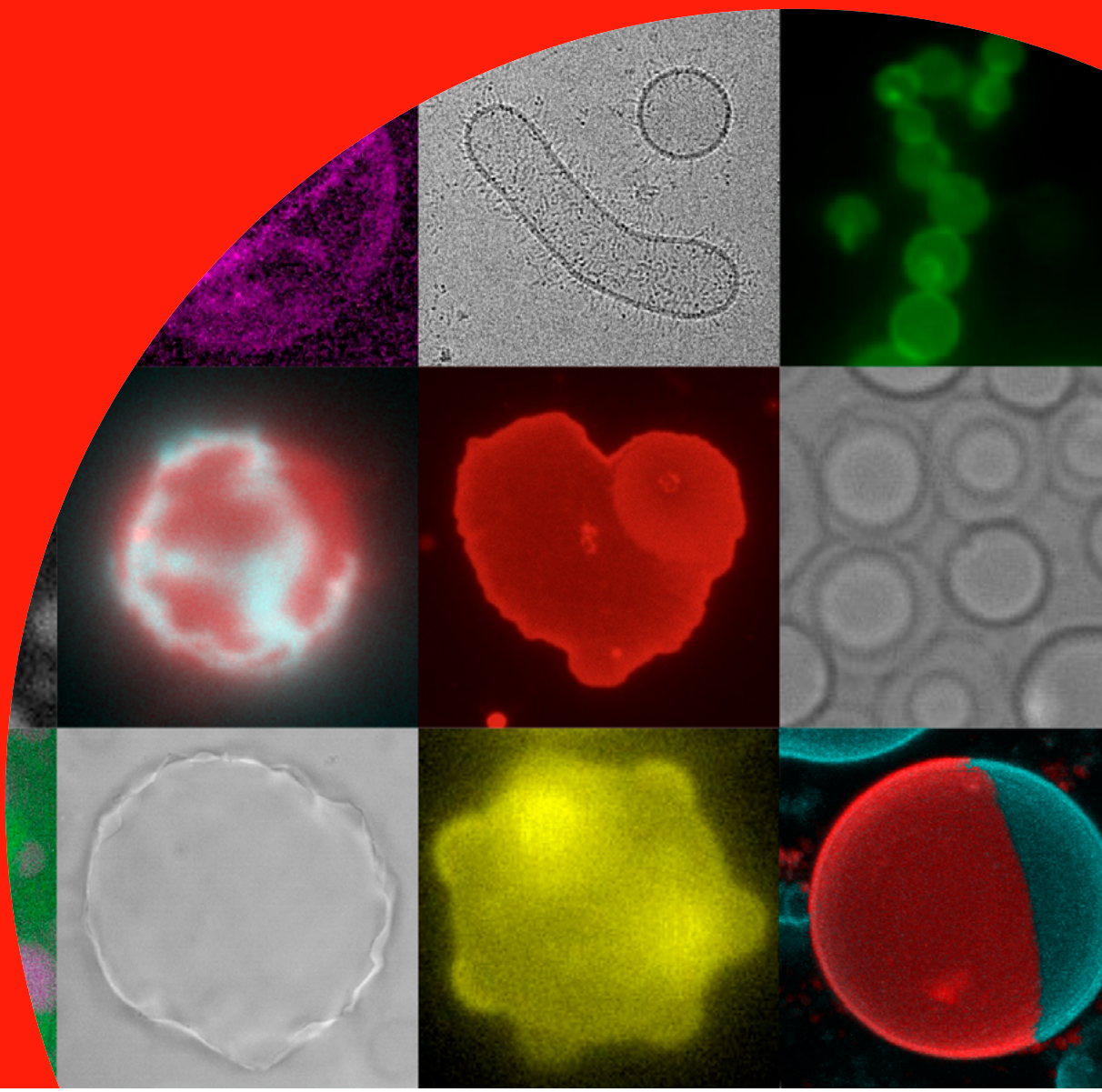
Designer Membranes and Bio-inspired Interfaces

26–27 March 2026

Wolfson College, Cambridge, UK



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Thursday 26 March

08:30	Registration and Refreshments
09:20	Welcome
09:30	(Invited) The shape of early life: primitive cells, primitive compartments **Claudia Bonfio,** University of Cambridge
10:15	Lipid flip-flop regulates the shape of growing and dividing synthetic cells **Rafael Lira**, Tu Delft
10:30	QuantGUV: A Standardised Pipeline for the High-Throughput Characterisation of Encapsulation in Synthetic Cells **Zak Marshall**, University of Surrey
10:45	Coffee Break and Poster Session 1
11:30	(Invited) Microfluidics, automation, and engineered bio membranes as enabling technologies in synthetic cell design **Yuval Elani**, Imperial College London
12:15	Bio-hybrid light harvesting membranes: exploring novel combinations of LH proteins, synthetic pigments, lipids, polymers and quantum dots **Peter Adams**, University of Leeds
12:30	Engineering Artificial Molecular Channels for Switchable Transmembrane Ion and Water Transport **Associate Javid Ahmad Malla**, Francis Crick Institute
12:45	Lunch and Poster Session 1
14:30	(Invited) The catalytic role of membranes in biological pattern formation **Petra Schwille**, Max Planck Institute for Biochemistry
15:15	Wax Esters as Prebiotically Plausible Modulators of Primitive Membranes **Krishnakavya Thaipurayil Madanan**, University of Cambridge
15:30	Characterizing the structure, interactions, and organization of membranized coacervate protocells and developing strategies to control them **Sadaf Javed**, Radboud University
15:45	Tea Break and Poster Session 1
16:30	(Invited) Engineering Hybrid Membranes as Durable Functional Interfaces for Biotechnology and Artificial Cells **Paul Beales**, University of Leeds
17:15	Developing bacterial outer-membrane models – balancing between greater physiological relevance and experimental control **Corrin Blake**, University College London

17:30 Probing the interaction of liposome delivery systems with Gram negative bacterial cell envelopes: a comprehensive investigative approach
Yixuan Yan, University of Birmingham

18:00 Drinks Reception

19:00 Conference Dinner

Friday 27 March

08:30 Arrival Refreshments

09:00 (Invited) Watching Translocation: From Botulinum Toxin to DNA Through Nanopores
Mark Wallace, King's College London

09:45 3D Printed Bioelectronic Model of the Intestinal Tissue Architecture
Maria Lopez Cavestany, University of Cambridge

10:00 Crowding-controlled adsorption and diffusion of streptavidin on supported lipid bilayers
Wanchung Chiang, CNRS LIPHY

10:15 Coffee Break and Poster Session 2

11:00 (Invited) Non-equilibrium giant unilamellar vesicles
Laura Alvarez, University of Bordeaux

11:45 Self-synthesizing artificial cells via enzymatic polymerization
Andrea Belluati, TU Darmstadt

12:00 Membrane prewetting by condensates promotes tight-junction belt formation
Karina Pombo-Garcia, Rosalind Franklin Institute

12:15 Lunch and Poster Session 2

14:00 (Invited) Leveraging Macromolecular Topology and Random Heterogeneity to Design Non-living Predators
César Rodriguez-Emmenegger, Institute For Bioengineering of Catalonia (IBEC) and Catalan Institution for Research and Advanced Studies

14:45 Soft But Tough! Engineering of Protein Nanosheet-Stabilised Microdroplets for Stem Cell Technologies
Julien Gautrot, Queen Mary University of London

15:00 Biomimetic Lipid-Based Lubrication for Therapeutic Solution in Osteoarthritis
Di Jin, Hong Kong City University

15:15 Tea Break and Poster Session 2

16:00 (Invited) Artificial Cells: from Soft Matter to Cell-Like Behaviours
Claudia Contini, Imperial College London

16:45 Emergent Motility of Self-Organized Particle-Giant Unilamellar Vesicle Assembly
Gaurav Gardi, Max Planck Institute For Intelligent Systems

17:00 Discriminating cancer and healthy prostate Extracellular Vesicles through membrane rigidity: a Molecular Dynamics approach
Lakshmi Kumar Kunche, Sapienza University of Rome

17:15 Poster Awards and Closing Remarks

17:30 End

Poster Session 1

P1.1 Probing Interactions at the Interface between Nucleic Acid Nanostructures and Lipid Membranes
Sofia Benedetti, University of Cambridge

P1.2 Liposomes in non-aqueous polar solvents
Ella Y L Ho, ISIS Neutron And Muon Source

P1.3 Ion conduction in single-walled carbon nanotubes
Dmitry Luchinsky, Lancaster University

P1.4 Emergent Motility of Self-Organized Particle-Giant Unilamellar Vesicle Assembly
Selcan Karaz Han, Max Planck Institute for Intelligent Systems

P1.5 BioPISA-Engineered Hierarchical Artificial Cells for Chemical-to-Biological Signaling
Gizem Cantörü, Technical University of Darmstadt

P1.6 Lipid bilayer interactions with a type II collagen-binding peptide suppress its targeting ability
Paramita Manna, Weizmann Institute of Science

P1.7 Understanding how curvature-sensing peptides capture extracellular vesicles via Gaussian molecular dynamics: the bradykinin case
Lakshmi Kumar Kunche, La Sapienza University of Rome

Poster Session 2

P2.1 Tunable phase behavior in synthetic cell membranes using modified emulsion phase transfer technique
Bashayr Khalifah, University of Cambridge

P2.2 ATP-responsive membraneless compartments in synthetic cells
Juliette Bucci, Department of Chemical Engineering and Biotechnology

P2.3 Polymer Brush-Templated Assembly of a Lipid Bilayer Network
Vahid Nasirimarekani, Max Planck Institute for Dynamics and Self-organization

P2.4 Coupling synthetic cell division and DNA segregation
Nastasja Kaletta, Max Planck Institute of Biochemistry

P2.5 Expressing Membrane-Less RNA Organelles in Lipid-Based Synthetic Cells
Akthar Hussain Mougamadou Soultane, University of Cambridge

P2.6 Elastohydrodynamic control of lipid membrane coarsening
Aditya Jha, Cavendish Laboratory, University of Cambridge

P2.7 Exploring DNA Linkers for Biomimetic Cell Adhesion of Red Blood Cells
Sebastian W. Krauss, Department of Chemical Engineering and Biotechnology, University of Cambridge

Prof. Laura Alvarez

Laura Alvarez is an Associate Professor at the University of Bordeaux, and leads the Soft BioColloids group at the Centre de Recherche Paul Pascal (CRPP, CNRS). She completed a joint PhD between the University of Bordeaux and KU Leuven on the dynamics of colloidal liquid crystals, followed by postdoctoral work at ETH Zurich on responsive, light-controlled active colloidal assemblies. Her research develops out-of-equilibrium soft-matter and bioinspired microsystems, using light, chemical gradients, and electric fields to program thermo-/electro-hydrodynamic interactions, active transport, and shape transformations in colloids and giant vesicles. The ultimate goal is to engineering functional, cell-mimetic microdevices and colloidal architectures. She served as an ESA consultant for Soft Matter and Biophysics, and currently runs microgravity experiments on giant lipid vesicles in collaboration with DLR (MAPHEUS 14,15&16). She is a beneficiary/partner of the Marie Skłodowska-Curie Doctoral Network SynSigCell and has been awarded with ANR JCJC, and ANR PRCI, and SNSF Spark grants. She is an active member of the Femmes et Science association in France with the mission of normalise the presence of women in STEM and outreach about physics, chemistry and space science.

Prof. Paul Beales

Paul Beales is Professor of Soft Matter and Biophysics in the School of Chemistry at the University of Leeds, where he heads the Functional Materials and Molecular Assemblies research section. Paul's first degree is in physics, before completing his PhD in the Soft Condensed Matter Group at the University of Edinburgh (2005). Following postdoc positions in chemical engineering departments in the US (Princeton, Yale), Paul established his independent research group in Leeds in 2010. The group's research interests primarily focus on engineering membranes and vesicles for biotechnology applications, often related to healthcare technologies. These include developing new tools for engineering artificial cells, formulating therapeutic delivery systems and using insights from some of these approaches to understand the design and function of biological systems. Paul is currently the UK lead of the UK-Japan ACROPATH project, which is developing artificial cells as novel tools for pathogen diagnosis. In 2025, Paul was awarded the Biological Physics Communications Prize by the Institute of Physics Biological Physics Group.

Dr Claudia Bonfio

Claudia Bonfio completed her PhD in Biomolecular Sciences at the University of Trento (IT), working on the origin and catalytic activity of ancient proteins. Later, as a Marie Sklodowska Curie Fellow and 1851 Research Fellow, she moved to Cambridge, where she looked into the chemical origin of cell membrane signalling. In 2021, she started her independent research career at ISIS in Strasbourg before moving back to the University of Cambridge in 2024 as a University Associate Professor following the award of an ERC Starting Grant and a UKRI Future Leader Fellowship. Her group is interested in designing and developing functional primitive cells capable of Darwinian evolution.

Dr Claudia Contini

Claudia Contini is an Assistant Professor in Biotechnology and Engineering Biology in the Department of Life Sciences at Imperial College London. Her research group focuses on bottom-up synthetic biology, membrane biophysics, and biohybrid systems. She holds a Master's degree in Pharmaceutical Chemistry from the University of Padua, Italy, and a PhD in Physical Chemistry from University College London, UK. Following her PhD, she continued her academic career at Imperial as a postdoctoral researcher and was awarded competitive fellowships, including the ISSF and BBSRC Discovery Fellowship. Her work has been recognised with prestigious awards, including the L'Oréal–UNESCO UK Fellowship and the Italy Made Me award. She is Co-Director of the Association of Italian Scientists in the UK, an IUPAC National Representative, and a member of the Royal Society of Chemistry Colloid & Interface Science Group.

Prof. César Rodriguez-Emmenegger

César Rodriguez-Emmenegger is a Research Professor at the Institute for Bioengineering of Catalonia (IBEC) and the Catalan Institution for Research and Advanced Studies (ICREA) in Barcelona, Spain. His research is driven by the vision of creating ***Quasi-living Materials:*** synthetic systems that recapitulate specific functions or behaviors we associate with living matter and harness them for biomedical applications.

Rather than focusing solely on adaptive responses, his work seeks to endow materials with **functional agency**, such as artificial phagocytosis to eliminate pathogens or endothelium-mimetic behavior to regulate blood–material interactions. He approaches living function as an abstract physical and organisational problem and **reverse engineers the function rather than its biological implementation**, across length scales, from the desired mesoscopic behavior to macromolecular building blocks whose chemistry, topology, and interactions encode collective, life-like function.

His group develops macromolecular systems whose **tailored chemistry, topology, and intrinsic heterogeneity** govern their self-assembly into functional biointerfaces and synthetic cells, spanning applications from antifouling and antimicrobial coatings to hemocompatible surfaces and phagocytic synthetic cells.

César studied Chemical Engineering at Universidad de la República (Uruguay) and obtained a PhD in Biophysics and Macromolecular Chemistry and Physics at the Institute of Macromolecular Chemistry in Prague, under the mentorship of Eduard Brynda and Aldo Bologna Alles. After postdoctoral research with Christopher Barner-Kowollik (Alexander von Humboldt Fellow) and research stays in Cambridge (W.T.S. Huck) and the University of Pennsylvania (Virgil Percec), he established his first independent group in Prague with a GACR Junior Grant. He later led a junior research group at the DWI-Leibniz Institute for Interactive Materials (Aachen) before joining IBEC in 2022, where his research is supported by an **ERC Consolidator Grant**.

Yuval Elani is a UKRI Future Leaders Fellow and Reader in the Department of Chemical Engineering at Imperial College London. Yuval studied Natural Sciences as an undergraduate (Cambridge, 2009) followed by a PhD in the Institute of Chemical Biology (Chemistry, Imperial College, 2015). After his PhD he held a series of fellowships working on various topics in biochemical engineering. He leads a diverse group of c. 25 researchers working on frontier research in biotechnology. His current research interests include biohybrid systems, synthetic cells, and autonomous laboratories for biomembrane design and discovery.

Dr Yuval Elani

Petra Schwille is Director at the Max Planck Institute of Biochemistry in Martinsried near Munich, Germany, and Honorary Professor at the LMU Munich. She studied physics and philosophy in Stuttgart and Göttingen, and graduated 1993 with Diploma in Physics at the Georg August University, Göttingen. She obtained her Ph.D. in 1996 from the TU Braunschweig, with a thesis on Fluorescence (Cross-)Correlation Spectroscopy, performed at the MPI for Biophysical Chemistry, Göttingen, with Nobel Laureate Manfred Eigen. After a postdoctoral stay at Cornell University, Ithaca, NY, she returned to the MPI Göttingen as a research group leader, financed by the BMBF Biofuture prize, in 1999. In 2002, she accepted a Chair of Biophysics at the newly established BIOTEC Center of the TU Dresden. Since 2012, she is heading the department Cellular and Molecular Biophysics at the MPI of Biochemistry and Honorary Professor of Physics at LMU Munich. Her scientific interests range from single molecule biophysics to the synthetic biology of reconstituted systems.

Prof. Petra Schwille

Mark Wallace is Professor of Chemistry at King's College London and Group Leader at the Francis Crick Institute. His research develops single-molecule and artificial membrane methods to understand how membrane proteins function, with particular focus on molecular transport across lipid bilayers. His group pioneered droplet interface bilayers, a platform now licensed to Oxford Nanopore Technologies, and has used this to develop optical single-channel recording and simultaneous single-molecule fluorescence imaging. Current work spans nanopore sensing, toxin and antimicrobial peptide mechanisms, membrane protein diffusion, synthetic cells, and the bottom-up design of artificial ion channels. He holds awards including the RSC Norman Heatley Award and the Gregorio Weber International Prize, and is a Fellow of the Royal Society of Chemistry.

Prof. Mark Wallace

(Invited) The shape of early life: primitive cells, primitive compartments

Claudia Bonfio, University of Cambridge

How did chemistry give rise to the first cells? Our lab investigates this question by exploring how primitive compartments, both membrane-bound and membraneless, could have emerged under prebiotic conditions and supported early biochemical function. We focus on the spontaneous diversification of lipids in the absence of enzymes, showing how prebiotic chemistries can generate complex membrane compositions with dynamic physical properties. These membranes can exhibit key behaviours such as fusion, division, and selective permeability, and may have played a critical role in early RNA replication and molecular organisation.

In parallel, we study peptide/oligonucleotide coacervates as an alternative strategy for compartmentalisation. These phase-separated droplets can stabilise and activate nucleic acids and interact actively with primitive membranes, offering a complementary model of primitive biochemical environments.

Together, these studies suggest that early cellular life may have emerged through a combination of interacting, enzyme-free compartments with distinct chemical origins. By integrating prebiotic chemistry, membrane biophysics, and systems approaches, we aim to reconstruct pathways from disordered molecular mixtures to functionally organised protocells.

Lipid flip-flop regulates the shape of growing and dividing synthetic cells

Rafael Lira, Tu Delft
Co-authors: *Marco van Tilburg, Siewert-Jan Marrink, and Cees Dekker*

Cells grow their boundaries by incorporating newly synthesized lipids into their membranes as well as through fusion of intracellular vesicles. As these processes yield trans-bilayer imbalances in lipid numbers, cells must flip lipid molecules across the bilayer to enable growth. Using giant and large unilamellar vesicles (GUVs and LUVs, respectively), we here recapitulate cellular growth and division under various conditions of transmembrane ‘flip flop’ of lipids. By dynamically monitoring the changes in reduced volume, spontaneous curvature and area difference of GUVs that grow by fusion of many small LUVs, the morphology of these growing ‘synthetic cells’ is quantified. We demonstrate that lipid flip flop quickly and generally relaxes curvature stresses and yields more symmetrically sized buds, without significantly compromising membrane integrity. Further increasing the neck curvature is shown to lead to bud scission. The mechanisms presented here offer fundamental insights into cell growth and division, which are important for understanding early protocells and designing synthetic cells that are able to grow and divide.

QuantGUV: A Standardised Pipeline for the High-Throughput Characterisation of Encapsulation in Synthetic Cells

Zak Marshall, University of Surrey
***Co-authors**: Reshma Bano, Pasha Dylan, Luisa Trifan, Callum Mckeaveny, André P. Gerber, and Wooli Bae*

The engineering of bottom-up synthetic cells relies on our ability to precisely encapsulate biomolecular machinery within membrane architectures. Giant Unilamellar Vesicles (GUVs) serve as the gold standard chassis for these systems due to their sizes and the ability to encapsulate molecules of interest. However, our ability to quantify encapsulation efficiency of molecules inside of GUVs is limited. Without precise information about concentration of molecules, evaluating the yield or efficiency of biochemical pathways within these confined environments remains a challenge.

In this work, we present QuantGUV, a specialised software and calibration pipeline designed to provide robust quantification of biomolecular encapsulation and production within GUVs. By leveraging our unique procedure to generate standard curves of GUV intensities using empty vesicle controls, we have determined internal concentrations of a diverse range of molecules, from small fluorophores, fluorescence proteins and nanoscale fluorospheres.

We further explore the physicochemical drivers of encapsulation, demonstrating how lipid concentration and internal aqueous volume ratios dictate formation dynamics and yield. By providing a multidimensional assessment of vesicle diameter, yield, and cargo concentration, QuantGUV offers a rigorous framework for the characterisation of designer membranes. This work advances the reliability of synthetic cell construction, bridging the technical gap between stochastic vesicle formation and predictable, functional biomimetic systems.

(Invited) Microfluidics, automation, and engineered biomembranes as enabling technologies in synthetic cell design

Yuval Elani, Imperial College London

Synthetic cells (SynCells) are bioinspired micromachines constructed from molecular building blocks, mimicking the form and function of biological cells. Despite their promise, SynCells are structurally simplistic, primarily consisting of spherical liposomes, unlike their biological counterparts which are highly compartmentalised. Given that form and function are intertwined, this lack of architectural complexity restricts the development of more sophisticated behaviours. In this talk, I will discuss our recent efforts to overcome these limitations by employing microfluidic assembly lines for SynCell production, enabling the creation of a wide repertoire of SynCell architectures. We harness this increased structural complexity to create a new generation of SynCells with biomimetic behaviours, most notably those capable of detecting external stimuli (including as temperature, light, and magnetic

fields) and initiating a biochemical response. Additionally, we have recently expanded our toolkit to access the nano-regime by using automated approaches to generate and screen lipid libraries. Together with rational design, this enables us to construct nano-organelles for multi-stage release of different payloads at defined time points, as well as to develop attolitre bioreactors for in situ biochemical synthesis.

Bio-hybrid light harvesting membranes: exploring novel combinations of LH proteins, synthetic pigments, lipids, polymers and quantum dots

Peter Adams, University of Leeds
Co-authors: *Ashley Hancock, Joel Whipp, Thomas Gregson, Masaharu Kondo, Simon Connell, David Swainsbury, and Takehisa Dewa*

Specialized biomembranes from plants have the role of absorbing sunlight and acting like a satellite dish to transfer energy and perform photochemistry. These "light-harvesting (LH) membranes" contain transmembrane LH proteins that are embedded with photon-absorbing pigments. Our research group has been undertaking a series of projects that take inspiration from nanotechnology and self-assembly approaches to generate novel bio-hybrid LH membranes. Firstly, we have generated model lipid membranes where the spectral range of LH proteins is augmented with synthetic chromophores. Small organic chromophores that absorb light at alternative wavelengths were assembled into lipid vesicles with LH proteins from plants or bacteria and high efficiency energy transfer was observed from the chromophores to proteins. Most recently, we generated photovoltaic devices that have improved performance due to a combination of plant LH proteins and these synthetic chromophores within model lipid membranes. Secondly, we used amphiphilic polymers as a replacement for lipids in membranes that contain plant LH proteins. The amphiphilic diblock copolymers used seem to provide a more robust membrane that increases the stability of the membrane proteins. Thirdly, we have assembled quantum dots (QDs) and lipids together into stable clusters of ~20 nm diameter. There was evidence of rapid QD-to-QD excitation energy transfer, which may be useful for future applications as photo-active nanomaterials. Overall, we hope that providing new insights into combinations of biological LH membranes and synthetic nanomaterials will provide valuable clues for future solar technologies.

Engineering Artificial Molecular Channels for Switchable Transmembrane Ion and Water Transport

Javid Ahmad Malla, Francis Crick Institute

Ion channels and aquaporins are ubiquitous biological components that facilitate complex and vital functions in living systems. Inspired by nature, synthetic chemists have made significant progress in designing artificial channels, which hold immense potential for applications in synthetic biology and artificial cells. Future advancements in these systems will be crucial for addressing channelopathies—diseases caused by ion channel malfunctions—that remain challenging to treat with current therapeutic approaches. Additionally, the exceptional ability of aquaporins to rapidly transport water while excluding salts has motivated their application in water purification and desalination, a growing global need.

Herein, I will present a synthetic ion channel whose activity is precisely regulated by three orthogonal stimuli: light, pH, and guest/ligand interactions. The channel is constructed from a pillar[5]arene functionalized with photoswitchable tetrafluorobenzene moieties, enabling efficient E:Z isomerization (E to Z: 87%, Z to E: quantitative). The differential rates of ion transport under different conditions form a switchable molecular logic gate that operates as an AND to OR gate. This system achieves a remarkable 170-fold modulation in activity through external stimuli, representing a significant advancement in synthetic ion channel design.

Additionally, I introduce aramid foldamers as artificial water channels. These will feature a selective filtration mechanism for desalination and single-channel water permeability rates of up to 10^8 - 10^{10} water molecules per second per channel—approaching the efficiency of natural aquaporins (~10^9). The quantified water to salt selectivity of channels reach a values of 10^9, which crosses the trade-off limits of commercial desalination membranes. Together, these studies provide an innovative blueprint for developing next-generation controllable channels with applications in synthetic biology and nanofiltration.

(Invited) The catalytic role of membranes in biological pattern formation

Petra Schwille, Max Planck Institute for Biochemistry

Living systems employ self-organized protein pattern formation to regulate important life processes in space and time. Although pattern-forming networks have been identified in various pro- and eukaryotes, their systematic experimental characterization is challenging due to the complex environment of living cells. In turn, cell-free systems are ideally suited for this goal, as they offer defined molecular environments that can be precisely controlled and manipulated. In my talk, I will demonstrate the power of reconstitution approaches in cell-free membrane environments for elucidating biological pattern formation, but also for designing entirely new pattern-forming systems including protein, DNA and RNA.

Wax Esters as Prebiotically Plausible Modulators of Primitive Membranes

Krishnakavya Thaipurayil Madanan, University of Cambridge

The emergence of stable yet dynamic membranes was a critical step in the origin of cellular life. Primitive membranes, likely composed of chemically simple amphiphiles, would have required mechanisms to tune their structural and dynamic properties in the absence of complex lipid biosynthesis. Identifying prebiotically plausible molecules capable of modulating membrane behaviour is therefore central to understanding early cellular evolution.

Wax esters are neutral lipids formed from fatty acids and fatty alcohols, both readily accessible under prebiotic conditions. Despite their chemical simplicity, their effects on membrane organisation and dynamics remain poorly characterised. Here, we investigate the influence of symmetric wax esters spanning a broad range of chain lengths (C8:0–C16:0) on model lipid bilayers.

Membrane properties were probed using environment-sensitive fluorescence assays, including Laurdan generalised polarisation, DPH anisotropy, and TMA-DPH anisotropy, enabling assessment of membrane order, hydrophobic core dynamics, and interfacial behaviour. Across all systems examined, incorporation of wax esters showed, chain-length-dependent changes in bilayer organisation. Laurdan measurements indicate increased membrane order upon wax ester incorporation, while anisotropy measurements reveal distinct, non-uniform effects on membrane dynamics that depend on both wax ester chain length and probe localisation.

Together, these results demonstrate that wax esters can modulate multiple aspects of membrane organisation despite their chemical simplicity. Our findings support the idea that neutral lipids such as wax esters may have contributed to tuning the stability and dynamic behaviour of primitive membranes, providing a plausible route toward functional protocellular compartments prior to the emergence of complex lipid regulatory systems.

Characterizing the structure, interactions, and organization of membranized coacervate protocells and developing strategies to control them

Sadaf Javed, Radboud University

How did life emerge on early earth? How can we fashion biomolecules into tissue-like biomaterials? These questions are two sides of the same coin. Compartmentalization—organization/assembly of molecules in contained spaces—enabled the chemical reactions important for life. Today, vesicles and coacervates are used to mimic cell compartments. Coacervates offer a biomolecule-rich microenvironment and vesicles demarcate protocell boundary and allow selective interaction with the surrounding environment. Previously, we introduced a method to make coacervates covered with lipid bilayers or membranized

coacervates (MCs). Now, we characterize MC surface and expand on the mechanism of MC formation, explaining their unique surface properties. We show the presence of transmembrane peptides on MC surface that maintain MC membrane integrity and act as nucleation sites for phase-separation. We also systematically record interactions between different MC populations and show that membrane and coacervate surface charge, length of coacervate polymers, and charge of coacervate and membrane components all influence MC-MC interactions and assembly. External stimuli, such as high and low temperatures and certain peptides can alter MC interactions. Membrane modification too, is an important tool for controlling MC-MC interactions and assembly. To this end, we propose a liposome modification and purification procedure, which uses coacervates as carriers of insoluble membrane functionalizing molecules. We can then use such functionalized liposomes to make MCs with different properties. MCs show that formation process confers unique properties to the resulting protocell structure, which then influence its behaviour. MCs present a system that is useful for origins-of-life research as well as for applied research of biomaterials, colloids, and coatings.

(Invited) Engineering Hybrid Membranes as Durable Functional Interfaces for Biotechnology and Artificial Cells

Paul Beales, University of Leeds

For engineered biomembrane interfaces to be viable for translation into real-world technologies, they must be durable enough to maintain their stability and function during an appropriate storage shelf-life and to withstand environmental challenges during their application. Lipid membranes, while biocompatible for functional biomolecular inclusions such as integral proteins, can exhibit poor long-term stability and lack resilience to complex media and varying environmental factors. Polymer-based membranes can be significantly more robust but may present additional challenges when incorporating biomolecular machineries. Our approach to this challenge has been to develop hybrid membranes composed of a blend of lipids and block copolymers. I will present data that investigates the material properties of these hybrid membranes and demonstrate that they can significantly enhance the functional lifetime of membrane proteins embedded within their matrix. Recognising that the initial polymers we have used for these hybrid membranes are not necessarily optimised for membrane protein technologies, more recently we have screened a broader range of polymers. This reveals a nuanced interplay between polymer structure and the properties of reconstituted proteins: the preferred polymer depends on the most important property to be optimised for a specific application (e.g. reconstitution efficiency, functional activity, durability, etc.). I will also present early work towards cell-free workflows to express mammalian membrane proteins into hybrid vesicles, with potential for efficient production of durable assay systems in the pharma industry.

Developing bacterial outer-membrane models – balancing between greater physiological relevance and experimental control

Corrin Blake, University College London
Co-authors: *Bart Hoogenboom and Luke Clifton*

Antimicrobial resistance is an increasing global health challenge, with Gram-negative bacteria posing a particular threat due to the presence of their additional protective barrier in the form of the outer membrane.

Alongside its medical importance, the outer membrane has become a subject of fundamental scientific interest following recent discoveries of its mechanical role, low fluidity and phase-separated organisation. Atomic force microscopy (AFM) has played a key role in enabling these insights through direct visualisation of outer-membrane structure in living bacteria[1].

To study such phenomena with increased levels of experimental control, we develop supported lipid bilayer models that reproduce essential features of the Gram-negative outer membrane in aqueous conditions. This implies bilayers that are asymmetric in phospholipid (PL) - lipopolysaccharide (LPS) contents, and the incorporation of the most abundant porin in E.coli, OmpF, ideally based on self-assembly via vesicle-fusion methods, rather than (experimentally more cumbersome) Langmuir Blodgett deposition.

AFM is used here to resolve nanoscale morphology and lateral heterogeneity in physiologically relevant conditions, revealing LPS-dependent changes in surface organisation of LPS-PL bilayers and confirming successful incorporation of OmpF within PL bilayers. Neutron reflectometry complements these measurements by determining membrane thickness and chemically specific information on leaflet composition and LPS distribution, thereby enabling quantitative assessment of compositional asymmetry that is not accessible by AFM alone. Together, these techniques demonstrate the formation of asymmetric membranes that more closely resemble the native bacterial outer membrane than conventional phospholipid models, while remaining structurally well defined.

As a first application of these model membranes, we have started to investigate interactions of antimicrobial peptides with membranes [2], including the antibiotic polymyxin B [3], and show how membrane composition and asymmetry influence peptide binding and membrane disruption.

[1] Georgina Benn, Irina V. Mikheyeva, Patrick George Inns, Bart Hoogenboom, PNAS, 118(44), 2021.
[2] Alex Hoose, Javier Garcia-Ruiz, Corrin Blake, Ciara C. M. Lally, Andrea Briones, Bart Hoogenboom, Christian D. Lorenz, Maxim G. Ryadnov, Langmuir, 41(6), 2025.
[3] Carolina Borrelli, Edward J. A. Douglas, Sophia M. A. Riley, Aikaterini Ellas Lemonidi, Gerald Larrouy-Maumus, Wen-Jung Lu, Boyan B. Bonev, Andrew M. Edwards, Bart W. Hoogenboom, Nature Microbiology, 10, 2025.

Probing the interaction of liposome delivery systems with Gram negative bacterial cell envelopes: a comprehensive investigative approach

Yixuan Yan, University of Birmingham
***Co-authors**: Sarah Gordon, Jayne Lawrence, Timothy Overton*

Antimicrobial resistance, often referred to as the 'silent pandemic', constitutes a major threat to global public health. Strategic development of drug delivery systems designed to interact particularly with the Gram-negative bacterial envelope barrier has become crucial for efficient delivery of antibiotics to bacterial cell interiors, as resistance continues to evolve and new treatment options remain scarce. The current study aims to comprehensively characterise the ability of a panel of conventional, fusogenic and biomimetic liposome formulations to interact with various Gram-negative bacterial cell envelope structures, using a range of biophysical and microbiological approaches. Langmuir monolayers and neutron reflectometry, flow cytometry and super-resolution microscopy will be employed to respectively generate model membrane-based, bacterial population-representative and single organism-focused data on the interaction of liposome formulations with different Gram-negative bacterial envelope structures. To date, biophysical characterisation (supported by flow cytometry) studies have suggested a rapid interaction of cationic liposomes with bacteria membrane-relevant monolayers, inducing a high degree of lipid exchange between membrane structures and liposomes. Interaction of liposomes with membrane models containing smooth lipopolysaccharide (LPS), mimicking wild-type Gram-negative bacteria, also favoured formation of lipid domains in comparison to rough LPS-containing models (representing chronically infecting bacteria). Further investigations of single-cell level interactions using super-resolution microscopy, and the delivery efficiency of ciprofloxacin to bacterial interiors from loaded liposomes will be studied. In doing so, the work will provide valuable insight into the existence of a universal 'best' vs. target organism-specific 'optimal' liposome formulation strategy for promoting bacterial cell envelope interactions and efficient antibiotic cargo delivery.

(Invited) Watching Translocation: From Botulinum Toxin to DNA Through Nanopores

Mark Wallace, King's College London

Understanding how molecules cross membranes sits at the heart of both mechanistic biology and synthetic membrane design. Yet translocation itself - the actual passage of a molecule across a bilayer - has remained difficult to observe directly. By combining single-molecule fluorescence tracking with simultaneous optical measurement of ionic flux in droplet interface bilayer systems, we can watch translocation happen in real time. We apply this to two problems: (1) the mechanism by which botulinum neurotoxin type A crosses membranes, where our data challenge the current consensus; and (2) the translocation of labelled DNA through protein nanopores, where simultaneous optical and electrical readout reveals how

molecular position maps onto the ionic current signatures responsible for nanopore sequencing.

3D Printed Bioelectronic Model of the Intestinal Tissue Architecture

Maria Lopez Cavestany, University of Cambridge
Co-author: *Roisin Owens*

The architecture of intestinal tissue is crucial for gut health, with the characteristic villi structures supporting diverse epithelial cell types that absorb nutrients, and the crypts hosting stem cells that continuously renew the tissue [1]. In modeling this environment in vitro, the use of organic electronic platforms allows for real-time, non-invasive probing of intestinal barrier function in longitudinal experiments [2]. The goal is to engineer a low-stiffness, conducting polymer scaffold with the microscale architecture of the extracellular matrix and the larger crypt and villi architectures, to act as a bioelectronic gut-on-a-chip model with greater biological complexity. Three regions of the intestinal tract were biomimetically modelled based on histology images from the literature: the proximal small intestine featured an alternating pattern of villi and crypts with dimensions of 720 × 1440 × 1200 μm (width × length × height), with crypts of 360 μm diameter and depth; the distal small intestine design had a similar architecture with cylindrical villi of 720 μm diameter and 1020 μm height and the same crypt design; and the colon consisted of a hexagonal array of crypts with the same diameter and depth [3]. The digital light printing (DLP) ink formulation was made up of 50% (v/v) high concentration PEDOT:PSS in DI water to make it conductive and 50% (v/v) of an acrylate mix which forms a soft hydrogel entrapping the conductive polymer, matching gut mechanical properties [4]. The mechanical properties of the biomimetic 3D printed scaffolds were quantified via compression testing and confirmed to match the physiological ranges of healthy gut tissue. The scaffolds were then integrated into an electronic transmembrane platform to validate the conductivity via electrical impedance spectroscopy and cyclic voltammetry [5]. These were also confirmed to be biocompatible and to support the growth of fibroblasts filling the structures. Overall, this bioelectronic gut-on-a-chip model combines biomimetic 3D architecture, physiologically relevant mechanical properties, and integrated electronic functionality to provide a versatile platform for studying intestinal physiology and disease in vitro.

[1] Rudolph et al. ACS Biomater Sci Eng, 2022.
[2] Pitsalidis et al. Chem Rev, 2022.
[3] Romanazzi et al. AIM Sciences, 2022.
[4] Lopez-Larrea et al. ACS Appl Polym Mater, 2022.
[5] Pitsalidis et al. Sci Adv, 2022.

Crowding-controlled adsorption and diffusion of streptavidin on supported lipid bilayers

Wanchung Chiang, CNRS LIPHY
Co-authors: *Oksana Kirichuk, Ralf Richter, Lionel Bureau, Galina Dubacheva, and Delphine Débarre*

Cell surfaces are fluid and densely populated, and molecular mobility plays a central role in regulating signal transduction and recruitment processes. However, how molecular crowding quantitatively controls adsorption and lateral diffusion on membranes remains poorly understood.

Here, we investigate the adsorption and surface diffusion of streptavidin (SAv) on supported lipid bilayers (SLBs) as a minimal and well-controlled model of a fluid cell membrane. Combining spectroscopic ellipsometry, confocal fluorescence imaging, and FRAP, we follow both the buildup of surface coverage and the evolution of lateral mobility over a wide range of surface densities.

We show that, beyond early transport-limited injection times, adsorption kinetics is a function of the cumulative dose, indicating that surface crowding controls the long-time behavior. Surface diffusion measurements reveal a strong, non-linear decrease of the diffusion coefficient with increasing coverage, allowing to tune the fluidity of the model membrane over two orders of magnitude. This dependence is quantitatively captured by a free-space probability model, in which diffusion is governed by the probability of finding sufficient free area for molecular rearrangements.

Using this diffusion-defined free-space reference, we demonstrate that adsorption and diffusion are controlled by the same underlying crowding constraint but probe different free-space thresholds.

(Invited) Non-equilibrium giant unilamellar vesicles

Laura Alvarez, University of Bordeaux

Cells, even in their simplest forms, exhibit adaptive motion and task execution, capabilities underpinned by their complex and hierarchized architecture, and their ability to dissipate energy. Replicating such intricate behavior at the microscale offers a pathway to uncover the fundamental physical and material ingredients required for biological complexity, while also inspiring the design of next-generation synthetic cells [1,2].

Here, I will demonstrate that using soft and adaptive compartments is the key to a new generation of biomimetic out-of-equilibrium systems. I will show our recent results on the fabrication of motile giant unilamellar vesicles (GUVs) driven out-of-equilibrium under external actuation [3]. In contrast to the traditional active colloids [4], active GUVs present an excellent

cell-model system, thanks to their membrane properties and their ability to enclose nano and micro-objects. We report on their run-and-tumble dynamics, reminiscent of bacteria dynamic patterns, and unexpected rolling motion when running temperature [5]. We further investigate controlled deformations and division-like events under electric-fields and light. We show that these two external fields provide a programmable handle to steer out-of-equilibrium behaviors in these synthetic cells, enabling membrane mechanics and shape transformations that mimic key features of cell division and protrusion formation.

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[3] V. Willems, A. Baron, D. A. Matoz-Fernandez, G. Wolfisberg, E. Dufresne, J. C. Baret, and L. Alvarez. Soft Matter (2025).

[4] Alvarez, L., Fernandez-Rodriguez, M.A., Alegria, A. et al. Reconfigurable artificial microswimmers with internal feedback. Nat. Commun. (2021)

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Self-synthesizing artificial cells via enzymatic polymerization

Andrea Belluati, TU Darmstadt

Artificial cells are useful as controllable microcompartments for synthetic biology and molecular systems engineering. Here we report polymer-based artificial cells that self-assemble during biocatalytic atom transfer radical polymerization-induced self-assembly (bioPISA). Myoglobin catalyses the growth of amphiphilic block copolymers that spontaneously form micelles, worms, and vesicle. During polymerization, vesicles encapsulate diverse cargo, including enzymes, nanoparticles, plasmid DNA, and cell lysate, yielding robust microreactors. The resulting compartments support enzymatic conversions and biomineralization reactions, linking membrane formation directly to function. When supplied with amino acids, lysate-loaded vesicles express proteins in situ, including a fluorescent reporter, demonstrating inducible activity in a fully compartmentalized format. Beyond single compartments, we implement sequential bioPISA reactions to generate internal subcompartments inside pre-formed vesicles, using the same enzymatic polymerization chemistry to build eukaryote-like organization in a bottom-up manner. These enzymatically synthesized GUVs therefore couple self-production, information-bearing cargo, and inducible expression, offering a membrane-based chassis for synthetic-cell prototyping and programmable multicompartment architectures.

Membrane prewetting by condensates promotes tight-junction belt formation

Karina Pombo-Garcia, Rosalind Franklin Institute

Biomolecular condensates enable cell compartmentalization by acting as membraneless organelles. How cells control the interactions of condensates with other cellular structures such as membranes to drive morphological transitions remains poorly understood. We discovered that formation of a tight-junction belt, which is essential for sealing epithelial tissues, is driven by a wetting phenomenon that promotes the growth of a condensed ZO-1 layer around the apical membrane interface. Using temporal proximity proteomics in combination with imaging and thermodynamic theory, we found that the polarity protein PATJ mediates a transition of ZO-into a condensed surface layer that elongates around the apical interface. In line with the experimental observations, our theory of condensate growth shows that the speed of elongation depends on the binding affinity of ZO-1 to the apical interface and is constant. Here, using PATJ mutations, we show that ZO-1 interface binding is necessary and sufficient for tight-junction belt formation. Our results demonstrate how cells exploit the collective biophysical properties of protein condensates at membrane interfaces to shape mesoscale structures.

Pombo-Garcia et al., Nature 2024,632,647-655.

(Invited) Leveraging Macromolecular Topology and Random Heterogeneity to Design Non-living Predators

César Rodriguez-Emmenegger, Institute for Bioengineering of Catalonia (IBEC) and Catalan Institution for Research and Advanced Studies

The fabrication of membranes for synthetic cells that reproduce properties of cell membranes remains a central challenge. Liposomes provide biomimetic thickness and mobility but lack robustness, whereas polymersomes are stable yet hindered by entanglement of the hydrophobic block. Here, I present i-combisome vesicles assembled from ionically linked comb polymers (iCPs) that resolve this trade-off.

iCPs are synthesized by appending anionic surfactants with lipid-long alkyl tails to cationic residues sparsely distributed along a hydrophilic polymer backbone. In water, they self-assemble into i-combisomes with membranes consisting of a bilayer of hydrophobic tails flanked by adsorbed polymer backbones. This architecture provides cohesive interactions and stability comparable to block-copolymer polymersomes, while suppressing chain entanglement and enabling biomimetic thickness, ultralow bending rigidity, and lipid-like lateral mobility.

A defining feature of i-combisomes is the decoupling of membrane properties from the degree of polymerization. Unlike block copolymers, assembly is governed by an amphiphilic repeating unit, allowing membrane thickness, flexibility, and dynamics to be independently programmed.

Using libraries of iCPs combined with simulations, we derived design rules to control properties and morphology.

These results expose a missing dimension in mean-field descriptions of membranes. While topology and repeating-unit packing are engineered, molecular heterogeneity emerges inevitably from the stochastic nature of polymer synthesis, producing amphiphilic units with different effective spontaneous curvatures. We propose that such units store elastic frustration that relaxes upon deformation, lowering kinetic barriers to invagination, fusion, and engulfment. Exploiting this behavior, we engineered phagocytic synthetic cells that predate on antibiotic-resistant bacteria through a purely physical, phagocytosis-like mechanism.

Soft But Tough! Engineering of Protein Nanosheet-Stabilised Microdroplets for Stem Cell Technologies

Julien Gautrot, Queen Mary, University of London
Co-authors: *Minerva Bosch-Fortea, and Jordi Gonzalez-Molina*

The microenvironment in which stem cells reside plays a critical role in the regulation of their phenotype, capacity to orchestrate repair processes and during the development of cancer. In addition to cytokines, growth factors and cell-cell adhesion, matrix adhesion and sensing of physical properties of the extra-cellular matrix play an important role in defining this context. Adipose tissues, such as sub-cutaneous fat or the bone marrow, constitute unique microenvironments playing key roles in stem cell biology and cancer. Mesenchymal stem cells (MSCs) and haematopoietic stem cells (HSCs) reside in these microenvironments with unique microstructure and mechanics, in which 90% of the volume of the tissue is constitute of adipocytes nested in a network of ECM proteins and other tissue resident cells. During metastasis, adipose tissues not only regulate cancer cell invasion, but also remodel significantly. We propose that recreating the biochemical (matrix composition, adhesive motifs) and physical (microstructure, mechanics) of adipose tissues will enable enhanced control of stem cell phenotypes and the study of cancer progression.

To develop adipo-mimetic microenvironments, we explore the engineering of cell-instructive organo-hydrogels, hydrogel-like materials in which nano- to micro-droplets are crosslinked together. This enables us to control the microstructure (microporosity), mechanics (nanoscale mechanics, toughness and local mechanical anisotropy) and biochemistry (cell adhesion motifs, degradation) with unprecedented level of control. We combine polymer design and protein engineering and self-assembly to develop a range of cell-instructive organo-hydrogels and show how this allows the control of microdroplet size, volume fraction as well as nano- to macro-scale mechanics. We show that this environment is particularly well suited for the culture of MSCs and HSCs in vitro and recreates key properties regulating the progression of cancers, for examples in the context of ovarian cancer.

Biomimetic Lipid-Based Lubrication for Therapeutic Solution in Osteoarthritis

Di Jin[1], City University of Hong Kong
Co-authors: *Jacob Klein, Yifeng Cao, and Paramita Manna*

Direct angstrom-level, nano-Newton force measurements with the surface force balance (SFB) have revealed that phospholipids, in the form of single-component lipid bilayers, are remarkably effective biolubricants, with friction coefficients comparable to those of synovial joints such as hips and knees. However, synovial joints contain over a hundred lipid species. This proliferation of lipids raises a central question: is it natural redundancy, or does it contribute synergistically to optimize lubrication at cartilage surfaces?

Existing SFB experiments on a limited number of mixed-lipid membranes have demonstrated that certain combinations can exhibit superior lubrication properties, yet the underlying physical principles remain unclear. To address this, we investigate the roles in the mixed-lipid membranes of the most common synovial lipids, and relate their presence to the synergistic behavior observed at the holistic level, particularly in dynamic membrane processes such as hydration lubrication and hemifusion. This research integrates molecular dynamics simulations, artificial intelligence, and AI-guided AFM experiments, enabling high-throughput exploration of the vast parameter space of mixed-lipid membranes. We also use the SFB—with its unique sensitivity and resolution in measuring membrane interactions —to validate and refine our conclusions.

As our understanding of these biophysical processes deepens, we can better interpret the design principles shaped by evolution and assess the extent of possible redundancy. Ultimately, these bio-inspired insights will guide the development of artificial, biocompatible lipid membranes with a spectrum of properties depending on their composition. These range from better lubrication treatments at one end, as for widespread joint-related diseases such as osteoarthritis, to better drug-delivery by lipid-based nanocarrier vesicles (liposomes or lipid nanoparticles) at the other, through more facile vesicle-membrane/cell fusion processes.

(Invited) Artificial Cells: from Soft Matter to Cell-Like Behaviours

Claudia Contini, Imperial College London

Artificial cells provide a versatile platform for reconstituting and interrogating life-like behaviours in a minimal and controllable setting. In our work, we engineer polymer vesicle-based systems that mimic fundamental cellular functions including shape change, motility, fusion, and responsiveness to external cues by designing programmable membrane architectures and internal components. These synthetic cells are built from modular, bioinspired elements that allow precise control over mechanical properties, compartmentalisation, and signalling. We use this framework to reconstruct cellular processes from the bottom up, enabling systematic exploration of how functional behaviours emerge from

defined molecular building blocks. In parallel, we develop biohybrid systems by integrating synthetic modules with living cells to enhance their stability, sensing capabilities, or responsiveness. Through this interdisciplinary approach, we aim to advance the principles of engineering biology and uncover how biological functions can be mimicked and extended in synthetic systems.

(Invited) Emergent Motility of Self-Organized Particle-Giant Unilamellar Vesicle Assembly

Gaurav Gardi, Max Planck Institute for Intelligent Systems
Co-author: *Selcan Karaz*

Giant unilamellar vesicles (GUVs), soft cell-sized compartments formed through the self-assembly of lipid molecules, have long been utilized as model systems and passive carriers in membrane biophysics and biomedical applications. However, their potential as dynamically responsive and motile systems remains largely untapped due to challenges in achieving controlled and sustained motion in soft, deformable structures. Here, an autonomous cell-like microrobot through the emergent self-assembly of GUVs (5-10 μm) and silica microparticles (1-3 μm) under alternating current electric fields is realized. Self-propulsion arises from asymmetric self-organization of the particles on the vesicle surface, enabling a reversible transformation of the assembly into an active structure. Unlike rigid colloidal systems, GUVs introduce unique features enabled by their soft lipid membranes: shape deformations, membrane tension-dependent motility, and field-triggered live bacteria release via vesicle bursting. Through experiments and simulations, the mechanisms underlying self-assembly and propulsion are investigated, and a dynamic phase diagram is constructed to map the motion regime as a function of field parameters. Finally, it is shown that these self-assembled structures are capable of reconfiguration in response to local constraints in the environment, suggesting potential applications in complex environments and advancing the potential of GUVs toward the rational design of cell-like microrobots or artificial cell systems.

Discriminating cancer and healthy prostate Extracellular Vesicles through membrane rigidity: a Molecular Dynamics approach

Lakshmi Kumar Kunche, Sapienza University of Rome
Co-authors: *Carlo Guardiani*, *Matteo Riboli, and Alberto Giacomello*

Exosomes have raised a significant interest for biomedical applications. For instance, the chemical biomarkers of the exosomes released by the PC-3 cancer cell line are already used for the diagnosis of prostate cancer. However, recent work by Whitehead and by LeClaire showed that cancer EVs membranes tend to be softer than those of the healthy ones.

In our study we compared healthy prostasomes with the PC-3 cancer variant. Starting from the experimental composition, we built a number of systems with compositional and number asymmetry and we computed the elastic moduli with both a spectral technique and a local analysis approach that allows to estimate the moduli of individual leaflets.

The PC-3 vesicles indeed, turned out to be more rigid than the prostasomes. Thus, while a mechanics based discrimination is still possible, this kind of diagnostics must be performed on a case by case basis.

The study of EVs also provided results with a much broader scope pertaining asymmetry, an almost universal property of membranes. In particular, we confirmed the additivity of the moduli of individual leaflets and we showed that the moduli of asymmetric membranes are intermediate with respect to those of their symmetric counterparts, in agreement with the elastic theory but in disagreement with some experimental results based on the phase transfer technique.

Our work however, also showed a coupling between the two leaflets revealing that the moduli do not only depend on the leaflet composition but also on the features of the partner leaflet.

Poster Session 1

P1.1: Probing Interactions at the Interface between Nucleic Acid Nanostructures and Lipid Membranes

Sofia Benedetti, University of Cambridge
***Co-authors**: Ioanna Mela, Lorenzo Di Michele, and Roger Rubio Sánchez*

Lipid–nucleic acid interactions play critical roles in both biological processes and biotechnological applications, including the development of advanced biomimetic systems such as synthetic cells. DNA and RNA nanotechnologies have emerged as programmable toolkits to engineer and control lipid membrane functionalities, incorporating complex, out-of-equilibrium behaviours in synthetic cells. However, lipid–nucleic acid interactions are still poorly understood, particularly when it comes to how complex RNA and DNA nanostructures couple to different lipid phases.

Here, we systematically investigate the interactions between nucleic acid nanodevices and zwitterionic lipid membranes, focusing on the role of nanodevice secondary structure. By assessing membrane attachment of simple DNA, RNA, and hybrid duplexes, we identify differential nanostructure binding with respect to membrane composition and phase behaviour.

We exploit this refined understanding to prescribe interactions between lipid bilayers and RNA origami, which we show to preferentially adhere to gel-phases via cation-mediated bridging. By producing the nanostructures from DNA templates with in vitro transcription reactions and designing their assembly to follow RNA co-transcriptional folding, we afford the possibility to genetically-encode membrane functionality. Beside their relevance to biology and vaccine nanotechnology, our findings will be useful to unlock the ability to engineer and control pathways for transport, remodelling, and signalling in next-generation synthetic cell platforms.

P1.2: Liposomes in non-aqueous polar solvents

Ella Y L Ho, ISIS Neutron and Muon Source

Antimicrobial resistance (AMR) occurs when microbes develop protective mechanisms against traditional antibiotics and is a major threat to global public health. To combat AMR and develop new treatments, we must first understand the mechanisms of AMR and the interaction between antimicrobial agents and cell membranes. Liposomes have been shown to be valid model systems to probe these interactions. However, many pre-existing studies are limited to aqueous media, overlooking nonaqueous polar solvents, such as glycerol, that can slow down vesicle pore-opening kinetics. Therefore, we aim to investigate the impact of nonaqueous polar media on the mechanism of AMR.

In our work, we present an investigation into liposome preparation in nonaqueous media, where the lipid composition mimics that of bacterial cell membranes. The buffer composition was varied by increasing glycerol content, and the membrane composition was varied to probe the effect of cardiolipin. Small-angle neutron scattering (SANS) measurements demonstrated the effect of glycerol on the morphology of the assembled lipid phase. The vesicle form factor, apparent in the aqueous control sample, is lost as glycerol content increased, suggesting that glycerol is disordering the liposome morphology. However, for liposomes with cardiolipin, their morphology is retained even in media containing 25% glycerol. These data demonstrate that the solvent media does in fact impact the formation of lipid membranes, which could have important applications in furthering our understanding of the mechanism of AMR.

P1.3: Ion conduction in single-walled carbon nanotubes

Dmitry Luchinsky, Lancaster University
Co-authors: *Will Gibson, Igor Khovanov, and Peter McClintock*

We study ionic transitions in condensed matter ion channels and their biophysical counterparts. Our aim is to reveal new features and to further investigate the importance of Coulomb blockade for noise-driven ionic transport. We investigated the cases of single positive ions K+ and Na+ in a single-walled carbon nanotube and the mixture of K+ and Na+ ions in the cell. In the case of the mixture of K+ and Na+, the concentration of ions was approximately twice lower than that of a single ion. We have also extended this experiment to include varying bias voltage. This produces a complex phase structure, ionic Coulomb Diamond, analogous to the electric counterpart. In the case of mixed K+ and Na+ ions we used samples with different concentration of these ions. We found a novel phase diagram that describes ionic conduction that is closely analogous to its electronic counterpart (Coulomb diamonds). But there are features of this diagram that are very specific to the ions and walls of the channel. The diagram provides a novel method for observing transport through these pores, as the gaps (blockade) in the conduction are observed as functions of bias and gate voltage. We use the approach to gain insight into the fundamental nature of the ionic conduction properties.

P1.4: Emergent Motility of Self-Organized Particle-Giant Unilamellar Vesicle Assembly

Selcan Karaz Han, Max Planck Institute for Intelligent Systems

Giant unilamellar vesicles (GUVs), soft cell-sized compartments formed through the self-assembly of lipid molecules, have long been utilized as model systems and passive carriers in membrane biophysics and biomedical applications. However, their potential as dynamically responsive and motile systems remains largely untapped due to challenges in achieving controlled and sustained motion in soft, deformable structures. Here, an autonomous cell-like microrobot through the emergent self-assembly of GUVs (5-10 μm) and silica microparticles (1-

3 μm) under alternating current electric fields is realized. Self-propulsion arises from asymmetric self-organization of the particles on the vesicle surface, enabling a reversible transformation of the assembly into an active structure. Unlike rigid colloidal systems, GUVs introduce unique features enabled by their soft lipid membranes: shape deformations, membrane tension-dependent motility, and field-triggered live bacteria release via vesicle bursting. Through experiments and simulations, the mechanisms underlying self-assembly and propulsion are investigated, and a dynamic phase diagram is constructed to map the motion regime as a function of field parameters. Finally, it is shown that these self-assembled structures are capable of reconfiguration in response to local constraints in the environment, suggesting potential applications in complex environments and advancing the potential of GUVs toward the rational design of cell-like microrobots or artificial cell systems.

P1.5: BioPISA-Engineered Hierarchical Artificial Cells for Chemical-to-Biological Signaling

Gizem Cantörü, Technical University of Darmstadt
Co-authors: *Nico Bruns, and Andrea Belluati*

Artificial cells still struggle to combine internal compartments with meaningful communication to living systems. Polymeric vesicles offer robust, tunable synthetic compartments, but adding hierarchical organization and biologically relevant signalling to these structures is a key challenge in bottom-up synthetic biology. We use enzyme-initiated polymerization-induced self-assembly (bioPISA) to build hierarchically organized polymer-based artificial cells. By controlling polymerization kinetics, we produce vesicles with defined size distributions and incorporate pre-formed nanoscale compartments during assembly to create multivesicular structures, multiple internal compartments organized within a single larger protocell-like boundary. This design mimics cellular compartmentalization and allows chemical reactions to be localized within nested synthetic environments.

We characterize the chemical activity of these artificial cells using chemiluminescent and fluorescent reactions confined within the compartments, showing sustained and spatially organized signal generation. To connect this synthetic activity to living systems, we integrate the artificial cells into biological assays with engineered bacteria carrying light-responsive genetic circuits. Chemical reactions in the polymer compartments produce molecular signals that alter bacterial gene expression, which we measure through reporter output under controlled conditions. These results establish a synthetic-to-biological communication pathway where hierarchically structured artificial cells process chemical reactions and relay them as biologically interpretable signals. This work shows how bioPISA-engineered artificial cells can operate as chemically active, compartmentalized systems that interface with and control living cells, advancing their potential as minimal synthetic cell platforms for communication and regulation.

P1.6: Lipid bilayer interactions with a type II collagen-binding peptide suppress its targeting ability

Paramita Manna, Weizmann Institute of Science
Co-authors: Evgenia Mitsou, Felipe Ptak Lemos, Daniel Ben-Hur, Nir Kampf, Tali Dadosh, and Jacob Klein

Articular cartilage maintains low friction through an intrinsic self-lubricating and self-healing system. However, alterations in the composition of bio-lubricants within synovial fluid—driven by ageing and injuries—can degrade the lubrication layer, increase friction and eventually lead to osteoarthritis (OA). Restoring cartilage lubrication is therefore essential for managing OA in its early stages. Lipids and liposome-based vectors demonstrated exceptional lubrication performance, achieving friction coefficients below 0.001 at loads up to 100 atm, comparable to that of healthy joints. However, their clinical potential is limited by rapid clearance from the joint cavity by the circulatory system, resulting in poor retention in the joints.

In recent years, WYRGRL, a type II collagen-targeting peptide, has been discovered to improve the retention of polymeric nanoparticles on cartilage. In this study, we conjugated WYRGRL to liposomes to target type II collagen in the articular joint and evaluated its effect on the lubrication performance of the liposomes. Atomic force microscopy and fluorescence imaging showed that the presence of the peptide hindered liposomes' adherence to collagen-coated mica, likely due to its interaction with the lipid bilayer, which potentially disrupted membrane integrity and the peptide's specificity towards collagen. This also negatively affected the lubrication performance of liposomes. Our results indicate that WYRGRL-mediated targeting is system-dependent and must be carefully evaluated to minimize system-specific unfavorable interactions.

P1.7: Understanding how curvature-sensing peptides capture extracellular vesicles via Gaussian molecular dynamics: the bradykinin case

Lakshmi Kumar Kunche, La Sapienza University of Rome
Co-authors: *Carlo Guardiani, and Alberto Giacomello*

Extracellular Vesicles (EV) have huge potential applications in biomedicine in fields like targeted drug delivery and advanced diagnostic assays. Their clinical application, however, is still limited by the difficulty of isolation and purification. The efficacy of the standard approach based on monoclonal antibodies is limited by the overlapping protein content of EV membranes. This is why alternative approaches based on curvature sensing peptides are particularly promising. In this work, using Gaussian Accelerated Molecular Dynamics simulations, we have characterized the mechanism of attachment of a bradykinin decapeptide to liposome-like and EV-like membranes.

After a period of diffusion in the bulk the peptide engages the membrane through electrostatic attachment and then switches to hydrophobic attachment through insertion of its phenylalanine residues in transient membrane defects. The effect of membrane curvature was simulated by applying surface tension to the membrane that increased the size and number of the membrane defects. The presence of these defects accelerates the peptide attachment and favors hydrophobic contacts. Experimental inversion of the peptide charge was shown to completely prevent the interaction with the membrane, while mutation of phenylalanines with larger aromatic or aliphatic residues significantly enhanced the peptide-membrane affinity, opening the door to tailored EV capture.

Poster Session 2

P2.1: Tunable phase behavior in synthetic cell membranes using modified emulsion phase transfer technique

Bashayr Khalifah, University of Cambridge
Co-authors: Akthar Hussain Mougamadou Soultane, Roger Rubio Sánchez, and Lorenzo Di Michele

Biological membranes are dynamic architectures that regulate processes essential to life. Lipid phase separation, through the formation of membrane domains, is thought to play a crucial role in several biological processes, including signal transduction and molecular trafficking. The ability to program lipid domain formation in artificial membranes is central to the design of sophisticated functionalities in bio-inspired devices such as synthetic cells. Despite progress in deploying lipid vesicles as synthetic cell chassis, advanced cell-like membrane-bound devices that both encapsulate bioactive machinery and recapitulate phase separation in lipid bilayers remain scarce. This arises from the limited solubility and consequently membrane incorporation of cholesterol in current Giant Unilamellar Vesicle (GUV) emulsion-based production techniques.

Here, we address this limitation using decane to modulate lipid solubility in the oil phase, thus affording finer control over cholesterol incorporation and membrane phase behavior while maintaining efficient encapsulation of vesicle contents. Systematic variation of cholesterol and decane ratios reveals that decane enables accessing phase states across the phase diagram, spanning from liquid order-liquid disorder (Lo/Ld) to gel/Ld coexistence or homogeneous membranes. To assess phase co-existence, we encapsulate amphiphilic DNA nanostructures that selectively partition into lipid domains, serving as programmable probes for Lo and Ld phases. Finally, we apply our optimized technique to engineer the inner leaflet of synthetic bilayers using membrane-active DNA nanostructures in the form of DNA origami line-actants, which modulate membrane lateral organization by organizing lipid domains. Altogether, this platform will unlock the development of sophisticated membrane-hosted pathways in synthetic cells like signaling cascades.

P2.2: ATP-responsive membraneless compartments in synthetic cells

Juliette Bucci, Department of Chemical Engineering and Biotechnology
Co-authors: *Niklas Pusinelli, Naoki Yoshida, Masahiro Takinoue, and Lorenzo Di Michele*

Synthetic biology aims to engineer artificial systems, termed synthetic cells[1], that display life-like organisation and functionalities. Within this framework, DNA nanotechnology has emerged as a powerful interdisciplinary approach for the bottom-up assembly of programmable, bio-inspired compartments and interfaces in synthetic cellular systems[2].

A key challenge in this field is mimicking the dynamic regulation of energy availability that characterises living cells. In such systems, this regulation is achieved through the coordinated action of membraneless organelles and adenosine triphosphate (ATP), which plays a central role in a wide range of cellular processes by serving as the primary source of chemical energy, enabling functions ranging from molecular transport across cell membranes to the biosynthesis of macromolecules[3].

Considering the central role of ATP and the ubiquity of membraneless organelles in living systems, engineering ATP-responsive compartments represents a critical step toward functional synthetic cells and biotechnological applications. We introduce ATP-responsive membraneless compartments constructed from tetravalent DNA nanostars by rationally embedding split ATP aptamers into their architecture. ATP binding drives aptamer reassembly, triggering compartment formation and enabling selective ATP sequestration and storage. By varying ATP concentration, we tune compartment stability and melting temperatures to precisely regulate ATP release. When assembled inside lipid-based synthetic cells, these ATP-responsive membraneless organelles act as dynamic energy reservoirs. Coupling them with ATP-dependent biological processes enables programmable organelle disassembly and on-demand ATP release, providing control over internal energy fluxes.

Overall, this work expands the toolkit for engineering responsive synthetic cellular systems by integrating ATP-regulated compartmentalisation with controlled energy delivery, enabling the construction of synthetic cells with programmable energy regulation.

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P2.3: Polymer Brush-Templated Assembly of a Lipid Bilayer Network

Vahid Nasirimarekani, Max Planck Institute for Dynamics and Self-organization

Polymer brush layers form a dynamic biointerface that can fundamentally alter the formation and behavior of lipid membranes. This study investigates the assisted formation of lipid bilayers on these tunable, compliant substrates. We find that the defining feature of the resulting film is its non-classical morphology: it possesses a interconnected network of structure characterised by a continuous bilayer matrix densely interspersed with nanoscale to microscopic defects and pores. This unique architecture is a direct consequence of dynamic lipid-polymer interactions during bilayer formation on the soft, permeable brush surface, which prevents the self-healing of topological defects. Consequently, this work demonstrates that soft polymer interfaces serve as effective templates for the development of complex, porous biomimetic membranes and offer a new path to materials with tailored transport properties.

P2.4: Coupling synthetic cell division and DNA segregation

Nastasja Kaletta, Max Planck Institute of Biochemistry
Co-author: *Petra Schwille*

A central goal of synthetic biology is the reconstitution of a minimal divisome able to achieve autonomous self-division of the membrane compartment. In our previous work, we demonstrated controllable membrane budding transformation via membrane-interacting DNA condensates. However, achieving fission of the daughter cells remained a critical challenge. Here, we reconstitute and characterize the prokaryotic segregation system ParMRC for controlled distribution of genetic material into daughter cells, offering an alternative to random distribution. Beyond enriching the synthetic cell, we hereby explore physical properties that may contribute to membrane division, including mechanically driven fission events. The ParMRC machinery was successfully targeted to a model of programmable DNA condensates (Y-motifs) mimicking the bacterial nucleoid. The combined effects of the ParMRC polymerisation motor and the capillary forces of membrane-interacting DNA condensates on the vesicle membrane will be investigated.

Together, our approaches offer a route towards synthetic systems in which cell division and DNA segregation are intrinsically coupled.

P2.5: Expressing Membrane-Less RNA Organelles in Lipid-Based Synthetic Cells

Akthar Hussain Mougamadou Soultane, University of Cambridge
Co-authors: Roger Rubio-Sánchez, Nada Farag, Maya Mueller, Giacomo Fabrini, Marina K. Kuimova, and Lorenzo Di Michele

A key goal of bottom-up synthetic biology is to create synthetic cells which perform out-of-equilibrium functions, such as growth and division. Giant Unilamellar vesicles (GUVs) are comparable in size to biological cells and reliably imitate their properties, making them a good cell mimic to reproduce these functions. Branched, multivalent RNA nanostructures, known as 'nanostars', where previously shown by Fabrini et al. to exhibit out-of-equilibrium growth from a DNA template. By encapsulating the template DNA inside the GUVs with all the transcription machinery required for the RNA nanostar growth, we can grow synthetic biomolecular condensates within these artificial cells. The ability to control the size, number and composition of these condensates as well as their ability to selectively recruit proteins, makes these condensates ideal models for synthetic membrane-less organelles. Moreover, these condensates can further be designed, in conjunction with adhesive moieties, to interact with and deform the membrane, allowing for various degrees of condensate-membrane wetting interactions to be observed. This system demonstrates key behaviours exhibited by biological cells, making it a good model to study and replicate membrane-less organelles in biological cells.

P2.6: Elastohydrodynamic control of lipid membrane coarsening

Aditya Jha, Cavendish Laboratory, University of Cambridge

Multicomponent lipid membranes can undergo phase separation, typically observed as the nucleation and subsequent growth of approximately circular domains that coarsen over time. Many experimental and physiological settings involve substantial hydrodynamic forcing. This study, therefore, focuses on the role of hydrodynamic flow in membrane coarsening, with the specific objective of identifying mechanisms by which external or internally generated flows can be used to control the temporal evolution of domain size and morphology. At the same time, lipid membranes are not purely fluid interfaces: they possess elasticity, leading to curvature-composition coupling that can introduce additional energetic penalties for domain growth and shape changes. Elastic restoring forces can suppress large-scale deformations, and, in some regimes, arrest coarsening altogether by stabilising domains at a finite length scale. We investigate this arrest phenomenon and quantify how the characteristic domain size evolves when membrane elasticity is coupled to hydrodynamic stresses. By analysing the combined effects of advection, viscous dissipation, and elasticity, we delineate the regimes in which flow accelerates coarsening, retards it, or drives a transition to a steady state with an effectively arrested domain size distribution.

P2.7: Exploring DNA Linkers for Biomimetic Cell Adhesion of Red Blood Cells

Sebastian W. Krauss, Department of Chemical Engineering and Biotechnology, University of Cambridge
Co-authors: *Nishant Baruah, Bortolo M. Mognetti, Gerhard Gompper, Roger Rubio-Sánchez, Pietro Cicuta, and Lorenzo Di Michele*

Ligand-receptor interactions are fundamental to cellular membrane dynamics, influencing a range of processes like cell-cell signaling and viral infections. These interactions govern how adjacent membranes recognize, bind, and respond to one another. To better understand these mechanisms, we developed a biomimetic approach that grants precise control over the strength of interactions between opposing membranes.

Our strategy employs short membrane-anchored amphiphilic DNA nanostructures featuring single-stranded 'sticky-ends', which are designed to bind through complementary sequences, providing an adaptive platform for membrane-membrane interactions. We implemented our platform to functionalize red blood cells (RBCs), creating cellular aggregates with programmable morphologies, ranging from doublets to star-like geometries. Additionally, we used DNA-functionalized particles to selectively bind RBCs. By tuning the sequence, we precisely controlled interaction strength, enabling RBCs to progressively envelop beads. Furthermore, we observed the rapid formation of strong bonds in situ using optical tweezers.

Finally, we employed computer simulations combining the mechanics of red blood cells with the thermodynamics of the DNA linker, to verify the experimentally observed trend. The simulation captured how the membrane increasingly wrapped around the particle with increasing sticky end length, quantitatively confirming the experimental measurements and providing a bottom-up understanding of the system [manuscripts in preparation]. This system could offer insights into the forces and dynamics of RBC aggregation and their interactions with pathogens, such as Plasmodium species responsible for malaria.

Designer Membranes and Bio-inspired Interfaces

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