor Architecture and Function**
11:40-12:00	*Urška Andrenšek*	**Wrinkling Instabilities of Unsupported Epithelial Monolayers**
12:00-12:20	*Primož Ziherl*	**Morphology of Vesicle Triplets**

12:20-12:30 **Closing word**

12:30-14:00 **Lunch**

14:00- **Departure**

CATIONIC LIPIDOIDS: PROTONATION-DRIVEN SELF-ASSEMBLY AND MEMBRANE-TARGETING ANTIMICROBIAL ACTIVITY

James Jennings, Dunja Ašćerić, Nermina Malanović, and Georg Pabst
University of Graz, Institute of Molecular Biosciences, NAWI Graz, 8010 Graz, Austria
BioTechMed Graz, 8010 Graz, Austria
Field of Excellence BioHealth – University of Graz, 8010 Graz, Austria

The increase of antimicrobial resistance in pathogenic bacteria is a public health crisis, as old treatments become ineffective and ordinary infections can become deadly once again. Membrane-active natural antimicrobial peptides (AMPs) and synthetic quaternary ammonium compounds (QACs) are amongst the most promising candidates for next-generation treatments. However, AMPs are susceptible to enzymatic degradation, while QACs can be toxic to human cells. Overall, the need for new antimicrobials requires high-throughput screening approaches, for which lipidoids offer the ideal molecular platform.

Synthetic "lipidoids" that mimic the structure and function of biological lipids are readily synthesized in large libraries with modular structures. Here, we introduce lipidoids containing multiple charged headgroups and hydrophobic tails (> 4) that mimic the structure of some bacterial lipids (e.g. lipid A and cardiolipin). Upon protonation, these multi-tailed lipidoids can self-assemble into lamellar, bicontinuous cubic and hexagonal liquid crystal phases, behaviour which resembles how lipid A aggregates. By screening 104 structurally-distinct lipidoids using minimum inhibitory concentration (MIC) assays, correlations between molecular shape and antimicrobial activity emerge. Biophysical techniques can be used to explore how interactions with bacterial membrane components may correlate with antimicrobial activity, paving the way to design rules for membrane-disrupting synthetic antimicrobials.

INTRINSIC LIPID CURVATURES OF MAMMALIAN PLASMA MEMBRANE OUTER LEAFLET LIPIDS AND CERAMIDES

M. Kaltenegger[1,2,3], J. Kremser[1,2,3], M. Frewein[1,2,3,4], P. Ziherl[5,6], D. Bonthuis[7], G. Pabst[1,2,3]

[1]*University of Graz, Institute of Molecular Biosciences, NAWI Graz, 8010 Graz, Austria*
[2]*BioTechMed Graz, 8010 Graz, Austria*
[3]*Field of Excellence BioHealth – University of Graz, 8010 Graz, Austria*
[4]*Institut Laue-Langevin, 38043 Grenoble, France*
[5]*Faculty of Mathematics and Physics, University of Ljubljana, SI-1000 Ljubljana, Slovenia.*
[6]*Jožef Stefan Institute, SI-1000 Ljubljana, Slovenia*
[7]*Graz University of Technology, Institute of Theoretical and Computational Physics, NAWI Graz, 8010 Graz, Austria*

We developed a global X-ray data analysis method to determine the intrinsic curvatures of lipids hosted in inverted hexagonal phases of dioleoyl phosphatidylethanolamine (DOPE). In particular, non-linear mixing effects of guest- in host- lipids on intrinsic curvature were considered. Therefore, we combined compositional modelling with molecular shape-based arguments in the model for the system's electron density. The technique was verified by all-atom molecular dynamics simulations and applied to a series of guest lipids: In addition to various phosphatidylcholines, sphingomyelin and ceramides of differing hydrocarbon chain composition were examined.

We report positive lipid curvatures for sphingomyelin and all phosphatidylcholines with di- saturated and monounsaturated hydro-carbons. Phosphatidylcholines with di- unsaturated hydrocarbons in turn yielded negative intrinsic lipid curvatures. All ceramides, with chain lengths varying between C2:0 and C24:0, displayed significantly negative lipid curvature values. Moreover, our analysis indicated non-additive mixing for C2:0 ceramide and sphingomyelin in DOPE- environment. This suggests for sphingolipids, that in addition to lipid headgroup and hydrocarbon chain volumes, also lipid- specific interactions contribute significantly to membrane curvature stress.

LIPID BILAYER CAVITATION AND ADHESION ENERGY USING MOLECULAR DYNAMICS SIMULATIONS

Marin Šako
Jožef Stefan Institute, Ljubljana, Slovenia

Liquids under tension are found in many systems around us in nature as well as in technology. Examples include lithotripsy and sonoporation of cell membranes [1,2], octopus suckers [3], catapulting mechanisms of fern spores [4,5], and the hydraulic system in plants [6,7]. Such systems under these metastable conditions are vulnerable to cavitation. Lipid membranes, as part of cell membranes, are found in almost every biological system. The study of cavity fromation in lipid membranes under tension plays an important role in the research of biological systems. In this context, lipid-lipid adhesion energy, as well as adhesion energy between lipids and other surfaces, is a crucial physical property seeing that it tells us a lot about the strength of interaction between lipids and other matter.
In this talk I will present the adhesion energies of several systems obtained from molecular dynamics simulations. More specifically, I will discuss how the lipid-lipid adhesion energy of a bilayer depends on the DLPC to DPPC ratio in each layer. Additionally, I will show how cavitation of alkane liquid and lipid bilayers looks like.

[1] Andrew J Coleman and John E Saunders. A survey of the acoustic output of commercial extracorporeal shock wave lithotripters. Ultrasound Med. Biol, 15(3):213–227, 1989.
[2] Claus-Dieter Ohl, Manish Arora, Roy Ikink, Nico De Jong, Michel Versluis, Michael Delius, and Detlef Lohse. Sonoporation from jetting cavitation bubbles. Biophys. J., 91(11):4285–4295, 2006.
[3] Andrew M Smith. Negative pressure generated by octopus suckers: a study of the tensile strength of water in nature. J. Exp. Bot., 157(1):257–271, 1991.
[4] KT Ritman and J A Milburn. The acoustic detection of cavitation in fern sporangia. J. Exp. Bot., 41(9):1157–1160, 1990.
[5] Xavier Noblin, NO Rojas, J Westbrook, Clement Llorens, M Argentina, and J Dumais. The fern sporangium: a unique catapult. Science, 335(6074):1322–1322, 2012.
[6] Abraham D Stroock, Vinay V Pagay, Maciej A Zwieniecki, and N Michele Holbrook. The physicochemical hydrodynamics of vascular plants. Annu. Rev. Fluid Mech., 46:615–642, 2014.
[7] Alexandre Ponomarenko, Olivier Vincent, Amoury Pietriga, Herve Cochard, E Badel, and Philippe Marmottant. Ultrasonic emissions reveal individual cavitation bubbles in water-stressed wood. J. Royal Soc. Interface, 11(99):20140480, 2014.

INTERLEAFLET COUPLING IN ASYMMETRIC LIPOSOMES

M.P.K. Frewein[1,2,3,4], F.A. Heberle[5], M. Doktorova[6], H.L. Scott[5,7], E.F. Semeraro[1,3,4], P. Piller[1,3,4], K.C. Batchu[2], O. Czakkel[2], Y. Gerelli[8], L. Porcar[2] and G. Pabst[1,3,4]

[1]*University of Graz, Institute of Molecular Biosciences, NAWI Graz, 8010 Graz, Austria*
[2]*Institut Laue-Langevin, 38043 Grenoble, France*
[3]*BioTechMed Graz, 8010 Graz, Austria*
[4]*Field of Excellence BioHealth – University of Graz, 8010 Graz, Austria*
[5]*Department of Chemistry, University of Tennessee, Knoxville, 37996, TN, USA.*
[6]*Center for Environmental Biotechnology, University of Tennessee, Knoxville, 37996, TN, USA.*
[7]*Shull Wollan Center, Oak Ridge National Laboratory, Oak Ridge, 37831, TN, USA.*
[8]*Department of Life and Environmental Sciences, Università Politecnica delle Marche, Ancona, 60131, Italy.*

Cellular envelopes contain a large number of lipid species that are distributed asymmetrically between the two leaflets of the bilayer. One of the enduring questions of plasma membrane architecture and lipid asymmetry concerns the possibility of interleaflet coupling even in the absence of proteins, which may influence a number of physiological processes. Currently conceived lipid-mediated coupling mechanisms consider either intrinsic lipid curvature, headgroup electrostatics, cholesterol flip-flop, dynamic chain interdigitation, or thermal membrane fluctuations.

We used asymmetric large unilamellar lipid vesicles, produced via cyclodextrin-mediated lipid exchange, and studied the effects of lipid asymmetry on membrane structure and dynamics. Using small-angle neutron and X-ray scattering as well as neutron spin-echo we found a high impact of asymmetry on lipid packing density and bending rigidity – even in the absence of cholesterol. These effects became more pronounced the further we approximated our systems to the composition of mammalian plasma membranes with phosphatidylethanolamine (PE) and phosphatidylserine (PS) opposed to phosphatidylcholine (PC) and sphingomyelin.

MEMBRANE ASYMMETRY AFFECTS ACTIVITY OF AN INTEGRAL MEMBRANE ENZYME

P. Piller, E.F. Semeraro, S. Keller, G. Pabst
University of Graz, Institute of Molecular Biosciences, NAWI Graz, 8010 Graz, Austria
BioTechMed Graz, 8010 Graz, Austria
Field of Excellence BioHealth – University of Graz, 8010 Graz, Austria

The outer membrane phospholipase A (OmpLA) is an integral membrane enzyme, which catalyzes the hydrolysis of phospholipids via the formation of a homodimer. Here, we studied the coupling of membrane asymmetry to the protein's function. To this end, we reconstituted OmpLA in symmetric and asymmetric liposomes (aLUVs) composed of palmitoyl oleoyl phosphatidyl-choline (POPC) and phosphatidylethanolamine (POPE) and studied its hydrolytic activity by high performance thin layer chromatography. We found that the basal activity of OmpLA was mostly unaffected amongst all symmetric and asymmetric membrane systems used in this study. In aLUVs however, the rate of hydrolytic cleavage of the acyl chains of POPC and POPE decreased by about one order of magnitude upon increasing the transleaflet asymmetric distribution of POPE. In contrast, lipid turnover in aLUVs reached nearly 100%, while OmpLA activity levelled off in symmetric vesicles at about half that value. Our results suggest that OmpLA activity reaches a kinetically trapped state in symmetric systems preventing the lipids from further hydrolysis. The asymmetric lipid environment and its consequently asymmetric lateral pressure distribution across the bilayer instead might favor dimerization of the enzyme leading to higher turnover numbers.

NANOCHANNELS AND NANODROPLETS IN POLYMER MEMBRANES CONTROLLING IONIC TRANSPORT

M. Kanduč,[1] R. Roa,[2] W. K. Kim,[3] and J. Dzubiella[4,5]
[1] *Jožef Stefan Institute, SI-1000, Ljubljana, Slovenia*
[2] *Departamento de Física Aplicada I, Facultad de Ciencias, Universidad de Málaga, E-29071, Málaga, Spain*
[3] *Korea Institute for Advanced Study, Seoul, 02455, Republic of Korea*
[4] *Applied Theoretical Physics – Computational Physics, Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, D-79104, Freiburg, Germany*
[5] *Research Group for Simulations of Energy Materials, Helmholtz-Zentrum Berlin für Materialien und Energie, D- 14109, Berlin, Germany*

Polymer materials with low water uptake exhibit a highly heterogeneous interior characterized by water clusters in the form of nanodroplets and nanochannels. Based on our recent insights from computer simulations, we argue that the water cluster structure has large implications for ionic transport and selective permeability in polymer membranes. Importantly, we demonstrate that the two key quantities for transport, the ion diffusion and the solvation free energy inside the polymer, are extremely sensitive to molecular details of the water clusters. In particular, we highlight the significance of water droplet interface potentials and the nature of hopping diffusion through transient water channels. These mechanisms can be harvested and fine-tuned to optimize selectivity in ionic transport in a wide range of applications.

COMPUTER SIMULATIONS OF MELTS OF RING POLYMERS WITH NON-CONSERVED TOPOLOGY: A DYNAMIC MONTE CARLO LATTICE MODEL

M.A. Ubertini and A. Rosa
Scuola Internazionale Superiore di Studi Avanzati (SISSA), 34136 Trieste, Italy

In this talk I will present computer simulations of a dynamic Monte Carlo algorithm for polymer chains on the FCC lattice which takes explicitly into account the possibility to overcome topological constraints by controlling the rate at which nearby polymer strands may cross through each other. By applying the method to systems of interacting ring polymers at melt conditions, we characterize their structure and dynamics by measuring, in particular, the amounts of knots and links which are formed during the relaxation process. In comparison to standard melts of unknotted and unconcatenated rings, our simulations demonstrate that the mechanism of strand crossing makes polymer dynamics faster provided the characteristic time scale of the process is smaller than the typical time scale for chain relaxation in the unperturbed state, in agreement with recent experiments employing solutions of DNA rings in the presence of the type II topoisomerase enzyme. In the opposite case of slow rates the melt is shown to become slower, and this prediction may be easily validated experimentally.

EFFECT OF RING RIGIDITY ON THE STATICS AND DYNAMICS OF LINEAR CATENANE

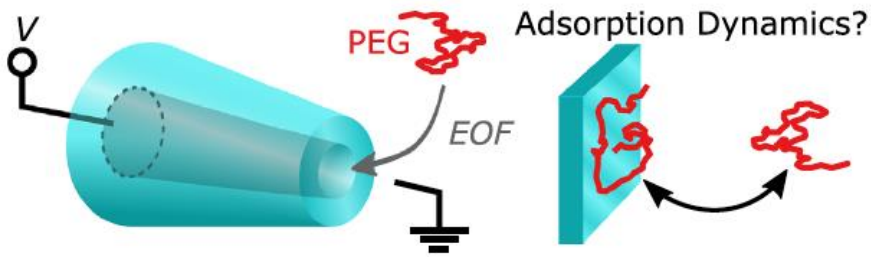
P. Chiarantoni and C. Micheletti
International School for Advanced Studies (SISSA), Trieste, Italy

We used molecular dynamics simulations to investigate the statics and dynamics of poly[n]catenanes for different bending rigidities of the constitutive rings. We show that stiffer rings yield catenanes with more extended and, at the same time, more flexible backbones. The softening of the backbone reflects the decreasing steric interactions of catenated rings as their shape becomes more oblate due to increased rigidity. The internal dynamics of catenanes is affected too. Going from flexible to rigid rings causes a severalfold slowing down of different processes, from segmental rotations and size fluctuations to Rouse modes. Finally, by considering the statics and dynamics of crowded solutions of catenanes, we isolate another emergent property controlled by the rigidity of the rings. Specifically, we show that catenanes with rigid rings hinder each other's motion more than those with flexible rings. Thus, in equally crowded solutions, the diffusion coefficient is smaller for catenanes with stiffer rings.

CURRENT FLUCTUATIONS IN NANOPORES REVEAL THE POLYMER-WALL ADSORPTION POTENTIAL

S.F. Knowles, N.E. Weckman, V.J.Y. Lim, D.J. Bonthuis, U.F. Keyser, and A.L. Thorneywork
Cavendish Laboratory, Department of Physics, University of Cambridge
Institute of Theoretical and Computational Physics, Graz University of Technology

Modification of surface properties by polymer adsorption is a widely used technique to tune interactions in molecular experiments such as nanopore sensing. Using experiments and Monte Carlo simulations, we investigate how the ionic current noise through solid-state nanopores reflects the adsorption of short, neutral polymers to the pore surface. The power spectral density of the noise shows a characteristic change upon adsorption of polymer, the magnitude of which is strongly dependent on both polymer length and salt concentration. In particular, for short polymers at low salt concentrations no change is observed, despite the verification of comparable adsorption in these systems using quartz crystal microbalance measurements. We propose that the characteristic noise is generated by the movement of polymers on and off the surface.



ON THE ROAD TO FUNCTIONALIZED TWO-DIMENSIONAL MATERIALS

I. Delač[1,2], D. Čapeta[1], A.L. Brkić[1], B. V. Tran[2], K. Houtsma[2], Q. Sun[3], N. Kerisit[4], F. Diederich[4], M. Stöhr[2], M. Kralj[1]

[1]*Center of Excellence for Advanced Materials and Sensing Devices, Institute of Physics, Zagreb, Croatia*

[2]*Zernike Institute for Advanced Materials, University of Groningen, the Netherlands*

[3]*Interdisciplinary Materials Research Center, Tongji University, Shanghai, P. R. China*

[4]*Laboratorium für Organische Chemie, ETH Zürich, Switzerland*

Scientific and technological interest in two-dimensional (2D) materials is motivated by the fact that today's electronic devices are based on planar microarchitectures. 2D materials are a promising basis for a new generation of electronic and other devices due to their superior electronic, optical and mechanical properties. However, there are issues to be addressed in order for these materials to be implemented in commercial devices. For start, precise and controlled synthesis and methods of manipulation are necessary for the successful integration in devices, as well as fine tuning of the properties of interest. In that regard, some properties of 2D materials can be tuned by functionalization (e.g. with molecular patterning) or mechanical modulation. We are interested in the functionalization of the 2D materials with an ordered (covalently or non-covalently bound) layer of organic molecules and subsequently, their influence on the properties of 2D materials. Starting point of our research is the synthesis, transfer and characterization of 2D materials. Next step is study of molecular self-assemblies on bulk substrates, and finally, functionalization of 2D materials with organic molecules. I will present research conducted in different stages of this process, as well as the current status of our work.

NANOMECHANICAL CROWDING AT THE INTERFACE BETWEEN RNA AND SOFT SURFACES

H.V. Guzman[1], M. Kanduč[1] and S. Poblete[2]
[1]*Department of Theoretical Physics, Jožef Stefan Institute, SI-1000 Ljubljana, Slovenia*
[2]*Instituto de Ciencias Físicas y Matemáticas, Universidad Austral de Chile, Valdivia 5091000, Chile*

Nanomechanical crowding remains theoretically unexplored at the interface of RNA molecules and soft surfaces. Existing RNA molecular models tend to reach very complex ensembles on themselves to be combined to e.g. soft matter mechanics. Here, we introduce a multiscale approach which couples a tractable RNA coarse-grained model [1] with an elastic energy component. Within this approach, we study the specific role of RNA's secondary structure patterns on the deformation of soft surfaces by characterizing representative RNA motifs. First, we study the specific role of RNA stem-hairpin and multibranch secondary structure motifs on its adsorption phenomenology [2]. Under controlled molecular crowding conditions we analyze the effects of conformational entropy and the interplay between surface energy per monomer and deformation lengths. Our findings add a novel way to address the mechanisms of response of encapsulated RNA inside crowded macromolecular environments, like the ones faced during RNA delivery.

[1] S. Poblete, H.V. Guzman, Structural 3D Domain Reconstruction of the RNA Genome from Viruses with Secondary Structure Models, Viruses, 13(8), 1555 (2021).
[2] S. Poblete, A. Bozic, M. Kanduc, R. Podgornik, H. V. Guzman*, RNA Secondary Structures Regulate Adsorption of Fragments onto Flat Substrates, ACS omega, 48 6, 32823–32831. (2021).

COMPLEXITY EMERGING FROM CROWDING IN A SELF-LIMITED SELF-ASSEMBLING SYSTEM

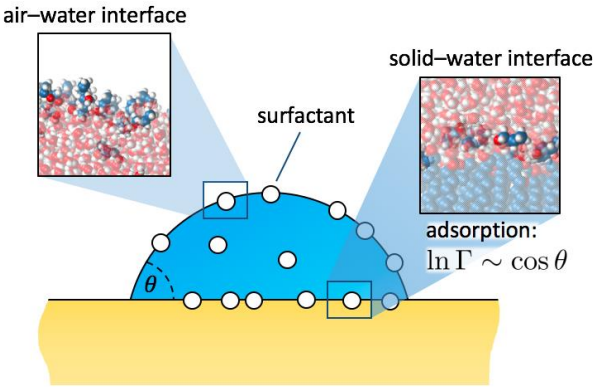
M. Becchi[1], R. Capelli[2], C. Perego[3], G. M. Pavan[2,3], and C. Micheletti[1]
[1]*Scuola Internazionale Superiore di Studi Avanzati - SISSA, Trieste, Italy*
[2]*Department of Applied Science and Technology, Politecnico di Torino, Torino, Italy* [3]*Department of Innovative Technologies, University of Applied Sciences and Arts of Southern Switzerland, Lugano-Viganello, Switzerland.*

A prime goal in self-assembly is guiding the constitutive building blocks from a dispersed state to complex ordered constructs. While changing monomers' shape and interactions can directly affect the self-assembly outcome, environmental conditions are also crucial, as in the paradigm that high monomer concentrations should be avoided as they antagonize the formation of ordered assemblies. Here, using a theoretical and numerical approach, we show how complexity may instead even emerge from crowding in self-assembling systems. We use a general-purpose model system where the curved shape of the monomers establishes a so-far unexplored avenue, namely the emergence of two complex ordered assemblies that compete for prevalence against a wide range of disordered aggregates. *Via* molecular dynamics and metadynamics simulations, we systematically study the system's self-assembly at different monomer concentrations, both in and out of equilibrium. Our results prove that higher-complexity ordered constructs can emerge as the dominant species for increasing monomer density. Further control over complexity is shown to be attainable with irreversible self-assembly, too. The emergent properties of the model system give a novel perspective on using environmental conditions to tune self-assembly complexity, offering a paradigm relevant from complex molecular systems to supramolecular constructs in synthetic chemistry and biology.

TUNING CONTACT ANGLES OF AQUEOUS DROPLETS ON HYDROPHILIC AND HYDROPHOBIC SURFACES BY SURFACTANTS

F. Staniscia, H.V. Guzman, M. Kanduč
Department of Theoretical Physics, Jožef Stefan Institute, SI-1000 Ljubljana, Slovenia.

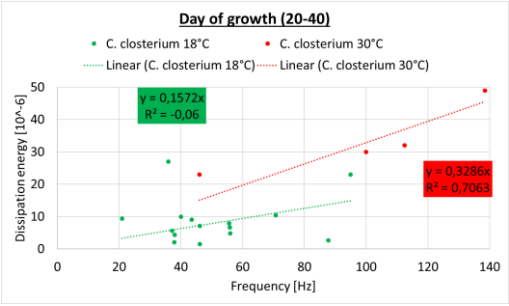
Adsorption of small amphiphilic molecules occurs in various biological and technological processes, sometimes desired, the other times unwanted (e.g., contamination). Surface-active molecules preferentially bind to interfaces and affect their wetting properties. We study the adsorption of short-chained alcohols (simple surfactants) to the water-vapor interface and solid surfaces of various polarities using molecular dynamics simulations. The analysis enables us to establish a theoretical expression for the adsorption coefficient, which exponentially scales with the molecular surface area and the surface wetting coefficient, and which is in good agreement with the simulation results. The competition of the adsorptions to both interfaces of a sessile droplet alters its contact angle in a non-trivial way. The influence of surfactants is strongest on very hydrophilic and very hydrophobic surfaces, whereas droplets on surfaces of moderate hydrophilicity are much less affected.



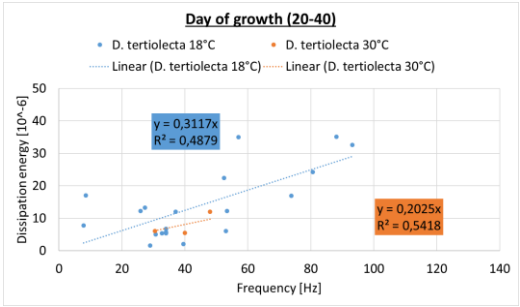
DISTINGUISHING ALGAL CELL SPECIES BY QUARTZ CRYSTAL MICROBALANCE

Ema Vlašić [1], Nives Novosel [2], Adrianna Zalewska [3], Anna Sobiepanek [3], Tomasz Kobiela [3], Nadica Ivošević Denardis [2], and Tomislav Vuletić [4]

[1] *Faculty of Science, University of Zagreb, Croatia;*
[2] *Ruđer Bošković Institute, Zagreb, Croatia;*
[3] *Faculty of Chemistry, Warsaw University of Technology, Warszawa, Poland;*
[4] *Institute of Physics, Zagreb, Croatia*



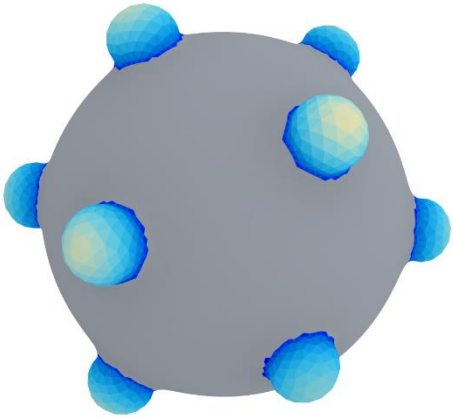
The study aimed to examine the effect of the physico- morphological properties of algal cells on binding efficiency to a surface modified sensor of a quartz crystal microbalance with dissipation monitoring (QCM-D). Two unicellular algae were tested; Cylindrotheca closterium encased with an organosilicate cell wall and Dunaliella tertiolecta as wall-less species. Cells were grown at 3 selected temperatures to examine their temperature tolerance. We found no correlation of the concentration of algae in the solution with the number of algae bound to the sensor. However, the correlation of this number to the resonant frequency shift [Δf] of the sensor was stronger. The viscoelastic properties (rigidity) of algae were represented by the dissipation factor shift, ΔD of the sensor normalized by Δf – i.e. by the adhered mass of algae. We found that the QCM-D method via this ΔD/Δf ratio may distinguish the viscoelastic properties of the studied species, in accordance with their reported mechanical properties. However, the values vary widely and the results for the two species overlap, which could be related to cell age and physiological activity. Our results could contribute to a better understanding of interactions between algae and substrate and the development of QCM-D devices towards biological research methods.



MECHANICS OF INACTIVE SWELLING AND BURSTING OF PORATE POLLEN GRAINS

A. Šiber[1] and A. Božič[2]
[1]*Institute of Physics, Zagreb, Croatia*
[2]*Department of Theoretical Physics, Jožef Stefan Institute, Ljubljana, Slovenia*

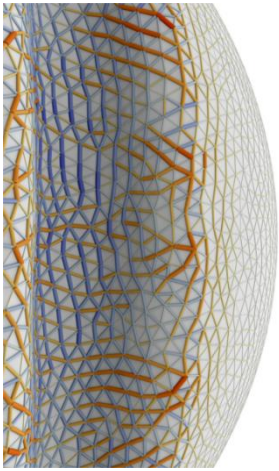
The mechanical structure of pollen grains, typically characterized by soft apertures in an otherwise stiff exine shell, determines their response to changes in the humidity of the environment. These changes can lead to grain infolding but also to excessive swelling and even bursting of pollen grains. We use an elastic model to explore the mechanics of pollen grain swelling and the role that soft, circular apertures (pores) play in this process. We identify and explore a mechanical weakness of the pores, which are prone to a huge inflation once the grain swells to a critical extent. This transition leads to the bursting of the grain and the release of its content. Our results shed light on the inactive part of the mechanical response of pollen grains to hydration once they land on a stigma as well as on bursting of airborne pollen grains when the air humidity increases.

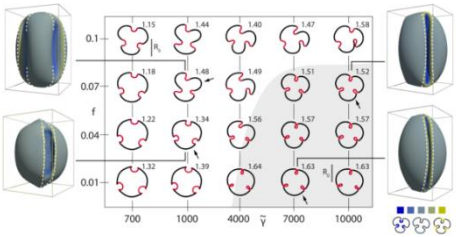


MECHANICAL DESIGN OF APERTURES AND THEIR ROLE IN INFOLDING OF POLLEN GRAINS

A. Božič[1] and A. Šiber[2]
[1]*Department of Theoretical Physics, Jožef Stefan Institute, Ljubljana, Slovenia*
[2]*Institute of Physics, Zagreb, Croatia*

Pollen carries male plant genetic material encapsulated in a hard protective shell containing flexible, soft regions—apertures. This mechanical structure of pollen shells guides their response to the changes in the humidity of the environment. Once pollen grains are exposed to the environment, they start to lose water and close in upon themselves in a process termed harmomegathy. This prevents further dehydration of the grains and allows for a safe transport of the genetic material. We investigate the infolding pathways of pollen grains by studying elastic deformations of inhomogeneous thin shells. Different pathways are governed by the interplay between the elastic properties of the hard and soft regions of the pollen shell and by the aperture shape, number, and size. We delineate regions of mechanical parameters of the pollen grain which lead to complete closure of all apertures, thus reducing water loss and presenting evolutionary viable solutions to the infolding problem. Understanding the mechanical principles behind pollen folding pathways should also prove useful for the design of the elastic response of artificial inhomogeneous shells.





INFLUENCE OF CELL SHAPE ON DYNAMICS OF RAC1

B. Ivšić[1], T. Vuletić[1], M. Šoštar[2] I. Weber[2]
[1]*Institute of physics, Zagreb, Croatia*
[2]*Ruđer Bošković institute, Zagreb, Croatia*

Cell movement depends on actin polymerization, which is regulated by signal proteins like small GTPases. It is known that activity of these proteins in eukaryotic cells is structured in spatiotemporal patterns like traveling and stationary waves, which in hand serve as templates for polarization of the actin cytoskeleton into functional domains. Patterns in protein concentrations are formed due to dynamic instabilities originating from non-linear protein interactions [1]. We made a 2D reaction diffusion model which simulates spatiotemporal patterns in protein concentrations using finite-elements method (FEM). We can apply it to a range of model cells shaped as circles, squares, ellipses and rectangles. Our interest is to examine the influence of cell geometry on pattern forming. Laser confocal microscopy provides the data on the movement of a fluorescent probe that specifically binds to the active form of Rac1 GTPase in vegetative Dyctiostelium cells [2]. With photolithography we prepared adhesive islands in non-adhesive polymer coating of PLL-PEG on glass slides. The islands were designed in the respective geometric shapes that we can model. Currently, with LCM we are studying whether the cells adopt those shapes and record the spatiotemporal patterns of the probe. We are testing whether our model is applicable, i.e. whether, according to the underlying experimental condition – the cell shape we can tweak the model to simulate the microscopy data.

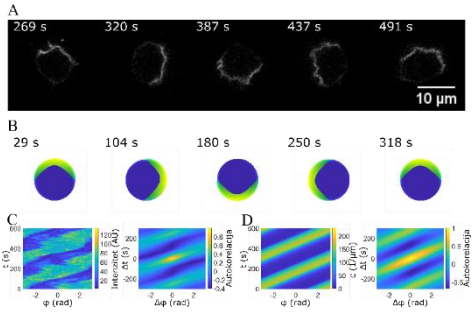


Figure 1 Rotation pattern. Comparison of experimentally measured dynamics of active form of Rac1 protein on the cell membrane and numerical simulations. (A) Clips gathered with confocal microscopy of a probe that binds to active form of Rac1 protein. (B) Results of numerical simulation. (C) Kymograph depicting fluorescence of mentioned probe in dependence on time and membrane position (left) and its autocorrelation function (right). (D) Kymograph of Rac1 concentration obtained with numerical simulation (left) and its autocorrelation function (right).

[1] Maeda, Yusuke T., et al. "Ordered patterns of cell shape and orientational correlation during spontaneous cell migration." *PloS one* 3.11 (2008): e3734.
[2] Filić, Vedrana, et al. "A dual role for Rac1 GTPases in the regulation of cell motility." *J Cell Sci* 125.2 (2012): 387-398.

FUNCTIONALIZATION OF 2D MATERIALS USING SOLUTE DROPLET DEPOSITION

A. L. Brkić[1], A. Supina[1], D. Čapeta[1], Š. Mandić[1], L. Ptiček[2], L. Racanè[2], I. Delač Marion[1]

[1]*Center of Excellence for Advanced Materials and Sensing Devices, Institute of Physics, Zagreb, Croatia*

[2]*University of Zagreb, Faculty of Textile Technology, 10000 Zagreb, Croatia*

Molecular self-assembly on 2D materials is a new, quickly developing research field that is focused on two goals: (I) modification of (opto)electronic properties of 2D materials, since molecular adsorption can influence properties like doping, bandgap, or optical response and (II) use of 2D materials as a decoupling layer to preserve properties (e.g., magnetic or catalytic) of the adsorbed molecules. We are interested in the impact of the functionalization with covalently or non-covalently bound organic molecules on the properties of 2D materials. In our current research, the primary method of organic molecules deposition is placing a drop of precise concentration solute on the chosen 2D material. The natural starting point is the characterization of 2D material after exposure to different solvents to differentiate between the effects of the solvent and the organic molecules. I will present our work on fine-tuning the solvent concentration, deposition volume, deposition method, and preliminary results when applying the technique to water-soluble organic molecules.

MICROSWIMMERS LEARNING CHEMOTAXIS WITH GENETIC ALGORITHMS

B. Hartl[1], M. Hübl[1], G. Kahl[1] and A. Zöttl[1]
[1]*Institute for Theoretical Physics, TU Wien, Austria*

Many bacteria and eukaryotic cells perform chemotaxis in order to swim or crawl towards different chemical stimuli [1, 2, 3]. Their chemotactic strategies and underlying biochemical mechanisms are highly diverse, and a number of theoretical models for chemotaxis have been developed. However, it remains unclear how the interactions between a cell's chemical receptors and intracellular chemotactic pathways are connected to the specific cell shape deformations that lead to efficient cell motion upwards chemical gradients. Here we demonstrate [4] that microswimmers are able to *learn* chemotaxis by developing simple internal decision-making machineries that control swimming movement based on measured chemical signals. We represent these machineries as artificial neural networks (ANNs), which we optimize and evolve with the help of Reinforcement Learning [5] and the NEAT genetic algorithm [6]. We apply our optimization scheme to the three-bead Najafi-Golestanian swimmer [7] and quantify the emerging swimming strategies by their fitness (mean swimming velocity) and complexity (number of ANN connections). Our investigation includes both spatial and temporal sensing of chemical gradients and we show how the presence of noise in a temporally sensing swimmer can lead to the well-known run-and-tumble behavior of various microorganisms.

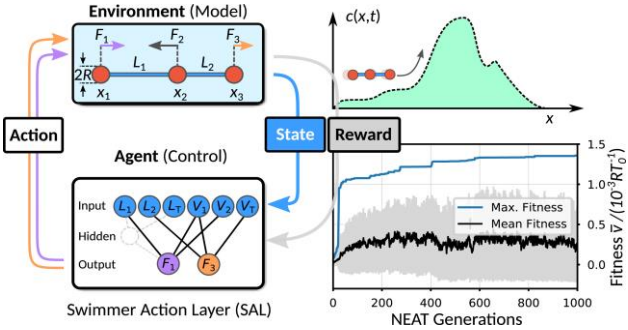


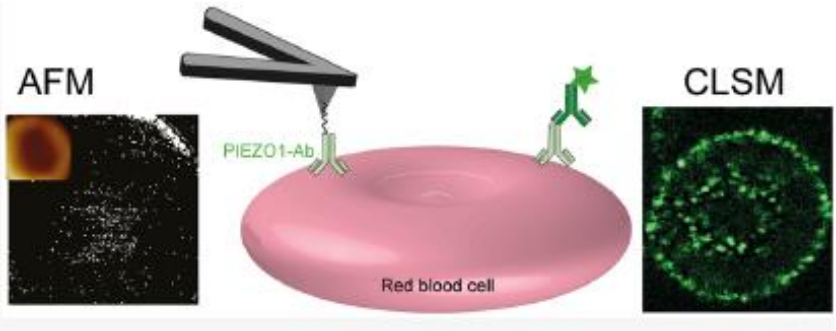
Figure 1: Schematic of our control mechanism and training progress.

[1] H.C. Berg and D.A. Brown, *Nature* 239, 500–504 (1972).
[2] E. Lauga, *Annu. Rev. Fluid Mech.* 48, 105–130 (2016).
[3] M. Polin, I. Tuval, K. Drescher, J.P. Gollub and R.E. Goldstein, *Science* 487, 487–490 (2009).
[4] B. Hartl, M. Hübl, G. Kahl and A. Zöttl, *Proc. Natl. Acad. Sci. U.S.A.* 118 (19), e2019683118 (2021).
[5] R. Sutton and G. Barto, *Reinforcement Learning: An Introduction* (MIT Press, 2017).
[6] K.O. Stanley and R. Miikkulainen, *Evol. Comput.* 10, 99–127 (2002).
[7] A. Najafi and R. Golestanian, *Phys. Rev. E* 69, 062901 (2004).

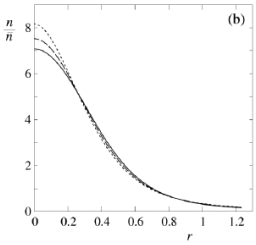
RED BLOOD CELL DISCOCYTE SHAPE AND LATERAL DISTRIBUTION OF PIEZO1 OVER ITS MEMBRANE

S. Svetina[1,2], B. Božič[1]
[1]*Insitute of Biophysics, Faculty of Medicine, University of Ljubljana, Ljubljana, Slovenia.*
[2]*Department of Theoretical Physics, Jožef Stefan Institute, Ljubljana, Slovenia.*

Piezo1 is a nonspecific membrane cation channel present in a variety of tissues where it plays a significant role in various physiological processes (Murthy et al., Nat. Rev. Mol. Cell Biol. 18, 771, 2017). Recently, it was shown, by high-resolution atomic force and confocal microscopy studies, that it is distributed on the red blood cell (RBC) discocyte membrane in a nonuniform manner, in that its



area density is larger than the average in regions of its poles and smaller than the average in the region of its rim (Dumitru et al., Nano Lett. 21, 4950-4958, 2021; upper part of the figure is from their abstract). Here we report that it is possible to interpret the lateral distribution of Piezo1 molecules on RBC membrane by the curvature dependent Piezo1 – bilayer interaction which is the consequence of the mismatch between the intrinsic curvature of the Piezo1 trimer and the curvature of the membrane at Piezo1´s location but without its presence. The obtained dependence of the area density on the distance from the discocyte axis (lower part of the figure) supports the model for the role of Piezo1 in the regulation of RBC volume (Svetina et al., Biophys. J. 116, 151, 2019).



MECHANICS OF A MULTILAYER EPITHELIUM INSTRUCT TUMOR ARCHITECTURE AND FUNCTION

V.F. Fiore[1], M. Krajnc[2,3], F. Garcia Quiroz[1], J. Levorse[1], H. A. Pasolli[4], S.Y. Shvartsman[2,5,6], and E. Fuchs[1]

[1]*Howard Hughes Medical Institute, Robin Chemers Neustein Laboratory of Mammalian Cell Biology and Development, The Rockefeller University, New York, NY, USA.*
[2]*Lewis-Sigler Institute for Integrative Genomics, Princeton University, Princeton, NJ, USA.*
[3]*Jozef Stefan Institute, Ljubljana, Slovenia.*
[4]*Electron Microscopy Resource Center, The Rockefeller University, New York, NY, USA.*
[5]*Department of Chemical and Biological Engineering, Princeton University, Princeton, NJ, USA.*
[6]*Department of Molecular Biology, Princeton University, Princeton, NJ, USA.*

Structural changes of epithelial tissues are typically indicative of oncogenic transformations. Using genetic manipulations, biophysical measurements, and computational modeling, we study morphologies of cancerous tissues in premalignant basal and squamous cell carcinomas—cancers that are associated with considerably different prognoses. We find that the two tumor types cause distinct morphological changes of the epidermis. These differences are mainly caused by distinct mechanical properties of the extracellular matrix, secreted by the respective mutated basal cells. In particular, softening and enhanced remodelling of the basement membrane promote tumor budding, while stiffening of the basement membrane promotes folding. Our findings suggest that mechanical forces function to shape premalignant tumour architectures and influence tumor progression.

WRINKLING INSTABILITIES OF UNSUPPORTED EPITHELIAL MONOLAYERS

U. Andrenšek[1,2], P. Ziherl[1,2], and M. Krajnc[1]
[1]*Jožef Stefan Institute, SI-1000 Ljubljana, Slovenia*
[2]*Faculty of Mathematics and Physics, University of Ljubljana, SI-1000 Ljubljana, Slovenia*

Buckling of epithelial tissues may be a result of different processes and properties of the cells. Forces generated within the actomyosin network and cells' surface properties can be studied by the differential-tension model, which describes tissues as tight packings of discrete cells with different surface tension of their apical, basal, and lateral sides. We study wrinkling instabilities of a two-dimensional tissue cross section. We derive a continuum approximation of a discrete cell-based model and compare it to numerical results. We find that under small external compression, model tissues undergo buckling, wrinkling or period doubling, depending on the surface-tension difference.

MORPHOLOGY OF VESICLE TRIPLETS

T. Chiba[1], Y. Sakuma[1], P. Ziherl[2,3], and M. Imai[1]
[1]*Department of Physics, Tohoku University, Sendai, Japan.*
[2]*Faculty of Mathematics and Physics, University of Ljubljana, Ljubljana, Slovenia.*
[3]*Jožef Stefan Institute, Ljubljana, Slovenia*.

Experimental studies of vesicle aggregates elucidated a number of phenomena induced by intermembrane adhesion. For example, a detailed comparison of the observed doublet morphologies and their transformations with theoretical results based on bending elasticity and contact adhesion revealed that the simple fixed-membrane-area model of a vesicle is not suitable for aggregates and that the two-tension model is more appropriate [1]. Here we investigate the shapes and shape transformations of triplets of vesicles filled with a fructose solution and suspended in a KCl solution, the KCl concentration controlling the effective strength of adhesion between the vesicles. We focus on the shape deformation of the different types of aggregates upon membrane expansion induced by heating, observing that at low KCl concentrations they transform into aggregates of weakly bound cigar-shaped vesicles whereas at high KCl concentrations they form compact spherical aggregates. These observations are compared to theoretical results obtained within the two-tension model and within an *ad hoc* cavity model developed so as to reproduce the compact aggregates. The agreement between the experimental and the theoretical results is reasonable but incomplete, pointing to several rather fundamental questions such as the spontaneous curvature of membranes in asymmetric solutions [2].

[1] K. Murakami, R. Ebihara, T. Kono, T. Chiba, Y. Sakuma, P. Ziherl, and M. Imai, Biophys. J. **119**, 1735 (2020).
[2] B. Rożycki and R. Lipowsky, J. Chem. Phys. **142**, 054101 (2015).