

TIME TABLE

Registration at 8.30 a.m.

TIME	Monday	Tuesday	Wednesday	Thursday	Friday
	October 4	October 5	October 6	October 7	October 8
09.00 - 09.45	Kanso	Polin	Wan	Friedrich	Cicuta
09.45 - 10.30	Cicuta	Polin	Wan	Friedrich	Cicuta
11.00 - 11.45	Polin	Kanso	Brumley	Eloy	Friedrich
11.45 - 12.30	Brumley	Kanso	Brumley	Eloy	Friedrich
14.00 - 14.45	Wan	Wan	Eloy	Kanso	
14.45 - 15.30	Eloy	Wan	Eloy	Kanso	
16.00 - 16.45	Friedrich	Cicuta	Polin	Brumley	
16.45 - 17.30	De Simone	Cicuta	Polin	Brumley	
18.00	Welcome aperitif				

ADMISSION AND ACCOMMODATION

The course is offered in a hybrid format, allowing participants the flexibility to attend either in person or remotely via the Microsoft Teams platform. Admission to on-site attendance is granted on a first-come, first-served basis to comply with the capacity of the lecture room.

Registration fees:

- **Early Bird On-Site Participation: € 650.00 + VAT***
Deadline: August 4, 2027
- **Late On-Site Participation: € 800.00 + VAT***
Deadline: September 22, 2027
- **Live Streaming Online Participation: € 250.00 + VAT***
Deadline: September 22, 2027

On-site participation includes a complimentary bag, five fixed menu buffet lunches, hot beverages, downloadable lecture notes.

Online participation includes downloadable lecture notes.

Application forms should be submitted online through the website: <http://www.cism.it>. A confirmation message will be sent to participants whose applications are accepted.

Upon request, and subject to availability, a limited number of on-site participants can be accommodated at the CISM Guest House for € 35 per person per night. To request accommodation, please contact: foresteria@cism.it

* where applicable; bank charges are not included - Italian VAT is 22%.

CANCELLATION POLICY

Applicants may cancel their registration and receive a full refund by notifying the CISM Secretariat in writing (via email) no later than:

- August 4, 2027, for early bird on-site participation;
- September 4, 2027, for late on-site participation;
- September 22, 2027, for online participation.

No refunds after the deadlines. Cancellation requests received before these deadlines and incorrect payments will be subject to a € 50.00 handling fee.

CISM GRANTS

A limited number of participants from universities and research centers who do not receive support from their institutions can request a waiver of the registration fee and/or free lodging.

Requests must be submitted via the CISM website by **August 4, 2027**. Applicants should select the relevant option in the online application form and provide a curriculum vitae and a letter of recommendation from their department head or supervisor confirming that their institution is unable to provide financial support. Preference will be given to applicants from countries that sponsor CISM.

For further information please contact:

CISM (Seat of the course)
Palazzo del Torso - Piazza Garibaldi 18 - 33100 Udine (Italy)
tel. +39 0432 248511 (6 lines)
e-mail: info@cism.it | www.cism.it



EMERGENT HYDRODYNAMIC-MEDIATED BEHAVIOUR IN MICRO-ORGANISMS

CISM Advanced School
coordinated by

Pietro Cicuta
University of Cambridge
Cambridge, UK

Eva Kanso
University of Southern California
Los Angeles, USA

Udine October 4 - 8 2027

EMERGENT HYDRODYNAMIC-MEDIATED BEHAVIOUR IN MICRO-ORGANISMS

Bring together applied mathematics, fluid mechanics, and biology, to show how minimal physical models can explain complex biological phenomena related to motile cilia at the microscale, while also pointing toward engineering applications such as biomimetic microswimmers, microfluidic pumps, and flow sensors.

This course will specifically cover examples where hydrodynamic interactions give rise to emergent, collective behaviour in microorganisms and ciliated systems - from synchronised beating and metachronal waves to swarming and optimised swimming strategies. At microscopic scales, viscous forces dominate over inertial forces (low Reynolds number), so fluid motion is governed by the linear Stokes equations. This regime permits powerful mathematical tools - such

as singularity solutions (Stokeslets, rotlets, stresslets) - as the building blocks to model how swimming organisms generate and interact with surrounding flows. The course will show how these tools are used to study organisms ranging from swimming bacteria to Volvox colonies, and how advection can dominate diffusion in nutrient transport at high Péclet numbers.

A central theme is motile cilia, their biophysics and how this results in synchronised dynamics. Individual cilia, each performing a periodic power-and-recovery stroke, coordinate through hydrodynamic and elastic couplings to produce travelling metachronal waves that enhance fluid transport. Students will be introduced to the nonlinear-dynamics frameworks - including the Adler equation and the Kuramoto model - used to describe how coupling strength, noise, and spatial arrangement determine

whether many interacting oscillators lock into coherent motion or remain to various extents disordered.

The course also connects microscale flow physics to physiology and technology. Examples include how ciliary arrays on coral surfaces drive three-dimensional flows that support oxygen and nutrient exchange, and how insights into flow sensing and ciliary control inform the design of artificial microswimmers, microfluidic devices, and hydrodynamic sensors.

- Fundamentals of low-Reynolds-number hydrodynamics and Stokes flow.
- Minimal singularity models of microbial swimming and propulsion.
- Motility and feeding in ciliates: individual and collective behaviour.
- Sensory and signalling processes

associated with cilia.

- Flow sensing, active/passive responses, and soft-body dynamics in flows.
- Mechanisms and biophysics of motile cilia and cilia beating.
- Synchronisation theory: noisy oscillators, the Adler equation, and the Kuramoto model.
- Mass transport by ciliary arrays, including lungs and coral physiology as case studies.
- Control of ciliary coordination, from single cells to multicellular/animal systems.

The course is aimed at doctoral students, early-career and senior researchers, and R&D technologists working in microfluidics, biophysics, soft matter, applied mathematics, and biomedical or biomimetic engineering who wish to gain a rigorous, cross-disciplinary grounding in the hydrodynamics of microscale living systems.

PRELIMINARY SUGGESTED READINGS

Lauga, E. & Powers, T. R. (2009). The hydrodynamics of swimming microorganisms. *Rep. Prog. Phys.* 72, 096601.

Elgeti, J., Winkler, R. G. & Gompper, G. (2015). Physics of microswimmers—single particle motion and collective behavior: a review. *Rep. Prog. Phys.* 78, 056601.

Guasto, J. S., Rusconi, R. & Stocker, R. (2012). Fluid mechanics of planktonic microorganisms. *Annu. Rev. Fluid Mech.* 44, 373–400.

Brumley, D. R., Wan, K. Y., Polin, M. & Goldstein, R. E. (2014).

Flagellar synchronization through direct hydrodynamic interactions. *eLife* 3, e02750.

Wan, K. Y. & Goldstein, R. E. (2016). Coordinated beating of algal flagella is mediated by basal coupling. *Proc. Natl Acad. Sci. USA* 113, E2784–E2793.

Bruot, N. & Cicuta, P. (2016). Realizing the physics of motile cilia synchronization with driven colloids. *Annu. Rev. Condens. Matter Phys.* 7, 323–348.

Kanale, A. V., Ling, F., Guo, H., Fürthauer, S. & Kanso, E. (2022). Spontaneous phase

coordination and fluid pumping in model ciliary carpets. *Proc. Natl Acad. Sci. USA* 119, e2214413119.

Hilfinger, A., Chattopadhyay, A. K. & Jülicher, F. (2009). Nonlinear dynamics of cilia and flagella. *Phys. Rev. E* 79, 051918.

Striegler, M., Diez, S., Friedrich, B. M. & Geyer, V. F. (2025). Twist–torsion coupling in beating axonemes. *Nat. Phys.* 21, 599–607.

Selvan, S. A., Duck, P. W., Pihler-Puzovič, D. & Brumley, D. R. (2023). Point torque representations of ciliary flows. *Phys. Rev. Fluids* 8, 123103.

Selvan, S. A., Duck, P. W., Pihler-Puzovič, D. & Brumley, D. R. (2025). Mass transport by ciliary point torques in flow. *J. Fluid Mech.* 1007, A14.

Selvan, S. A., Pacherres, C. O., Kühl, M., Butler, A., Dhillon, M. S., Blackall, L. L., Duck, P. W., Pihler-Puzovič, D. & Brumley, D. R. (2026). Unravelling three-dimensional active transport by ciliary arrays on coral surfaces. *PRX Life* 4, 023020.

Eloy, C. (2024). Hydrodynamics of flow sensing in plankton. *Eur. Phys. J. Spec. Top.* 233, 2733–2741.

INVITED LECTURERS

Pietro Cicuta - Cavendish Laboratory, University of Cambridge, UK
5 lectures on: Ciliated tissues. Open questions in ciliated tissues with a focus on lung epithelia, the state of the art in tissue culture methods for studying cilia, and imaging techniques used to observe ciliary behaviour within epithelial tissue. Also covers experimental model systems at colloidal scale.

Douglas Brumley - School of Mathematics and Statistics, The University of Melbourne, Parkville, Victoria, Australia
5 lectures on: Fluid flows and mass transport by ciliary arrays. Singularity solutions for modelling cilia in various geometries, mass transport by beating cilia in flow, three-dimensional flows and oxygen transport in coral cilia, and collective microbial dynamics.

Christophe Eloy - IRPHE, Centrale Méditerranée, Marseille, France
5 lectures on: Active and passive responses to flow. Hydrodynamics of flow sensing and its use for detection and navigation, how soft bodies respond passively and actively to surrounding flow, and the design principles underlying optimal hydrodynamic response.

Benjamin Friedrich - Technical University of Dresden, Germany
5 lectures on: Cilia synchronization: within a single cilium and between many cilia. Mechanisms of ciliary beating, cilia as noisy oscillators, cilia responding to flow, and synchronization via the noisy Adler equation, the noisy Kuramoto model, and spatially extended systems.

Eva Kanso - University of Southern California, Los Angeles, USA
5 lectures on: Cilia Across Scales. Organization, Function, and Evolution of Eukaryotic Life. External vs internal ciliary organization, modelling cilia from point forces to elastic filaments and porous media, and roles of cilia in multicellularity and symbiosis.

Marco Polin - Mediterranean Institute for Advanced Studies (IMEDEA), Mallorca, Spain
5 lectures on: Cilia beyond the beat. Structural organization of the axoneme, the mechanical properties of cilia, how cilia sense and respond to mechanical cues through mechanosensitivity, signalling, and the cellular processes underlying ciliary assembly and growth.

Kirsty Wan - University of Exeter, UK
5 lectures on: Control of ciliary coordination from single cells to animals. Microswimming fundamentals, gaits and waveforms of single ciliated cells, emergence of metachronal waves across ciliary arrays, and neural control mechanisms coordinating cilia.

LECTURES

All lectures will be given in English. Lecture notes can be downloaded from the CISM web site. Instructions will be sent to accepted participants.