Physics of ExB Staircases

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Microscale turbulence is well known to nonlinearly excite secondary mesoscopic structures such as fronts, avalanches or zonal flows. Such structures, which may appear as mutually exclusive, are yet broadly observed, especially near marginal stability –a regime of parameters also called the 'Dimits shift'. Such regimes are especially relevant to future large, hot experiments such as ITER. These organised structures are sensitive to assumptions of scale separation and are best understood in a flux-driven framework. Self-organisation of these competing mesoscopic structures and their impact on transport raise acute questions. Near marginality, (i) distinct turbulent states and flux levels can be obtained from almost identical underlying mean plasma gradients. This fact underlies a multivalued (bistable mostly) [1], non-monotonic flux-gradient landscape, with competition between mean (equilibrium) flow shear and zonal (fluctuating) flow shear [2]. In addition, (ii) turbulence spreading [3] is ubiquitous in flux-driven regimes, its more visible manifestations being the observation of fronts or avalanches. This fact underlies departure from a local or Fickian transport paradigm [4]. Connection between spreading and departure from local, single-valued flux-gradient landscapes is still debated. Besides breakdown of Fickian transport at microscales, flux-driven frameworks report (iii) mesoscale organisation near marginal stability with emergence of a tertiary structure, the "**ExB** staircase" [4]. Staircases are a sequence of zonal mean flow layers co-located with profile corrugations which statistically enclose regions of avalanching (strong transport). The zonal mean flow interspacing scale is about 40 to 50 ion Larmor radii, with a fat tail [2,5,6]. This emergent mesoscale near marginality (iv) is consistent with a transition from Bohm-like (avalanche-dominated) transport for small plasma sizes to gyro-Bohm like (staircase-regulated avalanching) transport for large plasma sizes [2]. Above marginal stability, as staircase organisation fades, avalanching activity is less regulated and Bohm-like confinement can be observed [7]. Interplay between layering and spreading, permeability of shear layers (staircase-related or otherwise) to extended transport events are seldom explored though could prove important for a deeper understanding of transport. Regarding robustness, (v) staircase organisation is numerically observed with adiabatic or kinetic [8,9] electron responses, in electrostatic or electromagnetic [10] frameworks. Gradient-driven approaches hinder emergence of such structures. Experimentally, density fluctuations measured with fast swept reflectometry on Tore Supra [11,5] have yielded the first identifications of regularly-spaced shear flow layers consistent with the staircase phenomenology. Many more machines have since confirmed this trend and shown additional features such as avalanche regulation by shear flows [9]. More experiments are required to fully document staircase regimes. Preliminary observations have yielded (vi) significant discrepancies in heat transport predictions between flux-driven approaches and gradient-driven or quasilinear approaches, in near marginal regimes with observed staircase patterning [12]. These observations are still in their infancy and require further investigation yet may have important consequences on reduced modelling as it pushes towards multivalued flux-gradient landscapes. Last but not least, (vii) several models have been proposed to account for staircase formation and will be reviewed [13-15,6]. This step is important to gain understanding of these phenomena and to build reduced models with confidence.

We propose to overview the questions above.

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