

Summary of thesis: Dynamics and subcritical transition focusing on spatially-localized turbulence in two-dimensional Kolmogorov flow

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In this thesis, understandings of dynamics and turbulence transition for subcritical regime are developed where spatially-localized turbulence (SLT) plays a key role. Two-dimensional (2D) Kolmogorov flow is theoretically and numerically treated, which is one of the simplest flows governed by the Navier-Stokes equations with a monochromatic forcing defined on a two-dimensional torus.

For subcritical regime where no unstable mode exists around the laminar solution, SLTs such as spot in channel flow and puff in pipe flow are widely observed in laboratory and numerical experiments. In this case dominant modes which are thought to govern the system are not necessarily determined and generally unknown, while unstable modes of the linear theory are generally dominant for subcritical regime. Localization in spatial directions should lead to scale separations of length scale comparing to the system size, and both the time and length scale separations make theoretical and numerical approaches further intractable.

One of the basic findings of this thesis is that the uniform flow perpendicular to the forcing direction makes the laminar solution stable. 2D Kolmogorov flow is simpler, more tractable and uniform than wall-bounded flows. We are able to investigate subcritical flow at low cost.

In main parts of the thesis, we discuss the two different cases in each of which phenomena focused on are affected by time scale separation. At the first part, intermittent direction reversal of spatially-localized turbulence is found. Spatially-localized turbulence moves with a constant speed on average, and it changes its own moving direction suddenly and intermittently. We discuss the relationship between chaotic dynamics described by the inner degree of freedoms and the direction reversal. The second topic is subcritical turbulence transition. A new example of subcritical turbulence transition governed by the 2D Navier-Stokes

equations without material walls. Theoretical estimation yields that critical Reynolds number of linear theory blows up to infinity even at a finite unit flow rate perpendicular to the forcing. Confirmed by numerical integration, the number of spatially-localized turbulences is allowed to change randomly by introducing a large drag forcing. The results also suggest that the subcritical transition belongs to the directed percolation universality class.