Experimental investigation of the circulation in quasi-2D turbulence

Hang-Yu Zhu*, Jin-Han Xie†, Ke-Qing Xia*,‡

We present an experimental study of the circulation in a quasi-two-dimensional turbulent flow driven electromagnetically. We show that the area rule of circulation[1] around simple loops holds in both the forward-cascade enstrophy inertial range (ΩIR) and the inverse-cascade energy inertial range (EIR): when the side lengths of a loop are all within the same inertial range, the circulation statistics depend on the loop area alone. We also find that for circulation around figure-eight loops, the area rule still holds in EIR but is not applicable in ΩIR. In ΩIR, the circulation is non-intermittent; whereas in EIR, the circulation is bifractal: space filling for moments of order 3 and below and a monofractal with a dimension of 1.42 for higher orders, as shown in figure 1. Our results demonstrate that in terms of circulation, turbulent flows exhibit a simpler behavior than velocity increments, as the latter are multifractals. Combined with the recent numerical results in high-Re 3D turbulence[2] and quantum turbulence[3] (see the inset in figure 1), this finding suggests that circulation may serve as a potential candidate for a more unified description of turbulence.

This work was supported by the National Natural Science Foundation of China (NSFC) (Grants No. 12102167, No. 12232010, No. 12072144, No. 92052102 and No. 12272006) and the China Postdoctoral Science Foundation (Grant No. 2021M701580).

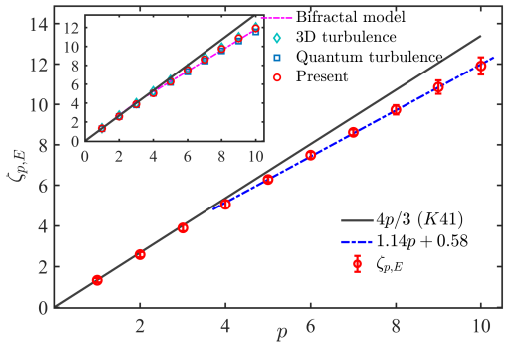

Figure 1: The scaling exponents of circulation moments in EIR. The high orders are fitted by a monofractal model. Inset displays bifractality observed in 3D turbulence[2], quantum turbulence[3] and our quasi-2D turbulence, and the bifractal model from Iyer *et al.*[2].

*Center for Complex Flows and Soft Matter Research and Department of Mechanics and Aerospace Engineering, Southern University of Science and Technology, Shenzhen 518055, China

†Department of Mechanics and Engineering Science at College of Engineering, and State Key Laboratory for Turbulence and Complex Systems, Peking University, Beijing 100871, China

‡Department of Physics, Southern University of Science and Technology, Shenzhen 518055, China

[1] A. A. Migdal, *Int. J. Mod. Phys. A* **9**, 08 (1994).

[2] K. P. Iyer, K. R. Sreenivasan, and P. Yeung, *Phys. Rev. X* **9**, 041006, (2019).

[3] N. P. Müller, J. I. Polanco, and G. Krstulovic, *Phys. Rev. X* **11**, 011053, (2021).