Diffusion in a two-dimensional chiral fluid

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Active matter typically sustains a steady energy exchange between its constituents and the surrounding medium. This yields a rich and complex non-equilibrium phenomenology; for instance, collective motion may emerge, sometimes with peculiar features such as chirality [1, 2]. We analyze in this experimental work the diffusive properties of a two-dimensional active chiral fluid composed of air-fluidized spinners. In particular, we show that diffusion is an antisymmetric tensor, the off-diagonal elements corresponding to a new diffusion coefficient that we term here as *odd diffusion*.

$$\mathcal{D} = \begin{bmatrix} D & -D^{\text{odd}} \\ D^{\text{odd}} & D \end{bmatrix} \quad (1)$$

We also show that the control parameter is the fluid flow (global) vorticity $\overline{\omega}$, that appears as a consequence of chirality, $\omega = (1/2)\epsilon_{ij}\partial_i u_j$, where ϵ_{ij} is the 2D Levi-Civita symbol and $\mathbf{u}$ is the fluid flow field. As we can see, this parameter governs the evolution of diffusive coefficients in the fluid. Very surprisingly, the same fluid can be (with the same particle density) either super-diffusive, sub-diffusive or diffusive.

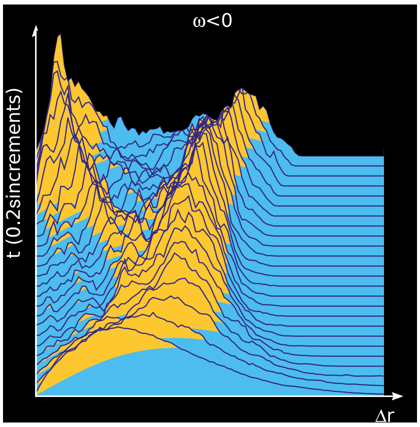

Fig. 1. This figure shows the time evolution of the distribution function of the mean squared displacements, which governs diffusive behavior in the chiral fluid. In orange and blue, regions above and under a gaussian distribution, respectively. Packing fraction $\phi = 0.45$, global vorticity $\overline{\omega}$ is negative in this series of experiments.

Strikingly as well, and for steady chiral flow, diffusion in the fluid slowly ages, as the distribution function of the mean squared displacements vs. time shows in Figure 1.

We demonstrate that D^{odd} is indeed experimentally measurable (we use a modified Green-Kubo relationship). Moreover, the diffusion coefficients D, D^{odd} data vs. the control parameter $\overline{\omega}$ collapse for all densities, as universal curves, as the analysis of experimental data yields in Figure 2.

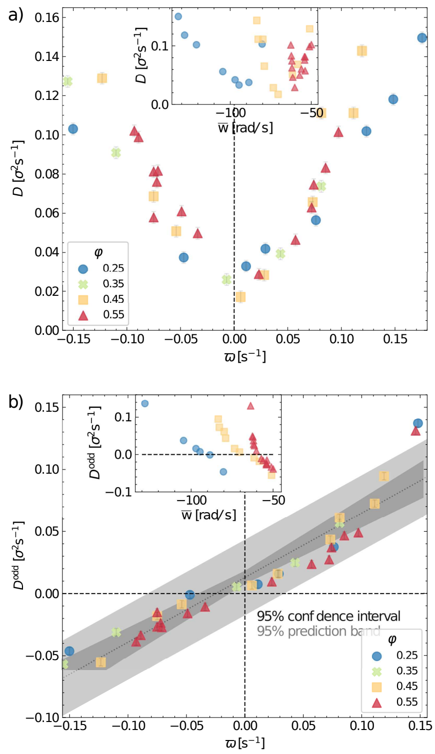

Fig. 2. Diffusion coefficients vs. global mean vorticity $\overline{\omega}$ for several experiment with different densities (packing fraction ϕ) (each denoted with a different symbol and color, see figure legend) (a) Diffusion coefficient D. (b) Odd diffusion D^{odd} coefficient

The experimental set-up, the rich diffusive behavior and the consequences for a number of important and complex biological processes will be discussed in more detail at the conference.

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[1] M. A. López-Castao and A. Márquez Seco and A. Márquez Seco and A. Rodríguez-Rivas and F. Vega Reyes (2022), Chirality transitions in a system of active flat spinners. Preprint: arXiv:2105.02850.

[2] Hargus, C., Epstein, J. M., & Mandadapu, K. K. (2021). Odd Diffusivity of Chiral Random Motion. Physical Review Letters, 127(17), 178001