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Clusters of heavy impurities in turbulent flows

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Dust, droplets and other finite-size impurities with a large mass density suspended in incompressible turbulent flows are commonly encountered in many natural phenomena and industrial processes. The most salient feature of such suspensions is the presence of strong inhomogeneities in the spatial distribution of particles. This phenomenon, dubbed *preferential concentration* can affect the probability to find particles close to each other and thus have influence on their possibility to collide or to have biological, chemical and gravitational interactions. The statistical description of such preferential concentrations remains largely an open question, with applications, for instance, in the growth of raindrops in subtropical clouds or in the formation of planetesimals in the early Solar System.

We present results of three-dimensional direct numerical simulations of heavy particles transported by an incompressible, homogeneous and isotropic turbulent fluid flow with, presently, a maximal resolution of 512^3 (corresponding to a Taylor-microscale Reynolds number $R_\lambda \simeq 185$).[1] The suspensions considered are very diluted, so that particle-to-particle hydrodynamic interactions and retroaction of the particles on the fluid can be disregarded. The particle motion is then integrated by a Lagrangian method, allowing a description in the full position-velocity phase space where their dynamics takes place. The particles are assumed to be much heavier than the fluid and much smaller than the smallest active scale of the flow, that is the Kolmogorov scale. In these asymptotics, they interact with the fluid only through a viscous drag. The response time τ_s of the particles is usually non-dimensionalized by a characteristic time of the fluid flow (typically, the eddy turnover time τ_η associated to the Kolmogorov scale η) to define the Stokes number $St = \tau_s/\tau_\eta$ that measures the inertia of the particles. The model we consider hence depend on only two parameters: the Stokes

[1] A 2048^3 simulation is going to be performed before the end of 2006.

number of the particles and the Reynolds number of the carrier flow. This allows for a systematic investigation.

After relaxation of transients, the phase-space density of particles becomes singular with its support on a dynamically evolving fractal set. This attractor is characterized by non-trivial multiscaling properties at scales much smaller than the Kolmogorov dissipative scale. Multifractality in phase space implies also multiscaling of the coarse-grained spatial distribution of the mass of particles. The scaling exponents of the latter accurately determined from the simulations are related to the spectrum of dimensions of the particle distribution. This approach based on the use of tools from dissipative dynamical systems catches the small-scale clustering of particles and can be modeled by suspensions in random flows.

For larger length scales inside the inertial range of turbulence, the particle distribution presents large voids where the mass is orders of magnitude below its average. Such regions are typically correlated with the vortical structures of the flow; this confirms the classical phenomenological pictures that in turbulent flow, eddies act as small centrifuges and eject heavy particles leading to their concentration in the strain-dominated regions. We show that in the inertial range, the particle distribution is not scale-invariant anymore. Dimensional analysis leads to predict that deviations from a uniform distribution are related to the local Stokes number $St(\ell) = \tau_s/\tau_\ell = \tau_s \varepsilon^{1/3}/\ell^{2/3}$, defined by non-dimensionalizing the response time of the particles by the eddy turnover time τ_ℓ of the turbulent flow at the scale ℓ considered. We show that this number does not quantify the particle distribution at inertial scales. We however obtained strong evidence that the latter depends only on a rescaled contraction rate. Particle distribution is characterized by voids spanning all scales of the turbulent flow; their signature in the coarse-grained mass probability distribution is an algebraic behavior for small mass densities.