DOCTORATE THESIS

On the phase-space distribution of heavy particles in turbulence

JAN MEIBOHM

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UNIVERSITY OF GOTHENBURG

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JAN MEIBOHM
Department of Physics
University of Gothenburg

Turbulent fluids laden with small, heavy particles are common in nature. Prominent examples of such turbulent suspensions are water droplets in warm clouds, as well as particulate matter or living organisms in the turbulent upper layer of oceans. Because of their inertia, heavy particles tend to distribute inhomogeneously over phase-space, and over configuration space. This phenomenon is referred to as clustering, and it is believed to have a strong impact on the rate of collisions between particles. The collision dynamics, in turn, is crucial for the time evolution of turbulent suspensions, as collisions enable the particles to grow in size.

In this thesis, I study the phase-space distribution of heavy particles in turbulence in terms of a simplified, statistical model that qualitatively captures the particle dynamics on the smallest length scales of turbulence. I use methods from dynamical systems theory, and the theory of large deviations, to describe the long-time behaviour of the particle distribution. In most parts of the thesis, I investigate suspensions of identical particles, and study statistical observables that characterise clustering in phase-space, and in configuration space.

For these 'mono-disperse' suspensions I analyse phase-space clustering in a one-dimensional limit by computing the large-deviation statistics of phase-space finite-time Lyapunov exponents, and the phase-space Renyi dimensions. Spatial clustering is studied by projecting the phase-space dynamics to configuration space. I show how the large-deviation statistics of spatial finite-time Lyapunov exponents is affected by this projection, and the effects it has on the spatial correlation dimension.

Finally, I extend the analysis to particle suspensions of two different sizes. I show that this 'poly-dispersity' has a strong effect on the phase-space distribution of particles, where it leads to a plateau in the distribution of separations and relative velocities.

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