Microfluidic Horizons 2026

Oral and Poster contributions

Padova

18 - 22 May 2026

Contents

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	DEPARTMENT OF PHYSICS AND ASTRONOMY
	Sunday 17 - ROOM ROSTAGNI
17:00	Pierluca Maffettone Plenary Lecture for Short Courses and Participants

	SAN GAETANO CENTER
	Sunday 17 - AGORA'
19:00	REGISTRATION & WELCOME COCKTAIL

Flow, wetting, and transport phenomena
Analytical and chemical applications
Organ-on-a-chip and translational models
Cells, microbes, and extracellular vesicles manipulation
Ecology and sustainable processes
Microfabrication and device engineering
Nanofluidics and molecular transport
High-energy spectroscopy and advanced imaging methods coupled with microfluidics
Space and microgravity research
Computational and data-driven approaches in microfluidics

Plenary Keynotes
Poster Sessions
Sponsor presentations

	SAN GAETANO CENTER - AUDITORIUM				
	Monday 18	Tuesday 19	Wednesday 20	Thursday 21	Friday 22
09:00	Registration & Welcome Coffee	Howard A. Stone (Plenary)	Andrew deMello (Plenary)	Nicole Pamme (Plenary)	Paolo Netti (Plenary)
09:20					
09:40	Opening				
10:00	Lydéric Bocquet (Plenary)	Guido Bolognesi	Xavier Viader-Godoy	Annie Colin	Simone Luigi Marasso
10:20		Chiara Neto	Giovanni Stefano Ugolini	Leonardo Severini	Nate Cira
10:40		Matteo Milani	Sigolene Lecuyer	Taieesa Peshkovsky	Anne-Laure Deman
11:00	Theo Emmerich	Coffee break	Coffee break	Coffee break	Coffee break
11:20	Corentin Trégouët				
11:40	Daniele Vigolo (Perspective)	Benoit Scheid	Cinzia Sada (Perspective)	Marco Rasponi (Perspective)	Riccardo Zamboni
12:00		Steffen Hardt			Daniele Tammaro
12:20	Sponsor presentations	Uros Tkalec	Valentina Arima	Valeria Garzarelli	Gilad Yossifon
12:40		Dario Pisignano	Beatrise Berzina	Gianpio Caringella	Roberto Piazza
13:00	Lunch and Exibitors	Lunch and Exibitors	Lunch and Exibitors	Lunch and Exibitors	Awards & Closing
13:20					
13:40					
14:00	Stéphanie Descroix (Plenary)	Charles Baroud (Plenary)	Roman Stocker (Plenary)	Giampaolo Mistura (Plenary)	
14:20					
14:40					
15:00	Athullya Baby	Delphine Débarre	David Scheidweiler	Alexandre Avaro	
15:20	Jean-François Berret	Sebastian W. Krauss	Giulia Ceriotti	Finn Box	
15:40	Iyad Abou Shakra	Simone Scalise	Willy Bonneuil	Jeffrey Everts	
16:00	Maxim Cazorla	Luca Potenza	Luca Lanotte	Riccardo Reale	
16:20	Coffee break and Exhibitors	Poster & Coffee	Coffee break and Exhibitors	Poster & Coffee	
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17:00	Onelia Gagliano (Perspective)		Enza Torino (Perspective)		
17:20		Giovanna Tomaiuolo (Perspective)		Social excursions	
17:40	Jessica Vandensteen		Alessia Foscarini		
18:00	Chloé Humbert	Emanuela Cutuli	Beatrice Crestani		
18:20	Jules Edwards	Catherine Xu	Solène Lenoir		
20:00				Social Dinner	

	DEPARTMENT OF PHYSICS AND ASTRONOMY
	Sunday 17 - ROOM ROSTAGNI
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	SAN GAETANO CENTER
	Sunday 17 - AGORA'
19:00	REGISTRATION & WELCOME COCKTAIL

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Plenary Keynotes
Poster Sessions
Sponsor presentations

	SAN GAETANO CENTER - ROOM "SPAZIO 35"				
	Monday 18	Tuesday 19	Wednesday 20	Thursday 21	Friday 22
09:00	Registration and Welcome Coffee	*Howard A. Stone (Streaming from Auditorium)*	*Andrew deMello (Streaming from Auditorium)*	*Nicole Pamme (Streaming from Auditorium)*	*Paolo Netti (Streaming from Auditorium)*
09:20					
09:40	*Opening (Streaming from Auditorium)*				
10:00	*Lydéric Bocquet (Streaming from Auditorium)*	Edoardo Maria Mollica	Hector Urra	Abhishek Viswanath	Enrico Turato
10:20		Luca Pellegrino	Mahdi Mansouri	Maede Pajouhande	Carlo Rigoni
10:40		Kerem Bozkurt	Ann-Kathrin Mertens	Pierpaolo Greco	Lorenzo Lombardi
11:00	Steffen Bisswanger	Coffee break	Coffee break	Coffee break	Coffee break
11:20	Mélanie Bulois				
11:40	Edoardo Sech	Martina Cicolini	Majid Layachi	Concetta Di Natale	Giacomo Guastella
12:00	Nicolas Bremond	Abdi Mirgissa Kaba	Jules Tampier	Marco Braibanti (Perspective)	Sateesh Jasti
12:20	*Sponsor presentations (Streaming from Auditorium)*	Johann Savinsky	Ali Gholizadeh		Sebastian Cremaschini
12:40		Edoardo Massarelli	Amir Hillman	Aymeric Allemand	*Roberto Piazza Awards & Closing (Streaming from Auditorium)*
13:00	Lunch and Exibitors	Lunch and Exibitors	Lunch and Exibitors	Lunch and Exibitors	
13:20					
13:40					
14:00	*Stéphanie Descroix (Streaming from Auditorium)*	*Charles Baroud (Streaming from Auditorium)*	*Roman Stocker (Streaming from Auditorium)*	*Giampaolo Mistura (Streaming from Auditorium)*	
14:20					
14:40					
15:00	Ole Milark	Rita Invernizzi	Adriano Tiribocchi (Perspective)	Federica Caselli	
15:20	Tillmann Carl	Constantinos Xenophontos		Sylvain Capet	
15:40	Nurul Mazlan	James Marquis	Marco Ellero	Ning Ji	
16:00	Oles Dubrovski	Raghu Krishna Moorthy	Lilia Losco De Cusatis	Aaron Streets	
16:20	Coffee break and Exhibitors	Poster & Coffee	Coffee break and Exhibitors	Poster & Coffee	
16:40					
17:00	Luiz Bueno (Perspective)		Stefania Caragnano		
17:20		Eleonora Pero	Jakob Wimmer	Social excursions	
17:40	Benedetta Marmiroli	Emma Dupont	Muhammad Waqas		
18:00	Aram Bugaev	Julien Renaudeau	Théo Rowden		
18:20	Yunpeng Zhang	Supratim Saha			
20:00				Social Dinner	

Plenary speakers

Sunday 17/05, 17:00 - Physics Department

Viscoelasticity as a Control Parameter in Microfluidic Flows

Pier Luca Maffettone

University of Naples Federico II, Italy

Monday 18/05, 10:00 - Auditorium

The molecular mechanics of fluids

Lydéric Bocquet

ENS Paris, France

Monday 18/05, 14:00 - Auditorium

Organ on chip development from basic research to clinical applications

Stéphanie Descroix

Curie Institute & IPGG, Paris, France

Tuesday 19/05, 9:00 - Auditorium

Simplifications when thinking about design and fabrication of microfluidic structures

Howard A. Stone

Princeton University, USA

Tuesday 19/05, 14:00 - Auditorium

Decoding cell-cell interactions in microfluidic droplets: cancer immunotherapy and beyond

Charles Baroud

Ecole Polytechnique & Pasteur Institute, Paris, France

Wednesday 20/05, 9:00 - Auditorium

Simple microfluidics for blood-based diagnostics

Andrew deMello

ETH Zurich, Switzerland

Wednesday 20/05, 14:00 - Auditorium

The Ocean at the microscale

Roman Stocker

ETH Zurich, Switzerland

Thursday 21/05, 9:00 - Auditorium

Microfluidics for clinical and environmental analysis in resource-limited settings

Nicole Pamme

Stockholm University, Sweden

Thursday 21/05, 14:00 - Auditorium

Passive and active control of drop motion on engineered surfaces

Giampaolo Mistura

University of Padua, Italy

Friday 22/05, 9:00 - Auditorium

Mechanomodulator chips: programming cells through controlled mechanical forces

Paolo Netti

University of Naples Federico II & IIT, Italy

Friday 22/05, 12:40 - Auditorium

Soft MatterS: Adventures of a physicist in the neglected dimension

Roberto Piazza

Polytechnic University of Milan, Italy

Perspective speakers

Monday 18/05, 11:40 - Auditorium

From Engineered Biology to Intelligent Sensing: The Expanding Role of Microfluidics

Daniele Vigolo
University of Sydney, Australia

Microfluidics has evolved from a tool for fluid manipulation to a versatile platform for controlling and interrogating biological systems with high precision. In this talk, I will present recent advances demonstrating how microfluidic technologies enable the engineering of physiologically relevant environments, as well as the emerging opportunity to integrate sensing and analysis within the same platforms. I will first highlight the development of a vein-on-chip system to model deep vein thrombosis, illustrating how controlled haemodynamics and microenvironmental conditions can recapitulate complex vascular phenomena in vitro. I will then discuss thermophoresis-driven hydrogel systems that generate continuous mechanical gradients, offering new approaches to study cell behaviour in biomimetic environments. Building on these examples, I will argue that the next phase of microfluidics lies in its convergence with advanced biosensing technologies. Microfluidic platforms are uniquely positioned to serve as front-end systems for point-of-care diagnostics, enabling precise sample manipulation, enrichment, and conditioning. Emerging strategies based on acoustophoresis and neuromorphic sensing will be presented as promising routes towards real-time, label-free analysis and early disease detection. This perspective outlines a shift from microfluidics as an enabling tool for biological modelling towards its role as a central component of integrated, intelligent diagnostic systems. By bridging engineered biology with sensing and decision-making, microfluidics is poised to play a key role in the future of decentralized healthcare.

Monday 18/05, 17:00 - Auditorium

A dynamic hydrogel-microfluidic strategy to investigate human neuromesodermal caudal development

Onelia Gagliano
University of Padua, Italy

Early human embryonic development emerges from finely tuned interactions between multiple germ layers that jointly orchestrate body axis formation, tissue patterning, and organogenesis. Alterations in these early events can give rise to severe congenital anomalies, particularly affecting posterior body structures, yet human-specific mechanisms remain poorly understood due to limited access to early embryos and the lack of controllable in vitro models. Here, we present a bioengineered platform that integrates human trunk-like structures derived from pluripotent stem cells within a dynamically tunable hydrogel–microfluidic system to model human caudal neuro-mesodermal development. A photo-responsive coumarin-functionalized hydrogel enables reversible bulk crosslinking and localized two-photon decrosslinking, allowing spatiotemporal modulation of the extracellular environment, while the coupled microfluidic device supports stable morphogen delivery under mechanically robust long-term culture conditions. In this setting, human trunk-like structures recapitulate key morphogenetic events, including symmetry breaking, axial elongation, and neuro-mesodermal segregation. The combination of photo-responsive hydrogel patterning and microfluidic delivery enables the generation of spatially defined signaling landscapes, providing a basis to implement controlled dorso–ventral patterning in future studies. Moreover, matrix-dependent effects on symmetry breaking suggest that the tunable mechanical properties of the platform could be leveraged to further refine tissue organization and regionalization. Overall, this dynamic system provides a reproducible, human-relevant framework to dissect biochemical and mechanical regulation of caudal development and to explore the origins of caudal malformations, with potential applications in disease modeling, drug screening, and developmental toxicology.

Monday 18/05, 17:00 - Room 35

Illuminating the Nanoscale in Flow: The Synergy of Microfluidics and Small-Angle Scattering

Viviane Lutz-Bueno
Paul Scherrer Institute, Switzerland

Microfluidics provides unprecedented control over fluid manipulation, offering precise continuous formulation, automated sample handling, and the generation of tailored kinematic fields, spanning pure shear to extensional and rotational flows, at low Reynolds numbers. However, fundamentally understanding the macroscopic flow behaviour and processing of complex fluids, such as polymers, colloidal suspensions, and biological macromolecules, requires directly probing their micro- and nanoscale structural evolution in situ. Small-Angle X-ray and Neutron Scattering (SAXS and SANS) are powerful, non-destructive analytical techniques capable of resolving molecular and mesoscopic structures from 1 to 500 nm. The integration of microfluidics with small-angle scattering represents a major paradigm shift for both fields. For the microfluidics community, SAXS and SANS serve as ”molecular microscopes” that enable the spatially and temporally resolved mapping of flow-induced phase transitions, nanoparticle growth, and molecular alignment directly within microchannels. Conversely, microfluidic devices serve as ideal, high-throughput sample environments for beamlines, drastically reducing the consumption of precious biological or isotopic samples (down to nanoliter volumes), while automating complex thermodynamic phase mapping and contrast variation measurements. This perspective talk will explore the state of the art in microfluidic-scattering integration. We will address the critical engineering challenges of transitioning from traditional, highly scattering, and deformable elastomers like PDMS to beam-compatible, high-pressure materials. Recent breakthroughs will be highlighted, including rapid prototyping with thiolene resins and the use of Selective Laser-Induced Etching (SLE) to carve arbitrary 3D microfluidics directly into fused silica. Furthermore, we will highlight advanced fluidic architectures specifically designed to leverage scattering diagnostics. Examples include the fluidic four-roll mill (FFoRM) for probing microstructures under tuneable, arbitrary 2D deformation fields, as well as complex contraction-expansion and wavy channels. By bridging the gap between microfluidic engineering and advanced scattering, researchers can unlock new pathways for high-throughput materials discovery, rational formulation design, and the fundamental study of soft matter out of equilibrium. As we look toward the horizon of next-generation neutron spallation sources and high-brilliance synchrotrons, the possibilities for time-resolved, microfluidic-scattering techniques are ever growing.

Tuesday 19/05, 17:20 - Auditorium

Blood microfluidics: multiscale insights from single-cell mechanics to blood-on-chip

Giovanna Tomaiuolo
University of Naples Federico II, Italy

Blood-on-chip technologies are emerging as powerful microfluidic platforms for the quantitative investigation of blood behavior under physiologically and pathologically relevant conditions [1]. By recreating key geometrical, mechanical, and biochemical features of the microvasculature, these systems enable controlled, high-resolution studies across scales —from single-cell biomechanics to collective dynamics, particle transport, and disease-related adhesion phenomena. Such approaches bridge the gap between simplified in vitro assays and the complexity of in vivo microcirculation. Microvasculature-mimicking networks allow the study of red blood cell (RBC) suspensions in channels with dimensions comparable to the cell size, where flow-induced deformation provides direct insight into membrane mechanics. Analysis of RBC dynamics under confinement enables quantitative estimation of membrane viscoelastic properties under physiologically relevant stresses. Alterations in deformability lead to measurable changes in cell behavior in confined flow, demonstrating the capability of blood-on-chip platforms to detect mechanically driven pathological signatures [2, 6]. At higher hematocrit, these systems enable investigation of collective RBC behavior. Flow-induced clustering in microcapillaries can be quantitatively characterized in terms of cluster size, velocity, and residence time as functions of hydrodynamic conditions and cell variability. These measurements elucidate how confinement and cell–cell interactions govern RBC spatial organization and contribute to blood' s non-Newtonian rheology and microvascular resistance [7]. Beyond intrinsic blood rheology, the particulate nature of blood critically regulates the transport of circulating microparticles (μPs), including drug delivery carriers. Microfluidic capillary models demonstrate that, in the presence of RBCs, particle velocity profiles and radial distributions are dictated by cell–particle hydrodynamic interactions. Margination —negligible in cell-free suspensions —is strongly enhanced by RBC-induced collisions that drive μPs toward the vessel wall, promoting their accumulation within the cell-free layer. Systematic investigation of shear rate, particle size, shape, stiffness, and surface properties reveals that geometrical and mechanical parameters play a dominant role in margination propensity. These findings provide quantitative design criteria for optimizing intravascular drug delivery systems [8]. Blood-on-chip strategies further extend to the modeling of microvascular pathophysiology. Endothelialized microfluidic devices reproducing small-vessel lumens under physiological flow enable real-time observation of Plasmodium falciparum-infected RBC adhesion. Controlled modification of the endothelial glycocalyx demonstrates its key role in regulating cytoadherence and sequestration processes associated with severe malaria, providing mechanistic insight into infection-driven microcirculatory dysfunction [9]. Overall, blood-on-chip technologies constitute a versatile and quantitative framework to investigate red blood cell biomechanics, collective flow phenomena, particle margination, and vascular interactions in both physiological and pathological conditions [10].

[1] Tomaiuolo, Biomicrofluidics 2014
[2] Tomaiuolo et al., Soft Matter 2009
[3] Tomaiuolo et al., Lab on a Chip 2011
[4] Tomaiuolo and Guido, Microvascular Research 2011
[5] Tomaiuolo et al., Cytometry: Part A 2012
[6] Lanotte, Tomaiuolo et al., Biomicrofluidics 2014
[7] Tomaiuolo et al., Physics of Fluids 2012
[8] D' Apolito, Tomaiuolo et al., Journal of Controlled Release 2015
[9] Introini et al, Journal of the Royal Society Interface 2018
[10] Pero et al., Cell Reports Physical Science 2024

Wednesday 20/05, 11:40 - Auditorium

From Opto-Fluidics to Photon Fluidics: Integrated Photonics as the Next Paradigm for Lab-on-a-Chip Sensing

Cinzia Sada
University of Padua, Italy

The convergence of microfluidics and integrated optics has progressively redefined the landscape of Lab-on-a-Chip technologies, enabling unprecedented control over light–matter interactions at the microscale. A coherent research trajectory advances from opto fluidic and opto-microfluidic platforms toward a unified framework, including photonic functionalities embedded within microfluidic architectures.

In this scenario, our recent works demonstrate the feasibility of fully integrated opto microfluidic systems based on lithium niobate substrates, combining microfluidic handling with guided-wave photonics in monolithic configurations. In particular, droplet-based optofluidic architectures exploiting Mach–Zehnder interferometric waveguides enable real-time, label-free detection of nanoscale analytes using a single visible wavelength, achieving sensitivity down to submicrometer particles such as microplastics dispersed in water and concentrations as low as 0.03 mg/mL. Complementarily, the integration of biochemical assays, within the same platform demonstrates quantitative analysis with nanoliter volumes, enhanced limits of detection, and statistical robustness over high throughput droplet ensembles.

These results highlight a crucial paradigm shift: optical sensing is no longer an external probing tool but becomes structurally embedded within the fluidic environment, enabling self-aligned, compact, and highly reproducible detection schemes. The interplay between droplet microfluidics and interferometric photonics provides multi-parametric sensing capabilities, where amplitude, phase, and temporal signal features encode information on particle size, concentration, and composition.

This perspective identifies key challenges and opportunities, including scalability, hybrid material integration, and the development of standardized architectures for sensing. Ultimately, optomicrofluidics emerges as a unifying paradigm with transformative impact across environmental monitoring, biomedical diagnostics, and soft-matter physics, paving the way toward fully autonomous, photonics-driven microanalytical systems.

Wednesday 20/05, 15:00 - Room 35

Lattice Boltzmann simulations and deep learning methods for soft flowing matter

Adriano Tiribocchi
IAC - CNR, Italy

Computational fluid dynamics is facing a rapid surge driven by recent advancements in high performance computing architectures and unprecedented opportunities offered by artificial intelligence. Among several numerical approaches currently available in the field, over the last twenty years the lattice Boltzmann methods have found major scope for the simulation of a large variety of problems in soft matter and microfluidics, ranging from multiphase and multicomponent flows to foams and emulsions. In this talk, I will discuss such models in the context of droplet microfluidics and their implementation on GPU architectures. I will also discuss recent results about the use of deep learning methods to enhance computational efficiency of lattice Boltzmann simulations, specifically for droplet tracking in flowing dense emulsions.

Wednesday 20/05, 17:00 - Auditorium

Small extracellular vesicles (sEVs): isolation, cargo loading, and targeted cell engineering within a microfluidic framework

Anna Menale[1]; Simona Silvestri[1]; Samuele Fiorenza[1]; **Enza Torino**[1,2]

[1] *University of Naples Federico II, Italy*

[2] *Interdisciplinary Research Center on Biomaterials (CRIB), Italy*

The efficient and reproducible intracellular delivery of functional biomolecular cargo remains a central challenge in both fundamental biomedical research and translational applications. Current methodologies are frequently limited by high costs, multistep protocols, and limited control over delivery efficiency, ultimately affecting scalability and experimental reproducibility. In this context, small extracellular vesicles (sEVs) have emerged as promising endogenous nanocarriers, owing to their intrinsic biocompatibility, low immunogenicity, and capacity to mediate intercellular communication. Nonetheless, the lack of standardized, cost-effective strategies for their isolation, engineering, and application continues to hinder their broader implementation.

In this perspective, we discuss the development of a custom-designed microfluidic platform that integrates sEV isolation, cargo loading, and delivery within a modular and scalable framework. The system is based on simplified microfluidic architectures that enable precise control of hydrodynamic conditions, thereby reducing reagent consumption, processing time, and operational complexity. Such an approach addresses key limitations of conventional techniques while promoting process reproducibility and sustainability.

sEVs processed through the platform were characterized using nanoparticle tracking analysis (NTA) and cryogenic transmission electron microscopy (cryo-TEM), confirming uniform size distribution and preservation of vesicular morphology. Functional validation was performed through real-time cell analysis (xCELLigence) and confocal microscopy, demonstrating effective cargo transfer and cellular compatibility in vitro.

Beyond the technical implementation, this work highlights the broader potential of microfluidic technologies in redefining EV-based delivery systems. The proposed framework supports the transition toward standardized, scalable, and environmentally sustainable platforms for advanced in vitro modeling and cell engineering. Such developments are expected to play a pivotal role in enabling next-generation biomedical applications, including personalized therapies and precision medicine.

Thursday 21/05, 11:40 - Auditorium

May the force be with your chips: Mechanically Active Models for Preclinical Research

Marco Rasponi
Polytechnic University of Milan, Italy

While biochemical signals have long been the focus of biological research, it is now established that **physical forces** are equally vital in governing tissue homeostasis and development. **Organ-on-Chip (OoC)** technology stands at the forefront of this shift, offering a sophisticated interface to merge microfluidics and biomaterials with the mechanical complexities of the human body. Our research focuses on recreating these dynamic environments to enhance the physiological relevance of preclinical models. Key milestones from our lab include:

Beating Technology: The development of a platform providing cyclic uniaxial stretch, which we demonstrated is a fundamental requirement for the functional maturation of 3D cardiac microconstructs [1].

Musculoskeletal Modeling: Adapting these mechanical stimuli to cartilage models, where we successfully replicated hallmarks of osteoarthritis through controlled, confined compression [2,3].

Gastrointestinal Dynamics: Expanding our scope to the gut, where the integration of peristaltic-like motion has allowed for a deeper exploration of the complex interplay between the host and its microbiome [4].

By precisely engineering the mechanical landscape, we can significantly improve the fidelity of OoCs. These advancements provide a more accurate lens through which to study disease progression, regenerative strategies, and fundamental developmental biology.

References:
[1] Marsano A, et al. Lab on a Chip, 2016.
[2] Occhetta P, et al. Nature Biomedical Engineering, 2019.
[3] Mainardi A, et al. Advanced Healthcare Materials, 2025.
[4] Ballerini M, et al. . Nature Biomedical Engineering, 2025.

Thursday 21/05, 12:00 - Room 35

Exploring Microfluidic Phenomena in Microgravity: Prospective ESA Experiments and Platform Concepts

Marco Braibanti
ESA, Netherlands

Microgravity provides a unique environment to decouple gravitational effects from microscale fluid dynamics, opening new avenues for studying transport, mixing, and interfacial phenomena. This contribution presents a set of prospective microfluidic experiments under consideration within ESA frameworks, focusing on capillarity-driven flows in reduced gravity. We outline experimental concepts designed for parabolic flights, sounding rockets, and orbital platforms, together with key technological challenges including integration, reliability, and autonomous operation. Potential scientific outcomes are discussed alongside applications in space exploration. The presentation aims to define research priorities and identify enabling developments required to fully leverage microfluidics in future ESA missions.

Oral contributions
Monday 18/05, 11:00 - 12:20

Auditorium

Brain-inspired nanofluidics with electromechanical ionic memories

Authors: Theo Emmerich[1]; Nathan Ronceray; Simon Mayer[2]; Saurav KV; Marianna Mitsionni; Aleksandra Radenovic

[1] *CNRS, Lyon, France*

[2] *EPFL, Lausanne, Switzerland*

Living organisms use ions flowing and accumulating within (sub)nanoscale aqueous protein channels to process information. This process occurs at energy costs orders of magnitude lower than those of man-made computers. The contrast is striking: Lee Sedol defeated AlphaGo in one game while consuming only ~20 W, about 50,000 times less power than the compute infrastructure supporting AlphaGo. This observation highlights the remarkable capacities of biological brains and motivates the development of brain-inspired ionic computing. This nascent field aims to implement data storage and processing using artificial nanoscale fluidic channels.
In this presentation I will display experimental results illustrating the birth of this field. I will present Nanofluidic memory devices: 2D channels, highly asymmetric channels and protein-based channels. Through direct imaging approaches and analytical modeling, we will elucidate electromechanical mechanisms at the root of ionic memory. Finally, we will see how these devices can be integrated into logic circuit, opening the path for brain-inspired liquid hardware.

References
[1] Robin, P. et al. Long-term memory and synapse-like dynamics in two-dimensional nanofluidic channels. Science 379, 161–167 (2023).
[2] Saurav, K. V. et al. Direct imaging reveals electromechanical ionic memory in 2D nanochannels. Preprint at `https://doi.org/10.48550/arXiv.2509.11637` (2025).
[3] Emmerich, T. et al. Nanofluidic logic with mechano–ionic memristive switches. Nat. Electron. 7, 271–278 (2024).
[4] Mayer, S. F. et al. Lumen charge governs gated ion transport in β-barrel nanopores. Nat. Nanotechnol. 1–9 (2025) doi:10.1038/s41565-025-02052-6.

Hidden Ionic Current Loops in Ion-Exchange Membranes Under Open-Circuit Flow Conditions

Authors: Timothée Derkenne[1]; Annie Colin[1]; Corentin Tregouet[1]

[1] *MIE, CBI, ESPCI Paris, Université PSL, CNRS 75005 Paris, France*

Ion-exchange membranes play a central role in micro- and nanofluidic technologies for desalination, osmotic energy conversion, and electrochemical separation. Their performance is commonly characterized by macroscopic quantities such as selectivity and open-circuit voltage (OCV), often assumed to be intrinsic material properties. However, experimental observations increasingly challenge this assumption, especially under flow conditions where concentration polarization develops. In particular, the strong and systematic dependence of the OCV on hydrodynamic conditions remains insufficiently understood. Clarifying the physical mechanisms underlying this behavior is essential for accurate membrane characterization and for the rational design membrane-based devices.

We investigate the origin of flow-dependent OCV variations using a milli-fluidic cell in which two electrolyte streams of different KCl concentrations are separated by a cation-exchange membrane. The cell geometry allows precise control of flow velocity, membrane dimensions, and concentration ratios over several orders of magnitude. Open-circuit potentials are measured under steady-state conditions, and segmented electrodes are used to probe spatial variations of electrochemical activity along the membrane. Post-mortem electrode analysis and direct current measurements provide evidence of internal current circulation despite the absence of net external current. To rationalize these observations, we develop a two-dimensional transport model based on coupled Nernst–Planck equations under electroneutrality, accounting for advection, diffusion, and electromigration in the electrolytes, as well as selective transport in the membrane. Donnan equilibrium is imposed at membrane interfaces, and electrode kinetics are incorporated through Nernst boundary conditions and finite interfacial resistance. The model self-consistently determines the spatial distribution of concentrations, local current density, and membrane potential under the global open-circuit constraint.

Experiments reveal that the OCV is not solely determined by the imposed concentration ratio and membrane material, but strongly depends on flow velocity, membrane length, and electrolyte concentration. At low velocities, the OCV can decrease by more than 30% compared to its high-velocity plateau. Electrode segmentation and surface analysis demonstrate the existence of steady, closed loops of ionic current circulating within the cell, driven by spatially varying concentration polarization along the flow direction. The model quantitatively reproduces the measured OCV curves across a wide range of conditions using a limited set of physically meaningful parameters. It shows that finite membrane selectivity allows counter-propagating ionic fluxes, leading to a reversal of the dominant charge carrier along the membrane and to local changes in effective selectivity, including sign inversion. As a result, selectivity emerges as a spatially varying property rather than a uniform membrane characteristic. These internal current loops can persist when a net external current is allowed and translate directly into reduced extractable power in closed-circuit operation.

This work demonstrates that open-circuit conditions in ion-exchange membrane systems can host substantial internal ionic circulation, fundamentally altering the interpretation of OCV and selectivity measurements. These findings have direct implications for membrane characterization, reverse electrodialysis performance, and electrode design, highlighting the benefits of electrode segmentation to suppress parasitic current loops. The results open new perspectives for controlling spatially resolved ionic transport in micro- and nanofluidic systems, and motivate future studies on loop dynamics and their exploitation in advanced electrochemical devices.

Room 35

The counter-intuitive motion of droplets and bubbles in co-axial channel flows

Authors: Steffen Bisswanger[1]; Tobias Baier[1]; Steffen Hardt[1]

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The motion of droplets and bubbles inside a channel flow is an important aspect of many microfluidic applications and can, in a broader context, also serve as a lab-scale model system for transport processes that occur in large-scale reaction columns in process engineering. In a series of experiments, we demonstrate and explain the unique and counter-intuitive behavior of droplets and bubbles in a channel flow with a specific flow configuration: a co-axial flow of (partially) miscible components. For studying droplets in this context, we inject a mixture of ethanol and oil into a sheath flow of water and leverage the ouzo effect to create the droplets [1]. For studying bubbles, we inject ethanol that is oversaturated with CO2 into water, resulting in the creation of bubbles inside the channel. Depending on the composition, these co-axial flow configurations can obviously result in large concentration gradients in the radial direction, which, however, inevitably also create concentration gradients in the axial direction. This is due to the combination of the flow in axial direction and the species diffusion in radial direction. As a result, a droplet (or bubble) in this flow configuration experiences solutal Marangoni forces in axial direction, as well as in radial direction if the droplet is not centered inside the channel. The axial Marangoni force can easily dominate over the drag and buoyancy forces, resulting in droplets traveling upstream inside the channel and bubbles descending against buoyancy. At the same time, the radial concentration gradients effectively keep the droplets (or bubbles) centered, conveniently avoiding wetting of the channel walls. Besides the aesthetically pleasing dance the droplets and bubbles perform inside the channel, there are also practical implications for possible microfluidic applications, like a novel type of pipette that uses Marangoni forces to withdraw tiny droplets or bubbles from a container for further processing.

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Soft Matter (2026), Advance Article.

In-air droplet generation in microchannels using co-flow focusing configuration

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Multiphase microfluidics involving bubbles and droplets in microchannels is central to many applications in chemical and biological fields, such as micro-emulsification and micro-encapsulation. However, most studies involve systems with a liquid continuous phase, whereas in-air microfluidics remains largely unexplored owing to the difficulty of achieving stable configurations, despite the numerous advantages it could offer.

Here, by combining optical microscopy with high-speed visualization and using the co-flow focusing droplet generator previously developed in our group (*Ref. [1]*), we succeed, for the first time to the best of our knowledge, in generating droplets in air in a controlled manner within a microchannel. This setup enables a systematic experimental investigation of water droplet formation and transport dynamics in a confined air flow at the microscale.

By varying the flow rates of both phases, we analyze flow regimes, droplet size, generation frequency, as well as droplet velocity and position. The explored flow range corresponds to gas Reynolds numbers from 47 to 600 and Weber numbers from 0.11 to 22, which can involve gas velocities of 100 m/s in the outlet capillary. The liquid phase operates with Reynolds numbers ranging from 2 to 40 and Weber numbers from 0.0029 to 2. This wide parameter space allows observation of three distinct flow regimes: jetting, dripping, and a bistable transient regime characterized by hysteresis between dripping and jetting, as well as the transition from in-liquid to in-air microdroplets. Remarkably, droplet generation frequencies exceeding 10 kHz and droplet velocities of the order of 10 meters per second are measured. The whole results clearly evidence the dominant role of inertial effects in this in-air microfluidic configuration with Laplace number of about 3000.

At this stage, numerous additional phenomena remain to be fully explored. Depending on the operating conditions, oscillations of droplets or jets are observed in the outlet capillary. In the dripping regime, oscillatory modes may also appear during droplet detachment from the nozzle. Overall, this work demonstrates for the first time the feasibility of generating water droplets with an air flow inside microchannels at ultra-high throughput, offering a new pathway for oil-free encapsulation applications.

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Two-Phase Flow in Micro-Venturi: analysis of the complexity of Cavitation flow under Microscale Confinement.

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Recent advances in microfabrication have enabled the development of microscale platforms for biotechnological and chemical applications, opening new perspectives also for the controlled exploitation of hydrodynamic cavitation. Compared to traditional macroscale systems, microfluidic configurations provide enhanced surface-to-volume ratios, improved control of operating conditions, and stronger coupling between interfacial phenomena and flow dynamics. These features make microscale cavitation particularly attractive for applications such as intensified oxidation, improved micromixing, accelerated mass transfer, and enhanced chemical and biological reaction efficiency. In this work, cavitation development in a micro-Venturi channel is experimentally investigated, with the aim of identifying the distinctive characteristics of microscale cavitating flows and their departure from classical macroscale cavitation shedding. The study of cavitation is of growing interest in the context of microscale fluid mechanics representing one of the few examples of turbulent-like dynamics in microchannels and plays a key role in enhancing interfacial transport phenomena beyond purely diffusive mechanisms. The analysis of the two-phase flow reveals a strong coupling between phase change, confinement effects, surface forces, and hydrodynamic instabilities, leading to a flow regime dominated by Kelvin–Helmholtz instability. The study is part of a broader multiphysics investigation aimed at evaluating the effectiveness of cavitation-assisted processes for the decolourization of selected azo dyes, which are of significant concern for water safety in the textile industry. Both cavitation in pure water and cavitation with the addition of H_2O_2 are analysed. Flow dynamics were characterized through the combined analysis of high-speed imaging and pressure measurements, allowing direct correlation between cavitation structures and pressure fluctuations. The comparison between these two cases provides the foundation for the subsequent qualitative and quantitative assessment of the results. Image- and pressure-derived signals supported the formulation of a qualitative hypothesis of the differences observed between the flow regimes, which was subsequently proven using quantitative signal-processing approaches not commonly applied in this field: Fragmentation Level and Wavelet Frequency Analysis. The fragmentation dynamics of cavitation structures were further investigated using image-processing algorithms based on fractal dimension estimation, which proved to be a robust quantitative descriptor of structure morphology. Higher tendency of bubble structures fragmentation is proven in this way for cases having H_2O_2 addition. These results were systematically correlated with Wavelet Frequency spectral analyses of pressure signals, revealing the occurrence of intense bubble collapse events and distinct high-frequency pressure emissions depending on the shape and evolution of the cavitating structures reaching up to 30-80 kHz. Moreover, no high frequency contribution is demonstrated when small vapor structures implode or proximity to big vapor region cause damping effect. Overall, this work provides new insight into how cavitation phenomena evolve when transitioning from macro to microscale systems, highlighting the critical role of confinement and interfacial effects. In addition, it introduces data analysis methodologies that are transferable to a broader class of microscale multiphase flow systems beyond the specific case investigated here.

Microfluidics for emulsion science and product development

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Emulsions, heterogeneous mixtures of two immiscible liquids to which surfactants are added, are a very widespread material encountered in various fields, from cosmetics to food and biotechnology. Microfluidics has proven to be an ideal tool for designing custom emulsions with controlled size and composition. However, while micrometre size droplets are an ideal template or microreactor for the creation of advanced products dedicated to applications in life science, their production in large quantity is still challenging.

We developed a microsystem composed of thousands of shallow microchannels emerging in a deeper one and where droplets are formed through the so-called step-emulsification mechanism. The addition of an intermediate channel depth is shown to homogenize droplet production rate and thus droplet size which is here below 10 micrometres. This micro-emulsification system is demonstrated to be valuable for producing calibrated magnetic microspheres, shaped from the emulsion droplets, that finds application in biomolecules or cells extraction from biological samples.

It is also a suitable platform for investigating emulsion stability against coalescence linked to transport of surfactants from the continuous phase towards the freshly created interfaces. The surfactants transport is a combination of advection, related to droplet motion, and diffusion that depends on the geometrical features of the microsystem. A critical surface concentration of surfactant below which coalescence occurs is estimated for various oils. The stability criterion is a function of chemical nature of the oil as well as its viscosity. This microsystem also allows to investigate the role played by the nature of the surfactant, the presence of micelles and their dissociation rate as well as the effect of ions on the stability against coalescence during the emulsification of a concentrated emulsion.

Moreover, the capability to produce monodisperse emulsions with a finely tuned droplet size at a high throughput allowed us to study the rheological behaviour of model concentrated emulsions. We find that droplet size distribution has a major impact on the flowing features of concentrated emulsions. Shear-bands take place in such a system without requiring attractive forces between droplets as previously observed. We attribute this intriguing phenomenon to a variation of the orientation of the crystalline structure that is formed by the monodisperse emulsion droplets, which is related to a different friction between droplets layers.

Oral contributions
Monday 18/05, 15:00 - 18:40

Auditorium

Accessible Microfluidic Platforms for Studying Flow–Cilia Interactions in Airway Epithelium

Authors: Athullya Baby[1]; Viridiana Carmona Sosa; Jose Foz Romão de Oliveira; Jurij Kotar; Clare Elizabeth Bryant; Teuta Pilizota; Pietro Cicuta

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In vitro models of the airway epithelium are essential for studying respiratory physiology yet commonly used systems rely on static culture conditions that lack mechanical stimulation at the tissue surface. In particular, conventional air–liquid interface (ALI) Transwell models maintain epithelial tissues without fluid flow on either the apical or basal side, leading to limited control over shear stress and a progressive loss of coordinated ciliary alignment.
To overcome these limitations, we developed two low-cost, microfluidics-compatible platforms; TransChips and an affordable lung-on-chip system; that introduce controlled fluid flow while remaining simple to fabricate and operate. The TransChip platform enables defined shear flow over the apical surface of differentiated, ciliated airway epithelial tissues. Using this system, we demonstrate that externally imposed flow strongly influences ciliary orientation, promoting robust and directional alignment.
In parallel, we present a cost-effective lung-on-chip device that independently supplies continuous basal perfusion for nutrient delivery while applying apical shear stress. This platform supports stable long-term culture and provides a practical, accessible alternative for incorporating physiologically relevant flow into airway epithelial models.

Mucus pumping from artificial magnetic cilia in an open to air microfluidic channel

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Pulmonary bronchi are lined with a thin layer of mucus, which protects the airways from foreign particulate, such as dust and pathogens. In order to remove this mucus from the lung, the epithelium of the lung is covered in ciliated cells, which beat, moving the mucus up and out of the bronchi to the throat. Dysfunction in this mucociliary clearance can originate from both the cilia, such as cilia dyskinesia, and the mucus itself, such as in the case of cystic fibrosis, resulting in impaired breathing, infection and an increase in mortality [1]. One approach to studying mucociliary clearance has been using artificial cilia, and in particular microfabricated magnetic cilia [2].

We use artificial magnetic cilia which are fabricated using soft lithography, and filled with iron microparticles, lining a circular microchannel, as previously reported previously [3]. These artificial cilia are actuated by placing the microchannel above a rotating set of permanent magnets, which actuate with a slow active stroke, and a rapid recovery stroke, caused by a magneto-elastic instability [4]. The microchannel is filled with fluid which can be pumped by the cilia. In order to better mimic mucociliary clearance, we leave the top fluid surface open to air. To overcome surface tension effects, the microchannel is made hydrophilic by plasma activation, and surfactants are added to fluid solutions when necessary, resulting in a flat air-liquid interface.

Flow in our channel is measured using particle tracking velocimetry of suspended tracer particles. The flow profile in all fluids resembles that of fully developed flow with the maximum velocity achieved on the surface of the fluid. This flow is dependent upon the specifics of the cilia pathway, and proportional to their frequency. Flow generated is measured to decrease relative to viscosity in giant micelle solutions and in model snail slime mucus. Importantly, we show that the relationship between flow rate and viscosity is not the same in micelle and mucus solutions.

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Bronchus on a chip (BOC)

Authors: Christophe Blanc[1]; Gladys Massiera[1]; Iyad Abou Shakra[1]; Cecilia Urena[2]; Delphine Muriaux[3]; Jabir El Asri[1]; John De Vos[2]; Elisabeth Pinel[3]

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The human bronchial epithelium is a dynamic barrier that forms the first line of defense against inhaled threats such as pollutants and respiratory pathogens. Its protective role mainly depends on two key cell types: i) goblet cells that secrete mucus, a viscoelastic fluid that traps foreign particles entering the human body and ii) ciliated cells, which have hair-like structures that beat in a synchronized way to generate mucus flow. This process is known as mucociliary clearance and ensures a continuous removing of dust and pathogens, supporting normal airway function. In vitro models of human bronchial epithelium (HBE) are mainly provided by 2D culture on transwell inserts where cells are placed at the air–liquid interface to allow differentiation into ciliated and goblet cells and thus a functional bronchial epithelium. While HBE ALI cultures are traditionally considered as the gold standard, they have some limitations as a model: the 2D geometry and stiffness of the insert is not reflecting the HBE environment and the inserts hinder the imaging required to characterize accurately cells beating coordination.

Here, we engineered a 3D bronchus-like perfusable structure optimized for high-resolution live-cell imaging required for cilia beating and mucus flow analysis. The microfluidic chip contains a cylindrical lumen molded inside a chamber filled with collagen, connected to two reservoirs of culture medium. This geometry allows cells to grow at the air–liquid interface formed between the collagen hydrogel and the air inside the lumen, and the nutrients to diffuse from the reservoirs through the hydrogel. The lumen coating is chosen to grow either primary cells or induced pluripotent stem cells. The "mini-bronchus" can be alternatively be perfused with medium or air, and its diameter can be varied from 200 to 1000 microns, covering the size range for bronchioles.

This organ-on-a-chip model uniquely incorporates physiologically relevant features and will allow real-time visualization of key respiratory processes including ciliary motion, mucus transport, viral docking and entry, infection spread, and response to drug treatment within a biomechanically relevant airway environment. This platform will be used in the first place to test how exposition of the bronchial epithelial tissue to pollution can favor infection by respiratory viruses. The functionality of the tissue will be assessed thanks to the biophysical tools we previously developed to characterize cilia beating coordination, based on the tracking of cilia motion and mucus flow. On more fundamental aspects, we are investigating how the curvature of the tissue affect the cilia coordination and its typical length scales.

Modeling brain diseases on a chip for ethical and successful drug development

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Despite extensive preclinical efforts, effective therapies for brain disorders remain scarce, largely due to the limited predictive power of existing experimental models. While many candidate compounds show robust efficacy in animal models, translation to human patients has been disappointing. This gap underscores the need for scalable, human-relevant platforms capable of recapitulating key aspects of brain circuit organization while remaining compatible with drug discovery pipelines.

Human induced pluripotent stem cells (hiPSCs) have opened new perspectives by providing access to the patient' s own genetic, molecular, and cellular context. However, their relevance in vitro is frequently limited by their use in isolated and artificial culture systems that fail to reproduce tissue-level organization and circuit-level interactions. By integrating hiPSC-derived cells with organ-on-chip technologies, human stem cells can instead be deployed within engineered microenvironments that better recapitulate physiological architecture and function, enabling drug testing in reconstructed patient-specific tissues.

Here we introduce brain-on-chip models that recapitulate both healthy and pathological conditions, including Huntington' s disease and neurodevelopmental disorders. These microfluidic platforms rely on compartmentalized architectures that enable controlled neuronal connectivity, long-term culture, and functional interrogation, while remaining compatible with standardized fabrication and scalable experimental workflows. We are now developing "humanized" versions of these platforms by incorporating patient-derived stem cells for these neuropathological conditions.

Using these next-generation human brain-on-chip devices, we evaluate the therapeutic potential of neuroprotective compounds that have already demonstrated promising efficacy in various animal-based models of Huntington's disease. This work thus aims to facilitate and accelerate the transfer of therapeutic candidates toward clinical trials by providing predictive, human-relevant, and engineering-driven preclinical platforms that complement existing animal models.

Study of ADPKD mechanisms in a biomimetic kidney-on-chip

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The Autosomal Dominant Polycystic Kidney Disease (ADPKD), is the most common genetic kidney disease, leading to the development of numerous cysts in the renal tubules, and ultimately to kidney failure, without any curative treatment to date. Despite numerous genetic and cell biology studies of ADPKD, the precise mechanism of its cystogenesis, resulting from localized dilation of the renal tubules, remains misunderstood. Our hypothesis is that the mechanical stresses exerted within the tubules play a key role in cyst formation. Our team had developed a kidney-on-chip device in order to mimic the early tubular dilation specific to ADPKD, by using a deformable and tunable extracellular matrix. This microfluidic device enables us to replicate the particular geometry of the tubules and also to decouple flow shear stress and pressure effects on the tubular dilation. We have shown that different pathways can drive the dilation in our *in vitro* model of ADPKD, depending on the tubular segment studied [1]. In the proximal segment, early tubular dilation is associated with hyperproliferation, while in the collecting duct (mIMCD-3 cells) dilation is linked with a remodeling of the basement membrane and a squamous cell morphology. Moreover, mIMCD-3 tubules are highly sensitive to the extracellular matrix properties and the hydrodynamics constraints encountered. Strickingly, the flow shear stress alone can suppress the dilation specific to ADPKD observed in static condition, while the addition of pressure to this flow shear stress triggers a significant and rapid dilation.

Ongoing transcriptomics investigations will enable us to identify targets specifically sensitive to flow shear stress or pressure. They already suggest an involvement of genes that contribute to basement membrane remodeling or to the control of cytoskeletal dynamics. Our next step is to use our microfluidic chip to evaluate the effect of disruptive approaches to these key effectors on mimicked tubular dilation [2]. Finally, in a translational approach, we will integrate patient cells within our *in vitro* kidney tubules to replicate their dilation.

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Skin-on-a-chip for rapid and targeted assessment of chemical toxicity

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Objective : Development of an organ-on-a-chip dedicated to the study of chemical toxicity via the skin. The main technological objective presented here is based on the integration of biocompatible and photo-polymerizable hydrogel separators that can mimic the dermis, accommodate suitable co-cultures, and support the epidermis.

The organ-on-a-chip (OoC) technology can reproduce selected elements of human skin physiology, thus enabling the assessment of chemical substance toxicity in a relevant and representative manner while reducing the use of animal models [1]. This technology borrows from microfluidics a precise management of flows and from microfabrication, a potentially 3D compartmentalization, reproducing the natural architectures of epithelium/endothelium complexes.
In this context, we describe the development of a planar organ-on-chip (optimized for optical microscopy imaging) whose minimal complexity integrates a differentiated epidermis based on a keratinocyte cell line resting on a dermis-mimicking hydrogel. Inspired by J. Ahn et al. [2], the design includes a photo-polymerizable separator (e.g., GelMa) shaped in situ by DLP (Digital Light Processing [3]) directly within a chip previously fabricated in a cleanroom. Our study focuses particularly on optimizing the formulation leading to the integration of the hydrogel separator by adjusting the relative concentrations of prepolymer (GelMA), photoinitiator, and possibly polymerization inhibitor, as well as the UV dose required to induce gelation. We show that these parameters are crucial for optimizing geometry and adapting the hydrogel' s permeability while limiting its swelling [4].

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VEGF-A/C co-stimulation, without shear stress, triggers the polarization of lymphatic microvessels

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The lymphatic system is a network of unidirectional vessels that plays an essential role in the control of tissue homeostasis, immune surveillance, and is also involved in metastatic processes [1]. Its function is dynamically regulated by molecular signals —such as vascular endothelial growth factors (VEGFs) —and physical cues. While VEGFs and their associated receptors are known to promote endothelial proliferation [2], their broader roles in tissue organization remain under investigation. Using a lymphatic vessel-on-a-chip platform, we examine how lymphatic endothelial cells (LECs) respond to VEGF-A, VEGF-C, or their combination [3]. We find that co-stimulation synergistically enhances lymphangiogenic sprouting while preserving barrier integrity. Furthermore, co-induces axial polarization of the tissue along the vessel axis, even in the absence of external mechanical stimuli. This polarization requires the activation of the VEGFR2/VEGFR3 heterodimer and is disrupted by inhibition of the Src-dependent mechanotransduction pathway. Further co-stimulation enhances LEC motility and triggers vessel contraction. Finite element modeling suggests that contraction of the tubular geometry creates an intrinsic mechanical anisotropy of the matrix —softer in the circumferential than axial direction. This geometrically-encoded stiffness landscape directs cell migration along the stiffer axis, uncovering a form of durotaxis driven by curvature-induced anisotropy. These results highlight a previously unrecognized mechanism by which biochemical and biophysical cues direct lymphatic tissue polarization, offering new insight into how geometry and mechanosensing shape lymphatic function.

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Room 35

Confined unidirectional drying of colloidal dispersions: evaporation-driven transport and flow in a 1D microfluidic geometry

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Solvent evaporation of a complex fluid, such as a colloidal dispersion, is a fundamental step to many industrial processes, including, for example, coating and printing. However, predictive control of the final structure requires an improved understanding of the physical mechanisms governing evaporation-driven flows, particle transport, and consolidation. Confined unidirectional drying offers a well-defined one-dimensional microfluidic geometry in which the coupled evaporation, flow, and transport can be quantitatively probed.

In confined drying geometries, recent theoretical models predict that evaporation-driven transport in colloidal dispersions is governed by distinct regimes, including a capillary-limited regime that is independent of the relative humidity (RH) [1,2]. However, these predictions have not been validated experimentally.

Drying experiments were performed on two aqueous dispersions (Ludox HS-40 and AS-40) of charged silica nanoparticles of different diameters (11 nm and 22 nm), confined in glass capillaries ($0.1 \times 1 \times 100$ mm^3) and in self-built Hele-Shaw cells with similar confinement, in an RH-regulated environment. In this configuration, evaporation of water occurs only at one end of the capillary, leading to an evaporation-driven flow that concentrates the nanoparticles at the interface and results in the growth of a porous medium through which water transport is governed by capillary and Darcy-like flows. The evolution of the drying front was observed using multiple optical techniques, including Raman spectroscopy to measure the water content in the solid region, Mach–Zehnder interferometry to determine concentration profiles in the non-solid region, and bright-field and fluorescence microscopy to monitor evaporation flux and internal flows.

During drying, multiple phenomena can be observed, including the build-up of concentration gradients and a solid front, the evaporation rate and therefore the transport of water through this solid material, the invasion of air at the tip of the capillary, and crack formation in the solid material. Depending on the relative humidity, we observe both a flow-limited regime, in which the evaporation rate depends on RH, and a capillary-limited regime, in which evaporation is independent of RH. This regime is correlated with the size of the nanoparticles, which influences the pore size of the solid material and therefore the critical capillary pressure. Additionally, we show that cracks in the solid material do not significantly influence the transport of water through the material. All experiments lead to measurements of the permeability, the maximum packing fraction, and the concentration-dependent collective diffusion coefficient of the dispersion.

Overall, these results provide a direct experimental validation of evaporation-driven transport regimes in confined colloidal drying and establish confined unidirectional drying as a microfluidic platform for precise optical characterization of complex fluids.

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A Marangoni-powered micropump converting vertical heat-supply in translational motion

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On small length scales, temperature gradients at fluid interfaces give rise to Marangoni stresses, a phenomenon caused by the temperature dependence of the surface tension. In a Stokes flow regime, where viscous forces dominate inertial forces, these stresses can induce fluid flow. This mechanism has previously been examined to propel micron-sized particles and to drive flow in microfluidic systems. A key disadvantage of existing pumping concepts is the requirement of a horizontal temperature gradient, which limits the achievable length and direction of such systems. In this presentation, we present a concept that overcomes these disadvantages and enables length-independent pumping with vertical instead of horizontal heat supply. The concept presented comprises a channel with integrated periodic microstructures at the bottom. These structures enclose air and vary in heat conductivity to create an environment where water can effectively be pumped through a channel of an arbitrary length. Using numerical simulations, we investigate how microstructure geometry affects the induced flow and determine the achievable flow rates. Furthermore, we discuss the potential applicability of the concept as a cooling mechanism.

Droplet Friction and Fluid Interactions on Superhydrophobic Doubly Re-entrant Microstructured Surfaces

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Superhydrophobicity is a remarkable surface property observed in nature and widely exploited in engineering applications such as anti-wetting, anti-fogging, and anti-fouling coatings [1]. Achieving robust superhydrophobicity typically relies on micro-/nanostructure, among which doubly re-entrant architectures have emerged as particularly effective due to their re-entrant curvature that stabilizes liquid–air interfaces even for intrinsically wetting liquids [2]. While the static and dynamic wetting properties of doubly re-entrant surfaces have been widely reported, a quantitative understanding of how their geometric parameters govern droplet friction and mobility remains largely unexplored [3,4]. Here, we systematically investigate the frictional behaviour of water droplets moving on superhydrophobic doubly re-entrant surfaces using a cantilever-based force sensing approach coupled to a motorized translation stage. This approach enables direct measurement of friction and adhesion forces in the micro-Newton (μN) range. Water droplets were translated across the surfaces at controlled velocities spanning two orders of magnitude (0.1–10 mm s^{-1}). A series of doubly re-entrant surfaces were fabricated with independently varied structural parameters, including pillar spacing and spacing-to-diameter ratio. Despite exhibiting similar apparent static water contact angles in the range of approximately 130°–148°, the surfaces displayed pronounced differences in frictional behaviour. This indicates that contact angle alone is insufficient to predict droplet mobility on microstructured surfaces. Systematic friction measurements reveal that pillar geometry plays a dominant role in controlling droplet friction. In particular, reducing pillar diameter while increasing inter-pillar spacing significantly lowers friction forces by minimizing solid–liquid contact and suppressing contact-line pinning. An optimized design with a pillar diameter of 50 μm and a spacing-to-diameter ratio of 4:1 exhibited ultra-low friction forces as low as 3.47–4.12 ± 2.86 μN, representing one of the lowest friction regimes observed in this study. However, excessively large spacing was found to compromise the ability of the structure to mechanically support droplets, indicating an important trade-off between friction reduction and liquid retention. Velocity-dependent measurements further reveal non-linear friction at higher translation speeds, suggesting changes in contact-line dynamics as velocity increases. Complementary evaporation studies demonstrate that surface geometry influences droplet pinning and evaporation modes, with implications for deposit formation and coffee-ring effects on superhydrophobic microstructures. Overall, this work provides new mechanistic insight into how doubly re-entrant microstructural design governs droplet friction and mobility, beyond what can be inferred from static wetting measurements. The findings establish design principles for engineering low-friction, high-mobility superhydrophobic surfaces, with direct relevance to microfluidic droplet transport, and self-cleaning materials.

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Gas-Shear-Triggered Marangoni Instability for On-Demand Micromixing and Surfactant Contamination Sensing in Open-Surface Microfluidics

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We report a contactless, gas-actuated interfacial instability that turns a quiescent, surfactant-laden water surface into a robust, low-mode recirculating flow above a sharp gas-flow threshold. The platform is a simple circular well (Petri-dish geometry) capped by a plate with a central orifice of radius rc: an impinging gas jet spreads radially and applies a tangential shear stress that decays approximately as one over r along the gas–water interface. Below a critical gas flow rate Qc, the interface remains essentially motionless. Above Qc, we observe a reproducible azimuthal symmetry breaking dominated by a dipolar mode, producing a pair of counter-rotating surface vortices and strong interfacial transport, quantified by particle tracking velocimetry.

To rationalize the onset and mode selection with a minimal model suitable for microfluidic design, we derive a ring-wise linear stability theory for the surfactant concentration. The applied gas traction is mapped to an interfacial shear response, so that in the axisymmetric base surfactant profile shear stress competes directly with Marangoni stress due to surfactant concentration gradients. Regularity at the center and rotational symmetry imply decoupled azimuthal Fourier modes; a Frobenius/Taylor regular-branch of sin(m*theta) form yields a compact inner-edge closure for the radial log-slope at the ring, approximately m/rc, enabling an explicit dispersion relation. The resulting growth rate has a simple "traction versus diffusion" form, predicting a threshold Qc that scales with interfacial elasticity, orifice radius rc, and surfactant diffusivity. To capture the observed recirculating topology away from the ring, we complement the traction-driven (potential) surface response with a screened-Stokes/Brinkman streamfunction response driven by the azimuthal Marangoni traction at r equals rc, which naturally selects an eddy length scale and reproduces the dipolar pattern.

Beyond fundamental interest, the effect provides a practical actuator for open-surface microfluidics: gas flow rates above Qc yield on-demand micromixing in shallow wells, with the option to produce chaotic advection by utilizing two independent orifices. Conversely, because Qc depends sensitively on interfacial properties, the onset of flow itself can serve as a rapid readout for surface contaminants, turning a single gas flow sweep into a quantitative assay.

Microfluidic devices for synchrotron Small Angle X-ray Scattering Experiments

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Micro-nanotechnology has blurred the borders between material science, chemistry and biology. The miniaturization of chemical and biological assays, promoted by micro-nanofluidics, requires both a careful selection of the fabrication methods and the development of tailored materials for the specific applications. As a consequence, interdisciplinarity is becoming fundamental in the combination of microfabrication and characterization techniques aimed at the construction of new devices that create new sample environments, allowing to access new fields of investigation (1). In this communication, we want to underline the advantages obtainable by combining microfluidics with synchrotron Small Angle X-ray Scattering (SAXS). SAXS is a standard method for structural characterization at the nanoscale between 1 nm and 100 nm, with excellent in situ, time resolved and operando capabilities, and providing unique information on the nanostructure and kinetics of soft and condensed matter. In this communication, two microdevices for SAXS investigations will be presented. The first is a microfluidic device to feed water through the pores of a mesoporous material thin film (which has an ordered structure with uniform connected pores in the size range 2-50 nm) in order to maintain the hydration of model lipid membranes. The idea is to prove the possibility to use mesoporous materials as "active" sample holders which are able to deliver fluids (2). The second is a microfluidic device which is transparent to UV-visible light in one direction and to X-rays in the perpendicular one, for the study of photoactive systems using UV-visible spectroscopy and/or SAXS (3). The research has been performed at the microfabrication laboratory and at the Austrian SAXS beamline at Elettra-Sincrotrone Trieste (Italy).

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Synergistic coupling of microfluidic reactors with synchrotron X-ray absorption spectroscopy

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Detection of active species in (photo)catalysts is a crucial step towards understanding and optimization of reaction mechanisms. X-ray absorption spectroscopy (XAS) is an extremely powerful tool to selectively probe local atomic and electronic structure around element of interest. Its sensitivity towards active species can be further enhanced by a modulation-excitation (ME) approach, using periodic stimuli, such as light. However, in liquid-phase reactions, diffusion limitations, product accumulation, and gradual pH shifts can obscure the direct photoinduced response of the catalyst. This makes the detection of light-induced structural changes elusive and limits the mechanistic understanding.

In this work, we overcome these limitations by synergistic combination of microfluidic setups with in situ and operando XAS. We have designed several microfluidic reactors for chemical synthesis [1], homogenous and heterogenous catalysis [2] and photocatalysis. The latter was used with the ME-XAS coupled with real-time UV-Vis analysis of the reaction products. The efficiency of the approach was demonstrated using photocatalytic degradation of Rhodamine B over Pt/TiO_2. Pt species were found to be present in Pt(0) state, not showing any XAS changes during catalysis in the conventional batch cell. To get deeper insights on the structural changes, a thin layer of the catalyst was deposited on a 1 mm channel of the microfluidic reactor with built-in directional UV source. The changes of both XAS and UV-vis data were monitored over periodic light ON/OFF experiment flowing RhB solution at 1, 20 and 60 mL/h. We demonstrate that high flow rates of the substrate through the microreactor are indispensable to resolve light modulated differences in Pt L_3-edge spectra –undetectable and low flow rates of the solution. Supported by ab initio modelling and comparing with the experimental data collected under gas phase conditions, the observed spectral modulations were successfully assigned to the formation of platinum hydrides.

Beyond advancing the mechanistic understanding of several chemical processes, this approach establishes a general platform for time-resolved operando XAS studies of metal speciation across diverse liquid-phase (photo)catalytic reactions.

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Coupled Birefringence–SAXS–PIV Analysis of Wormlike Systems Under Extensional Flow in Contraction–Expansion Microchannels

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Microfluidic devices are ideally suited for the study of complex fluids undergoing large deformation rates in the absence of inertial complications, providing access to well-defined extensional and shear flows that are difficult to achieve in conventional rheometric geometries. Previous studies employing narrow-width microfluidic channels, however, have faced challenges in accurately quantifying flow-induced deformation in long-chain systems, owing to limited spatial resolution, short residence times, and uncertainties in local flow conditions. Here, we combine advanced microfluidic design with multimodal in-flow characterization—including flow birefringence measurements, synchrotron-based small-angle X-ray scattering (SAXS), particle image velocimetry (PIV), and numerical simulations—to resolve how wormlike micelles and semiflexible polymers respond to extensional and shear deformation in contraction–expansion microfluidic geometries.

Two complementary microfluidic devices were developed for this purpose. A glass–SU8 contraction–expansion chip enables precise control of flow kinematics and quantitative optical measurements under flow, while a multilayer microfluidic chip incorporating thin diamond X-ray windows provides high X-ray transmission and mechanical stability for in-flow SAXS experiments. Together, these platforms allow direct correlation between microfluidic flow fields and molecular-scale structural response under non-equilibrium conditions.

Using these devices, we investigate the flow-induced ordering of three representative wormlike systems with distinct molecular architectures and interaction mechanisms: semiflexible wormlike polymer chains (ctDNA), ionic wormlike micelles formed by CTAB/NaSal, and nonionic wormlike micelles based on C12E6/n-dodecanol. ctDNA behaves as a semiflexible wormlike chain with a large persistence length and relatively slow relaxation dynamics, leading to strong extensional alignment but limited capacity for rapid structural reorganization. In contrast, CTAB/NaSal forms highly dynamic ionic wormlike micelles whose contour length and connectivity are governed by electrostatic interactions and micellar scission–recombination processes, resulting in pronounced viscoelasticity and rapid flow-induced restructuring. The nonionic C12E6/n-dodecanol system exhibits weaker electrostatic interactions and slower breaking dynamics, providing a complementary wormlike micellar system with distinct relaxation pathways and sensitivity to extensional stresses.

In-flow SAXS measurements corroborate these differences by revealing pronounced anisotropic scattering and clear azimuthal intensity modulation downstream of the contraction region, directly reflecting variations in alignment strength and relaxation behavior among the three systems. Velocity fields obtained from PIV were incorporated into numerical simulations using a Giesekus constitutive model. The resulting extensional stress distributions quantitatively reproduce the experimentally observed optical anisotropy, highlighting strong agreement between structural, optical, and hydrodynamic measurements.

Together, these results establish a unified multimodal microfluidic framework for probing flow-induced ordering in wormlike systems and provide mechanistic insight into how extensional stresses govern molecular alignment in confined microfluidic environments, demonstrating the potential of microfluidic platforms as enabling interfaces for high-energy spectroscopic studies of complex fluids under non-equilibrium flow conditions.

Oral contributions
Tuesday 19/05, 10:00 - 13:00

Auditorium

Surface Chemistry-based Continuous Separation of Colloidal Particles via Diffusiophoresis and Diffusioosmosis

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The separation of colloidal particles is of great importance in many fields, such as purification, sensing, and bioanalysis. However, separating particles based on their surface physico-chemical properties remains challenging. Here, we present an innovative microfluidic strategy enabling the continuous separation of colloidal particles based on their surface chemistry. Through experimental and theoretical analyses, we demonstrate that diffusiophoresis and diffusioosmosis enable the separation of carboxylate polystyrene particles with similar sizes and apparent zeta potentials but distinct surface concentrations of carboxyl groups, as well as the separation of protein-coated from bare polystyrene particles.

In the proposed approach, the particles are exposed to salt concentration gradients generated in a double-junction microfluidic device, fed with low and high electrolyte concentration streams [1,2]. A steady-state salt concentration gradient is generated in the transverse (width-wise) direction, perpendicular to the flow. This leads to the accumulation of particles by diffusiophoresis and their migration either outward or inward due to a competition between particle diffusiophoresis and diffusioosmotic fluid flow at the channel walls. As the particles move across environments with varying salinity levels, their dynamics are affected by the sensitivity of their electrophoretic mobility –and consequently, their apparent zeta potential, which is proportional to it –to the local salt concentration.

For low and moderately charged particles, the magnitude of the apparent zeta potential, measured via electrophoretic light scattering, decreases monotonically with the salt concentration, in agreement with Gouy-Chapman theory. For highly charged particles, the dependence of apparent zeta potential on the salt concentration has a non-monotonic trend, due to the electric double layer polarisation and surface conductance. As a result, particles with the same surface charge sign but different charge magnitudes can exhibit opposite sensitivities of apparent zeta potential (and thus electrophoretic and diffusiophoretic mobility) to salt. By harnessing these effects, carboxyl-modified polystyrene particles with low carboxyl group concentrations can be separated with high efficiency from those with high carboxyl group concentrations [3]. Similarly, carboxyl-modified polystyrene particles coated with bovine serum albumin can be fully separated from bare particles [4].

This simple microfluidic approach, which relies on an easy to-operate device with no external

energy source, has discipline-spanning potential for the continuous separation of colloids distinguished solely by surface properties such as chemical composition, roughness, permeability, and heterogeneity, that influence the onset of surface conductance within the electric double layer and thus the sensitivities of their apparent zeta potential and diffusiophoresis mobility to the salt concentration. Our microfluidic strategy is particularly promising for point-of-care diagnostics, including bioparticle sensing, sorting, preconcentration, and analysis.

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Gas accumulation at liquid-liquid interfaces

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Dissolved atmospheric gases are typically assumed to have negligible influence on liquid behaviour because their solubility is considered too low to affect macroscopic properties. However, long-standing observations contradict this view: for example, it is well known that dissolved gases can accumulate at solid hydrophobic surfaces immersed in water;[1] the emergence of long-range hydrophobic interactions has been ascribed to nanobubble cavitation between two hydrophobic surfaces; [2] as the concentration of dissolved gases in an oil-in-water emulsion decreases, the average time of droplet coalescence significantly increases.[3,4]

In this work, we developed a precise droplet rise experiment that explores the effect of gas enrichment at oil microdroplets as a function of the gas content.[5] By using high speed video microscopy, we measure a faster rise velocity for microdroplets of gassed oil (silicone oil and hexadecane) released in ultrapure quiescent gassed water, than expected based on a no-slip boundary condition. We fit the rise velocity with a slip length that increases from a few □m for partially gassed liquids, to several hundred □m for fully gassed oils and water. Interfacial gas enrichment governs these effects, demonstrating that dissolved gases actively shape liquid–liquid interfacial transport beyond classical predictions. Negligible or negative slip was measured for fully degassed systems, and for contaminated systems, confirming that the liquid-liquid interface is immobilised when impurities are present.

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Rheofluidics: single-drop oscillatory rheology with microfluidics

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The measurement of frequency-dependent viscoelastic moduli is of paramount importance in many fields, from material science to biology, and is typically accomplished in bulk materials using commercial rheometers. The trend towards miniaturization in the biotechnology, manufacturing and chemical processing industries has motivated the extension of viscoelastic measurements to microscopic objects with well-defined shape and size such as droplets, vesicles, microcapsules, or even single cells. For instance, local mechanical probes such as AFM nanoindentation can be used to probe single-cell stiffness, and micropipette aspiration probes the interfacial properties of droplets and vescicles. Despite their versatility, these techniques are characterized by complex deformation geometries and a relatively low throughput, which makes them unfit to sample highly heterogeneous populations such as those typical of biological samples. To this end, novel microfluidic approaches have been recently developed to measure the stiffness of cells and droplets flowing through narrow channels. These approaches are well-suited for applications requiring a high throughput, but they lack the fine control of stress and strain required by quantitative mechanical measurements.

Here, we present a novel technique called Rheofluidics, which combines the high throughput of microfluidics with the versatility of traditional rheological probes. Like a stress-controlled rheometer, Rheofluidics measures the time-dependent deformation of droplets subject to a well-defined hydrodynamic stress, whose time evolution is controlled by the shape of the microfluidic channel in which the droplets are flowing. To validate this approach and to demonstrate the power of this technique, we study the linear and nonlinear rheology of oil droplets, hydrogel beads and lipid vesicles, extracting their viscoelastic properties with a throughput more than 1000 times higher than that of standard rheology.

Super-fast bullet bubbles transported in cylindrical capillaries under pressure-driven flow

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When transported by a pressure-driven flow in a cylindrical capillary, bubbles may exhibit very fast velocities. In this paper, we show that when the bubbles are largely deformable, that is, at large capillary numbers Ca, the velocity of the bubble can be larger than the maximal velocity of the flow that transports them. We call this regime "super-fast". However, the situation changes when inertial effects become significant at higher Reynolds numbers (Re), leading to a decrease in the bubble's relative velocity for sufficiently large values of the Laplace number, defined as $La = Re/Ca$. In this article, we uncover the conditions for which the super-fast regime exists: the deformability of the bubble is crucial, and hence the capillary number needs to be larger than a critical value, yet smaller than a threshold above which the bubble breaks up. The two limiting capillary numbers are presented in a phase diagram as a function of the bubble size and the Laplace number.

Contactless sampling from droplet arrays using electric fields

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Droplet microarrays provide a multitude of parallel compartments for (bio)chemical reactions and find various applications in fields such as high-throughput screening [1]. The ability to draw samples from these tiny reaction spaces is instrumental for monitoring assays or withdrawing liquid for further processing. We present a method for parallel sampling from droplet microarrays that is based on pulsed electric fields. The array is arranged between parallel capacitor plates to which a voltage is applied. As a result, droplets that are significantly smaller than the original droplets pinch off and are deposited on a surface facing the array substrate. In this way, a parallel contactless sample transfer from arrays with about one hundred droplets becomes possible. We consider aqueous droplets as well as droplets of dimethyl sulfoxide and quantify the mean and standard deviation of the transferred volume. In addition, we study the fluid mechanics of sample transfer using high-speed imaging. The high-speed images reveal a surprisingly complex sample transfer process. After switching on the electric field, a droplet from the array gets attracted to the upper surface, after which it bounces back. The sample transfer is finally achieved from an oscillating sessile droplet which gets in contact with the upper surface. We qualitatively explain this by electrohydrodynamic tip streaming through which charges are deposited that repel the sessile droplet.

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Interfacial dynamics of water droplets on liquid crystal films

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Liquid–liquid interfaces are central to open microfluidics, yet programming interfacial mass transfer and reading out droplet motion or flow history without embedded hardware or tracer particles remains challenging. We present a liquid crystal (LC) platform in which water droplets interacting with LC films –by impact or translation –control liquid–liquid transport while simultaneously generating optically readable textures that encode the droplet' s mechanical footprint and pathway [1-4].

Droplet impact on LC films provides a direct route to controlling water–LC exchange through the coupled roles of LC mesophase order and impact-driven interfacial deformation. By tuning the LC state and impact conditions, both the magnitude and direction of liquid–liquid mass transfer can be regulated within the same material system [3]. This impact-mediated mechanism also enables a droplet-based printing concept in which collision triggers the release of highly viscous cargo from an LC film onto an LC receiving surface, extending droplet impact approaches beyond conventional inkjet-compatible viscosity ranges.

Droplet motion can also write a persistent record of its pathway when the LC film is micropatterned [4]. In a hexagonal lattice of micrometer-scale pillars with homeotropic anchoring, confinement stabilizes elastic dipole–pillar pairs that form disordered polar textures under water. When a water droplet moves across this structured LC interface, interfacial shear realigns dipoles cooperatively into stable domains. The resulting textures encode droplet direction and trajectory, providing a label-free method to reconstruct microscale flow histories by polarized optical microscopy.

Overall, these results establish LC films as reconfigurable open microfluidic media in which droplet impact and translation enable programmable liquid–liquid transport and topological recording of droplet pathways, offering a versatile basis for adaptive printing, interfacial processing, and flow diagnostics.

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Additive fabrication technologies for multi-flow and 4D microfluidics

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The incorporation of functional and stimuli-responsive materials into complex three-dimensional (3D) architectures offers a powerful route for improving device performance. These strategies have found application in areas including optoelectronics, soft robotics, energy harvesting, and droplet microfluidics [1–3]. In particular, while droplet-based microfluidics enables precise control of fluid manipulation and reactions at the microscale, devices fabricated using standard approaches (such as photolithography, micromachining, milling, and soft lithography) can remain limited in their geometric complexity and in the practicability of integration of functional and smart materials. Additive manufacturing has stably emerged as a powerful set of fabrication technologies enabling the realization of microfluidic devices with complex and customizable geometries [3]. 3D printing allows for fast prototyping and scalable production of various microfluidic devices, including those capable of high-throughput emulsion generation. In addition, the emergence of four-dimensional (4D) printing technologies further expand the design capabilities by enabling printed components that can evolve over time, with shape or physical properties varying in response to external stimuli.

Here, ongoing work in our group on the development of microfluidic platforms for the generation and characterization of complex emulsions and biomedical platforms will be reviewed. Microfluidic devices incorporating flow-focusing geometries were fabricated using Digital Light Processing (DLP) 3D printing and employed to produce water-in-oil droplets [4], whose formation and assemblies were analysed in depth upon varying channel design. Current efforts focus on developing functional layers and systems, capable to respond to external stimuli such as light and magnetic fields, in a controlled way. Applications include light-responsive 3D-printed architectures [6], and magnetically actuated micro-structured elements, offering great potential for integration into advanced, adaptive microfluidic systems and associated biomedical platforms.

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Room 35

Bacterial motility effects on leaf surface exploration

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The aerial surfaces of plants support diverse microbial communities essential to plant function and survival.
The factors that determine where bacteria first attach and grow on plant leaves remain poorly understood. While microbial colonization of the phyllosphere—leaf, stem, and flower surfaces—has been widely studied, most work has focused on later stages shaped by biological and chemical interactions. Here, we isolate the physical contribution by recreating realistic leaf topographies in microfluidic devices and examining bacterial behavior in the absence of biological and chemical cues. We show that purely hydrodynamic interactions with the surface are sufficient to trap motile bacteria in epidermal grooves, guiding early spatial distribution.
Our microfluidic device, developed using two-photon nanolithography and PDMS molding, allows high-resolution imaging of bacterial behavior under controlled conditions.
We observed that motile bacteria, including *E. coli* and a native phyllosphere isolates such as *Pseudomonas syringae*, preferentially accumulate in grooves between epidermal cells.
E. coli and *P. syringae* cells were respectively 39% and 22% more likely to be trapped in grooves than on cell tops.
Over several hours, these regions also hosted significantly larger colonies, with E. coli colony area being 50% greater in grooves than on cell tops.
These findings, paired with mathematical models, illuminate how bacterial motility and hydrodynamic interactions shape microbial colonization patterns on plant surfaces.
More broadly, they contribute to our understanding of how topographical features influence microbiome assembly in living systems.
By enabling controlled, high-resolution observation, our method allows for a mechanistic understanding of biological phenomena that are otherwise difficult to disentangle in vivo.

Reduction of bacterial colonization on buckling-induced wrinkled surfaces under fluid shear

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Microbial colonization and biofilm formation drive infection persistence and the spread of antimicrobial resistance, particularly under flow conditions typical of medical and natural environments. Here, we combine spontaneously buckled wrinkled topographies with microfluidic platforms to investigate the adhesion of Pseudomonas aeruginosa and Staphylococcus aureus across shear rates of 0.4–200 s−1. Wrinkled surfaces with tunable wavelengths (0.5–20 μm) are fabricated and characterized using optical, atomic force, and scanning electron microscopy. Sinusoidal wrinkles with a 2 μm wavelength reduce bacterial colonization by over 70% when oriented perpendicular to flow, while folded wrinkles of 5 μm achieve more than 90% reduction across broader shear regimes and suppress biofilm formation by over 85% relative to flat controls. These topographies retain antifouling performance under pulsatile flow. This work demonstrates a scalable, chemical-free strategy for passive biofilm control through geometric surface design, enabling durable antimicrobial materials for biomedical and industrial applications.

Influence of Surface Chemistry and Substrate Material on Bacterial Attachment and Biomineralization in Microfluidic Flow Cells

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Microbially induced calcium carbonate precipitation (MICP) often uses ureolytic bacteria, such as Sporosarcina pasteurii (S. pasteurii), which hydrolyze urea and, in the presence of sufficient Ca^{2+}, promote calcium carbonate ($CaCO_3$) precipitation. MICP has been proposed or applied in engineering applications (e.g., soil strengthening, well sealing, hydraulic barriers), but controlling where and when ureolysis occurs remains challenging. MICP is a coupled process involving bacterial transport, attachment, growth, biofilm formation, nucleation, and $CaCO_3$ precipitation. Here, we use microfluidic flow cells with controlled surface chemistry to investigate the role surface properties, particularly charge and hydrophobicity, play in bacterial attachment, growth, and MICP. It is essential to have well-controlled conditions for microfluidics to be a valuable experimental method to determine system characteristics of MICP processes.

Two types of microfluidic devices were used to study the impact of surface properties, one made of stacked borosilicate glass/silicon/borosilicate glass and the other made using polydimethylsiloxane (PDMS). PDMS is considered hydrophobic and, at least initially, negatively charged while also being gas-permeable. Glass is generally hydrophilic, typically negatively charged, and gas impermeable. Surface modifications of glass flow cells established hydrophobic or positively charged surfaces through silanization with either 1H,1H,2H,2H-perfluorooctyltriethoxysilane (FOTS) to increase hydrophobicity or 3-aminopropyl-methyl-diethoxysilane (APMDES) to introduce terminal amine groups, yielding a net positive surface charge.

Bacterial attachment, growth and $CaCO_3$ precipitation in the flow cells were visualized using a combination of light and fluorescence microscopy involving SYBR Green® staining. Images were acquired before injection of the $CaCl_2$- and urea-containing cementation solution and again after ~80 pore volumes of cementation solution had passed through the microfluidic device.

Experiments conducted in PDMS flow cells with and without a nitrogen headspace demonstrated that oxygen had only a minor effect on bacterial attachment and $CaCO_3$ precipitation. In untreated glass flow cells, bacterial attachment and $CaCO_3$ precipitation were marginal. Cells remained mostly suspended and formed micrometer-sized, low-density flocs of cells, extracellular polymeric substances, and $CaCO_3$, which were largely flushed out of the flow cell. This likely reflects the net negative surface charge of both S. pasteurii cells and untreated glass under the prevailing pH (>8).

In surface-modified glass cells, bacterial attachment and $CaCO_3$ formation were significant and comparable to PDMS. Cells appeared immobilized and only a negligible number of cells were transported by the flow. In contrast to the micro-flocs in the untreated glass flow cells, cells attached readily, and dense, surface-attached biofilms formed in the APMDES-treated flow cells. Since APMDES-treated glass presents terminal amine groups and is net-positively charged, attractive bacteria–surface interactions are hypothesized to promote attachment, biofilm formation, $CaCO_3$ nucleation and aggregate growth. In FOTS-modified glass flow cells, hydrophobic interactions between the bacterial surface and the substrate may likewise enhance attachment and $CaCO_3$ precipitation.

In conclusion, the two glass surface modifications in these microfluidic models demonstrate that surface chemistry strongly influences bacterial attachment and, consequently, the characteristics of observable MICP behavior in microfluidics. These approaches support future microfluidic studies and emphasize the importance of controlling the surface properties, and when needed, strategies to enhance bacterial attachment in larger scale applications.

A printable OECT for simple integration in capillary-driven diagnostic assays

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In 2003, the World Health Organization summarized key requirements for diagnostic tests through the ASSURED criteria (affordable, sensitive, specific, user-friendly, rapid, equipment-free, delivered), which continue to guide the design of accessible, reliable point-of-care (POC) technologies. Advances in microfluidics and portable instrumentation have accelerated the adoption of POC technologies in clinical care, supporting faster diagnosis and disease monitoring, as well as in food safety and low-income contexts where laboratory access and long turnaround times can limit effective access to healthcare.

Microfluidic "labs-on-a-chip" enable precise handling of microliter-scale samples under laminar flow and reduce reagent consumption, making them attractive for a wide range of POC applications, where efficient fluid management is crucial for delivering reliable results and minimizing sample volume. Although the silicon polymer PDMS has long dominated microfluidic fabrication, limitations in scalability and fabrication costs motivate a transition toward alternative substrates that are more compatible with scalable production and have lower environmental impact.

Paper and nitrocellulose are particularly attractive for POC solutions, since they are low-cost, disposable, and intrinsically microfluidic via capillary flow. Nitrocellulose-based lateral flow assays (LFAs) are widely used rapid tests, yet traditional colorimetric readouts suffer from limited sensitivity and subjective interpretation, especially at low analyte concentrations. Signal-enhancement approaches using nanolabels can improve sensitivity and provide quantifiable outputs in LFAs, but often increase assay complexity and costs.

Organic electrochemical transistors have stood out as highly sensitive analytical devices for biosensing, owing to their operation at low voltages and their intrinsic compatibility with aqueous environments. Among organic mixed ionic-electronic conductors employed as OECTs active materials, PEDOT:PSS is extensively adopted because of its high performance and suitability for solution-based processing. In parallel, advances in additive manufacturing and increasing attention to scalable and sustainable fabrication have guided the search for alternatives to conventional fabrication routes. Dispense printing is a non-contact printing strategy that has recently been applied to rapid prototyping of printed electronics, including sensors and OECTs on flexible polymeric substrates. Despite this progress, nitrocellulose and lateral flow assay membranes have not yet been investigated as OECT substrates, likely due to their porosity and mechanical fragility.

Motivated by the need for affordable quantitative sensing integrated with cellulose microfluidics, we developed a printable organic electrochemical transistor (OECT) on nitrocellulose, enabling straightforward integration of an analytical transistor into cellulose-based biochemical assays. By combining hydrophobic barriers with a solid-state electrolyte interface, the device separates a wet sensing region from a protected dry active area, enabling capillary-driven sample delivery while preserving transistor stability. With a maximum transconductance of approximately 4 mS, the device exhibits a LOD of 0.01 mM for dopamine when integrated into a capillary-driven nitrocellulose strip. Requiring low operating voltage and consequently reducing power requirements, the system supports integration into portable diagnostic platforms, while the generated currents in the milliampere range simplify signal acquisition and processing. The proposed strategy aims to complement capillary-driven, paper-based POC platforms with an electronic output, supporting scalable, low-cost POC diagnostics aligned with ASSURED principles.

Towards Engineering High-redox-potential Enzyme Variants using a Confocal Absorbance-activated Droplet Sorting (cAADS)

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Directed evolution (DE) is a process of iterative variant generation, screening, and selection to find enzyme variants with improved or specialized functional properties. Advances in droplet-based microfluidics have further expedited DE allowing for rapid screening of large enzyme libraries [1]. Enzyme-expressing genes can be compartmentalized with a fluorogenic substrate inside picoliter-scale water-in-oil emulsions for a high-throughput (~2 kHz) fluorescence-activated droplet sorting based on the enzyme performance. However, fluorogenic assays for enzymatic systems are limited.

To address this limitation, absorbance-based detection assays, which represent a larger spectrum have been reported [1, 2]. A range of different chromogenic substrates can be tested using these techniques, unlocking previously unaccessed sequences. Nevertheless, absorption is weak at the micron scale and droplet-interface-induced scattering decreases detection sensitivity. Measurements are therefore often performed at a cost of increasing droplet sizes or acquisition times, which limits throughput to <1 kHz. Moreover, studies to date have been mostly focused on absorbance-based identification and enrichment of enzymes with improved activity or thermostability (e.g., phenylalanine dehydrogenase [2]). However, redox potential, a key enzyme property that governs electron transfer (i.e., oxidation-reduction kinetics), remains largely unexplored via DE.

Here, we address the challenges associated with signal sensitivity using a custom confocal Absorbance-Activated Droplet Sorting (cAADS) system [3]. The illumination and detection optics of the confocal imaging platform are spatially conjugated and focused on the same diffraction-limited spot, allowing precise absorbance detection of droplets inside a microchannel and rejecting out-of-focus scattered light.
The increased sensitivity allows us to conduct absorbance measurements at ultrahigh throughput (5.4 kHz) from droplets as small as 10 pL, and sorting of 50 pL droplets at frequencies up to 2.6 kHz with 99% efficiency. The methodology is demonstrated by enrichment of active Bilirubin Oxidase (BOD) variants. Ultimately, we can screen libraries of ~1 million variants per day using chromogenic substrates as specific redox potential markers. As a proof of concept, a bacterial BOD with a low redox potential (+0.34V vs. Ag/AgCl at pH 7 [4]) will be used as a model with the objective to identify a BOD with a redox potential ~+0.5V vs. Ag/AgCl at pH 7 that can be efficiently used in biofuel cells.

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Population-Resolved Analysis of Lipid Nanoparticle Sterile Filtration Enabled by Microfluidic Flow Control

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Lipid nanoparticles (LNPs) are central to RNA- and gene-delivery therapeutics, and are increasingly produced using microfluidic mixers. However, LNP sterile filtration during downstream processing remains inherently challenging because LNP dimensions are comparable to the pore size of sterilizing-grade membranes (100 - 200 nm). In this regime, LNP passage and retention are governed by particle softness, deformability, and population heterogeneity leading to non-classical filtration that is not adequately captured by rigid-particle models. Conventional bulk characterization techniques, such as dynamic light scattering (DLS), provide limited insight into how population heterogeneity governs early membrane interactions and fouling behavior.

Here, we present a microfluidic framework that combines (i) controlled LNP synthesis, (ii) microfluidically enforced constant-flux filtration using a commercial sterilizing-grade syringe filter, and (iii) population-resolved LNP characterization by asymmetrical flow field-flow fractionation with UV and multiangle light scattering (AF4-UV-MALS). LNPs were produced by mixing a lipid-in-ethanol stream with an acidic aqueous stream in a microfluidic staggered herringbone mixer. AF4-UV-MALS analysis of LNPs formed under identical flow conditions revealed distinct population structures depending on cargo loading: unloaded LNPs form a predominantly single size population, whereas PolyA-loaded formulations exhibit an additional subpopulation of larger particles.

Microfluidic, pressure-driven flow control enabled precise low-flux operation (<50 LMH) and real-time transmembrane pressure (TMP) monitoring. This low flux operation creates a transport-controlled regime in which early-stage particle-membrane interactions can be probed before flux-induced cake compaction. In this way, a conventional sterilizing-grade filter is effectively turned into a microfluidic testbed for soft-particle filtration.
Under identical constant-flux conditions, PolyA-loaded LNPs exhibited a systematically stronger TMP increase than unloaded LNPs, indicating higher hydraulic resistance that cannot be explained by bulk-averaged size metrics alone. AF4 -UV-MALS analysis reveals that the minor, loading-induced large-particle subpopulation disproportionately contributes to an increased filtration resistance.

By directly linking microfluidically controlled filtration dynamics to population-resolved particle structure, this work shows that particle heterogeneity, rather than mean particle size, governs LNP filtration behavior. More broadly, it demonstrates how microfluidic flow control can be coupled to macroscale filter geometries to isolate and quantify early-stage, population-driven fouling phenomena. The presented approach offers a general microfluidic framework for mechanistic analysis of nanoparticle–membrane interactions, with implications for the design of microfluidic filtration modules and for the integration of sterile filtration in microfluidic LNP production and downstream processing.

Light-Sheet Imaging Flow Cytometry for cells and single-particle scanning

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Light-sheet fluorescence microscopy (LSFM) uses planar illumination to selectively excite a thin optical section of the sample, enabling three-dimensional imaging with reduced photobleaching and phototoxicity [1]. Imaging flow cytometry (IFC) enables high-throughput analysis of large cell populations but is limited to two-dimensional images and relatively low spatial resolution [2]. The combination of LSFM with flow-based imaging provides a possible approach for achieving high-throughput single-cell analysis while preserving optical sectioning and high resolution [3]. The system incorporates multi-wavelength laser excitation via single-mode fiber delivery and multiband detection, enabling multicolor imaging and co-localization analysis of cells and bioparticles in flow.

We present a single-objective imaging system that integrates LSFM and IFC to enable automatic sample scanning with effective background suppression through optical sectioning. This system is designed to acquire high, near-isotropic images of biological samples in flow. The system exploits a microfluidic chip incorporating a 500 μm right-angled prism that generates a thin, focused light sheet orthogonal to the flow direction, while samples flow axially toward the detection objective. Near-isotropic resolution is achieved through axially scanned light-sheet excitation, synchronized with the rolling shutter of a scientific CMOS camera, via a tunable lens.

System performance was evaluated using fluorescent microbeads and biological samples spanning sizes from hundreds of nanometers to tens of microns, including single particles and cells such as macrophage. We present volumetric imaging of fixed and live cells under continuous flow with effective optical sectioning.

We further apply the system to the study of bioparticles, including extracellular vesicles (EVs). Conventional flow cytometry lacks spatial information, hindering unambiguous assignment of fluorescence signals to individual bioparticles, while imaging flow cytometry is limited by strong fluorescence background fluorescence given by the out of focus particles, particularly when studying EVs at high concentrations. This limits the study to one single particle at a time. The proposed light-sheet imaging flow cytometer enables parallel acquisition of multiple particles per frame, targeting 100 samples/frame.

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Oral contributions
Tuesday 19/05, 15:00 - 18:40

Auditorium

Mechanical regulation of cell adhesion to the blood vessel wall

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Blood cell - vessel wall interactions are critical both for the flow of red blood cells, and for the control of white blood cell adhesion to the walls (e.g. at a site of inflammation). However, the biochemical and mechanical cues governing their tight regulation are still poorly understood, in particular because of the challenge of non-invasive investigation of cell-wall short-range interactions under flow in a complex environment. Using a home-built platform combining advanced biochemical surface functionalization, microfluidics and high-speed interferometric imaging [1], we have investigated experimentally the role of the softness of the vessel wall outer layer in the regulation of blood cell homing under flow. This brush, named glycocalyx and mainly composed of charged exopolysaccharides, is both thick (up to 1µm) and extremely soft (down to a few Pa in compression modulus). We have demonstrated that these peculiar mechanical properties induce a short-range repulsion of non-interacting cells, in good agreement with the theory of elastohydrodynamics that accounts for the effect of substrate deformation under hydrodynamic forces. We have thereby provided the first experimental evidence of this "soft biolubrication" effect at play at small scale [2]. On the other hand, we have shown that these same mechanical properties are a critical factor that stabilizes the homing of cells bearing specific receptors (CD44) for one of the main compound of the glycocalyx, hyaluronan (HA). Furthermore, we have shown that the mechanical barrier created by the glycocalyx screens interactions with surface receptors involved in the adhesion cascade in a CD44-dependent manner. Our results thus highlight the role of the glycocalyx as a gatekeeper for the adhesion to the blood vessel wall.

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Microfluidic Micropipettes: A Chip-Based Platform for Membrane Mechanics at Scale

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The mechanical properties of lipid membranes play an important role in diverse processes, ranging from cellular processes like endocytosis and cytokinesis to cell-cell interactions as well as for diseases like cancer or blood disorders and vesicle based drug delivery systems. Established techniques to probe these mechanics, like micropipette aspiration or optical tweezers however, typically suffer from low throughput. Alternatively, bulk methods like rheometry or scattering techniques primarily provide ensemble-averaged mechanical readouts, such as overall stiffness. These limitations make it challenging to obtain statistically robust measurements of membrane mechanics with a single vesicle resolution.

Here, we introduce a microfluidic platform designed to overcome these limitations, by incorporating hundreds of micropipette like confinements on a single chip. This design enables parallel trapping followed by mechanical characterization of giant unilamellar vesicles (GUVs) in a single experiment. This strategy significantly increases the throughput compared to the sequential testing of one vesicle at a time in conventional techniques. The forces acting on the membrane can be precisely tuned via the applied flow rates, which press the vesicle against the constriction. To quantify the flow, single particle tracking as well as particle image velocimetry was used on tracer particles. Furthermore, the custom geometries of the constrictions, allow for well-defined, controllable mechanical testing. The platform also enables in situ exposure of GUVs to membrane-active compounds, such as surfactants or organic particles, facilitating direct observation of their impact on membrane mechanics. Switching the external medium multiple times between buffer and the substance of interest can be used to probe the dynamic uptake coupled to the resulting change of the mechanics, which further allows to quantify the reversibility of these effects.

This high-throughput approach allows the measurement of membrane mechanics and detects the dynamic response towards compounds of interest. Our platform opens the possibility for systematic screening of libraries, providing a quantitative framework to study the interactions between solutes and their impact on membranes.

A Microfluidic device for single-cell analysis of Leukemia T cell growth and proliferation

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We develop a mother machine-like microfluidic device specifically designed to track the proliferation of single T-cells via live-cell microscopy.
Although numerous microfluidic setups have been developed to study cell proliferation at the single-cell level, most of them are optimized for bacteria, which do not require particularly demanding growth conditions, or for use on adherent cells, which are easier to restrain.
We present a device designed to track the proliferation of suspension cells, featuring an array of microchannels that trap cells, without altering their physiological growth conditions, easing their monitoring while allowing for controlled growth conditions. Each microchannel, whose geometry has been optimized through CFD simulations, allows a single cell to enter and proliferate while maintaining a continuous flow of nutrients, ensuring long-term monitoring over multiple generations.
We show the advantages of this system in characterizing the processes of cell growth and division. Indeed, through time-lapse microscopy it is possible to identify and characterize each individual cell within the channels, measuring key parameters such as cell size at different cell cycle stages and duplication time.
In particular, we first test the device reproducing and extending the results we found in a previous work, where we showed that proliferating human Jurkat T cells exhibit symmetric volume division. Then, we use the mother machine to follow the growth and division of human primary T cells at single cell level over multiple generations by measuring: (i) duplication time, assessing the effect of growth in isolation; (ii) cell size dynamics, from birth to mitosis, to determine their growth mechanisms; (iii) the effect of shear stress on cell growth by varying the inclination of trapping channels.
Overall, our device design can be easily adapted and can be used to study different cell types and sizes while maintaining the same high trapping efficiency.

Droplet microfluidic multistep platform for high-throughput active selection of cellulolytic microorganisms.

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Background and aims: The selection of cellulolytic microorganisms, together with the ability to bridge the genotype-to-phenotype gap, is essential for biotechnological applications such as biofuel production, lignocellulosic waste valorisation, and soil bioremediation. Conventional screening methods based on cultivation on selective solid media are typically time-consuming, low-throughput, and biased towards fast-growing taxa, thereby overlooking many valuable candidates such as slow-growing or rare strains. To overcome these limitations, we encapsulated single cells in picolitre droplets, each functioning as an individual bioreactor for clonal growth, and subsequently screened them using the PicoSorter, a novel microfluidic platform enabling high-throughput and simultaneous microfluidic operations for the selection of cellulose-degrading cultures.

Methods: The PicoSorter integrates picoinjection with absorbance-activated droplet sorting (AADS) on a single microfluidic chip, enabling the execution of multistep optical assays in droplet format. Individual microbial cells are encapsulated in 50 pL droplets containing carboxymethylcellulose (CMC) and Congo red dye, which binds to cellulose polymers. Following off-chip incubation and injection of MOPS/NaCl buffer into the droplets, the microcultures were sorted based on their transmittance signal, as droplets encapsulating cellulose-degrading strains exhibited measurable absorbance changes.

Results: The PicoSorter integrates several key components within a compact double-layer design, including a droplet reinjection chamber, spacing channels, a buffer picoinjection section with a first set of electrodes, a serpentine mixing region, channels for high–refractive index oil, and a sorting section equipped with a bias oil channel and a second set of electrodes. Altogether, these features enable accurate transmittance detection from droplets and ensure optimal sorting performance.
Initial tests to quantitatively assess CMC concentrations revealed a correlation between droplet transmittance signals and CMC content. Validation using a binary microbial community composed of Cellulosimicrobium cellulans (cellulolytic) and Escherichia coli (non-cellulolytic) demonstrated successful detection of microbial cellulolytic activity after dynamic incubation in Bushnell Haas droplets supplemented with CMC and Congo red. The PicoSorter achieved sorting rates of up to 0.6 kHz and high enrichment factors, indicating that our approach effectively enriches cellulolytic microorganisms.

Conclusions: The PicoSorter addresses the limitations of traditional microbiological isolation protocols, opening new opportunities for both academic research and biotechnological applications. Its versatility allows for broad applicability across different microfluidic assays. Beyond the proposed optical assay, the PicoSorter can also be used to detect fast reactions involving substrates that leak from droplets into the oil phase or between droplets. This method represents significant progress in microbial screening and enrichment, and the developed device can be applied across diverse areas of modern environmental microbiology, including biofuel production, bioremediation, and sustainable industrial processes.

Hydrodynamic Manipulation of Cells for Label-Free Viability Assessment in Microchannels

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Cell viability is a fundamental parameter in biomedical research, as it reflects the functional state of a cell population by integrating key aspects of cellular health, including membrane integrity, metabolic activity, and proliferative capacity [Khalef et al.(2024)]. It plays a critical role in diagnostics and pharmacological studies, supporting the investigation of pathological processes, therapeutic efficacy, and host–pathogen interactions [Archambaud et al.(2024)].

Conventional viability assays are predominantly label-based, relying on chemical markers. Although accurate, they are invasive, often limited to end-point measurements, require complex instrumentation, and are ill-suited for integration into portable platforms [Madorran et al.(2025)]. These limitations motivate the development of non-invasive, on-chip systems able of evaluating cell viability while preserving sample integrity and reducing operational complexity.

This work presents a novel mechanobiological approach for label-free, on-chip cell viability assessment based on hydrodynamic manipulation in microfluidic channels. The proposed paradigm exploits the hypothesis that cells respond to hydrodynamic mechanical stresses according to their biological condition. In more details, cells are subjected to oscillatory hydrodynamic forcing, which, maintaining them out of equilibrium with respect to the surrounding fluid, generates characteristic motion signatures reflecting key biophysical properties, including cell size, density, deformability, and membrane integrity [IT Patent n.102025000005856].

In this context, an automated, label-free, image-based system was developed to extract these hydrodynamic signatures using a Digital Particle Image Velocimetry (DPIV)-based algorithm [Torrisi et al.(2023)]. Initial assessments successfully differentiated viable and apoptosis-induced yeast cells from inert particles based on their hydrodynamic response [Cutuli et al.(2025), Biomed. Signal Process. Control]. While inert particles passively follow the imposed flow, viable cells exhibit stronger mechanical opposition, whereas apoptotic cells display intermediate behaviour consistent with partial loss of mechanical integrity. Further validation across different cell lines, including HL60 cells, demonstrated sensitivity to unhealthy states induced by exposure to 5-azacytidine for 24h and 48h. Longer treatment times resulted in progressively weaker opposition to flow, consistent with gradual degradation of cellular biophysical properties. These results were benchmarked against standard biochemical viability assays (MTT), confirming the reliability of the proposed approach.

Despite its accuracy, the DPIV-based analysis is computationally intensive, thus limiting real-time applicability. To overcome this limitation, a lightweight deep learning model (APVnet) was developed to extract cell hydrodynamic signatures in real-time, achieving millisecond-scale inference with a minimal memory footprint [Cutuli et al.(2025), under review in Eng. Appl. Artif. Intell.]. Finally, to enhance portability, a smartphone-based reflective microscope was designed and prototyped to adapt the methodology to point-of-care scenarios and resource-limited environments, where access to standard, bulky and expensive, optical microscopes may be constrained. The system leverages the smartphone’ s built-in flash and a reflective module to enable bright-field imaging using native components. Benchmarking against a conventional microscope showed no statistically significant differences in estimating cellular dynamic responses ($p\text{-value} \in [0.4553, 0.5597]$), supporting its suitability for on-chip viability assessment outside standard laboratory settings.

Overall, the proposed platform combining hydrodynamic manipulation, label-free optical monitoring, AI-enhanced real-time analysis in either lab-microscopes and smartphone-based solution, represents a significant step toward automated cell viability assessment in microfluidic environments, with strong potential for next-generation point-of-care applications.

Direct, high-throughput linking of single-cell imaging and gene expression

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Single-cell technologies have become a crucial tool for investigating biological systems by enabling detailed characterisation of cellular heterogeneity. Beyond measurements of individual modalities such as the transcriptome or proteome, multi-omic approaches capturing multiple molecular identities from the same cell, have provided further insights into dissecting complex biological processes. However, in contrast to these advances in molecular profiling, the physical dimension such as cell size, shape, and mechanics is almost entirely lacking. Here, we present a high-throughput microfluidic platform, im-seq, to directly connect single-cell imaging with gene expression.

To date, efforts to link optical phenotype data with sequencing readouts at the single-cell level have been limited in throughput, relying on imaging cells either under static conditions or in fully deterministic flow-based systems. Static, array-based approaches are inherently limited in throughput and do not scale easily. Deterministic flow-based systems are more scalable, but the need for highly precise control limits their analysis rate.

Im-seq overcomes these limitations by deliberately harnessing randomness, rather than enforcing determinism. We generate millions of multimodal barcodes by encapsulating random combinations of hydrogel beads, each of which is uniquely identifiable both optically and by sequencing, in droplets. This approach enables simultaneous capture of physical phenotypes and transcriptomic profiles from individual cells in flow, combining the versatility of imaging-based characterisation with the scalability of droplet sequencing workflows. Currently, im-seq can record linked imaging and mRNA sequencing data for single cells at a rate of hundreds per cell per minute. We have applied im-seq to investigate the relationship between gene expression and physical phenotype in haematopoietic cell lines, demonstrating the power of large, multimodal datasets in interrogating cellular function.

We thus provide a general and scalable strategy for multimodal single-cell characterisation at high throughput, enabling gene expression–phenotype studies not feasible under existing workflows. Moreover, the implementation is relatively simple, requiring only a commercially available microscope and syringe pumps, without complex liquid handling such as valves and controlled cell/droplet dispensing. We anticipate that im-seq will open new avenues for studying the relationship between cell phenotypes and gene expression programmes, and for leveraging multimodal signatures to understand cell behaviour in health and disease.

Room 35

Microfluidic control of nutrient microgradients and lag phases in spatially confined bacterial monolayers

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Nutrient availability and physical constraints strongly regulate bacterial growth in microscale environments. In spatially structured systems, confinement, fluid flow, and consumption by the bacterial population generate nutrient microgradients that lead to heterogeneous growth and spatially organised metabolic states. Bacteria adapt to multiple carbon sources either through co-utilisation, where nutrients are consumed simultaneously, or through hierarchical uptake, in which bacterial cells preferentially metabolise the most favourable carbon source and only later switch to alternative substrates. This sequential strategy gives rise to lag phases—transient non-growing adaptation periods whose duration depends on nutrient composition and strain. While lag phases are well characterised in bulk cultures, their spatial organisation and coupling to microscale nutrient transport remain poorly understood.

Here, we use microfluidic family machine devices combined with time-lapse fluorescence microscopy to investigate how nutrient microgradients, lag phases, and spatial confinement jointly shape bacterial growth in non–well-mixed environments. These microfluidic chips enable the controlled growth of *E. coli* monolayers under precisely defined geometrical constraints and steady nutrient flows, allowing direct manipulation of the bacterial physicochemical microenvironment.

We developed a physical model describing carbon diffusion and hierarchical uptake in spatially confined populations under controlled nutrient influx. The model predicts a trade-off between growth on less favourable carbon sources—promoted by microgradients—and the duration of lag phases, which together determine population-level growth dynamics.

Microfluidic experiments with fluorescent *E. coli* strains quantitatively validate the model predictions, revealing how nutrient microgradients imposed by flow and confinement spatially regulate metabolic adaptation at single-cell resolution. By combining microfluidic manipulation, fluorescence imaging, single-cell image analysis, and modelling, this work establishes a quantitative framework to study microbial growth and adaptation in structured environments, highlighting the power of microfluidics to dissect microbial physiology at the microscale.

Stronger at the seams: Antibiotic stress enhances amino acid leakage and cross-feeding

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Microbial communities perform essential ecosystem functions, from driving biogeochemical cycles to aiding digestion in the gut. Their metabolic diversity creates both redundancy and complementarity. Over time, some microbes discard costly biosynthetic pathways (as described by the Black Queen Hypothesis), becoming auxotrophs reliant on cross-feeding nutrients from neighbours. In turn, cross-feeding of metabolites like amino acids becomes critical for community stability. Widespread antibiotic use perturbs these communities and promotes resistance, yet its effects on interspecies metabolic interactions remain poorly understood.

We investigated how antibiotics influence nutrient sharing using a microfluidic co-culture platform on family machine chips. Prototrophic E. coli capable of synthesising all essential amino acids were paired with different single-gene knockout auxotroph strains, each requiring a specific amino acid. These cocultures were grown on-chip under sub-minimum inhibitory concentration (MIC) gradients of a ribosome–inhibiting antibiotic to impose sub-MIC stress. The microfluidic device enabled precise control of antibiotic levels and real-time observation of cell growth. We continuously monitored growth dynamics and amino acid exchange between strains under various antibiotic conditions. We hypothesised that antibiotic stress would disrupt internal metabolic processes, reducing amino acid synthesis from prototrophs and thus weakening cross-feeding.

Expectedly, without antibiotics, prototroph–auxotroph pairs stably coexisted via mutualistic cross-feeding of leaked amino acids (allowing auxotroph growth without external supplementation). However, contrary to expectation, introducing moderate antibiotic stress actually enhanced metabolic exchange. Under sub-MIC antibiotic concentrations, auxotrophs grew more robustly likely due to increased amino acid leakage from prototrophs. Inhibiting protein synthesis in prototrophs likely caused intracellular amino acid buildup, leading to greater release of these metabolites into the environment. This heightened nutrient release strengthened cross-feeding interactions and supported auxotroph proliferation despite the stress.

Our findings reveal a counterintuitive consequence of antibiotic exposure; the reinforcement of metabolic dependencies within microbial communities. Rather than simply suppressing growth, sub-MIC antibiotics can tighten cooperative links by amplifying nutrient sharing. This insight suggests that antibiotics may paradoxically stabilise certain community interactions even as they inhibit individual cells. Such effects highlight the complexity of antibiotic impacts beyond resistance, potentially shaping host-associated microbiomes by helping pathogens or commensals survive therapeutic stress or even invade stable microbiome communities. Overall, our study underscores the importance of accounting for community-level responses when evaluating antibiotic strategies or microbiome interventions.

Novel Microfluidic Systems to Simulate Multiscale Bacterial Transport Through a Contaminated Aquifer

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Subsurface microbial communities play critical roles in the attenuation of anthropogenic contaminants, as well as global biogeochemical cycling. It has been established that bacterial partitioning (*i.e.,* whether the organism is sediment attached or planktonic) may drastically affect the levels of metabolic activity and rates of bio-degradation. At the highly contaminated Field Research Center, sediment-attached cells account for upwards of 90% of total biomass but exhibit considerably lower metabolic activity (on a per cell basis). Due to inherent sampling challenges, accurate prediction of the distribution and partitioning of microbial communities within the subsurface remains largely unresolved. This, combined with the shift in partitioning driven by environmental perturbation, underscores the need for tools capable of measuring field relevant attachment/detachment kinetics.

Microfluidics allow for the direct observation of attachment kinetics, which at larger scales are obscured by microbial growth, the destructive nature of sediment sampling, and the inability to capture data over relevant timescales. However, to date, microfluidic devices have largely lacked field relevance, limiting their applicability to larger scales. To directly observe attachment kinetics while minimizing microbial growth effects and preserving field relevance, we developed silicon microfluidic devices derived from field-based, micro-computed tomography. Multiple device geometries have been produced, iteratively incorporating relevant surface charge, roughness, tortuosity, and pore-throat distributions, all of which could substantially impact partitioning. Developed microfluidic platforms also offer the advantage of allowing direct comparison with more traditional mesoscale transport approaches, such as packed bed reactors (PBRs). Fabricated devices have been used to investigate the transport of the gram-negative, GFP expressing, field isolate *Stenotrophomonas GW821-FHT01H02 (H02)*, a highly ubiquitous bacterium in both groundwater and sediments. Here, we compare bacterial transport behavior at field-relevant velocities across these scales and demonstrate that incorporating attachment and detachment rates measured at the microscale improves the prediction of transport times in mesoscale models.

Analysis of other environmental variables (*e.g.,* pH, DO, and heavy metals) have previously failed to explain in-situ partitioning of *H02.* Our results indicate that small changes in seepage velocity substantially change *H02* attachment kinetics. An increase in velocity from 7 to 14 mm/hr resulted in an approximate 3x reduction in bacterial attachment, mirroring results from the PBR studies. Under the high flow condition, an equilibrium detachment rate of 8%/hr was observed, while no appreciable detachment was observed under the low flow condition. Additionally, we combined image-processing techniques with computational fluid dynamics modeling to examine how localized fluid shear influences bacterial attachment. Results indicate a greater tendency for cells to attach to the shadowed side of columns, with this preference becoming more pronounced with increased velocity.

Finally, to examine how community context may reshape these dynamics, we introduced an additional RFP-expressing bacterial field isolate into the devices *(Pseudomonas N2E2). N2E2*, an efficient biofilm former, altered the relationship between velocity and *H02* partitioning, allowing *H02* to form biofilms at velocities exceeding its typical tolerance. Together, these findings establish a cross-scale framework in which microscale measurements and hydrodynamic mapping inform mesoscale transport predictions, advancing mechanistic understanding of microbial attachment and partitioning in porous media.

Multiscale modelling of biofilm extracellular matrix using ‘resistance-in-series’ effect

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Biofilms are complex communities collectively organized by microbial cells embedded within an extracellular matrix. The analysis of biophysical interactions [1] between matrix environment and microbial cells [2] is an active topic in the field of bacterial multicellularity. Modelling of these extracellular environmental cues driving the biofilm formation require a revisit to fundamentals of biochemical transport phenomena and the underlying mechanistic actions. Over the past four decades, numerous standard mathematical models [1, 3, 4] have been developed to describe different stages of biofilm formation and predict substrate mass transport as a function of macroscale parameters such as biovolume and thickness of biofilm. However, they generally do not account for the interplay between microbial cell surface and the surrounding polysaccharides (PS) due to lack of any rate kinetics data at the microscale length scales [1, 2]. Our laboratory has recently developed expertise in leveraging super-resolution confocal microscopy to analyze distinct morphologies of extracellular environment in early-stage bacterial biofilms. We have thereby developed a new modelling platform based on emerging biofilm morphologies driven by the heterogeneous matrix environment.

We proposed a continuum particle geometry to theoretically conceptualize microbial cell (cell as core) to be surrounded by capsular matrix (polymeric capsule as shell), forming a “cell-capsule” structure. Our multiscale transport model [5] uses different particle packing arrangements that mimic the heterogeneous matrix structure. Considering initial adhesion of *Staphylococcus sp.* to the inert substratum as a case study, distinct structural features recorded recently in our laboratory clearly suggests capsule formation around the bacterial cell. By exploiting the above spatial distribution of bacterial capsule varying over time, cell concentration is determined using classical reaction-diffusion analysis. Different reaction kinetic expressions representing PS production and cell growth are coupled to cell diffusion in two-dimensional continuum space. Using a known history of the cellular characteristics in the inoculating feed with fixed cell diameter (ca. 1 μm), simulated versions of microcolonies of varying capsule thickness along the distance from the substratum are investigated.

Physiologically relevant estimates of particle flux provided preliminary evidence on how capsule structures are spatially arranged to produce an equivalent ‘resistance-in-series’ effect. Using the cell-capsule approach [5], we previously observed that the decrease in oxygen flux at steady-state conditions is likely due to the radially distributed patterns in biofilm morphology. By providing the quantitative data on these structured features with continuous time, an interesting trend of thick capsule formation as a potential survival mechanism to reduce the rate of cellular adhesion is proposed. Therefore, the above findings potentially complement ongoing experimental campaigns on how cell-scale morphogenesis controls the early-stage biofilm formation.

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Insights Into Flow-Driven Platelet Dynamics and Thrombus Morphology

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The flow-induced morphology of platelet aggregates is emerging as a key mechanobiological indicator of thrombotic risk and coagulation disorders. Thrombus formation is a dynamic process in which flowing platelets adhere to a pro-thrombotic surface, aggregate, and grow, progressively reshaping the vessel wall topography and altering the local hemodynamic environment. While shear forces and hematocrit are known to influence platelet transport and adhesion, their coupled role during thrombus growth, which introduces evolving geometrical heterogeneities, remains poorly understood. The aim of this study is to elucidate how shear flow and hematocrit jointly regulate thrombus evolution under flow by combining blood-on-chip experiments with resolved numerical simulations.

Microfluidic experiments were performed in collagen-coated blood-on-chip devices using human blood at varying hematocrit and wall shear rate. Real-time platelet adhesion and aggregation were imaged using high-resolution confocal microscopy. Advanced 3D image analysis enabled a quantitative and detailed characterization of thrombus morphology and structural features associated with thrombus growth and stability. Resolved three-dimensional simulations of blood flow in microchannels featuring a sinusoidal wall were used to investigate how aggregate-induced surface heterogeneities reshape local hemodynamics and platelet margination. The sinusoidal wall was used as a simplified model of mural platelet aggregates observed in microfluidic experiments. Blood was modeled as a suspension of deformable red blood cells and nearly rigid platelets. A combined lattice-Boltzmann, immersed-boundary, and finite-element approach was employed to resolve cell dynamics, cell-free layer formation, and platelet margination near the sinusoidal wall.

Microfluidic experiments show that increasing hematocrit enhances platelet surface coverage promoting the stabilization of platelet aggregate adhesion to the wall. In contrast, shear rate primarily controls aggregate elongation and alignment along the flow direction. Numerical simulations reveal that aggregate-induced surface heterogeneities generate spatial variations in cell-free layer thickness and local shear rate. Platelet margination is mainly governed by hematocrit and is most effective where the local cell-free layer thickness matches platelet size. Shear rate, instead, plays a secondary role in platelet margination but strongly modulates local shear rate gradients around the aggregate, suggesting a dominant influence on platelet adhesion dynamics. Overall, this work presents a quantitative microfluidic framework to study thrombus evolution under flow, providing a direct link between platelet aggregate morphology, local hemodynamics and blood-cell transport.

Combining inertial pre-enrichment and immunomagnetic sorting for CTC isolation from blood

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The isolation of Circulating Tumor Cells (CTCs) directly from blood by liquid biopsy could lead to a paradigm shift in clinical cancer care by contributing to earlier diagnosis and the development of personalized treatment [1]. Nevertheless, CTCs must be recovered with high recovery rates and high purity within a short processing time, and through a user-friendly workflow. These specific requirements have so far limited the use of CTCs in clinical studies. The main issues lie in efficiently separating CTCs from white blood cells (WBCs), as they are present at ultra-low concentrations in blood (approximately 10 CTC and 10^7 WBCs for 1mL of blood). Several microfluidic methods have been developed to isolate CTCs from other blood cells, either by exploiting biological properties differences, a sorting approach complexified by the heterogeneity of cell surface markers, or by relying on physical properties differences such as size, deformability, and dielectric properties. While this latter approach enables high-throughput, label-free processing, the strong overlap in physical properties between CTCs and other blood cells limits its potential of separation. As a result, although numerous systems have been developed, there is currently no device that fully meets the required performance criteria in terms of CTC recovery [2] .

In this work, we aim at combining these two separation strategies on a single microfluidic chip, to benefit from the high purity of this combination, while minimizing the risk of CTC loss associated with sample manipulation.

First, we developed a compatible pre-enrichment module based on size discrimination using Dean vortices. The spiral-shaped channel generates secondary flows perpendicular to the main stream, resulting in size-dependent particle trajectories. Different spiral geometries were tested, varying the width, aspect ratio, or cross-sectional shape of the channel to achieve cell separation at a flow rate compatible with the downstream immunomagnetic function. The optimal design allowed for effective separation between white blood cells and CTC-mimicking cells (HCC827, MDA, MCF7, PC3) at a flow rate of 50 mL/h [3].

This immunomagnetic sorting function implements an array of ferromagnetic microtraps to capture remaining WBCs, magnetically labeled [4]. It has been improved to operate at compatible flow rates with high WBC capture efficiency, by optimizing channel section, labeling percentage, WBC concentration and chip-to-magnet distance. Capture performances were assessed with magnetically labeled WBCs from whole blood sample. The immunomagnetic chip demonstrates high capture rates, achieving over 94% WBC capture at 30 mL/h and maintaining strong efficiencies at high flow rates, with more than 80% capture at 120 mL/h. These results, showing high capture performances for both microfluidic functions at comparable operating flow rates, are promising for their integration onto a single chip, enabling CTC sorting with high recovery, purity, and robust overall performance.

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Mimicking sap transport in vascular plants using microfluidics

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Sap transport in vascular plants is ensured by a complex network of two "microfluidic channels", xylem and phloem, coupled by a biological membrane. Evapotranspiration drives a flow of almost pure water through the xylem, from the roots to the leaves. In parallel, the sugars produced in the leaves by photosynthesis generate a large turgor pressure allowing their transport in the phloem towards the roots, shoots and fruits. The size of this system makes it well-suited for investigation in controlled systems, such as those provided by microfluidics. This work investigates the osmotic driven transport of sugars in the phloem, known as the Münch mechanism. A microfluidic chip was engineered, consisting of two parallel channels coupled by a hydrogel membrane permeable to water, with a molecular weight cut-off (MWCO) of a round 1 kg/mol and able to resist up to 10 bar of hydrostatic pressures [1]. The hydrogel was photo-crosslinked *in situ* using a maskless photolithography device projecting collimated UV patterns. Solutes like dextran (10 kg/mol) induce stable osmotic flows in the channels (M>MWCO). In contrast, transient flows are observed with solutes of smaller molecular weights because of their permeation through the membrane. We show that the dynamics of this transport can be described by a model coupling forward osmosis and solute permeation under dilute conditions, which was verified experimentally to and allowed to estimate the membrane reflection and diffusion coefficients for a wide range of solutes [2]. In the future, our objective is to expand this study to higher solute concentrations, as found in the phloem of plants, and couple the current device to an artificial xylem in which the water is at negative pressure, involving the integration of supplementary hydrogel membranes.

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Temporal signature of Shear Stress Regulates Renal Epithelial Mechanotransduction

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Mechanical forces generated by fluid flow are essential regulators of epithelial physiology in vivo, particularly in renal tubules where cells experience sustained yet dynamically varying fluid shear stress (FSS). While the influence of shear magnitude on epithelial behavior has been extensively studied, how temporal variations in shear independent of spatial heterogeneity and geometric complexity modulate epithelial responses remains poorly understood. In particular, it is unclear how epithelial cells respond to continuous versus time-varying mechanical inputs when subjected to identical mean shear levels.

Here, we investigate renal epithelial mechanotransduction in a microfluidic channel specifically designed to impose the same average FSS under two distinct flow regimes-continuous and intermittent Swith static culture serving as a baseline control. The curvature-free channel architecture ensures spatially uniform shear, enabling isolation of temporal mechanical effects without confounding contributions from geometry-induced gradients. The device is fabricated using a hybrid workflow combining 3D-printed molds with soft-lithography-based PDMS replication, allowing rapid prototyping with precise control over channel dimensions and flow uniformity.

Live-cell calcium imaging is employed as a sensitive and rapid readout of mechanosensitive signaling, enabling quantitative comparison of intracellular calcium responses across flow regimes and exposure durations. Our results show that, despite identical mean shear magnitudes, intermittent flow induces more heterogeneous and spatially non-uniform calcium activation compared to continuous flow, with a larger fraction of cells exhibiting elevated calcium responses. In contrast, continuous shear produces a more uniform but comparatively attenuated calcium signaling profile across the epithelial monolayer. These differences persist across exposure durations, indicating that temporal modulation of shear influences both the magnitude and variability of mechanosensitive signaling.

These signaling responses are complemented by fixed-cell analyses of actin cytoskeletal organization, tight junction integrity (ZO-1), and nuclear morphology. Intermittent FSS is associated with increased cytoskeletal remodeling and altered junctional patterning relative to continuous shear, suggesting differences in tension distribution and cell-cell coupling. Additionally, flow-induced changes in nuclear shape and orientation are observed under intermittent loading, pointing to a coupling between temporal mechanical cues and nuclear mechanotransduction.

We hypothesize that intermittent FSS permits partial mechanical recovery between loading phases, limiting full adaptation to shear and thereby sustaining mechanosensitive signaling relative to steady exposure. Importantly, these effects emerge in the absence of spatial shear gradients, demonstrating that temporal dynamics alone are sufficient to regulate epithelial mechanotransduction. Overall, this study establishes a minimal yet mechanistically informative framework for probing time-dependent mechanical regulation in epithelial systems, with direct relevance to microfluidic kidney-on-chip platforms incorporating controlled, time-varying flow cues.

Oral contributions
Wednesday 20/05, 10:00 - 13:00

Auditorium

Microfluidic Conditioning for Studying Learning and Adaptive Dynamics in Bacteria

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Biological systems are a unique class of active matter in which individual units —living cells— consume energy to process information and adapt to changing environments. Investigating such adaptive responses requires experimental platforms capable of delivering precisely controlled, time-dependent stimuli while enabling long-term, high-resolution observation at the single-cell level. Here we present a microfluidics setup to study history-dependent responses in bacterial cells and to probe how intracellular networks encode and process environmental information.

We focus on how gene regulatory and signaling networks enable cells to integrate past stimuli and modulate future responses. To this end, we track gene expression using fluorescent reporters in individual bacteria confined within two-dimensional microfluidic chambers. The microfluidic device enables fine control of the extracellular environment by dynamically modulating medium composition (e.g., antibiotics, nutrients) with well-defined spatial and temporal profiles. This simple and versatile setup allows rapid switching, periodic stimulation, and long-term conditioning protocols while maintaining stable growth conditions and optical accessibility. By combining controlled microfluidic perturbations with quantitative single-cell measurements, we can systematically explore how environmental histories shape phenotypic states and collective behavior.

Overall, this work highlights microfluidics as a powerful tool for interrogating non-equilibrium biological dynamics and adaptive processes in living matter. Beyond its biological implications, the approach provides a general framework for designing microfluidic experiments that couple precise environmental control with dynamical readouts, enabling studies of memory, robustness, and information processing in living matter.

Tracking microbial interactions, metabolic and population dynamics in paired microfluidic chambers

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Microbial interactions are fundamental to the assembly and function of microbiomes. Yet, our understanding of how specific interaction mechanisms can drive broader ecological outcomes and population dynamics remains limited. We describe the use of a microfluidic geometry that enables direct population pairing, cell observation and tracking, as well as quantitative metabolite detection, to monitor interactions in bacteria associated with the leaf microbiome. This approach enabled the identification of key metabolic mediators, revealing recipient-specific patterns of carbon substrate and cofactor complementation. By linking these patterns to emergent dynamics observed between pairs of bacteria, we identified metabolically driven feedbacks that could lead to a variety of ecological outcomes –from outcompetition to coexistence characterized by oscillating population abundances. Our results provide a detailed mapping of metabolic mechanisms to emergent population trajectories among environmental microbes, which help inform strategies for designing microbiomes with desired steady states.

A Microfluidic Toolbox to Study Bacterial Surface Exploration

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Understanding how physical and chemical cues shape the organization of bacteria on surfaces is essential, particularly in the context of biofilm formation and antibiotic resistance. Biofilms arise when bacteria colonize solid substrates, a process that occurs across a wide range of biological tissues and synthetic materials. In the opportunistic pathogen *Pseudomonas aeruginosa*, early surface exploration driven by twitching motility plays a key role in the development of three-dimensional colonies and is closely linked to virulence.
Here, we present a set of approaches that allow precise control over the physico-chemical properties of surfaces inside microchannels, while enabling in situ imaging of bacterial behavior. Using these platforms, we investigate how surface exploration by *P. aeruginosa* is influenced by substrate rigidity [1], topography, fluidity or polarity [2] —parameters that modulate motility and thus tune colony formation. Overall, this work provides a versatile experimental toolbox for the microfluidics and biophysics communities, offering new ways to probe the mechanisms underlying bacterial surface exploration.

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Microfluidics and polariton chemistry

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Microfluidics focuses on the manipulation of fluids at the micrometer scale, enabling precise flow control, transport, and reaction conditions. This technology has gained increasing importance in biomedical and bioanalytical research, leading to microfluidic systems capable of reproducing physiologically relevant flow and transport phenomena in cellular microenvironments [1] or efficient cell and microparticle separation [2]. In chemical research, diffusion-dominated mixing in microfluidic reactors enables highly controlled reactions, improving yields, selectivity, and safety, particularly for hazardous processes [3].

In catalytic chemistry, an emerging and rapidly evolving field is polariton chemistry, which introduces new opportunities for controlling chemical reactivity through light-matter interactions [4].

Polariton chemistry relies on the strong coupling between molecular vibrational or electronic transitions and the electromagnetic modes of an optical cavity, leading to the formation of hybrid light-matter states known as polaritons, which can alter potential energy surfaces and modify reaction pathways [5].

Recent studies have demonstrated that energetic coupling between vibrational levels of reactants and an optical cavity, known as vibrational strong coupling (VSC), can accelerate reaction rates, suppress competing pathways, or enhance selectivity toward specific products in ways considered unconventional within the framework of classical catalysis. These effects are particularly attractive when combined with microfluidic environments, where confinement, precise flow control, and efficient heat and mass transfer already play a critical role. The integration of polariton chemistry with microfluidic systems thus opens new avenues for reaction control, enabling non-thermal and non-chemical strategies to steer catalytic processes toward desired outcomes [6].

In this context, we present the potential and challenges of this research field by investigating ester deprotection reactions under VSC in Fabry–Pérot microfluidic cavities, monitored via product absorption in the UV–Vis spectral range. We introduce an analytically sound method for extracting reliable kinetic information from absorption spectra, specifically designed to mitigate errors caused by cavity interference fringes. The method allows for tracking and correcting kinetic data for cavity relaxation processes during the reaction and provides rigorous guidelines for VSC characterization, including extraction of the true, loss-corrected Rabi splitting, confirming its expected dependence on the square root of the concentration. By applying rigorous data processing based on pseudo-first- or second-order kinetic equations, a marked improvement in the rate constant was observed. This established methodology provides a reliable analytical tool essential for future spectroscopic investigations of VSC, adaptable to other reactions and operating conditions.

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Operating regimes and design rules for microscale surface ion conduction sensing

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Electrokinetic and electrochemical sensors have several advantages over lab-based assays. In many cases, sensors are more rapid, with fewer reagent additions and sample pretreatment steps. Sensors that leverage the influence of a target recognition event on charge transport are among the most sensitive because they translate localized target binding into a change in a system-scale property.

Ion concentration polarization (ICP) is an electrokinetic phenomenon forming an ion depletion zone (IDZ) and an ion-enriched zone (IEZ) at opposing ends of a perm-selective membrane (ICP) or an electrode (fICP) when an electric field is applied across it. The low ionic conductivity of the IDZ leads to a strong (>10-fold) local enhancement of the electric field and the formation of concentration and electric field gradients at the IDZ boundary. The non-linear migration of ions and non-linear effects in these gradients have been leveraged for focusing and continuous separation of charged species, and more recently, for sensing applications.
An ICP based microscale ion conduction sensor consists of a microfluidic channel containing packed beds of microbeads. Hybridization or binding of a target to a packed bed of microscale beads modulates the surface charge, and in turn, the conduction of electrolyte counterions along the bead surfaces. Binding or hybridization of a target, therefore, leads to changes in a current-voltage curve (CVC) measured across the bed, including shifts in the slope and in the onset voltages where non-linear processes begin to influence ion transport. Our results indicate that this strategy is broadly relevant to label-free sensing of nucleic acids, virions, proteins, and small molecules, in both the presence and absence of pre-enrichment. Findings from these studies introduced important fundamental questions regarding the impact of analyte charge and size, ionic strength, bead surface charge, and device dimensions on the sensitivity and specificity of the surface charge-based sensors. Here, we present a systematic study and a range of operational regimes for microscale surface ion conduction sensing for bioanalytical applications.

Room 35

Bacterial swimming in a complex model fluid: implications for mucus barrier penetration and in-vitro microfluidic systems

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In nature, many biological fluids that host or block bacterial populations, such as mucus, exhibit non-Newtonian rheology. To investigate the spatial exploration of Escherichia coli, a model multiflagellated bacterium, in such environments, a tunable motility medium based on Carbopol was employed. Increasing the concentration of soft carbomer grains transitioned the medium from a Newtonian fluid to a yield-stress gel. Bacterial motion was tracked using a novel 3D Lagrangian tracking system within a simple microfluidic chamber, enabling the collection of extensive individual trajectories for both a wild-type and a smooth-swimming mutant. Key motility properties —swimming velocities, persistence time, and diffusivity—were characterized up to the point where a complete motility barrier forms at high Carbopol concentrations, arresting bacterial swimming via a biobarrier (Urra et al., 2025).

Our results demonstrate that local mechanical heterogeneity and resistance to penetration can override the innate run-and-tumble navigation strategy. This leads to a "medium-assisted" exploration scenario, characterized by forced directional switching and stop-and-go kinematics, which is closely linked to the mechanical flexibility of the flagellar bundle. These dynamics, precisely quantified using microfluidic platforms, provide a fundamental framework for understanding bacterial motility in biologically relevant complex fluids like mucus. Mucus, a biopolymer hydrogel primarily composed of mucins, shares critical rheological features with carbopol gels, notably viscoelasticity and a microscopic yield stress. The transition observed in our controlled microfluidic environments—from altered swimming to a motility barrier—directly mirrors the challenge pathogens and commensals face when penetrating the mucosal layer. The emergent stop-and-go motion and medium-assisted reorientations are likely fundamental mechanisms for navigating the poroelastic network of mucins, where flagella constantly interact with obstacles and regions of varying stiffness.

Consequently, this work establishes that the physical properties of the environment are as crucial as biological steering in determining bacterial dispersal in structured fluids. The critical dependence on flagellar bundle flexibility suggests that adaptation to mucus may involve not only biochemical sensing but also the evolution of motility apparatuses with specific mechanical proficiencies to overcome the rheological barrier.

By providing a tunable model system, this work also offers a versatile platform for in vitro microfluidic studies. The ability to precisely control rheological properties via Carbopol enables the recreation of key tissue-like conditions—such as the mucosal layer—within microfluidic chips. This facilitates the controlled observation of bacterial motility, barrier penetration, and response to mechanical gradients under conditions that mimic biologically relevant complexity. This approach can enhance the design of experimental platforms that simulate hostile or protective environments, with direct applications in infection studies, probiotic research, and the development of strategies to modulate bacterial colonization at mucosal interfaces.

Transport of swimming cells by chaotic advection in porous media

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Transport of microorganisms is an integral part of many natural and industrial processes, such as energy storage, bacterial infections, and soil remediation. With almost half of the living microorganisms living in porous media, the interplay between bacterial motility, and flow-induced transport identifies the niche selection and colonization. To do so, cells need to explore the widest space possible to increase their chance of finding a suitable condition. This is while, increasing the cell density will increase the chance to occupy a space. For survival, environmental cells need to find a balance between dispersion and densification.

Previous researches have shown the densification of cells in 2D porous media. However, the environmental habitat of bacteria is a 3D space, which recently has been shown that has a chaotic dispersal behavior. This would raise the question on how does chaotic advection (i) smears the densification pattern and (ii) dictates the lateral dispersal of cells?

Here, we explore experimentally the various regimes over which chaotic advection and cell motility control both the fine structure of densification and the large-scale transport of swimming cells in porous media flows. To do this we use a versatile 2.5D micromodel which combines the precise control of the microstructure allowed by standard lithography techniques while emulating the hydrological hallmarks of 3D porous media flows. Surprisingly, we find that densification and dispersion can coexist—cells maintain local aggregation even as chaotic advection drives maximal lateral spreading. These findings provide new insights for predicting microbial colonization in subsurface flows and optimizing bacterial transport in bioremediation and bioreactor design.

Microscale Insights into Depth Filtration - The Role of Internal Surface Roughness

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Deep bed filtration is widely applied in bioprocessing, virus filtration, and water purification to remove small impurities, such as particles or virus fragments. However, more needs to be understood about the parameters that influence particle capture and deposition. Detailed simulations and microfluidic filtration experiments with straight pores have been widely investigated, yet realistic membrane porosity features such as pore gradients and roughness have not been addressed in detail. The internal membrane morphology is assumed to have a strong effect on filtration performance. Therefore, this study introduces a new microfluidic membrane mimicking device (MMD) and methodology that analyzes spatio-temporal particle collections in a deep bed filtration MMD with gradually decreasing pore size toward the retentate side. The design allows us to systematically tailor an internal filter surface roughness to investigate its influence on differently sized soft particles and the consequences for filtration performance, in particular, particle capture. Optical investigation and quantitative evaluation show enhanced particle–pillar interactions for increased roughness. This results in a reduced penetration depth and reduced particle breakthrough. The modes of capture or filtration phenomena, such as pore blocking, bridging, or dendrite formation, differ significantly between smooth and rough membrane filter structures. In the case of rough inner filter surfaces, those phenomena lead to a less distinct decrease in volumetric flow, allowing a longer filtration process. The microfluidic study offers a detailed investigation of how microscale phenomena influence the filtration process. The results provide a fundamental understanding of microscale filtration effects based on roughness and, hence, motivate a tailoring of the internal membrane filter surface according to the filtration problem at hand.

Microfluidic Emulsion Metamorphosis into Giant Unilamellar Vesicle

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A fundamental component of biological cells is their membrane which is constituted by lipidic bi-layer contributing to their mechanical properties and transfer processes. Similarly, Giant Unilamellar Vesicles (GUVs) are micrometer-sized (1-100 µm) droplets within a bi-layer of arranged lipids, making them an ideal candidate for quantitatively studying cell behavior, specifically ion transport through the cell membrane.

In this context, monodispersity of the GUVs, control of the bi-layer composition and throughput are key parameter in their synthesis. Here, we present a microfluidic approach using double emulsions of water in oil in water as templates for the GUVs.

With a non-embedded co-flow-focusing configuration for microfluidic droplet generation, called RayDrop, we generate in water octanol-shell (oil phase) double emulsions of controlled thickness by tuning the flow-rates during generation. For thin shells (1-2 µm), such objects eventually collapse at rest. By using a lipid-octanol mixture instead, we observe that octanol de-wets after few minutes and separates from the droplet, leaving an extra-thin shelled object.

We show that the templates can remain stable for several days and that de-wetting of the octanol from the shell can be triggered by external medium change. We explore the influence of dilution of the templates suspension caused by the medium change. We also investigate the effect of octanol-saturation in the outer medium surrounding the templates and its effect on de-wetting. We then rationalize the drainage dynamics leading to de-wetting in the context of the lubrication theory.

Regarding the extra-thin shelled object resulting from the de-wetting, preliminary mechanical and osmotic tests show a membrane-like behavior. Moreover, With the adequate shell composition, one can also induce ion transport phenomenon through said membrane. In addition, using the RayDrop, we access a large range of template sizes.

The above make this microfluidic approach a straightforward and simple strategy towards the fabrication of monodisperse size-controlled GUVs with customizable membrane-composition.

Clogging of non-circular particles in a 2D hopper

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Flows of particles through constrictions occur in a broad range of situations, both in nature and in the industry. When the orifice is sufficiently small, clogging can occur, leading to an intermittent or permanent interruption of the discharge. Over the past two decades, extensive work has been conducted to understand the physics and statistics of clog formation. Most of these studies were performed using cylindrical or spherical model particles. However, particles in practical situations often exhibit complex shapes that affect their interactions and flow behavior. In particular, faceted and non-convex particles can interact through multiple contacts, which can strongly influence the probability of clog formation.

Here, we experimentally investigate the role of particle geometry in clogging by studying the flow of dense suspensions of non-Brownian gear-shaped and square-shaped particles in a 2D microfluidic hopper. The particles are fabricated using a photo-lithographic projection method. A PDMS channel is filled with a UV-curable polymer solution and exposed to a UV beam, resulting in the formation of a solid particle. The shape and size of the fabricated particle is controlled by placing a mask on the path of the UV beam. By repeating the fabrication process, the microfluidic channel is filled with hundreds of identical particles. All the particles are then densely packed using a Quake-valve, before being discharged through the channel constriction.

By measuring the average number of particles escaping the channel before a clog forms, we find that interlocked and face-to-face contacts significantly influence the clogging probability. Through systematic shape variations, we show that the clogging probability of gear-shaped particles varies non-monotonically with the fraction of particle surface available for interlocking. This behavior, also reported in other systems of non-convex particles, arises from a competition between the ease of interlocking and the strength of the interlocked contacts. We further demonstrate that the scaling of clogging probability with the outlet-to-particle size ratio deviates from the scaling law reported for circular particles. This deviation is explained by the resistance to rolling due to the multiple contacts between neighboring particles. Experimental results are compared with numerical simulations to gain further insight into the underlying arching dynamics.

Engineering Evaporation in Microfluidic Circuits: From Vapor and Temperature Mapping to Predictive Design Rules

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Evaporation remains a pervasive yet often underestimated source of error in microfluidic platforms, particularly as liquid volumes approach the nanoliter and sub-nanoliter scale. In life-science workflows such as sample preparation, biochemical assays, and thermal cycling, even modest evaporative losses can compromise volumetric accuracy, alter solute concentrations, and limit experiment duration. While evaporation has been extensively studied in open systems (e.g., droplets and thin films) and in simple confined geometries such as single microchannels, evaporation in realistic microfluidic circuits—comprising interconnected chambers, wells, and channels—remains poorly quantified and difficult to predict.

In this work, we present a combined experimental and theoretical investigation of evaporation in microfluidic circuits spanning simple single-path geometries to complex, multi-path networked designs. Using controlled heating experiments, we quantify evaporation rates of liquid plugs with volumes ranging from approximately 1 μL down to 100 nL. To directly probe vapor transport within the devices, we employ fluorescence-based thermo-sensitive coatings (TSCs) that enable spatial mapping of temperature and relative humidity inside the microfluidic chips during evaporation. These measurements provide a direct visualization of vapor gradients inside confined microfluidic circuits.

Guided by these observations, we develop a diffusion-limited evaporation model based on Fick's law and a lumped-element framework. Each channel, chamber, or well is treated as a resistance to diffusion, allowing complex circuits to be reduced to equivalent series and parallel resistance networks, analogous to electrical circuits. This approach yields a single effective diffusion length that governs the evaporation rate, even for geometrically complex designs. Analytical expressions are derived for both uniform channels and non-uniform geometries, including pyramidal wells relevant to multi-well plate architectures.

Across all investigated designs, the measured evaporation rates are accurately predicted by the model, with deviations below 7% for most geometries. Importantly, we find that, within the isothermal and diffusion-limited regime explored here, evaporation is insensitive to contact-line position or pinning at chamber edges. Instead, the dominant control parameters are the global vapor-diffusion pathways defined by channel length, cross-section, depth, and auxiliary leakage routes. For larger chambers, localized condensation can transiently enhance vapor gradients and increase evaporation, an effect that is captured qualitatively by the resistance framework.

Beyond explaining evaporation losses, this study establishes practical design rules for engineering microfluidic circuits with predictable evaporative behavior. By framing evaporation as a network-level transport problem rather than a local interface phenomenon, the presented approach opens new opportunities for evaporation-aware microfluidic design, improved assay robustness, and controlled evaporation strategies in applications ranging from life-science automation and diagnostics to wearable and portable microfluidic devices.

Bridging Continuous and Digital Microfluidics: On-Demand Extraction of Preconcentrated Species

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Ion-exchange membranes enable selective ion transport by allowing counterions to pass through while blocking co-ions, giving rise to ion concentration polarization (ICP) under an applied electric field. This effect creates distinct regions of ion depletion and enrichment near the membrane-electrolyte interface. At the edge of the depletion zone, where sharp conductivity gradients form, a balance between convection and electromigration facilitates the continuous concentration of dilute analytes such as bioparticles. ICP-based methods have been widely used to enhance the sensitivity of bioanalytical systems, often relying on ion-permselective membrane pairs and applied voltages to trap preconcentrated plugs [1]. However, such techniques require continuous flow and voltage to maintain the concentrated zones, complicating extraction of discrete concentrated droplets for further analysis [2]. Digital microfluidics (DMF) offers precise control of discrete droplets through patterned electrodes, enabling key operations like merging, splitting, and extraction in lab-on-a-chip devices. While efforts have been made to merge continuous and discrete microfluidics, current hybrid systems often rely on oil phases or fixed geometries that limit functionality, particularly for extracting concentrated droplets. Addressing this gap, the present study presents a hybrid platform for interfacing a continuous-flow microchannel with a DMF platform via a stagnant fluid region. This configuration enables the transfer of preconcentrated biomolecules, formed by ICP, into individually addressed droplets while maintaining their concentrated state, paving the way for efficient sample isolation and downstream processing in hybrid microfluidic systems. The experimental findings were corroborated by both simulations and analytical modeling, demonstrating qualitative consistency.

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Oral contributions
Wednesday 20/05, 15:00 - 18:40

Auditorium

Oxygen Gradients shape Cross-Feeding and Drive Emergent Spatial Organization in Gut Commensal Bacteria

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Microbial interactions unfold within environments structured by physical transport and chemical gradients, yet most mechanistic studies rely on well-mixed systems that obscure how metabolism and ecology influence one another. To examine how spatial heterogeneity reshapes microbial interactions in the gut, we investigated how oxygen gradients affect a canonical polysaccharide-mediated interaction between *Bacteroides thetaiotaomicron, a strict anaerobe and primary degrader of dietary starch*, and *Escherichia coli*, a facultative anaerobe incapable of complex polysaccharide hydrolysis.

By combining microfluidic experiments, Rna-seq, genetic perturbations, isotope tracing, and reaction–transport modeling, we show that the ecological outcome of this trophic interaction depends strongly on environmental context. In well-mixed cultures, *E. coli* exploits metabolites released during polysaccharide degradation by *B. thetaiotaomicron*. Under spatially structured conditions that generate crypt-like oxygen gradients, however, this interaction is fundamentally transformed. The two species segregate into complementary spatial niches: polysaccharide degradation by *B. thetaiotaomicron* supports *E. coli* growth in oxygenated regions, while E. coli respiration locally depletes oxygen, thereby expanding the anoxic habitat available to the anaerobe.

Together, these results show how coupled metabolic and environmental feedbacks convert a simple cross-feeding interaction into a facilitative and dynamic niche-construction process, illustrating how spatial structure reshapes microbial interactions.

Simultaneous real-time imaging of oxygen gradients and microbial community spatial organization in confined environments

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The ecological functioning of subsurface environments—including soils, lake and marine sediments, and aquifers—is strongly controlled by redox processes mediated by diverse microbial communities inhabiting porous media. The composition and spatial organization of these communities arise from the coupled effects of pore-scale geometry, fluid flow, microbial interactions, and microscale geochemical heterogeneity. Understanding how these factors jointly shape microbial community structure is essential for predicting subsurface ecosystem functioning and its role in biogeochemical cycling. However, progress is hindered by the limited accessibility of opaque porous matrices, which complicates direct observation of microbial dynamics and their local physicochemical environment.

Microfluidic approaches provide a great opportunity to address these challenges. Specifically, microfluidic devices that mimic the pore structure and flow conditions of natural soils and sediments are being used as powerful tools to investigate the dynamics of microbial colony formation. When combined with fluorescently tagged microorganisms, microfluidics enables non-invasive, real-time visualization of microbial colonization, self-organization, and interactions under well-defined physicochemical conditions. In parallel, microfluidic integration with transparent optical sensors, such as optodes and luminescent nanoparticles, has been shown to allow mapping of microscale physicochemical gradients, e.g., oxygen concentrations, driven by microbial activity coupled with advection and diffusion processes.

Despite these advances, the simultaneous imaging of microbial community dynamics and geochemical gradients remains technically challenging. Most existing luminescent sensors emit in the visible part of the light spectrum, overlapping spectrally with commonly used fluorescent protein tags, thereby preventing concurrent detection within a single microfluidic platform.

Here, we present a sensing microfluidic platform integrating a transparent oxygen optode emitting in the near-infrared (NIR) region of the spectrum. Spectrofluorometric characterization shows that this NIR-emitting optode avoids spectral overlap with widely used fluorescent reporters, enabling simultaneous, high-resolution imaging of different microbial populations and oxygen dynamics at the microscale.

We demonstrate the capabilities of this platform by examining the colonization of sandy sediment under flow by an aerobic microbial community and the resulting development of microscale oxygen gradients. The community comprises two bacterial strains with contrasting cell morphologies—elongated and rounded—engineered to express mScarlet and GFP, respectively. Our results reveal distinct spatial organization patterns and cluster morphologies between the two strains, consistent with morphology-dependent colonization under flow. Moreover, the data suggest that distinct cell morphologies differentially influence local oxygen gradients, highlighting a direct link between microbial physical traits and microscale redox dynamics.

Beyond this proof of concept, the proposed approach is broadly applicable to a wide range of microbial ecological applications. Spectral analyses suggest that up to four microbial populations could be imaged simultaneously alongside oxygen dynamics, and ongoing advances in NIR luminescent sensor chemistry are expanding the range of measurable physicochemical parameters. Moreover, the platform is compatible with complementary microscale analytical techniques, such as SIMS or synchrotron-based methods, enabling integrated investigations of microbial activity, geochemical gradients, and mineral transformations relevant to subsurface ecosystem functioning.

Mechanical interactions between bacteria and grains in a model soil

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Bacteria are well-recognised as having a beneficial effect on the structure of soil in that they favour soil aggregation and increase soil pore connectivity. Soil opacity renders its dynamic imaging at the microscale difficult, so our knowledge on bacterial activity in soil largely results from end-point measurements. Microfluidic chambers enable the dynamic observation of bacteria in model porous environments at fine temporal and spatial resolutions. Microfluidic-based investigations have revealed some of the biophysical principles governing bacterial growth in porous media, including under fluid flow, amongst grains of sand-mimicking shape, and in packed soft particles. However, the mechanical interactions between growing bacterial colonies and rigid moving grains, akin to sand grains, remain unexplored. Here, we incorporate grain mobility into the microfluidic toolkit. We form mobile divided media in microfluidic chambers by polymerising hydrogel grains (approx. 40 µm in diameter and height) in situ and let Green Fluorescent Protein (GFP)-expressing Bacillus subtilis colonise the interstitial space between the resulting hydrogel grains. We observe grain movement along the axes of bacterial density gradients. Grains move at velocities of up to a few µm/h for several hours. We make the novel observation of a "granular respiration" where pores occupied by dense bacterial colonies widen before partially shrinking back. We link the direction of movement of grains to bacterial growth kinetics and propose a simple theoretical model linking bacterial growth pressure to the elastic deformation of the grain network to interprete the observed displacements. The balance between the time of bacterial division and the time of growth-pressure relaxation into the adjacent pores determines whether the substrate is compressed or relaxes. That relaxation time scales with the effective viscosity of the colony inside the divided medium, and determining how that viscosity varies with colony growth is a key objective of our current work. This work provides a first insight into the effect of bacterial growth-induced pressure onto divided media and suggests a mechanism by which bacteria could mechanically modify soil structure.

Microfluidic investigation of dairy fouling dynamics

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Understanding fouling formation and preventing its consequences are crucial in the dairy industry to improve the efficiency of unit operations and the quality of the products. To date, most of the literature associated dairy fouling development with the heat-induced denaturation of whey proteins, which leads to their aggregation and progressive adsorption onto surfaces. Nevertheless, this hypothesis has a major flaw: fouling also occurs at temperatures below the denaturation threshold (≈ 70℃). This is the case, for example, in falling-film evaporators, used in the dairy industry for vacuum concentration prior to spray drying. These considerations highlight the need to explore the impact of other process parameters, besides temperature, to fully understand fouling. However, shedding light on fouling dynamics is extremely challenging with the current experimental methods, given the size and structure of dairy equipment. Therefore, a real-time observation of the phenomenon is still lacking, especially at the micron scale.

To address these crucial open questions, we employed an original rheofluidic approach to investigate the role of shear rate in the formation of dairy deposits. Our outcomes showed how, at sub-denaturation temperatures, shear not only increases the amount of whey protein deposits but also promotes their structural complexity. Encouraged by these results, we also performed direct observations of the fouling growth in microfluidic devices replicating the typical environmental and flow conditions of falling-film evaporators. These observations enabled the discrimination between the simultaneous and competitive mechanisms governing protein aggregation in the bulk solution and those occurring at the surface. This preliminary study also allowed for a first characterization of the kinetics of deposit growth.

The miniaturization approach therefore proves to be effective in providing a better overview of the microscopic mechanisms leading to fouling propagation and of the factors influencing this phenomenon. This represents a first step toward the development of more comprehensive predictive models and innovative mitigation strategies.

Microfluidic Lab-on-chip technologies for extracellular vesicle enrichment and detection

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Introduction
Liquid biopsy and the use of selected biomarkers from biological fluids, greatly enhance an increasingly patient-centered approach, avoiding invasive tests and tissue biopsies. Extracellular Vesicles (EVs) act as a snapshot of the cells from which they originate and as a repository of crucial information, facilitating the direct extracellular transfer of proteins, lipids, and miRNAs/mRNAs/DNAs. Despite EVs show great potential as powerful biomarkers, their isolation, and characterization remain challenging. Lab-on-Chip (LoC) technologies represent innovative tools to overcome the limits of standard methods and we aim to implement these technologies for EV investigation.

Methods
We design customizable LoC devices based on the experimental needs, starting from fluid dynamic simulations and using microfabrication techniques (micro-milling and 3D printing). We develop two different LoCs exploiting the microfluidic approach and electrochemical detection for EV enrichment and characterization. Large- and small-EVs were isolated by ultracentrifugation and characterized by high-resolution flow cytometry, western-blot, and transmission electron microscopy.

Results
We developed an in-flow device using molded-plastic substrates assembled on a glass slide to create a microfluidic chamber for dynamic cell culture. Oral squamous carcinoma (OECM-1) and neuroblastoma (SH-SY5Y) cell lines were seeded into the device to allow a complete replacement of the medium in the dynamic condition within 2,4,8 and 24h at controlled flow rate (10 µl/min). We observed increased EV production and decreased EV size in dynamic versus static condition. Moreover, we realized a biosensing platform for EVs electrochemical characterization. Functionalized microelectrodes were used for Differential Pulse Voltammetry measurements to build a calibration plot considering different EVs membrane and cargo proteins (Flotilin-1, CD9, CD81, CD63 and Alix). With this method we were able to demonstrate i) the possibility to detect very low concentrations of EVs from cell supernatant and ii) the retention of sample integrity.

Conclusions
The key goals of the LoC technologies are to eliminate high-impact procedures, reduce time and cost, and preserve EV morphology. Our systems allow us to study the release of EVs under dynamic cell culture conditions that mimic the physiological scenario at the cell surface, and to identify arrays of biomarkers associated with EV subclasses. The next step is to integrate microfluidic sorting and electrochemical characterization into a benchtop device that can be customized to meet clinical needs.

Droplet microfluidic device for the purification of highly concentrated and ultrapure extracellular vesicle from human plasma

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Extracellular vesicles (EVs) are nanometre-sized double-layered phospholipid vesicles that circulate in body fluids, carrying genetic information from their parent cells, making them highly suitable for liquid biopsy[1]. Despite their value, their current use in clinical practice is still limited. Among the limiting factors, one of the most critical is their isolation. Conventional approaches are characterised by low purity and scarce throughput, or poor reproducibility[2]. Here, we propose a platform for EV isolation by affinity capture using magnetic beads, based on droplet microfluidics[3]. Monophasic microfluidic has been used for this scope with a low capture efficiency[4], mainly due to bead sedimentation and low throughput, being limited to a few tens of microlitres, whereas clinical applications require larger sample volumes (0.5 −1 ml). On the contrary, by confining both samples and beads in droplets, the beads cannot escape the droplet itself, and importantly, the spontaneous formation of recirculation zones within the droplet promotes the mixing. In our case, beads are functionalised with Anti-CD9 antibodies targeting specific EV tetraspanins present on the membrane. The microfluidic device is fabricated by replica molding and being coupled with a series of low-cost optical sensors, syringe pumps and pressure controllers. The entire isolation process operates in a relatively short time (about 4.5 hours), processing three samples at a time and handling sample volumes of up to 2 ml per sample. The platform was initially validated from the microfluidic point of view: throughput, automation, magnetic bead handling[5]. The EV isolation capability from human plasma samples was then investigated among three different techniques using microfluidics, in-batch protocols, and ultracentrifugation, operating a systematic comparison with commonly used methods. Fresh human plasma from healthy donors was used, without the need for preconcentration steps. Isolated EVs were characterized by the commonly used techniques (NTA, confocal microscopy, BCA, and WB) showing very positive outcomes. In particular, we obtained about 60% EV isolation efficiency (by NTA and BCA) and positive WB analysis (CD9, CD29), showing a 10-fold higher signal from the samples processed by the microfluidic platform rather than the in-batch protocol. Moreover, the microfluidic samples result definitely purer in the target proteins than the ultracentrifuge samples. Dedicated experiments for EV elution and in-droplet analysis are under investigation.
Given these results, we strongly believe that droplet microfluidics represents a promising technology for the isolation in clinical practice.

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High-yield extracellular vesicle production from microorganism producer cells under rotating motion in baffled vessel and functional validation in a biomimetic gut-on-chip model

Authors: Solène Lenoir[1]; Thomas Hainaut[1]; Brice Lapin[1]; Jose-Efrain Perez[1]; Tiphaine Le Roy[2]; Claire Wilhelm[1]

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Background: Extracellular vesicles (EVs) are spherical, bilayer-enclosed particles that are released in a constitutive manner by nearly all cell types and which play a key role in the intercellular communication and the regulation of both physiological and pathological processes. As non-replicating agents with nanometric sizes and loading capacities, interesting biochemical properties and unequalled biocompatibility, EVs have positioned themselves as key agents for numerous therapeutic applications. They can be used as drug delivery vehicles or disease biomarkers, for instance. An emerging domain is that of bacterial EVs (BEVs). As key mediators of the microbiota-host crosstalk, they offer exciting additional biomedical prospects in particular in the development of novel therapies for inflammatory bowel diseases (IBD). However, other than standard protocols, there are only few studies of novel stimuli to enhance the secretion of BEVs to meet these therapeutic needs.

Methods: Here, we introduce a patented high-throughput production method, supported by a published article, that relies on the introduction of hydrodynamic shear stress on producing cells to promote their vesicles release. The probiotic strain Escherichia coli Nissle 1917 was used for the proof-of-concept and was cultured while being submitted to high-speed rotations up to 24 hours in a specialized rotating vessel. Produced BEVs were characterized by cryo-EM imaging and the impact of hydrodynamic and standard conditions on the protein cargo of EVs was explored through proteomic analysis and functional in vitro assays. Their therapeutic potential was further studied using a biomimetic Gut-on-chip model featuring a functional epithelial layer (Caco-2/TC7 and HT29-MTX at a 6:1 ratio) interfaced with a collagen-based matrix. Fluorescently labeled BEVs were perfused into the epithelial tubule to study their internalization.

Results: Overall, the results showed a clear increase both in bacterial growth and EV-yield when using our technology compared to control conditions, with an increase of produced EVs linked to the rotation speed of the stimulation. Observed EVs using cryo-EM show typical morphological types of BEVs including mainly outer-membrane vesicles for all conditions. Interestingly, proteomic analysis revealed an hydrodynamically-induced protein signature at the cargo level as shown through PCA and clustering analysis. Importantly, the produced EVs demonstrated potential therapeutical properties, with demonstrated effects in pro-inflammatory responses, exhibiting different efficacy when produced under hydrodynamic stimulation. Preliminary microfluidic assays further confirmed that these BEVs are efficiently internalized by the intestinal epithelial cells within the Gut-on-chip device.

Conclusion & Perspectives: This integrated approach demonstrates that our novel shear-stress technology significantly outperforms traditional BEV production methods in terms of yield and speed, reducing production time from several days to only 24 hours. The produced EVs offer similar morphological characteristics as standard condition while also differing through cargo content and potential therapeutical properties. The Gut-on-chip model now serves as a high-resolution platform to investigate the functional impact of these “hydrodynamically-primed” vesicles. Ongoing studies aim to evaluate how these BEVs modulate the epithelial functionality and integrity by studying the expression of tight junction proteins both at the mRNA and protein level by RT-qPCR and fluorescence microscopy respectively.

Room 35

Thermodynamically Consistent Discovery of Polymeric Constitutive Equations using a GENERIC-guided Neural Network framework and application to CFD of complex fluids

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I will present a versatile computational framework that employs Physics-Informed Neural Networks (PINNs) to discover constitutive equations for the extra-stress in rheological models of polymer solutions [1]. In this framework, the training of the neural network is guided by a metamodel for the conformation tensor that adheres to the GENERIC formalism (General Equation for Non-Equilibrium Reversible–Irreversible Coupling) [2]. The use of GENERIC enables a reduction of the parameter space by restricting the search to thermodynamically admissible fluid models —that is, those that strictly satisfy the First and Second Laws of Thermodynamics. The discovery of different geometric blocks within GENERIC includes irreversible entropic contributions, anisotropic mobility terms related to the friction tensor, and specific choices of the objective derivative for the microstructural variables. We discuss the potential of data-driven PINN approaches to identify such models and compare various training strategies, including viscometric and complex flow data. The PINN strategy is incorporated into CFD tools for the simulation of polymeric flows using RheoTool-OpenFOAM. Fluid dynamics results will be presented to assess the accuracy of the aforementioned methodology. Finally, I will discuss possible outlooks and perspectives on using this approach to accelerate multiscale polymer simulations and/or to directly incorporate experimental data into the model.

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CFD-guided Design and Experimental Validation of Microfluidic Systems for Drug Encapsulation

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Advances in drug delivery increasingly rely on microfluidic systems for encapsulation, yet experimental optimization can be time-consuming and resource-intensive, requiring multiple iterations to identify suitable operating conditions. Computational fluid dynamics (CFD) provides a complementary tool, enabling systematic investigation of flow behavior, droplet formation, and overall device performance without extensive experimental trials. This study presents a combined numerical-experimental framework to develop a microfluidic system enabling drug encapsulation for controlled delivery. A multiphase CFD model was implemented to predict flow dynamics, interfacial behavior, and droplet formation mechanisms in order to identify operating conditions capable of producing target particle sizes. Experimental tests confirmed the predicted droplet formation regimes and particle dimensions, showing strong agreement with CFD predictions and demonstrating that the validated model can effectively support design decisions while reducing experimental iterations. The approach highlights the potential of CFD-driven optimization to improve microfluidic drug encapsulation systems.

Multiphysics modeling of single-particle photoacoustic excitation in a microfluidic platform

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Microfluidic systems enable precise fluid handling at the microscale and offer huge potential for integrating multiple functions for rapid, on-chip analysis (Petruzzellis et al., 2024). In this context, while numerous studies have successfully focused on device fabrication and particle manipulation within microchannels, the downstream detection often still relies on off-chip tools such as microscopes and particle counters (Shi et al., 2024). Embedding photoacoustic (PA) detection into microfluidic platforms for particle detection and counting could represent an effective strategy to integrate sensing functionalities directly onto the microfluidic chip (Kishor et al., 2017). PA detection is a label-free technique based on the optical absorption of short laser pulses, which induce pressure waves through thermoelastic expansion. Then, it is inherently background-free, as signals originate exclusively from absorbing analytes, and it overcomes the limitations of conventional absorption detection associated with weak absorption, light scattering, and opaque samples. Moreover, PA detection enables multiparameter analysis by probing the optical, mechanical, and thermal properties of the particles in the fluid (Barbosa & Mendes, 2022), providing information on cell size, morphology, and internal structures (Yao & Wang, 2013).

Despite this potential, a critical gap persists at the single-particle scale: the intrinsic thermoacoustic response of micrometer-sized polymer particles—especially polystyrene (PS), widely used as calibration standards and microplastic surrogates—has not been systematically characterized. Most existing studies focus on ensemble behavior, leaving unresolved the fundamental mechanisms governing heat deposition, elastic deformation, and acoustic emission from individual particles, as well as their propagation in the fluid (Schnepf, von Moers-Meßmer, & Brümmer, 2023).

To address this gap, we present a first-principles, time-resolved multiphysics finite-element framework implemented in COMSOL Multiphysics as a digital twin of photoacoustic excitation of a single particle in a microfluidic environment. The model couples transient heat transfer, thermoelastic deformation of a dye-free PS microsphere, and acoustic wave generation and propagation in water under pulsed excitation at the PS intrinsic absorption band (around 3400 nm), where water absorption is limited. By varying the pulse duration from nanoseconds to milliseconds, we identified the transition from stress-confined impulsive excitation with elastic ringing to a quasi-static thermomechanical regime, and quantified how propagation reshapes signal amplitude and spectrum at standoff distances relevant for on-chip detection. For validation of the digital twin, we assembled a basic experimental setup consisting of a microfluidic device and a photoacoustic excitation system based on a Fabry–Perot interband cascade laser to excite PS microspheres in distilled water. This setup was used to experimentally verify the predicted pulse regimes and to analyze the resulting signal spectra.

Looking ahead, this workflow could be readily extended to biological specimens (cells, vesicles, aggregates) by adapting material parameters and geometries without altering the modeling architecture. In this way, it is expected to bridge controlled studies on PS particles with label-free assays on real samples, advancing computational and data-driven design, optimization, and interpretation of next-generation microfluidic platforms integrated with PA detection.

Multiphysics model of magnetic bead collection for lab-on-a-disc platforms

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Magnetic microbeads are a key tool in automated immunoassays, where they enable selective capture, concentration, and purification of low-abundance analytes.
On microfluidic platforms, magnetophoretic bead collection remains a major performance bottleneck, demanding precise control within microfluidic environments and repeated execution during binding, washing, and dilution steps. Consequently, the system is highly sensitive to microfluidic design and selected operating parameters and often requires extensive empirical tuning. To overcome these limitations, we present a comprehensive, experimentally validated computational framework designed to predict and optimize magnetic bead collection processes in rotating lab-on-a-disc systems.
The core of this work is a finite-element multiphysics model that resolves the coupled interactions governing bead motion, namely magnetic- and centrifugal forces, viscous drag, magnetophoresis-induced convection, and cooperative bead aggregation into chains.
Two-way coupling between bead motion and fluid flow enables the emergence of convection driven by bead slip velocity. This effect is known to significantly accelerate particle transport but remains rarely included in microfluidic design tools. The model additionally incorporates realistic bead–wall flux conditions, allowing direct prediction of bead surface accumulation and collection fractions. Finally, it accounts for bead aggregation into chains and adjust both the drag and magnetic force accordingly to the number of beads within a chain.
To establish quantitative accuracy, the simulations are validated using a dedicated rotating platform with real-time imaging of Dynabeads™ M-270. The model reproduces experimentally measured concentration fields, temporal collection curves, and characteristic timescales with high fidelity, despite relying solely on physically grounded parameters without any empirical fitting. This predictive capability enables systematic exploration of geometric and operational parameters that are challenging to assess experimentally.
In this work, we highlight the investigation of magnet field intensity by varying magnet–fluid distance, a critical geometric variable with direct implications for instrument design. Simulations performed for distances between 2.0 and 6.0 mm reveal a robust and approximately linear relationship between magnet–fluid spacing and collection time: larger distances weaken magnetic field gradients, reduce bead slip velocities, delay chain formation, and diminish induced convection. As a result, increasing the gap from 2mm to 6mm roughly triples the time required to reach a given collection fraction. This result is valid for the 95% threshold commonly targeted for reliable immunoassay workflows. This simple and transferable scaling rule offers immediate practical value for designers of centrifugal microfluidic instruments and cartridges.
Similarly, we show that for a fixed design, varying the rotational speed from 300 rpm to 800 rpm decreases the collection time of a given fraction exponentially. This result offers another immediate practical guide for selecting the rotational speed of a fixed design.
By combining detailed physics-based modeling with experimental validation, this work provides a generalizable in-silico tool that reduces reliance on costly trial-and-error prototyping and supports data-driven optimization of magnetic separation modules. The computational framework is broadly applicable to platform architecture, disc-magnet alignment, bead selection, and rotational protocol design, contributing to more efficient and robust microfluidic immunoassays.

Machine Learning-Based Design Optimization of a Microfluidic Micromixer for Enhanced Mixing Performance

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Efficient mixing in microfluidic systems at low Reynolds numbers remains a major challenge due to dominant laminar flow and slow diffusive transport. Micromixers play an important role in many biomedical applications such as lab-on-chip platforms, biochemical assays, drug delivery etc. Conventional micromixer design usually depends on parametric sweeps based numerical optimization, that requires high computational cost and often fails to fully explore complex design spaces. Recent advances in machine learning (ML) offer new approaches to improve design optimization, reduce unnecessary simulations, and identify effective, non-intuitive geometric configurations that enhance mixing performance under practical constraints.

In this study, a ML-based framework is proposed to optimize the micromixer design using Bayesian Optimization (BO) and Constrained-Bayesian Optimization (CBO) approaches combined with Gaussian Processes (GP). For this purpose, python is integrated with COMSOL Multiphysics to create an automated simulation framework that allows the system to create geometry, meshing, simulation, data extraction and dataset generation. Important geometrical configurations of micromixer design such as rectangular shape obstacle size, channel length, channel width, spacing between the obstacle and angles are used as design variables. Mixing index and pressure drop are selected as the main objective and design constraints respectively.

BO is then employed to suggest new design candidates that provide the best balance between finding new designs and improving promising ones. Moreover, CBO approach ensures satisfaction of pressure drop limits. The expected outcomes provide significant improvement in micromixer design with enhanced mixing performance and pressure drop compared to baseline study. In addition, the proposed ML framework is expected to identify optimal flow perturbation mechanism that stimulates chaotic advection and flow mixing at low Reynolds numbers. Overall, the proposed ML framework combined with multiphysics simulation provides valuable insights to enhance mixing performance and accelerate scalable microfluidic device development.

A self-driven microfluidic laboratory to explore coacervation

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Coacervation is a liquid-liquid phase separation that can occur when macromolecules with opposite charges are mixed in solution. Beyond its fundamental aspects in physical-chemistry [1] and biology [2, 3], coacervation is also of industrial interest for the encapsulation and controlled release of active substances [4] as well as in the formulation of modern shampoos, making it possible to balance cleansing and conditioning in a single product when using antagonistic active ingredients [5]. The minimum description of coacervation requires a phase diagram, showing the state of the solution as a function of thermodynamic variables. However, as coacervation is highly multifactorial (it depends on the nature of the active ingredients, pH, salinity, temperature, etc.), acquiring such phase diagrams can be particularly tedious.
In this context, we developed a self-driven lab [6] that can build coacervation phase diagrams in full autonomy. The system is based on digital microfluidics [7, 8, 9] where coacervation takes place in nanoliter drops, in which the composition can be controlled through automated delivery of actives, and where AI-assisted image analysis permits us to assess some aspects of the kinetics of liquid-liquid phase separation. Conducted in a near-real time manner, the analysis may allow the choice of the next experiment to be performed based on previous results. Specifically, we will present the benefits (in terms of experimental budget, time and consumables) of different exploration methods which we have developed: usual grid and random versus AI-assisted curiosity and boundary search.

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Oral contributions
Thursday 21/05, 10:00 - 13:00

Auditorium

Microfluidic studies for predicting the state of charge in redox flow cells

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Microfluidics provides exceptional control over experimental conditions in electrochemistry, particularly regarding mass transfer and the local distribution of current. This precise control over surface phenomena and transport opens new opportunities for studying metal deposition processes, electrode morphology, and optimizing charge cycles in batteries.

In this work, we leverage microfluidics to investigate the charging behavior of a zinc-air redox battery. The originality of our approach lies in the development of a quantitative charging model based on data extracted from microfluidic experiments. The interfacial dynamics are measured at high electrolyte flux in a microfluidic device using electrodes with a small surface area. The evolution of the deposit surface is monitored and modeled using in-operando techniques based on linear sweep voltammetry (LSV). In the case of zinc, employing the Cachet model, the LSV curve at low potential is sensitive to the morphological state of the electrode, providing a direct measure of the evolution of its surface area.

Based on these measurements, we construct a quantitative model that couples mass transport, interfacial kinetics, and deposit dynamics, enabling the prediction of cell voltage under various experimental conditions, such as electrode size and electrolyte flow rate.

This framework allows us to examine the effect of segmented electrodes on energy efficiency and deposit morphology. Our results demonstrate that optimal electrode spacing significantly reduces dendrite formation and lowers the energy required for charging. For example, at a current density of 30 $mA \cdot cm^{-2}$ and a flow rate of 0.125 $cm \cdot s^{-1}$, no dendrites form when four electrodes are spaced 8–13 mm apart, whereas dendrites appear when electrodes are connected or spaced only 3 mm apart. These findings show that controlling mass transfer, enabled by microfluidics, allows precise manipulation of deposit morphology and optimization of battery energy efficiency.

In conclusion, microfluidics represents a powerful tool for studying and modulating local electrochemical phenomena, with direct applications in the design of safer and more efficient batteries. Our work on the zinc-air battery demonstrates that precise control of charging conditions and electrode segmentation not only prevents dendrite formation but also reduces the energy required for charging. This highlights the potential of microfluidic approaches for enhancing battery performance, optimizing energy efficiency, and guiding the development of advanced electrochemical storage systems.

Effect of Microfluidic and Thin-Film Liposome Production on the Insertion and Binding Efficiency of a Metal Chelator

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The method employed for liposome preparation plays a critical role in defining their physicochemical properties, which in turn strongly influence their stability, functionality, and suitability for downstream applications. Conventional bulk techniques, such as thin film hydration followed by extrusion, are widely used and well established; however, they rely on multi-step, time-consuming procedures and may suffer from limited batch-to-batch reproducibility.1 These drawbacks can represent a significant limitation, particularly in view of large-scale production and clinical translation. In recent years, microfluidic technologies have emerged as a promising alternative for liposome fabrication, offering continuous, automated, and potentially scalable production with precise control over size and narrow size distributions.2 Despite these advantages, microfluidic liposome preparation typically involves the controlled mixing of aqueous and organic phases, most commonly using ethanol as the organic solvent. While this approach enables efficient vesicle formation, it also raises concerns regarding the partial incorporation of solvent molecules into the lipid bilayer.3 Although purification strategies are routinely applied to remove the organic solvent, residual ethanol traces often persist and their impact on liposome structure and functionality is frequently overlooked. In this study, a systematic comparison between thin film hydration and microfluidic preparation of DMPC liposomes was carried out to evaluate the influence of the production method on vesicle properties. The physicochemical characteristics of the resulting liposomes, including size distribution and thermal behavior, as well as membrane fluidity, were investigated using dynamic light scattering (DLS), differential scanning calorimetry (DSC), and fluorescence anisotropy measurements. These complementary techniques allowed a detailed assessment of the effects induced by residual ethanol within the lipid bilayer, highlighting differences in membrane organization and phase behavior between the two preparation methods. Beyond basic characterization, particular attention was devoted to evaluating the functional performance of liposomes as carriers for active molecules. To this end, the insertion efficiency and Cu(II) binding capability of 2-(hydroxyamino)-3-octyltridecanal were investigated. This synthetic amphiphilic compound, endowed with long alkyl chains, is specifically designed to favor stable insertion into lipid bilayers while retaining metal-chelating functionality. The incorporation of the molecule and its ability to complex Cu(II) ions were studied using UV–Vis spectroscopy and fluorescence quenching experiments. The comparative analysis reveals that residual solvent traces associated with microfluidic preparation significantly influence not only the physicochemical properties of liposomes but also the functional behavior of the embedded chelating agent. In particular, changes in membrane fluidity and organization were found to directly affect the efficiency of molecular insertion and metal complexation. Overall, this work underscores the critical importance of solvent selection, purification efficiency, and a thorough understanding of the effects of trace solvent contamination when designing liposomal formulations. These considerations are especially relevant for the development and clinical translation of microfluidics-fabricated liposomes intended for biomedical applications.

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Label-free 2D quantitative imaging of concentration gradients using Fabry-Pérot interferometry

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Chemical concentration gradients at the microscale are omnipresent, shaping fundamental processes in a wide range of systems from cell signaling to transport phenomena. Despite their ubiquity, visualizing chemical gradients typically requires the addition of labels, such as fluorescent dyes, for optical readout. Because dyes bleach, or may interfere with the processes of interest, i.e. up to inducing toxicity for biological systems, alternative, label-free approaches are sought after. For systems that lack optical contrast, interferometric methods are a label-free solution that relate refractive index (RI) to a compound's identity or concentration in situ. I will present here a tool that expands on the principles of Fabry-Pérot interferometry to two dimensions to obtain RI mapping within a microfluidic chip. By tracking fringes of equal chromatic order our tool achieves a RI resolution of 1e-5 refractive index units per image pixel, for instance sensitive to 1 mM changes in concentration of NaCl. The tool, which we named RIO for refractive index observer, mounts onto any microscope and I will report its resolution and RI precision, as well as demonstrate its potential by quantifying dynamically evolving concentration gradients of dissolved NaCl in a microfluidic channel and concentration gradients resulting from catalytic reactions. We envisage that RIO will give unprecedented access to a broad range of microscale phenomena, from polymerization and enzymatic reactions to cell signaling and electrochemical processes.

Passive Microfluidics Device with On-Demand Activation for Dynamic Cell Culture and Gradient Formation

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Over the past few years, the development of passive microfluidic Lab-On-Chip (LOC) platforms has opened promising avenues for studying cellular invasion assays. These systems are increasingly relevant in oncology, tissue engineering, and regenerative medicine.
By eliminating the need for external fluid handling systems (e.g., electric pumps), these platforms facilitate wider adoption in laboratory environments. However, despite their advantages, replicating complex tissue architectures in vitro remains a considerable challenge. Innovative strategies are still required to accurately construct multicellular structures and to enable controlled, on-demand intercellular communication.
The aim of this work is to design and characterize a novel microfluidic device that enables controlled communication between two or more chambers - each potentially housing different cell populations –using hydrophobic microchannels. By exploiting the hydrophobic properties of specific channel regions, communication between compartments can be activated on demand by applying a mild pressure.
This setup is intended to provide a robust model for examining cancer cell migration, embryogenesis, neuronal development, and intercellular signalling in response to various stimuli. Current efforts focus on fabricating a polydimethylsiloxane (PDMS)-based device bonded to a standard culture dish. The design incorporates multiple wells interconnected by passive (super)hydrophobic microchannels. A unique aspect of this design is the functionalization of PDMS with carbon nanotubes (CNTs). This modification, originally developed for broader applications, not only enhances the device's hydrophobic properties but also ensures the channels remain stable over time.
In this work, these chambers have been characterized with the perspective of being used for the invasion/migration of cells from the primary tumor site. Specifically, the experimental design is planned in the following way: a tumor sphere is obtained on-chip into one of the device' s wells; a second well, confined by a hydrophobic septum, is filled with culture medium containing TGF-β, able to induce detachment and migration of cells from the spheroid once in communication with the former.
The timing of this assay is identified according to the research needs, and in particular, the communication between wells is activated on demand by applying a mild pressure on the septum, able to overcome hydrophobicity, inducing a kind of passive micro-pumping among chambers, which allows medium exchange among the chambers and the creation of a diffusion gradient. The first phase of this work analyzes the optimization of fabrication parameters and the dynamics of gradient occurrence. Lately, a demonstrator of biological application has been provided.

A modular "Pharmacist–Nurse" microfluidic platform for real time multi input multi output control of mammalian cell microenvironments

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The problem. Cybergenetics promises real-time, personalised optimisation of therapies for non-communicable diseases by closing the loop between measurement and control in living systems. Translation is stalled by a hardware gap: there is no *in vitro* platform for real-time, multi-input multi-output (MIMO) control of mammalian microenvironments. Many optimisation strategies run open-loop [1], and prevailing microfluidic devices cannot impose multiple, time-varying biochemical inputs needed to separate treatment effects from spontaneous disease dynamics [2].

Our solution. We present a modular microfluidic platform for MIMO cybergenetic control composed of a signal-generation device ("Pharmacist") coupled to a cell-culture device ("Nurse"). The Pharmacist is a multilayer PDMS chip with 12 inlets partitioned into four hydraulically isolated modules implementing: (i) healthy, (ii) pathological, (iii) healthy + treatment, and (iv) pathological + treatment. Normally-open membrane valves and on-chip peristaltic micropumps provide programmable dosing, while integrated staggered herringbone mixers (SHMs) rapidly homogenise selected inputs prior to delivery. The Nurse is a mechanically clamped PDMS culture module built from interchangeable parts: a 300 µm-thick PDMS stencil containing forty 700 µm-diameter chambers and a flow layer with four parallel perfusion channels (ten chambers each). A reconfigurable two-step workflow enables precise seeding via a removable Chamber Extender for manual pipetting or acoustic droplet ejection (ADE); after overnight adhesion, the Extender is replaced with the flow layer and connected to the Pharmacist via capillaries.

Results. We characterised all twelve peristaltic micropumps and identified a linear dosing regime (0–2 Hz) with minimal intra-pair variability, delivering up to ~2 µL·min^{-1} per pump. SHM geometry was optimised in COMSOL for rapid mixing and validated experimentally, achieving a mixing index ≥ 0.95 within ~10 mm downstream at a total flow of 10 µL·min^{-1}. We demonstrate complex, time-varying multi-chemical waveform generation by independently modulating the concentration of two fluorescent tracers (Cy5 and fluorescein), overcoming a common limitation of valve-based platforms where coupled peristaltic actuation restricts independent control of final media composition [3–5]. Finite element analysis predicts that, at an inlet flow of 10 µL·min^{-1} and chamber depths of 100–500 µm, media exchange occurs in 9–17 min while maintaining shear stress below 0.5 dyn·cm^{-2}. Experimentally, the clamped interface remained leak-tight under 10 psi for 24 h with no cross-channel contamination, and static seeding at 10^6 cells·mL^{-1} yielded well-spread adherent cells.

Conclusions. By combining independently addressable dosing, rapid on-chip mixing, and modular, leak-tight culture, the Pharmacist–Nurse platform enables programmable, time-varying MIMO microenvironments for closed-loop control of mammalian systems. Our work supports real-time control of signalling and drug response, benchmarking of control algorithms, and systematic studies that decouple treatment efficacy from disease progression.

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Room 35

A Microfluidics-Based Platform for 3D Printing Architected, Functionally Graded Polymer Foams

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Functionally graded materials offer a powerful conceptual framework for designing compositionally graded mechanical responses from a single material. Such a material will enable the tailoring and tuning of physico-mechanical properties across the structure. However, the existing manufacturing techniques for developing functionally graded polymer foams face challenges in integrating the compositional control and monodispersity with architectural precision. This work introduces a protocol for the digital manufacturing of functionally graded polymer foams using a scalable manufacturing method. We introduce a Microfluidics-based 3D printing platform to produce high internal phase emulsions (HIPEs) that can be photo-crosslinked via emulsion templating. Two monomer foams with distinct mechanical responses were selected and dynamically mixed using a micro-mixer coupled to a microfluidic chip. A hydrophobic, shear-thinning support bath solution was optimized to ensure rheological compatibility and structural stability with the HIPEs. Depending on the defined geometry, different flow profiles were generated to 3D print HIPEs in the bath solution with a composition gradient and a fixed porosity of 85%. The printed foams were photo-cured, and the excess bath solution was washed off. Mechanical properties of the foams were evaluated, and a programmable mechanical response of Young's modulus (0.02- 10 MPa) and energy absorption capacities of up to 0.15 J/Cm3 was obtained. This work establishes microfluidics-assisted 3D printing as a stable, scalable platform for the programmable fabrication of functionally graded polymer foams and thereby broadens the scope of producing mechanically heterogeneous materials.

From Low to High Throughput: Microfluidic-Powered 3D Bioprinting

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Despite significant advances in 3D bioprinting, achieving high printing speed, efficiency, and homogeneity in biological samples remains challenging. These limitations restrict its practical application in tissue engineering, particularly in fabricating complex tissues such as skeletal muscle. Microfluidics offers promising strategies to overcome several of these issues.

This project introduces a high-throughput, combinatorial microfluidic-assisted 3D bioprinter designed to address these gaps. The device is compatible with standard multiwell plates and can print up to 96 distinct material sequences in about two hours, enabling rapid screening of cells and biomaterials.

While initially intended for skeletal muscle bioink screening, the system's capabilities extend further. Printing different materials side-by-side enables heterogeneous constructs, whereas printing the same material simultaneously with all nozzles provides high-throughput homogeneous fabrication. The ability to handle a wide range of viscosities, diverse biomaterials, customizable parameters, and full automation gives the system advantages beyond those of current bioprinters.

The bioprinter uses open cartridges that store diverse bioinks and connect to a pressure controller that applies periodic positive and negative pressure. This gentle mixing prevents cell sedimentation and maintains bioink homogeneity, addressing a major limitation of conventional approaches.

The printer head contains up to 12 microfluidic chips (pens) acting as nozzles, each with a mixing compartment for passive homogenization. These nozzles move independently in the vertical direction via servomotors, while a robotic arm handles horizontal positioning. Each chip is connected to a syringe pump regulating bioink flow, and a low-density oil minimizes residue to ensure consistent operation. The process is fully automated through custom Python code coordinating pumps, motors, and the robotic arm. The microfluidic chips are fabricated with biocompatible transparent resin using SLA 3D printing, allowing seamless geometries and high control over microchannel architecture.

Printing begins with the head aspirating defined volumes of bioink from the cartridges. It then deposits the materials into the well plate filled with printing bath in a programmed pattern. After each printing step, the head moves to a washing station where the oil flushes out residual bioink. This cycle continues until all wells contain distinct combinatorial sequences. For skeletal muscle applications, printed samples are cultured for 14 days and analyzed with image-processing techniques to identify optimal formulations.

The modular design supports additional accessories such as active mixing or photocrosslinking. For high-viscosity inks, the printer head performs pipetting cycles in a separate plate to ensure proper mixing. When photoinitiators are present, a UV-lamp mask aligned with the wells enables selective photocrosslinking, reducing unnecessary UV exposure and preventing cellular or biomaterial damage.

Overall, this bioprinter provides significant advantages in speed, simplicity, affordability, and homogeneity. Its high-throughput capabilities and precision make it a powerful tool for tissue engineering and biomaterial screening, accelerating the development of functional artificial tissues.

Microfluidic gradient generator integrated with organic transistors for rapid dose curve measurements.

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Electrolyte-gated organic transistors (EGOTs) are highly sensitive biosensing platforms whose electrical response is governed by ionic transport and interfacial processes occurring within the electrolyte. In this work, we integrate EGOT devices with a microfluidic cell [1] to systematically investigate how controlled mass transport, diffusion, and interfacial self-assembly influence gate functionalization and transistor performance. The microfluidic architecture enables precise manipulation of electrolyte composition and flow conditions, decoupling diffusion-driven phenomena from surface-limited reactions at the gate electrode.

A microfluidic H-mixer is aligned with arrays of EGOT gate electrodes to generate stable diffusive interfaces between parallel streams. This configuration produces a well-defined longitudinal concentration gradient along the main channel, which is exploited to modulate the local kinetics of self-assembled monolayer (SAM) formation on adjacent gate electrodes. Using short-chain alkanethiols (3-mercapto-1-propanol, 6-mercapto-1-hexanol, and 8-mercapto-1-octanol) under flow rates between 2 and 50 $\mu L \cdot min^{-1}$, we correlate microfluidic transport regimes with electrical readout. The drain–source current systematically decreases along the axial direction of the microchannel, reflecting spatially varying surface coverage and interfacial capacitance.

For short-chain thiols, the current evolution indicates diffusion-limited surface reactions governed by the microfluidic concentration gradient. In contrast, longer-chain thiols yield gate responses that are largely insensitive to axial position, consistent with slower surface diffusion and the formation of more compact, energetically stable SAMs. These results demonstrate that microfluidic control enables reproducible, position-resolved functionalization of transistor gates, allowing the construction of dose–response curves when antibody is streamed along amine terminated functionalization.

Beyond surface assembly, the platform has been further tested for nucleic acid miRNA detection. The sensing mechanism relies on competitive hybridization between solution-phase probe–target complexes and surface-bound probes at the gate electrode, enabling discrimination of oligonucleotide sequences [2] differing by point mutations or deletions. Overall, the microfluidic–EGOT integration provides a versatile framework for controlling interfacial chemistry, improving biosensing reproducibility, and probing transport-limited processes in electrolyte-gated devices.

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Polymeric Smart Carriers by Microfluidic, for encapsulation of labile biomolecules in triple breast cancer fight

Author: Concetta Di Natale[1]; Daniele Tammaro[1]; Elena Lagreca[1]; Lilia Losco De Cusatis[1]; Pier Luca Maffettone[1]; Yosra Ibrahim[1]

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Microfluidic technologies offer unique control over the synthesis of polymeric particles enabling precise encapsulation strategies for labile therapeutic agents. In this work, we report a microfluidic approach for the generation of micronsize templated polymeric particles designed for the encapsulation of labile anticancer drugs targeting triple-negative breast cancer (TNBC). Using flow-focusing microfluidic devices, highly monodisperse double emulsions are produced with independent control over inner core size, shell thickness, and overall particle diameter. The mild hydrodynamic conditions and short residence times inherent to the microfluidic process preserve the chemical integrity and bioactivity of labile therapeutic compounds. The resulting particles exhibit narrow size distributions (CV < 5%), high encapsulation efficiency, and controlled release profiles, highlighting their potential to overcome stability and delivery challenges associated with conventional formulation techniques. This platform provides a versatile and reproducible strategy for the development of advanced drug delivery systems aimed at improving therapeutic efficacy and reducing systemic toxicity in the treatment of triple-negative breast cancer.

Encapsulated Leidenfrost Droplets: Thermal Antibubble in Microgravity

Authors: Aymeric Allemand[1]; Benoit Scheid[1]; Cyril André[2]; Jonas Miguet[3]; Stéphane Dorbolo[2]

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[3] *MSC, France*

Antibubbles are fluid objects consisting of a liquid droplet encapsulated by a thin gaseous shell and fully immersed in a surrounding liquid. Their stability is typically limited by gas drainage and shell rupture, making them short-lived under terrestrial conditions. When the encapsulated droplet is composed of a volatile liquid and the surrounding medium is superheated, evaporation-driven gas production can inflate and sustain the shell, providing an alternative mechanism to delay antibubble collapse. This configuration can be seen as an encapsulated Leidenfrost droplet. However, in antibubbles, the thermalization of the initially cool inner droplet limits shell expansion, with evaporation rates highly sensitive to vapor shell thickness. Here, we report for the first time the formation and evolution of a thermal antibubble under microgravity conditions. The absence of gravity-driven drainage dramatically enhances antibubble stability, allowing us to isolate and investigate evaporation processes limited primarily by heat transfer. This unique environment enables a comparison with classical Leidenfrost systems while introducing new physical mechanisms specific to encapsulated geometries. Experiments are conducted in a temperature-controlled chamber filled with silicone oil heated to 120℃. Volatile hydrofluoroether (HFE) droplets, with a boiling temperature of 56℃, are injected into the superheated liquid. Upon immersion, rapid evaporation at the droplet interface generates a self-sustained gas shell, leading to the formation of a thermal antibubble. In microgravity, this system can be viewed as a drainage-free, encapsulated Leidenfrost droplet, where shell dynamics are governed by heat and mass transfer.

High-speed imaging is used to resolve the temporal evolution of both gas bubbles and antibubbles. In the absence of drainage, thermal antibubbles exhibit significantly increased lifetimes, exceeding 2s on average—approximately an order of magnitude longer than their terrestrial counterparts. Analysis of the antibubble volume evolution reveals two distinct regimes controlled by the evaporation timescale. An initial growth phase is driven by evaporation of the inner droplet, followed at longer times by a decrease in antibubble volume.
To explain the evaporation-driven growth regime, we develop a simplified one-dimensional, time-dependent heat transfer model. Contrary to intuitive expectations, convective heat transfer within the gas shell plays a dominant role, enhancing thermal transport despite the confined geometry. This mechanism accounts for the observed evaporation rates and volume increase during the early stages of antibubble evolution.
The subsequent volume decrease is elucidated by examining gas bubble dynamics and the associated mass transfer processes at the oil–vapor interface. Because HFE is partially miscible in silicone oil, vapor saturation within the gas shell enables the dissolution of HFE vapor into the surrounding superheated liquid, thus explaining the long-timescale shrinkage of the antibubble. Incorporating this effect allows us to fully describe the observed volume evolution.

What initially appeared as a model system dominated by diffusive heat transfer thus reveals a richer interplay between evaporation, convective heat transfer, and mass transfer in microgravity. These results provide new insights into evaporation-driven phase-change processes in encapsulated systems and highlight the importance of microgravity experiments for uncovering transport mechanisms usually neglected under normal gravity.

Oral contributions
Thursday 21/05, 15:00 - 16:20

Auditorium

Locally recirculating flow at near-zero Reynolds number

Authors: Alexandre Avaro[1]; Leon Valentin Gebhard[1]; Gabriel Amselem[2]; Charles Baroud[1]

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While external flow control is straightforward to implement in microfluidics, it is fundamentally limited in its ability to generate spatially localized flow patterns or complex flow topologies. Programming localized, non-trivial flow patterns remains challenging, which limits the ability to mix local samples or to transport fluid between regions of microfluidic devices.

Here, we introduce a new approach to generate programmable and localized flow around micro-patterned features in microfluidic chips. Our PDMS device consists of a thin and wide microfluidic channel flanked by two air chambers [1]. When vacuum is applied to the air chambers, the ceiling of the microfluidic channel deforms downward, displacing the liquid inside. In parallel, hydrogel structures that span the height of the channel are photo-patterned within the channel with controlled geometry and horizontal extension.

The device is operated by actuating each of the chambers independently, applying oscillating pressure sequences that are out of phase with each other. This forcing breaks the temporal and spatial symmetry of the flow in the microfluidic channel and produces a net fluid flux. The resulting flow pattern depends on the frequency of the pressure sequences and their amplitude, in addition to the hydrogel shape.

The flow production is investigated for a cylindrical hydrogel at $\mathrm{Re} = 10^{-4}$ by performing PIV of the flow field averaged over one period of the forcing. The vertical ceiling displacement generates a circumferential net flow localized around the hydrogel cylinder, with mean velocities in the range of 10-50 μm/s. The phase difference between the actuators provides direct control over both flow direction and magnitude. The latter is maximal when the chambers are actuated with a phase delay of $\pi/2$. The opposite delay reverses the rotation direction, while delays of 0 or π produce no net flow. Flow velocity can be further tuned by adjusting the actuation frequency or amplitude, or by modifying the hydraulic resistance at the channel inlet and outlet.

This phenomenon represents a form of flow rectifier in which the hydrogel structures convert sequential ceiling deformations into rotational flow, through the asymmetric resistance created by the oscillating geometry of the microfluidic chip. It can be applied to generate local flow patterning within a wide channel, without any moving parts in contact with the fluid. The principle may be extended to more complex flow patterns by varying further the shape or number of the features, or by adding additional air chambers with different phase differences, which opens new possibilities in reconfigurable microfluidic flow control.

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Dynamics of evaporating, interconnected droplets

Authors: C. Ren[1]; S. G. Subramanian[1]; A. L. Hazel[1]; F. Box[1]; S. Jain[1]; A. Juel[1]

[1] *University of Manchester, UK*

We report on the dynamics of a pair of droplets, connected together by a microchannel and undergoing constant contact radius evaporation. We see that for droplets of equal contact radii, unidirectional flow can arise from differences in droplet geometry and results in the larger droplet feeding the smaller droplet as they evaporate out. However, for droplets of unequal contact radii, the shape of the droplet pair can invert during the evaporation process, causing a reversal in the flow direction. A stability analysis shows that the droplets' transportation on a short-time scale is underpinned by a supercritical pitchfork bifurcation. However, over a long time-scale, the loss of volume to evaporation allows the system to step through a series of states, corresponding to quasi-steady solutions of the droplet geometry on a short-time scale. If the symmetry of the contact radii is broken, the supercritical pitchfork bifurcation unfolds. Thus, we show that the droplet shape inversion and the associated flow reversal can be understood as a jump from the disconnected to connected branch of the bifurcation, which establishes symmetry breaking as a mechanism to induce evaporation-driven flow reversal in connected droplets.

Stokes drag on a sphere in a three-dimensional anisotropic porous medium

Authors: Jeffrey Everts[1]; Bogdan Cichocki; Andrej Vilfan

[1] *University of Warsaw, Poland*

In soft matter and biology, liquids permeating porous media are often found due to the occurrence of (polymeric) fibers, membranes, and colloidal particles. It is a key challenge to describe the flow through such systems —typically at a low Reynolds number—while also accounting for the precise porous microstructure of the medium. Therefore, understanding the macroscale flow properties often requires a coarse-grained approach. In the Brinkman-Debye-Bueche (BDB) method, the porous features of the system are represented by an effective mesoscopic medium that exerts an additional force density on the permeating fluid that is linear in the fluid velocity.

In this talk, we will consider the case when the effective porous medium exhibits (nematic) anisotropy. In particular, we study the hydrodynamic drag force exerted on a sphere in such a medium. This problem is analyzed using the Brinkman-Debye-Bueche equations with an axisymmetric shielding (or permeability) tensor. Using the exact Green' s functions for this model fluid within a single-layer boundary element formulation, we numerically compute the friction tensor for a translating sphere subjected to stick boundary conditions. Furthermore, we derive approximate analytical expressions for small anisotropy using the Lorentz reciprocal theorem. By benchmarking this result against the numerical solutions, we find that a linear approximation is valid in a broad parameter regime. Our results are important for studying self diffusion in general anisotropic porous media, but can also be applied to small tracers in nematic fluids composed of disk- or rodlike crowders.

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Mitigating sedimentation in syringe-driven microfluidic systems

Authors: Maryamsadat Ghoreishi[1]; Lucia Iafrate[1]; Zita Salajkova[1]; Giovanna Peruzzi[1]; Chiara Scognamiglio[1]; Giancarlo Ruocco[1]; Marco Leonetti[3]; Gianluca Cidonio[4]; Federica Caselli[5]; Riccardo Reale[6]

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Many microfluidics and lab-on-chip (LOC) systems rely on syringe-based systems for the precise movimentation and delivery of cells and microparticles. Despite their widespread use, these systems remain vulnerable to sedimentation (i.e. the gravity-driven settling of suspended particles) which leads to non-uniform sample concentrations, clogging, reduced reproducibility, and unreliable outcomes in diagnostic assays, microfluidic cytometry, and tissue engineering applications. This study introduces a dual approach to mitigate sedimentation, integrating predictive theoretical modelling with an active hardware-based solution.

First, we developed and validated a mathematical model that describes particle sedimentation dynamics within horizontally oriented syringes, the configuration most commonly employed in microfluidic setups [1]. The model provides estimates the concentration half-life, which is the time required for the effective particle concentration to decrease by 50%, as a function of system parameters: particle and buffer properties, syringe geometry, and operating flow rate. This predictive framework enables users to determine the usable lifetime of a sample before substantial particle loss occurs. Model predictions were validated through Finite Element Method (FEM) simulations and experimental studies using polymeric and biological particles. The results demonstrate that, in unstirred and suboptimal conditions, sedimentation can reduce the effective particle concentration by up to 90% within 25 minutes. Moreover, the model provides practical guidance for mitigating sedimentation, showing that appropriate choices of syringe barrel diameter and nozzle eccentricity can substantially extend the concentration half-life.

Successively, we developed the Syringe Electromagnetic Controller (SEC) [2], a compact and low-cost device designed to actively suppress sedimentation and thermal drift in syringe-based experiments. The SEC enables both stirring and temperature regulation within standard syringes through electromagnetic actuation. Compared with passive approaches and existing commercial systems, the SEC is inexpensive (<€50), open-source, and highly customizable, facilitating broad adoption in both academic and translational research. The device employs a magnetically actuated stir bar that oscillates inside the syringe, driven by an external electromagnetic coil mounted on a 3D-printed support. The same coil is also used to provide controlled heating, regulated via a closed-loop feedback system using a thermistor, achieving temperature stability within ±0.5 ℃ of the set point. Experimental validation confirmed that the SEC effectively prevents sedimentation of cells and microparticles for periods exceeding 25 minutes, maintaining stable flow, consistent sample concentrations, and temperature. Flow cytometry–based viability assays further showed that neither magnetic stirring nor localized heating significantly compromised cell health, with viability consistently exceeding 85%.

By combining predictive sedimentation modelling with real-time, active syringe control, this work establishes a robust framework for improving sample handling in syringe-based microfluidic workflows. The proposed solutions are readily applicable to 3D bioprinting, point-of-care diagnostics, and microfluidic screening platforms, where consistency, precision, and cell viability are essential. Overall, this integrated approach addresses a key limitation of current lab-on-chip technologies and enables more reliable, reproducible, and scalable biological experiments.

Room 35

Cutting-Edge Trends in Microfluidic Impedance Cytometry

Author: Federica Caselli[1]

[1] *Dipartimento di Ingegneria Civile ed Ingegneria Informatica, Università degli Studi di Roma "Tor Vergata", Italy*

Microfluidic impedance cytometry (MIC) is a label-free, high-throughput technique that characterizes individual flowing particles/cells based on their interaction with a multifrequency electric field [1]. It has been successfully applied in various scenarios, including life-science research, diagnostics, and environmental monitoring. In this talk, I will discuss two emerging trends that promise to enhance the capabilities and adoption of the technique: the integration of MIC with other microfluidic tools, towards multifunctional single-cell analysis platforms [2], and the synergy with Artificial Intelligence (AI) for effective analysis of impedance data in challenging scenarios [3, 4].

MIC is a simple technique: the sensing element is just a microchannel with embedded electrodes, and the electronic acquisition system is suited for portable implementation. Accordingly, the technique lends itself to integration with other microfluidic techniques. Five categories can be identified based on the main goal of the combination: (i) improving the multiparametric characterization capability by coupling MIC with an additional sensing modality; (ii) enabling on-chip sample preparation steps to increase the accuracy of MIC measurements or to enrich selected populations prior to MIC analysis; (iii) stimulating the sample to elicit desired responses; (iv) sample carrying/confinement into droplets or microcarriers to provide tailored support or microenvironment; and (v) impedance-activated sample sorting to enable downstream analysis or reuse.

Increasing the functionalities of the microfluidic system to fulfill the lab-on-a-chip vision calls for a "brain" that controls the platform by deciding tasks based on the signals received from the sensing units. To accomplish this, AI-based solutions are highly promising, as they enable real-time perception and decision-making in complex tasks. The synergy between AI and MIC is currently a very active research field. Both signal-space and feature-space approaches have been successfully demonstrated for applications including, e.g., fast dielectric spectroscopy, coincidence arbitration, and cell population analysis. However, further research efforts are needed to address issues such as the need for target values in supervised learning and the potential fragility of the developed tools.

Acknowledgment
The research was supported under the National Recovery and Resilience Plan (NRRP), Mission 4, Component 2, Investment 1.1, funded by the European Union –NextGenerationEU –Project CUP E53D23002530006.

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Impact of microalgae physical properties on inertial migration in spiral microchannels

Author: Sylvain Capet[1]; Adriana Pereira C.Sánchez[2]; Cécile Formosa[2]; Lucien Baldas[1]; Bruno Lartiges[3]; Pascale Magaud[1]

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Microfluidics has emerged as a powerful tool for the manipulation of bioparticles, enabling operations such as sorting, immobilization and encapsulation. While these approaches are predominantly applied in biomedical and environmental diagnostics, their extension to industrial processes remains limited. One such application is the production of microalgae-based biofuels, for which the dewatering step constitutes a major technological bottleneck. Currently relying on centrifugation or filtration techniques, this step is energy-intensive and economically costly.

Inertial microfluidics offers a passive alternative to address this limitation by exploiting hydrodynamic lift forces arising from particle–flow interactions in laminar Poiseuille flow. These forces induce the lateral migration and focusing of suspended particles at well-defined equilibrium positions within microchannels. By coupling inertial focusing with flow separation, the fluid phase can be efficiently removed, enabling concentration of microalgal suspensions without external fields. Hill and co-authors (Hill C., 2022 doi:10.1016/j.biteb.2022.101014) developed a spiral device that achieves a concentration factor of 130 starting from a suspension of Chlorella vulgaris of about 0.5% v/v initial volume fraction. Based on in situ visualization of microalgal migration, we subsequently demonstrated that an optimized spiral microsystem could be designed to enable more energy-efficient microalgae concentration. However, these visualizations also revealed distinct migratory behaviours depending on microalgal cultures and growth ages. In the present work, we investigate the flow behaviour of Chlorella vulgaris suspensions of different cultures and growth ages with the aim of improving the understanding of how microalgal physical properties influence the inertial focusing phenomenon.

Our experiments are conducted in a spiral microchannel with a rectangular cross-section of 170 × 30 µm², six loops, a single central inlet and four outlets. Various C.Vulgaris cultures and growth ages are investigated. A direct optical method using a high-speed camera is used to assess 2D statistical distributions of particles at multiple locations within the microchannels. In parallel, the size (imaging) and deformability (force spectroscopy) of microalgae before and after passing through the spiral microchannel are characterized using atomic force microscopy (AFM). The microalgae density and aspect are also determined using Lumisizer measurements and transmission electron microscopy (TEM) observations.

Our results show that C.vulgaris microalgae purchased from Greensea (France) cultivated in MC102 medium focus efficiently near the inner wall, with up to 99% of the cells confined within less than one-fifth of the channel width. In contrast, C.vulgaris (CCAP 211/11B) cultivated in Wright’ s Cryptophyte (WC) medium exhibit a different migration behavior: while a fraction of the cells migrates toward the conventional equilibrium position near the inner wall, others align with the flow direction to form evenly spaced trains located in the central region of the channel. The exact location of this region depends on the Reynolds number in a non-trivial manner. Differences in microalgal size, density, deformability, and morphology are examined to elucidate the origins of these distinct behaviors.

These results provide insight into interparticle interactions within confined flows, revealing how they influence particle dynamics.

Field-free trapping and control of microbes by flow shaping

Authors: Ning Ji; Brian Tighe; Daniel Tam[1]

[1] *TU Delft, Netherlands*

Studies of microbial behavior often require trapping and steering single cells while preserving their motility and stimulus–response dynamics. Existing manipulation techniques achieve precise control using optical, acoustic, electric, or magnetic fields, but these approaches introduce additional forces that can conflate field-mediated microbial responses and limit the interpretation of microbial behavior. Hydrodynamic confinement, by contrast, relies only on the fluid environment experienced by the cell and is therefore minimally invasive; however, it has so far lacked the fast, programmable, closed-loop control needed for robust manipulation of active microorganisms.

Here, we present a microfluidic platform that enables real-time trapping and steering of single passive particles and motile microbes using only pressure-driven flows. Time-varying flow fields are shaped through model predictive control with update rates of 20–35 Hz, enabling robust closed-loop manipulation without external fields. This platform enables systematic and quantitative investigation of microbial decision-making in response to time-dependent stimuli, including chemical and phototactic cues. The device consists of a Hele–Shaw microfluidic chamber formed by two PMMA (acrylic) plates separated by an adjustable gap height (100–500 μm). One plate incorporates multiple microscale inlets, whose layout and chamber geometry can be customized. Flow rates through these inlets are continuously adjusted by a controller that explicitly accounts for the dynamics of the actuation system.

First, we achieve precise trapping and steering of a passive tracer bead (≈11 μm diameter). The bead can be moved over several millimeters in 5 s to a new prescribed position with 2 microns accuracy and can be trapped for tens of minutes. By translating the setpoint in time, particles can be guided along prescribed trajectories. Next, we use our platform as a “soft” hydrodynamic trap for the motile green alga Chlamydomonas reinhardtii in dark light conditions. While hydrodynamically confined, the stochastic motility of the swimmers leads to a bounded diffusive behavior around the trapping location. Trajectory statistics reveal a mean position centered at the setpoint and a mean-squared displacement that is ballistic at short times and saturates at long times, consistent with an active Brownian particle confined by a harmonic potential.

Finally, we extend the platform toward single-cell stimulus–response measurements by integrating a localized optical stimulus delivered through a fiber-coupled LED while maintaining hydrodynamic trapping. The trapped swimmer exhibits negative phototaxis, manifested as a steady positional offset from the hydrodynamic setpoint and a reduction in oscillation amplitude and frequency with increasing light intensity. Interpreting this offset as a balance between phototactic swimming and hydrodynamic restoring velocities enables quantitative estimation of the phototactic drive as a function of light intensity, wavelength, and stimulus location.

Microfluidic tools for genotyping and phenotyping single cells

Author: Aaron Streets[1]

[1] *University of California, Berkeley, USA*

Over the past decade, microfluidic technology has greatly impacted the throughput and precision of single-cell genomic analysis such that tens of thousands of cells can be profiled in a single experiment. The dominant method for single-cell genomic analysis has been single-cell RNA sequencing, and recent development of droplet microfluidic platforms has enabled the generation of large-scale human cell atlases based on whole-transcriptome analysis. While the transcriptome provides extensive information about cell type and cell state, there are many aspects of cellular identity that cannot be measured with RNA sequencing, including morphological phenotypes, lipid composition, and even non-coding genetic variation. Furthermore, high-throughput single-cell RNA-seq can be costly, especially if the cell-type of interest is rare. We present a suite of microfluidic tools for multimodal characterization of single cells, that also allow for genotype- and phenotype-based enrichment of single cells prior to RNA-sequencing. First we present a novel strategy for encapsulating cells in hydrogel beads. This approach allows for genotype-based enrichment using fluorescent activated cell sorting. Next, we present a microfluidic platform that enables high-content image-based sorting of single cells before RNA sequencing. Together, these tools allow for deep sequencing of rare cell types that are not identifiable through antibody-based profiling of surface protein markers.

Oral contributions
Friday 22/05, 10:00 - 12:40

Auditorium

Lab-on-a-Chip development for barrier model monitoring

Authors: Simone Luigi Marasso[1]; Francesca Frascella[1]; Lucia Napione[1]; Alberto Ballesio[1]; Raquel Cuelopez[1]; Jovana Babic[1]; Martina Cicolini[1]; Matteco Cocuzza[1]

[1] *Politecnico di Torino, Italy*

The aim of this research is to develop a Lab-on-a-chip (LOC) platform for monitoring barrier models, in particular a skin barrier one, that could be used for testing personalize therapies. The LOC device comprehends two levels of microfluidics with integrated Organic Electrochemical Transistor (OECT) biosensors for monitoring in-situ the conditions of the in vitro cellular model and relevant biomarkers. OECT have been selected since they are able to work also in contact with wet environment and humidity for long periods. The first step was the design of the multi-layer microfluidic device in CAD, in details: i) a culture chamber with an additional layer for hosting a membrane, ii) two OECT inside a sealing layer to be in contact with the top and with the bottom parts, iii) a filling chamber for the lower part of the central membrane and iv) a microfluidic structure to allow connection between the culture medium and the OECT sensors. Two versions of the platform were designed to incorporate two different membranes for cell culture: a PolyCarbonate (PC) and a silk fibroin based. The two membranes were rispectively (38 ± 3) μm PC one and (210 ± 10) μm for the silk one. The designed platform was made in Polydimethylsiloxane (PDMS) using replica molding technique. The master molds were obtained in CAD software as the complementary of the different layers and 3D printed with a PolyJet technology (Stratasys J35), as well as the sealing plugs. The PDMS was casted on the molds and cured at 80℃ for 2 hours and then extracted and the in/outlet obtained by punching. The three layers were bonded with plasma embedding the membrane. The OECT chips with the electrodes were fabricated in clean room environment and then completed in the additive manufacturing laboratory by the inkjet deposition of the channel material PEDOT:PSS, with three different values of the drop spacing (80, 100 and 120 μm). The characterization of the fabricated devices included leakage tests (by dyed PBS solution) and electrical measurements of the OECTs. The platform with PC membrane showed good results in terms of leakage and flow, while the one with silk membrane requires further optimization to avoid bending and leakages between the two layers through the membrane. A proof of concept of the biosensing capabilities of the integrated OECTs was performed by measuring the response of the devices to different concentrations of Ang2 in PBS solution, through gate functionalization with the corresponding antibodies. The future work will involve the optimization of the version of the platform with silk membrane to improve sealing and flow conditions, the seeding of an in vitro skin model on the membranes, the functionalization of OECT gates for specific biomarker detection, the characterization of the biosensor in that specific case and the real-time monitoring of cellular responses under various conditions. This work is part of the research activities funded by the Italian National Recovery and Resilience Plan (PNRR) within the Digital Driven Diagnostics, Prognostics and Therapeutics for Sustainable Health Care (D34HEALTH) Foundation.

Surface patterned omniphobic tiles (SPOTs) for versatile, high-throughput liquid handling

Authors: Nate Cira[1]

[1] *Cornell University, New York, USA*

Manipulating liquids efficiently and precisely is a common need across scientific disciplines. Moreover, the study of complex systems often requires experimental approaches able to assess many variables at once. To address the constraints of conventional approaches, we introduce Surface Patterned Omniphobic Tiles (SPOTs)—a scalable, low-cost platform that combines geometry and surface engineering to leverage capillarity for liquid metering and manipulation. By building on discontinuous wetting principles, SPOTs enable hundreds to thousands of independent experiments in parallel without the need for complex robotics or costly consumables. The system supports a broad range of liquid types and volumes (from <10 nL to >10 µL) with high precision.

We showcase how SPOTs empower diverse applications, from optimizing enzyme kinetics and mapping reaction landscapes in high-throughput chemistry, to screening antimicrobial combinations, evaluating combinatorially different perovskite materials, and genotyping microbial isolates. The simplicity and versatility of SPOTs allow researchers from biology, chemistry, and materials science to rapidly prototype, test, and iterate experiments at high throughput and high performance, giving an accessible tool for data-driven discovery.

How could chitosan, a bio-based polymer, help replace synthetic polymers in the fabrication of microfluidic devices?

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Lab-on-a-chip (LoC) devices are miniaturized analytical devices that integrate various functions (mixing, sorting, trapping, etc.), enabling the manipulation of cells and molecules in small volumes in a controlled environment. They cover a wide range of applications, particularly in the biomedical field, and due to the growing demand for rapid, individualized point-of-care testing, the market for miniaturized medical diagnostics is expected to reach $22.63 billions by 2029 [1]. However, most of them are currently made from petroleum-based polymers, and the increase in single-use tests will have a negative impact on the environment, both during manufacture and disposal. In the wake of growing environmental awareness, bio-based polymers have emerged as promising candidates for LoC production. Despite their potential, few studies have been published on the subject. The most widely used bio-based polymers are cellulosic materials. Fluids are transported through the device by capillarity action, and the resulting LoCs are suitable for a wide range of diagnostic applications, but not for cell manipulation. Other bio-based polymers, such as (i) zein, a by-product of ethanol production from corn, (ii) silk hydrogels, or (iii) poly(lactic acid) (PLA), have been reported, but none of them meet the specifications for LoCs in terms of micropatterning, water resistance, biocompatibility, and biodegradability [2¬]. All these preliminary results tend to indicate that this research field is promising and should be pushed further to propose a range of potential solutions. Ideally, the alternative to petroleum-based polymers for the manufacture of LoCs should be a set of complementary bio-based materials, which would enable to choose the best suited solution for each given application. Having a range of materials and technologies would also help avoiding new ecological imbalances induced by the intensive production of a single bio-based material, and whenever local production would be possible, it could also support the local economy and limit transport.
In this context, we have conducted research to develop a process for manufacturing chitosan-based lab-on-a-chip devices. Chitosan is a non-toxic, biocompatible, biodegradable and antimicrobial polysaccharide composed of D-glucosamine and N-acetyl D-glucosamine units. Obtained from the deacetylation of chitin, the second most widespread natural polymer on Earth, it is industrially produced by valorizing wastes from the seafood industry (several million tons per year). Initial research has enabled us to develop an eco-friendly protocol for thick film formation and chitosan neutralization. The water-resistance was improved by neutralization of these chitosan films in sodium hydroxide-based solutions. Hot embossing and micro-milling were evaluated for engraving channels in chitosan films, and we manufacture the first chitosan fluidic microsystems [4]. These initial results are promising, and we believe that this research will encourage the development of more environmentally friendly microfluidic devices.

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Wetting-Driven Thin-Film Transfer: A Microfluidic-Inspired Approach to Green Electronics

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The rapid expansion of electronic technologies has intensified concerns regarding electronic waste, resource depletion, and the environmental impact of manufacturing processes. These issues are particularly critical for emerging classes of ultra-thin, flexible, and disposable electronics, where short device lifetimes are often paired with fabrication routes that remain energy-intensive, chemically aggressive, and poorly recyclable. Conventional microfabrication techniques largely inherited from silicon-based electronics rely on complex photolithographic workflows, hazardous solvents and etchants, and single-use substrates, thus limiting their alignment with the principles of green electronics, circularity, and sustainable manufacturing.

To address these challenges, the field of sustainable electronics is increasingly exploring alternative fabrication paradigms that minimize material consumption, reduce chemical waste, and enable substrate reuse. Transfer-based approaches offer an attractive strategy by decoupling device fabrication from the final application, thereby expanding the choice of substrates and protecting fragile or unconventional materials [1]. These techniques rely on conventional fabrication, such as physical vapor deposition, involving a donor substrate. In a second step, the functional electronics elements are detached and transferred to the desired substrate. However, most existing transfer methods rely on sacrificial layers between the donor substrate and the functional elements, inherently introducing additional materials, solvents, and processing steps that increase waste, cost, and environmental burden. Although sacrificial layer materials and compatible solvents have been developed to enable bio- and environmentally friendly transfer methods [2,3], the sacrificial layers always involve an extra limiting step and material losses, which increase the cost and are time-consuming.

In this contribution, we present a sacrificial-layer-free transfer method inspired by wet-processing and microfluidic principles, exploiting interfacial energy and wetting contrast to enable the spontaneous release of ultra-thin functional layers. Functional elements are patterned directly onto superhydrophilic donor substrates (contact angle <10°) using shadow-mask-assisted sputtering. Upon immersion in water, the interfacial energy mismatch induces autonomous delamination of the functional layer, which floats on the water surface and can be transferred onto a wide range of target substrates without chemical etchants, adhesives, or mechanical force.

Importantly, the donor substrate remains chemically unaltered, retains its hydrophilic properties, and can be immediately reused, enabling zero material loss and full process recyclability. The method is compatible with diverse functional materials, including dielectric, metallic conductors (Cu, Ag, Ti), and semiconductors, enabling the transfer of multilayer device architectures. We have proven the full transfer of temperature and gas sensors, using both thermistors and resistive sensors. Notably, the method presented is compatible with exotic substrates, such as stretchable polymers, delicate natural materials (including insect wings or bird feathers), and complex 3D substrates relevant to flexible electronics and microfluidic platforms. By eliminating sacrificial materials and reducing chemical and energy inputs, this approach provides a scalable route toward low-impact, circular microfabrication and represents a step forward in the development of truly green electronic technologies.

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Design, Experimental, and Modeling Analysis of a 3D-Printed Hybrid Straight-Ridge and Split-and-Recombine Micromixer toward Nanoparticle Production

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Microfluidic devices are increasingly recognized for their portability and high sensitivity, making them highly suitable for applications ranging from diagnostics to chemical synthesis and biotechnology. Fluid flow in miniaturized systems is typically characterized by low Reynolds and high Peclet numbers, thus requiring very long channels to obtain adequate mixing. To address this challenge, this study investigates a micromixer design that combines a split-and-recombine approach with chaotic flow dynamics to achieve high-efficiency mixing in a compact geometry.
The mixing mechanism within the device is thoroughly examined using Computational Fluid Dynamics (CFD) simulations. The mixing efficiency is quantified in terms of Coefficient of Variance (CoV), which is calculated by analysing cross-sectional images obtained from simulations. The effect of different design parameters on the mixing efficiency is evaluated. Furthermore, the printability of the optimized micromixer design is evaluated using Digital Light Processing (DLP) 3D printing technology. The printed micromixer is then optically analysed to assess the accuracy of the fabrication compared to the Computer-Aided Design (CAD) model.
The performance of the printed device is experimentally tested with coloured fluids at varying Reynolds numbers to validate the mixing efficiency calculated by the model.
The results offer new insights into how specific geometric and operational parameters influence mixing efficiency in the peculiar low Reynolds number situation typical of microfluidics. These insights have potential applications in the optimization of nanoparticle manufacturing processes, particularly in scenarios involving hydrophobic polymer solutions mixed with non-solvents, as well as in the formulation of lipid-based nanoparticles for biomedical applications such as drug delivery and gene therapy.

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Integrating Microrobots into Microfluidic Devices: Toward Active and Reconfigurable Lab-on-a-Chip Systems

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Microfluidic devices have become indispensable tools for chemical analysis, diagnostics, and single-cell studies due to their precise control over small volumes, boundary conditions, and physicochemical environments. However, most microfluidic systems remain fundamentally passive: their functionality is largely dictated by fixed channel geometries, static electrodes, and externally imposed flow fields. At the same time, recent roadmaps in micro- and nanorobotics [1] emphasize that despite major advances in propulsion and functionality, practical deployment of microrobots is still limited by challenges in control, reliability, scalability, and system-level integration. Integrating microrobots directly into microfluidic devices offers a natural and powerful pathway to address these challenges, enabling active, adaptive lab-on-a-chip systems in which mobile agents complement—and fundamentally extend—the capabilities of the underlying microfluidic architecture. When embedded within microfluidic environments, microrobots benefit from confinement, well-defined interfaces, and globally applied fields, which together enhance stability, addressability, and functional robustness. Field-driven Janus microrobots are particularly well suited for such integration. Electrically powered metallodielectric Janus particles enable fuel-free propulsion under uniform electric fields and act as mobile microelectrodes, locally amplifying electric fields and gradients. This capability enables label-free cargo manipulation via dielectrophoresis, selective transport of synthetic [2] and biological payloads, and spatially localized interactions with cells and subcellular components. Within microfluidic devices, these mobile functionalities enable operations that are difficult or impossible to realize using static structures alone, including targeted electroporation [3], enhanced gene and molecular delivery, selective organelle manipulation, and programmable single-cell interrogation. The integration of microrobots into microfluidic devices becomes substantially more powerful when hybrid magnetic–electric [4] or opto-electronic [5] actuation is employed. Magnetic fields provide robust steering, rolling, and navigation across a wide range of solution conductivities, while electric fields offer frequency-tunable propulsion modes, reversible cargo loading and release, and controllable surface interactions. When combined with closed-loop feedback control, this hybrid framework enables precise and repeatable navigation of individual microrobots within microfluidic chambers, overcoming particle-to-particle variability under global actuation and addressing a key limitation identified in current microrobotics roadmaps. Overall, integrating microrobots into microfluidic devices shifts lab-on-a-chip platforms from passive flow-based systems to active, reconfigurable microsystems. This synergy directly addresses critical bottlenecks in microrobotics—control, reproducibility, and functional integration—while enabling new modes of manipulation, interaction, and automation with significant implications for single-cell analysis, targeted delivery, and next-generation microfluidic technologies.

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Room 35

Viscoelastic diode bridge for simple and sensitive rheological analysis of small volumes

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Viscoelastic fluids exhibit a broad range of behaviors that can be traced back to the coupling between viscous and elastic stresses that is not found in Newtonian fluids, such as pure water[1]. Viscoelasticity is the consequence of adding a small amount of large polymers to water. The result is turbulence-like fluctuations at small Reynolds numbers (Re<1) which in turn leads to changes in flow resistance. The flow properties of the viscoelastic fluid is a function of polymer content, making it highly relevant to perform rheological analysis of fluids in a broad range of application areas.

What limits the use of rheology as a tool for process monitoring, quality control and diagnostics is that standard rheometers are typically bulky, expensive and complicated to operate. They are therefore often found in dedicated laboratories leading to a time delay between sample collection and answer. Especially for medicine, the requirement for relatively large sample volumes limits their applicability and creates discomfort for the patients during sample collection. Highly trained staff are needed for their operation.

We offer a simple solution that addresses these concerns with conventional rheometers and that builds on our past work on viscoelastic fluctuations in microchannels[2, 3]. A rectifier is made by connecting four fluidic diodes[3] in a microfluidic device, just like the well-known electrical rectifier. We leverage the fact that the fluidic diodes only work for viscoelastic fluids and that their flow properties depend on the polymer composition of the fluid. We short-circuit the diode bridge with an observation channel where we detect the resulting unidirectional flow for viscoelastic fluids and zero flow for Newtonian fluids using particle tracking. Similarly, we monitor the total flow rate as a function of applied pressure in the inlet channel, to derive the viscosity. We show different responses for different concentrations and molecular masses of viscoelastic solutions of polyethylene oxide, DNA, hyaluronic acid, mucin, nanocellulose, at minute volumes of down to 10 microliter and concentrations down to 0.04%, something that is very challenging if not impossible using standard rheological methods.

In industry, we envision our simple device to open up for comprehensive rheology process monitoring and for quality control. In medicine, we envision not only to broader clinical use, with relevance for osteoarthritis (synovial fluid), but also home-use by patients, e.g. those in need of continuous monitoring with relevance for cystic fibrosis (sputum) and xerostomia (saliva). On the long term, the diode bridge be might be useful as a pump driven by ambient vibrations in wearable fluidics, in analogy to piezoelectric energy harvesting applications.

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Active Rosensweig Patterns

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Ferrofluids, colloidal dispersions of magnetic nanoparticles, are renowned for pattern formation like few other materials. The Rosensweig instability of a horizontal ferrofluid-air interface in perpendicular magnetic field is especially well known: this instability sets the air-ferrofluid interface into an array of spikes that correspond to a new free energy minimum of the system. However, once the pattern is formed, it does not exhibit any notable thermal or non-equilibrium fluctuations –it is passive. In this work, we present an active version of Rosensweig patterns. We realize them experimentally by driving a dispersion of magnetic nanoparticles with an electric field into a non-equilibrium gradient state and by inducing an instability using a magnetic field. The coupling of magnetic forcing and electrically driven convection leads to patterns that can be adjusted from quiescent classic Rosensweig-like behavior (low activity) to highly dynamic ones displaying peak and defect dynamics (high activity). We analyze the results using an active agent-based approach as well as from a continuum perspective. We propose a minimal Swift–Hohenberg type model to capture the essential dynamics of these active patterns. Our results suggest that classic equilibrium systems exhibiting pattern formation can be activated to display considerably more complex dynamic phenomena inspired by living systems.

Controlled Formation of Poly(lactic acid) Stereocomplex via Microfluidic Processing

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Poly(lactic acid) (PLA) is a widely used bio-based polymer due to its renewable origin, biodegradability, and versatility across packaging, biomedical, and additive manufacturing applications. Poly(lactic acid) (PLA) is an extremely attractive material due to its unique crystallization versatility: it can crystallize not only in the homopolymeric form from poly(L-lactic acid) (PLLA) or poly(D-lactic acid) (PDLA), but also as stereocomplex (SC) crystals through the association of enantiomeric PLLA and PDLA chains [1]. This dual crystallization capability enables access to crystalline structures with distinct and tunable thermal and mechanical properties, broadening the range of potential applications for PLA. Stereocomplex crystals exhibit tighter chain packing and significantly higher melting temperatures, resulting in improved thermal stability, mechanical strength, and long-term durability. Despite their promising properties, current stereocomplex production methods—primarily melt processing and solution casting—offer limited control over crystal purity, spatial localiza- tion, and reproducibility. High processing temperatures, complex thermal histories, and bulk crystallization often lead to the coexistence of stereocomplex and homochiral crystals, while preventing direct observation of stereocomplex nucleation and growth. In this work, we develop a continuous, solution-based microfluidic platform with a Y-junction geometry for the controlled production of PLA stereocomplex crystals at room temperature. Enantiomer-pure PLLA and PDLA solutions in chloroform are combined under well-defined flow conditions, enabling precise control over residence time and mass transport. By exploiting the markedly lower solubility and higher thermodynamic stability of PLA stereocomplex crystals in chloroform compared to homochiral α-form PLA [2], stereocomplexation is selectively favored while competing homocrystallization is suppressed. We demonstrate that increasing the resi- dence time systematically enhances the stereocomplex fraction at the outlet. Rational device design guided by diffusion and crystallization timescales further enables tunable control over stereocomplex formation and productivity under continuous flow. The output materials are quantitatively characterized using X-ray scattering techniques and differential scanning calorimetry (DSC), allowing precise determination of crystalline structure, stereocomplex content, and thermal properties. In addition, the transparent microfluidic platform provides direct optical access to the region where the enantiomeric solutions interact, enabling real-time observation by optical and polarized light microscopy. Overall, this study introduces a novel, continuous microscale strategy for PLA stereocomplex production and provides new insights into stereocomplexation kinetics under well-defined, non- equilibrium conditions, paving the way for scalable manufacturing of high-performance, fully bio-based polymer materials.

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Directional fluidity induced by asymmetric wall roughness

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The yielding transition of soft glassy materials plays a crucial role in the flow and processing of complex fluids, including dense emulsions encountered in microfluidics and industrial applications. In this work, we investigate how asymmetric surface microroughness influences the flow of yield-stress emulsions through microchannels, with a focus on geometry-driven control of droplet and emulsion dynamics. We compare two engineered roughness geometries—herringbone riblets and wedge-shaped patterns—that introduce topological asymmetry along the flow direction. Experiments with yield-stress emulsions show that these patterns can enhance flow either in a directional way or selectively across the channel cross section: herringbone riblets induce pronounced flow banding with peak enhancement near the groove tips, while wedge-shaped ramps promote flow enhancement along the rising slope. Complementary numerical simulations using 2D Lattice Boltzmann methods highlight the interplay between pressure gradient, surface geometry, and non-Newtonian rheology in determining flow response. This combined experimental and computational study sheds light on how controlled surface design can modulate emulsion flow and droplet behavior under confinement, with potential implications for rheological control in microfluidic and industrial processes.

Deciphering equatorial magnetoaerotaxis of magnetotactic bacteria using microfluidics

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Magnetotactic bacteria navigate redox gradients through magnetoaerotaxis—passive magnetic alignment coupled with active aerotactic swimming toward optimal oxygen levels. The consensus model, based on run-reverse motility in model species like AMB-1/MSR-1, assumes bacteria reduce 3D search to 1D by swimming along magnetic field lines. However, this framework (i) does not account for the diverse swimming behaviors across MTB phyla, including the run-tumble and complex helical trajectories of species like the bilophotrichous Magnetococcus marinus MC-1 (ii) does not explain the presence of MTB at the equator.
To understand how morphology and motility couple with magneto-aerotaxis across latitudes, we compared MC-1 and AMB-1 under three geomagnetic conditions using 3D Helmholtz coils and microfluidics: magnetic field parallel and antiparallel (poles), and perpendicular (equator) to oxygen gradients. Surprisingly, MC-1 departs from field-aligned swimming when gradients are perpendicular to the magnetic field, exhibiting run-tumbles and misaligned reversals that enable spatial exploration orthogonal to the magnetic field. This allows MC-1 to migrate along oxygen gradients even when strong perpendicular magnetic fields are applied, as demonstrated during dynamic gradient switching. In contrast, AMB-1 maintains mostly run-reverse behavior and struggles with perpendicular migration.

These results explain why coccoid MTB like MC-1 dominate at the geomagnetic equator, where magnetic fields are perpendicular to oxygen gradients—a scenario where traditional, unidimensional magneto-aerotaxis would be disadvantageous. Our findings demonstrate that MC-1 adaptively varies its swimming strategy to navigate complex environmental geometries, highlighting the importance of species-specific motility in understanding MTB ecology and distribution.

Optical Splitting of Droplets on Engineered Lithium Niobate Surfaces

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The controlled and reproducible **splitting** of liquid droplets is a key function in many fields and for microfluidic applications. In recent years, various strategies have been used to achieve this task. In this work, we present an optofluidic technique based on an engineered surface composed by coating a z-cut iron-doped lithium niobate (**Fe:LiNbO3**) crystal with a lubricant-infused layer (**LIS**), which provides a very slippery surface for prolonged use. The illumination of the crystal with a light spot induces the accumulation of surface charges of opposite signs on the two opposite crystal faces as a result of the **photovoltaic effect**. If the light spot is intense enough, microliter water droplets (corresponding to a few millimeters in size) placed near the illuminated area split into two charged fragments: one fragment remains trapped by the bright spot, while the other one moves away from it. The latter fragment does not move randomly, but follows one of three well-defined trajectories separated by 120°, which reflect the anisotropic crystalline structure of Fe:LiNbO3 . Numerical simulations explain the behavior of water droplets within the framework of the forces induced by the interplay of **photovoltaic effects** and **thermo-piezo stresses**, induced by laser illumination, which originate simultaneously within the illuminated crystal [1]. The time required for the droplet splitting is characterized by varying experimental parameters such as droplet volume, illumination intensity, or mutual distance between the spot and the droplet [2]. Interestingly, the same splitting behavior is also observed for **organic liquid droplets**. Unlike water, organic liquids do not contain ions and can be polarized by the evanescent field
generated by the surface charges of Fe:LiNbO3. The study of the splitting time can provide a valuable feature in applications that require splitting and coalescence of droplets, such as chemical microreactors and biological encapsulation and screening.

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Poster contributions
Tuesday 19/05, 16:20 - 17:20

Poster TU-1

Zero-leakage sealing systems for storable propellants

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Despite major advances in rocket technology, recent incident reports indicate that complete reliability remains an ongoing challenge. TFor launchers to achieve high reusability at the lowest cost with minimal environmental impact, resilience is a critical requirement for almost all launch vehicle subsystems. Among these, fluid valves remain a major concern; failures in sealing systems, such as the recent issues observed in Boeing's Starliner capsule, highlight the difficulty of maintaining effective seals under extremely severe working conditions, including cryogenic temperatures and aggressive fluids.

The aim of this research is to understand and characterize micro-leakage flows within such rocket sealing systems. To address this, a predictive model capable of quantifying leakage flows between the valve seal and seat is being developed and validated against experimental data provided by industrial partner Safran Aero Boosters. The flow physics in these sealing interfaces typically fall within the slip flow regime, with Knudsen numbers ranging from 0.01 to 0.1. To accurately model fluid behavior at this magnitude, the Lattice Boltzmann Method (LBM) is employed via the open-source software OpenLB. The LBM offers many advantages at such scales. It is a highly parallelizable algorithm, allowing for much faster calculations and the implementation of complex boundary conditions is straightforward. Additionally, it can capture fluid behavior at the mesoscopic scale, where the no slip conditions start to break down and classical NSE no longer hold true. A critical advancement presented in this work is the implementation of specific slip boundary conditions to correctly resolve the non-zero velocity at the walls, which is essential for accurate prediction in micro-channels.
A major methodological pivot from previous work concerns the geometric representation of the sealing interface. Early models relying on Gaussian statistics proved to be insufficient to capture the complex, multi-scale topography of industrial finishes. An innovative digital twin" generation method based on Spectral Synthesis has then been developed. Using Power Spectral Density (PSD) analysis of raw profilometry data from valve seats, we reconstruct 3D surfaces that statistically replicate the spectral signature of authentic production parts. This ensures that the numerical domain is equivalent to the physical microscopic geometries.

Given that the surface roughness of valve seals can reach values as low as 0.1\mu m to ensure leak-tightness, resolving fluid flow at this magnitude requires extremely fine meshes, requiring requesting high computation resources. Consequently, the workflow is implemented on the Tier-1 supercomputer LUCIA (Cenaero, Belgium). This paper presents the complete predictive framework: from the spectral generation of realistic rough surfaces and the determination of effective gap heights based on experimental data, to high-fidelity LBM simulations of rarefied gas flows. The model is still to be validated against leakage rate test campaign results.s Bbut it is hoped to provide a robust tool for designing the next generation of "zero-leakage" space launchers components.

Poster TU-2

Modelling red blood cell flow through geometric disturbances to alter their cross-sectional distribution

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Flowing blood through microfluidic devices has numerous applications, such as blood-plasma separation or isolation of circulating tumour cells [1]. In order to optimise those devices, an understanding of the mechanisms changing the cross-sectional distribution (CSD) of red blood cell suspensions is necessary. In this work, we numerically investigate how two different geometrical structures, a narrowing of the channel and a bifurcation, alter the CSD of the red blood cell suspension, and the conditions for the suspension to recover its pre geometrical disturbance distribution [2, 3].

We model blood as a suspension of deformable particles in a continuous fluid [1]. We simulate the continuous fluid with the lattice-Boltzmann method, and we model the red blood cells with an isotropic and hyperelastic model (Skalak' s model). The fluid-structure interaction between the red blood cells and the fluid is resolved using the immersed boundary method. This method has previously been shown to reproduce the physics of red blood cell suspensions.

Our results show that by flowing the suspension through a geometric narrowing, the width of the CSD is narrowed in a haematocrit (concentration of red blood cell) dependant way, while the centre of mass of the CSD is unchanged. On the other hand, when the suspension reaches a bifurcation, the centre of mass of the CSD is shifted towards the inner side of the bifurcation, while the width of the CSD is less affected. The mechanisms to recover from those changes in CSD differ as well. On the one hand, when the CSD of the red blood cells is narrowed through the geometric constriction, the pre disturbance distribution is recovered through cell-cell interaction, making the length scale of the recovery haematocrit dependant [4]. On the other hand, when the suspension reaches a bifurcation and the centre of mass of the distribution is changed, the recovery mechanism is due to the lift force driving red blood cells away from the channel wall, and is largely independent of haematocrit, with a fixed length scale of 25 channel diameters [5].

In this work, we model red blood cells as a suspension of deformable red blood cells and flow them through geometric disturbances (a narrowing of the channel and a bifurcation) to investigate how the cross-sectional distribution of the suspension changes. Our results show that one can modulate the centre of mass or the width of their CSD separately, and we investigate the length scale and mechanisms for the recovery of the CSD. This work shows different ways that one can modulate red blood cell suspensions in microchannel to manipulate blood in microfluidic devices.

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Poster TU-3

Numerical Investigation of a Cristae-Inspired Passive Micromixer for Microfluidic Applications

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Microfluidic lab-on-a-chip (LOC) systems integrate key analytical processes, such as sample preparation, reaction, separation, and detection, within miniaturized platforms for chemical and biomedical applications. Efficient fluid mixing has been a major challenge in these systems due to the dominance of laminar flow and low Reynolds number conditions, where mixing is predominantly dependent on slow molecular diffusion. Achieving rapid and homogeneous mixing within limited channel lengths is difficult. In this study, a bioinspired passive micromixer is developed based on the cristae architecture of mitochondria, which is known for maximizing surface area and transport efficiency in biological systems. The micromixer incorporates cristae like microstructures within a straight microchannel to produce continuous flow deflection, stretching, and folding, thereby promoting chaotic advection without taking the advantage of external energy sources. This design preserves the fundamental advantages of passive micromixers, that include structural simplicity, low fabrication complexity, and ease of integration with the lab-on-a-chip platforms. Numerical simulations were carried out to investigate the mixing performance of the proposed micromixer under laminar flow conditions across a range of Reynolds numbers (Re<100) that are relevant to microfluidic applications. Mixing efficiency is evaluated using concentration field analysis and a mixing index. The results have shown a significant improvement in the mixing efficiency in comparison to the conventional straight microchannel, attributed to increased interfacial area and enhanced transverse flow generated by the cristae-inspired geometry. The proposed design has shown the potential of mitochondrial-inspired microarchitectures for improving passive micromixing performance and provides a promising approach for advancing microfluidic mixing in biomedical diagnostics, chemical synthesis, and microscale analytical systems.

Poster TU-4

Opto-microfluidics as a promising solution for an effective and fast detection of solid contaminants in liquids

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The issue of microplastics (MPs) pollution is becoming increasingly significant for the environment and health due to the uncontrolled release of plastic waste. It is also a health concern, particularly when considering their release in pharmaceutical liquid products. This serious contamination, which has become a concern since the last few years, demands the development of new methodologies for the sensing of MPs, particularly when the latter are dispersed in water. Opto-microfluidics is a promising solution for the effective and fast detection of MPs. This is due to its inherent capability of handling and dealing with liquid samples, while ensuring high-throughput analysis. In this work, we used a droplet-based opto-microfluidic device integrated on a lithium niobate substrate in order to analyse water droplets containing plastic microspheres with a diameter lower than one micrometre. Their detection is achieved by combining both the multispectral imaging and the analysis of the transmitted light intensity through the droplets, distinguishing between liquid solutions from those with suspensions of MP particles in concentrations up to few mg/g. The focus of this study is the interaction between light droplets, with a particular emphasis on assessing the impact of various factors on sensing. These factors include microplastics size and concentration and identification and investigating the relative detection limits.

Poster TU-5

Modular Comb-Shaped Fluorosurfactants for Functional Droplet-Based Microfluidics

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Droplet-based microfluidics is a growing technique used in biology, chemistry and material science, enabling high-throughput applications in the fields of synthetic biology and single-cell biomedical analysis. These systems rely on stable, monodisperse water-in-fluorinated oil (w/o) droplets, typically stabilized by fluorinated surfactants. Current diblock and triblock commercial copolymers surfactants are based on poly(ethylene glycol) (PEG) and perfluoropolyether (PFPE) chains (PEG-PFPE), however, their limited chemical reactivity restricts further functionalization and application versatility.

Here we report on a new class of comb-shaped oligomeric fluorosurfactants consisting of a hydrophilic N vinylformamide (NVF) backbone functionalized with long PFPE side chains. The NVF backbone is water-soluble, biocompatible, and readily functionalizable through partial hydrolysis to N vinylamine, enabling the introduction of additional chemical moieties. The synthesis involves cationic oligomerization of NVF, controlled hydrolysis, and subsequent side-chain and functional group conjugation, providing a modular and customizable surfactant platform.

The designed comb-shaped fluorosurfactants stabilize droplets for several weeks and show preliminary biocompatibility. Functionalized variants incorporating fluorescein or biotin were successfully produced, enabling fluorescence labelling and biomolecular capture at droplet interfaces. This modular surfactant system expands the functional capabilities of droplet microfluidics and opens new opportunities for advanced bio- and materials-based applications.

Poster TU-6

Sustainable Amidation of Polyhydroxyalkanoates: From Green Synthesis to Dynamic Antimicrobial Testing in Microfluidic Platforms

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Polyhydroxyalkanoates (PHAs) represent a premier class of bio-based polyesters with significant potential as eco-friendly alternatives to traditional plastics; however, their inherent hydrophobicity often limits their processability and biological applications. This research proposes a sustainable chemical modification strategy to overcome these limitations through a novel amidation process employing the biocompatible ionic liquid choline taurinate ([Ch][Tau]) to introduce sulphonic moieties on the polyester backbone. This green chemistry approach enables precise control over the degree of functionalization and the resulting amphiphilic properties. The obtained structures, composed of hydrophobic (polyester) and hydrophilic (taurine) units, showed the ability to self-assemble in an aqueous environment and encapsulate usnic acid, a powerful antimicrobial agent. A key innovation of this work lies in the comprehensive evaluation of the antimicrobial performance of modified PHAs, both alone and in the presence of usnic acid. The antimicrobial characterisation was conducted through a dual-stage experimental setup comparing static and dynamic conditions. While traditional static assays provided a baseline for antibacterial efficacy, the core of our characterization utilized advanced microfluidic platforms to simulate physiologically relevant environments. By implementing dynamic microfluidic testing, we were able to monitor bacterial behaviour and material-pathogen interactions under continuous flow and controlled shear stress. This microfluidic approach proved essential to demonstrate that the [Ch][Tau]-modified PHAs maintain superior antimicrobial activity and anti-fouling properties even under hydrodynamic regimes, which are not capturable via standard static methods. These findings highlight the potential of functionalized PHAs as versatile biomaterials for high-performance applications, such as wound healing and advanced drug delivery systems, where performance under flow is a critical requirement. This study underscores how the synergy between sustainable macromolecular engineering and microfluidic characterisation can unlock the full potential of next-generation biopolymers.

Poster TU-7

Study of the transmembrane transport of ions into lipid vesicles prepared using different methods

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The transmembrane transport of ions by membrane-bound proteins is an essential biological process for maintaining cellular ion balance. Disrupted ion transport by dysfunctional channels, associated with diseases such as cystic fibrosis and epilepsy, could be alleviated by synthetic ion carriers [1]. Before testing the activity of the synthetic ion carriers in real cells, it is generally studied in cell-mimicking lipid vesicles. These cell models can be prepared by different methods, resulting in the formation of vesicles having varied sizes and properties. Large unilamellar vesicles (LUV) with a size range of 100-200 nm and giant unilamellar vesicles (GUV) of size 5-100 μm are potential cell models to study ion transport across the membrane [2].

Here, we present the ion transport studies performed in LUVs prepared by the extrusion method [3] and in GUVs prepared by microfluidics using a double emulsion template [4] and the gel-assisted method [5]. Vesicles of different sizes require ion transport studies to be performed using different methodologies, such as fluorescence spectroscopy in LUVs and fluorescence microscopy in GUVs. We first investigated ion transport in LUVs using fluorescence spectroscopy to compare different macrocyclic transporters [6]. Based on these results, we then examined the activity of the most effective macrocyclic transporter in GUVs prepared by the above-mentioned methods, visualizing ion transport using fluorescence microscopy.

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Poster TU-8

Nanoformulations of Cu complexes for medical use: a preliminary study

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Copper–dithiocarbamate complexes (Cu-DTC) have demonstrated the ability to induce cell death in certain tumor cell lines, making them potential candidates for the development of new anticancer treatments. However, their clinical application is limited by poor water solubility, which negatively affects bioavailability and drug delivery. To overcome this limitation, the present study investigates the encapsulation of Cu-DTC complexes within liposomes, aiming to enhance solubility and stability, and achieve a controlled and effective release of the active compound.
The study was developed in several phases. Initially, three copper complexes, namely Cu(DASD)2, Cu(DEDC)2, and Cu(DBODC)2, were synthesized and characterized by infrared (IR) and elemental analysis. The solubility studies revealed that the copper complex with DASD ligands was insoluble, while the one with DEDC ligands was soluble but only at low concentrations, and the complex with DBODC ligands showed better solubility. Consequently, only the latter two complexes were selected for further experiments.
A preliminary encapsulation of these two complexes into liposomes made by phosphatidylcholine (PC) was performed using the ethanol injection technique to evaluate both the size of the liposomes and the amount of loaded active substance. The size of the liposomes increased slightly in the presence of the active compound. The encapsulation capacity of the $Cu(DEDC)_2$ complex determined by UV analysis was found to be very low, making it unsuitable for further studies, while the Cu(DBODC)2 complex resulted in sufficient encapsulation efficiency to justify its use in subsequent experiments.
Afterwards, the study was transferred to the microfluidic system. Empty liposomes were produced by varying lipid concentration, FRR and TFR parameters. Then, Cu(DBODC)2 complex was added to the selected formulations, showing an average size less than 200 nm with a slightly increase over time. The encapsulation of the active compound determined by filter centrifugation followed by UV analysis reached 80% of drug loading.
Finally, Franz diffusion cells experiment using a cellulose membrane and H_2O:EtOH (50:50 v/v) as the receiving phase at 37 ℃, were conducted to evaluate the release of the active ingredient. The formulations were tested and compared with the copper complex dissolved in ethanol at the same concentration. Samples were collected for eight hours and analyzed by UV spectroscopy. The free complex in ethanol did not diffuse through the membrane, instead accumulating on its surface, as evidenced by yellow colour. The diffusion of the encapsulated complex from liposomes showed a biphasic release profile, with a rapid initial phase up to 2 hours, followed by stabilization with approximately 20–40% drug released after 6–8 hours.

Poster TU-9

Microfluidic Synthesis of Cu Nitroprusside Nanoparticles for Cancer Therapy

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Sodium nitroprusside is an FDA-approved medication used during hypertensive crises. When this drug reacts with metallic salts, it forms metal–nitroprusside complexes, which have good electrochemical and photocatalytic activities. Recently these complexes have been studied for cancer treatment. Under acidic conditions –such as those found into the tumor cells –metal-nitroprusside materials decompose and promote Fenton and Fenton-like reactions, generating reactive oxygen species (ROS) that kill cancer cells. Metal nitroprusside synthesis is typically performed in batch processes and often use non-green solvents. As a result, controlling nanoparticle size and uniformity, while also using green solvents, remains challenging. In this study, we used microfluidics to synthesize copper nitroprusside nanoparticles (CuNNPs) in citrate buffer as a strategy to overcome the limitations of batch production and the use of non-green solvents, obtaining CuNNPs with sizes in the 20–30 nm range, confirmed by TEM images. XRD and TGA analyses confirmed that CuNNPs obtained by the traditional batch method are anhydrous, while CuNNPs synthesized via microfluidics in citrate buffer correspond to the hydrated form. We compared the cytotoxicity of citrate-buffer microfluidics-synthesized CuNNPs (hydrated) and traditional batch-synthesized CuNNPs (anhydrous) in Kuramochi (ovarian cancer), Colo201 (colon cancer), and FT190 (normal) cells.The results showed that the IC_{50} values for microfluidics-synthesized CuNNPs versus batch-synthesized CuNNPs were 2.72 ± 1.54 vs 1.48 ± 0.80 μg/mL (Kuramochi) and 7.47 ± 3.81 vs 6.21 ± 1.93 μg/mL (Colo201), while in normal FT190 cells the microfluidics-synthesized CuNNPs were much less cytotoxic (IC_{50} = 158.00 ± 37.47 μg/mL) than batch-synthesized CuNNPs (IC_{50} = 5.93 ± 0.32 μg/mL), suggesting minimal toxicity. These findings highlight the potential of CuNNPs as a cancer nanomedicine while emphasizing the need for further in vivo/organ-on-a-chip investigation to confirm their safety and effectiveness.

Poster TU-10

Simple tunable ionic memristor based on access resistance to a cation-selective membrane

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One of the striking results of the artificial-intelligence revolution is the energy consumption associated with it, especially compared to the energy consumed by a human brain. Among many differences between classical computing and brain functioning, the architecture and the carriers are among the most important. In a computer, the data are stored and processed in different location, while these tasks are not spatially differentiated in a brain. Bridging this gap could be possible with a new electronical device called a memristor, whose resistance depends on the current that crossed it in the past. Regarding the carriers, brains use ions (iontronics), which can be of different natures, while computers are limited to electrons. Multiplying the possible carriers could open new routes for more complex operations. In the past recent years, many examples of nanofluidic devices proved to be memristors, due to different physical phenomena. Most of them work thanks to tailor-made nanopores with specific geometries, and thanks to the control of the nanopore surface charge.

In this work, we present a microfluidic system based on a commercial ion-selective membrane which behaves as a resistor, a diode, or a memristor depending on the typical time of the writing/reading processes. The simplicity of the device allows us to precisely pin-point the physical phenomena at stake in these processes, and to open new routes for simple design of iontronic memristors.

The experimental setup consists of a unique ion-exchange membrane (Nafion) separating two similar electrolytes. Selective membranes are known to create concentration polarization under current. The geometry of the setup is hence designed such as the dominating resistances are located in these concentration polarization zones. This is achieved using masking windows creating an access resistance to the membrane [1]. A 1-Volt sinusoidal voltage is imposed on the system at different frequencies, and the I-V response is measured to characterize the memristor effect. A model based on the Poisson-Nernst-Planck (PNP) equations is developed to rationalize the experimental results.

Results shows that the symmetry between the two sides of the membrane yields two different memristor signatures: the hysteresis loops in their I-V curves are self-crossing (asymmetrical configuration) or not (symmetrical configuration), as predicted by the model of Kamsma [2]. Moreover, the system behaviour has been mapped according to the configuration, frequency and radius of the mask opening. Three different regions of behaviours were determined for a symmetric and an asymmetrical configuration: diode, memristor and resistor. These mapping is very close to the results of our theoretical model based on the concentration polarization at the membrane.

The experimental characterization of our Nafion-based memristor is well described by our PNP model considering concentration polarization and membrane access resistance. In the future, this model system will enable comparison with tailor-made nanopores [3], and motivates miniaturization and parallelization of the present device.

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Poster TU-11

Microfluidic studies in hemorrhagic shock of varying degrees

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Red blood cells play a central role in blood flow. Their role in macro- and microcirculation cannot be overstated. Microfluidity in the tiniest capillaries is key to adequate blood supply to organs, tissues, and systems in both healthy and pathological conditions. Microcirculation plays a particularly important role in studying brain circulation, where the capillaries of the arachnoid space are sometimes three times smaller than the red blood cell itself. The specifics of this mechanism are difficult to study in various pathological conditions. However, the more closely a condition is linked to the physical and spatial properties of blood, the more difficult it is to determine the fundamental mechanisms regulating red blood cell behavior. Hemorrhagic shock is one such condition. In hemorrhagic shock, microcirculation is critically disrupted, and the delivery of oxygen and nutrients to tissues due to acute blood loss manifests as the inability of capillaries to adequately support exchange, leading to multiple organ failure. Assessing the state of microcirculation (for example, in the skin) helps monitor the effectiveness of therapy.
Highly controlled studies using microfluidic systems
play an important role in understanding the behavior of red blood cells under the influence of pathogenic environmental factors and in selecting selective protective measures against them.
Studying pathological aggregation and deformation of red blood cells is important. Understanding the mechanism of aggregate formation under conditions of normal and increased viscosity is highly relevant for hemorrhagic shock of varying severity. We used microfluidic chips for red blood cells. These miniature devices reproduce microcirculatory conditions to study the deformability, transport, and properties of red blood cells at a scale that mimics capillaries, allowing for analysis of red blood cells. It turned out that during the first and second stages of hemorrhagic shock, red blood cell deformability remained unchanged, but red blood cells aggregability changed. During the third stage of hemorrhagic shock (the uncompensated stage), red blood cells aggregability and deformability changed dramatically. Assessing the elastic properties of red blood cell is crucial for assessing the degree of oxygen delivery.
Thus, our microcirculation simulation allowed us to assess red blood cell erythrocyte deformability and aggregability, which is crucial for clinically assessing the stage of hemorrhagic shock.
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Poster TU-12

Microfluidic Single-Cell Analysis of CAR-Induced Modulation of NK Cell Cytotoxicity

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Chimeric antigen receptor (CAR) therapies have transformed hematological cancer treatment by enabling immune cells to specifically target tumour antigens. Natural Killer (NK) cells are emerging as a promising CAR platform due to their favourable safety profile and broader accessibility. However, NK cells exhibit pronounced functional heterogeneity, with only subsets capable of efficient cytotoxic and serial killing. How CAR expression influences this heterogeneity at the single-cell level remains poorly understood, as cytotoxicity bulk assays obscure individual cell behaviour.

To address this, we employ a droplet-based microfluidic platform to analyse CAR-NK cell cytotoxicity at single-cell resolution. Individual CAR-NK cells are co-encapsulated with multiple target cells, enabling imaging-based quantification of killing dynamics. Droplets are subsequently sorted based on cytotoxic activity, allowing downstream single-cell analysis of killer and non-killer populations.

Preliminary results show an approximately 10% increase in serial killers and monokillers among CAR-NK cells compared with untransduced controls, indicating that distinct killing phenotypes persist after CAR engineering. Sorted killer CAR-NK cells exhibit a trend toward lower CD16 expression, consistent with its known shedding during serial killing. Ongoing studies examine the impact of CAR density and different CAR constructs.

This platform will be extended to multi-omics profiling, including single-cell RNA sequencing, to identify molecular signatures underlying cytotoxic potency. These insights will inform NK cell engineering strategies and support the optimization of next-generation CAR-NK immunotherapies.

Poster TU-13

Investigating the antimicrobial activity of free and encapsulated Green Tea in microfluidic environments

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Biofilm-forming microorganisms adhere to surfaces and are embedded within an extracellular polymeric substance (EPS) matrix; they are, therefore, up to 1,000 times more resistant to antibiotics than their planktonic counterparts. This resilience poses a significant global health and economic challenge. This study investigates the antibiofilm efficacy of free and encapsulated polyphenol-rich Green Tea (GT) as a potential alternative for preventing or mitigating biofilm-associated infections.

Surface colonization and biofilm formation by clinically relevant *Pseudomonas aeruginosa* and *Klebsiella pneumoniae* were monitored under fluid shear stress, within PDMS microchannels, via phase-contrast and fluorescent microscopy.

The inhibitory effect of Green Tea was investigated by solely dissolving GT in the culture medium or encapsulating it within nanoparticles constituted by a matrix of a synthetic self-surfactant polyester, polyhydroxybutirate-co-hydroxyexanoate (PHBHHx). GT-PHBHHx loaded nanoparticles were compared to unloaded PHBHHx equivalents and to free GT to decouple and investigate the specific and potential antimicrobial effects of the natural compound and the self-surfactant polyester.

Both free Green Tea and GT-loaded nanoparticles exhibited anti-colonization and antibiofilm properties in a fluidic environment. These findings highlight the promising potential of natural polyphenols and self-surfactant polyesters as innovative agents for the prevention and treatment of biofilm-related infections.

Poster TU-14

Dynamics of Perception-induced Heat Shock responses in Caenorhabditis elegans

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Cells protect themselves against heat stress through a variety of highly conserved mechanisms to prevent protein damage and maintain cellular integrity and function. The most studied response to rapid increases of temperature is the heat shock response (HSR), which triggers the expression of heat shock proteins (HSPs), which then act as chaperones
to prevent protein misfolding. While the HSR is well-studied in single cells, much less is known about whether in multicellular organisms, the HSR is purely cell-autonomous and whether the HSR can, for instance, be induced or modulated by systemic inputs such as the neuronal perception of heat.
In C. elegans, temperature perception is mediated by the AFD neuron, located in the head of the animal. To what extent AFD activity is involved in the HSR across tissues is still a subject of research. Most approaches have focused on either abolishing AFD activity or
genetic ablation of the neuron. However, fewer teams have tried to obtain physiological activation of the AFD neurons by increasing the temperature only in the anterior region of the worms. Does exposing the head to HS-inducing temperatures produce the same effects as full body heat shocks?
To address this question, we developed a long-term imaging platform to immobilize adult worms and apply a steep temperature gradient along the antero-posterior axis of the worm. We used a microfluidics solution based on the WormSpa chip by Kopito and Levine [1], that we position on a coverslip patterned with transparent micro-heaters made from Indium Tin Oxide (ITO). Using high-resolution infrared camera measurements, we show that with optimized micro-heater patterns, temperature gradients up to 12K/mm can be achieved within our device. Thus, our setup allows us to control the temperature within C. elegans at the microscale across the animal, while permitting high resolution live imaging in immobilized animals. To characterize potentially non cell-autonomous dynamics of the C. elegans HSR we use two reporter strains: 1) Endogenously-tagged GTBP-1::RFP [2] and 2) Endogenously-tagged HSP90-mCherry (provided by Eric Cornes). By first applying uniform temperature increases across animals we identified tissue-specific dynamics of our HSR reporters. For instance,
accumulation of GTBP-1 in stress granules in intestinal cells and embryos takes between 4 to 10 min and requires temperatures of 29 to 31℃. However, a similar response in the germline and mature oocytes takes longer (10-20 min) requires higher temperatures (32-34℃). Interestingly, we did not observe such tissue specific differences in activation times for HSP-90.
Preliminary results using our temperature gradient setup indicate that stress granules appear only in the region exposed to the high temperature for both germline and embryos. However, the intestinal cells show stress granule formation along the entire body, even in animal parts not subjected to heat shock. Our results indicate that the HSR is highly tissue-specific and neuronal inputs may modulate its dynamics only in a subset of tissues.

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Poster TU-15

Microfluidic GUV Sizing and Sorting for Synthetic Cells Sabine

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Synthetic cells are bioengineers' route to understand the molecular blueprint of life. We want to find the spatiotemporal combination of biomolecules that will divide a cell-like giant-unilamellar vesicle (GUV) and sustain biochemical homeostasis post-division. Synthesizing GUVs typically results in a broad range of GUV sizes, e.g. 1-100 μm. However, a consistent GUV size is crucial for gaining control and understanding of the synergistic integration of biomolecules. We therefore set out to make monodisperse GUVs of 1-5 μm, as foundation
for synthetic cells. We developed an analysis pipeline to determine the GUV size from its volume, using confocal microscope z-stack series. We show that the maximum size of GUVs in the population can be chosen by the height of a microfluidic chip. In addition, a microfluidic deterministic lateral displacement (DLD) bumping array can sort GUVs at a theoretical and an apparent cutoff size. Finally, we show that proteoGUVs biochemical behaviour is dependent on GUV size. Future work includes the microfluidic integration of DLD-array with
chip height for consistent synthetic cell experiments.

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Poster TU-16

Microfluidic focusing, rolling and sorting of pollen grains

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The incidence of pollen allergies is steadily increasing, now affecting 20-30% of the global population (Alska et al., 2025). Several factors contribute to this. First, there is an increase in sensitization to pollen, for which the "hygiene hypothesis" is considered a major cause (Platts-Mills, 2015). Furthermore, urbanisation entails an increased exposure to air pollutants that have been linked to greater severity of allergic reactions (Zhao et al., 2016). Additionally, climate change seems to play a crucial role: with increasing carbon dioxide concentration and warmer temperatures, plants can grow more and flower for longer, leading to greater pollen production (Ariano et al., 2010, Ziska et al., 2019).
Therefore, monitoring pollen is, and will be, crucial to deepen our understanding of its distribution and epidemiological implications. Currently, most of the pollen monitoring and counting is performed manually from Hirst type volumetric traps (Hirst, 1952), making it both expensive and time-consuming. This prevents real-time monitoring and dense sampling, since the observation stations must be checked by trained personnel at best daily. Recently, there have been attempts to automate pollen sampling and identification both in Germany (Oteros et al., 2015) and Switzerland (Sauvageat et al., 2020). However, such devices are still costly and can only reliably identify a few pollen taxa.

Our work focuses on conceiving microfluidic devices that allow for automated pollen monitoring, with the overarching goal of real-time automated classification and counting of pollen grains. The first step towards such an ambitious objective is to develop a microfluidic platform able to acquire sharp images of pollen grains from different perspectives in a continuous flow.
We have employed 2.5D hydrodynamic focusing to capture high-resolution images of pollen grains flowing in our device by confining the sample at the bottom of the channel (Patel et al., 2023). By doing so, the pollen grains are also subjected to a steep gradient of shear forces, thereby inducing rotation within the camera's field of view (Kleiber et al., 2020). Therefore, we can obtain several images of the same pollen grains from different angles. This will allow us to obtain a reliable training dataset for a neural network programmed to automatically classify pollen from microscopic images.

Concurrently, we are exploring how acoustic forces can help achieve focusing and multi-angular imaging of pollen. As proof of concept, we employed a bulk acoustic wave device comprising a silicon-glass chip and a piezoelectric element actuated with dual frequency (Jonai and Akiyama, 2023), thus achieving two-dimensional focusing of the pollen grains.

This work is the first step to achieve automated, real-time pollen monitoring. We envision an inexpensive microfluidic platform that can be deployed in every location of interest, able to provide images of the airborne pollen grains at any given time.

Poster TU-17

Microscale impact of bacterial activity on evaporating interfaces

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Soil evaporation is a globally significant process which returns a fifth of terrestrial precipitation directly to the atmosphere. As soil is a porous medium composed of aggregates that create pores filled with water and air, this large scale process is governed by microscale air-water interface dynamics. An efficient drying of soil is ensured by capillary flows along water films which must be continuous from the top of the soil down to the evaporative front [1]. Evaporation is therefore sensitive to processes that impact the properties of the interface between air and water, such as adsorption of surface active molecules or changes in grain wettability.

Soil is rich in bacterial life, with a typical number of 10^{10} bacteria per gram of top soil. These many bacteria are also diverse, with some strains having strong affinity to air-water interfaces. As part of their colonisation of interface, some bacteria produce biosurfactants which alter significantly the surface tension of air-water interfaces. Later, biofilms forming there can confer visco-elastic properties to these interfaces, changing fundamentally their responses to pressure variations [2]. My thesis project investigates how bacterial colonization of air-water interfaces and the subsequent changes of their mechanical properties impact drying dynamics.

To this end, we propose a capillary microfluidic device to model a soil pore with an open air-water interface under evaporative forcing at one end. We control the water pressure in the microfluidic device to simulate a varying evaporative front, and confirm that our design reproduce sudden interface jumps at critical pressures as in Haine's jumps in soil. Initially, the characterization of water loss is necessary to understand the drying dynamics in our model [3]. We characterize the controlled drying rate at the air-water interface that can be achieved in this device by varying the relative humidity of a forcing air-flow inside the channel. As a model soil bacterium, we demonstrate that *Bacillus subtilis* can significantly modify the interfacial properties that are key to the pinning of the evaporative interface, due to the release of the biosurfactant surfactin [2] into the water phase. In our microfluidic device, such release leads to interface properties such as surface tension varying with time as surfactant progressively accumulates at the interface as a result of evaporation-driven flow and continuous surfactant production. Futhermore, the evaporative flow is favorable to biofilm development, associated to further changes of the mechanical properties of the air-water interface. Our device potential opens the door to probing *in-situ* the mechanical properties of these modified air-water interfaces under different drying conditions, and can shed light on how bacterial activity modifies their dynamics, with implication for understanding larger scale impact on drying soils.

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Poster TU-18

Deciphering and controlling biofilm formation in functionalized porous matrices

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Bacteria motility is a key factor in understanding bacteria activity and the interaction with their surroundings. Confinement within porous matrices, concentration, and flow are some of the most critical parameters affecting bacteria motility [1]. Dense bacterial colonies can give rise to specific multicellular aggregates such as biofilms. These structures limit movements but provide greater protection against harmful agents, resulting in the most common form that can be found in infection scenarios [2]. We recently investigated the motility of B. subtilis, a model microorganism non-pathogenic and simple to manage, under different degrees of confinement induced by PEGDA porous hydrogels [3]. The bacterial motility, along with the pore morphology, was characterized by Laser Scanning Confocal Microscopy (Fig. 1) and particle tracking. The dynamical behavior of the bacteria at short times was estimated through mean squared displacements (MSDs) revealing that the run-and-tumble dynamics of unconfined B. subtilis progressively turns into sub-diffusive motion with increasing confinement. Analyzing single-trajectories, we showed that the average dynamical behavior is the result of complex displacements, in which active, diffusive and sub-diffusive segments coexist. These findings were interpreted using a recently proposed hopping and trapping model. Moreover, we found that the introduction of negative charges in the polymer network of the hydrogel, through the addition of acrylic acid, determines globally a reduction of the available pore volume for the bacteria displacement. All the results collected so far, obtained in a 2D section of the hydrogels, are not however sufficient to fully understand biofilm formation on complex surfaces of 3D porous materials. We therefore recently extended these studies to investigate motility in 3D under similar confinement conditions, and in comparison with the bulk phase. These studies are the starting point for a comprehensive characterization of confined bacterial motility in 3D, that will later consider more complex interactions (gel functionalization) as well as variations of the size and shape of the pore architecture. Furthermore, another aspect we are planning to determine is the dependence of the bacterial activity on the presence of flow in all the proposed cases. For this purpose, various flow regimes will be applied and explored using appropriate microfluidic devices. This can represent an innovative research field, as bacterial biofilm formation has so far been mainly studied under static conditions, with limited attention to the specific hydrodynamic regime imposed.

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Poster TU-19

Contactless Droplet Manipulation Using Lithium Niobate–Based Liquid Marbles

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Liquid marbles are droplets encapsulated by a layer of hydrophobic or superhydrophobic particles which provide a versatile platform for contactless liquid handling in microfluidic systems. Their ability to minimize solid–liquid interactions makes them attractive for applications ranging from microreactors to sensing and actuation. In this work, we report the fabrication of stable liquid marbles using lithium niobate ($LiNbO_3$) powder rendered superhydrophobic via polydimethylsiloxane (PDMS) surface modification. While lithium niobate is a well-established functional material with piezoelectric, ferroelectric, and electro-optic properties, its intrinsic hydrophilicity has previously limited its use in liquid marble systems.

Superhydrophobic lithium niobate particles were prepared by coating $LiNbO_3$ powder with PDMS, resulting in a low-surface-energy layer on the particle surface. The PDMS-modified powder exhibited strong water repellency and readily adhered to the liquid–air interface. Liquid marbles were formed by gently rolling aqueous droplets over a bed of the modified lithium niobate powder, leading to uniform particle coverage and complete encapsulation of the liquid core. The resulting liquid marbles demonstrated excellent non-wetting behavior and mechanical stability. The droplets retained their spherical shape and structural integrity during handling, rolling, and translational motion on solid substrates, with no observable liquid leakage or substrate wetting. The robustness of the particle shell indicates effective PDMS-mediated hydrophobization and strong particle attachment at the interface, both of which are critical for microfluidic manipulation.

The integration of lithium niobate into liquid marbles introduces a new class of functional droplets with the potential for field-responsive actuation and sensing. Owing to the intrinsic electromechanical and optical properties of lithium niobate, these liquid marbles offer opportunities for externally addressable microfluidic elements, such as electrically or mechanically stimulated droplets and optically active microreactors. This work expands the material palette for liquid marble microfluidics and provides a foundation for multifunctional droplet systems in next-generation microfluidic architectures.

Poster TU-20

Microfluidic Fabrication of Biopolymer Microdroplets for Photodynamic Antimicrobial Therapy

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Antibiotic resistance is one of the major global challenges, as resistance to all antibiotics currently in clinical use has been reported, while only a limited number of new medications are being developed. In this context, antimicrobial photodynamic therapy (aPDT) has emerged as a promising alternative for the treatment of chronic wound infections. This approach relies on light-activated photosensitizers to generate reactive oxygen species (ROS) that kill pathogens without promoting resistance. Among available photoactive molecules, methylene blue (MB) is particularly attractive because it has been used clinically for over a century, exhibits broad antimicrobial activity, and absorbs light strongly in the red spectral region (660-670 nm), which enables deep tissue penetration.

To localize MB exposure and promote faster wound healing, the photosensitizer is commonly immobilized within alginate hydrogel systems. Alginate hydrogels provide a biocompatible and transparent matrix that helps reduce off-target effects. However, most existing solutions rely on bulk alginate gels or polydisperse beads produced by batch emulsification methods. These approaches result in wide-size distributions and poorly controlled MB loading, resulting in undefined and irreproducible dosing. Furthermore, despite the central role of ROS in aPDT, current studies do not quantify ROS output per-bead, nor address how ROS generation changes over repeated light activation cycles. This limits the predictability, optimization, and long-term applicability of alginate-based aPDT systems.

To overcome these limitations, we developed a water-in-oil droplet microfluidic system. A polydimethylsiloxane (PDMS) on glass microfluidic chip with a cross-junction geometry was designed to generate highly monodisperse water-in-oil droplets. The system was optimized by adjusting aqueous and oil phase flow rates, alginate concentration, and Tween 80 surfactant content in mineral oil, as well as CaCl2 crosslinking conditions. The resulting microbeads were characterized by optical imaging to determine size, uniformity, and stability. After loading with MB, ROS generation was quantified on a per-bead basis under controlled light activation. This platform allows direct assessment of photodynamic behavior across microbead populations.

Overall, this work establishes a reproducible and quantitative framework for controlled aPDT dosing, enabling direct correlation between microbead design and photodynamic output. In the future, this approach may support the development of localized and reusable antimicrobial treatments, including wound dressings, catheter or implant coatings, and flow-based disinfection systems where predictable and controllable photodynamic activity is required.

Poster TU-21

Step emulsification device for high-throughput droplet generation for biomedical applications

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In droplet microfluidics two immiscible fluids, usually an aqueous phase and an oil phase, are brought together at specially designed channel junctions to generate controlled emulsions. For biological applications, the emulsions consist of water-in-oil droplets stabilized by surfactants. Each droplet acts as an isolated microreactor, allowing the stable separation of chemicals, biomolecules and cells, while simultaneously reducing reagent consumption and enabling higher-throughput experimentation compared to bulk methods [1]. Despite these advantages, droplet-based microfluidic technologies remain limited in their ability to scale up droplet production to meet the demands of biotechnological and biomedical applications. Current systems typically achieve droplet generation rates on the order of 12–15 kHz [2, 3], whereas many applications require throughputs in the MHz range [4].

The most commonly employed droplet generation strategies are shear-based and include co-flow, T-junction, and flow-focusing geometries. In contrast, droplet generation via step emulsification relies on Rayleigh–Plateau instability: droplets form as the dispersed phase flows through a long, shallow microchannel and subsequently expands into a deeper and wider reservoir [5]. This approach represents a promising solution, as it enables highly monodisperse and automated droplet production with significantly lower material consumption compared to shear-based techniques.

In this work, we present an exploratory study of step emulsification for high-throughput droplet generation. A microfluidic device was designed and fabricated using a combination of multilayer photolithography, soft lithography and 3D printing. The device incorporates 60 nozzles to produce droplets in parallel. Water-in-oil emulsions were generated under controlled flow conditions and device performance was characterized by measuring droplet diameter and production rate.

Consistent with previous studies on step emulsification [6], droplet diameter is primarily governed by nozzle geometry and remains largely independent of the flow rate over the investigated range. The generated droplets exhibit excellent monodispersity, with a coefficient of variation below 3%, and demonstrate stable formation across operating conditions. These results highlight the robustness and scalability of step emulsification for producing uniform droplets in high-throughput biological applications that require to analyse large volumes of droplets efficiently.

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Poster TU-22

Formulation of hydrocolloids and rheometry on-chip

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Abstract:
During the formulation of food, cosmetic, and pharmaceutical products, hydrocolloids are widely used to achieve desired rheological properties. The objective of this project is to develop a microfluidic system capable of (i) mixing formulations with different rheological properties at the microscale, and (ii) performing on-chip characterization of non-linear rheological properties at high shear rates while using small sample volumes. This approach allows the construction of ternary diagrams linking composition to rheological properties.
A theoretical framework was established to relate the volumetric flow rate and pressure drop in a straight rectangular microchannel to the viscosity of Non-Newtonian fluids, considering the Weissenberg-Rabinowitsch-Mooney correction.
The microfluidic system is fabricated using Digital Light Processing (DLP) 3D printing or Poly(methylmethacrylate) (PMMA) micromilling, pressure sensors based on technology of the Micro-ElectroMechanical Systems (MEMS) are embedded in the microchannel in order to quantify the pressure drop. Several experimental tests were conducted using this microfluidic rheometer, showing good agreement with conventional rheometry measurements.
Following validation of the system, ternary diagrams correlating composition with rheological properties were generated for starch suspension in acqueous-glycerol solutions.

Poster TU-23

Engineering of a device for the measurement of the optical out-of-plane surface conductivity in two-dimensional materials

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We present the design of a polymeric device for the experimental measurement of out-of-plane surface optical conductivity in bilayer graphene. Out-of-plane optical constants of 2D materials are experimentally elusive because the substrate on which 2D materials are deposited hides the contribution of the out-of-plane constants to their optical response. Until now only the observation of the out-of-plane surface susceptibility of monolayer graphene was reported.
We adopt an experimental approach that consists in two steps. The first is a standard ellipsometric measurement on a bilayer graphene sample, deposited on a transparent polydimethylsiloxane (PDMS) substrate. In a second step, we remove the substrate contribution. We place the same sample in a prism-shaped mold, we pour non-polymerized PDMS on it and wait for complete polymerization. Owing to the replicant properties of PDMS we obtain a bilayer graphene totally immersed in the PDMS prism without spurious interfaces. In this second step, the light reflected from the sample is much less than in the previous experiment. This forced us to develop a homemade ellipsometric setup working at a 633 nm. Our experiment produces 4 experimental data, Δs and Ψs from the sample deposited on the PDMS substrate and Δi and Ψi from the immersed sample (Figure 1). From these it is possible to obtain the in-plane and the out-of-plane surface susceptibilities ($\chi_\parallel$,$\chi_\perp$) and surface conductivities ($\sigma_\parallel$,$\sigma_\perp$). Results are reported in Table 1, that compares them with those obtained for the monolayer and for bulk graphite. We note that $\chi_\parallel$ and $\sigma_\parallel$ for the bilayer are practically equal to the values measured for monolayer graphene and for bulk graphite. This result is confirmed by a lot of other experimental studies. Out-of-plane optical constants behave differently, as they are shown to increase with increasing number of layers. This is the main result presented here.

Poster TU-24

In-Vitro Microfluidic Platform for Localized Controlled Brain Drug Delivery

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The effectiveness of state-of-the-art systemic treatments for brain disorders is limited not only by the difficulty of crossing the blood–brain barrier but also by off-target drug interactions. Here, we present a brain-oriented microfluidic device and in-vitro setup that enables both convection- and diffusion-mediated drug release through a defined interface in a flexible delivery structure, while simultaneously monitoring drug transport behavior in real time. The device is based on a flexible microtube with externally accessible inlet and outlet ports located outside the tissue. A microscale hole is created in the tube wall using laser-based milling, forming a localized infusion site through which drug molecules can diffuse or be convectively delivered into the surrounding environment. The in-vitro setup allows direct real-time monitoring of ultra-low flow rates at the infusion site, complemented by optical imaging to visualize spatial infusion profiles and spectroscopic measurements to quantify time-dependent drug release concentration. Results demonstrate stable delivery of low drug concentrations, with controllable alternation between diffusion- and convection-driven mechanisms, as well as independent control of each transport mode. The device and setup were validated in a relevant agarose-based brain model. This platform provides a tool for continuous, localized delivery and monitoring of fluidically administered drugs into the brain and has the potential to improve therapeutic outcomes for a range of neurological disorders.

Poster TU-25

Anomalous diffusion in 2D interconnected microstructures

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Diffusion governs the dynamics of a wide range of physical, chemical, and biological systems. While classical Brownian motion provides a framework for standard diffusion, many heterogeneous and crowded environments give rise to anomalous diffusion, where transport deviates from Gaussian statistics and linear mean square displacement (MSD) scaling. We investigate the diffusion of colloidal particles in networks, focussing on how structural connectivity influences transport dynamics in heterogeneous environments. Microstructures, including the Sierpinski gasket, random square arrays, and spinodal patterns, were fabricated using maskless photolithography to serve as models for heterogeneous environments and then mapped onto network representations. Colloidal tracers suspended in solution were tracked to yield diffusion observables, such as MSD diffusion exponents and return probabilities, which were then compared with numerical random walk simulations on the network representations of the fabricated structures. Our results demonstrate how structural heterogeneity influences transport dynamics, highlighting connections between network topology, fractal geometry, and anomalous diffusion exponents. These findings demonstrate that complex network theory provides a useful framework for interpreting transport in disordered systems and establish microfabricated structures as versatile platforms for studying anomalous diffusion.

Poster TU-26

Transport of microalgae in curved channels at finite flow inertia

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The valorization of microalgae for energy or pharmaceutical applications strongly relies on the harvesting stage, which consists of the separation of microalgae from the culture media to obtain a more concentrated biomass.
The aim of this study is to investigate the potentiality of microfluidics as an alternative separation process, with reduced resource consumption compared to standard processes. We consider the particular case of microalgae with rigid membranes such as Chlorella Vulgaris. Previous studies have revealed that using spiral microchannel, with small height-to-width ratio (λ), allows efficient separation of inert and biological microparticles, like algae or pathogens, when the flow inertia is finite at the particle scale. While the spiral device seemed to allow good separation performance, the particle transport properties were not well characterized. To fill in this gap, we first study the dynamics of the carrier fluid and second the forces experienced by the microparticles in curved microchannel flows.
The study is mainly based on numerical simulations of the fluid flow using the in-house code JADIM. Source terms based on the Force Coupling Method (FCM) allows capturing the hydrodynamic interactions between the freely moving particles and the flow. The forcing term, written in the form of a multipole expansion based on Stokes flow, is adapted to capture finite flow inertia at the particle scale in curved flow geometry. Moreover, the numerical results are compared with experiments carried out (in our group) using microalgae with similar size.
The flow features are investigated as a function of the Dean number (product of the Reynolds number Re and the square root of δ, the channel curvature) for $\lambda = 0.17$.
Secondary flows, in the form of a vortex pair, take place in the curved channel flow. While their intensity increases with Re and δ, two scaling laws are proposed for flow regimes dominated by viscous and inertial forces, respectively. Freely moving neutrally buoyant single particles, of diameter equal to the fifth and eighth of the channel height, are studied. While the particles are transported by the main flow and by the secondary vortices, they also experience inertial lift along the local strongest gradient of the streamwise velocity. The balance between the drag along the secondary vortices and the inertial lift across the streamwise flow, leads the finite size particles to focus near the inner channel wall for $0.006 \leq \delta \leq 0.04$ and $30 \leq \mathrm{Re} \leq 160$. Nevertheless, we show that the maximum of the streamwise velocity shifts towards the outer wall as the Reynolds number is further increased, suggesting the decrease of the lift force along the radial direction near the inner wall, and subsequently the potential shift of particle equilibrium away from the inner wall.
Furthermore, we carried out simulations of suspension flow with volumetric concentration up to 10%. These simulations allow to study the suspension dynamics as a function of flow inertia and to evaluate the efficiency of microalgae concentration in microfluidic devices.

Poster TU-27

Friction Force Measurements on Molecularly Mixed Hydrophilic-Hydrophobic Slippery Covalently-attached Liquid-like Surfaces

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Low pinning surface coatings are important for smooth motion of contact lines in capillaries and microfluidics. One approach is to use slippery liquid-infused porous surfaces (SLIPS) to create a continuous liquid-lubricating layer [1]. However, these layers tend to be hydrophobic, and the infused liquid lubricant can leak or deplete over time, or cause toxicity issues depending on the lubricant. Recently, Cho et al. have presented a novel method for fabricating permanently substrate-bound molecularly mixed Slippery Covalently Attached Liquid-like Surfaces (SCALS) capable of being tuned from hydrophilic to hydrophobic over a contact angle range 40o-103o whilst retaining low contact line pinning [2]. These layers possess liquid-like behaviour with flexible polymer chains anchored only at one end to the substrate, behaving like a permanent layer of liquid lubricant, and are stable and non-toxic. Here we optimise this new approach to functionalizing surfaces and report sessile droplet contact angle and contact angle hysteresis measurements, and static and kinetic friction force measurements based on a previously reported cantilever-type experiment [3]. This approach allows the direct measurement of friction and adhesion forces in the micro-Newton (μN) range, where the water droplets were translated across the fabricated surfaces at controlled velocities spanning two orders of magnitude (0.1 to 10 mm/s). The friction force is interpreted within a strong dilute defects model [4,5]. This provides a robust platform for designing surfaces for various applications such as in medical devices, biological equipment, and marine applications.

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Poster TU-28

Spontaneous Coulomb fissions of drops on lubricated surfaces

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Charged water drops are more widespread than commonly acknowledged. For example, raindrops typically carry charges of order Q~1 pC, while routine pipetting in the laboratory produces drops with Q~50 pC. Here, we show that such modest charging can spontaneously generate periodic Coulomb fissions for evaporating water drops on lubricated surfaces. The drop periodically elongates over a timescale of seconds and subsequently emits small droplets with more than 60 successive cycles observed over 30 min. Interestingly, the underlying instability can be quantitatively predicted by a model taking into account two fissility thresholds: one marking the onset of drop elongation and another triggering fission. The drop shape undergoes a supercritical bifurcation that culminates in a fission where a fine liquid jet is expelled within microseconds, which disintegrates into 40-50 microdroplets. The phenomenon spans an extraordinary range of length scales (from millimetres to microns) and
time scales (hour to microseconds), with broad potential applications ranging from nanoscale fabrication to electrospray ionization.

Poster TU-29

An Integrated Wideband Electrorotation Platform for Automated Single-Cell Dielectric Characterization

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Electrokinetic techniques are increasingly adopted to characterize cellular dielectric properties due to their non-invasive and label-free nature [E. O. Adekanmbi et al., 2019]. Among these, electrorotation (ROT) emerges as a particularly accurate method for probing dielectric response at the single-cell level [A. Goater et al., 1999].

ROT involves the application of a rotating electric field with varying frequency to suspended cells, inducing a measurable rotational motion that depends on their dielectric properties. Analysis of the rotation rate as a function of frequency yields a characteristic rotation spectrum, which enables quantitative estimation of key parameters such as membrane capacitance and cytoplasmic conductivity.

Conventional ROT platforms are constrained by complex and expensive instrumentation, predominantly low-frequency operation, and the absence of integrated automation for signal generation and data analysis. This results in workflows that depend heavily on manual procedures reducing reproducibility, limiting throughput, and hindering widespread adoption in biological laboratories.

In this context, we developed the Electro-Cell Physiometry (ECP) Platform, an integrated ROT system that combines hardware, software, and standardized experimental workflows into a single, user-friendly platform [Moscato et al, 2024]. The ECP Platform consists of three main components: (i) a ROT-chip optimized for high-frequency operation; (ii) a High-Frequency Quadrature Signal Generator (HF-QSG) that delivers wideband rotating electric fields for full-spectrum dielectric characterization; and (iii) the ECP-Framework, a computational environment that fully automates ROT experiments, including cell segmentation, tracking, angular velocity calculation, and dielectric parameter extraction [Moscato et al., 2025].

The ECP platform was initially validated in the low-frequency regime (30 kHz–1 MHz) [Moscato et al., 2024]. Distinct area-specific membrane capacitances were measured, with CaCo-2 cells showing the highest values (25.47 ± 4.6 mF/m²), CCD-841 intermediate values (19.02 ± 1 mF/m²), and OPM2 the lowest (12.58 ± 1.1 mF/m²). Statistical analysis confirmed these differences to be significant, reflecting distinct membrane structures and demonstrating the system' s ability to resolve meaningful dielectric variations.

Subsequently, full-spectrum ROT measurements were performed up to 200 MHz on HL-60 and HeLa cells, covering both low- and high-frequency regimes. Low-frequency measurements revealed cell-specific membrane properties, with statistically significant differences in membrane capacitance (HL-60: 14.8 ± 2.68 mF/m²; HeLa: 30.4 ± 5.74 mF/m²). High-frequency analysis further enabled the estimation of cytoplasmic conductivity, which was found to be comparable between the two cell lines (HL-60: 0.516 ± 0.14 S/m; HeLa: 0.425 ± 0.07 S/m). These results demonstrate the platform' s capability to extract both membrane and cytoplasmic dielectric parameters reliably, highlighting its potential for comprehensive single-cell characterization across a broad frequency spectrum.

Overall, the proposed ECP platform advances electrorotation beyond a specialized laboratory technique, establishing a standardized, automated, and accessible system for cell dielectric characterization, enabling simultaneous manipulation and measurement of multiple cells within a high-throughput platform.

Future work will focus on integrating microfluidic architectures with embedded flow-control functionalities to support fully automated sample replacements, including cell transport, and repositioning, while leveraging AI-enhanced analysis for real-time angular velocity estimation and further advancing embedded optics toward a compact, self-contained electrorotation system.

Poster TU-30

Dynamics of 2D microfluidics crystals in patterned Hele-Shaw cells

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We present the results of an ongoing experimental study about the statics and dynamics of 2D microfluidic crystals confined in a patterned microchannel. More precisely, droplets of uniform size are produced with a T-junction and inserted into a Hele-Shaw cell whose top is patterned with micrometric holes made by standard lithography techniques. A small hole etched in the top wall generates an attractive force that can be estimated from geometric arguments [1]. In the presence of external flow, the droplet pushed by the continuous phase can remain trapped only if the pinning strength of the hole is sufficient to balance the drag force. An anchored drop can remain stationary indefinitely as long as the driving flow rate remains below a critical value that depends on the sizes of the well and droplet. The statics and dynamics of pressure driven 2D droplet crystals in the patterned Hele-Shaw are recorded via a video camera and the time position of the crystal droplets is deduced by using machine learning visual methods.

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Poster TU-31

Contact Line Instabilities in Sliding Viscoelastic Drops

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Controlling the motion of non-Newtonian drops on surfaces is essential for applications ranging from inkjet printing to biomedical devices and food processing. While the macroscopic behaviour of viscoelastic drops sliding on tilted hydrophobic surfaces has been characterized—showing reduced velocities [1] and elongation [2] compared to Newtonian fluids—the microscopic mechanisms behind these differences remain poorly understood.

To address this gap, we developed a high-speed, high-resolution reflection microscopy setup that enables direct visualization of the contact line of sliding drops. Using water-soluble polyelectrolyte solutions, we reveal how viscoelasticity influences the dynamics of the receding contact line and, consequently, drop motion. Our experiments demonstrate that viscoelasticity can destabilize the receding contact line, triggering filament formation. This instability previously observed in the coating of thin viscoelastic films [3,4], is reported here for the first time in sliding drops.

We further highlight the critical role of polymer charge in this process: while cationic and non-ionic polymers promote filament formation, anionic polymers do not, a difference that we link to the distinct wetting properties of the solutions. In conclusion, we clarify the interplay between rheology, surface interactions, and drop dynamics.

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Poster TU-32

Slippery Liquid-Like Surfaces with Tunable Wettability

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Low droplet friction is desirable in many circumstances in which liquids interact with solid surfaces, such as for increased heat transfer, efficient atmospheric water capture and antifouling.[1] This study explores the fabrication of surface-grafted, liquid-like layers with ultralow static droplet friction, made from a mixture of hydrophobic polydimethylsiloxane (PDMS) and hydrophilic methoxy polyethylene glycol (mPEG).[2] Both polymers are liquid at room temperature and, when mixed, lead to slippery layers with contact angle that can be tuned from that of pure PDMS to that of pure mPEG. A contact angle hysteresis of 0.9 ± 0.3 ° was obtained on mPEG9–12 layers. This is the lowest hysteresis reported for any hydrophilic covalently attached liquid surface and represents the lowest contact line friction ever observed on a solid planar surface.

As the PDMS fraction in the mixed layer increased, so too did contact angle hysteresis, reaching a maximum value of 9 ° at 70% PDMS, before returning to 2 ° for the pure PDMS layer. Atomic force microscopy mapping of the liquid layers revealed that the two polymers are fully mixed on the surface, even at high surface fraction of both components. The model by Reyssat & Quéré,[3] devised to explain contact angle hysteresis for surfaces with dilute defects, explains the observed results well. This study shows that liquid-like surfaces can be achieved that are more slippery than conventional self-assembled monolayers and share the same capacity to gradually tune surface wettability.

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Poster TU-33

Study of the hydrodynamics of micrometric particles within droplets confined in microchannels for biochemical applications

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Droplet microfluidics has emerged as a powerful platform for biological applications[1], enabling the generation of highly controlled aqueous emulsions dispersed in an oil phase with surfactants. The presence of the droplet-oil interface alters the droplet internal hydrodynamics, leading to modified recirculation patterns and stagnation points compared with monophasic flows. This has important implications for the internal mixing of liquids confined in droplets, as has been deeply investigated in the literature[2]. However, if, instead of liquid-liquid mixing, droplets contain micrometric particles, commonly used in biochemistry for isolation purposes, the recirculation is less obvious. In fact, depending on their size and density compared to those of the surrounding medium, these microparticles may exhibit different behaviours. For example, according to the size and speed, particles are confined in specific regions[3,4]. Despite these preliminary results, a systematic study of the heavy-bead recirculation dependencies from droplet volume, flow rate, channel dimension and the related consequences on specific applications is still missing. Here, we present a methodical analysis of the accumulation of beads denser than the medium (about 2-fold), for different capillary numbers (between 3e-4 and 5e-3), droplet volumes (30nL-3uL), and microchannel size (diameter from 300um to 800um). We observed that, as the droplet length-to-channel width ratio (L/W) of the droplet gets smaller, the mixing is improved. Moreover, an increase in the flow rate causes the beads to accumulate at the rear of the droplet. This behaviour contrasts with what is typically observed for liquids inside droplets. This raises the question whether it is preferable to operate at high flow rates, leading to bead accumulation but strong recirculation of the analytes within the droplet, or at lower flow rates, where fluid motion is less pronounced but the beads remain more uniformly dispersed throughout the droplet. To address this question, we performed an enzymatic reaction inside droplets, in which the enzyme was immobilised on the beads while the analyte was freely dispersed in the droplet. When the temporal increase in fluorescence signal arising from the enzymatic reaction was measured, we found that the overall reaction efficiency is higher when the beads are well dispersed, even though fluid mixing is weaker under these conditions. These results indicate that bead dispersion and thus the conditions to maximise it, rather than fluid mixing alone, define the optimal operating conditions in bead-based droplet microfluidics.

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Poster TU-34

Fickian Non-Gaussian Diffusion Induced by Structural Heterogeneity

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Fickian non-Gaussian diffusion (FnGD) remains a major open question in soft matter, with its emergence linked to structural or dynamic heterogeneity. Recent model systems show that FnGD is typically preceded by anomalous diffusion, with both regimes closely intertwined. [1, 2].
We investigate colloidal tracer diffusion in heterogeneous environments with static translational disorder of micron-sized pillars. Using maskless photolithography, we fabricated micropillar arrays with tunable randomness, symmetry, and density. Particle tracking of colloidal particles diffusing through the pillar arrays in microfluidic cells extended two orders of magnitude beyond the Brownian time, significantly surpassing previous FnGD studies. We examined particles with varying mass densities and concentrations [3].
We observed the emergence of FnGD behaviour at different timescales at suitable pillar area fraction, depending on the particle' s concentration and the system's aging time. These results provide a foundation to bridge numerical simulations [2], diffusion in optical traps [4], and in complex networks [1].

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Poster TU-35

Cubosome penetration in pancreatic tumor spheroids using a microfluidic chip

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One of the challenges faced in medicine regarding the treatment of cancer is the delivery and the stability of the anticancer drug to the tumor. Thus nanoparticles (NPs) offer a way to help the delivery of a specific drug but also a protection against degradation [1]. However, the lack of tumor treatment based on NPs means that we still need to develop new platforms and also new types of NPs. We work here with self-assembled lipids called cubosomes, that are a promising tool for drug delivery thanks to their capacity to be loaded with hydrophilic or hydrophobic components and their encapsulation efficiency. A crucial point is to quantify the penetration of these cubosomes in biological tissues, a necessary step to ensure their efficiency in vivo. In this study, we developed a microfluidic chip that allows the immobilization of multiple 3D cell aggregates (here A338 spheroids, murine cell line affected with pancreatic cancer). These spheroids constitute a classical in vitro 3D tissue model. The microfluidic technology is based on a previous work in the team, which was developed to reproduce the micropipette aspiration technique on a chip [2]. In parallel, the unique design of the chip allows a rapid change of media around the sample and can help understand the penetration and effect of many compounds such as cubosomes on spheroids. These cubosomes can be loaded with fluorescent molecules such as Oregon Green DHPE or DiR for direct fluorescence of cubosomes, or fluorescein-DA to detect esterase activity in cells. Preliminary results on penetration show that cubosomes loaded with Oregon Green can penetrate up to the center of the A338 spheroids. The micropipette aspiration technique can be used to perform mechanical measurements on 3D biological samples: we could measure the elasticity and viscosity of the cell line, and evidence that permeability can play a role in tissue' s deformations.

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Poster TU-36

Affinity Characterization of the GreenB1 Aptamer in Pancreatic Ductal Adenocarcinoma Using 2D, Organoid, and Organ-on-Chip Models

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Background. Despite advances in cancer diagnosis and therapy in recent years, pancreatic ductal adenocarcinoma (PDAC) remains one of the most aggressive malignancies due to the pancreas's unique microenvironment. Therefore, innovative targeted therapeutic strategies are urgently required. Aptamers and their conjugates offer a promising approach, as these single-stranded oligonucleotides fold into distinct three-dimensional structures that enable high-affinity and selective binding to target molecules. GreenB1 is an integrin β1 (ITGB1) specific aptamer and it is frequently overexpressed in tumor cells. Characterization across diverse model systems and experimental conditions would facilitate a deeper understanding of integrin expression patterns and evaluate GreenB1' s potential as a vector for targeted therapy. The integration of multiple PDAC model systems including cell lines, patient-derived organoids, and organ-on-chip and microfluidic platforms will enable comprehensive evaluation of aptamer and tumour-cell binding capacity under physiologically relevant and dynamically controlled microenvironmental conditions.

Aim. The aim of this study was to characterise the affinity of the GreenB1 aptamer in pancreatic ductal adenocarcinoma (PDAC) using advanced microphysiological organ-on-chip platform, alongside conventional static 2D and organoid models.

Methods. GreenB1 affinity and experimental condition optimisation were first performed in established PDAC cell lines (CAPAN-2, MIA-PaCa) and in PDAC and normal pancreatic organoids derived from patient biopsies under static conditions, using ImageStreamX Mark II (Cytek Biosciences). These optimised parameters were then translated to organ-on-chip microfluidic system, fabricated using 4-channel CellBox Labs chips. CAPAN-2 cells were seeded at a density of 1 × 10^6 cells/mL, and 50 µL was transferred to the top channel of the chip. Prior to aptamer binding, cells were cultivated for two weeks until full monolayer confluency was achieved under a flow rate of 2 µL/min. GreenB1 binding under dynamic flow was assessed using immunofluorescence (IF), with additional signal amplification strategies applied to enable GreenB1 detection under microfluidic conditions.

Results. Flow cytometry analysis demonstrated that CAPAN cells exhibited the highest affinity for GreenB1 and were therefore selected for downstream optimisation and organ-on-chip experiments. Optimal binding was achieved with 500 nM GreenB1 following one hour of incubation. Direct detection of GreenB1-FAM by IF was limited due to reduced signal intensity under flow. However, implementation of signal amplification methods enabled successful visualisation of GreenB1 binding in both static cultures and within the microfluidic organ-on-chip system.

Conclusion. This study successfully established and translated GreenB1 binding conditions from static cell culture to a microfluidic organ-on-chip model of PDAC. These findings support the further use of PDAC organ-on-chip models as a proof-of-principle platform for the development and assessment of aptamer-based targeted drug delivery strategies.

Acknowledgements.

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Poster TU-37

An Automated and parallelized microfluidic cell culture device using three-layer Ostemer-322 devices with an integrated NOA-84 membrane

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Cell-based in vitro assays are indispensable tools for biomedical scientists, tissue engineers, biologists, and pharmacologists. Cell morphology, protein expression, differentiation, migration, functional phenotype, and viability are strongly influenced by the biochemical composition of the culture medium, surface chemistry/modifications, and whether cells are maintained in 2D or 3D microenvironments. Microfluidic cell culture platforms have therefore been developed to culture and analyse multiple tissues or organoids of distinct origin under physiologically relevant, in vivo-like conditions. A key architecture enabling such systems is the membrane-integrated, multilayer microfluidic design incorporating pneumatically actuated valves. Despite the demonstrated advantages of membrane-integrated microfluidic cell culture systems,the automation, integration, miniaturization, and parallelisation of multilayer, membrane-integrated platforms remain at an early stage of development.To enable next-generation advanced in vitro cell culture systems, simple and reliable fabrication workflows that support rapid prototyping of three-layer, membrane-integrated microfluidic devices are of course a need. In such platforms, vertically stacked layers allow functional compartmentalization (e.g., culture/flow layer + membrane + control layer) and provide a practical route toward automation, miniaturization, and assay parallelization within a compact footprint.A key driver for automated multilayer operation is the integration of pneumatically actuated valves (Quake-inspired architectures), which enables programmable routing, metering, switching, and multiplexing of reagents—capabilities that are essential for parallelized screening, dynamic stimulation, and time-resolved cell culture assays. While PDMS soft lithography has been widely adopted for multilayer valve systems due to its low-cost rapid prototyping, optical clarity,biocompatibility and ease of bonding, PDMS introduces major limitations for controlled biological assays, including channel deformation from high compliance, bubble formation and osmolality drift due to high water-vapour permeability, absorption of small hydrophobic molecules, and leaching of uncured oligomers that can alter cell physiology. These effects directly undermine reproducibility when the goal is automated, long-duration, and parallelized testing.

To address these constraints while retaining fast prototyping, we investigate a thiol–ene/thiol–epoxy thermoset (Ostemer-322) as an alternative multilayer material and integrate a NOA-84 (Norland Optical Adhesive-84) membrane between the flow and control layers to realize a three-layer valve-enabled platform by the culture of MCF-7 cells. Both the polymers, Ostemer-322 and NOA-84 undergoes a two-step curing process: UV-initiated thiol–ene polymerization produces an intermediate that is readily released from molds and assembled, while leaving reactive functional groups available for bonding; subsequent thermal curing drives thiol–epoxy crosslinking to yield a chemically resistant, low-permeability, mechanically robust device suitable for stable operation. By combining this thiol–ene thermoset with a membrane-integrated, Quake-inspired architecture, the resulting platform is designed specifically to enable automated reagent control and scalable parallelization of cell-cultures in multilayer microfluidic systems.

Poster contributions
Thursday 21/05, 16:20 - 17:20

Poster TH-1

Pressure-Encoded Control in Fully 3D Printed Microfluidics: An FDM and FEA Approach

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Microfluidic device development often demands labour-intensive fabrication and complex control setups. Here, we introduce a fully 3D printed pneumatic valving platform that combines simulation-driven design, flexible filament, and direct-print integration to enable rapid, assembly-free prototyping. Using fused deposition modeling (FDM) with flexible thermoplastic polyurethane (TPU), we fabricate functional valves and microchannels in a single manufacturing step with no post-processing required.

We first characterise the hyperelastic response of printed TPU through mechanical testing, generating accurate material parameters for Finite Element Analysis (FEA). These simulations predict valve deformation and actuation behaviour under varying pressures, giving designers precise control over performance before printing. By adjusting valve geometry, we produce a library of valves that each close at distinct pressure thresholds —all powered from a single, regulatable source. This "pressure-encoded" approach eliminates complex multi-channel routing and reduces control hardware to a single inlet, preserving functionality while simplifying system architecture.

To realise functional devices, we print the TPU structures directly onto an optically transparent substrate using a pick-and-place procedure. This integration offers two advantages: immediate optical accessibility for observing valve dynamics, and rapid validation of simulated behaviours in physical tests. The resulting devices exhibit predictable and tunable valve actuation. The results align well with our predictions using FEA, which confirms the reliability of our model-informed design pipeline.

This method combines material-aware simulation with additive manufacturing to create lightweight adaptive microfluidic systems. By embedding functionally distinct valves into a single pressure domain, we streamline fluidic automation without compromising flexibility or control. This approach not only accelerates the prototyping cycle, but also opens new avenues for accessible, modular lab-on-a-chip systems fabricated entirely through low-cost consumer-grade printing technology.

Poster TH-2

Numerical Analysis of Compound Droplet Formation and Dynamics Using Complex Fluids in a Co-Flow Microchannel

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Compound droplets have attracted significant attention in recent years due to their wide-ranging applications in targeted drug delivery, nanoparticle synthesis, encapsulation technologies, and biomedical diagnostics. Their ability to encapsulate multiple functional materials within a single droplet enables controlled release, enhanced stability, and multifunctional performance, making them highly desirable in advanced microfluidic systems. Microfluidic technology has emerged as a powerful and versatile platform for the controlled generation of compound droplets, offering precise manipulation of flow conditions, fluid properties, and interfacial phenomena to tailor droplet size, morphology, and dynamics [1]. Among various microfluidic configurations, co-flow microchannels are particularly advantageous due to their simple geometry, stable operation, and capability to produce highly monodisperse droplets.

In the present work, a co-flow microfluidic device is numerically modeled to investigate the formation and transport dynamics of compound droplets using a Computational Fluid Dynamics (CFD) solver. The system consists of three immiscible phases, wherein a non-Newtonian fluid is employed as the droplet-forming phase to closely represent realistic biofluids and polymeric solutions commonly encountered in drug delivery applications [2]. The interface dynamics between the three immiscible fluids are captured using the Coupled Level Set and Volume of Fluid (CLSVOF) method [3]. A comprehensive parametric study is performed to elucidate the effects of key operating parameters, including flow rate ratios, viscosity ratios, and interfacial tension, on the size, shape, velocity, and generation frequency of compound droplets. The results reveal that systematic variation of flow conditions provides effective control over droplet size and shape. Furthermore, non-dimensional scaling correlations are developed to relate the droplet characteristics to governing parameters, such as the Reynolds number, Weber number, and capillary number, offering a predictive capability for device design. Distinct flow regimes, namely squeezing, dripping, and jetting, are identified and mapped within the operational parameter space. Overall, the findings offer fundamental insights into the mechanisms of compound droplet formation and identify key controlling factors for precise droplet manipulation. The results provide valuable insights for optimizing microfluidic systems aimed at critical mineral extraction, drug delivery, and other biomedical applications requiring controlled encapsulation and transport of complex fluids.

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Poster TH-3

Predictive 3D Multiphysics Modeling and Experimental Validation of Particle Trajectories in SSAW Microfluidic Devices

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The analysis of biological and environmental samples is of fundamental importance for human health and safety. In particular, the ability to extract target-sized particles from complex suspensions is highly relevant across several fields, ranging from environmental monitoring to biomedical applications (Caragnano et al., 2025). Especially when only limited sample volumes are available, the development of efficient microfluidic particle sorting techniques becomes a key requirement. Among the available techniques, surface acoustic wave (SAW)–based acoustophoresis represents an attractive solution due to its label-free and contactless approach (Friend & Yeo, 2011; Lenshof et al., 2012). One metric for quantifying the efficiency of these devices is the ability to accurately predict particle trajectories. In SAW-based microfluidic devices, this task remains challenging, as particle motion results from the interplay between acoustic radiation forces and hydrodynamic drag, and depends on multiple strongly coupled parameters, including particle size and material properties, interaction with the acoustic field, flow conditions, and device geometry (Bruus, 2012).

In this work, we present a fully coupled three-dimensional multiphysics numerical model for the prediction of particle trajectories in standing SAW (SSAW) microfluidic devices. The model sequentially couples piezoelectric actuation of the substrate, acoustic wave propagation in the fluid, steady-state laminar flow, and time-domain particle tracing under the combined action of acoustic radiation and drag forces. This approach enables a quantitative description of particle motion under realistic operating conditions, overcoming the limitations of simplified analytical and two-dimensional models commonly adopted in the literature (Fakhfouri, Devendran, Ahmed, et al., 2018; Fakhfouri, Devendran, Albrecht, et al., 2018; Guo et al., 2015). Numerical simulations are performed for polystyrene (PS) particles with diameters of 6 and 20 μm in distilled water, selected to match the characteristic size range of blood cells in perspective of future blood-sorting applications. Simulations are carried out at discrete operating conditions, and are used to identify the operating point yielding the most pronounced lateral particle deflection within the explored conditions.

Experimental measurements are conducted using fluorescent PS microspheres in a SSAW-based microfluidic device operated at its resonance frequency. Particle trajectories are extracted from fluorescence microscopy images, and the lateral deflection is quantified with respect to a reference trajectory obtained in the absence of SSAW excitation. In our operating conditions, simulated and measured lateral deflections are found to be in good agreement, with relative discrepancies on the order of 5–10%, compatible with the experimental uncertainty associated with trajectory extraction and averaging.

Poster TH-4

Automated Characterization of Jet Breakup Dynamics in Newtonian and Viscoelastic Fluids using Deep Learning and Computer Vision

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The precise characterization of capillary jet breakup and droplet formation is fundamental to numerous applications, from inkjet printing to biochemical assays. While high-speed imaging provides detailed temporal data on these fast-evolving phenomena, manual analysis remains a significant bottleneck, particularly for large datasets involving complex fluid behaviors. This study presents an automated, high-throughput computational framework designed to extract quantitative physical metrics from high-speed images of microfluidic jets.

Our methodology integrates a custom-trained U-Net convolutional neural network (CNN) for semantic segmentation with advanced post-processing algorithms. The pipeline addresses critical challenges in microfluidic imaging, such as motion blur during the inertial-capillary regime and the segmentation of fine viscoelastic filaments. We implement a sliding-window inference strategy to process high-aspect-ratio images without resolution loss, coupled with morphological reconstruction techniques to resolve fragmentation artifacts common in low-contrast transition zones.

To quantify the breakup dynamics, the system automatically tracks key geometric parameters, including jet length, filament width, droplet aspect ratio, and pinch-off time. A Region of Interest (ROI) filtering mechanism, combined with dimensional constraints, ensures robust tracking of the primary jet and satellite droplets, effectively mitigating noise and coalescence artifacts.

Preliminary results demonstrate the algorithm's capability to accurately distinguish between the "snap-off" breakup mode of Newtonian fluids (water, glycerol) and the "beads-on-a-string" structure characteristic of viscoelastic fluids (PEO solutions). This approach significantly reduces data processing time and provides a scalable solution for investigating the rheological properties of complex fluids under extensional flow.

Poster TH-5

Deep learning based segmentation of microfluidic impedance cytometry signals: the first demonstration of cross-setup generalizability

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Microfluidic impedance cytometry (MIC) is a high throughput, label free technology for single cell analysis, with applications in cell classification and non invasive monitoring. However, extracting reliable biological information from MIC data remains challenging because the signals strongly depend on the experimental setup. This study investigates the integration of MIC with deep learning (DL) to enable effective processing of raw impedance data streams (i.e., electric current signals). Specifically, the research focuses on signal segmentation (i.e., event detection), which represents the first step of the processing pipeline and therefore influences the entire workflow.

For the first time, impedance data from multiple experimental setups were collected. They are characterized by raw traces with diverse attributes and event signals exhibiting distinct temporal shapes, thus forming a rich and comprehensive database. Several DL models were implemented and compared, including recurrent, convolutional, and encoder–decoder neural networks.

While all models demonstrated good segmentation performance, the encoder–decoder network outperformed the others, achieving a sensitivity and positive predictive value of 91.6% and 91.8%, respectively. Moreover, the network exhibited remarkable robustness when, after training, validation, and testing, it was further evaluated on additional previously unseen data.

We developed a universal framework for signal segmentation in MIC, addressing the challenge of cross-setup generalizability. By enabling efficient, high speed processing, the integration of MIC and DL lays the foundation for next generation single cell workflows with applications in diagnostics, drug discovery, and environmental monitoring.

Poster TH-6

On-Chip and Off-Chip Ion Concentration Polarization Strategies for Enhanced Biosensing

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The development of sensitive point-of-care (POC) diagnostics is often hindered by low target analyte concentrations and matrix interference. This work presents a comprehensive microfluidic framework leveraging Ion Concentration Polarization (ICP) to overcome these challenges through two primary pathways: integrated on-chip and off-chip preconcentration of biomolecules for several biosensing methodologies.

ICP exploits the formation of ion-depleted and ion-enriched zones near ion-selective membranes, such as Nafion, under an applied electric field. This phenomenon triggers a symmetry breaking in ion concentration, leading to an intensified electric field at the depletion layer. Charged biomolecules are trapped at the edge of this depletion zone due to a field-gradient-focusing effect, where the electrophoretic velocity of the analyte is balanced by counteracting advection—driven by pressure or electroosmosis. This mechanism enables continuous accumulation of analytes, significantly increasing local concentrations.[1]

For on-chip biosensing applications, we integrated ICP-preconcentration directly with local electrochemical sensing. This platform supports both coupled and decoupled operation modes, facilitating the continuous detection of bioanalytes such as Homovanillic acid (HVA) in artificial sweat with enhancement factors ranging from 10 to 100. [2] Additionally, a dynamic buffer exchange operation using a Y-junction design effectively removes neutral inhibitory species—reducing them to 0.015 of initial levels—while retaining the preconcentrated analyte plug.

To enhance existing diagnostic infrastructure, we developed a customized, pump-free ICP-based device compatible with commercially available immunoassays. Utilizing built-in hydraulic pressures, the device captures targets from large sample volumes and facilitates the on-demand extraction of preconcentrated microliter-sized droplets. Validated with standard ELISA and Lateral Flow Assay (LFA) kits, this pre-step improved the limit of detection (LOD) for IgG antibodies by one order of magnitude without requiring modification of original assay protocols.[3]

The results demonstrate that ICP-based preprocessing effectively bridges the gap between fundamental electrokinetics and practical clinical application. By unifying sample purification, programmable plug manipulation, this framework provides a robust solution for the next generation of sensitive, portable diagnostic tools capable of operating in complex biological environments.

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Poster TH-7

Exploring light-driven bacterial behavior in microfluidic chambers

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Light is a key environmental cue shaping microbial dynamics in the ocean, yet its role in regulating bacterial motility remains poorly understood. As part of a study exploring light-mediated microbial interactions within the phycosphere, we investigated the behavioral response of the marine bacterium *Alteromonas macleodii* to controlled illumination. Using high-speed video microscopy and microfluidic chambers, we observed a marked increase in swimming speed upon exposure to blue light (455 nm). This photoresponse was wavelength-specific, as no comparable effect was detected under red light. These findings suggest that *A. macleodii* possesses a functional blue-light sensory pathway influencing its motility, potentially mediated by flavin-based photoreceptors such as BLUF or LOV-domain proteins. Given the ecological ubiquity of *A. macleodii*, such light-dependent behavioral plasticity could have important implications for microbial positioning, nutrient acquisition, and interactions within the illuminated layers of the ocean. Ongoing work tests how this photoresponse varies under different light regimes and across distinct phases of the bacterial life cycle, as well as how light sensitivity shapes behavior in complex optical microenvironments mimicking the phycosphere. Together, these results reveal light as a dynamic regulator of bacterial motility and microscale ecological interactions.

Poster TH-8

Role of cholesterol and microparticles on the structural and mechanical properties of lipid monolayers

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This study investigates the effects of cholesterol and microparticles on the structural and mechanical properties of DPPC monolayers, which serve as models for lung surfactants at the air-water interface. Using compression isotherms, fluorescence imaging, and interfacial rheology, we show that cholesterol incorporation increases the elasticity of DPPC monolayers by inserting its steroid rings between the hydrophobic tails of the lipids. The addition of microparticles further enhances the elastic modulus at low frequencies, indicating a change in the mechanical properties of the monolayer. These findings offer insight into the role of both natural and artificial components (e.g. solid micro-pollutants) in modulating the behavior of lung surfactant models and their potential environmental implications.

Poster TH-9

Diffusion-Driven Microfluidics for Bias-Free Measurements of Flagellar Motor Dynamics in Magnetotactic Bacteria

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The bacterial flagellar motor (BFM) is the macromolecular rotary machinery responsible for bacterial motility through flagellar rotation. Its dynamics are tightly regulated by environmental sensing mechanisms, including multiple taxis pathways [1]. In magnetotactic bacteria (MTB), both chemical and magnetic cues modulate BFM behavior, enabling navigation in complex environments [2]. This work aims to establish a quantitative steady-state model of motor dynamics in Magnetospirillum gryphiswaldense (MSR-1) as a foundation for studying how the motor adapts to and integrates chemical stimuli.

Beyond sensory inputs, the BFM is intrinsically mechanosensitive: variations in external load, shear stress, or medium viscosity induce adaptive stator remodeling [3]. While this property is essential for robust motility, it introduces a significant experimental bias in tethered-cell assays, where rotational dynamics are commonly used as a proxy for BFM activity. In particular, even weak fluid flows can alter motor behavior independently of sensory signaling, complicating the interpretation of chemotactic responses.

To minimize flow-induced perturbations while preserving precise chemical control, we developed a PDMS-based microfluidic platform featuring a three-channel architecture interconnected by a porous array of micropillars [4]. This design allows independent perfusion of distinct solutions in the lateral channels, while the central chamber—containing tethered bacteria—remains hydrodynamically isolated. Chemical stimuli are delivered exclusively by diffusion across the micropillar arrays, effectively decoupling chemical gradients from mechanical forces.
This microfluidic system enables unbiased, high-resolution tracking of BFM rotational dynamics under well-defined chemical conditions, providing a robust experimental framework for quantitative chemotaxis studies in magnetotactic bacteria.

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Poster TH-10

Liposomes for Ophthalmic Administration of Nutlin-3a prepared by Microfluidic Approach

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The ocular delivery of therapeutic agents is generally restricted by the eye's natural barriers, necessitating advanced drug delivery systems. Novel drug-delivery technologies, such as liposomes, are raising attention as potential ophthalmic drug delivery systems, due to their capacity to encapsulate and efficiently deliver also highly lipophilic drugs. In this respect, the present study strives to develop and produce liposomes formulation able to encapsulate and allow the ophthalmic delivery of Nutlin-3a, a small non-genotoxic inhibitor of the MDM2/p53 interaction, that has shown interesting therapeutic potential against proliferative vitreoretinal diseases. Liposomes were produced via innovative microfluidic approach, and their size distribution was evaluated by dynamic light scattering, and centrifugal field flow fractionation. Nutlin-3a encapsulation efficiency was evaluated via ultrafiltration and HPLC. Moreover, morphological, and structural characterization were conducted using transmission electron microscopy and Fourier-transform infrared spectroscopy, respectively. Through microfluidic formulation studies, phosphatidylcholine liposomes (5.4 and 8.2 mg/mL in 10% ethanol) were selected for their optimal characteristics: a round vesicular structure, a mean size of ~150 nm, low polydispersity (PDI < 0.2), and efficient Nutlin-3a loading. [1]. Biological assays on RPE cell models demonstrated that Nutlin-3a-loaded liposomes significantly reduced cell viability and migration, highlighting their potential for future ophthalmic applications.

Poster TH-11

Microfluidic investigation of cancer cell migration under confinement and interstitial flow

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Cancer metastasis critically depends on cell migration through physically confined and flow-driven microenvironments. In this study, we investigate breast cancer cell migration in a microfluidic platform that mimics a heterogeneous, collagen-coated constriction network under interstitial flow. Migration of MDA-MB-231 cells in a two-dimensional network of micron-scale pores was compared with migration in an unconstrained microchannel. Confinement reduced average migration speed and prolonged superdiffusive motion, while transient increases in velocity were observed during passage through constrictions. The effect of interstitial flow was examined across multiple flow rates, revealing enhanced migration speed, directional bias along streamlines, and persistent superdiffusive behavior under flow. Numerical simulations confirmed heterogeneous velocity and shear stress distributions within the network. These findings highlight how geometric confinement and fluid flow jointly regulate cancer cell migration in microfluidic environments, with implications for understanding physical mechanisms underlying metastatic invasion.

Poster TH-12

Magnetically Driven Ferrofluid Transport for Pump-less Cooling in 3D-Printed Channels

Author: Bingchao Wang[1]; Adam Stokes; Jonah Mack; Yaojue Xiong

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Efficient thermal management in compact and sealed systems remains challenging due to the reliance on bulky mechanical pumps and the limited design flexibility of conventional cooling architectures. In this work, we present a pump-less ferrofluidic cooling approach that leverages electro-permanent magnet (EPM) actuation combined with 3D-printed fluidic channels to enable programmable and localized heat transport in confined environments. Additive manufacturing enables rapid prototyping of channels with varied geometries, including straight, serpentine, and branched configurations, providing a flexible platform to explore the coupling between channel topology, magnetic actuation parameters, and thermal behavior.

Magnetic fluid circulation is driven by externally placed EPM units that generate spatially and temporally controlled magnetic field gradients. By sequentially switching neighboring EPMs, a traveling-wave magnetic actuation scheme is formed, producing an effective magnetic pressure that drives ferrofluid flow through the printed channels without moving mechanical components. Compared to continuously driven electromagnetic coils, EPM-based actuation avoids sustained Joule heating by maintaining magnetic fields without continuous power input, making it particularly suitable for thermal management applications where actuator-induced heating must be minimized. This digital actuation strategy enables reversible flow direction, rapid on–off control, and waveform-tunable transport, while maintaining the magnetic field with negligible static power consumption.

A simplified coupled dynamic framework is introduced to relate EPM pulse timing and strength to magnetic body forces, flow resistance within the channels, and the resulting heat-transfer response. The framework supports parameter selection and experimental design by revealing key trends linking flow rate, thermal transport, and electrical energy input. A modular experimental platform incorporating localized resistive heating and temperature monitoring is established to evaluate flow controllability and cooling response across different channel geometries and actuation schemes.

This study establishes an integrated experimental and modeling framework for investigating magnetically driven ferrofluid transport for thermal management applications. Initial observations suggest that channel topology plays a critical role in balancing hydraulic resistance against magnetically induced driving forces. These results highlight fundamental design trade-offs between increasing heat-transfer surface area and maintaining achievable flow under pump-less magnetic actuation, pointing toward compact, low-power, and reconfigurable thermal management solutions for high-density electronic systems.

Poster TH-13

Integrated microfluidic platforms with low process volumes for the efficient formulation of lipid nanoparticles and scalable production

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Lipid nanoparticles (LNPs) are a key delivery platform for nucleic acid–based therapeutics, yet early-stage formulation development is often constrained by high material consumption and limited throughput. We present two complementary technologies addressing these challenges: FLIPS, an automated low-volume particle formulation system optimized for screening, and FDmiX, a scalable microfluidic mixing platform for reproducible LNP production.

FLIPS is a single-line, semi-automated encapsulation system designed for formulation volumes in the microliter scale. It employs compressed-air–driven fluid transport, fully reusable fluidic components, and an automated cleaning workflow to minimize cross-contamination and downtime. Integration of a proprietary microfluidic platform and a compact filling station enables formulation volumes below 1 mL, reducing material consumption compared with conventional syringe-pump-based systems. FLIPS is engineered to achieve processing times under 120 s per formulation, and material waste below 30 %, supporting efficient and reproducible screening workflows.

In a proof-of-concept study, LNPs formulated from an ionizable lipid system encapsulating eGFP mRNA were produced at a total flow rate of 25 mL·min⁻¹. From a total formulation volume of 1 mL, 700 µL of product was recovered. Particle characterization by dynamic light scattering and nanoparticle tracking analysis demonstrated narrow size distributions and low polydispersity (Z-average = 65 nm, PDI = 0.05), comparable to LNPs produced using conventional syringe-pump setups. Encapsulation efficiencies exceeded 95 %, indicating that automation and miniaturization did not compromise formulation performance.

The FDmiX microfluidic mixing platform complements FLIPS by providing highly efficient micromixing across a wide flow range (10–1.000 mL·min⁻¹). This enables consistent control of critical LNP quality attributes from low-volume screening to high-throughput production, facilitating translation between development stages.

Together, the FLIPS and FDmiX systems constitute an integrated, resource-efficient solution for LNP formulation, enabling rapid screening with minimal material use while maintaining scalability and reproducibility suitable for scale up development.

Poster TH-14

A CMOS-Integrated Lab-on-a-Chip System for Continuous Cellular Imaging and Thermal Control

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Biological systems in space are exposed to elevated levels of ionising radiation and environmental stressors that are difficult to replicate on Earth, yet continuous in-situ measurements of cellular responses during spaceflight remain limited. Existing space biology experiments are often constrained by payload mass, optical complexity, and the need for crew intervention, restricting experimental duration and temporal resolution. There is therefore a growing need for compact, autonomous platforms capable of long-term cellular monitoring under tightly constrained resources.

We present a compact lab-on-a-chip system that integrates a microfluidic device directly on top of a CMOS image sensor for simultaneous biological cell counting, thermal manipulation, and super-resolution imaging. Cells flowing through the microchannel are recorded in close proximity to the sensor, enabling lens-free detection and real-time counting without conventional optics. Super-resolution phase images are reconstructed using ptychographic phase retrieval from multiple overlapping intensity measurements, providing detailed information on cell morphology. Localised heating is achieved using integrated resistive heaters, allowing controlled thermal stimulation of the cellular environment under continuous flow. The platform enables correlation between cell number, morphology, and temperature, offering a scalable, low-mass, and low-power approach for studying cellular responses to radiation and environmental stress. This system is well suited for autonomous spaceflight biology experiments as well as terrestrial applications where compact and continuous biophysical monitoring is required

Poster TH-15

Low-Cost Paper-Based Lab-on-Chip: Creating Hydrophobic Barriers using Common Materials for Microfluidic uses

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Although microfluidic lab-on-a-chip devices have revolutionized analytical chemistry and point-of-care diagnostics, their widespread adoption remains limited due to high manufacturing costs and the requirement for specialized fabrication equipment, particularly in resource-constrained settings. This study introduces an innovative, remarkably inexpensive technique for creating paper-based microfluidic devices by employing hydrophobic barrier materials on porous filter paper substrates with easily available household items. This approach is perfect for situations with limited resources, as it significantly reduces production expenses and enhances accessibility

Easy adoption and scalability are made possible by the fabrication technique, which allows accurate specification of microfluidic channels inside the porous media without the need for costly equipment or cleanroom facilities. One significant breakthrough that streamlines the production process without sacrificing functional integrity is the use of everyday household items as hydrophobic agents. Scanning electron microscopy (SEM) was used for thorough characterisation in order to examine surface morphology and verify the development of distinct hydrophobic barriers. In order to evaluate the structural integrity and fluidic behaviour of the channels, porosity tests were also carried out on both treated hydrophobic sections and untreated filter paper.

Excellent hydrophobic barrier development with clear, sharp channel borders is shown by the results. Significant variations in surface morphology between hydrophobic and hydrophilic regions—which are essential for regulated capillary-driven fluid flow—were found by the SEM examination. The devices' constant and predictable fluid dynamics were made possible by their uniform coating morphology. These microfluidic devices made from paper showcased functional effectiveness by reaching flow rates suitable for analytical applications, even with their low material expenses. The platform's economic benefit is illustrated by the reality that the cost per device is many times lower than that of conventional polydimethylsiloxane (PDMS)-based microfluidic devices.

This technology fills a vital demand for accessible and reasonably priced analytical chemistry platforms and diagnostic tools, especially in resource-constrained environments. It is a desirable option for point-of-care testing applications due to its robust performance, low cost, and simplicity of production.. In order to further improve device performance and utility, future work will integrate computational fluid dynamics (CFD) modelling to optimise channel shapes and flow characteristics customised for certain analytical tasks.

This paper-based microfluidic platform provides a useful substitute for conventional microfabrication methods by fusing ease of use, affordability, and dependable fluidic control. It has the potential to greatly increase the scope of diagnostic technologies.

Poster TH-16

Controlling and optimising deformation modes of a pneumatically actuated single-layer PDMS device

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The elasticity of PDMS has been instrumental in advancing important microfluidic technologies, ranging from early valves [1] to sophisticated organ-on-a-chip systems [2]. However, the complex multilayer fabrication often required for these devices restricts their broader applicability. To address this, Jain and Belkadi [3] recently introduced a single-layer geometry consisting of a wide and thin microfluidic channel, running parallel to two large air chambers. Controlling the pressure in the air chambers was shown to control the position of the ceiling in the microfluidic channel, with negative pressures lowering the ceiling and positive pressures raising it. While promising for biological applications, the operational range of this device has lacked rigorous characterisation, forcing reliance on trial-and-error design.

Here, we combine finite element method (FEM) simulations with experimental validation to investigate the actuation mechanism and optimise ceiling displacement. Using a Neo-Hookean model parametrised by six geometric variables, we performed a global sensitivity analysis (Sobol' s method) on 14,336 simulations. This revealed the geometric features driving deformation magnitude and allowed us to identify the configuration for maximal displacement through a targeted sweep of the three most critical parameters: PDMS layer height, channel width, and air chamber width.

Beyond displacement amplitude of the ceiling, the simulations also provide insights about the mechanisms governing the shape of the displaced ceiling. Depending on the interplay of localised compression and extension, the ceiling adopts either a U-shaped profile with a minimum at the symmetry plane, or a W-shaped profile where the center bulges upwards between two minima.The transition shape in between those two profiles is of particular interest, as it is characterised by a homogenous, flat downward deflection of the ceiling. A second sensitivity analysis identifies the parameters governing these contributions, enabling the prediction of the transition between deformation regimes. Experimental measurements of ceiling displacement validated the FEM model for three chip geometries, confirming all the predicted deformation shapes. Finally, by applying the maximised deformation geometry and modifying the channel cross-section, we demonstrate the fabrication of a fully closing microfluidic valve within a single-layer PDMS chip.

By eliminating complex multilayer fabrication, this approach renders reconfigurable technology widely accessible, facilitating its application in mechanobiology and the development of dynamic, easily manufacturable organ-on-chip systems.

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Poster TH-17

High-Resolution Dielectric Spectroscopy of Single Flowing Cells

Authors: Marta Righetto[1]; Riccardo Reale[1]; Federico Carneri[2]; Alessandra Mistretta[2]; Marta De Zotti[3]; Daniela Roversi[2]; Paolo Bisegna[1]; Adele De Ninno[4]; Federica Caselli[5]

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Dielectric properties of cells are central to life science research and label-free diagnostics. Microfabrication now enables single-cell electrical measurements, but existing platforms face a trade-off: trapped-cell systems offer high frequency resolution with low throughput, while flow-based systems provide high throughput with limited frequency resolution.

Building on recent work by Morgan' s group (ACS Sensors, 5(2), 423–430, 2020; Lab Chip, 25(12), 2939–2948), we present a novel microfluidic impedance cytometry platform capable of rapid dielectric characterization of flowing cells at 14 simultaneous, logarithmically spaced frequencies between 250 kHz and 50 MHz, achieving an unprecedented resolution of 6.1 data points per decade. We validate the approach on red blood cells (RBCs) and yeast cells, both under native conditions and under chemical or physical stress. Specifically, in the case of RBCs we investigate the exposure to two antimicrobial peptides (i.e., 1 μM DNS-PMAP23 and 20 μM trichogin GA IV), whereas for yeast cells we consider prolonged exposure to high temperature (i.e., 30 minutes at 70℃).

Individual flowing cells pass through the sensing region of the microfluidic chip, which comprises two measurement zones. Each measurement zone uses a standard differential wiring scheme and is connected to a lock-in amplifier. The two lock-in amplifiers use distinct frequency sets to characterize cell impedance and operate in a synchronized mode. For each measured cell, the impedance traces acquired from the two measurement zones are combined and processed by a tailored algorithm to obtain the experimental impedance spectrum. This experimental spectrum is then fitted with an appropriate shell model to obtain the cell dielectric properties.

Significant changes in the dielectric spectra of treated versus native RBCs were observed, which translate into different values of the dielectric properties estimated via model fitting. Control RBCs are characterized by (median values): 2.7 μm radius, 0.95 μF/cm2 membrane capacitance, and 0.41 S/m cytoplasm conductivity. Incubation with DNS-PMAP23 and with trichogin GA IV is associated with larger (3.1 μm) and smaller (1.9 μm) median radius, respectively. Both peptides induce a reduction in membrane capacitance and an increase in cytoplasm conductivity. For the yeast cells, while the control sample exhibits a typical relaxation behavior, the spectrum of the heat-treated cells remains almost constant across the probed frequency range. In fact, heating induces coagulation of intracellular content with consequent decrease of intracellular conductivity.

We believe that the developed technology, overcoming the longstanding trade-off between high throughput and high frequency resolution, will accelerate novel discoveries in the field of single cell electrical characterization and associated applications in diagnostics and life science.

Poster TH-18

Microfluidic Fuses: Flow-Induced Choking in Channels

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Fluid-structure interactions are commonly used in the development of microfluidic analogues of microelectronic devices. Examples that exist already in the literature include microfluidic diodes, transistors, and capacitors. In this talk, we theoretically and experimentally explore a microfluidic fuse, a device which prevents fluid flow above a determined critical flow rate. These devices consist of a channel formed along the axis of a cylindrical elastomer, confined on all sides by a rigid mold. The softness of the elastomer permits shape-morphing of the channel in response to fluid forcing. Beyond the critical flow rate, flow-induced deformation causes the channel diameter to increase in nearer the flow inlet, displacing elastomer towards the flow outlet, where the channel constricts. If the magnitude of this deformation is sufficient, the channel will constrict to the point that fluid flow is inhibited (the flow is “choked”). For this proof-of-concept device, we demonstrate the robustness of this choking mechanism, explore the tunability of the critical choking flux, and compare with theoretical predictions.

Poster TH-19

The interaction between a microfluidic jet and a water-oil interface

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Despite the extensive investigations of jet formation and breakup in co-flowing microfluidics, far less attention has been given to how a microfluidic jet interacts with an interface between two immiscible fluids. Here we experimentally study the interaction between a microfluidic jet and a water-silicone oil interface in a nested, co-flowing capillary microchannel. An inertial jet of water is fired through silicone oil, towards the interface and we study the interaction between the jet and the interface post coalescence. By varying the Weber number of the jet and the channel confinement, four distinct regimes emerge within the parameter space: piercing, tunnelling via vortex ring formation, tunnelling via cascading vortex ring formation, and tunnelling via flow-focusing. We rationalise the distinct regimes by considering the balance between the jet inertia and the restoring surface tension of the interface, and the geometric confinement experienced by the intruding jet.

Poster TH-20

Simulation of water transport in porous media with variable wettability, such as the catalytic layer of a hydrogen fuel cell

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Proton exchange membrane fuel cells (PEMFCs) are subjected, during their lifetime, to freeze / thaw cycles of water produced in the catalytic layers and remaining after cell shutdown. However, in situ freeze/thaw experiments show that, for the specific types of PEMFCs investigated here, these cycles have no measurable impact on electrochemical performance and suggest that there is no significant degradation of the internal structure. This observation raises a fundamental question: where is the water located when the cell is shut down, and how is it redistributed within the porous medium constituting the catalytic layer at the nanoscopic scale?

To answer this question, we use a two-phase computational fluid dynamics approach based on a Cahn–Hilliard phase-field model implemented in Comsol Multiphysics, while neglecting disjoining pressure and evaporation in a first step. This approach allows us to explicitly describe the dynamics of liquid–gas interfaces. Particular attention is paid to modelling the dynamic contact angle through the introduction of a molecular self-layering contact angle model that depends on both the interface front velocity and the equilibrium contact angle. This approach makes it possible to go beyond static descriptions of wetting and simplified pore network model formulations that rely on a single equivalent contact angle for all surfaces, which are often insufficient to describe complex geometries involving multiple solid surfaces with distinct properties.

Two-dimensional simulations are performed on idealized geometries representing simple patterns, at scales characteristic of the porous media of catalytic layers. These configurations allow us to systematically study the influence of the coexistence of two distinct equilibrium contact angles, associated with different solid surfaces, on interface displacement and water transport. We also identify an ideal geometric case of a cylindrical pore in which the contact angle varies locally and for which an analytical solution is available. This case highlights the limitations of Cassie's law, which is commonly used to predict an equivalent contact angle. Three-dimensional numerical simulations are then carried out to explore and propose an alternative law for defining a relevant equivalent contact angle in complex geometries.

These results shed new light on the mechanisms of water redistribution in porous catalyst media in PEMFCs and highlight the importance of a dynamic and geometrically consistent description of wetting to understand two-phase transport phenomena.

Poster TH-21

Stability Analysis of a Capillary Rise Model with the Slip Boundary Condition

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Capillary-driven flow is a key transport mechanism in many microfluidic systems, graphic products, porous medium, and biological microchannels. Classical models of capillary rise, most notably Washburn's equation, have been widely used to describe the movement of the liquid column in narrow tubes. This nonlinear second-order ordinary differential equation predicts that the equilibrium height (Jurin's height) can be approached either monotonically or through damped oscillations, a behavior that has been confirmed by experiments.

In this work, we extend the classical Washburn's model by introducing a slip boundary condition at the channel wall. The introduction of a slip parameter is motivated by experimental observations, where the no-slip assumption may fail, particularly during the initial stages of liquid motion. Starting from the fundamental conservation laws of mass and momentum, we derive a physically consistent model that includes inertial effects in addition to capillary, viscous, and gravitational forces. The explicit presence of inertia represents a key difference from simplified models that are commonly used in microfluidic applications.

After appropriate scaling, the governing equation relies on a single dimensionless parameter. This formulation allows systematic study of different flow regimes and provides a basis for stability analysis. Using linearization around the equilibrium height, we show that, in the presence of slip, the system reaches the equilibrium state either monotonically or oscillatory, in analogy with the classical no-slip case. These results, however, are valid only locally, as the analysis assumes initial conditions close to equilibrium.

To establish convergence to the equilibrium height for a broader range of initial conditions, we perform a nonlinear stability analysis by introducing a Lyapunov function based on energy estimate. This approach allows us to rigorously prove asymptotic stability and to determine the basin of attraction of the equilibrium state. The results provide insight into the global dynamics of capillary rise with slip and are relevant for the design and interpretation of microfluidic experiments where wall slip and inertial effects cannot be neglected.

These results hold for any positive value of the nondimensional slip parameter in the model, and for all values of the ratio h_0/h_e in the range $[0, 3/2]$, where h_0 is the initial height of the fluid column and h_e is its equilibrium height.

I. Rapajić, S. Simić, E. Süli, Modeling capillary rise with a slip boundary condition: Well-posedness and long-time dynamics of solutions to Washburn's equation, Physica D: Nonlinear Phenomena 481 (2025) 134842.

Poster TH-22

Capillary Transport with Rough Walls and Imposed Flux: A Microfluidic Model of Plant Xylem Flow

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Capillary-driven transport through narrow conduits is central to microfluidic systems, where surface forces, wall geometry, and externally imposed fluxes jointly determine flow dynamics. In this work, we study water uptake in plants by modelling the xylem as a naturally occurring microfluidic capillary, in which sap rises under capillary action and transpiration-induced suction. Based on this biologically motivated system, we develop a modified Bosanquet-type model that integrates key physical effects relevant to microscale transport [1].

Specifically, we incorporate an effective friction term arising from wall protrusions and corrugation, analogous to roughness in microfabricated channels, and include corrections to surface tension due to dissolved ions and curvature-dependent effects through a Tolman-type correction. An externally imposed transpiration flux is introduced via boundary-driven diffusion and evaporation at the leaf level, enabling controlled forcing of the capillary flow. The resulting system provides a minimal yet rich framework to study the interplay between wetting, confinement, and imposed flux in narrow channels.

We identify a dimensionless tuning parameter, ξ, representing the relative strength of capillary and hydrostatic forces, which governs qualitative changes in system dynamics. In the absence of imposed flux, the model exhibits transitions between oscillatory and non-oscillatory capillary rise depending on ξ, while the rate of rise is controlled primarily by the effective friction parameter. When transpiration is included, the system stabilizes around a nonlinear center, while significantly increasing the maximum height attained by the fluid column.

Using dynamical systems analysis, we obtain scaling laws for (i) the time required for the column to reach its maximal height as a function of wall friction, and (ii) the characteristic decay time of oscillations as a function of ξ. We further analyze the competing effects of imposed flux and wall corrugation, highlighting regimes in which increased roughness can suppress sustained oscillations, maintaining the flow regime in the vicinity of the equilibrium point.

Our results demonstrate how biologically inspired capillary systems can illuminate general principles of microscale flow, wetting, and transport under confinement. By bridging capillary physics with nonlinear dynamics, this work offers insights relevant to both natural and engineered microfluidic systems operating under strong surface and boundary-driven effects.

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Poster TH-23

Kinetic barriers in oil de-wetting from thin-shell double emulsions towards biomimetic synthetic cells

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Bottom-up synthetic biology aims to construct synthetic cells that recapitulate, understand, and repurpose biological behaviors. Phospholipid giant vesicles (GVs) represent an excellent model for a simplified cell membrane and have been extensively explored in the field. To produce meaningfully biomimetic compartments, GVs need to be cell-sized, unilamellar, and need to encapsulate molecules of interest in high yield. Double emulsion templated techniques excel at this, guaranteeing vesicle unilamellarity, control over size, and near 100% encapsulation efficiency, representing the state-of-the-art for the formation of GV-based synthetic cells. The transition from thin-shell double emulsion to a phospholipid bilayer involves de-wetting of the oil carrier from the membrane, which is governed by the spreading coefficient of the oil over the two aqueous phases. This balance of surface tensions needs to favor contacts between the inner and outer aqueous phases, mediated by a phospholipid bilayer, compared to oil-water interfaces stabilized by a lipid monolayer. This constrains the composition of the outer aqueous phase to include additional surfactants that lower the interfacial tension between it and the oil carrier. The spreading coefficient assigns a thermodynamically favored endpoint to the system. However, thermodynamics alone do not account for the kinetics of oil removal. De-wetting initiation is a stochastic process that requires adhesion of the two lipids monolayers to begin [1]. The monolayer contact area expands, driven by the balance of interfacial tensions, until a droplet-associated GV is formed, without full detachment of the oil droplet from the underlying aqueous compartment. Our results show these droplet-associated GVs are stable in suspension for several days and full de-wetting can be achieved by mechanical means (e.g. narrow channels in microfluidic devices, centrifugation) or osmotic deflation of the vesicle [2,3]. To date the inconsistency of full de-wetting is a major bottleneck in the wide adoption of microfluidic techniques to assemble synthetic cells.

We aim to address this issue systematically, by characterizing oil de-wetting dynamics and putting them in relation with the oil content of the double emulsion, membrane composition, and surfactant presence in the outer aqueous phase. Lipid composition in particular is critically underexplored and represents a promising avenue for limiting the use of additional surfactants. These results further our understanding of the kinetic barriers to oil removal, ultimately enabling more robust microfluidic assembly of synthetic cells.

Poster TH-24

Hydrodynamic dispersion in flowing networks induces bacterial (mis)communication

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Bacterial environments are inherently dynamic, with fluid flow constantly shaping their physicochemical landscape in non-trivial ways. Quorum sensing (QS) is a key mechanism by which bacteria communicate through the diffusion of QS molecules, termed autoinducers, to cope with these dynamic conditions. Quorum sensing mediates the attachment and detachment of bacteria, by regulating the production of surface adhesins and surfactants (1) or by controlling transitions between motile and sessile lifestyles (2). Physical diffusion of autoinducers couples local production to collective response (3), whereas advective transport can disrupt this coupling by washing the signals away and generating spatial heterogeneities (4) and regulating biomass accumulation in spatially structured environments (5).

Here we investigate the role of hydrodynamic dispersion in porous media on the QS communication footprint. While dispersion can increase the spreading of the communication zone, it can also suppress communication through dilution. We developed a microfluidic PDMS-glass porous system incorporating two inlets, one for a background flow and one for the introduction of synthetic autoinducer molecules, therefore mimicking the communication footprint in the wake of a colony. We combined this approach with fluorescence microscopy of a dual-labeled *Staphylococcus aureus* strain (mKate constitutive, GFP for QS activation). This strategy enables simultaneous visualization of the spatiotemporal dynamics of bacterial growth, viability, and QS activity. We also developed an advection-dispersion model to predict the spatial footprint of QS activation.

We observe QS response from single cells to early biofilm colonies, under different Péclet numbers tuned by the flow rate. By combining experiments with the transport model, we identify regimes in which hydrodynamic dispersion either promotes or suppresses QS and highlight key parameters that shape the QS footprint in porous media. These observations also provide insights into how autoinducer concentration gradients coupled with shear forces can create preferential colonization patterns and shape flow and transport in porous media.

These findings provide new insights into these couplings between flow, transport and quorum-sensing-controlled biological responses and may thus inform on the biofilm dynamics involved in environmental, health and bioengineering applications.

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Poster TH-25

Soft objects in textured microchannels: a friction-based sorting mechanism

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Microfluidic technologies provide powerful tools for manipulating and sorting microscopic objects and play an important role in diagnostics and therapeutic research. Conventional sorting strategies are generally based on physical properties such as density or size, using techniques like centrifugation or microfluidic filtration, while more advanced approaches take advantage of how cells respond to external stimuli, including light or magnetic fields, enabling active sorting in microfluidic devices. Recently, cell deformability, have emerged as highly informative biomarkers, reflecting internal mechanical states linking to disease progression, immune activation, and differentiation [1, 2]. In confined microchannels, soft objects, including droplets, capsules, and biological cells, typically maintain mobility via a thin lubrication film that prevents direct contact with channel walls. However, recent research indicates that micro-scale wall textures can disrupt lubrication, causing soft objects to trap at low velocities but glide smoothly at higher speeds [3]. This surface roughness creates a sharp transition in frictional behavior compared to standard lubricated motion. Under a fixed flow condition, this mechanism introduces a critical role for deformability, as more rigid objects tend to experience higher resistance, while more deformable ones remain efficiently transported by the flow. Consequently, capsules consisting of a liquid core enclosed by an elastic membrane, resembling the mechanical behavior of living cells, serve as an ideal physical model to investigate these bio-inspired sorting mechanism.

The project focuses on exploiting friction-based transitions to design microfluidic devices that sort soft objects exclusively by deformability. By tunning surface topography and flow conditions, we investigate how objects with different mechanical properties follow distinct trajectories, enabling passive, mechanical sorting without external fields. To address this, we are developing a novel device using elastic capsules, produced via specific protocols to ensure defined mechanical properties. The work involves analyzing the physical interaction between capsules and textured channel walls, while quantifying how friction forces depend on parameters such as flow rate, surface texture geometry, capsule size, and deformability. Initial experiments focus on probing the behavior of single capsules, expecting stiffer ones to deviate while softer ones remain unperturbed. This framework aims to establishing the link between surface texture and particle deformability, laying the groundwork for future sorting applications.

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Poster TH-26

When Shape Matters: Surface Chemistry and Anisotropic Particle Retention in Depth Filtration

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Many medically and environmentally relevant pathogens, including viruses and bacteria, exhibit pronounced shape anisotropy, ranging from spherical to elongated geometries. Their removal in pharmaceutical manufacturing and water treatment commonly relies on membrane-assisted depth filtration. Despite its widespread use, a mechanistic understanding of how membrane surface chemistry and particle geometry govern retention remains limited. Direct in-situ visualization of single particle behavior within real filtration membranes is highly complex. Consequently, mechanistic insights are largely derived from microfluidic membrane-mimicking devices (MMD) using spherical model particles. This raises the fundamental question: to what extent are these results transferable to the transport and capture of non-spherical colloids?

Here, we address this question using a microfluidic depth filtration MMD that enables systematic control over collector surface chemistry and direct visualization of particle dynamics. We investigate (i) the role of surface chemistry in depth filtration and (ii) the extent to which filtration behavior depends on particle shape. First, transport and retention of spherical poly(ethylene glycol) diacrylate (PEGDA) particles are quantified on polydimethylsiloxane (PDMS), oxygen-plasma-treated PDMS, and Poly(diallyldimethylammonium chloride) (PDADMAC)- and Poly(styrenesulfonic acid) (PSS)-modified collector surfaces. Identical filtration conditions are then applied to rod-shaped PEGDA particles with aspect ratios of 1.5 and 3 on PDMS and PDADMAC collectors. Across all particle geometries, the minimum particle diameter is kept within a comparable range.

For spherical particles, we found that filtration performance is strongly governed by surface chemistry. However, hydrophilicity alone is insufficient to predict fouling behavior. Surfaces with similar charge but differing wettability exhibit different flux declines. Instead, surface charge and specific collector–particle interactions emerge as the dominant parameters of retention. Breakthrough analysis reveals particle passage on hydrophilic surfaces, whereas hydrophobic PDMS achieves complete retention, underscoring the nontrivial interplay between wettability and electrostatic interactions in depth filtration.

In contrast, for rod-shaped particles, trends established for spherical colloids are not directly transferable. Breakthrough behavior and flux decline are insensitive to surface chemistry and remain within a comparable range across collectors. Particle geometry instead emerges as the dominant parameter. Surface chemistry primarily influences pore-scale particle orientation, broadening the distribution of orientations relative to the flow direction. Increasing particle aspect ratio leads to reduced flux decline and lower breakthrough, as elongated particles are retained earlier within the porous structure.

Collectively, these results demonstrate that particle shape fundamentally alters filtration mechanisms, limiting the predictive value of spherical model systems for anisotropic pathogens and highlighting the need to explicitly account for particle geometry in the design and interpretation of depth filtration processes.

Poster TH-27

AC-enhanced chiral drift of helical microswimmers in viscous pipe flow

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We study microfluidic separation of helical particles with opposite chirality in pressure-driven flow through a cylindrical capillary. Chirality couples the local shear to an axial drift relative to the carrier flow, so left- and right-handed helices acquire equal-magnitude drift in opposite directions, enabling axial separation downstream. We show that adding a small oscillatory modulation to an otherwise steady pressure drive provides an additional, frequency-tunable handle: the AC contribution to the drift has a resonance-like dependence on rotational diffusivity, so the drift can be selectively amplified for particles whose rotational relaxation rate matches the forcing rate. This offers a practical way to enhance separation performance while retaining a simple channel geometry and mild shear conditions relevant for biological helices.

On the modelling side, we start from Jeffery’ s equation for an axisymmetric body in a linear Stokes flow and include isotropic rotational Brownian motion. At the ensemble level this yields a Fokker–Planck equation for the orientation probability density on the unit sphere. In the small-tilt regime near the channel axis we project this equation onto the first spherical harmonic to obtain a closed Debye-type evolution equation for the transverse first moment of the orientation, which quantifies the shear-induced radial bias of the ensemble. For a combined steady and oscillatory shear profile, this reduced equation can be solved analytically; after averaging over many oscillation periods we obtain an explicit drift law that separates into a steady contribution and an AC-enhanced contribution.

We discuss how the effective chiral coupling coefficient entering the drift law can be estimated from hydrodynamic calculations or calibrated in steady shear. Combining the predicted drift with axial and radial translational diffusion yields compact design rules for capillary length, mean flow rate, and modulation amplitude that ensure both good axial resolution and negligible wall contact. Finally, we outline how Langevin simulations of Jeffery-plus-noise dynamics in a Poiseuille profile can be used to validate the reduced theory and guide microfluidic designs for separating synthetic helices, bacterial flagella, or other chiral filaments.

Poster TH-28

Robust fabrication of ultra-soft PDMS microcapsules as a biomimetic model for red blood cells

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Red blood cells (RBCs) can display a wide range of behaviours, depending on the capillary number (Ca, ratio of viscous to surface tension forces) and confinement parameters. However, real RBCs are not easily available, biodegradable and highly variable. Since they do not contain a nucleus, we propose to model RBCs as membrane-encapsulated liquid droplets, which gives flexibility to tune their physical properties.

Our first generation of capsules relied on nested capillaries to produce a double emulsion, which forms elastic capsules by curing the middle polymer phase. The capsules are deflated by osmosis to reproduce the high physiological ratio of surface area to volume in RBCs [1]. We find that a selectively functionalized microfluidic chip constitutes a faster, more robust method to produce the double emulsion and allows for parallelization [2].

The second generation of capsules aims to better recapitulate RBC deformation in flow. For this, we make the capsules softer to extend the range of available flow conditions parametrised by Ca, we match the high viscosity ratio of the RBC core to the surrounding fluid and approximate the RBC biconcave shape. We proceed to explore the motion and deformation of this generation of capsules under shear flow, by comparison with typical RBC dynamics [3]. This allows us to benchmark single capsules for the subsequent study of suspension flows in complex media, to identify the role of mechanics in the microcirculation under healthy and diseased conditions.

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Poster TH-29

Bioinspired Microfluidic Chips for the Selection of High-Motility Sperm Cells and In Vitro Fertilization

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Male infertility affects a significant proportion of couples seeking assisted reproductive technologies (ART), with sperm quality being a key determinant of fertilisation success. Conventional sperm preparation via density gradient centrifugation (DGC) subjects cells to mechanical and oxidative stress, risking DNA damage and compromising the very parameters it seeks to improve. Replicating the selective, low-shear environment of the female reproductive tract, therefore, represents a compelling strategy for more physiologically relevant sperm preparation.

To address this, a bioinspired microfluidic chip was designed and fabricated from Poly(methyl methacrylate) (PMMA) using laser microfabrication. The device comprises 200 parallel microchannels operating under laminar flow, enabling passive motility-based sperm sorting without centrifugation. Clinical semen samples were processed using both the microfluidic sorting (MSS) device and conventional DGC, with sperm quality assessed by computer-assisted sperm analysis (CASA) for motility parameters and the sperm chromatin dispersion (SCD) method for DNA integrity.

Microfluidic sorting produced consistent and statistically significant improvements over DGC across every functional parameter examined. Total motility reached $95.5 \pm 4.1\%$ following MSS compared to $87.2 \pm 8.7\%$ after DGC, while progressive motility improved markedly from $59.7 \pm 13.1\%$ to $81.4 \pm 6.3\%$. Normal morphology and DNA integrity followed the same trend, with intact DNA proportions reaching $98.0 \pm 2.0\%$ after MSS versus $96.0 \pm 4.4\%$ after DGC.

The PMMA-based bioinspired microfluidic chip demonstrates clear superiority over DGC as a centrifugation-free sperm preparation platform. By harnessing intrinsic sperm motility under physiological flow conditions, it yields higher-quality cell populations with greater motility, morphological normality, and genomic integrity - positioning it as a promising and clinically translatable tool for ART.

Poster TH-30

Development of a Biomimetic Hybrid Nanofiber Membrane towards Lung-on-a-Chip Applications

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The alveolar basement membrane (BM) plays a critical role in maintaining the structural and functional integrity of the lung air-blood barrier. Replicating its nanoscale architecture, mechanical compliance, and biological activity remains a fundamental challenge in lung-on-a-chip (LoC) device development, as conventional synthetic membranes fail to fully recapitulate native BM characteristics.

This study reports the fabrication and characterisation of biomimetic electrospun nanofiber membranes as candidates for LoC integration. Three membrane types were investigated: poly(ε-caprolactone) (PCL), PCL-collagen, and a novel PCL-gelatin composite. Membranes were systematically characterised for morphology by scanning electron microscopy (SEM), chemical composition by attenuated total reflectance Fourier transform infrared (ATR-FTIR) spectroscopy, mechanical properties (tensile testing), wettability (contact angle measurements), and biocompatibility (confocal fluorescence microscopy; PrestoBlue metabolic assay with MRC-5 fibroblasts).

SEM analysis revealed randomly oriented fibrous morphologies with consistent thickness (10 μm) across all formulations. The PCL-gelatin membrane produced the finest fiber diameter (0.803 ± 0.134 μm), most closely approximating the nanoscale fibrillar architecture of the native alveolar BM. ATR-FTIR confirmed successful protein incorporation, with crosslinking evidenced by enhanced amide band intensity. Mechanically, PCL-gelatin presented the most balanced profile - highest tensile strength combined with intermediate stiffness - offering the closest approximation to native tissue compliance. Both composite membranes demonstrated complete surface wettability, in contrast to hydrophobic PCL controls, confirming that protein incorporation fundamentally transforms surface character. Biocompatibility assessment via Live/Dead imaging confirmed high cell viability across all membranes, while PrestoBlue assay demonstrated enhanced and sustained MRC-5 proliferation on PCL-gelatin over 96 hours. A prototype microfluidic device was assembled, with the membrane integrated between Polydimethylsiloxane (PDMS) and Cyclic olefin copolymer (COC) layers.

Collectively, the PCL-gelatin hybrid nanofiber membrane demonstrates strong potential for physiologically relevant LoC models, with on-chip cell culture identified as a key direction for future validation.

Poster TH-31

Evaluation of Additive Manufacturing techniques' impacts on generation of microfluidics utilized in bio-applications

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Microfluidic technologies have become indispensable in tissue engineering, primarily due to their ability to manipulate fluids at a scale commensurate with biological microenvironments. However, while biological parameters are frequently prioritized, there remains a critical need to evaluate these platforms from a rigorous engineering perspective to achieve high-throughput optimization and structural fidelity. This study provides a comprehensive characterization of three distinct additive manufacturing (AM) modalities—Fused Deposition Modelling (FDM), Stereolithography (SLA), and Two-Photon Polymerization (2PP)—and compares them against a novel ABS-PDMS hybrid casting methodology for the fabrication of microfluidic chips.

The evaluation focused on critical engineering metrics: surface roughness (Ra), minimum unblocked channel resolution, dimensional accuracy, fabrication lead time, cost-efficiency, and practical viability for biological integration. Surface topography is a determinant factor in microfluidic performance, as it directly influences the transition from laminar to turbulent. In this work, the internal topography of microchannels fabricated via the aforementioned methods was quantified using contactless focus variation microscopy.

A standardized microfluidic design was implemented across all fabrication platforms to produce hollow alginate microfibers via a coaxial core-shell flow mechanism. The stability of this coaxial jet is maintained by the low Reynolds number (Re) inherent to the microscale geometry, ensuring a stable laminar interface. The resulting hollow fibres were subjected to rigorous mechanical testing to evaluate their tensile strength and elastic modulus, which are crucial for maintaining structural integrity under physiological perfusion pressures.

To assess the biological functionalization of these fibres, the chemistry of fibres was optimized to facilitate a cell-friendly environment for Human Umbilical Vein Endothelial Cells (HUVECs). By refining the physical and chemical properties of the alginate matrix, we achieved significant cell attachment and proliferation. Longitudinal observations confirmed the self-organization of HUVECs into an integrated, confluent lumen within the hollow fibres. Our findings demonstrate a direct correlation between fabrication resolution and biological biomimicry; specifically, the high-resolution capabilities of 2PP and optimized hybrid casting allowed to produce narrower hollow fibres, yielding cellular lumens with diameters approaching those of native human blood capillaries. This study establishes a benchmark for selecting fabrication techniques based on the required balance between architectural complexity and biological functionality.

Poster TH-32

Axial patterning control in neural organoids via microfluidic platforms through morphogen gradients and ECM modulation

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Human neural morphogenesis is a fundamental process of embryonic development that guides the formation of the central nervous system. It originates from an elongated structure called neural tube, which regionalizes and patterns giving rise to distinct neuronal identities spatially organized along its two main axes (antero-posterior and dorso-ventral). Neural tube patterning is regulated by multiple intrinsic and extrinsic factors acting through a coordinated cross-talk between biochemical and biophysical signals. Gradients of signalling molecules known as morphogens, secreted by surrounding tissues, provide spatial information along the major developmental axes. In addition to biochemical cues, cell behaviour is strongly influenced by biophysical signals arising from the local microenvironment. Extracellular matrix (ECM) properties and mechanosensing have a central role during the earliest stages of human neural development; however, how developing neural tissues integrate mechanical cues with morphogen-driven signalling to coordinate cell fate specification, spatial patterning, growth, and morphogenesis remains poorly understood.

Due to ethical constraints and limited experimental accessibility, direct investigation of early human neural development is not feasible in vivo, underscoring the need for physiologically relevant human in vitro models. Human pluripotent stem cell–derived neural organoids represent a powerful alternative, as they self-assemble into three-dimensional structures that recapitulate key aspects of human neural development while allowing experimental accessibility and external control. Nonetheless, current organoid-based approaches present important limitations: morphogens are typically supplied uniformly through the culture medium, resulting in limited spatial control over patterning, while the ECM is often treated as a passive component. Consequently, biochemical and biophysical cues cannot be independently or jointly tuned in a controlled and spatially defined manner, restricting the ability of existing models to dissect their synergistic roles during human neural patterning.

To address these limitations, this work aims to develop an in vitro platform to spatially guide human neural tube patterning by combining controlled morphogen gradients with the modulation of extracellular matrix properties, enabling the investigation of how biochemical and mechanical cues jointly regulate early neural tissue organization.

Neural organoids are subjected to neural differentiation and patterning protocols and cultured within microfluidic devices designed to generate stable, reproducible and tuneable morphogen gradients with well-defined geometry. The platform enables the application of opposing gradients of dorsal and ventral morphogens—Bone Morphogenetic Proteins (BMPs) and Sonic Hedgehog (SHH), respectively—recapitulating key signalling axes observed in vivo. Integration of the microfluidic system with extracellular matrices of different stiffness allows systematic modulation of the mechanical microenvironment. Morphogen distribution and diffusive properties are characterized through in silico modelling, while the combined effects of biochemical gradients and ECM mechanics on neural patterning are analysed at the level of cellular differentiation.

Overall, this experimental approach provides a controlled experimental framework to investigate how biochemical and mechanical cues cooperatively shape morphogenetic patterning in human neural organoids.

Poster TH-33

Microfluidics devices for precise patterning of organ-on-chips

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An organoid is a miniature three-dimensional biological structure that mimics certain functions of an organ, though not all. Pluripotent stem cells which can multiply almost indefinitely and differentiate into various types of specialised cells or adult stem cells are used to create organoids. These cells are cultured in vitro under specific conditions promoting their differentiation and spatial organisation, thus mimicking the development of cells in an embryo or adult tissues capable of self-regeneration. Embryonic Stem Cells (ESCs) or Induced Pluripotent Stem Cells (IPSCs) can make brain and spinal organoids. Indeed, these cells can be differentiated into neural cells, thanks to knowledge of how neural cells are specified in vivo. Despite progress, current in vitro models cannot fully replicate the complex cellular diversity and spatial organisation in the nervous system, such as the brain or spinal cord. This limitation restricts their effectiveness in biomedical applications.

Inspired by tissue patterning mechanisms during early brain embryonic development, we designed and microfabricated a device that enables localized delivery of morphogens to human embryonic stem cell (hESC) colonies to generate spatially patterned brain and spinal organoids. The device allows precise control over the position, size, and timing of morphogen exposure while preserving standard culture conditions. Cell dynamics and fate specification were analysed using live imaging and immunostaining.

I will present proof of concept of localized stimulation of tissues by our microfabricated devices using BMP stimulation of hESC as a benchmark assay. Functional validation showed that cells exposed to BMP4 patches specifically responded to the signal, as shown by localized pathway activation and changes in cell identity, while surrounding regions remained unstimulated. These results confirm that the device enables precise spatial control of morphogen delivery and effective basal signal reception by pluripotent cells. In the future, combining this approach with micropatterning and differentiation protocols will allow the controlled generation of spatially organised organoids.

Poster TH-34

Pulmonary surfactant propagation in biomimetic airways : Relevance for adult acute respiratory distress syndrome (ARDS).

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Pulmonary surfactant deficiency or dysfunction is associated with several respiratory pathologies, including neonatal respiratory distress syndrome (RDS). In premature infants, lung immaturity limits surfactant production, increasing alveolar surface tension and causing severe breathing difficulties. To treat this condition, surfactant replacement therapy (SRT), based on intratracheal instillation of exogenous surfactant, was developed and has proven highly effective in neonates, becoming standard clinical practice.
SRT was later explored in adults, particularly for acute respiratory distress syndrome (ARDS), but clinical outcomes have been inconclusive. We hypothesize that this discrepancy arises from differences in surfactant distribution between adult and neonatal lungs, due to the greater geometric complexity of the pulmonary tree and the presence of an airway mucus layer.
To date, exogenous pulmonary surfactant propagation has been studied mainly through theoretical models and numerical simulations[1], while experimental investigations remain scarce[2]. In particular, surfactant–mucus interactions and their impact on surfactant distribution in branched adult airway geometries have not been systematically explored.
Here, we propose a microfluidic approach to experimentally study the propagation of exogenous pulmonary surfactant (Curosurf®) in simplified geometries that mimic distal pulmonary airway bifurcations. These bifurcations, representative of the last generations of the airways in adults, are regions where geometric confinement, capillarity, and interfacial effects are dominant, and where the most relevant surfactant–mucus interaction phenomena are expected to occur during propagation.
The system is based on PDMS microfluidic bifurcations, in which the surfactant is introduced in the form of plugs generated via classical T-junction configuration [3–5].
In a first stage, the study focuses on uncoated microfluidic devices, with the aim of establishing a reproducible experimental baseline for surfactant distribution in simple bifurcations. In a later stage, the system evolves toward more biomimetic configurations by incorporating polymeric coatings based on snail mucin as a model of pulmonary mucus, in order to investigate how the presence of this viscoelastic layer affects surfactant propagation and distribution in pulmonary bifurcations.

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