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How the Propagation of Heat-Flux Modulations Triggers $E \times B$ Flow Pattern Formation

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Recently, a new class of $E \times B$ flow pattern, called an "$E \times B$ staircase," was observed in a simulation study using the full-f flux driven GYSELA code. Here, $E \times B$ staircases are quasi-regular steady patterns of localized shear layers and temperature profile corrugations. The shear layers are interspaced between regions of turbulent avalanching of the size of several correlation length ($\sim 10\Delta_c$). In this work, a theory to describe the formation of such $E \times B$ staircases from a bath of stochastic avalanches is presented, based on analogy of staircase formation to jam formation in traffic flow. Namely, staircase formation is viewed as a heat flux "jam" that causes profile corrugation, which is analogous to a traffic jam that causes corrugations in the local car density in a traffic flow. To model such an effect in plasmas, a finite response time τ is introduced, during which instantaneous heat flux relaxes to the mean heat flux, determined by symmetry constraints. The response time introduced here is an analogue of drivers' response time in traffic flow dynamics. It is shown that the extended model describes a heat flux "jam" and profile corrugation, which appears as an instability, in analogy to the way a clustering instability leads to a traffic jam. Such local amplification of heat and profile corrugations can lead to the formation of $E \times B$ staircases. The scale length that gives the maximum growth rate falls in the mesoscale range and is comparable to the staircase step spacing.

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