Clustering formation of inertial particles in high Reynolds number isotropic turbulence

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Clustering of inertial heavy particles in high Reynolds number turbulence is an important fundamental process, e.g., for raindrop formation in atmospheric clouds. The particle distribution shows multiscale clusters and voids. The clustering formation and destruction are driven by the particle velocity divergence. The divergence and convergence of inertial heavy particles in homogeneous isotropic turbulence are investigated. To this end, a tessellation-based technique[1] is applied to three-dimensional direct numerical simulation (DNS) data[2,3], in which particles are tracked by a Lagrangian method, to directly access to the particle velocity divergence $\mathcal{D} = \nabla \cdot \boldsymbol{v}$.

The divergence is computed based on the temporal rate of change in tessellation volumes[1]. Figure 1(a) shows a spatial distribution of $\mathcal{D}$ in a thin sliced domain, where $\mathcal{D}$ is normalized by the Kolmogorov time τ_η. Negative and positive values of $\mathcal{D}$ indicate cluster formation and destruction, respectively. Figure 1(b) shows the Fourier spectrum $E_D(k)$ of $\mathcal{D}$ computed based on an analytical technique[2]. Here, $E_D(k)$ is compared with the spectrum $E_Q(k)$ of Q, which is the second invariant of fluid velocity gradient tensor. When the particle relaxation time τ_p is smaller than a flow time scale[4], $\mathcal{D}$ can be approximated as $2\tau_p Q$. The peak of $E_D(k)$ is located at a smaller wavenumber than the peak of $E_Q(k)$, indicating that for the Stokes number of $St = 1.0$, the scale of particle clustering formation is larger than the scale of smallest turbulence eddies. Further analyses on the Stokes-number dependence and the scale-dependence of particle clustering formation will be presented.

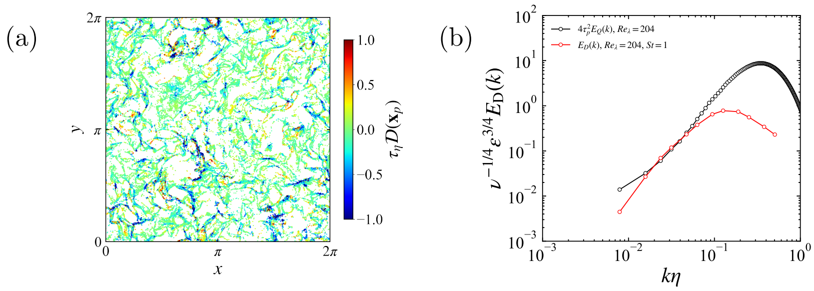

Figure 1: (a) Spatial distribution of $\mathcal{D}$ in the range of $0 < z < 4\eta$. (b) Energy spectra $E_D(k)$ (red) and $E_Q(k)$ (black). The vertical axis is normalized by the kinematic viscosity ν and the energy dissipation rate ϵ, and the horizontal axis is normalized by the Kolmogorov scale η. The DNS data for the Taylor-microscale Reynolds number $Re_\lambda = 204$ and the Stokes number $St = 1.0$ are used.

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[1] Oujia et al., *J. Fluid Mech.* **905**, A14 (2020).
[2] Matsuda et al., *J. Atmos. Sci.* **71**, 3569 (2014).
[3] Matsuda et al., *Phys. Rev. Fluids* **6**, 064304 (2021).
[4] Maxey, *J. Fluid Mech.* **174**, 441 (1987).