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Scale-selection due to collisional zonal flow damping in the Cahn-Hilliard model of zonal staircase

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$E \times B$ Zonal flows (ZF) are a prime example of self-organized nonlinear structures in magnetized plasmas [1], and can regulate turbulence and reduce transport. Therefore, understanding its spatial structure is very important for fusion research. In particular, the $E \times B$ staircase has been observed from both gyrokinetic simulations [2-4] and tokamak experiments [5,6]. While there has been steady theoretical progress in understanding the formation mechanism, its dependence on key physical parameters has not been investigated in detail to date. In this work, we show – both analytically and numerically – that the collisional zonal flow friction $\mu \sim \nu_{ii}$ –with ν_{ii} the ion-ion collisionality- limits the radial scale, i.e. staircase step-size – of the staircase. The relation between the staircase amplitude and the staircase step-size is shown for different values of the ZF friction μ normalized to the hyper-viscous layer width τ_h [Fig.1, left].

This is confirmed in 1D numerical simulations of the Cahn-Hilliard model extended to include zonal flow friction. Figure 1 (right) shows the zonal flow staircase profile normalized to the reference amplitude at $\mu\tau_h = 0.01$, for different values of zonal flow friction μ. Only a portion of the radial domain is shown. The staircase step-size Δ is found to scale as $\Delta \sim \frac{1}{\sqrt{\mu}}$ in the regime where the hyper-viscous layer width δ_h is negligible, and scales much weaker with μ otherwise.

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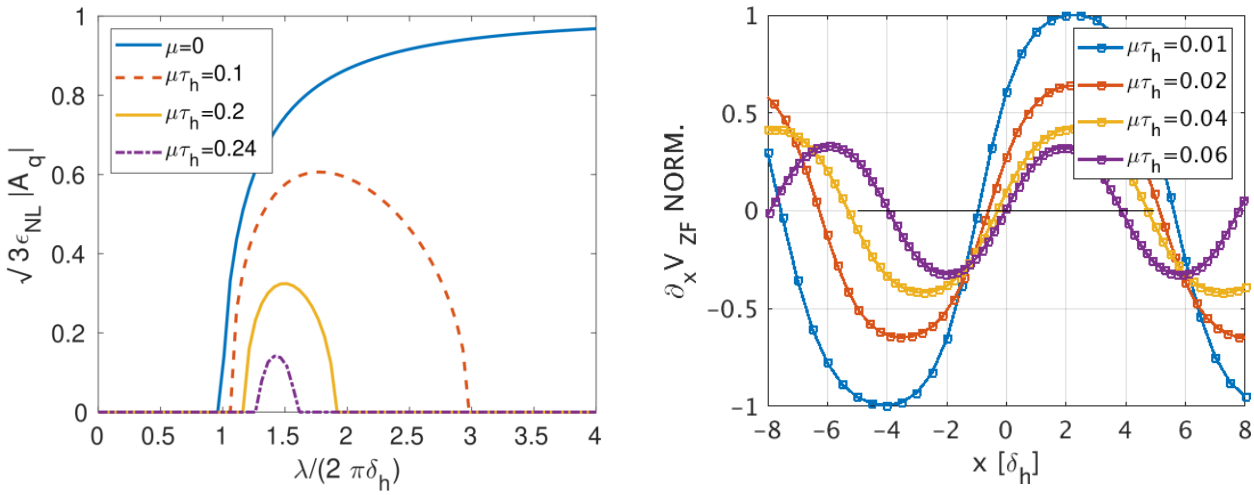

Figure 1(left) Relation between staircase ZF amplitude $|A_q|$ and staircase step-size λ, for different values of ZF friction μ, and (right) ZF staircase profile for different values of ZF friction.