

Gyrokinetic simulations with external resonant magnetic perturbations: island torque and nonambipolar transport with plasma rotation

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Abstract

Static external resonant magnetic field perturbations (RMPs) have been added to the gyrokinetic code GYRO [J. Candy and R.E. Waltz, J. Comp. Phys. **186**, 545 (2003)]. This allows nonlinear gyrokinetic simulations of the nonambipolar radial current flow j_r , and the corresponding $\vec{j} \times \vec{B}$ plasma torque (density) $R[j_r B_p / c]$, induced by magnetic islands that break the toroidal symmetry of a tokamak. This extends the previous GYRO formulation for the transport of toroidal angular momentum (TAM) [R.E. Waltz, G.M. Staebler, J. Candy, and F.L. Hinton, Phys. Plasmas **14**, 122507 (2007); errata **16**, 079902 (2009)]. The focus is on electrostatic full torus radial slice simulations of externally induced $q = m/n = 6/3$ islands with widths 5% of the minor radius, or about 20 ion gyroradii. Up to moderately strong $E \times B$ rotation, the island torque scales with the radial electric field at the resonant surface E_r , the island width w , and the intensity I of the high- n micro-turbulence, as $E_r w \sqrt{I}$. The radial current inside the island is carried (entirely in the $n = 3$ component) and almost entirely by the ion $E \times B$ flux since the electron $E \times B$ and magnetic flutter particle flux cancel. The net island torque is null at zero E_r rather than at zero toroidal rotation. This means that while the expected magnetic braking of the toroidal plasma rotation occurs at strong co- and counter- current rotation, at null toroidal rotation, there is a small co-directed magnetic acceleration up to the small diamagnetic (ion pressure gradient driven) co-rotation corresponding to the zero E_r and null torque. This could be called the residual stress from an externally induced island. At zero E_r the only effect is the expected partial flattening of the electron temperature gradient within the island. Finite-beta GYRO simulations demonstrate nearly complete RMP field screening and $n = 3$ mode unlocking at strong E_r .

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