Self-consistent gyrokinetic simulations of magnetic islands in tokamaks

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Abstract

The evolution of magnetic islands in tokamak plasmas is investigated employing gyrokinetic simulations performed with the particle-in-cell code ORB5 in the collisionless limit. Both linearly unstable tearing modes and turbulence-driven magnetic islands are investigated. Linear simulations confirm the expected trends of the growth rate with respect to e.g. electron mass and plasma beta. At higher values of beta, the tearing mode is suppressed and a mode with the same helicity but with twisting parity, coupled with the neighbouring poloidal harmonics, is destabilized. It is shown that strongly driven modes can produce turbulence even in the case of flat background pressure profiles through Kelvin-Helmholtz unstable flows around the island
separatrix. This can lead to a strong reduction of the island size (1). In the presence of pressure gradients, magnetic islands are in general driven nonlinearly by fast-growing microinstabilities, until decoupling occurs when the island size is comparable to the eddy size, confirming previous gyrokinetic studies in toroidal geometry. After decoupling from the turbulence, further growth
can occur even in the absence of a linear drive through the coalescence of small scale islands into larger ones, as observed also in recent fluid simulations (2). Magnetic islands are found to rotate in the electron diamagnetic direction in the linear phase, unless only ion temperature gradients are present. At the end of the exponential-growth phase, the rotation stops and flips usually to ion diamagnetic direction. The influence of the island on density and temperature profiles is discussed.

1. F. Widmer et al., "Linear and nonlinear dynamics of self-consistent collisionless tearing modes in toroidal gyrokinetic simulations", Phys. Plasmas. **31**, 112505 (2024).
2. D. Villa et al., "Zonal fields as catalysts and inhibitors of turbulence-driven magnetic islands", Phys. Plasmas. **32**, 017001 (2025).

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