PARTICLE TRANSPORT IN WEAKLY TURBULENT RAYLEIGH-BÉNARD CONVECTION

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Abstract We present data from a numerical study of two-particle dispersion of passive tracers in the weakly turbulent state of Spiral Defect Chaos in Rayleigh-Bénard convection. In a Lagrangian frame of reference, we investigate the competition between molecular diffusion and advection. We consider high aspect ratio systems ($width/height \geq 10^2$) and focus on the tracer dispersion in the horizontal plane.

LAGRANGIAN TWO-PARTICLE STATISTICS IN RAYLEIGH-BÉNARD CONVECTION

The process of mass transport by convection is of high interest for science and application. Here we investigate the transport of tracers in weakly turbulent, spatio-temporally chaotic Rayleigh-Bénard convection (RBC) [2]. In particular, we show how tracers are transported in systems of large lateral extent showing Spiral Defect Chaos (SDC).

We obtain the particle trajectories from numerical simulations of the Boussinesq equations. For this we use a GPU-parallelized Galerkin scheme that allows to simulate systems of high aspect ratio $\Gamma = width/height \geq 100$. We use two Chandrasekhar functions to project the Boussinesq equations into the plane and then use a pseudospectral solver with second order time integration. The system size is mostly limited by the amount of memory available. In our current GeForce GTX 680 system with 4 GB of memory, we can simulate within 2 days one horizontal thermal diffusion time for an aspect ratio of $\Gamma = 100$. In the numerically obtained flow field, particle trajectories are integrated with a fourth-order Runge-Kutta scheme, with Gaussian noise added to the particle positions (to simulate molecular diffusion). The parallelized implementation allows for simultaneous integration of $N \geq 10^4$ trajectories.

While the advective fluid motion in the Bénard system depends on the fluid's thermal diffusivity κ, the diffusion process can be described by the mass diffusion coefficient $\mathcal{D}$. The nondimensional Lewis number $\mathcal{L} := \mathcal{D}/\kappa$ characterizes the relative influence of the diffusion mechanism [3]. We take a Lagrangian approach [5, 6] and describe the relative dispersion of two particles. We only consider motion in the horizontal plane and neglect the vertical motion, since the system's aspect ratio Γ is large. We are calculating the pair dispersion $R^2(t) := \langle|\vec{x}_{i,2D}(t) - \vec{x}_{j,2D}(t)|^2\rangle$ for pairs of particles that start at the same location. Under these conditions, several scaling regimes can be identified, that deviate from the initial 2D diffusion regime of $R^2(t) = 8\mathcal{D}t$ and show superdiffusivity.

We compare our low Ra simulations to numerical studies by Emran et al.[1, 4] on the Lagrangian dynamics of passive tracers in strongly turbulent RBC with aspect ratios of $\Gamma \leq 12$.

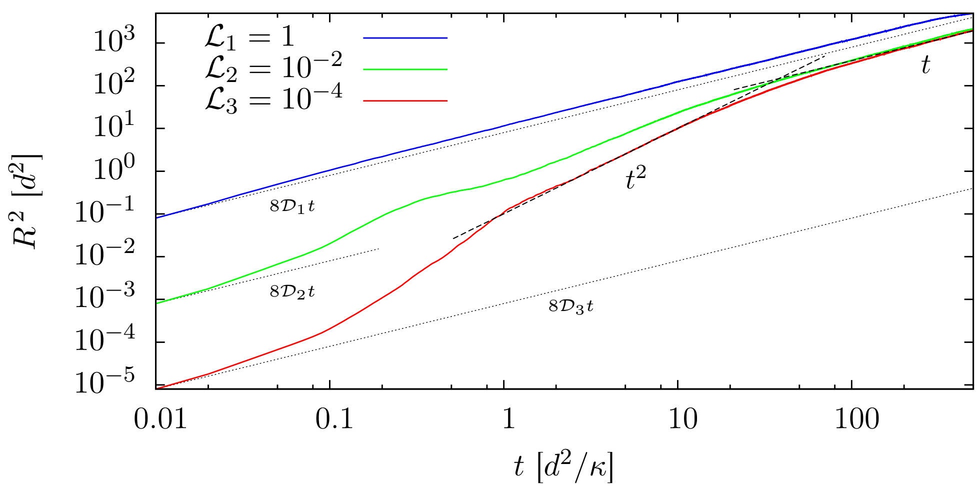

Figure 1. Temporal evolution of the 2D pair dispersion $R^2(t)$ for different Lewis numbers $\mathcal{L}$. DNS Results from 10^4 particle trajectories in Spiral Defect Chaos inside a square convection cell of aspect ratio $\Gamma = 200$ (with periodic boundaries) at $Ra = 3500$, $Pr = 1$. d is the system height, κ the thermal diffusivity of the fluid.

References

[1] J. Bailon-Cuba, M. Emran, and J. Schumacher. Aspect ratio dependence of heat transfer and large-scale flow in turbulent convection. *J. Fluid Mech.*, **655**:152–173.

[2] E. Bodenschatz, W. Pesch, and G. Ahlers. Recent developments in Rayleigh-Benard convection. *Annu. Rev. Fluid Mech.*, **32**:709–778, 2000.

[3] K.-H. Chiam, M. C. Cross, H. S. Greenside, and P. F. Fischer. Enhanced tracer transport by the spiral defect chaos state of a convecting fluid. *Phys. Rev. E*, **71**:036205, Mar 2005.

[4] M. S. Emran and J. Schumacher. Lagrangian tracer dynamics in a closed cylindrical turbulent convection cell. *Phys. Rev. E*, **82**:016303, Jul 2010.

[5] J. Salazar and L. Collins. Two-particle dispersion in isotropic turbulent flows. *Annu. Rev. Fluid Mech.*, **41**:405–432, 2009.

[6] F. Toschi and E. Bodenschatz. Lagrangian properties of particles in turbulence. *Annu. Rev. Fluid Mech.*, **41**:375–404, 2009.