DY 8: Fluid Physics 2 - organized by Stephan Weiss and Michael Wilczek (Göttingen)

Time: Monday 11:00–13:00 Location: DYa

DY 8.1 Mon 11:00 DYa

Interpreted machine learning: Explaining relaminarisation events in wall-bounded shear flows — Martin Lellep[1], Jonathan Prexl[2], Bruno Eckhardt[3], and •Moritz Linkmann[4] — [1]School of Physics and Astronomy, University of Edinburgh, UK — [2]Dept. of Civil, Geo and Environmental Engineering, Technical University of Munich, Germany — [3]Dept. Physics, Philipps-University of Marburg, Germany — [4]School of Mathematics and Maxwell Institute for Mathematical Sciences, University of Edinburgh, UK

Machine Learning (ML) is becoming increasingly popular in fluid dynamics. Powerful ML algorithms such as neural networks or ensemble methods are notoriously difficult to interpret. Here, we use the novel Shapley Additive Explanations (SHAP) algorithm (Lundberg & Lee, 2017), a game-theoretic approach that explains the output of a given ML model, to ascertain which physical processes are significant in the prediction of relaminarisation events in wall-bounded parallel shear flows. The flow is described by an established low-dimensional model whose variables have a clear physical and dynamical interpretation in terms of known representative features of the near-wall dynamics, i.e. streamwise vortices, streaks and linear streak instabilities. We consistently find only three modes to play a major role in the prediction: the laminar profile, the streamwise vortex, and a specific streak instability. SHAP thus distinguishes representative from significant features, hence we demonstrate that it is an explainable AI method which can provide useful and human-interpretable insight for fluid dynamics.

DY 8.2 Mon 11:20 DYa

Small scale structures of turbulence in terms of entropy and fluctuation theorems — André Fuchs[1], •Joachim Peinke[1], Matthias Wächter[1], Silvio M Durate Queiros[2], Alain Girard[3], and Pedro G Lind[4] — [1]ForWind, Inst Physik , 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. The statistical fluctuation theorems set the occurrence of positive and negative entropy events in strict relation, which is consistent with a stochastic description of the turbulence by a Fokker-Planck equation. Most interestingly the entropy concept of cascade trajectories is linked to turbulent structures: Whereas trajectories with entropy- production show expected decreasing behavior; trajectories with entropy-consumption end at small scale at 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. Our current research indicates that the velocity increment dynamics through scales in the cascade process can be described by applying an instanton approach.

DY 8.3 Mon 11:40 DYa

Statistical geometry of material loops in turbulence — Lukas Bentkamp[1], Theodore D. Drivas[2], Cristian C. Lalescu[3], and •Michael Wilczek[1] — [1]Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany — [2]Stony Brook University, Stony Brook, USA — [3]Max Planck Computing and Data Facility, Garching, Germany

Turbulent mixing is often characterized by the statistics of one- or two-particle dispersion. An even more comprehensive characterization of the complexity of turbulent mixing can be achieved by capturing the evolution of extended material lines and surfaces. Here, we investigate the statistical geometry of material loops, i.e. closed material lines, by combining simulations, statistical turbulence theory, and dynamical systems theory. Tracking these structures in direct numerical simulations of homogeneous isotropic turbulence reveals that, while the loops develop convoluted shapes over time, their statistical geometry approaches a stationary state. In particular, their curvature distribution forms clear power-law tails, which we analytically determine in the framework of the Kraichnan model. Dynamically, we show that the high-curvature regime is dominated by the formation of isolated folds and that the power-law exponent can be related quantitatively to finite-time Lyapunov exponents. Thereby, the statistical geometry of material lines can be traced back to their dynamical evolution.

DY 8.4 Mon 12:00 DYa

Velocity measurements in rotating Rayleigh-Bénard convection and the Boundary Zonal Flow — Marcel Wedi[1], •Denis Funfschilling[2], and Stephan Weiss[1] — [1]Max-Planck-Institute for Dynamics and Self-Organization, Göttingen, Germany — [2]Université Strasbourg, France

Rotating turbulent thermal convection is of great importance in various astro- and geophysical systems, where the buoyancy driven flow strongly influenced by Coriolis forces due to rotation of the celestial bodies. It has been studied for decades in the so-called Rayleigh-Bénard setup, where a horizontal fluid layer is heated at the bottom and cooled at the top and rotated around the vertical axis. We investigate the horizontal velocity field using 2D-particle image velocimetry (PIV) in a cylindrical cell ($H = 196\,\mathrm{mm}$ high) with aspect ratio $\Gamma = D/H = 1$. We use water and various water-glycerol mixtures as working fluid resulting in a Prandtl number (Pr) in the range $6 \leq Pr \leq 70$ and Rayleigh numbers (Ra) $10^8 < Ra < 2 \times 10^9$. With our rotating table we reach Ek as low as 10^{-5}. We are mainly interested in studying the recently discovered *Boundary Zonal Flow* (BZF, see Zhang et al., Phys.Rev.Lett. 2020). The BZF is observed in a region close to the lateral sidewall with a cyclonic flow, i.e, a positive mean azimuthal velocity that is separated from and anticyclonic bulk, with negative mean azimuthal velocity. We measure the size of the BZF as a function of Ek and Ra, and compare the results with DNS (Zhang and Shishkina, 2020).

DY 8.5 Mon 12:20 DYa

Transport and rotation statistics of self–propelled ellipsoids in turbulence — •Jose-Agustin Arguedas-Leiva and Michael Wilczek — Max Planck Institute for Dynamics and Self–Organisation, Am Fassberg 17, 37077, Goettingen, Germany

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.

DY 8.6 Mon 12:40 DYa

Lagrangian Turbulence at Unprecedented Reynolds Numbers — •Christian Küchler[1,2], Antonio Ibanez Landeta[1,2], Jan Molacek[1], and Eberhard Bodenschatz[1,2,3] — [1]Max-Planck-Institute for Dynamics and Self-Organisation, Göttingen, Germany — [2]Institute for the Dynamics of Complex Systems of the University of Göttingen, Germany — [3]Cornell University, Ithaca, USA

The Lagrangian reference frame, in which turbulence is viewed by tracking fluid elements over time, is the natural framework for studying transport and mixing phenomena (Sawford (2001)) and previously unexplored properties of turbulence (Toschi & Bodenschatz (2009)). Particularly important Lagrangian dynamics occur at large Reynolds numbers, e.g. the formation of clouds and precipitation. To our knowledge, the Variable Density Turbulence Tunnel (Bodenschatz et al. (2014)) is the only apparatus capable of generating turbulence at Taylor-scale Reynolds numbers up to 6000, while permitting Lagrangian measurements. In addition, the turbulence generation is highly adjustable through a uniquely flexible active grid (Griffin et al. (2019)) and by tuning the pressure of the working fluid SF6 up to 15 bar. Here we present the first measurements of Lagrangian particle tracking in this high-pressure environment. We describe the particle injection mechanism, the high-speed camera setup, and the illumination system. We present initial results of particle accelerations at Reynolds numbers greater than 3000, marking the highest Reynolds numbers at which such statistics have ever been recorded. Finally, we provide an outlook on the overall capabilities of the setup.