# Minding the gaps in pipe flow

Anna Frishman[*], Shai Kapon[*], Tobias Grafke [†]

The transition to turbulence in subcritical flows is spatially and temporally intermittent. Pipe flow is a prime example, where turbulence initially appears in the form of well-defined localized structures called puffs. For high enough Reynolds numbers, Re $> 2300$, a homogeneous turbulent state becomes possible, and puffs are replaced by expanding structures called slugs. We perform DNS of pipe flow in this regime, considering Re $= 2450, 2500, 2550$. The turbulent phase is here characterized by spatial and temporal intermittency: turbulence fills the entire pipe but laminar gaps randomly open-up, and then randomly close back, see top panel of Fig.1. While large enough gaps contract with a rate equal to that of slug expansion, smaller gaps can persist and have a well-defined average size, see bottom panel of Fig. 1. We show that such laminar gaps embedded in turbulent flow are mirror images of turbulent puffs embedded in laminar flow. They can persist within turbulence due to a self-tuning mechanism: narrower gaps tend to expand while wider gaps tend to contract. Mirroring puffs, such gaps have a (weak) front whose speed is determined by the homogeneous turbulence upstream of the gap, and a (strong) front which tunes its speed to that of the weak front. As Re is increased such gaps become smaller: increasing Re decreases the speed with which laminar flow (within the gap) invades the upstream turbulence. To match this decrease in speed, the propagation of the downstream turbulence into the gap must slow down, which occurs for a flatter adjacent laminar profile. Such a profile is achieved by arresting the relaxation of the laminar flow towards Hagen-Poiseuille at an earlier stage by a decrease in the gap size. Finally, we measure gap lifetimes and show they follow an exponential distribution, the mean lifetime decreasing with Re. Such an exponential distribution is to be expected if the closing of the gaps is interpreted as an escape from a chaotic saddle.

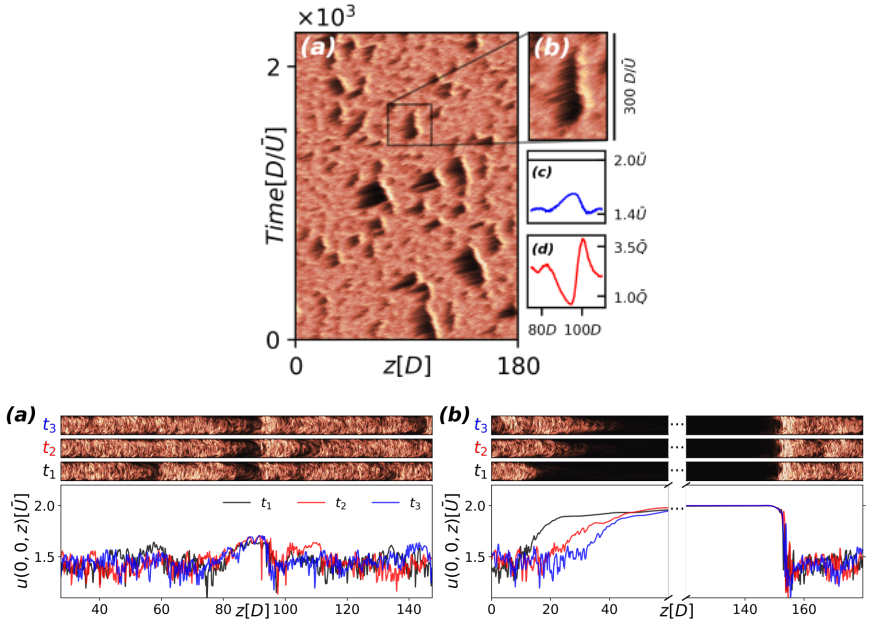


Figure 1: Pipe flow at $Re = 2500$. Top panel: multiple laminar gaps embedded within turbulence ($\bar{Q} \equiv \bar{U}/100$). Bottom panel: (a) A laminar gap with a persistent size and shape (b) A large laminar gap over the same time-span appreciably contracts.

[*]Department of Physics, Technion Israel Institute of Technology, 32000 Haifa, Israel
[†]Mathematics Institute, University of Warwick, Coventry CV4 7AL, United Kingdom