22nd International Couette–Taylor Workshop
Barcelona, Spain | 28 – 30 June 2023

Title: Instability-driven turbulence

Abstract: In this talk I will survey recent progress in understanding instability-driven turbulence in both two (2D) and three (3D) dimensions. Turbulence in 3D is characterized by a forward transfer of energy, to small scales, while in 2D energy is transferred in the opposite direction, towards large scales. When driven by a prescribed stochastic force, the latter leads to the formation of large scale structures in the form of vortices or jets. When the turbulence is driven instead by a wavenumber-localized instability superposed on stochastic forcing, the inverse energy transfer may be arrested and no large scale condensate forms. We find that when a control parameter measuring the fraction of energy injected by instability is increased, the system undergoes two transitions. For a regular large-scale vortex condensate (LSC) forms. For shielded vortices (SVs) emerge and coexist with the condensate. At a second, larger value of the control parameter, the condensate breaks down, and a gas of weakly interacting vortices with broken symmetry spontaneously emerges, characterized by the preponderance of vortices of one sign only and suppressed inverse energy cascade. The number density of SVs in this broken symmetry state slowly increases via a random nucleation process. At late times a dense SV gas emerges, which persists back down to small values of, where it crystallizes to form a hexagonal lattice. It is observed that individual SVs are trapped in the lattice at small, up to a sharp threshold, above which the mean square displacement of SVs increases linearly with time and the system exhibits a nonequilibrium second order melting transition. These findings provide new evidence for a strong dependence of the phenomenology of 2D turbulence on the forcing.

I will compare this phenomenology with that observed in highly anisotropic but three-dimensional systems focusing on condensate formation in rapidly rotating Rayleigh-Benard convection via both reduced dynamics and direct numerical simulations (DNS) of the Navier-Stokes equation. I will conclude with a discussion of the boundary zonal flow (BZF) observed in both experiments and DNS in cylinders, its robustness under perturbation and its relation to the precessing wall modes present in this system. Finally, I will suggest a simple intervention that suppresses the BZF and its role in contaminating Nusselt number measurements in the laboratory, thereby enabling laboratory studies of geostrophic turbulence in laterally confined systems.

Speaker: Edgar Knobloch