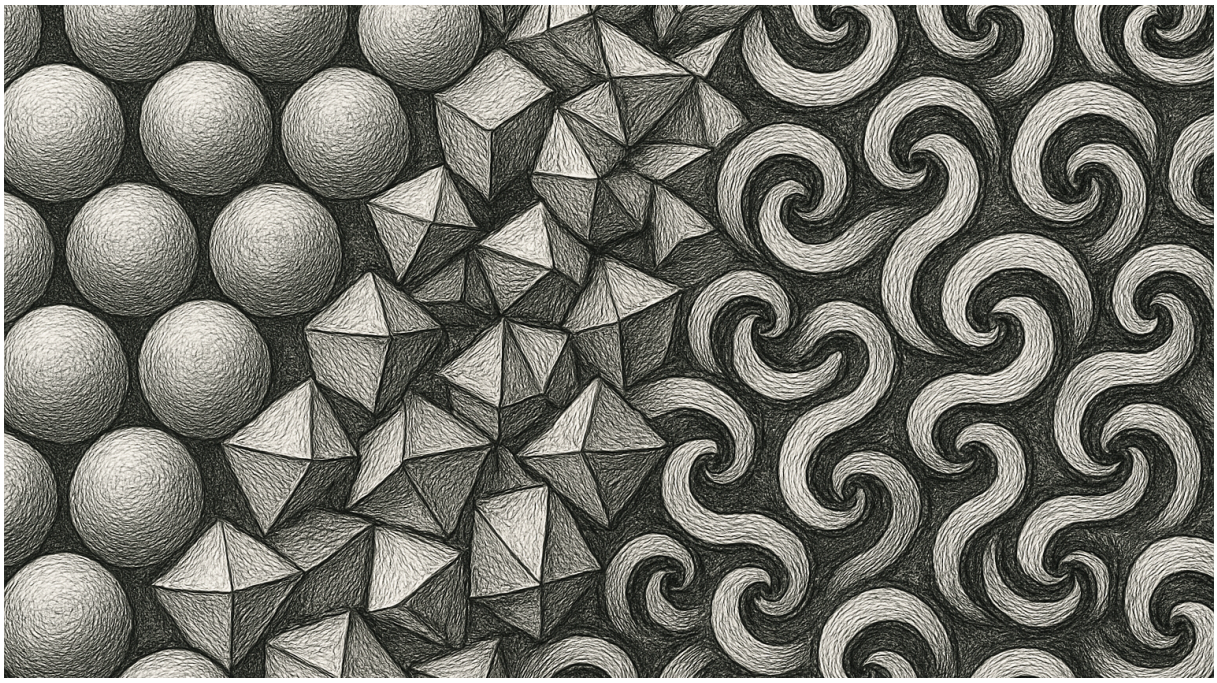

Chiral particles and Odd fluids

12–14 January 2026

Eindhoven University of Technology

Meeting program

Scientific committee:
Federico Toschi, Bernhard Mehlig, Detlef Lohse, Vincenzo Vitelli, Greg Voth

Organizing committee:
Federico Toschi, Xander de Wit, Ziqi Wang, Marjan Rodenburg

Fluids & Flows group, Eindhoven University of Technology

Meeting program

Monday 12 January

10:00–11:00 Registration and welcome coffee
11:00–11:15 Opening remarks
11:15–12:00 *Bernhard Mehlig* – Fluid-inertia torques from particle-shape symmetry
12:00–12:30 *Mees Flapper* – Settling chiral particles in turbulent flow
12:30–14:00 Lunch
14:00–14:45 *Xander de Wit* – The surprising fate of turbulence in fluids with odd viscosity
14:45–15:15 *Sanjay Shukla* – Gyroviscosity modifies the laminar-turbulent transition in pipe flow
15:15–16:15 Coffee break & discussions
16:15–17:00 *Tom Witten* – Meta suspensions: engineering self–organized suspensions via particle shapes and directed forcing
17:00–17:30 *Josephine Gissinger* – Numerical method for computing resistance tensors of complex-shaped particles in Stokes flow
17.30–19.00 Reception drinks at *Zwarte Doos*

Tuesday 13 January

09:00–09:15 Drop-in
09:15–10:00 *Hartmut Löwen* – Odd diffusive spheres and chiral active polymers
10:00–10:45 *Anke Lindner* – Chiral transport in viscous flows: from micro-helices to bacteria
10:45–11:15 Coffee break
11:15–12:00 *Michel Fruchart* – Chirality across scales in tissue dynamics
12:00–12:45 *Greg Voth* – Chiral design for laminar and turbulent sedimentation
12:45–14:15 Lunch
14:15–14:45 *Chunlai Wu* – Tracking the rotation of light magnetic particles in turbulence
14:45–15:30 *Ziqi Wang* – From localization to stochastic resonance: controlling particle dynamics in turbulence
15:30–16:00 *André Freitas* – Intermittency suppression in turbulence via forced light particles
16:00–16:45 Coffee break & discussions
16:45–17:30 *Luca Biferale* – Learning how to stir oblate particles in complex flows
19:00–21:00 Dinner at *Kazerne, Eindhoven*

Wednesday 14 January

09:00–09:15 Drop-in
09:15–10:00 *John Sader* – Acoustic propulsion of nanoparticles and near-hydrodynamic electron flows
10:00–10:45 *Anne Juel* – Inertialess sedimentation of rigid and elastic sheets
10:45–11:15 Coffee break
11:15–11:45 *Sander Huisman* – Chiral particles in turbulent Taylor-Couette flow
11:45–13:30 Lunch
13:30–14:15 *Jeremie Bec* – Inertia and flexibility in the turbulent transport of elongated particles
14:15–14:30 Coffee break
14:30–15:30 Discussion: future directions in chiral particles and odd fluids
15:30–16:15 *Gautier Verhille* – Dynamics of flexible fibers in turbulence
16:15–17:00 *Detlef Lohse* – Settling dynamics of an oloid
17:00–17:10 Closing remarks

Chiral Particles and Odd Fluids

Book of Abstracts

Fluid-inertia torques from particle-shape symmetry

Bernhard Mehlig

Numerical simulation of particle motion in fluids at low particle Reynolds numbers is often based on empirical force and torque models obtained by fitting force and torque from ab-initio computations for simple particle shapes such as spheres, spheroids, or cylindrical disks and fibres. To do the same for more complex particles shapes, one needs to first know how particle shape constrains the dependence of force and torque on flow velocity, its gradient, and on particle orientation. Here we use symmetry analysis and perturbation theory to determine the forms of the hydrodynamic torques on particles settling in a quiescent fluid, for particle shapes with different point-group symmetries, at low but non-zero particle Reynolds numbers. This talk is based on the preprint "Fluid-inertia torques from particle-shape symmetry" by L. Sundberg, F. Candelier, N. Fintzi, G. Voth, J. L. Pierson, K. Gustavsson & B. Mehlig.

Settling chiral particles in turbulent flow

Mees Flapper

Chiral particles are experimentally investigated while settling in water with various turbulence intensity levels. The location and orientation of the particles are tracked over time, allowing the close investigation of the particles' settling dynamics. Starting with quiescent particle settling, the chiral particle's orientation dynamics are studied, revealing a strong translation-rotation coupling. From the tracked particles, we analyse the orientation and rotation dynamics, revealing any preferential alignment and rotation. Consequently, we illustrate the effect of turbulence on these observed dynamics. Surprisingly, multiple settling modes are identified, which we characterise by their orientation dynamics. Finally, we attempt to clarify these settling modes using a theoretical model of a simplified chiral particle in Stokes flow.

The surprising fate of turbulence in fluids with odd viscosity

Xander de Wit

Turbulent flows can be altered in very far-reaching ways by the presence of non-dissipative components in the viscosity tensor of the fluid. Such viscosity, called odd, Hall- or gyro-viscosity, can emerge in chiral systems ranging from plasma and bio-active media to quantum fluids. Using a combination of theory and direct numerical simulations in 3D, we show that odd viscosity yields a tendency to invert the direction of the turbulent energy cascade. This results in an intermediate range of scales of the flow in which kinetic energy condensates, producing a well-defined pattern in the flow. The flow statistics in this condensate range are entirely different from conventional turbulent flows, being fully self-similar and non-intermittent. At yet smaller scales, when odd viscosity becomes even more dominant, we show that we can enter a regime dominated by wave-turbulence as evidenced from spatio-temporal energy spectra and theoretical arguments.

Gyroviscosity modifies the laminar-turbulent transition in pipe flow

Sanjay Shukla

We investigate the transition to turbulence in a three-dimensional pipe using direct numerical simulations in the presence of odd viscosity. While classical pipe flow is linearly stable and exhibits turbulence only through sudden, finite-amplitude transitions at high Reynolds numbers, we show that introducing odd viscosity fundamentally alters this picture. The modified system becomes linearly unstable, leading to the onset of turbulence at significantly lower Reynolds numbers.

Meta suspensions: engineering self–organized suspensions via particle shapes and directed forcing

Tom Witten

The expected sedimentation motion of a suspended body is simply a downward drift at constant speed. This simple motion is greatly enriched for generic asymmetric shapes whose effective center of mass is at a generic point. Barring special symmetries, such objects evolve into one of up to three final rotational states, depending on initial orientation. The entire motion is governed by a 3×3 "mobility matrix" that gives the proportionality of angular velocity to the gravitational force vector. In the richest case, the force vector for any initial direction must reach one of three final states defined in the body frame. Two of these are fixed orientations: the body rotates at constant speed around the selected body axis. In a third final state the object's orientation executes a fixed limiting periodic motion about a changing direction in the body. The mobility matrix dictates the shape of this orbit and the positions of the fixed points. It also governs the set of initial orientations that migrate to each final state. This final state selection is time irreversible. We identify the invariant features of the mobility matrix that enable such selection. Further features govern whether the final state is a global fixed point, two fixed points or two fixed points plus a limiting orbit. We demonstrate experimental validations of these predicted motions by our collaboration *. We review how these methods may be generalized to create bound-state motions of pairs of objects and to control the spatial uniformity of an entire suspension.

*Tiago Pernambuco, Wenting Cheng, Justin Burton, Haim Diamant, TW.

Numerical method for computing resistance tensors of complex-shaped particles in Stokes flow

Josephine Gissinger

Chiral particles are often characterized by a non-zero B resistance tensor and a complex shape. Here, we present an innovative tool to compute the hydrodynamic resistance of particles with arbitrary shape in Stokes flow. The method is derived from the Stokesian Dynamics approach (Durlofsky et al. 1987) and accommodates both rigid and deformable objects in an unbounded fluid or near a plane wall. Particles are represented by an assembly of spherical elements that collectively reproduce their geometry and motion. This coarse-grained description preserves the essential hydrodynamic interactions while drastically lowering computational costs compared with conventional boundary-element or mesh-based methods. The numerical computations show excellent agreement with analytical and experimental data. This framework thus provides a versatile and efficient tool for modeling hydrodynamic interactions of complex-shaped particles in microfluidic and biological systems.

Odd diffusive spheres and chiral active polymers

Hartmut Löwen

In this talks we summarize recent results obtained for odd-diffusive spheres and chiral active polymers. For normal diffusive systems, repulsive interactions typically reduce the dynamics as signalled by a reduction of the long-time self-diffusion coefficient. Contrarily, in odd-diffusive systems, collisions can enhance the self-diffusion due to a mutual rolling effect. An active polymer composed of chiral active monomers is shown to exhibit a spontaneous self-wrapping. Finally we propose a simple thermodynamic approach to inertial chiral active gases. Our results are obtained by theory, simulation and realization of odd and chiral systems in granular experiments on vibrobots.

Chiral transport in viscous flows: from micro-helices to bacteria

Anke Lindner

Chirality is widespread at the nano- and micro-scale, appearing in both rigid structures such as DNA, spirochetes, or bacterial flagella, and in dynamic processes like the beating of cilia or sperm tails. These microscopic asymmetries often drive larger-scale symmetry breaking, from mucus flows in the lungs to helical swimming paths and particle drift in shear flows. Understanding this link is essential for microorganism transport. In this work, we investigate the role of chirality in the transport of passive and active particles within microfluidic systems. We first analyze how the swimming strategy of E. coli, shaped by flagellar chirality and surface interactions, produces asymmetric transport and rheotactic drift. We then extend these studies to passive chiral particles fabricated by high-resolution microprinting, allowing precise control over particle geometry. Understanding how chirality governs transport in viscous flows has implications for guiding bacterial motion and designing microscale separation devices.

Chirality across scales in tissue dynamics

Michel Fruchart

Chiral processes that lack mirror symmetry pervade nature from enantioselective molecular interactions to fundamental particles. An outstanding challenge consists in bridging the multiple scales between microscopic and macroscopic chirality, especially out of equilibrium. In this talk, we combine theory, experiments and modern inference algorithms to study a paradigmatic example of dynamic chirality transfer across scales: the generation of tissue-scale flows from subcellular forces. The distinctive properties of our microscopic graph model and the corresponding odd viscoelasticity are (i) inhomogeneous cell proliferation and (ii) nonreciprocal dynamics that cannot be expressed as an energy gradient. To overcome the general challenge of inferring microscopic model parameters from noisy high-dimensional data, we develop a nudged automatic differentiation algorithm (NADA) that can handle large fluctuations in cell positions observed in single snapshots. This data-calibrated microscopic model quantitatively captures proliferation-driven tissue flows observed at large scales in our experiments. Beyond chirality, our inference algorithm can be used to extract interpretable graph models from limited amounts of noisy data of cellular systems such as networks of convection cells and flowing foams.

Chiral design for laminar and turbulent sedimentation

Greg Voth

We perform experiments on sedimentation in Stokes flow as well as in turbulence to advance our understanding of how to design shapes to control translation-rotation coupling. This is called the chiral design problem, somewhat misleadingly since breaking mirror symmetry is not a necessary feature. In low Reynolds number sedimentation, we find rich non-linear dynamics with a prominent bifurcation surface in the space of center of force offset from the center of mobility. The reference co-centered particle with diagonal translation-rotation coupling tensor plays a central role in our understanding of sedimentation. In turbulent flows we see clear signatures of preferential rotation of chiral inertial particles. Here the eigenvalues of the translation-rotation coupling tensor play the primary role. Typically particles have both positive and negative eigenvalues and so their preferential rotation has different signs depending on the direction of the slip velocity in the eigenframe of the translation-rotation coupling tensor.

Tracking the rotation of light magnetic particles in turbulence

Chunlai Wu

Particle-laden turbulence involves complex interactions between the dispersed and continuous phases. Given that particles can exhibit a wide range of properties, such as varying density, size, and shape, their interplay with the flow can lead to various modifications of the turbulence. Therefore, understanding the dynamics of particles is a necessary first step toward revealing the behavior of the multiphase system. Within the context of particle dynamics, accurately resolving rotational motion presents a significantly greater challenge compared to translational motion. We propose an experimental method to track the rotational motion of spherical, light, and magnetic particles with sizes significantly smaller than the Taylor microscale, typically an order of magnitude larger than the Kolmogorov scale of the turbulence in which they are suspended. The method fully resolves all three components of the particle angular velocity using only 2D images acquired from a single camera. This technique enables a detailed investigation of the rotational dynamics of magnetic particles subjected simultaneously to small-scale turbulent structures and external magnetic forcing. Beyond advancing the study of particle dynamics in turbulence, this approach opens new possibilities for actively modulating turbulence through externally applied magnetic fields.

From localization to stochastic resonance: controlling particle dynamics in turbulence

Ziqi Wang

Light and rotating particles provide a unique window into the elusive dynamics of turbulence at its smallest scales. In this talk, we explore how external forcing–either oscillatory or magnetic–couples with turbulent vortices to induce transitions and resonances in particle motion. We show that small light particles can undergo a localization–delocalization transition under modulated forcing, while magnetic particles exhibit stochastic resonance when hydrodynamic stresses interact with an applied rotating magnetic field. Both phenomena reveal how turbulence acts as an effective, tunable noise source that can strongly modulate particle response. These findings establish a unified framework where controlled particle-vortex interactions not only probe the fine structure of turbulence but also open routes to active manipulation of particle dynamics in complex flows.

Intermittency suppression in turbulence via forced light particles

André Freitas

We investigate how turbulence is reshaped by the presence of externally forced light particles, using high-resolution direct numerical simulations with four-way coupling. The particles are subject to an oscillatory force that in turn locally affects the fluid flow through momentum exchange at the position of the particles. Since the light particles preferentially concentrate in high vorticity regions, this leads to an intricate preferential turbulence modulation. We show that through this modulation, the forced light particles strongly reduce the intermittency of the flow, shedding new light on the delicate relationship between vortex filaments and turbulence intermittency.

Learning how to stir oblate particles in complex flows.

Luca Biferale

We will discuss data-driven tools to learn how to optimally stir shape-changing particles in complex flows. Discussing benchmarks against optimal solutions and future applications.

Acoustic propulsion of nanoparticles and near-hydrodynamic electron flows

John Sader

This talk discusses two topics. (1) The motion of nanoparticles trapped in acoustic fields have been observed to undergo autonomous propulsion. This phenomenon has been attributed to the generation of a steady streaming flow, with a reversal in the propulsion direction at a distinct frequency. We report a theory enabling its calculation and explore the physical mechanism underlying this reversal. (2) Near-hydrodynamic electron flows have been realized in recent experiments, where momentum-conserving collisions dominate the flow behavior. We analyze these flows using a matched asymptotic expansion of the governing linearized Boltzmann equation. The developed theory is used to solve two-dimensional Poiseuille flow in the near-hydrodynamic regime, where non-hydrodynamic corrections are found to compete with the classical Hall or odd viscosity.

Inertialess sedimentation of rigid and elastic sheets

Anne Juel

The handling and processing of microscale materials involves a rich variety of sedimentation processes in the Stokes limit of vanishing inertia, where trajectories depend sensitively on particle shape. We study the settling of an elastic disk under its own weight. The sedimentation flow generates viscous loading on the disk which may deform and/or reorient, and thus in turn alter the flow. We find that, unlike a slender flexible fibre, an elastic disk sedimenting in a large tank does not evolve towards a steady state but instead exhibits a myriad of complex reorientation and sedimentation paths depending on its initial orientation. To unravel these complex dynamics, we select a disk whose stiffness is such that it adopts U-bent shapes during settling and study its behaviour by comparison with the settling of a rigid U-shaped disk *. The rigid disk reorients with a periodic sequence of pitching and rolling motions, and we find that the periodic nature of the reorientation dynamics is robust to deformation. However, the elastic disk opens as it pitches to a flat near-vertical configuration where it reorients its spine before buckling back into a U-shape as it rolls.

*T. Miara, C. Vaquero-Stainer, D. Pihler-Puzović, M. Heil & A. Juel, Dynamics of inertialess sedimentation of a rigid U-shaped disk, Comms. Phys. 7, 47, 2024.

Chiral particles in turbulent Taylor-Couette flow

Sander Huisman

This talk investigates chiral particles, which break mirror symmetry, in turbulent Taylor–Couette flow. These particles generally display a translation-rotation coupling moving through a quiescent fluid. Here we performed experiments using large chiral particles (typical size 5 mm) in turbulent Taylor–Couette flow, for Reynolds numbers $9 \cdot 10^3 \leq \mathrm{Re} \leq 1.5 \cdot 10^5$. The density-matched chiral particles are studied in a dilute regime ($\phi = 1.7 \cdot 10^{-4}$), where their location and orientation are tracked over time to investigate the particle-fluid coupling. We investigate whether the translation-rotation coupling observed at low Reynolds numbers is still observable over the measured high Reynolds numbers, using the tracked location and orientation. Similarly, we verify whether the chiral particles display a preferred location or orientation, and whether the left-handed and right-handed particles show different rotation statistics. The location data show that the chiral particles closely follow the structure of Taylor vortices. Hence, the orientation data and rotation data of the chiral particles are split between the Taylor vortices and particle chiralities. The results show no difference in rotation and orientation dynamics between chiralities. Rather, the particle dynamics are flow-dominated, where the flow vorticity determines the specific particle dynamics.

Inertia and flexibility in the turbulent transport of elongated particles

Jeremie Bec

The transport of elongated particles in turbulence is governed by the coupled effects of inertia, deformation, and flow fluctuations. I will present recent results showing how flexible fibers in wall-bounded turbulence undergo a pole-vaulting migration away from boundaries, a mechanism rooted in their deformation and impulsive interactions with the walls. I will then show how inertial and rigid fibers respond to shear and turbulent eddies, exhibiting preferential alignment, intermittent tumbling, and shape-dependent transport statistics. Together, these results clarify how inertia and flexibility set distinct pathways for the migration, alignment, and rotational dynamics of elongated particles in turbulence.

Dynamics of flexible fibers in turbulence

Gautier Verhille

I will present an experimental study on the influence of the deformability of flexible fibers on their transport in turbulent flows. This study is mainly focused on the rotational dynamics of fibers which has been extensively studied for rigid fibers in turbulence. A model will then be proposed to explain the modification of the rotation rate by the deformation of the fibers.

Settling dynamics of an oloid

Detlef Lohse

This talk presents a combined experimental and computational investigation of an oloid-shaped particle settling in a quiescent fluid. The oloid, a unique convex shape with anisotropic geometry, provides a distinctive model for exploring how a particle's shape and orientation affect its settling dynamics. The settling oloids are tracked experimentally for Galileo numbers $48 \leq \mathrm{Ga} \leq 5.4{\cdot}10^3$, using two particle sizes (Deq = 21.6 mm, and Deq = 10.8 mm). The density ratio between the particle and fluid $\Gamma = \rho_p/\rho_f$ ranges from $1.11 \leq \Gamma \leq 1.30$ in the experiments. Computationally, the Galileo numbers $10 \leq \mathrm{Ga} \leq 100$ are simulated, where $\Gamma = 2$. The experimental findings and numerical results are in good agreement, and give a consistent idea of the oloid settling dynamics. Our results indicate two distinct falling modes for the oloid, separated by Galileo number. The stable mode is characterised by a preferential orientation, with a rotation around the vertical axis, whereas the tumbling mode has randomly distributed orientation and rotation statistics. We characterise the falling velocity, orientation, and rotation dynamics of the oloids over a range of Galileo numbers. Additionally, the influence of the initial orientation is revealed to determine the rotation dynamics at low Galileo numbers.