Staircase Structure in a Melting Flow

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Plasmas near marginality are likely to occur in future magnetic confinement devices such as ITER. Far from equilibrium, magnetically confined, near marginal plasmas develop into an organized critical state of isolated transport micro-barriers and sectors of avalanche-like transport. This global pattern of micro-barriers and avalanching zones creates a pressure profile resembling a staircase. In this step-like pressure profile, there are regions of corrugation which are an enduring layer of localized shear and flat regions where strong mixing, and transport occurs. The key feature here is the containment of avalanche activity by the series of micro-barriers, which is essential for confinement.

A staircase profile of scalar concentration forms in a simple system of stationary, convective cells, set in a fixed array. In this setup, the interplay of two disparate time scales, the cell turn-over time and the diffusion time determines transport from cell-to-cell. This ratio is the Peclet number (Pe). For Pe > 1, there is fast mixing within the cells and slow mixing across the boundaries of the cells. This disparity gives a simple example of staircase formation. It should be noted that there is no dynamical feedback in this system, thus it is simpler than the ***E*** *x* ***B*** shear predator-prey scenario. Here we study the effects that a fixed global shear and some variability of the spatial pattern of turbulent mixing have on the staircase structure.

First, we study the resilience of the staircase by imposing a spatially varying cross-profile shear flow (N.B. The shearing rate introduces a third time scale) and show that as shearing strength is increased, the staircase profile breaks down and total scalar confinement decreases. Next, we study the staircase structure at different evolutionary stages of a “melting” vortex crystal. The “vortex crystal” is simply the array of cells and “melting” is related to turbulence induced variability in the structure. The goal here is to examine how the staircase evolves as vortex scatter increases. The melting flow structure is created by slowly increasing the Reynolds number in the Navier-Stokes equation which includes a forcing and drag term, thus, scattering the vortex crystal. By injecting a scalar concentration into the crystal, we observe that the scalar forms a flamelet network pattern (i.e., scalar flows along and around vortices). On a global scale, this forms a web structure, thus, showing the scalar’s path in the flow. By systematically varying the vortex crystal state (i.e., Reynolds number), one uncovers that the staircase structure is resilient and that the web is not destroyed though "holes” do appear. The relation between the web and staircase structures (i.e., mergers) is elucidated.

References

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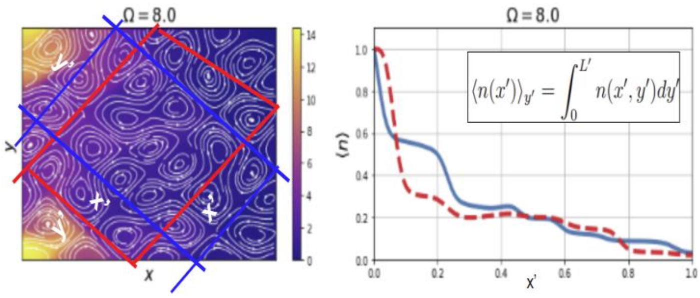

Figure 1. Crystal with scalar concentration at Ω= 8. On the left figure, we can see mergers/connections of vortices. These mergers are reflected on the averaged in *y'* scalar profile on the right, by the elongated staircase step on the red dashed line. As we increase the degree of melting, staircase steps start to merge. Despite the cellular array becoming more turbulent, the staircase structure persists, but steps become less regular.