DY 3: Fluid Physics of Turbulence

Time: Monday 9:30–12:30 Location: ZEU 118

Invited Talk DY 3.1 Mon 9:30 ZEU 118

Disentangling Lagrangian Turbulence — Lukas Bentkamp, Cristian Lalescu, and •Michael Wilczek — Max-Planck-Institut für Dynamik and Selbstorganisation, Göttingen

Turbulence remains a paradigmatic challenge for nonequilibrium statistical physics. The rapid evolution of computational power and experimental techniques, however, has brought significant progress over the past decades. In this presentation, I will discuss how simulations provide insights into the structure and dynamics of turbulence and inform the development of a statistical theory of turbulence. In particular, I will focus on Lagrangian tracer particles, which sample turbulence in space and time. On their roller-coaster ride through turbulence, tracer particles frequently encounter extreme accelerations which are closely related to the intermittent spatial distribution of intense flow structures such as vortex filaments. This mixed history of flow conditions leads to very complex particle statistics with a pronounced scale dependence. Categorizing Lagrangian particle data from simulations by means of their accelerations reveals that Lagrangian turbulence can be decomposed into much simpler, close-to-Gaussian sub-ensembles for a range of Reynolds numbers. Based on this observation, we develop a comprehensive theoretical framework for Lagrangian single-particle statistics that captures the acceleration, velocity increments as well as single-particle dispersion.

DY 3.2 Mon 10:00 ZEU 118

Statistical geometry of material loops in turbulence — •Lukas Bentkamp[1,2], Cristian Constantin Lalescu[1], Theodore Dimitrios Drivas[3], and Michael Wilczek[1,2] — [1]Max Planck Institute for Dynamics and Self-Organization, Am Faßberg 17, 37077, Göttingen, Germany — [2]Faculty of Physics, University of Göttingen, Friedrich-Hund-Platz 1, 37077, Göttingen, Germany — [3]Department of Mathematics, Princeton University, Princeton, NJ 08544, United States of America

Understanding turbulent transport involves a close investigation of the multi-scale properties of turbulence, since they impose different transport mechanisms at each scale. At small scales, for example, chaos drives trajectories of initially close particles to diverge exponentially. By considering extended structures like material lines, which are passively advected and deformed by the flow, we probe not only this exponential separation, but the general stretch-and-fold mechanisms that lead to turbulent mixing at all scales. Here, we present a study of the statistical geometry of closed material lines. In particular, we complement fully resolved direct numerical simulations of homogeneous turbulence with the analytically tractable Kraichnan model, which allows, for example, for a closer investigation of the fractal dimension, length, curvature and torsion of the loops. By studying these quantities, we gain insight into the geometrical structure of the underlying turbulent flow.

DY 3.3 Mon 10:15 ZEU 118

Machine learning in subcritical plane Couette flow — •Stefan Zammert — Philipps-Universität Marburg

Plane Couette flow shows transient turbulence for Reynolds numbers where the laminar flow is linearly stable. In this so-called subcritical range the time evolution of the flow is deterministic but a turbulent trajectory eventually returns to the laminar state without any obvious precursor.

We study small periodic domains of plane Couette flow and use neural networks to predict if a turbulent trajectory returns to the laminar state within a fixed time T. The performances of the network for variations of the input variables are compared with the goal to minimize the amount of input variables necessary for a good prediction.

Having a reliable and fast method to predict the the decay of turbulence by using a limited set of input quantities which is also easily accessible in experiments might for example be helpful for active turbulence control.

DY 3.4 Mon 10:30 ZEU 118

Small scale structures of turbulence in terms of entropy and fluctuation theorems — Andre Fuchs[1], •Joachim Peinke[1], Matthias Waechter[1], Silvio M. Duarte Queiros[2], Alain Girard[3], and Pedro G. Lind[4] — [1]Institute of Physics and ForWind, University of Oldenburg, — [2]Centro Brasileiro de Pesquisas Fisicas and National Institute of Science and Technology for Complex Systems, Rio de Janeiro - RJ, Brazil — [3]INAC-SBT, UMR CEA-Grenoble, 38054 Grenoble, France — [4]Department of Computer Science, OsloMet - University, N-0130 Oslo, Norway

Experimental evidence that the integral fluctuation theorem as well as a detailed-like fluctuation theorem holds for large entropy values of the turbulent cascade processes. Stochastic equations describing the scale-dependent cascade process are derived. From individual cascade trajectories an entropy term can be determined. Since the statistical fluctuation theorems set the occurrence of positive and negative entropy events in strict relation, we are able to verify how cascade trajectories, defined by entropy-consumption or entropy-production are linked to turbulent structures: Where as trajectories with entropy-production show expected decreasing behavior; trajectories with entropy-consumption end at small scale velocity increments with finite size and show a lower bound for small scale increments. This indicates a tendency to local discontinuities in the velocity field.

DY 3.5 Mon 10:45 ZEU 118

The boundary zonal flow (BZF) in turbulent rotating convection — •Stephan Weiss[1,7], Xuan Zhang[1], Marcel Wedi[1], Dennis v. Gils[2], Robert E. Ecke[3], Lukas Zwirner[1], Guenter Ahlers[4], Susanne Horn[5], Eberhard Bodenschatz[1,6], and Olga Shishkina[1] — [1]MPI for Dyn. and Self-Org., Göttingen, Germany — [2]Twente University, NL — [3]Los Alamos National Lab., USA — [4]UCSB, USA — [5]Coventry University, UK — [6]Georg-August University Göttingen, Germany — [7]Max Planck – University Twente Center

Thermal convection under the influence of rotation is one of the main driving forces for flows in astro- and geophysical systems. There, Coriolis forces are usually larger then centrifugal forces and vertical scales (i.e., in the direction of the rotation axis) increases compared to horizontal scales. Therefore, experiments are often conducted in cylinders of rather small aspect ratios ($\Gamma = D/H$) between their diameter (D) and height (H), as then the centrifugal forces remain small. We show by using experiments and DNS that in rotating thermal convection in a confined domain with no-slip boundaries, a large-scale flow structure (boundary zonal flow - BZF) develops at the lateral sidewalls, which reaches from the bottom to the top of the cell. In the BZF the vertical velocity and thus the heat transport is severely enhanced. The BZF is periodic in azimuthal direction with a wave number of twice the aspect ratio Γ. While the fluid moves in cyclonic direction close to the sidewall, the entire structure drifts in anticyclonic direction. The BZF is crucial for extrapolating experimental results onto natural systems and also plays an important role in many engineering applications.

DY 3.6 Mon 11:00 ZEU 118

Transport and rotation statistics of self–propelled ellipsoids in turbulence — •José–Agustín Arguedas–Leiva and Michael Wilczek — Max Planck Institute for Dynamics and Self–Organization (MPI DS)

Many plankton species are motile. Motility is, for example, key for grazing and evading predation. Apart from the swimming speed, shape is a critical parameter in defining the response to hydrodynamic flows. A comprehensive understanding of the relation between the relevant particle parameters, shape and motility, and their transport properties and encounter rates in turbulent flows is still missing. Here, we study self–propelled ellipsoids in turbulence as a simple model for motile microorganisms in aquatic environments. Using direct numerical simulations we find non–trivial dispersion properties and rotation statistics as a result of a complex interplay between turbulent advection, motility, and particle spinning and tumbling rates. We show that one important aspect is the effect of rotation on particle transport. In contrast to spinning, tumbling constantly changes particle orientation. As tumbling rates are shape–dependent, this leads to intrinsically different transport properties for differently shaped particles. Our investigation thus helps to characterize the intricate dynamics of self–motile ellipsoids in turbulent flows and sheds light on the role played by shape and motility.

15 min. break.

DY 3.7 Mon 11:30 ZEU 118

Small-scale averaging coarse-grains passive scalar turbulence
— •Tobias Bätge[1,2] and Michael Wilczek[1] — [1]Max-Planck-Institute for Dynamics and Self-Organization, Göttingen, Germany — [2]Faculty of Physics, University of Göttingen, Germany

Capturing the multi-scale dynamics of turbulent flows remains a theoretical and computational challenge. Therefore, many practical applications require a coarse-grained description, which treats the small scales effectively. How can we obtain such effective large-scale equations? Here, we address this problem at the example of a simple, one-dimensional model for the advection of a passive scalar field. Similar to the Kraichnan model, the scalar is advected by a Gaussian random field and subject to diffusion. Despite its simplicity and analytical tractability, this model shows non-trivial features such as intermittency, anomalous scaling and a dual scalar cascade. We propose that effective large-scale equations can be obtained by ensemble-averaging over the small-scale velocity fluctuations. We show that this procedure leads to an effective diffusivity reminiscent of phenomenological eddy viscosity models. To test our approach, we quantitatively compare the large-scale dynamics and statistics of fully resolved simulations with the ones obtained from our effective large-scale equation. This confirms the ability to reproduce the large scales of a fully resolved system.

DY 3.8 Mon 11:45 ZEU 118

Rayleigh-Taylor Instability in Merging Soap Bubbles —
•Patricia Pfeiffer[1], Qingyun Zeng[2], Beng Hau Tan[3], and Claus-Dieter Pfeiffer[1] — [1]Otto von Guericke University Magdeburg, Germany — [2]Nanyang Technological University, Singapore — [3]MIT Alliance for Research and Technology, Singapore

The coalescence of centimeter-sized soap bubbles is studied using high-speed optical imaging. An interference pattern is observed in the area where the bubbles touch each other shortly before merging. This interference rings suggest that the bubbles are forming a dimple before merging and entrap a tiny volume of air between them. Upon merging a water bridge is formed between both bubbles at the crest of the dimpled region, where the distance between the two bubbles is smallest. The rim of the spreading film accelerates for a brief moment, simulations predict less than 1 *s and expands radially from the point of contact. During that time a Rayleigh-Taylor instability sets in resulting in an instability of the rim front. This instability is mainly visible in the area of the dimple since a higher curvature in that regime induces a higher velocity of the rim. At later times, the rim heals into a circular shape. Depending on the surfactant concentration the entrapment of gas pockets is possible with increasing surfactant concentration. However above the critical micelle concentration no further effect of the surfactant concentration on the instability of the rim is observed.

DY 3.9 Mon 12:00 ZEU 118

On the Inertial Range Scaling at Extreme Reyolds Numbers
— •Christian Küchler[1,3], Gregory P. Bewley[2], and Eberhard Bodenschatz[1,2,3] — [1]Max-Planck-Institute for Dynamics and Self-Organization, Göttingen — [2]Cornell University, Ithaca, NY, USA — [3]Georg August University Göttingen

Kolmogorov predicted in 1941 that universal scaling laws emerge in the increment statistics of turbulent velocities in the limit of infinite Reynolds numbers. In the past it has been found that this limit - if existent - requires extreme Reynolds numbers, which are difficult and expensive to create in a well-controlled turbulent flow. The Variable Density Turbulence Tunnel (Bodenschatz et al., 2014) is the first wind tunnel capable of producing such extreme Reynolds numbers finally allowing us to systematically study the long-standing Kolmogorov prediction and its refinements. The experiment combines the low kinematic viscosity of pressurized SF_6 and an active grid with individually controllable tiles (Griffin et al., 2019). With Nanoscale Thermal Anemometry Probes developed and generously provided by Princeton University (e.g. Bailey et al. (2009), Vallikivi et al. (2014)) we adequately resolve the small scale turbulence. We present results that logarithmic derivatives of structure functions differ from conventional scaling laws of isotropic turbulence. However, these local scaling exponents approach a universal form at some critical Reynolds number. We show that those results are well-described by the generalized self-similar spectrum of decaying turbulence introduced by Yang et al. (2018). It further allows us to extract the scaling exponent.

DY 3.10 Mon 12:15 ZEU 118

Asymmetries of Lagrangian Coherent Structures —
•Gerrit Maik Horstmann[1,2], Jeffrey Tithof[2], and Douglas H. Kelley[2] — [1]Institute of Fluid Dynamics, Helmholtz-Zentrum Dresden - Rossendorf, Bautzner Landstr. 400, 01328 Dresden, Germany — [2]Department of Mechanical Engineering, University of Rochester, Rochester, New York 14627, USA

Lagrangian coherent structures (LCSs) are the dominant barriers to mixing in a fluid flow. LCSs are either the most repelling or most attracting material surfaces in the flow over a given time interval and are computed using velocity fields evolving either forward or backward in time, respectively. Using data from different 2D and 3D laboratory experiment and direct numerical simulations (DNS), an asymmetry between repelling and attracting LCSs growing with the Reynolds number is revealed. In 2D, this asymmetry is characterized by attracting LCSs occurring over a larger fraction of the spatial domain and moving in a more irregular way than repelling LCSs. Studying an analytical model that captures the salient features of this asymmetry, it can be argued that LCS asymmetry is tied to the direction of the energy cascade in turbulence and exhibits opposite trends in 2D versus 3D. In the 3D flows, it is further observed that attracting LCSs are stronger than repelling LCSs indicating the existence of a second, possibly independent, asymmetry. These results are partially connected to recent discoveries of temporal asymmetry in turbulence suggesting LCSs as an alternative analyzing tool for studying some fundamental properties of turbulent flows.