Direct numerical simulations and multiple states of Taylor-Couette flow under realisitic boundary conditions

Marvin Kriening*[1], Zhongzhi Yao[1], Mohammad S. Emran[1], Jiaxing Song[1], Andrei Teimurazov[1], and Olga Shishkina[1]

[1]Max Planck Institute for Dynamics and Self-Organization – Germany

Abstract

Self-organization of convection rolls exhibits behavior commonly observed in many externally driven turbulent fluid flows in confined geometries. Recent studies indicate that such flows can further exhibit different statistically stationary states, characterized by varying flow structure length scales and transport properties, even when the control parameters remain the same.

The coexistence of multiple states in fully turbulent flows challenges conventional expectations based on Kolmogorov's theory, which posits that strong turbulence should explore the entire phase space. Taylor-Couette flow (a flow between two independently rotating coaxial cylinders) is, alongside Rayleigh-Bénard convection, one of the predominant systems for studying multiple states in turbulence.

The dimensionless control parameters of this system are the Taylor number (Ta), representing the rotational strength, the rotation ratio of the inner and outer cylinder (a), the aspect ratio () describing the systems geometry and the radius ratio (η = r/r). The main global response parameters are the torque, indicating the angular momentum transport between the cylinders, and the dimensionless angular velocity flux (J/J).

In this study, we aim to investigate multiple states in turbulent Taylor-Couette flow for large Taylor numbers, under realistic boundary conditions. Using the finite-volume code GOLDFISH, we conduct direct numerical simulations (DNS) of Taylor-Couette flow for a broad Ta-range, with no-slip boundary conditions on all side walls and considering only inner cylinder rotation. We extend the classical angular-momentum-flux framework to account for axial transport, which leads to a significantly improved agreement with the

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*Speaker

Eckhardt–Grossmann–Lohse model. Using modal energy budgets, we identify transition mechanisms and quantify the accessible phase-space volume while also seeking potential upper and lower bounds on stable roll configurations by expanding the velocity field in terms of Laplace eigenfunctions, assuming that the roll size in 3D flows is constrained by the elliptical instability.