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Resonant Mode-Particle Interactions and Transport Barriers in toroidal plasmas under the presence of an Edge Radial Electric field

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Resonant mode-particle interactions crucially determine particle, energy and momentum transport and confinement performance in fusion devices. Non-axisymmetric perturbative modes exist either due to intrinsic instabilities, or due to intentionally applied magnetic fields and affect particles with specific kinetic characteristics by modifying specific locations of the particle's phase space [1] and parts of their momentum distribution [2, 3]. Conditions for resonant interactions can be formulated on the basis of the Guiding Center (GC) approximation [4] and the utilization of the three Constants Of the Motion (COM), namely the energy, the canonical toroidal momentum, and the magnetic moment, uniquely labeling each GC orbit in an unperturbed axisymmetric equilibrium. The resonant conditions are determined by the mode numbers and the Orbital Spectrum of the GC motion that is the bounce/transit and bounce/transit-averaged toroidal precession frequencies of trapped and passing particles [5, 6]. In addition to the equilibrium magnetic field and the perturbative modes, a radial electric field, localized in the vicinity of the plasma edge, is known to accompany H-mode operation in fusion plasmas [7] with the consequent formation of an Edge Transport Barrier (ETB) suppressing the turbulence-driven transport due to E×B shear flow and improving plasma confinement [8-10].
In this work, we show that, although the radial electric field does not perturb the integrability of the GC motion in an axisymmetric equilibrium, it drastically modifies the topology of the phase space and the ion prompt losses, as well as the Orbital Spectrum and therefore the conditions for resonant mode-particle interactions under the presence of non-axisymmetric perturbations. Moreover, it enables the formation of Shearless Transport Barriers (STB) [11], persistently bounding particle orbits and reducing extended particle, energy and momentum transport. The calculation of a kinetic-q factor enables the accurate prediction of the location of the resonances and the STBs in the phase space of the system that is systematically confirmed by numerical particle tracing simulations, suggesting a valuable tool for investigating and controlling plasma transport under the presence of various non-axisymmetric perturbations.

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