# DY 5: Fluid Physics: Turbulence and Convection

Time: Monday 9:30–12:15 Location: MOL 213

**Invited Talk** DY 5.1 Mon 9:30 MOL 213

**Extreme events, entropies and instantons for turbulence and water waves** — •Joachim Peinke, André Fuchs, and Matthias Wächter — Inst. of Physics, University of Oldenburg, Germany

Complex systems like turbulence and ocean waves can produce extreme events like large changes in wind speed or monster waves. It has long been debated whether coherent structures or special statistical properties are essential for the understanding. Here we show a comprehensive stochastic approach for Lagrangian and Eulerian turbulence, as well as, for waves, leading to a joint multi-point statistic. We consider cascade trajectories through scales as realizations of a stochastic Langevin process that can be deduced from data. Knowledge of the stochastic equations allows determination of the entropy production of each cascade trajectory. Trajectories with negative entropies are linked to large fluctuations like extreme wind speeds or monster waves. Thus entropy seems to select different structures. Furthermore, negative and positive entropy values are balanced by rigorous fluctuation theorems, so that extreme and normal fluctuations are mutually dependent. In this way the entropy concept links statistics with the coherent structure approach. Finally, trajectories concentrate around an optimal path, called instanton, which is the minimum of an effective action given by the estimated stochastic equations. Entropons, defined as instantons conditioned on fixed entropy values, pinpoint the trajectories responsible for the emergence of non-Gaussian statistics at small scales. Ann. Rev. Cond. Matt. Phys. 10, 107-132 (2019), EPL 137, 53001 (2022), Phys. Rev. Lett. 129, 034502 (2022)

DY 5.2 Mon 10:00 MOL 213

**Discrete and Continuous Symmetry Reduction for Minimal Parametrizations of Chaotic Fluid Flows** — •Simon Kneer and Nazmi Burak Budanur — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

Mathematical laws that govern fluid motion preserve their shape under translation, rotation, and reflection of coordinates. Consequently, most hydrodynamic systems of interest exhibit a set of symmetries, the action of which on the fluid states commutes with the dynamics. In complex flows, typical non-laminar fluid states are not invariant under these symmetries. Thus, each solution of the system has many dynamically equivalent symmetry copies. For data-driven model reduction methods, such as undercomplete Autoencoders, this multiplicity is not desired since it results in an artificial inflation of the training data which does not yield any physical insight. We consider this problem in the sinusoidally-driven Navier-Stokes equations in two dimensions, i.e. Kolmogorov flow, which is symmetric under continuous translations as well as discrete rotations and reflections. We formulate a symmetry reduction that combines first Fourier mode slicing with invariant polynomials that yields a fully invariant formulation of the corresponding dynamical system. Through this symmetry reduction, we are able to find a minimal approximation to the inertial manifold of this system as well as ordinary differential equations on this manifold that describe the dynamics.

DY 5.3 Mon 10:15 MOL 213

**Spontaneous symmetry breaking for extreme vorticity and strain in the three-dimensional Navier-Stokes equations** — •Timo Schorlepp[1], Tobias Grafke[2], Sandra May[3], and Rainer Grauer[1] — [1]Institute for Theoretical Physics I, Ruhr-University Bochum, Germany — [2]Mathematics Institute, University of Warwick, United Kingdom — [3]Department of Mathematics, TU Dortmund University, Germany

We investigate the spatio-temporal structure of the most likely configurations realizing extremely high vorticity or strain in the stochastically forced three-dimensional incompressible Navier-Stokes equations. Most likely configurations are computed by numerically finding the highest probability velocity field realizing an extreme constraint as solution of a large optimization problem. High-vorticity configurations are identified as pinched vortex filaments with swirl, while high-strain configurations correspond to counter-rotating vortex rings. We additionally observe that the most likely configurations for vorticity and strain spontaneously break their rotational symmetry for extremely high observable values. Instanton calculus and large deviation theory allow us to show that these maximum likelihood realizations determine the tail probabilities of the observed quantities. In particular, we are able to demonstrate that artificially enforcing rotational symmetry for large strain configurations leads to a severe underestimate of their probability, as it is dominated in likelihood by an exponentially more likely symmetry-broken vortex-sheet configuration.

DY 5.4 Mon 10:30 MOL 213

**Delayed onset in spanwise rotating compressible convection** — •Kevin Lüdemann and Andreas Tilgner — Institute for Astrophysics and Geophysics, Göttingen, Germany

We are investigating compressible convection with spanwise rotation in direct numerical simulations meaning that the direction of gravity and the axis of rotation are perpendicular to each other. This is a model for the equatorial region of gas planets like Jupiter or Earth's outer core. Both consist of compressible liquids ranging many orders of magnitude in density variations for Jupiter to about 20 percent of density changes for earth outer core. We are more interested in moderate density changes since those are realizable in laboratory experiment like the one performed in Lyon. From a parameter study in the number of density scale heights controlling the compressibility and the Ekman number controlling the global rate of rotation, we find that the onset of convection is delayed by compressibility and rotation. Additionally, a horizontal drift of the many slender convection rolls has been found at the onset for high rotation rates. An extensive study is presented highlighting these unforeseen results.

DY 5.5 Mon 10:45 MOL 213

**Offshore wind: Evidence for two-dimensional turbulence and role of sea horizon** — •So-Kumneth Sim[1], Joachim Peinke[2], and Philipp Maass[1] — [1]Fachbereich Physik, Universität Osnabrück, Germany — [2]Insitut für Physik & ForWind, Universität Oldenburg, Germany

We analyze offshore wind speeds with a time resolution of one second over a period of 20 months [1]. Wind speed power spectra show a scaling behavior that is governed by three- and two-dimensional turbulence [2]. The latter is observed for frequencies lower than a crossover frequency $f_{2D}$. An analysis of the third moment (third-order structure function) of wind speed fluctuations provides strong evidence of this transition to two-dimensional turbulence [3]. We argue that $f_{2D} \sim \bar{v}/d$, where $\bar{v}$ is the mean wind speed and $d$ the distance between the measurement device and the sea horizon. For the regime of two-dimensional turbulence, two scaling regimes are predicted, which originate from an inverse energy and an enstrophy cascade. Our results indicate that the scaling due to the inverse energy cascade occurs at low frequencies and is followed by the scaling of the enstrophy cascade at higher frequencies. This in agreement with the theoretical prediction but contrary to earlier observations.

[1] S.-K. Sim, J. Peinke, P. Maass, arXiv:2203.07685 (2022).
[2] X. Larsén, S. Larsen, E. Petersen, Boundary-Layer Meteorol. 159, 349 (2016).
[3] R. Cerbus, P. Chakraborty, Phys. Fluids 299, 111110 (2017).

**15 min. break**

DY 5.6 Mon 11:15 MOL 213

**Convective turbulent superstructures in Rayleigh-Benard convection** — •Hiufai Yik[1], Stephan Weiss[1,2], and Eberhard Bodenschatz[1] — [1]Max Planck Institute for Dynamics and Self-Organization — [2]Max Planck Center for Complex Fluid Dynamics

We report experimental results on turbulent superstructures in high-turbulence thermal convection. The 0.7 m high, 3.5 m wide and 0.35 m deep rectangular cell was installed in the Göttingen U-Boot and filled with sulphur hexafluoride at pressures up to 19 bar. Convection in this installation can be investigated up to Rayleigh numbers Ra = 10^13 at Prandtl numbers of about 0.8. More than 200 thermistors were distributed in the upper and lower plates for temperature and heat flux measurements, and 20 additional thermistors in the centre of the cell to measure the fluid temperature along the longitudinal axis. We report the results on turbulent superstructures and their dependence on heat transport and boundary conditions. For this purpose, the upper and lower plates of the convection cell were each divided into 4 sections, with an independent temperature control allowing both homogeneous and inhomogeneous temperature boundary conditions and the selection of different turbulent superstructures.

DY 5.7 Mon 11:30 MOL 213

**Statistical field theory for a stochastic linear advection-stretching model for turbulence** — Lukas Bentkamp, Maurizio Carbone, and •Michael Wilczek — Theoretical Physics I, University of Bayreuth, 95440 Bayreuth

A major obstacle in developing a statistical field theory of turbulence is the analysis of the functional equations that govern the complete statistics of the flow field. Simplified models of turbulence may help to develop such a statistical framework. In this contribution, we discuss the stochastic linear advection and stretching of an incompressible passive vector field as a model for small-scale turbulence. The model encompasses non-Gaussian statistics due to an intermittent energy flux from large scales to small scales, thereby displaying hallmark features of turbulence. We explore this model using the Hopf functional formalism, which naturally leads to a decomposition of the complex non-Gaussian statistics into Gaussian sub-ensembles based on different realizations of advection and stretching.

This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (Grant agreement No. 101001081).

DY 5.8 Mon 11:45 MOL 213

**Description of laminar-turbulent transition of an airfoil boundary layer measured by differential image thermography using directed percolation theory** — •Tom T. B. Wester, Joachim Peinke, and Gerd Gülker — ForWind, University of Oldenburg, Institute of Physics, Oldenburg, Germany

Transition from laminar to turbulent flow is still a challenging problem. Recent studies indicate a good agreement when describing this phase transition with the directed percolation theory. This study presents a new experimental approach by means of differential image thermography (DIT) enabling to investigate this transition on the suction side of a heated airfoil. The results extend the applicability of the directed percolation theory to describe the transition on curves surfaces. The experimental effort allows for the first time an agreement between all three universal exponents of the (1+1)D directed percolation for such airfoil application. Furthermore, this study proves that the theory holds for a wide range of flows, as shown by the various conditions tested. Such a large parameter space was not covered in any examination so far. The findings underline the significance of percolation models in fluid mechanics and show that this theory can be used as a high precision tool for the problem of transition to turbulence.

DY 5.9 Mon 12:00 MOL 213

**How to generate turbulence with highest Reynolds numbers in the wind tunnel** — •Lars Neuhaus, Michael Hölling, and Joachim Peinke — ForWind, University of Oldenburg, Institute of Physics, Oldenburg, Germany

In order to study objects like buildings, vehicles or wind turbines under the influence of wind fluctuations, the generation of laboratory flows that resemble atmospheric turbulence is of prime importance. This is where active grids come into play, allowing to excite the wind tunnel flow in a user-defined way. With a blockage induced flow design, it is possible to recreate atmospheric flows through their time series or to create single coherent structures such as gusts defined by industrial standards. In addition, it is possible to generate turbulence with large integral length scales through a random driving that follows a stochastic process. Velocity fluctuations with correlation lengths and thus integral scales much larger than the transverse dimensions of the wind tunnel can be generated. By combining active grid excitation with fan speed modulation, it is additionally possible to generate a flow characterized by an inertial range of four decades and an integral Reynolds number of $2 * 10^7$. By a newly developed active grid it is furthermore possible to vary the turbulent properties over height to mimic height dependencies found in the atmosphere and also to generate a turbulent non-turbulent interface.